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Saturs

Saturs	2
1. Laika notikumu reģistrācijas un mērīšanas sistēmas prototipu aprobācija dažādos reāliem apstākļiem pietuvinātos scenārijos, kur nepieciešama pikosekunžu precizitāte	6
1.1. Satellite Laser Ranging and Laser Time Transfer	6
1.1.1. Event timing in Satellite Laser Ranging	7
1.1.2. Event timing in Laser Time Transfer	8
1.1.3. Conclusions	10
1.2. Signal Time Analyzer	10
1.2.1. Event timing in Jitter analysis	11
1.2.1.1. Implicit jitter measurement	11
1.2.1.2. Explicit jitter measurement	12
1.2.2. Event timing in pulse signal modulation analysis	12
1.2.3. The event timing in analog signal representation and analysis	13
1.2.4. Conclusions	16
1.3. LIDAR and 3-D scan systems	16
1.4. Free-Falling Absolute Gravimeters	17
1.4.1. Event timing in serial Gravimeters	18
1.4.2. Event timing in a specifically modified Gravimeter	19
1.4.3. Conclusions	21
1.5. Single Photon Counting Systems	21
1.5.1. Principle of operation	21
1.5.2. Event timing in Single Photon Counting System	22
1.5.3. Interpolator linearity estimation	23
1.5.4. Conclusions	24
1.6. References	24
2. Superplatjoslas impulsu tuvdarbības radara sistēmas prototipu aprobācija reāliem apstākļiem pietuvinātos scenārijos zemgarozas kartogrāfijā un objektu fiksēšanā caur EM caurlaidīgu sienu	27
2.1. Perceived shortcomings in the applications	27
2.1.1. GPR experiment	28
2.2. Dynamic range improvements	29
2.3. Signal processing improvements	32
2.4. Software, user interface and feature improvements	34
2.5. Hardware reliability improvements	35
3. Viedo transporta sistēmas sensoru tīklu prototipu aprobācija reāliem apstākļiem pietuvinātos scenārijos, kas saistīti ar 3D datorredzes pielietošanu, sensoru datu ieguvu un apstrādi, kā arī ar ceļa infrastruktūras attīstību	36
3.1. Real-time object tracking in 3D space using mobile platform with passive stereo vision system	36
3.1.1. Related work	36
3.1.2. Proposed method	36
3.1.2.1. Ground plane removal	38
3.1.2.2. Detection	38
3.1.2.3. Segmentation	39
3.1.2.4. Tracking point update	40
3.1.2.5. Kalman filter and reprojection	41
3.1.2.6. Ego motion compensation	41

3.1.2.7.	Tracking multiple targets	42
3.1.2.8.	Error recovery	43
3.1.3.	Implementation	43
3.1.3.1.	Setup	44
3.1.3.2.	Configuration	44
3.1.4.	Experimental results.....	44
3.1.5.	Approbation	45
3.1.6.	Conclusion and Future Work	46
3.2.	Smart road studs for dangerous road situation warnings	46
3.2.1.	Hardware.....	47
3.2.2.	Software	48
3.2.3.	Evaluation	48
3.2.4.	Conclusion and Future Work	50
3.3.	Published results	50
3.4.	References.....	50
4.	Plaukstas attēlu un ķermeņa muguras formas datu reģistrācijas un informācijas apstrādes sistēmu aprobācija	52
4.1.	Biometric person recognition system.....	52
4.1.1.	Development of biometric system	52
4.1.1.1.	Connecting our system to existing door control system (relay module)	52
4.1.1.2.	Palm capturing device.....	53
4.1.1.3.	Software	53
4.1.2.	Possible further improvements	55
4.1.3.	References.....	55
4.2.	Ķermeņa muguras formas datu reģistrācijas sistēmas aprobācija.....	55
4.2.1.	First 16 sensor prototype approbation in “Unihouse Ltd”	56
4.2.2.	Development of new prototype with 63 sensor nodes	56
4.2.2.1.	Efficient data acquisition	57
4.2.2.2.	New sensor node design.....	58
4.2.2.3.	Data acquisition and processing.....	59
4.2.3.	Second 63 sensor prototype approbation in rehabilitation centre “Mēs esam līdzās”.	60
4.2.4.	Published results	61
4.2.5.	References.....	62
5.	Uz rotācijas leņķiem balstītas datu pārraides iekārtas prototipa aprobācija reāliem apstākļiem pietuvinātos scenārijos	63
5.1.1.	Main research directions	63
5.1.2.	Today and in the future: Some directions of the work.....	65
5.1.3.	Perspektīvas	66
5.1.4.	References.....	66
6.	Elastīgas antenas izstaroto signālu parametru novērtēšana	67
6.1.	Estimation of the antenna capabilities	67
6.1.1.	Introduction.....	67
6.1.2.	Geometry and materials of the antenna	68
6.1.3.	Tests of the antenna	69
6.1.3.1.	Resonance properties	69
6.1.3.2.	Resistance and capacitance of the structure.....	71
6.1.4.	Measurements of resonance of the textile Bi-Quad antenna	71
6.2.	Estimation of the shielding capabilities	73

6.2.1.	Microwave transition and reflection	73
6.3.	Conclusion	76
6.4.	Acknowledgment	76
6.5.	References	76
7.	Komunikācijas sistēmas prototipa aprobācija reāliem apstākļiem pietuvinātos scenārijos, kas saistīti ar mobilo objektu vietas noteikšanu ar augstu precizitāti, kā arī bezvadu datu apmaiņu starp kustīgiem objektiem un attālinātiem serveriem	78
7.1.	Performance Calculation of Two layer Communication Vehicular Network	78
7.1.1.	Distribution of the vehicle in the coverage area of the base station	78
7.1.2.	Two Layer Vehicular Network	81
7.1.3.	Opnet Simulation of Two Layer Network Model	86
7.1.4.	Experimental estimation of vehicular network	89
7.1.4.1.	Experimental Estimation of IEEE802.11n for Short Range Vehicular Network	89
7.1.4.2.	Experimental Estimation of IEEE802.11n and 3G for Two-stage Network	91
7.1.4.3.	Experimental Estimation of IEEE802.11n and 4G for Two-stage Network	94
7.1.5.	Conclusion	97
7.2.	Multiple Frequencies Precise GNSS RTK System Research in Dynamic Mode	97
7.2.1.	Devices used in the research	98
7.2.2.	TOPCON GRS-1 GNSS Receiver Testing in Dynamic Mode	99
7.2.3.	Research of complex system	104
7.2.4.	Conclusions	108
7.3.	Appraisal of Feasibility of Using Vehicle-to-Vehicle Communications for Safe Passage of Unsignalled Road Intersection under Varying Conditions	109
7.3.1.	Algorithm application feasibility	109
7.3.2.	Vehicle equipment configuration	111
7.3.3.	Tests results	112
7.3.4.	Conclusions	115
7.4.	References	116
8.	Viedo radio tīklu sistēmas modeļa izveide un aprobācija reāliem apstākļiem pietuvinātos scenārijos, kas saistīti ar efektīvu daudzu ceļu video datplūsmu pārraidi mobilos bezvadu ad-hoc tīklos, t.sk., izmantojot viedas antenas savstarpējo traucējumu samazināšanai	117
8.1.	Ievads	117
8.2.	Literatūras pārskats	119
8.3.	Analītiskā metode	121
8.3.1.	Teorētiskie pamati	121
8.3.1.1.	SNIR aprēķins	122
8.3.1.2.	Datu pārraides ātruma noteikšana	122
8.3.2.	Metode tīkla veiktspējas novērtēšanai	123
8.3.3.	Sākotnējās metodes pielāgošana daudzu ceļu pārraides pētījumiem	126
8.3.4.	Pārraides shēmu atrašana, balstoties uz CSMA/CA protokola darbību	128
8.3.5.	Metodes ierobežojumi	129
8.3.6.	Virziendarbības izmantošana ad-hoc tīklā	130
8.3.6.1.	Virziendarbības pamati	130

8.3.6.2.	Antenas virzienu diagrammu iegūšana	131
8.3.6.3.	ZF-BF.....	132
8.3.6.4.	Uztvertās jaudas aprēķins virziendarbības gadījumā	133
8.4.	MATLAB rīks daudzu ceļu caurlaides spējas noteikšanai	133
8.4.1.	Bloku paskaidrojums	134
8.4.1.1.	Tīkla un pārraides parametru uzstādīšana.....	134
8.4.1.2.	Mezglu un tīkla objekta izveide	135
8.4.1.3.	Maršrutēšana	135
8.4.1.4.	Ceļu komplektu raksturlielumu iegūšana.....	135
8.4.1.5.	Pārraides shēmu atrašana	135
8.4.1.6.	Vienmērīga pārraides ātruma atrašana.....	136
8.4.1.7.	Antenas elementu svāra koeficientu atrašana	136
8.4.1.8.	Parametru konvertācija uz NS2 un simulācija	136
8.4.2.	Rīka validācija salīdzinot rezultātus ar NS2	136
8.5.	Vairāku ceļu pārraides efektivitāte	138
8.5.1.	Caurlaides spējas atkarība no ceļu skaita vienmērīgām plūsmām	139
8.5.2.	Ceļu raksturlielumi un to ietekme uz caurlaides spēju	140
8.6.	Virziendarbības antenu efektivitāte	144
8.7.	Secinājumi.....	147
8.8.	Atsauces	148
Pielikums #1		149
Pielikums #2		150
Pielikums #3		151
Pielikums #5		153
Pielikums #6		154
Pielikums #7		155
Pielikums #8		156

1. Laika notikumu reģistrācijas un mērīšanas sistēmas prototipu aprobācija dažādos reāliem apstākļiem pietuvinātos scenārijos, kur nepieciešama pikosekunžu precizitāte

The main object of this year activity is to show real applications for event timing systems requiring the picosecond precision for time measurements.

During this period of time research was done on the problems related to the Event Timer (ET) using in the following real application systems:

- Satellite Laser Ranging and Laser Time Transfer;
- Multifunctional Time Analyzer;
- LIDAR and 3-D scan systems;
- Free-Falling Absolute Gravimeters;
- Single Photon Counting Systems.

Solving the first problem allows to register time measurements in the time-scale related to UTC and using any pairs of time-tags for the corresponding range calculation. The Event Timer module application in Time Analyzers requires special transformation of analyzed signals into event sequences and registration of these events with very high precision. LIDAR and 3-D Scan systems are the systems that use ranging to get outlines of the scanned objects and for improved performance they require using of Event Timers with high repetition rate and high time resolution. In gravimetry systems, very small deviation of the gravitational acceleration has to be detected and that requires time registration with appropriate very high accuracy. In a number of physical measurements related to the considered studies, the properties of matter requires high stability and linearity of time instant registration at photon detection. The developed Event Timer can provide for achieving such high stability and linearity.

1.1. *Satellite Laser Ranging and Laser Time Transfer*

Satellite Laser Ranging (SLR) systems measure the round trip time of flight of ultra short pulses of light to satellites equipped with retroreflectors. The first observation station with such systems appeared in 60s. In 1998 SLR stations around the world have agreed to form the International Laser Ranging Service society to enhance geophysical and geodetic research activities. Now about 80 SLR stations are included in this society and 50 of them supply global data centers by ranging information on a regular basis. Besides the precise orbit determination of the geodetic satellites the global network of SLR stations has evolved into a powerful source of data for studies of the solid Earth and its ocean and atmospheric systems. The precise orbit determination provides for spaceborne radar altimeter missions mapping the ocean surface, for mapping volumetric changes in continental ice masses, and for land topography. SLR presents a means for subnanosecond global time transfer, and a basis for special tests of the Theory of General Relativity. More information about Satellite Laser Ranging and Earth Science is presented in [1.1].

1.1.1. Event timing in Satellite Laser Ranging

Routine SLR stations are working with lasers emitting pulses at 10 MHz frequency for Low Earth Orbit and geodetic satellites (round trip time is less than 50 ms) and at 5 MHz for GPS satellites (round trip time is 130-140 ms). In such case the round trip of the light pulse is completed before the next pulse is emitted and the known Time Interval counters (SR620 from Stanford Reserach, HP5370 from Hewlett Pakkard, SeTIC from IECS) are widely exploited for ranging. To support such “slow” mode of ranging, the more precise A033-ET (A032-ET) is employed in a cyclical mode and the internal gating can be used. The time diagram of the involved events and procedures is shown in Fig.1.1.

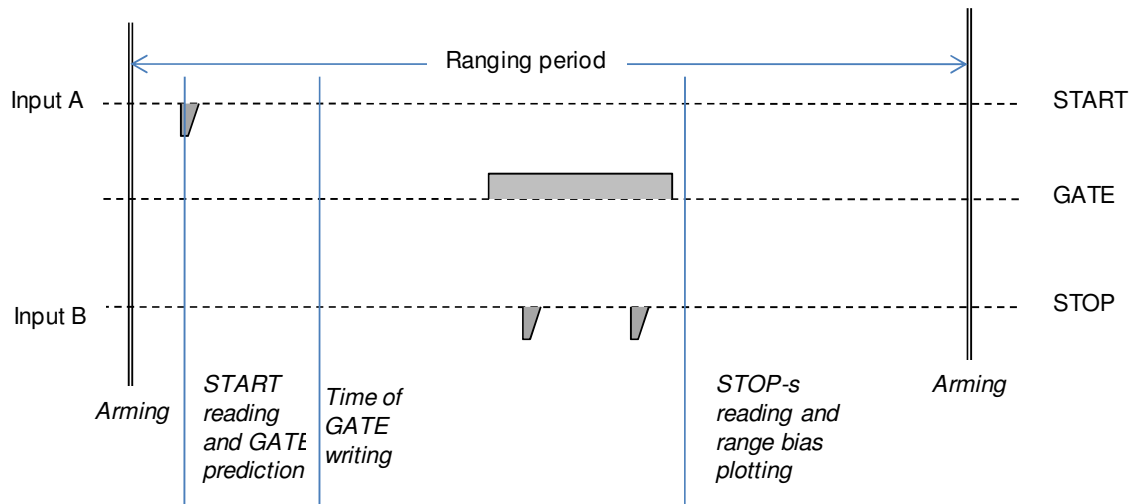


Figure 1.1 Time diagram of A033-ET operation in cyclical mode

Number of STOP events is defined by customer specifics. For example, Riga Event Timing System designed for Riga SLR station [1.2] has additional STOP event that characterizes the video impulse from the photomultiplier. This information provides for refinement of the registered range value. The structure and functionality of this system is considered in [1.3].

In 2004 new Laser Ranging systems appeared with ranging repetition rate 2 KHz that was restricted by the specially developed event timer on the base of Dassay timing modules having 400 us dead time [1.4]. Latter this SLR station has successfully approbated our A032-ET for 10 KHz ranging [1.5]. The previously used Time Interval Counters actually cannot be applied for KHz ranging as then multiplex START-s and corresponding STOP-s would have to be incorporated into at least 80 (!) counters for geodetic satellite ranging in 2 KHz frequency:

$$\text{Round trip time} / \text{Interval between START-s} = 40 \text{ ms} / 0,5 \text{ ms} = 80 \text{ Counters.}$$

In case of KHz SLR, the A033-ET (A032-ET) is working in continuous mode with external gating by mean of pulses arrived in Input GATE (Fig.1.2).

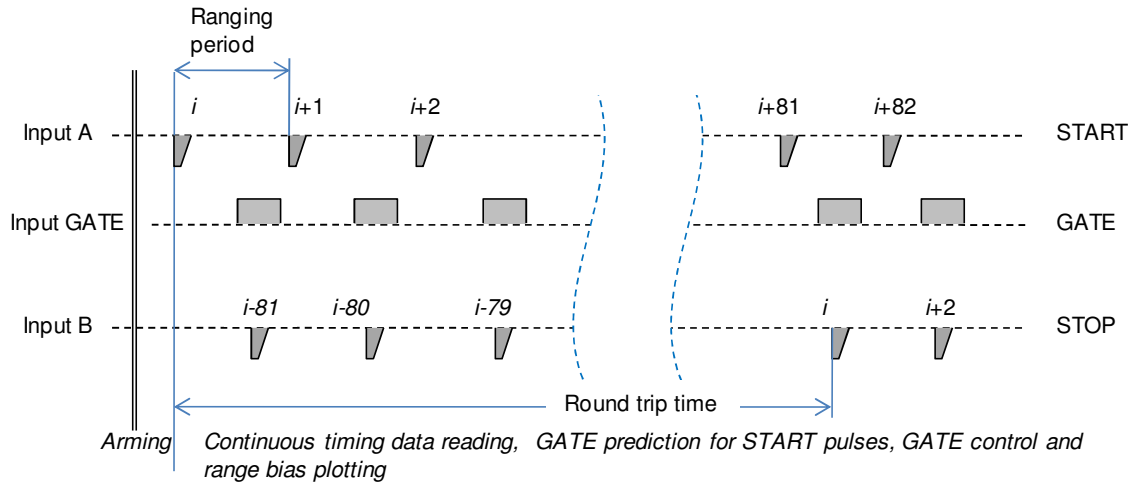


Figure 1.2 Time diagram of A033-ET operation in continuous mode

A special device is needed for gating control. Such gating control can be implemented in alternative ways:

- get timing data from ET, recognize the START events which in ET are marked specifically, predict times of according STOP-s and issue the GATE pulse to the Input GATE of the ET;
- register the START event by simple timer with medium precision (0.5 ns is enough), predict the time of according STOP and issue the GATE pulse to the ET or directly to Single Photon Avalanche Diode (SPAD) control;
- control the laser pulse emission [START event] so that a corresponding STOP pulse hit to predicted GATE area controlled via Input GATE of the ET or directly at SPAD.

We developed the device of the first type and checked it in combination with A032-ET [1.6] and A033-ET [1.7]. A similar device has been implemented in Potsdam SLR station on the base of a microcontroller [1.8]. A number of devices of the second type were developed in Graz and are used in some SLR stations [1.9]. The devices of third type are developed and used in some China SLR stations [1.10] [1.11].

1.1.2. Event timing in Laser Time Transfer

Laser Time Transfer between Satellites and ground stations is based on SLR and additional on-board Event Timer in Satellite. Such experiments are carried out from 2007 in the frameworks of international collaboration projects, but now the main forces are concentrated in the project “Laser Time Transfer” of the European Space Agency mission “Atomic Clock Ensemble in Space”.

The principle of Laser Time Transfer (LTT) is illustrated in Fig.1.3.

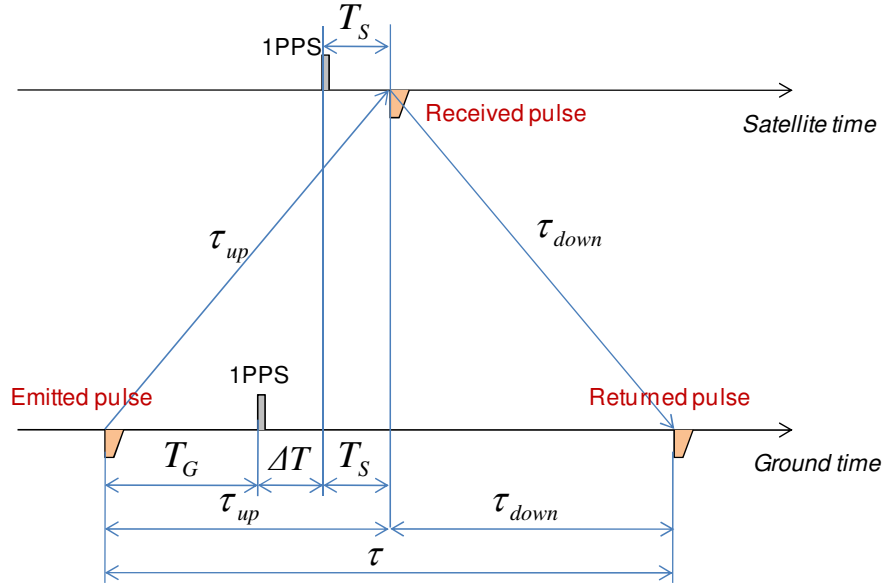


Figure 1.3 The principle of Laser Time Transfer [1.12]

In accordance to the notations in Fig. 1.3, the clock difference ΔT between satellite and ground clock is:

$$\Delta T = \tau_{up} - T_S - T_G, \quad (1.1)$$

where

τ_{up} - laser pulse flight time from the ground to satellite;

T_G - time difference between the pulse emission and 1PPS in the ground clock;

T_S - time difference between the received pulse and 1PPS in the satellite clock.

For LTT experiment in China, two Riga Event Timers are used on the ground (Fig.1.4). Event Timer 1 is applied for measuring the start and stop events at high precision SLR. Through identifying corresponding Start-and-Stop events, the laser pulse flight time for ground-satellite-ground τ is obtained. After considering the correction of the Earth rotation (Sagnac effect), the laser pulse flight time for ground-satellite up τ_{up} is to be calculated. Event Timer 2 measures the time interval T_G between the start event and 1PPS on the ground clock. According to the principle of LTT, the precision of measured up τ_{up} and T_G directly affects that of clock difference between satellite and ground.

The precision of time transfer in these first experiments was about 200 ps, while the accuracy for synchronizing ground clocks can be better than 50 ps, as the continuous work in European Space Agency mission “Atomic Clock Ensemble in Space (ACES)” shows. For such synchronization the collaboration with the International Laser Ranging Service is needed for ACES module tracking and receiving ranging data from the ACES.

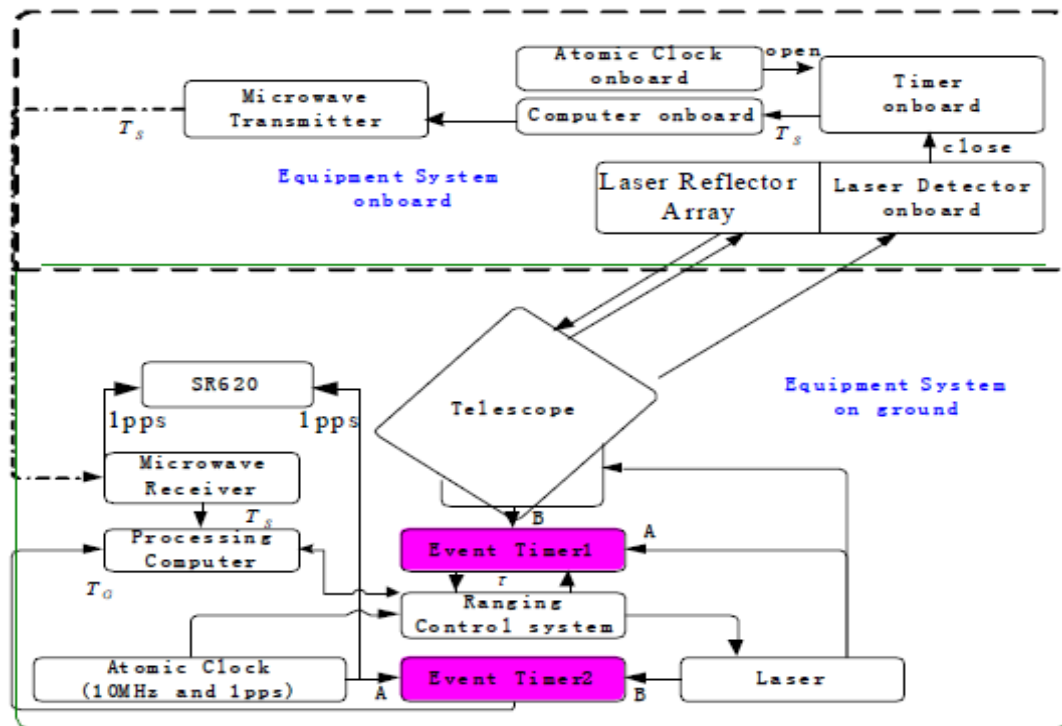


Figure 1.4 Riga Event Timers in LTT experiments [1.12]

1.1.3. Conclusions

So far 23 SLR stations have Riga Event Timers and this is almost 50 % of all stations participating in the International Laser Ranging Service network. In the framework of collaboration agreements with Scientific Institutions involved in SLR problems, a number of KHz custom-specific ranging systems have been developed and put into operation.

Shanghai SLR station was the first one from the China SLR stations that, in collaboration with Riga Institute of Electronics and Computer Science, began using of Riga Event Timer for SLR and the related applications. After integration of Riga ET into specific event timing systems, it has been successfully applied for SLR and LTT experiment. The analysis of the obtained measurement data has shown that the performance characteristics of Riga Event Timer (such as RMS resolution, stability, non-linearity, etc.) satisfy the high precision requirements of SLR and LTT. Following the Riga ET applications at Shanghai SLR station, several SLR stations in China also started to use this ET for developing kHz SLR and for advanced test equipment.

1.2. Signal Time Analyzer

The high measurement rate and high precision of the Event Timer A033-ET allows to analyse signals and get both usual and very specific characteristics of these signals.

1.2.1. Event timing in Jitter analysis

1.2.1.1. Implicit jitter measurement

The Event Timer application for jitter characterization in case of clock generators is considered in [1.13]. The general jitter model based on the phase progression of the timed clock generator is considered there.

If we register the time instants $\{t_0, t_1, \dots, t_k, \dots, t_N\}$ when the clock signal crosses the most significant level for this signal characterization, we can build a phase progression on the timing interval $t_N - t_0$ (Fig.1.5). For a sinusoidal signal and its jitter characterization the most significant are instants when the signal has zero value.

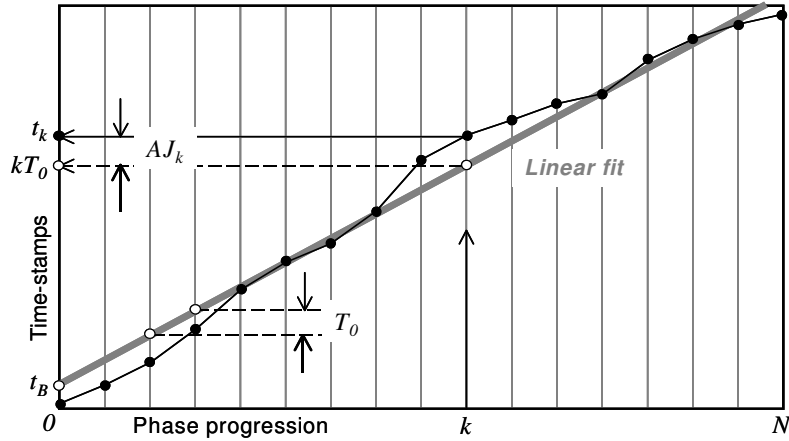


Figure 1.5 Phase progression of the timed clock generator

Deviation of the actual incrementing of the time-stamps from their ideally linear incrementing represents dynamics of jitter accumulation. This accumulated jitter presents the time difference between linear function and the real signal:

$$AJ_k = t_k - (kT_0 + t_B), \quad k = 0, 1, \dots, N. \quad (1.2)$$

The accumulated jitter function is the basic function which characterizes the clock generator deviations from the ideal clock with the stable period. All other known jitters functions are derivatives from this accumulated jitter:

periodic jitter function (first difference)

$$PJ_k = AJ_k - AJ_{k-1}; \quad k = 1, 2, \dots, N; \quad (1.3)$$

cycle-to-cycle jitter function (second difference)

$$CJ_k = PJ_k - PJ_{k-1}; \quad k = 2, 3, \dots, N. \quad (1.4)$$

The differences of higher order can be calculated in the same manner if it is needed but their physical essence is not clear.

An approach to statistical jitter analysis, based on the simplified theoretical model of jittered clock oscillators, provides correct quantitative interpretation of the measurement results. Experimental research confirms the possibility of estimating these parameters with femtosecond precision by using the event timer with a time precision of about of two picoseconds. However, the model not always fully conforms to the real cases, indicating a more complicated nature of jitter accumulation for typical clock oscillators.

Generally it seems that the considered technique of jitter measurement could complement the traditional oscilloscope-based technique, offering comparable precision, simpler and cheaper solution as applied to the jitter of input signals limited in upper frequency to hundreds of MHz. Expected advantages of this technique also concern a versatile characterization of clock oscillators in a wide time-range [1.13].

1.2.1.2. *Explicit jitter measurement*

The considered approach is applicable in the case where the analyzed generator is characterized by the variance that is more than the measurement error of the ET. In other cases the special method using Event Timer and a delay line should be used [1.14].

This method is based on the high-precision event timing of two sequences: one sequence of arriving events and the second sequence of the same events delayed for a constant delay. This method allows using of a single measurement channel rather than three channels as it is needed in the case of application of the known “three-cornered hat” method. Despite the additional impact of the delay deviations, the proposed method allows to estimate the measurement device precision with subpicosecond precision. In result this estimation becomes the accountable factor for simultaneously executed measurements of external clock generators and allows estimating the generator’s own jitter, which may be less than the Event Timer precision.

On the basis of the developed methods, we have measured the jitter dependence on the time interval values for time intervals generated by T5300U. Obtained measurement results (Fig.1.6) differ from the given in T5300U generator data sheet and they are more precise. The developers of this instrument from the Institute of Telecommunications Department of Electronic Engineering of Military University of Technology in Poland have agreed to that.

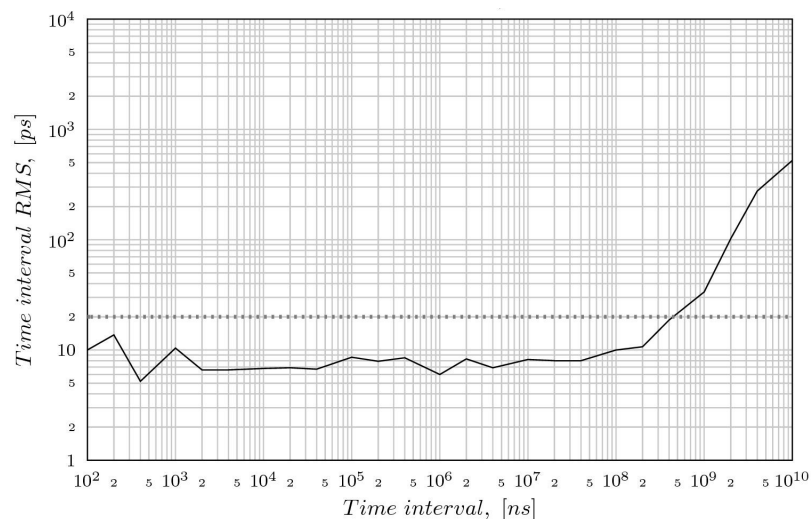


Figure 1.6 Jitter dependence on time interval for generator T5300U measured by A033-ET

1.2.2. *Event timing in pulse signal modulation analysis*

The measurements of time instants t_k , when the modulated signal crosses the preset level, can be used not only for estimating signal jitter characteristics, but also

for revealing and reconstructing the modulation frequency (demodulate signal) in cases of frequency or phase modulation of carrier signal with stable period. The modulating frequency changes instantaneous periods $t_{k+1} - t_k$ and they can be detected by observing the period of the deviation function calculated from (1.3) and shown in Fig.1.7). This function period can be calculated by means of FFT of this period deviation.

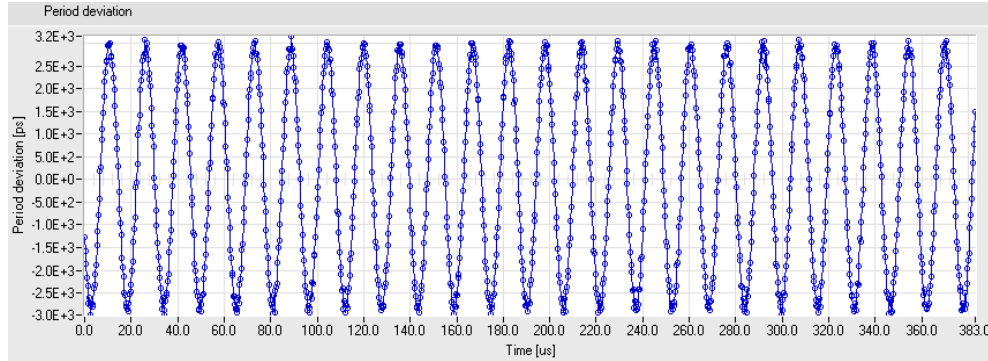


Figure 1.7 Period deviation function for frequency modulated signal

In case of constant modulation frequency its reconstruction precision depends on how many its periods are fit into a continuous measuring time. Considering the A033-ET performance characteristics (single-shot RMS resolution 3 ps, and buffer memory volume 16K time-stamps) the maximal resolution for modulation function is about 0.1 Hz [1.15].

An amplitude modulation of the signal cannot be discovered from the time instants of zero crossings but if the crossing level is shifted from the zero this modulation become visible (Fig.1.8). Knowing the crossing level offset we can calculate not only the modulation frequency but the amplitude variation range, too. Considering the A033-ET performance characteristics, the maximal resolution for amplitude modulation is for modulation depth about 0.1 % [1.15].

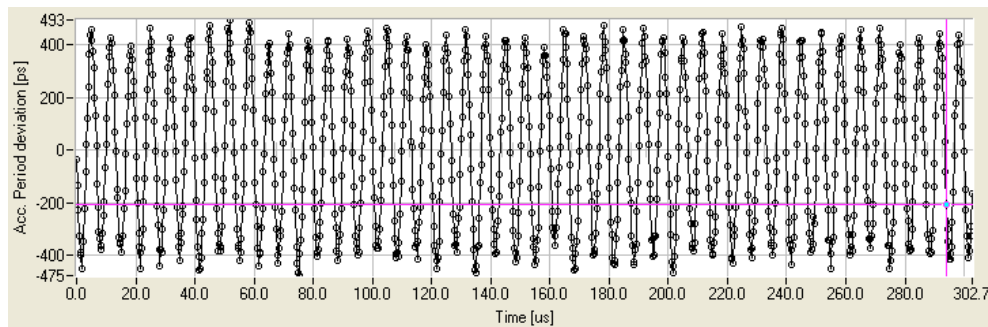


Figure 1.8 Period deviation function for amplitude modulated signal

1.2.3. The event timing in analog signal representation and analysis

More general approach for analog signal representation and analysis by mean of event timing is considered in [1.16]. This approach is based on timing of crossing instants of analyzed signal and reference sinusoidal signal. The reference sinusoidal signal is the internal master clock signal of the Event Timer (ET) that is used for

crossing instant timing. To support the high accuracy and precision the ET the hardware provides for high stability of this reference signal both in constant phase shift and constant amplitude. But for a detection of crossing events and deriving specially selected events to the ET input the additional schematic has been developed (Fig.1.9).

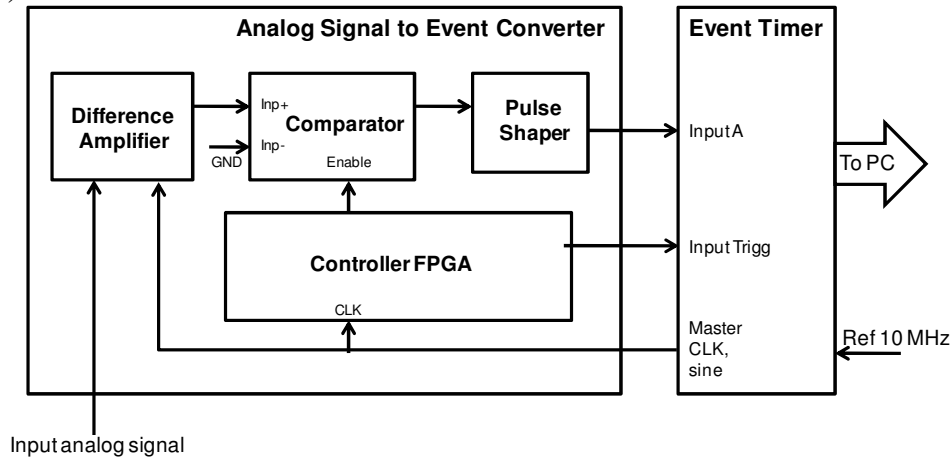


Figure 1.9 Crossing instant conversion into events for the Event Timer

The Difference Amplifier amplifies the difference between the input signal and the sinusoidal reference signal to facilitate the Comparator operation. This is necessary because the time deviation of Comparator output signal depends on the input signal relative slope and this can impact crossing event timing. Pulse Shaper forms a short sharp pulses and provides identical pulses that are registered by the ET as events. Controller provides the selection of such crossing instants that are randomly distanced in time and any interval is greater than the „dead time“ of the ET. Randomly selected crossing events allow to represent and analyze the input signals without aliasing for frequencies higher than half of the reference signal frequency. Signal to the Input Trigg is used to start digitalization in predefined pseudorandom sequence position that helps to reconstruct the random intervals values. The signal-to-event convertor implementation is shown in Fig.1.10.

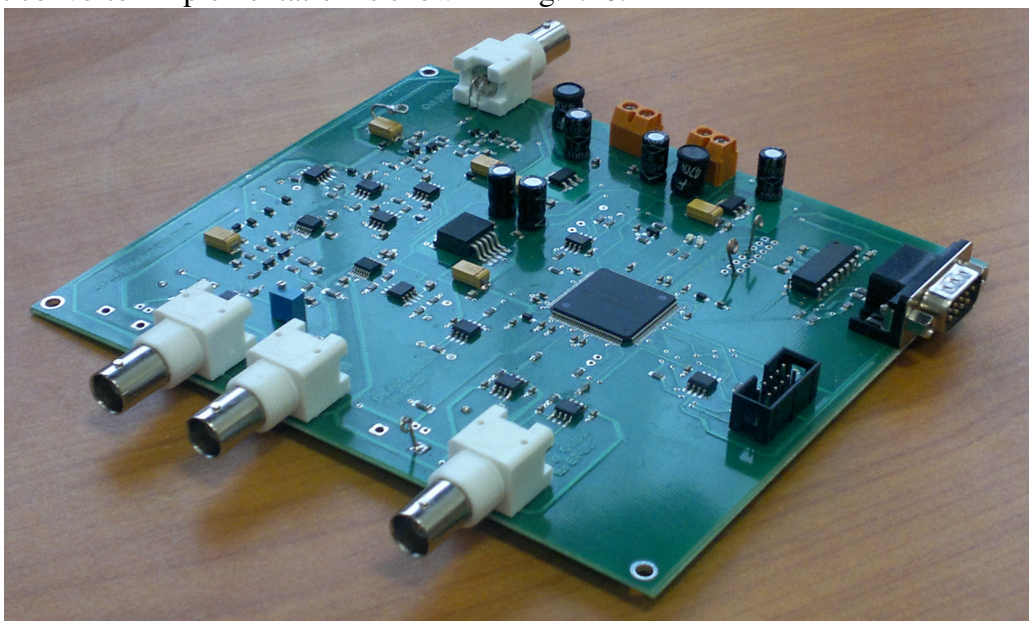


Figure 1.10 Analog signal-to-event converter implementation

To illustrate this approach to digital representing of original analog signals, a triangle waveform signal has been digitised. The signal-to-event converter generates events at instants when the sin-wave signal crosses the triangle signal. These events are timed by the ET and after the phase offset excluding these time values are substituted into expression for the reference signal:

$$r(t_k) = A_r \sin(2\pi f_r t_k); \quad k = 1, 2, \dots, N. \quad (1.5)$$

In such a way we get the instantaneous sample values of the reference sine-wave signal. Evidently they are also the recovered sample values of the input signal. These sample values are displayed in Fig. 1.11 and power spectrum obtained from the 512 timed events is shown in Fig.1.12.

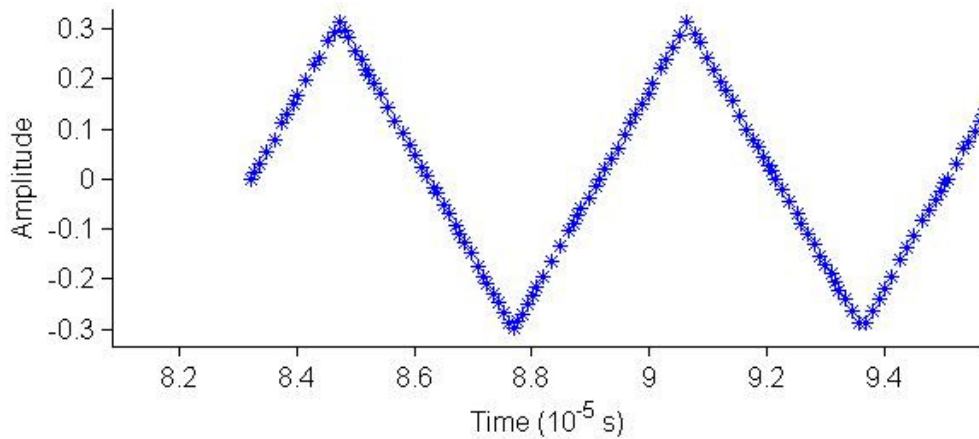


Figure 1.11 Recovered values of the analyzed triangle waveform signal

While input signal parameter estimation often is simple enough, alias-free processing of them in time and frequency domains, in particular, input signal waveform reconstruction is more complicated. For this aim the so-called SECOEX method (SEquential Component EXtraction method) is used and the spectrograms given in Fig. 1.13 were obtained on the basis of it. This method is described in sufficient detail in [1.17] and it can be used for versatile alias-free digital signal processing, including Discrete Fourier Transform, signal parameter estimation, analysis of this specific type of digital signals and signal waveform reconstruction.

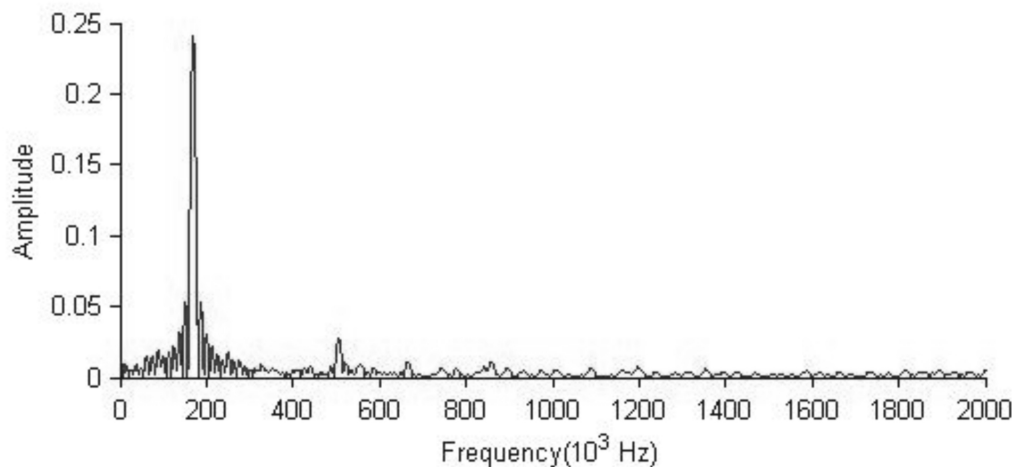


Figure 1.12 Power spectrum of the analyzed triangle waveform signal

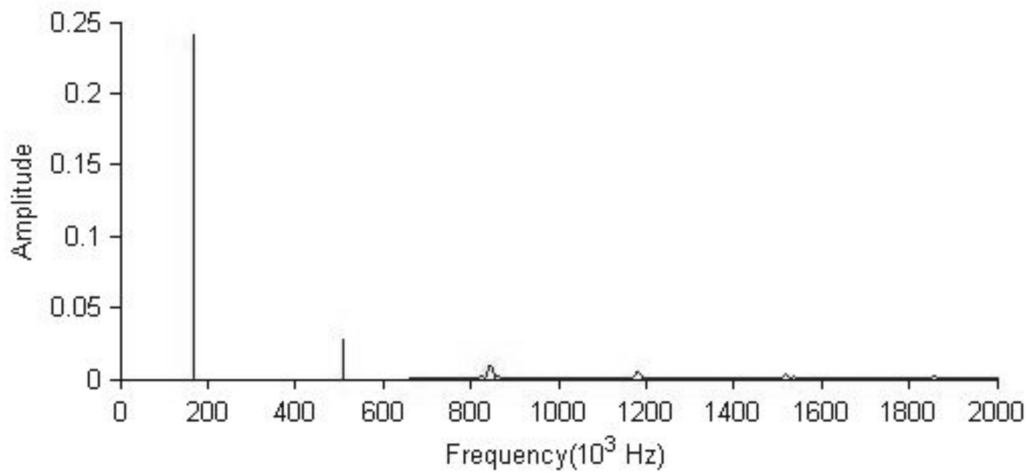


Figure 1.13 Spectrograms built by the SECOEX method

The results of the direct Fourier transform were used then for reconstructing the signal waveform shown in Fig. 1.14.

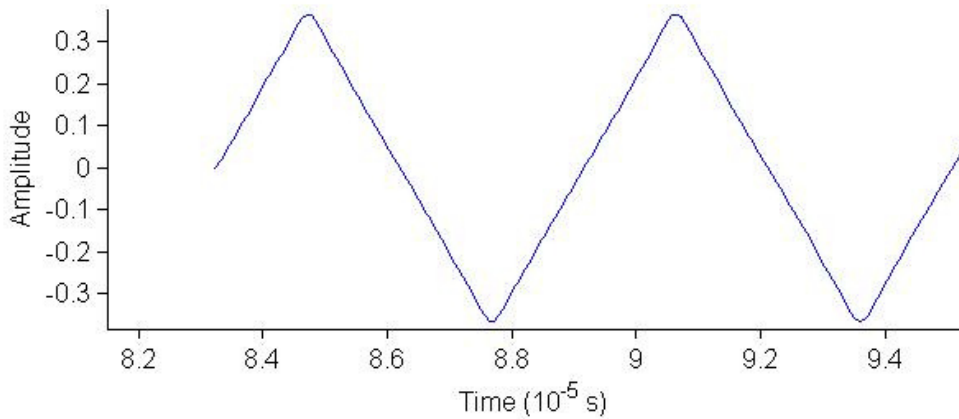


Figure 1.14 Triangle waveform reconstructed on the basis of the input signal spectrum analysis

1.2.4. Conclusions

All considered methods show the real applications of the Event Timer A033-ET and Event Timer module that has been developed in the framework of this project. This report presents approbation of the considered methods to estimate the usefulness of the Event Timer in signal analysis area. Some of these methods will be used in framework of another project related to the development of Multifunctional Signal Time Analyzer [1.18].

1.3. LIDAR and 3-D scan systems

LIDAR and 3-D scan systems are very similar to the ranging system as it has been seen in ILRS Wrokshops. A number of specialists in SLR are engaged in LIDAR and 3-D Scan problems [1.19] [1.20] [1.21].

One of the main operation in LIDAR and 3-D scan system is a time-of-flight measurement for emitted laser pulses and reflected by particles in atmosphere or by surface of the moving and stationary objects. The specifics of such measurements is in multiple responses to a single shot. The cyclic mode of the Event Timer A033-ET can provide for such measurements carried out with high resolution (the time diagram is identical to that shown in Fig.1.1 only the number of STOP-s in opened GATE is usually greater than two). The repetition rate for LIDAR and a especially 3-D scan systems is very significant and the Event Timer module with USB interface can provide average measurement rate equal to more than 1 million measurements per second and up to 20 millions in bursts for 2600 measurements.

One more specific feature of the LIDAR and 3-D scan system is the necessity to analyze the returned pulse power and change of forms that depend on a reflectance of irradiated objects. This information about returned pulses should be registered and processed simultaneously with the ranging information.

Lately a lot of attention is paid to scanning and observing of space debris. Although the Radars were used in routine scanning, now a new concept based on „active“ and „passive“ LIDAR system is developing. The „active“ LIDAR systems operate in all spacecrafts and in many satellites and they are working in the same way as Radar systems. The „passive“ LIDAR systems are supposed to use a group of SLR stations around the world for simultaneous observing the same space area but only one of the SLR station is shooting by the laser into this space area. It is clear that in this case all time scales should be synchronized and this can be done by the Laser Time Transfer facilities.

Here we consider the problem of tracking space objects that is not investigated sufficiently and their calculated trajectories precision is much worse than the gate position requirements for usual SLR. However all space objects have very high velocity and a small number of disturbing factors. That helps as then their trajectories can be extrapolated on the basis of the data gathered directly before. The range prediction method realized in RTS-2006 [1.2] and the developed Range Gate Generator [1.7] can be used in such systems.

The optical surveying of a flying object allows detecting and defining the trajectory of such object on the basis of long-time observation and complex calculation but using the laser tracking together with an optical monitoring essentially simplifies the problem solution. The optical system reveals variations of the object movement trajectory in two coordinates (X,Y) and the laser ranging gives the movement in the third coordinate. In this case the optical system finds and follows up the object and laser tracking starts the object ranging with a wide gate and approximate position of it while the sufficient data are obtained to predict the time gate position more precisely.

1.4. Free-Falling Absolute Gravimeters

Gravimeters are used for petroleum and mineral prospecting, seismology, geodesy, geophysical surveys and other geophysical research, and for metrology. Free-Falling Absolute Gravimeters measure the local gravity in absolute units, usually $\text{Gal} = 1 \text{ cm/s}^2$. The milligal (mGal) and microgal (μGal) refer respectively to one thousandth and one millionth of a gal. The standard gravity at Earth surface varies from 976 up to 983 Gal, depending on latitude and elevation of the place where it is measured. The

gravity variation with height is about 310 μGal per meter of height. Density variations within the Earth's crust cause variations of gravity up to hundreds of milligals.

1.4.1. Event timing in serial Gravimeters

The classical free-falling absolute gravimeter is based on precise tracking of a free-falling object in vacuum. The falling object contains an optical retroreflector and laser beam directed to this object interferes with the reflected beam and that produces the optical fringes during the movement. The Fig.1.15 shows the laser beam traveling between falling retroreflector and reference retroreflector until a superposition of the emitted and reflected beams is registered by the photodetector.

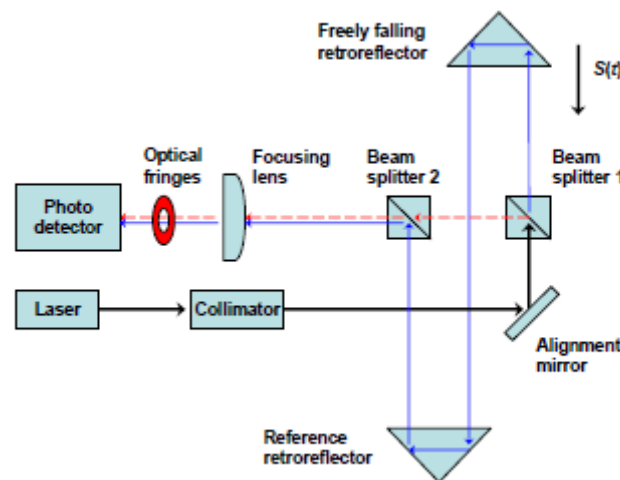


Figure 1.15 The optical part of the free-falling absolute gravimeter [1.22]

Photo detector output generates a swept sinusoidal signal representing the fringes. During the falling distance about 25 cm and the beam wavelength 633 nm instantaneous frequency is increased from 4 KHz up to 7 MHz generating more than million periods (fringes). The distance between fringes is equal to half of the beam wavelength. An ordering number of the fringe defines the distance of the object from the start point but the time interval from the falling start moment up to this fringe defines the time of acceleration. In result we can calculate up million points of the falling trajectory and find the gravity value.

There are many other factors as deviation from vertical, vibration, laser beam instability, impact of near located great density objects and so on. All these factors should be taken into account for precise gravity measurement. But there are at least two factors that essentially impact on the precision:

- Fringe detection by means of zero-crossing is not precise, because this precision depends on rapidly varying frequency from 4 KHz up to 7 MHz [1.22].
- Time Analyzers used for these zero-crossing registration have typical time resolution of about 70 – 100 ps RMS [1.23].

How to avoid zero-crossing we will consider in the next section but for increasing the precision of zero-crossing timing we suggest to use Riga Event Timers. The 2.5 – 3.0 ps RMS resolution of these Timers and continuous time-logs registration into

internal memory at 12.5 MHz rate will allow to register all zero-crossings with high precision. In all Riga Event Timers the internal timescale is synchronized with the external 10 MHz Frequency Standard, usually GPS-disciplined crystal or rubidium generator, and this provide the timescale stability on all measurement cycles.

1.4.2. Event timing in a specifically modified Gravimeter

One of the main problems in all existing free-fall absolute gravimeters is the precise processing of the swept sine signal from the photodetector. Usual zero-crossing can not solve this problem because of blurrines and essential distortions of the optical interference signal. We propose to replace the laser interferometer with very high resolution for distances measurement by other system that provides very high resolution in time measurements.

Let us look at ballistic free-fall absolute gravimeter and suppose that the Event Timer and picosecond pulse laser are used in such a configuration (Fig. 1.16).

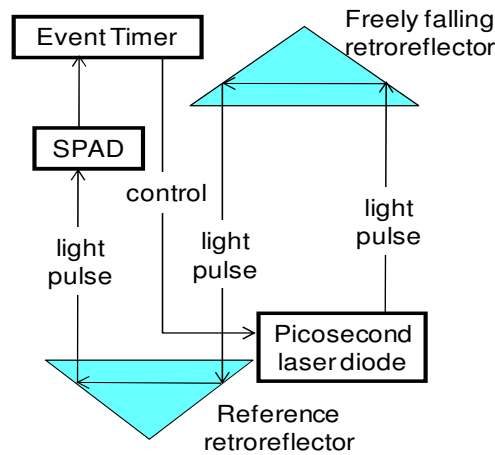


Figure 1.16 Modified optical part of the free-falling absolute gravimeter

The requirements for adjusting additional optical elements (splitters and mirrors) in this configuration are not so strong as in the case of the laser interferometer. The trigger pulses from the Event Timer are applied to the laser diode with preset stable frequency synchronized with the internal timescale of the Event Timer. Time instants of the emitted light pulses are denoted as t_j^E in Fig.1.17.

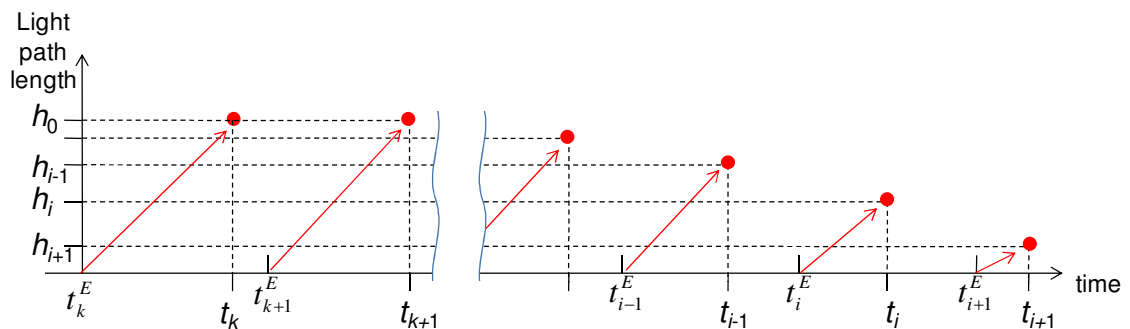


Figure 1.17 The sequential tracked positions of a free-falling object

The returned light pulses from the falling retroreflectors are detected by SPAD (Single Photon Avalanche Diode) and their time instants t_k are recorded by the Event Timer.

The Event Timer does not register time instants t_k^E it simply registers time instants t_k . Fig.1.18 presents discrete values of function $F(t)$ taken at precisely defined period T . In this figure the scales are chosen for best visualization only.

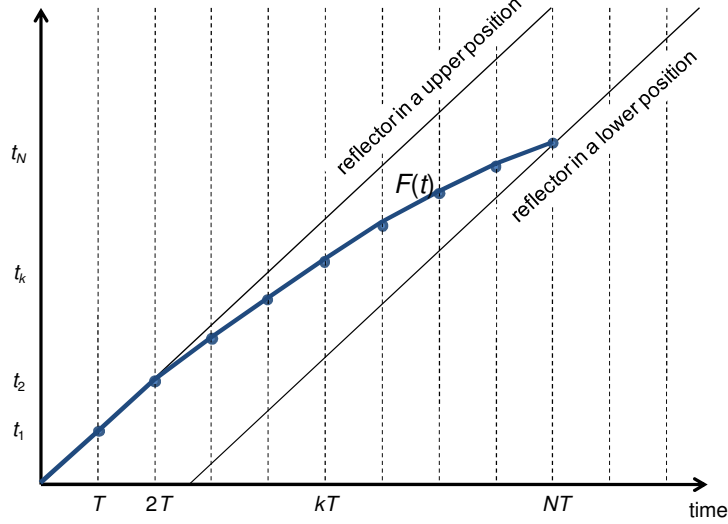


Figure 1.18 Tracking times for a falling object

Assuming the time begins at start of falling, we can express the k -th value of this function as:

$$t_k = kT - \frac{g \cdot [T^2 + (2T)^2 + \dots + (kT)^2]}{2 \cdot c} = kT - gT^2 \cdot \frac{k(k+1)(2k+1)}{12 \cdot c}, \quad (1.6)$$

where c is speed of light in vacuum.

The number N of points $\{t_1, t_2, \dots, t_k, \dots, t_N\}$ is defined by a chosen period T of the ranging frequency and the time of falling. The time of free falling from the height $h_0 = 25$ cm is:

$$T_{fall} = \sqrt{2h_0 / g} \approx \sqrt{2 \cdot 0.25 / 9.8} \approx 0.226 \text{ (s)} \quad (1.7)$$

and the „dead“ time of the Timer A033 is 50 ns, so the maximal number N is:

$$N = T_{fall} / 50 \text{ ns} \approx 4517540. \quad (1.8)$$

In result the precision of one time-tag of the A033-ET (that is equal to 3 ps or in distance $\Delta h \approx 1$ mm = 0.001 m) will be refined by averaging on N values for $\sqrt{4517540} \approx 2125$ times and gives the relative error for g (m/s^2) evaluation:

$$\varepsilon = \Delta h / 2h_0 / 2125 = 0.001 / 0.5 / 2125 \approx 1 \cdot 10^{-8}. \quad (1.9)$$

This precision is equalent to 1 uGal and teoretically can be obtained at one measurement cycle. But there can be different problems in computation (the Least Square fitting for 4.5 millions points is a hard work) or distortions in light pulses reflections and so on. To estimate the real precision it is necessary to approbate the proposed approach in real devices.

1.4.3. Conclusions

The Riga Event Timer can provide measurements of a time for optical fringes with much better resolution than the other known Time Analysers allowing to get the same precision at about 200 times reduced number of repetitions.

The proposed free-fall gravimeter modification with the pulse laser and Riga Event Timer provides the measurements of function $F(t)$ discrete values with 3 ps precision for the free-falling object. After this function Least Square fitting the relative error in the gravitational acceleration g evaluation becomes about 1 μGal that allows essentially to increase the precision of the existing gravimeters and to obtain good results faster.

The considered approach has been presented in IAG Symposium on Terrestrial Gravimetry: Static and Mobile Measurement, 17– 20 September, 2013, Saint Petersburg, Russia, and it caused a lot of interest of Gravimeter developers from Russia and China.

1.5. Single Photon Counting Systems

Time-resolved fluorescence spectroscopy is a powerful analysis tool in fundamental physics as well as in the life sciences. Implementing it in the time domain requires recording the time dependent intensity profile of the emitted light upon excitation by a short flash of light, typically a laser pulse. The best solution of this problems is Time-Correlated Single Photon Counting (TCSPC) [1.24]. With periodic excitation (e.g. from a laser) it is possible to extend the data collection over multiple cycles and one can reconstruct the single cycle decay profile from single photon events collected over many cycles [1.25].

1.5.1. Principle of operation

The sketch drawing of the TCSPC method is shown in Fig.1.19. A laser pulses excites an atom of an analyzed sample and after some very short time the last emits photon which should be registered. Time intervals between the laser pulse emission (Start pulse) and photon detection (Stop pulse) and their distribution characterize the analyzed sample in the best way. To achieve good results it is necessary to provide for high precision (about tens picoseconds) and very large number of such accumulated intervals.

So far the Time Interval Counters have been used for such measurements. The main problem of using these Counters is the low repetition rate that leads to long-continued analysing process taking into account only 1 up to 5 percent from laser the pulses producing the photon emission.

The resolution of interval estimation should be high as well because this resolution defines the accuracy of these interval histogram that is the main facility for specifying different substances. In TCSCP methods the resolution usually is specified by Full Width Half Maximum (FWHM) of the timing error distribution.

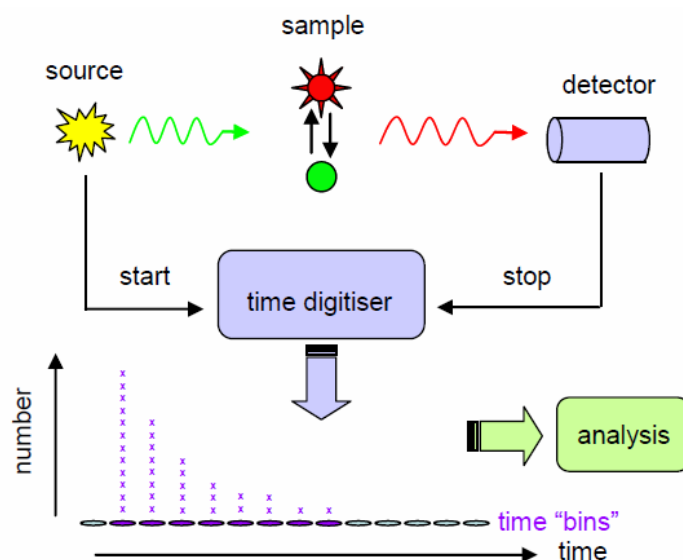


Figure 1.19 Generic TCSPC for Fluorescence
(from Horiba presentation by D. McLoskey, in Riga, June 13, 2012)

1.5.2. Event timing in Single Photon Counting System

The Riga Event Timer can provide very high repetition rate up to 20 MHz for 2600 measurements and 12.5 MHz for internal buffer memory. The „dead time“ of A033-ET is 50 ns and this defines the maximum repetition rate not allowing direct measurement of the fluorescence decay that lasts from tens picoseconds up to some nanoseconds. However this problem can be resolved by using two Timers, one of which measures times of Start events while the second one measures the time instants of Stop events. To check the possibility of such measurements and the measurement resolution, we did an experiment with one signal source splitted to inputs of two Event Timers A033-ET. The time-tags differences of the corresponding time-tags are presented in Fig.1.20 and their histogram in Fig.1.21.

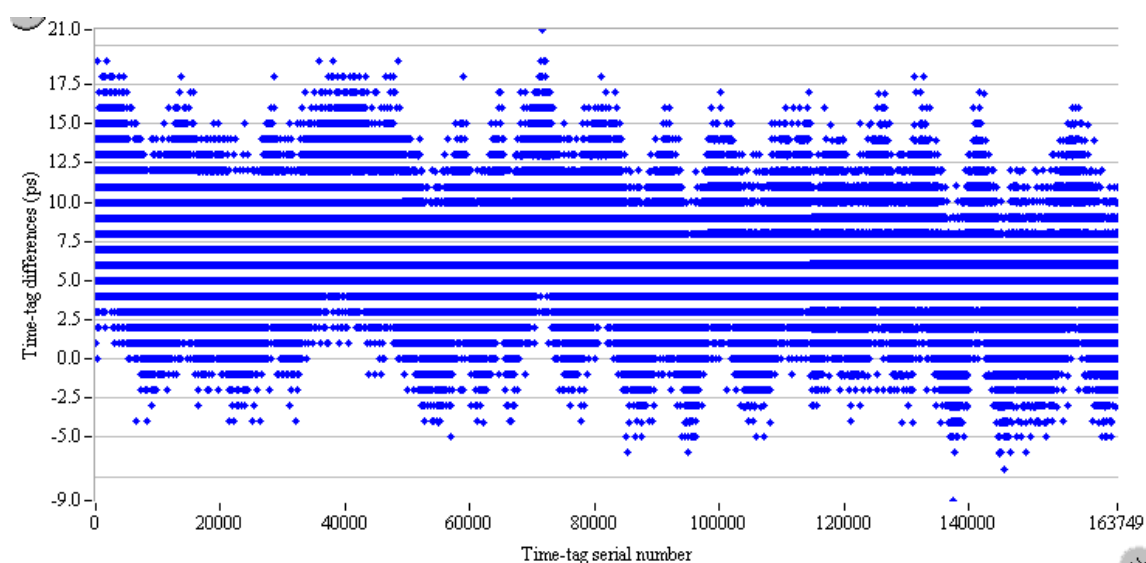


Figure 1.20 Short interval measurements executed by two Event Timers A033-ET

The time interval between two measurements is 80 ns and in one measurement cycle 16380 intervals are measured (restricted internal memory of A033-ET). After this the timing data are read from the Timer memory, written into disc file and then new measurement cycle starts. Ten such cycles take more than 10 min. In result some time trend of the measured interval values can be seen as it is shown in Fig.1.20. In spite of this trend the resolution in standard deviation (STD) and Full Width Half Maximum (FWHM) are very good (see Fig.1.21).

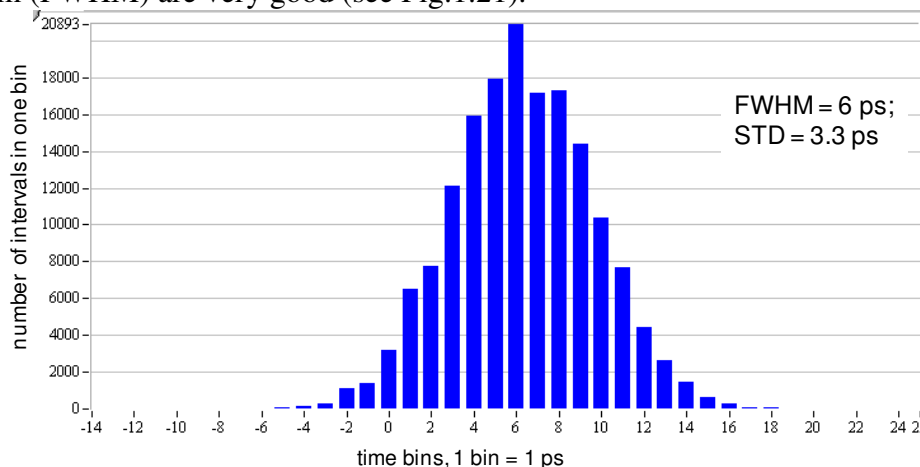


Figure 1.21 Histogram of intervals measured by two Event Timers A033-ET

1.5.3. Interpolator linearity estimation

The TCSPC method requires very high interval linearity of all measurements. Very small nonlinearities lead to Histogram distortion and impair the capability of distinguishing substances with similar properties.

To check the A033-ET linearity, randomly distributed intervals from 0 up to 100 ns were used in the test setup shown in Fig.1.22.

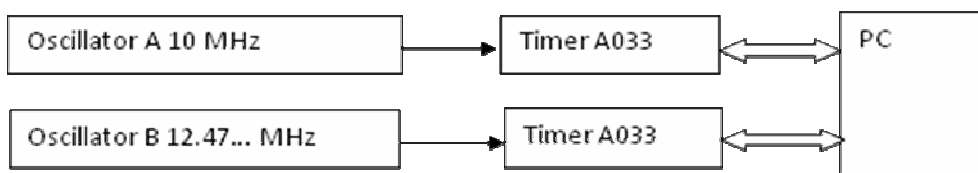


Figure 1.22 Test setup for nonlinearity verification

The next Fig.1.23 explains a method for selection of intervals between time-tags from two Timers and events generated by two independent generators A and B.

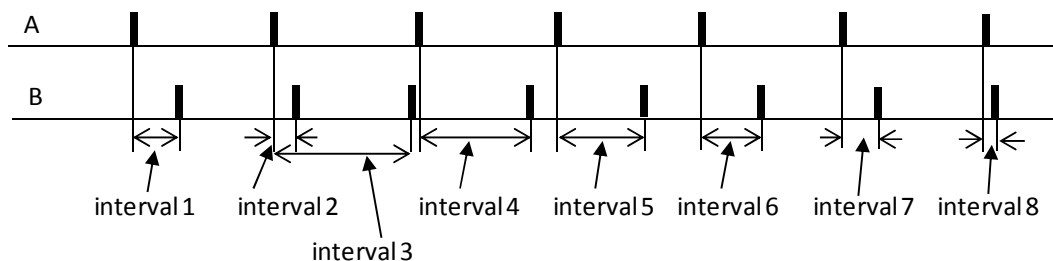


Figure 1.23 Extraction of all intervals that are in 100 ns range

The measurement actually was cyclic rather than continuous. At each cycle 16384 intervals are evaluated and distributed into 1 ps classes from 0 ps up to 100020 ps (+20 ps taking into account a jitter of Oscillator A - AFG3251). Oscillator B – Event Timer Test Generator ETTG – has jitter less than 1 ps. The data are accumulated during about 300 000 measurements cycles. The resulting histogram for intervals in the range from 0 up to 100000 ps is shown in Fig.1.24.

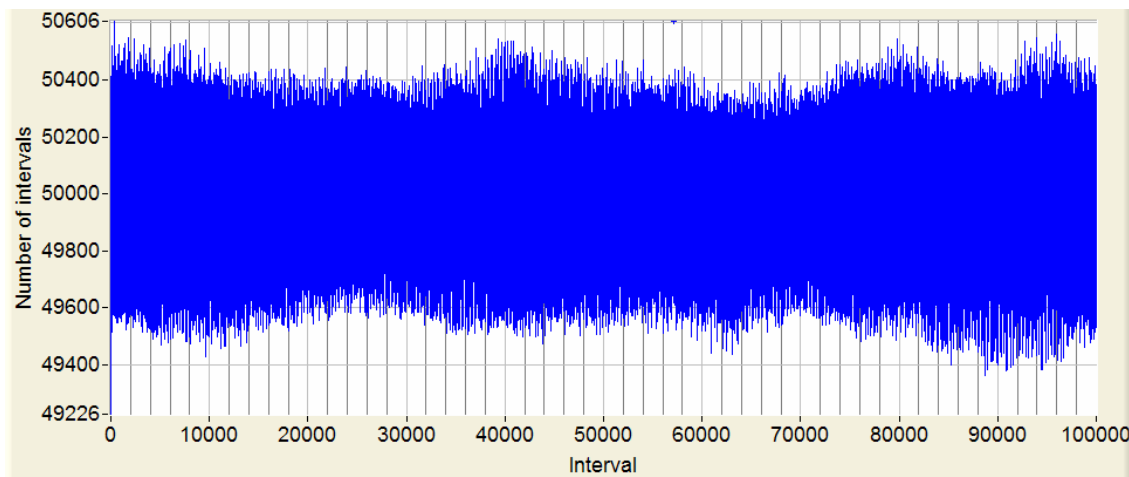


Figure 1.24 Distribution of measured intervals in the range 100 ns

Calculated standard deviation of numbers of intervals in one bin is 225. For the mean number 50000 in one bin we get a relative error less than 0.5 % and for 1 bin equal to 1 ps we get the nonlinearity less than 5 femtosecond.

1.5.4. Conclusions

The experiments with couple of Event Timer A033-ET, executed in accordance with requests from the HORIBA representative Dr.D.Mc.Classky, show that Event Timers satisfy requirements of TCSPC method in repetition rate, resolution in couple and linearity.

1.6. References

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2. Superplatjoslas impulsu tuvdarbības radara sistēmas prototipu aprobācija reāliem apstākļiem pietuvinātos scenārijos zemgarozas kartogrāfijā un objektu fiksēšanā caur EM caurlaidīgu sienu

This year we have continued to improve our ultra wide band radar system to be able to perform GPR surveys and human tracking through electromagnetic transparent wall. Results achieved this year:

- perceived shortcomings in the applications (Section 2.1);
- improved receivers dynamic range from 24dB to 71.3dB (Section 2.2);
- signal processing improvements (Section 2.3);
- software, user interface and feature improvements (Section 2.4);
- hardware reliability improvements (Section 2.5).

2.1. *Perceived shortcomings in the applications*

Field experiments were performed with following UWB radar system prototype.

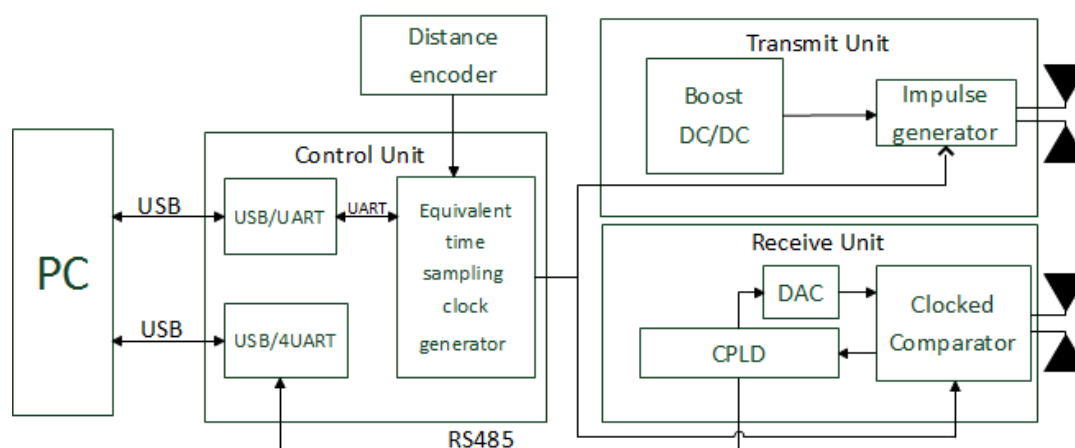


Figure 2.1 Universal multi-channel UWB radar system prototype

System is universal 4 receiving antenna system (In Figure 2.1 only 1 receiving antenna is depicted) for through-wall imaging (TWI) and ground penetrating radar (GPR) systems.

Radar system is designed as universal multi-channel UWB radar system. In order to see how this system performs in various radar applications we test it both for GPR and through wall imaging applications. Several initial experiments were performed to test system in real environment for GPR and TWI. Experiment objective was to find out problems system has to deal with during application based tasks.

2.1.1. GPR experiment

The described system is mounted on wheelbarrow as GPR. System uses distance encoder to sample each A-scan in equally spaced distance. Each A-scan is visualized on PC while performing survey.

In this experiment a metal plate (40x20cm) was buried in 1m depth (dry soil and sand medium, Figure 2.2).



Figure 2.2 Preparation for the experiment

Survey was 2m long as depicted in Figure 2.3.

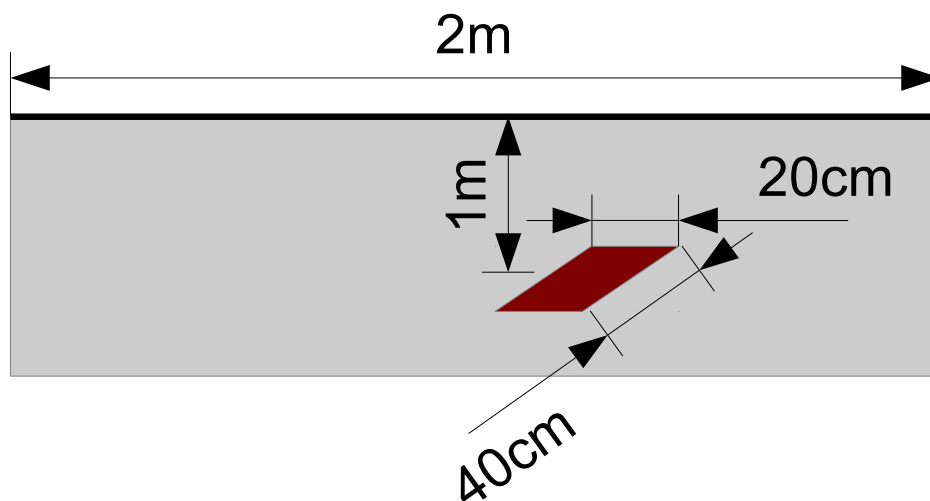


Figure 2.3 Schematics of the survey

However, no reflections from object were detected. As it turned out later, system was unable to detect such reflections because of low receiver dynamic range. To overcome this issue and increase receiver dynamic range, an adaptive compensation algorithm was developed.

2.2. Dynamic range improvements

Radar receiver is designed as clocked comparator. Both comparator inputs are connected to wideband bowtie antenna and so called input signal tracking is performed using feedback where voltage change on one input is compensated with equivalent voltage change on second input (Figure 2.4).

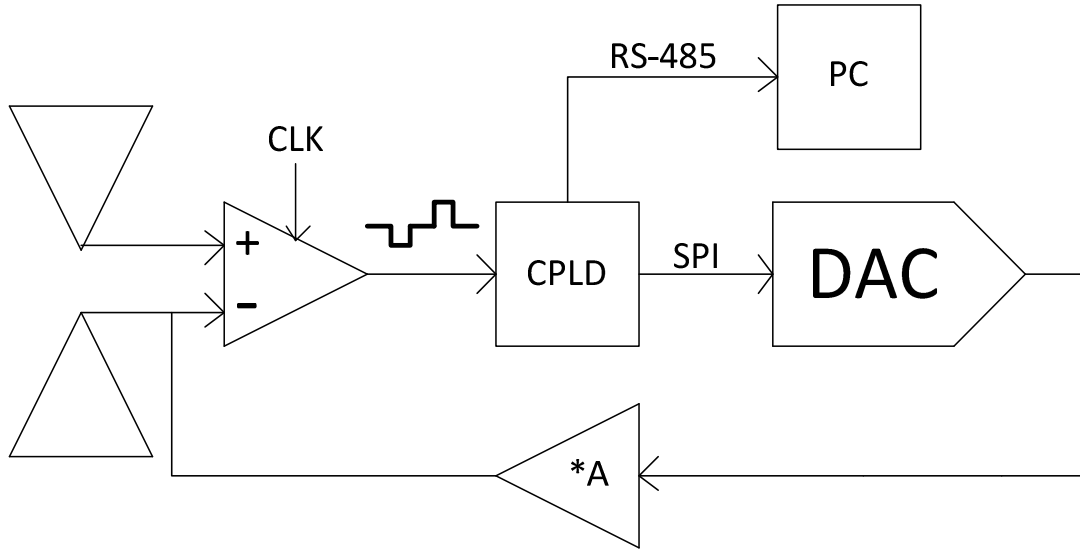


Figure 2.4 Clocked comparator radar receiver

If the voltage on comparator output is positive, DAC's output voltage is increased, but if the voltage on comparator output is negative, DAC's output voltage is decreased by some voltage step. Voltage step can stay constant over time or it can be varied to adapt input signal properties. It is experimental tested that using adapting voltage step a greater receiver's dynamic range can be achieved.

Tracking algorithm changes voltage step depending on whether signal is tracked or not. Voltage step is doubled if voltage is increased or decreased by the same voltage step 3 times in a row:

$$A_n = A_{n-1} \pm step = A_{n-2} \pm 2 \cdot step. \quad (2.1)$$

Signal is considered to be tracked and voltage step is halved if n , $n-2$, $n-4$, $n-6$ and $n-8$ samples equivalent:

$$A_n = A_{n-2} = A_{n-4} = A_{n-6} = A_{n-8}. \quad (2.2)$$

Now, let's see how this adapting tracking algorithm affects receivers dynamic range.

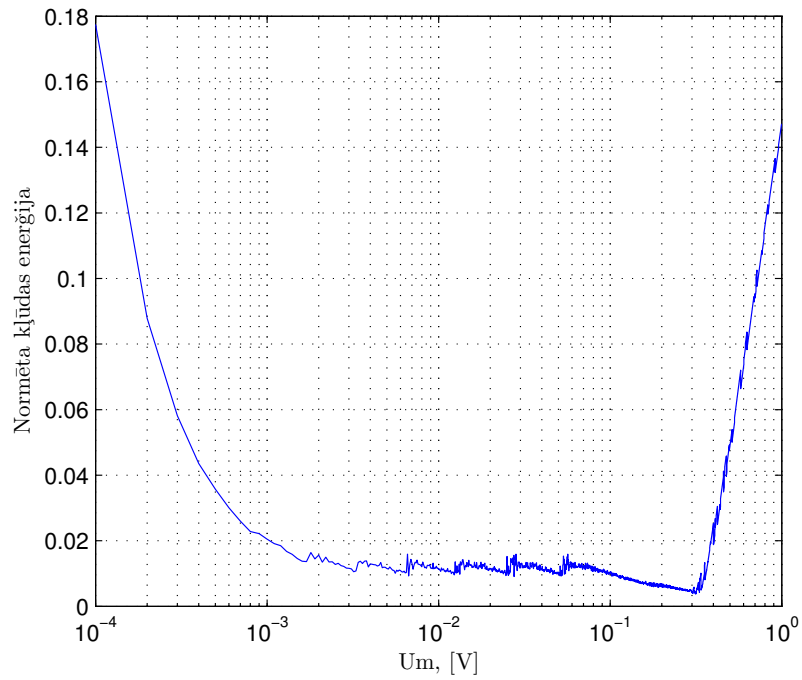


Figure 2.5 Receivers error threshold using adapting voltage step

Input signal amplitude is changed between 100μV and 1V. Error is calculated as error energy over input signal energy:

$$d = \frac{1}{\|x\|} \sqrt{\sum_{i=1}^n (x_i - y_i)^2} \quad (2.3)$$

$$\|x\| = \sqrt{\sum_{i=1}^n x_i^2}, \quad (2.4)$$

where x – input signal, y – tracked signal, $\|x\|$ – input signal norm.

In Figure 2.5 it can be seen, that for 10% error threshold input signal can be received with amplitude 20μV to 735mV. Receiver's dynamic range then is

$$20 \cdot \log_{10} \left(\frac{735 \cdot 10^{-3}}{200 \cdot 10^{-6}} \right) = 71.3 \text{ dB}.$$

Modeling receiver with constant voltage step 100μV, it can receive signal for 10% error threshold with amplitude within 700μV and 11mV (Figure 2.6). Receiver's dynamic range then is

$$20 \cdot \log_{10} \left(\frac{11 \cdot 10^{-3}}{700 \cdot 10^{-6}} \right) = 24 \text{ dB}.$$

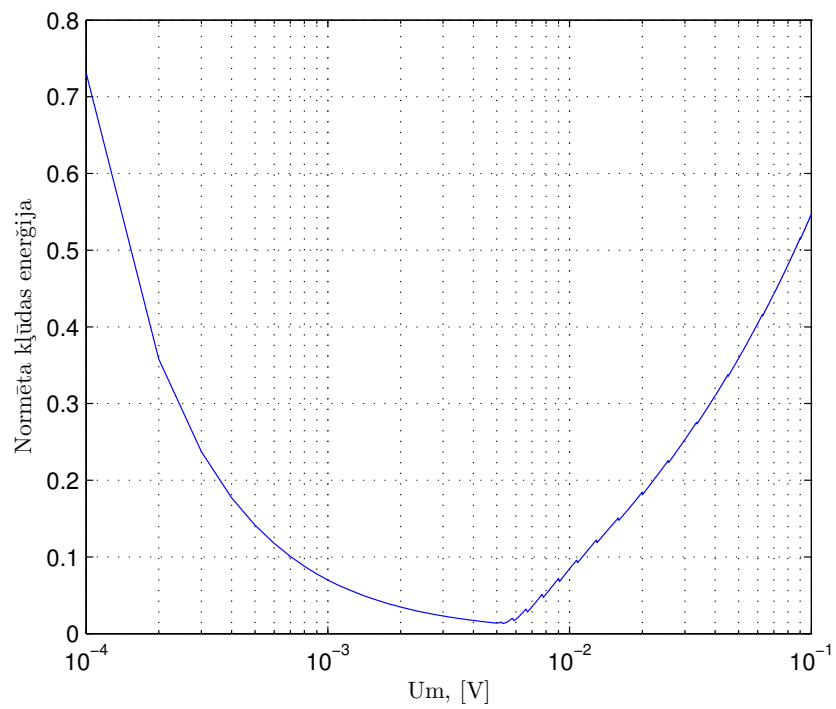


Figure 2.6 Receivers error threshold using constant voltage step

Now, when using adaptive signal tracking algorithm, metal plate buried in 1m depth can be distinguished from surrounding clutter (Figure 2.7).

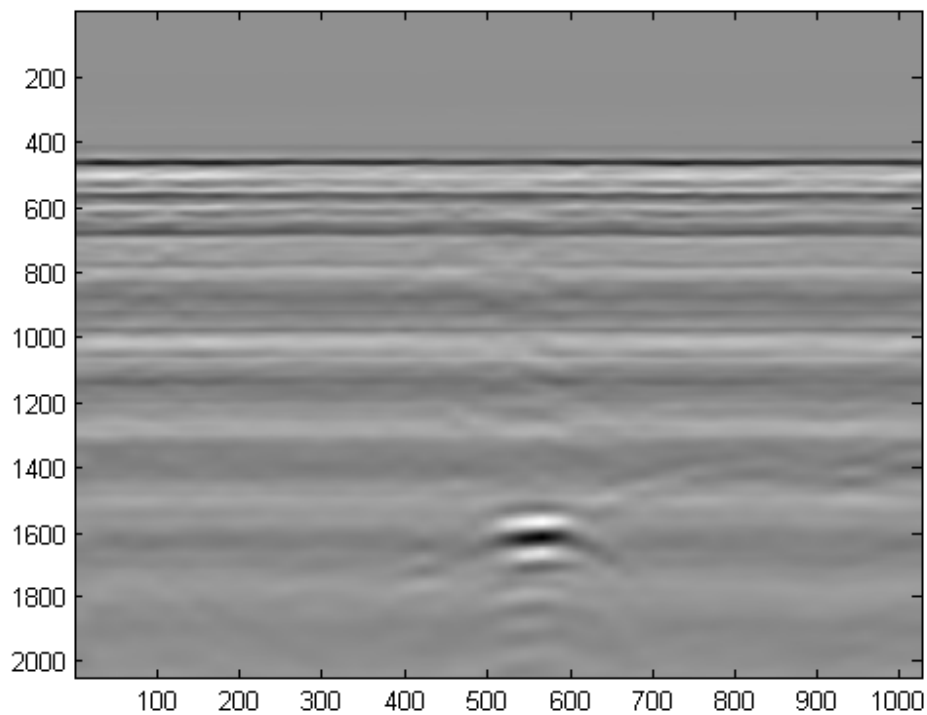


Figure 2.7 Detection of metal plate

2.3. Signal processing improvements

A new TWI signal processing algorithm for moving human body tracking through electromagnetic transparent wall was developed.

The main goal for this signal processing algorithm is to distinguish a small signal change in much larger background noise (clutter) which is equivalent to distinguishing signal reflection from human body from other reflections.

Signal processing algorithm is based on principal component analysis (PCA), more specifically - Karhuen-Loeve transformation.

In order to test UWB radar system with new signal processing algorithm for through wall imaging applications, two experiments were performed. First, object tracking in 1D using one receiving antenna, second, object tracking in 2D using 2 receiving antennas. In both experiments objects are located in radar's line of sight. To extract distance between each receiving antenna and dynamic, object, a complex signal processing algorithm based on Karhuen-Loeve transformation is used.

In 1D tracking a metal plate is located in front of radar in 1.7 meter distance (Figure 2.8). Metal plate is moved closer and further from radar with 30cm amplitude and data is recorded with UWB radar and ultrasound sensor simultaneously.

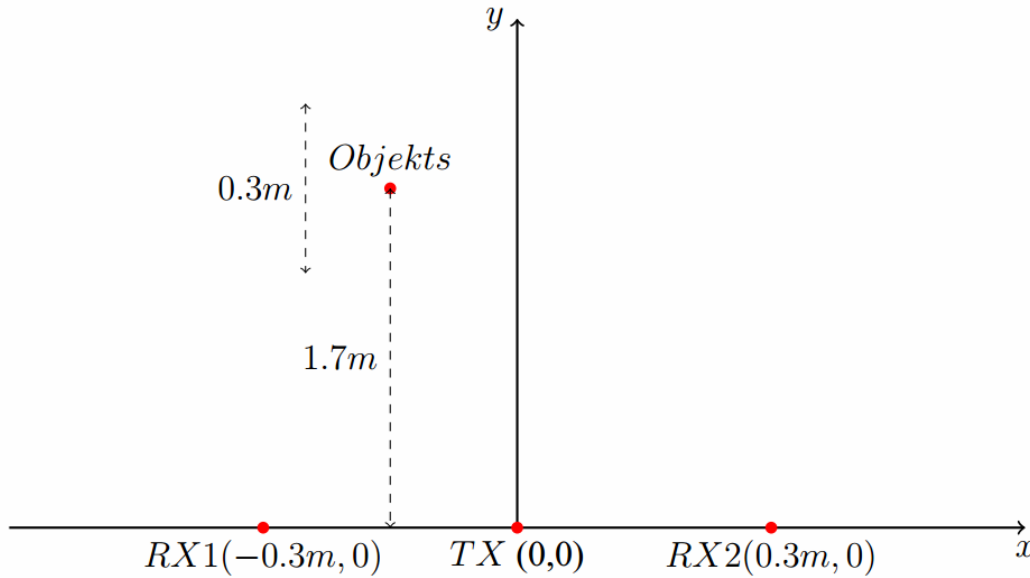


Figure 2.8 Setup of 1D experiment

Results are depicted in Figure 2.9. Object movement is clearly distinguished both with UWB radar and ultrasound sensor.

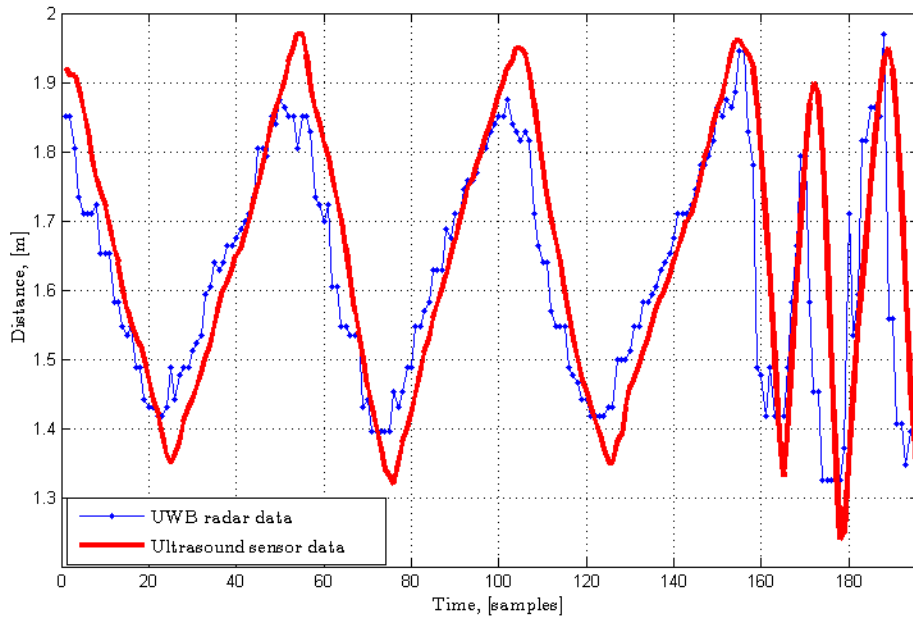


Figure 2.9 Results of 1D experiment

In 2D tracking a man is standing in front of radar in 2m distance (Figure 2.10). Man is walking slowly towards receiving antenna RX2 keeping distance to radar constant. Radar is now using two receiving antennas and distance from object to each receiving antenna is transformed into object coordinates in 2D coordinate system.

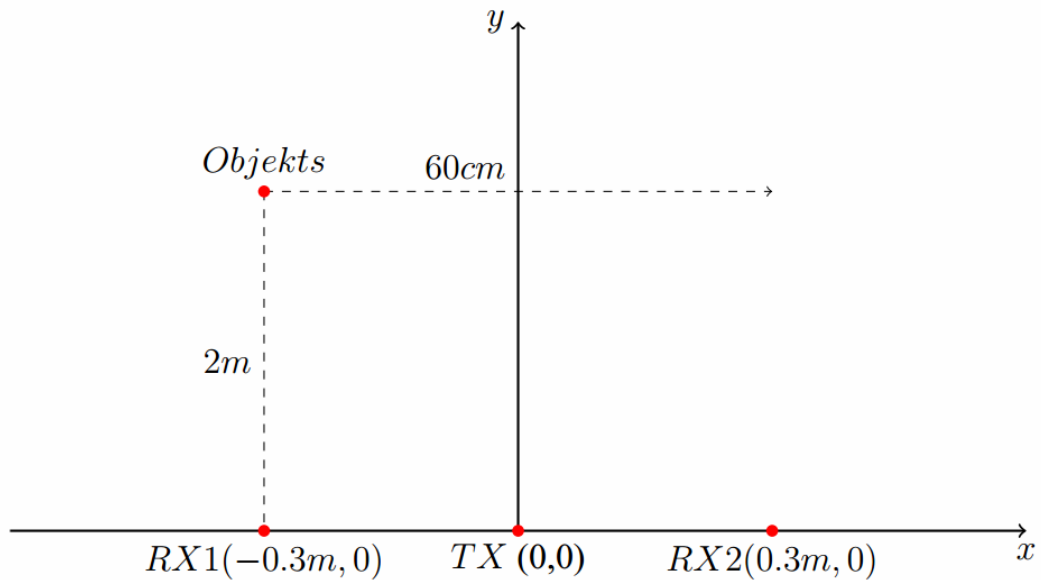


Figure 2.10 Setup of 2D experiment

Results are depicted in Figure 2.11. Resulting swarm of points is clearly located around exact object movement trajectory.

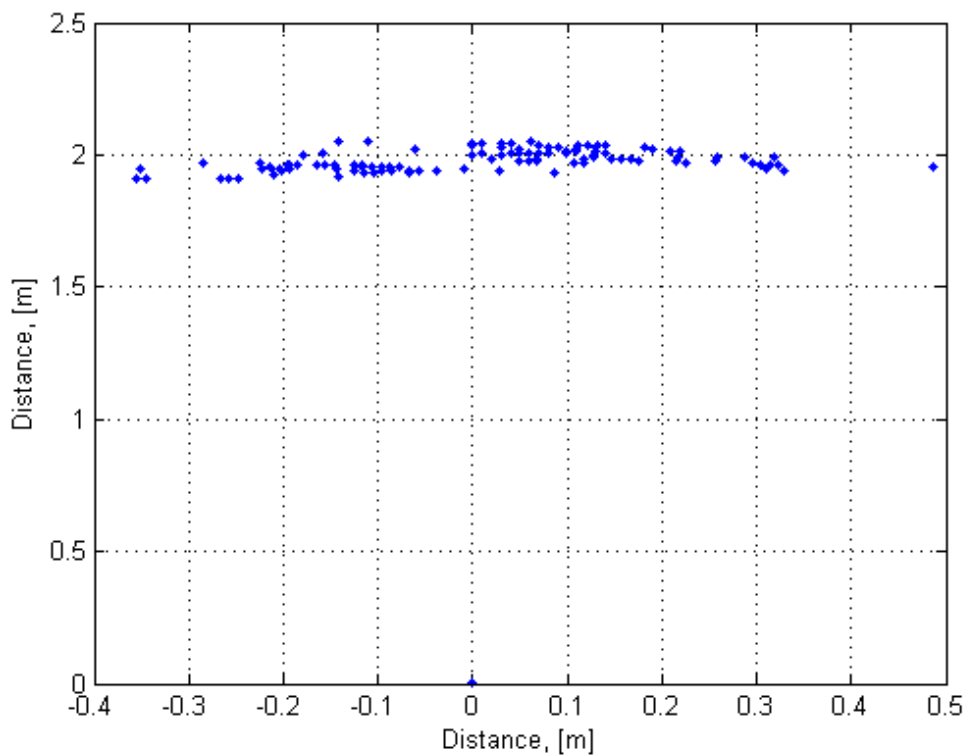


Figure 2.11 Results of 2D experiment

2.4. Software, user interface and feature improvements

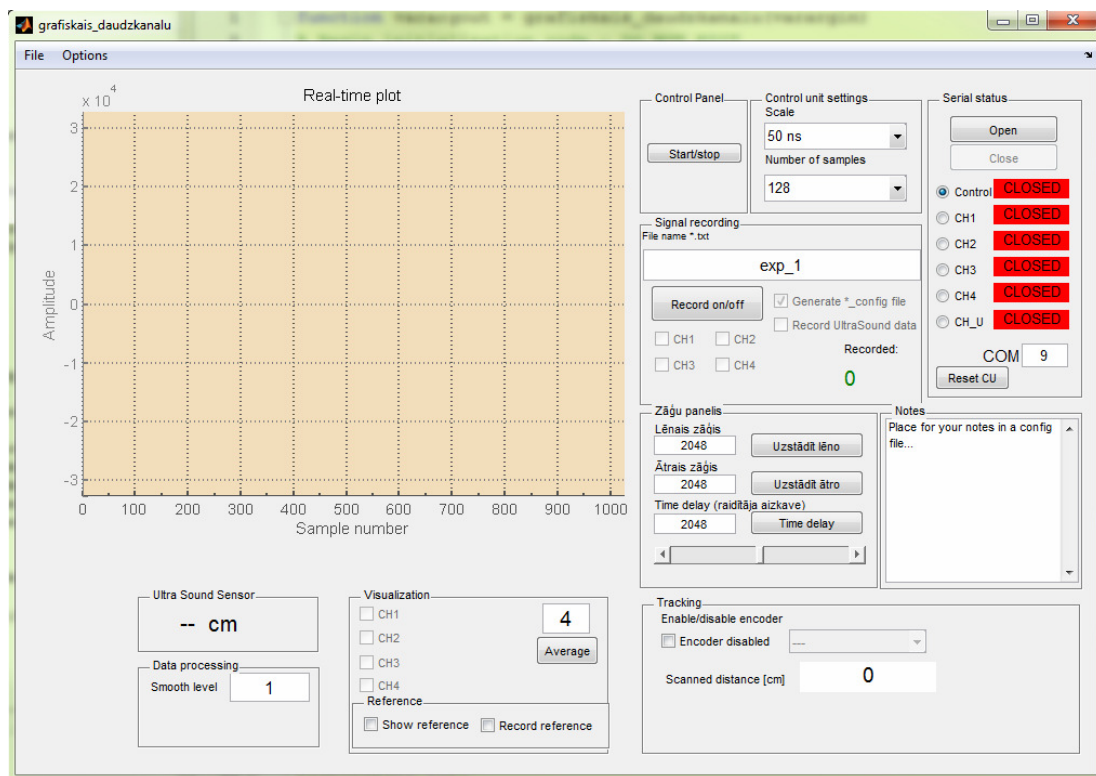


Figure 2.12 Radar software user interface

Radar software (Figure 2.12) is based on MATLAB engine with added features like:

- 4 channel data storing;
- easy radar reconfiguration (time window, samples per trace, etc);
- distance encoder sampling and configuring;
- SEG Y file format support.

2.5. *Hardware reliability improvements*

Since last year a great deal of effort was devoted to make our radar hardware more reliable and user friendly. In this respect a new radar prototype was designed which is mounted into a plastic enclosure (Figures 2.13 and 2.14). This leads to less denial rate and better user experience using this system.



Figure 2.13 Radar prototype (front panel)



Figure 2.14 Radar prototype (rear panel)

3. Viedo transporta sistēmas sensoru tīklu prototipu aprobācija reāliem apstākļiem pietuvinātos scenārijos, kas saistīti ar 3D datorredzes pielietošanu, sensoru datu ieguvī un apstrādi, kā arī ar ceļa infrastruktūras attīstību

3.1. *Real-time object tracking in 3D space using mobile platform with passive stereo vision system*

Real-time object tracking in 3D space is an actual research topic in several domains as robots and smart vehicles. Traditional methods in most cases rely on relatively expensive active elements as radars, lasers or LiDAR's (Light Detection and Ranging). Relatively inexpensive solutions as passive 3D stereo vision based tracking methods yet are relatively slow and therefore unsuitable for time critical systems as Adaptive Cruise Control (ACC) or Advanced Driver Assistance Systems (ADAS). In this paper a method for real-time image processing is proposed that is capable to track an object using only 0.1-0.2ms for processing of each frame and is based on the segmentation in dense point cloud data.

3.1.1. *Related work*

Passive 3D stereo vision for vehicles has been an active research interest for years now [3.7] [3.8] as it can significantly increase safety and efficiency of transportation systems. Existing safety systems mostly use tracking-by-detection, robust, but characterized by slower calculations and in turn slower response times. System described in [3.2] uses multiple cues for pedestrian detection and tracking and takes at least 100ms per frame. Solution mentioned in [3.8] uses evolutionary algorithm for vehicle detection and tracking and takes about 30ms per frame. Approach explained in [3.7] uses structure from motion together with several descriptors for complete dynamic 3D scene analysis that takes more than 300ms per frame. For systems as ACC or a frontal collision detection fast and precise tracking is the most important characteristic therefore detection could be performed on less frequent basis. Modern computer technologies are capable to do real-time stereo vision on CPU as well as on GPU (graphics processing unit)(for a good comparison on stereo algorithms running on GPU see [3.6]). Embedded techniques allow up to 200FPS [3.10]. All this is a well-formed basis for the creation of new tracking methods based on performance of computer hardware and software.

3.1.2. *Proposed method*

The method described in this paper is based on fast execution speed for a robust target tracking using constrained per-frame segmentation of the point cloud data and a 6D Kalman filter for filtering of the position and velocity. An example frame for input and output are given in Fig. 3.1.

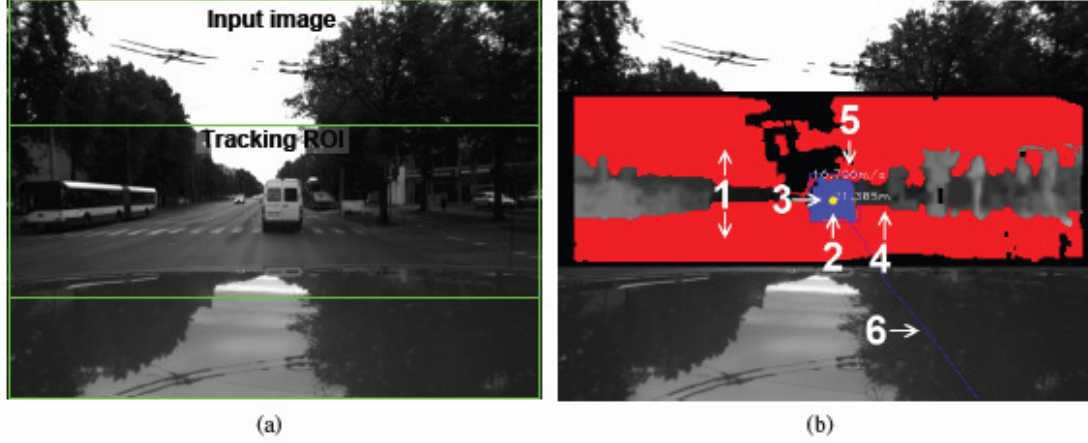


Figure 3.1 (a) Input image (b) Output image showing the ground and sky plane removal(1), segmented surface (2), reprojected tracking point (3), distance to the tracked vehicle (4), speed of the tracked vehicle (5) and reprojected path of the tracked vehicle (6)

The first step consists of acquiring and rectifying of stereo images using the intrinsic and extrinsic parameters calculated during calibration. Next step is calculation of disparity using rectified images. As the method relies on performance then the execution time stereo matching algorithm is highly significant, LIBELAS described in [3.4] was selected for this task. All calculations are done in the absolute units of length and not in pixels therefore allow setting realistic constraints. Calculation into a point cloud can be done with transformation:

$$\begin{aligned}
 W &= d/b + c_{dx}/b \\
 x &= (x_s + c_x)/W \\
 y &= (y_s + c_y)/W \\
 z &= f/W
 \end{aligned} \tag{1}$$

where d is disparity at screen coordinate (x_s, y_s) , c_x and c_y are the x and y of the optical center, b the baseline between cameras, c_{dx} difference between left and right camera x optical center (usually 0 or close to 0) and f the focal length. Main steps are given in Algorithm 1.

Algorithm 1 Tracking algorithm

- 1: Rectify input images and calculate disparity map
 - 2: Calculate point cloud using the disparity map
 - 3: Remove ground plane
 - 4: Calculate ego vehicle position R_T , direction R_R and speed R_K with visual odometry
 - 5: Compute occupancy map and detect targets
 - 6: Init tracking point screen coordinates x_s, y_s with detected values x_d, y_d
 - 7: Segment using the tracking point's screen coordinates x_s, y_s and constraints
 - 8: Calculate centroid in segmented area to get measurement x_m, y_m and check constraints
 - 9: Calculate average z value in segmented area to get measurement z_m and check constraint
 - 10: Update Kalman filter with x_m, y_m, z_m
 - 11: New tracking point is Kalman filter's x, y, z
 - 12: Reproject tracking point to screen x_s, y_s
 - 13: Compensate the target's position, speed and direction
-

3.1.2.1. Ground plane removal

The ground plane creates a smooth gradient – potential reason for segmentation leak and encompassing the whole ground surface. In proposed stereo system the camera height value is used as the point's y coordinate representing the vertical position relative to the cameras in absolute units of length. If cameras are mounted h_c distance from the flat ground, then ground can be removed by checking if point y position is above a certain threshold $y > -h_c$, where $y = 0$ at camera level. In typical case cameras are not perfectly parallel to the ground and the points have to be rotated with angle α around the cameras as origin. There are several known methods to detect ground that would allow the calculation of the angle α . Some are using homography [3.1], v-disparity [3.11] or ground plane detection in Euclidean space [3.9]. Trough testing detection in Euclidean space was chosen. While it is slower than v-disparity because of RANdom Sample Consensus algorithm, it returns better results with smaller error (for comparative study see [3.9]). In an outdoor environments sky has to be removed the same way, because the disparity algorithm tends to calculate erroneous disparity for the sky. The value h_s is the distance to upper cutoff plane. Equation for rotation and thresholding is:

$$D_{x,y} = \begin{cases} D_{x,y} & , (z \cdot \sin(\alpha) + y \cdot \cos(\alpha)) \in [-h_c, h_s] \\ 0 & \end{cases}, \quad (2)$$

where $D_{x,y}$ is disparity at position $(x; y)$ and therefore invalidates all points outside the range $[-h_c; h_s]$ and α is the angle between the ground plane and cameras. Because the execution speed of the system is essential, the ground detection is not performed every frame, but twice a second. The influence of minor road bumps which would cause segmentation problems if the ground is not removed entirely is mitigated in next steps using Kalman filter.

3.1.2.2. Detection

An obligatory prerequisite for the tracking of the object is at least one initial point on its surface. This point is found via plan-view occupancy map, which is used for general purpose obstacle detection in front of the observer. The occupancy map works by point binning. The observed world is divided into x/z bins. Vertical direction is not used because the ego vehicle cannot move in the vertical direction and thus any object after the ground and sky removal is a potential obstacle. Bin size B_s was empirically chosen as 25x25cm as a compromise for speed, precision and the possibility to distinguish smaller individual objects. Bins are assigned a value B_v , which shows how many points are inside the bin. Then maximums are found in the occupancy map which corresponds with individual objects. To ignore small ground irregularities a bin is considered to have an obstacle in it if there is at least B_t points inside it. Obstacles are only searched in a region in front of the vehicle. Point binning is performed and maximums are found using equations:

$$B_v(x, z) = \sum_{i=0}^n p(x, z) \in B_i(x, z) \quad (3)$$

$$\max \left[\sum_{q \in S} G_\sigma(|(x, z) - q|) \cdot B_v(x, z) \right] \quad (4)$$

where $p(x; z)$ is the point, $B_i(x; z)$ is the bin i at position $x; z$, G_σ being the Gaussian convolution operator and S being the size of the kernel. When an obstacle is detected, then one point inside the bin is taken and reprojected as the seed point $(x_d; y_d)$ for segmentation. Fig.3.2(a) shows the reprojected occupancy map where height and color represent the number of points in the bin and Fig. 3.2(b) shows the detected objects with circles reprojected underneath them showing the position.

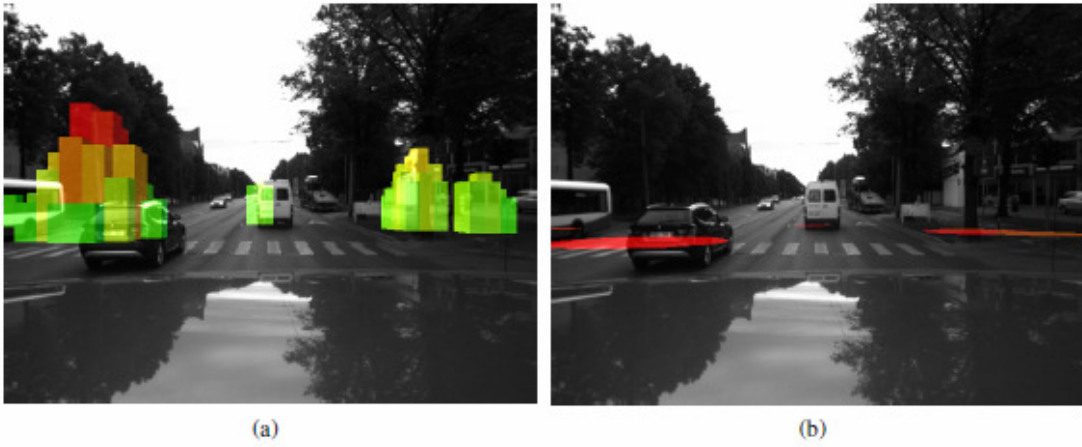


Figure 3.2 (a) Occupancy map projected over the input image (b) Detected objects

3.1.2.3. Segmentation

The detected initial point is assumed as the seed point and afterwards used for the segmentation in the disparity map via constrained flood fill algorithm. Constraints are C_s - the z distance from the seed to the current point and C_p - the z distance from the current point and its parent point (i.e. the adjacent point it came from). The point cloud gets less dense farther from the camera and a compensation value C_d must be added to the constraints. Relation between disparity and distance is:

$$z = \frac{f \cdot b}{d} \quad (5)$$

The partial derivative of this equation gives the amount of distance change when changing the disparity:

$$C_d = \left| \frac{\partial z}{\partial d} \right| = \left| \frac{f \cdot b}{d \cdot d} \right| \quad (6)$$

Segmentation is done by checking every point starting at the seed for these constraints as:

$$S(x, y) = \begin{cases} 1 & |z_{x,y} - z_{x_o, y_o}| \leq C_s + C_d \text{ and} \\ & |z_{x,y} - z_{x_p, y_p}| \leq C_p + C_d \\ 0 & \end{cases}, \quad (7)$$

where z is the depth position in absolute units of length, $(x; y)$ is the point position, $(x_o; y_o)$ is the seed position and $(x_p; y_p)$ is the parent position. Effectively, this operation segments a surface whose points are in a certain depth range. The C_s constraint deals with noise and allows the segmentation to stop at steep gradients, while still allowing different shapes for the targets. The C_p constraint limits the maximum segmentation depth and is used to at least partially escape segmentation leaks in the case that ground plane forms a smooth gradient. The worst case scenario - overflow to horizontally adjacent objects (see Fig. 3.4(a)) is solved in next steps using Kalman filter.

After segmentation the target object is selected and corresponding area is the detected surface. It should be noted that this segmentation can not be used for disjointed objects – it can not segment a part of a larger object as it would converge on the largest perpendicular surface to the observer.

3.1.2.4. Tracking point update

The calculation of the centroid in the detected surface is performed with:

$$C = \frac{\sum_{i=1}^k p_i}{k}, \quad (8)$$

The centroid position is the measured tracking point $(x_m; y_m)$ position in 3D space and the average distance for all points on the surface is the approximate z_m position. This seed point could be erroneous due segmentation leaks (see Fig. 3.4(a)) and subsequently - the reason for losing the tracking target. So before it is used in Kalman filter the position of the point $(x_m; y_m; z_m)$ is validated using following constraints $|x_m - x_{t-1}| \leq C_{xy}$ and $|y_m - y_{t-1}| \leq C_{xy}$ and $|z_m - z_{t-1}| \leq C_z + C_d$, where C_{xy} the maximum $(x; y)$ jump distance per frame, C_z maximum z jump distance per frame, and $(x_{t-1}; y_{t-1}; z_{t-1})$ the tracking point in the previous frame. Constraint for z is different from $(x; y)$, because points projected in 3D space have varying density - points closer to the camera are denser than the ones farther away and therefore distance difference increases when the target moves away from the observer. This is also why density compensation constraint C_d is used.

If the point complies with the constraints, it is used as a measurement for the Kalman filter. Otherwise, the Kalman filter is updated without a new measurement.

3.1.2.5. Kalman filter and reprojection

A standard Kalman filter uses a prediction step and an update step to estimate the state of a system, where measurement and the predicted state must be related with a linear transform. 6D Kalman filter is used to filter targets state space $x_k = (x; y; z; v_x; v_y; v_z)$ which has 3D position and velocity. The state transition model F and covariance Q are defined as:

$$F = \begin{pmatrix} 1 & 0 & 0 & \Delta t & 0 & 0 \\ 0 & 1 & 0 & 0 & \Delta t & 0 \\ 0 & 0 & 1 & 0 & 0 & \Delta t \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$Q = \begin{pmatrix} \Delta t^4/4 & 0 & 0 & \Delta t^3/2 & 0 & 0 \\ 0 & \Delta t^4/4 & 0 & 0 & \Delta t^3/2 & 0 \\ 0 & 0 & \Delta t^4/4 & 0 & 0 & \Delta t^3/2 \\ \Delta t^3/2 & 0 & 0 & \Delta t^2 & 0 & 0 \\ 0 & \Delta t^3/2 & 0 & 0 & \Delta t^2 & 0 \\ 0 & 0 & \Delta t^3/2 & 0 & 0 & \Delta t^2 \end{pmatrix}, \quad (9)$$

where Δt is the time between frames. Then the measurement $z_k = (x_m; y_m; z_m)$ is used to update the Kalman state space x_k . Tuning of Kalman filter parameters allows filtering out erratic jumps and still tracking a fast moving target. Kalman filter also allows calculation of the approximate direction in which the object is traveling relative to the ego vehicle. After filtering the position is reprojected back into 2D plane as the next seed point by doing the reverse of (1) expressed as:

$$\begin{aligned} W &= f/z \\ x_s &= W \cdot x + c_x, \\ y_s &= W \cdot y + c_y \end{aligned} \quad (10)$$

where $(x; y; z)$ is the 3D position of the point filtered by the Kalman filter and $(x_s; y_s)$ is the reprojected 2D point. Reprojection in 2D space instead of using 3D space is for the ease of segmentation as the point cloud represents the 2D image projection into 3D space and thus points do not overlap in such a fashion that would make 3D flood fill behave differently from a constrained 2D flood fill.

3.1.2.6. Ego motion compensation

Ego vehicle motion makes Kalman filtered position relative, but it is possible to compensate it using visual odometry. Here LIBVISO2 was used for fast visual odometry [3.5]. It calculates homogeneous transformation matrix R_A which allows

transforming a point from previous frame p_{t-1} into current frame p_t with relation $p_t = R_A \cdot p_{t-1}$. For motion compensation the translation and rotation must be separated into two homogeneous matrices:

$$\begin{aligned} R_T &= (p_{t(1,4)} \quad p_{t(2,4)} \quad p_{t(3,4)} \quad 1) \\ R_R &= \begin{pmatrix} p_{t(1,1)} & p_{t(1,2)} & p_{t(1,3)} & 0 \\ p_{t(2,1)} & p_{t(2,2)} & p_{t(2,3)} & 0 \\ p_{t(3,1)} & p_{t(3,2)} & p_{t(3,3)} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \end{aligned} \quad (11)$$

Ego vehicle speed now must be calculated. This is done by Kalman filtering the extracted translation matrix R_T . Used Kalman filter is the same as in previous section, but here R_T is used as measurement to get ego vehicle state estimate $R_K = x_k$. To compensate the ego motion the target's position is transformed into global coordinates by:

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} \cdot R_R + R_T, \quad (12)$$

To compensate speed:

$$\begin{pmatrix} v'_x \\ v'_y \\ v'_z \\ 1 \end{pmatrix} = \begin{pmatrix} v_x \\ v_y \\ v_z \\ 1 \end{pmatrix} \cdot R_R + \begin{pmatrix} R_{K(4,1)} \\ R_{K(5,1)} \\ R_{K(6,1)} \\ 1 \end{pmatrix}, \quad (13)$$

Direction is the calculated speed vectors direction. Magnitude of the vector is the velocity in the direction of travel.

3.1.2.7. Tracking multiple targets

As single target tracking is very efficient, then it is possible to track multiple targets using the same method. Only difference is that one ownership relation must be used. That means only one point in the point cloud can belong to one object. If the tested point belongs to another object, then it dismisses the point as if thresholding constraint had been broken. This also reduces impact of any leaks as objects cannot overlap. In case of occlusion the tracker will stop, because C_z constraint will be broken and then detection is used to start tracking when the target is visible again. Example of tracking multiple targets can be seen in Fig. 3.3.

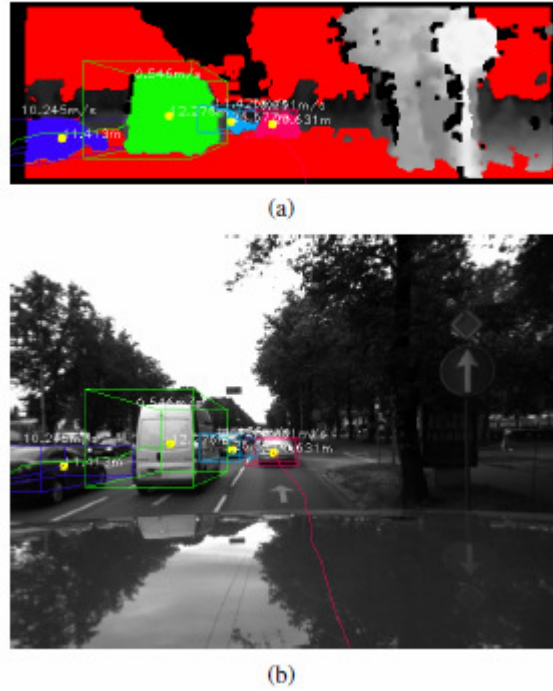


Figure 3.3 (a) Image showing segmented objects (b) Output image showing tracked objects

3.1.2.8. Error recovery

The real-world disparity map could be sparse due to noise or occlusions. As a result, the reprojected 2D seed point can fall into a position where disparity is unknown. The recovery from this state is attempted by searching around the invalid position for a valid point that meets all previous constraints. Point cloud transformation enforces x/y point adjacency (but not z), i.e., adjacent points in the depth map are also adjacent in the point cloud in the x/y direction. This means that the search can happen in the 2D plane around the invalid point in a search window until a valid point is found. The search pattern is a clockwise spiral starting at the invalid point, and therefore appropriate in cases of a noisy disparity map where a valid point is right next to the invalid one, because a regular window search could return a separate object at equal distance as the target (e.g., a vehicle in the next lane).

Other reasons for an invalid value could be broken constraints, as the target moving too fast relative to the frame rate or segmentation leak. In all these cases, error recovery is performed, and if the recovery process fails, then detection is performed on the input images to reacquire the target for tracking.

3.1.3. Implementation

The proposed tracking algorithm was evaluated on a mobile platform by tracking vehicles in front of the ego vehicle.

3.1.3.1. Setup

The setup includes PointGray Bumblebee XB3 Firewire camera with 24cm baseline mounted on a minivan roof-racks 174cm from the ground. All calculations were performed using 4 core 2.9GHz Intel i5 processor.

Developed software uses OpenCV for general purpose IO and drawing, LIBELAS library for fast disparity calculations, LIBVISO2 library for visual odometry, PointGray FlyCapture SDK for synchronized camera input, PointGray Triclops SDK for Bumblebee XB3 stereo rectification. Written in C++ and many parts are multi-threaded using OpenMP. Input images has the resolution of 640x480px and disparity is calculated and tracking done on a 640x210px region. Frame rate for this setup is on average 40FPS.

3.1.3.2. Configuration

Constraint	Value	Description
h_c	120cm	Camera height from the ground was 174cm, but noise and uneven surfaces require a safer value.
h_s	300cm	Sky plane distance above the cameras. More than the largest vehicle to be tracked.
α	1°	Camera angle relative to the ground. Facing slightly downwards.
C_p	200cm	Large enough to suppress the noise, but less than the length of most vehicles.
C_s	400cm	Allows segmentation even if it has sloped (turning) or uneven (objects sticking out the back) surface.
C_{xy}	70cm	Smaller than the distance between two side by side vehicles, so it allows to reduce leak impact.
C_z	150cm	About the maximum z jump distance in a typical city traffic, because of leaks and noise in the point cloud.

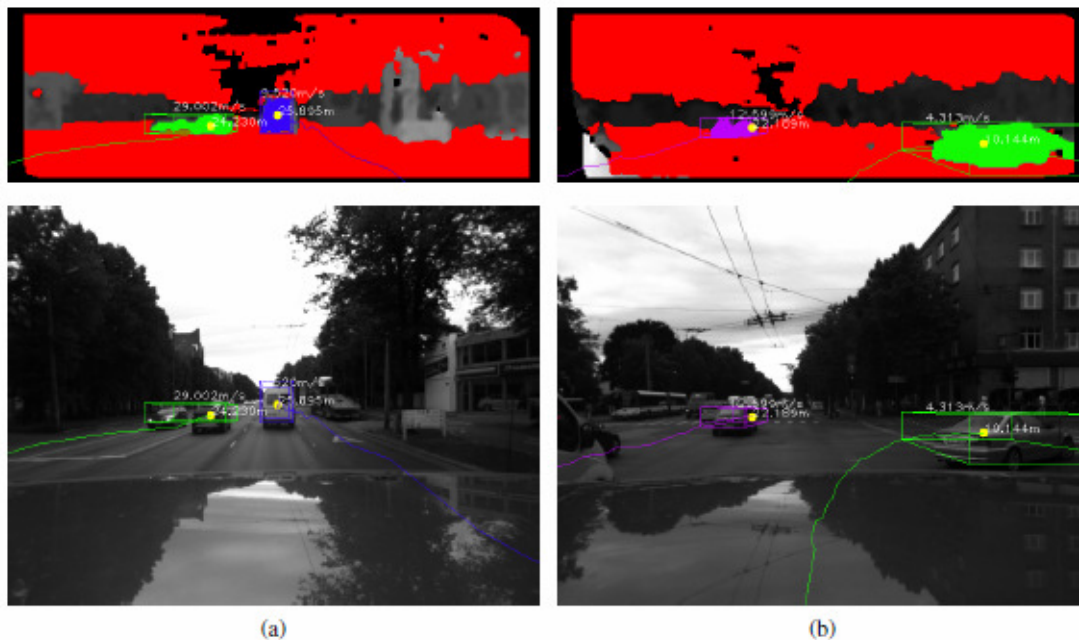
3.1.4. Experimental results

Method, implemented on the basis of described algorithm, was evaluated on a mobile platform by tracking vehicles in several urban scenarios, as well as on datasets used in [3.3]. During the tests the proposed method was able to track a vehicle constantly until it either went out of the field of view or was in a distance exceeding 50 meters. The tracking itself typically took about 0.1-0.2ms depending on the distance to the target (as closer targets have more segmented points and that requires

more calculations) while disparity calculation and visual odometry took about 15-25ms running in parallel. Video demonstration of the system can be seen at [3.12].

An example of segmentation leak induced by close vehicles in larger distance is given in Fig. 3.4(a). As result the centroid position is calculated somewhere on the other vehicles surface - it exceeds the C_{xy} jump constraint and therefore corresponding frames are dismissed by the Kalman filter.

In Fig. 4.4(b) it can be observed that the target vehicle is turning fast to the right and almost out of the field of view of the cameras. The ego vehicle was turning at that intersection as well and tracking was not lost during the turn. The problem can arise when the fast turning target stops as the Kalman filter has some delay which moves the tracking point too far and that can cause tracking loss. It is possible to tune the Kalman filter parameters to have less delay, but then it would have less robustness to noise. If the tracking is lost then the obstacle detector can be used to rediscover the target.



**Figure 3.4 (a) Output showing segmentation leak among closely spaced vehicles
(b) Output showing tracking of a turning target**

3.1.5. *Approbation*

Approbation of the developed prototype was performed together with American car club [3.13] and society “MB Club.lv” [3.14] – members of the Association of the Latvian car clubs [3.15]. Approbation included test drives with a car equipped with the developed prototype. Setup of particular test car is shown in Fig. 3.5. Test drives were performed using different road types including city streets and intercity highways during different lighting conditions including daytime and late evening time characterized by darkness. Approbation showed that particular solution has some minor flaws to be resolved (Appendix 3, Appendix 4) but overall is capable to be extended to commercial available technology.



Figure 3.5 Setup of the test vehicle during approbation activities

3.1.6. Conclusion and Future Work

In this work a robust real-time tracking method for traffic related scenarios was proposed that is able to track vehicles using 0.1-0.2ms per target and is configurable using main constraint parameters in absolute units of length. It was noticed, that while the approximated constraint values can be used there is still some experimental fine tuning necessary for best results. The segmentation could be improved by searching a volume in 3D space while knowing the size of the target - this would allow tracking partially obstructed objects. Maximum tracking distance could be increased by increasing the baseline of the system.

The tracking performed in the point cloud allows the usage of this method with LIDaR or Kinect - in this case performance will increase as the slowest operation is the disparity calculation and the visual odometry (which can also be calculated from point clouds). During tracking of multiple targets the performance can be increased by running all the individual calculations in parallel. Other potential performance improvements include usage of GPU or embedded solution that makes the tracking more robust and appropriate for faster targets. The improved system is intended as a prototype for Advanced Driver Assistance system and Adaptive Cruise Control system.

3.2. Smart road studs for dangerous road situation warnings

Safety is an important aspect of transportation systems for both, the drivers and pedestrians. Significant part of road accidents are related to driver inability to react in time on sudden hazardous situations, such as pedestrians or wild animals on the road,

a car stopped in case of emergency, or a slippery pavement segment. In this paper we propose an embedded system for driver visual notification in case of a hazard. The system can be unobtrusively added to existing road infrastructure, it is solar-powered and can function autonomously without human intervention. The evaluation shows, that proposed solution is able to detect several types of hazardous situations and report them to drivers.

Initial information about related work, approach, hardware, solar power supply and packaging is given in [3.16].

3.2.1. Hardware

The hardware of the IMilePost embedded device was slightly redesigned after first real world tests. Main changes included alternative temperature and humidity sensor SHT21 that was better suited information exchange protocol as well as alternative pyroelectric infrared sensor with integrated controller that was characterized by improved sensitivity and therefore longer detection distance. The hardware structure of redesigned embedded device is given in Fig. 3.6 and first prototype – in Fig. 3.7.

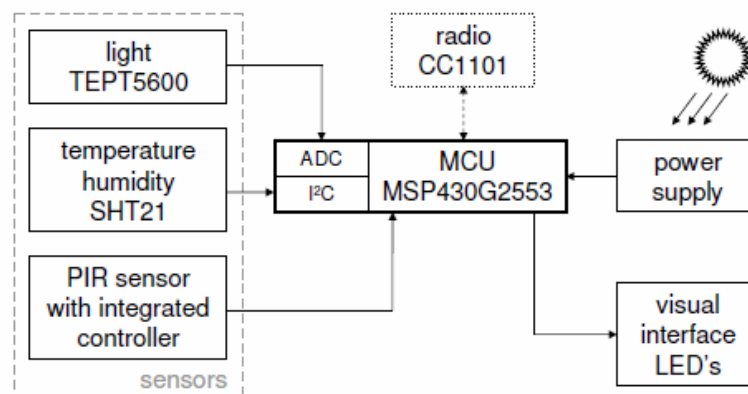


Figure 3.6 Structure of redesigned IMilePost embedded device



Figure 3.7 First prototype of IMilePost embedded device

3.2.2. Software

Flowchart of IMilePost embedded software is shown in Fig. 3.8.

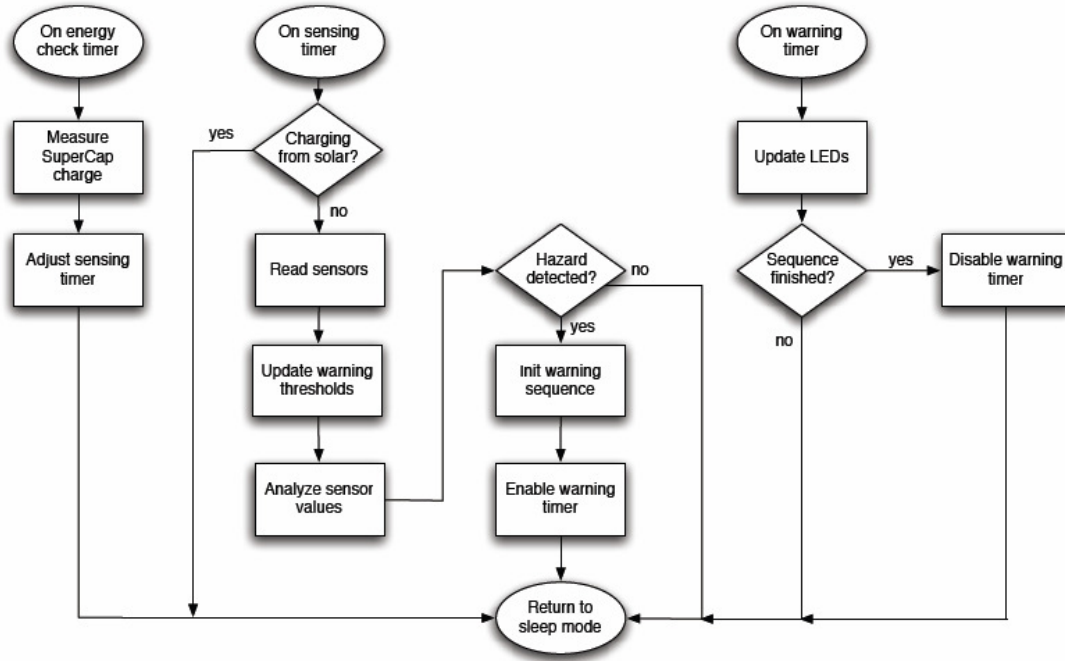


Figure 3.8 Flowchart of IMilePost embedded software consisting of three parallel tasks, initiated by system timers

During startup of the system (not shown in flowchart for simplicity) sensing and energy check timers are initiated. Periodically sensing interval is adapted, based on available energy budget.

In each sensing cycle, daylight time check is performed first. System is operating only in dark time of the day. All digital and analog sensors are being sampled, and warning thresholds are updated based on long-term averages. Sequential hazard detection is performed, based on priorities, described above. If at least one hazard is detected, warning sequence is initiated and warning timer is enabled.

In each warning cycle, LED status is updated according to actual displayed hazard type, and timer is disabled, when warning sequence is finished.

3.2.3. Evaluation

First evaluation of the experimental device was performed through tests of detection of approaching vehicles head lights. These tests were carried out during time of darkness (after 11PM) in urban environment on illuminated street. Weather conditions were typical for late autumn - it was cool and moist. The sensitivity of the experimental device is designed as adaptive configurable value. During this activity three sensitivity levels were tested - 100 m, 50 m, and 15 m. Each test scenario was performed with the set of 30 approaching vehicles.

During test with most sensitive configuration 83% of approaching vehicles were successfully detected (*true positive*). 7% of approaching vehicles had defect right head light and therefore not detected (*false negative*). 10% of approaching vehicles followed another approaching vehicle by small distance and therefore did not induce separate detection case. As peculiar *false positive* test case could be mentioned detection of a bicycle with working head light.

During test with medium sensitive configuration 90% (*true positive*) of approaching vehicles were successfully detected. Remaining 3% of approaching vehicles had weak head light reflectors, 3% drove during time of darkness without head lights turned on (!), and 3% followed another approaching vehicle by small distance.

During test with least sensitive configuration 87% (*true positive*) of approaching vehicles were successfully detected. The reasons for *false negative* cases were similar as in two previous test scenarios - 10% due following of another approaching vehicle by small distance as well as 3% due weak head light reflectors.

Conclusions from this test session were:

1. *True positive* rate of detection of approaching vehicles head lights could be assumed as sufficient for practical purposes but there is a need to determine critical boundary for vehicles with weak head light reflectors.
2. It is possible that there is a need to determine exact number of vehicles in approaching column as it could be significant according situation DangerPassingVehicle.

Second evaluation of the experimental device was performed through tests of detection of approaching vehicles head lights in urban and non-urban environment as well as detection of approaching human beings in non-urban environment. Other test parameters were similar to first test session. Each vehicles-related test scenario was performed with the set of 50 approaching vehicles but the human test subjects-related test scenario - with 12 approaching human test subjects.

During test in urban environment 76% (*true positive*) of approaching vehicles were successfully detected. The main reason for *false negative* cases were selection of a street with 2 lanes in each driving direction for the experiment - therefore vehicles from the second lane were detected just partially. Following tests in non-urban environment with similar lane configuration and much higher *true positive* rate conformed that this relatively low rate is characteristic for particular urban environment with illuminated streets that is not the primary environment for proposed solution.

During test in non-urban environment 94% (*true positive*) of approaching vehicles were successfully detected. The main reason for *false negative* cases were following of another approaching vehicle by small distance.

During human test subjects-related test scenario experimental device was placed in non-urban environment and test person walked towards the device from the 40 meters distance. In the moment when device detected approaching person the actual distance between the device and the person was measured. Maximal detection distance was 24 meters, minimal distance - 6 meters, and average distance – 16 meters. In the 66% of all test cases measured distance was greater than average distance.

Conclusions from this test session were:

1. *True positive* rate of detection of approaching vehicles head lights could be assumed as sufficient for practical purposes in typical environment for particular application.
2. The actual average detection distance for particular PIR sensor requires the placement of similar devices each 40 meters. That is less than typical distance between regular road side items but it could be applicable for particular locations with high wild animal density.

3.2.4. Conclusion and Future Work

This work describes an autonomous solar-powered embedded system for detection of particular dangerous road situations and creation of corresponding warnings to drivers using visual interface. The system was evaluated using real world scenarios including urban and non-urban traffic during time of darkness. The results show, that the system is able to detect separate approaching vehicles with reliability at least 83%, and detect separate approaching human test subjects in the average distance of 16 meters. Therefore it is suitable for warning of the drivers about particular dangerous road situations. The future work includes development of additional functionality for detection of other dangerous road situations as well as expansion of the hardware part with the aim to create specific homogeneous or heterogeneous wireless sensor network.

3.3. Published results

The results of real-time object tracking in 3D space related activities are described in paper „Real-time object tracking in 3D space using mobile platform with passive stereo vision system” [3.17] as well as presented in the International Conference on Signal Processing and Imaging Engineering (ICSPIE 2013, October 4-6, 2013) in Hammamet, Tunisia.

The results of smart road stud related activities are described in paper „IMilePost: Embedded Solution for Dangerous Road Situation Warnings” [3.18] as well as presented in the 1st International Conference on Artificial Intelligence, Modelling and Simulation (AIMS 2013, December 3-5, 2013) in Sabah, Malaysia.

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4. Plaukstas attēlu un ķermeņa muguras formas datu reģistrācijas un informācijas apstrādes sistēmu aprobācija

4.1. *Biometric person recognition system*

During previous year, biometric recognition system was developed. System allowed for person recognition using palm vein pattern, making it potentially safer than many authorization systems, as it is based on biological property that is hard to acquire without person knowing that. During this year system was tested in real life. Changes were made to biometric data processing algorithms to reduce chance of false positives and false negatives.

Our developed system consists of 3 main modules:

- personal computer, with appropriate software;
- module that connects our system with already existent electronic door locking system (relay module);
- palm capturing device, consisting of camera and LED control module.

More in depth these modules are explained in following sub-section.

4.1.1. *Development of biometric system*

4.1.1.1. *Connecting our system to existing door control system (relay module)*

Requirement for communication with existing system was to provide galvanically isolated switch that has to be closed to unlock the door. Simple low voltage relay was chosen to provide isolation. To increase reliability and provide some basic safety against errors in software, band pass filter was inserted between output of computer, and driver of relay, thus output signal from PC has to be toggled in order to open the door (Figure 4.1). This means, that door won't stay open if computer hangs up in state when output level is high, as oppose to directly controlling relay by high/low states from computer. Interfacing with computer is done by using FT232RL chip.

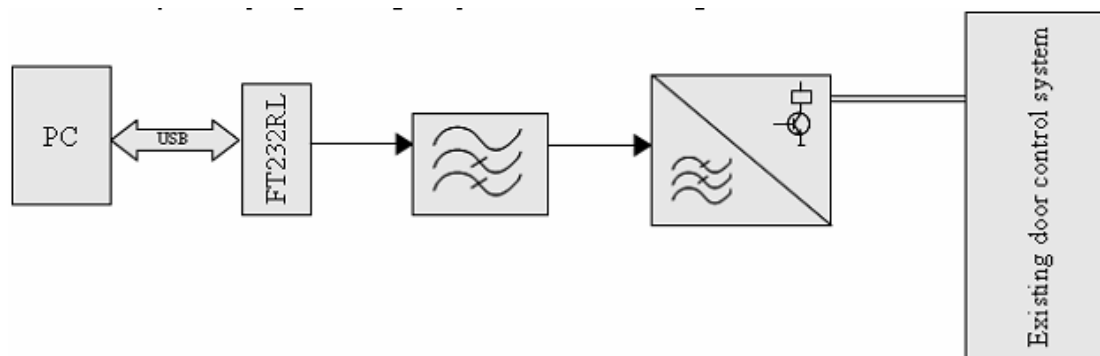


Figure 4.1 Connection with existing door locking system

4.1.1.2. Palm capturing device

Palm capturing device consists of mechanically rigid body, Videology 21K352 USB-C camera, LED control board, optics for camera. Camera has 1/4" Sony Ex-view® CCD, combined with IR transmissive objective and cold mirror, provides ability to acquire images of palm in near infrared spectrum, widely used to capture images of blood vessels in human palm. Illumination is provided by 16 LED's emitting 850nm light.

To inform person attempting to unlock door, two information LED's are provided. Yellow - palm is placed correctly, attempting to recognise person. Green – recognition successful, door is unlocked.

4.1.1.3. Software

Biometric recognition software is complement with external hardware, and is responsible for determining if person is allowed to enter through door or not.. Even though multithreading is used to improve performance of software, by splitting workload between processor cores, algorithm still is following simplified program flowchart provided in Figure 4.2.

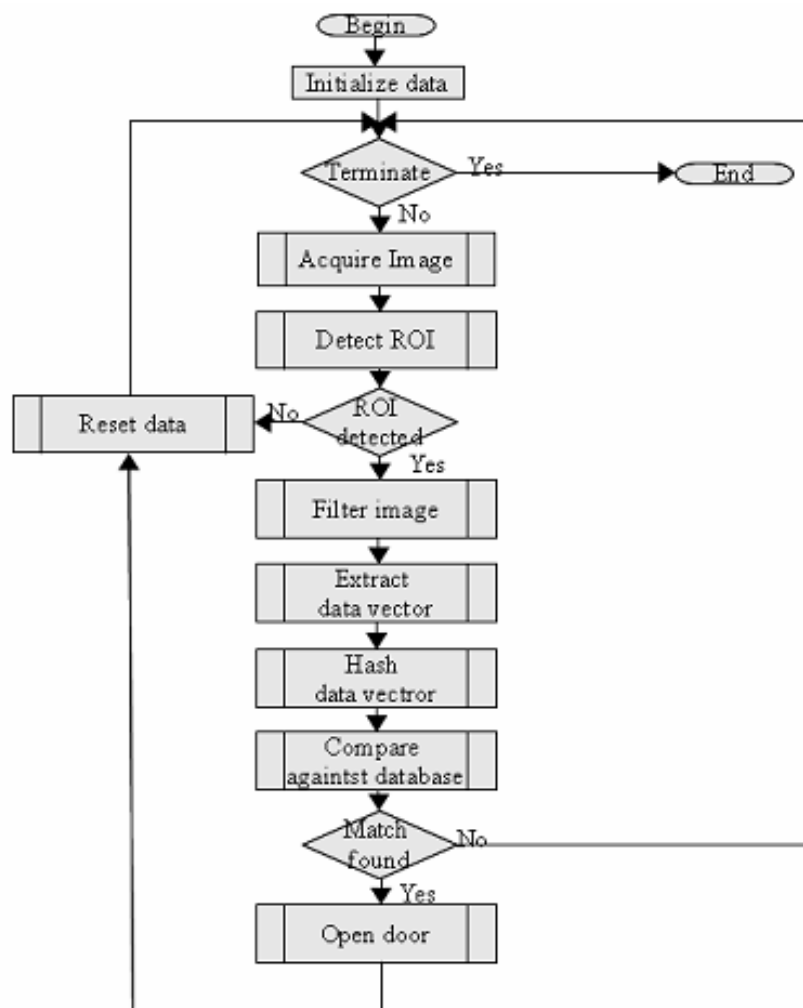


Figure 4.2 Simplified flowchart of recognition software

Image filtering is done by using Fast NH-CMF [4.1] and result is added to buffer, reducing noise and enabling to detect blood vessels not visible by filtering just one image.

Extracting data vector is done by dividing region of interest into cells and finding maximum vector in cell. As practical tests has shown this approach is prone to cases where there are multiple blood vessels (resulting in "jumping vector") in one cell, or where one vessel is located on border between cells (can result in "jumping vector" in multiple cells). To reduce these effects, weighted summation of extracted data vectors is done. This summation is done to each vector element individually before hashing is done. This results in value being same as value of vector from ROI, if always one vector in cell is detected, and weighted midpoint in case vector is "jumping". Actual value is closer to value detected more often. Contribution to performance is visible in Figure 4.3 (without summation) and Figure 4.4 (with summation).

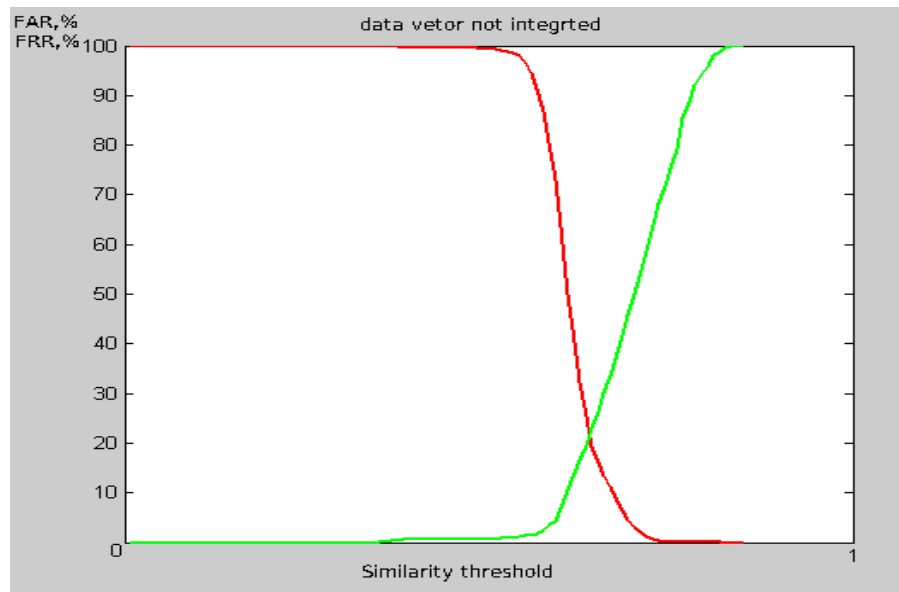


Figure 4.3 FAR and FRR without using summation of data vector

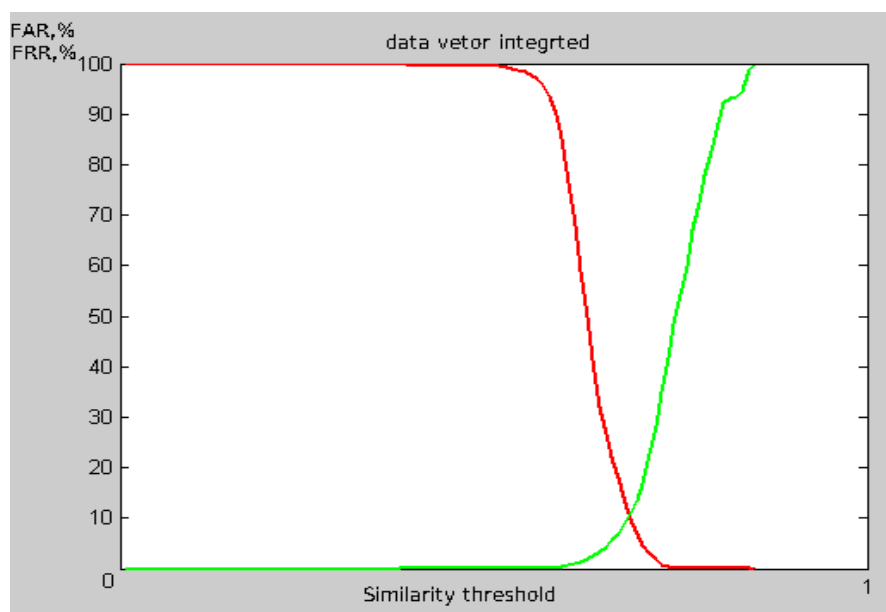


Figure 4.4 FAR and FRR using summation of data vector

Hashing is done using Biohash [4.2], providing one-way data conversion from values that describe vein pattern, into sequence of bits (biocode). If it were possible to reconstruct data from stored biocode into vectors describing most intensive vectors, it would be also possible to reconstruct image necessary to cheat system into preceiving image shown to camera as palm shown by person described in database, leading to opening of door.

In case person has been recognised, or if palm has left camera view, buffers used for summing filtered image and for summing data vectors.

4.1.2. Possible further improvements

It is still possible to further improve system, by improving ROI detection, resulting in more stable vector location, meaning less "jumping vectors" will be present. Another weak point is extraction of data vector, being fixed grid it is unstable in cases where blood vessel is at border of cell, as well as it is prone to losing data in more dense image parts, and extracting less stable vectors or even noise in places with less blood vessel density.

4.1.3. References

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4.2. *Kermeņa muguras formas datu reģistrācijas sistēmas aprobācija*

During last year project entered approbation phase. We collaborated with specialists from the field of medicine and patient rehabilitation in order to obtain professional feedback for applicability of our posture monitoring system, necessary prototype improvements and further development strategies of hardware and software to improve overall medical utility of the method. Our experimental prototypes were tested with real patients in both private and state medical institutions and received a number of suggestions for possible improvements, however, an overall positive feedback was received about system potential for medical applications. Based on received feedback we developed a new improved prototype which entered second approbation stage.

Also several publications and presentations were done covering the results of new innovative methods used in technical part of the posture monitoring system.

Results obtained in this period:

- approbation of 16 sensor prototype device;
- development of new improved prototype device;
- approbation of 2nd 63 sensor prototype device;
- publications and exhibitions.

4.2.1. First 16 sensor prototype approbation in “Unihouse Ltd”

Our first prototype [4.3] was approbated in “Unihouse Ltd” [4.4]. “Unihouse Ltd” is a technical orthopedics company, which deals with various types of limb prosthesis, orthosis, production and adaptation. Company staff includes some of the leading Latvian specialists in the field of orthopaedics. The aim of approbation was to evaluate systems utility in orthopaedics and physiotherapy. Approbation was performed in real life conditions, working with teenage (13-15 years old) patients with considerable posture defects, and was controlled by medical specialist.

During approbation process a number of possible improvements for the prototype device were pointed out and amended, such as sensor integration in sport style jacket for more facilitated use and sensor mounting on patient, more clear posture model visualisation, and improved functionality of data processing application. Also our technical specialist participated in physiotherapy classes to obtain better insight about specific monitoring and feedback requirements in physiotherapy process.

Several imperfections were emphasized such as limited posture measurement resolution, error of obtained posture model, requirement for more convenient sensor integration and reduction of data acquisition module size. However, overall feedback for possible system application in posture monitoring and feedback was positive. It was suggested that system could be applied as home exercise set to help scoliosis patients perform correct posture after treatment with hard braces. Another potential user group can be teenagers, who have potentially hazardous posture habits, but the deformations have not developed as far to diagnose scoliosis. System could help to improve posture and reduce development of spine deformations.

Full approbation review form “Unihouse Ltd” can be found in Appendix 6.

4.2.2. Development of new prototype with 63 sensor nodes

Taking into account results from the first approbation stage a new prototype was designed. To improve system resolution and accuracy the amount of sensors was increased almost four times reaching 63 sensors. To implement such an improvement a new method for sensor data acquisition was designed. Method is particularly effective for data acquisition from network of large number garment embedded sensor nodes. For new prototype the sensor nodes and data acquisition board were redesigned in order to implement our data acquisition method, reduce size of the hardware and allow more convenient hardware integration into clothing. Several features and improvements for the prototype were added, during approbation process.

4.2.2.1. Efficient data acquisition

In order to implement effective real-time data acquisition from sensor network and at the same time allow relatively easy sensor node integration into garment, a new method for data acquisition was designed [4.5]. Data acquisition was achieved by connecting devices in line topology (Figure 4.5). This allows to overcome addressing problems which occur in networks with large number of nodes. Method also reduces number of wires and provides simple wiring structure for convenient integration into garment or similar medium. At the same time method requires only conventional low-power hardware and provides reasonable data transfer speeds, which are essential aspects in number of applications.

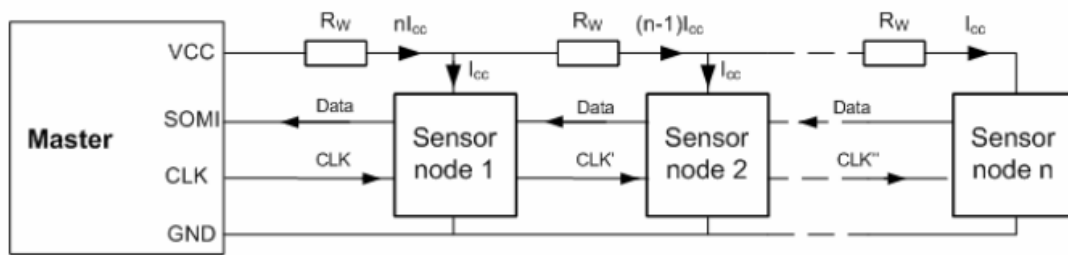


Figure 4.5 Structure of the sensor network [4.5]

Method is based on daisy-chained SPI, however several modifications have been applied, such as clock signal repetition in each sensor node. This reduces the network to multiple relatively simple and independent links between two adjacent sensor nodes in chain. The whole network can be formed with only 4 wires in total: 2 communication lines which connect sensors in series and 2 parallel power supply lines. In theory method allows to connect several hundred sensor nodes using conventional low-cost hardware (Figure 4.6).

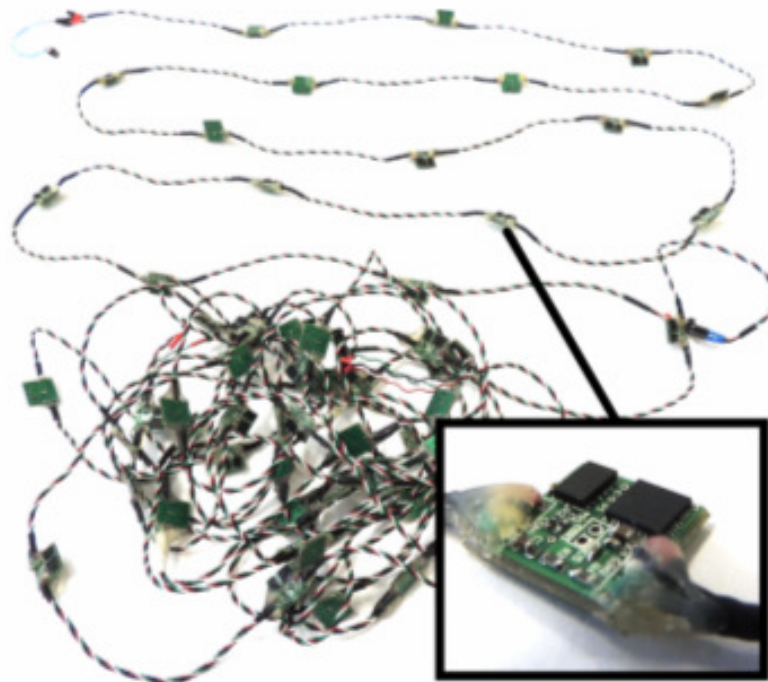


Figure 4.6 Sensor network with line topology [4.5]

After sensors have been connected in line, their layout can be customised depending on application, however, the line topology is always maintained. Sensor network was embedded in wearable garment according to layout visible in Figure 4.7. After first tests during approbation for more convenient and robust system operation the sensor network was integrated in custom made orthosis which was developed by Tonus Elast Ltd (Figure 4.10).

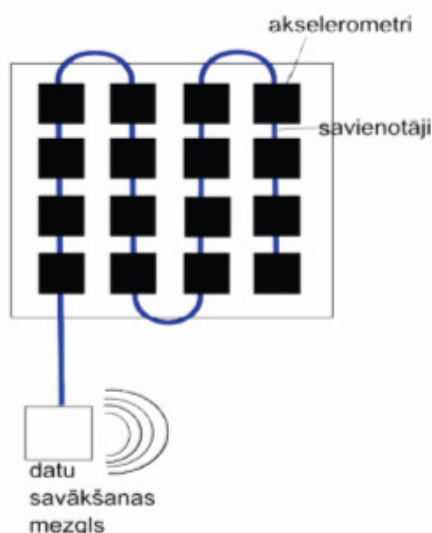


Figure 4.7 Sensor node layout on surface

4.2.2.2. New sensor node design

In order to implement our data acquisition method a new sensor node was designed. Each node consists of acceleration sensor LSM303DLHC, microcontroller MSP430G2553 and few miniature external passive components resulting in total size of just 13 x 13 x 2 mm (Figure 4.8). These nodes were specifically designed for connection with our data acquisition method and include all the necessary hardware. The on board microcontroller is the key component which provide interface between digital acceleration sensors and our sensor network topology. It also provides clock repetition with integral analogous comparator, thus reducing the number of external components and reducing total size of the sensor node.

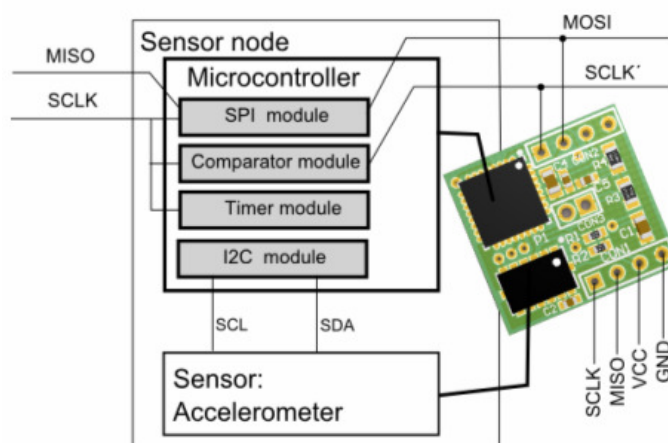


Figure 4.8 Structure of the sensor node [4.5]

4.2.2.3. Data acquisition and processing

For data acquisition from our network with line topology a new data acquisition board was custom designed. The board can be divided in several modules depending on their task:

- Data acquisition module is based on microcontroller MSP430G2553, and is directly connected to acceleration sensor network. It acts as a master for sensor network communication, receives all sensor data and transfers them to wireless module.
- Wireless module is based on Bluetooth transceiver BTM-222. It receives data from data acquisition module and transfers it to portable computing device, for example smartphone or tablet.
- Power module consists of 3.7V 3000mAh lithium polymer battery pack, voltage regulator TPS63031DSKT and battery charging circuit MAX1555. It provides power for both data acquisition board and sensor network and can last for up to 40 hours on a single charge.

The data acquisition board was enclosed in protective casing. The casing was custom CAD designed and manufactured with 3D printer (Figure 4.9).



Figure 4.9 Data acquisition board

An enhanced version of Android data processing application was developed to process data from all 63 sensors and draw corresponding posture model. Several other features were added such as ability to store different posture models, statistical graph of deviations of posture in time, etc. In Figure 4.10 are visible the new prototype applied to human back and also corresponding posture model from data processing application.

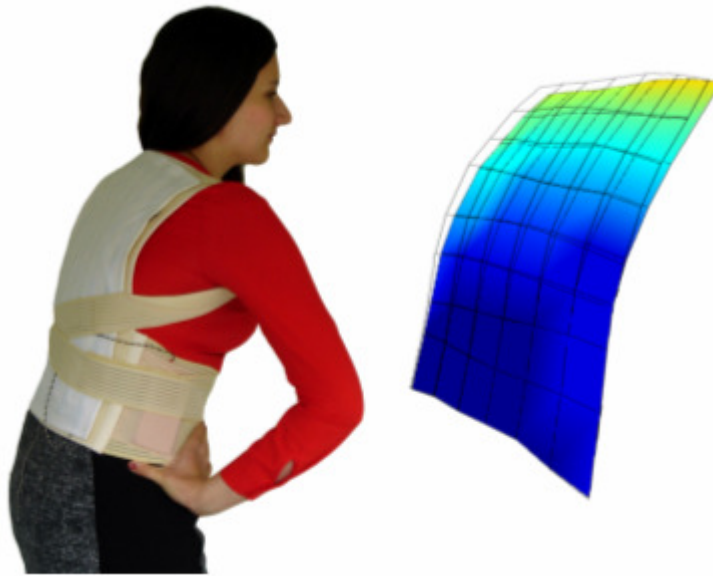


Figure 4.10 Sensor network embedded in orthosis and corresponding posture model

4.2.3. Second 63 sensor prototype approbation in rehabilitation centre “Mēs esam līdzās”.

The second prototype was approbated in rehabilitation centre “Mēs esam līdzās” [4.6]. This rehabilitation centre mainly deals with cerebral palsy patients, especially children with different movement disabilities. The aim of the approbation was to evaluate prototype operation in real rehabilitation conditions, when medical staff is using the system in work with real patients, and to evaluate systems potential for assisting the rehabilitation process.

During the approbation process (Figure 4.11) there was a close cooperation between the staff of Institute of Electronics and Computer Science and rehabilitation centre to improve the utility and convenience of experimental system. Based on recommendations from staff of rehabilitation centre a number of improvements of the system were introduced. In data processing application several new features were added such as more detailed user statistics. Also it was suggested to reduce the sensitivity of certain sensors in order to allow user more free arm movements before generating feedback alert, as it is necessary for users to perform certain actions during the rehabilitation trainings. Also based on several suggestions the application was modified to become more user friendly.

In addition, more convenient solution for the wearable harness was found in collaboration with Tonus Elast Ltd. The sensors were embedded in custom made orthosis. This solution also increased the protection of the electronic components, which made prototype device more robust to mechanical damage.

During the approbation process system proved to be useful in work with kids and teenagers who are diagnosed with decreased body muscle tonus and have posture defects. It was suggested that the system could potentially be used in rehabilitation, orthopedics and physiotherapy. Commercialization of such a system will give benefit in economic development.



Figure 4.11 Prototype approbation in rehabilitation centre "Mēs esam līdzās"

In addition, medical staff from rehabilitation centre in collaboration with researchers from Institute of Electronic and Computer Science participated in "25th European Academy of Childhood Disability" (EACD 2013), where they presented poster "Virtual Reality Rehabilitation System for Children with Cerebral Palsy" [4.7], which was based on the results obtained in approbation process.

Full approbation review form rehabilitation centre "Mēs esam līdzās" can be found in Appendix 7.

4.2.4. Published results

During last year of the project several scientific publications have been done covering different parts of our system. Publication about our first prototype was presented in "2nd International conference on Medical Information and Bioengineering (ICMIB2013)", and was published in "Journal of Medical and Bioengineering" [4.3]. Some innovative sensor network data processing ideas were presented in "17th International Conference Electronics 2013" [4.8]. The new data acquisition method described in section 4.2.2 was presented in "2013 IEEE Conference on Open Systems" [4.5]. Some of the results obtained during approbation process in rehabilitation centre were presented in "25th European Academy of Childhood Disability" [4.7]. In addition, some research results were described in master thesis by R. Cacurs [4.9].

Our system was presented in several exhibitions to rise popularity of the research results. Our experimental prototype was presented in 20th International trade fair for innovative electronics production "Productronica 2013", held in München, Germany. Also system was presented in exhibitions "Innovations in fashion and textile industry" held by Baltic Fashion Federation in Art Academy of Latvia and international invention exhibition "2nd International Invention Exhibition MINOX 2013".

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5. Uz rotācijas leņķiem balstītas datu pārraides iekārtas prototipa aprobācija reāliem apstākļiem pietuvinātos scenārijos

Pētījumi bija saistīti ar uz rotācijas leņķiem balstītu ortogonālo transformāciju izpēti. Šo pētījumu galvenie rezultāti ir sekojoši:

- izstrādātas jaunas Vispārinātā Elementārā Jakobi Rotatora arhitektūras (potenciāls pieteikums patentiem);
- atsevišķi šo arhitektūru varianti realizēti uz FPGA bāzes;
- izveidots strādājošs Simulink modelis uz Vispārināto Unitāro Rotāciju (VUR) balstītai sakaru sistēmai;
- atsevišķas Simulink modeļa sastāvdaļas jau ir realizētas uz FPGA bāzes (piem., Jakobi rotators, SVD algoritms).

Līdz gada beigām ir plānots pabeigt arī reālā laikā strādājošu maketu uz FPGA bāzes.

Pētījumu rezultāti apkopoti divās publikācijās [5.1] [5.2]. Divas citas publikācijas [5.3] [5.4] ir iesniegtas un gaida publicēšanu nākošajā gadā. Rezultāti ir bijuši par pamatu arī vienam promocijas darbam [5.5].

5.1.1. Main research directions

- Novel classes of real and complex (unitary) transforms (1D&2D);
- novel parametrical DeRe (like wavelets) filters (1D&2D);
- shape resonance;
- novel data transmission systems (GONDM);
- Matlab/Simulink Toolbox;
- tools for automation of VHDL/Verilog code generation of “angular” devices;
- architectures for rotators (rotation cells).

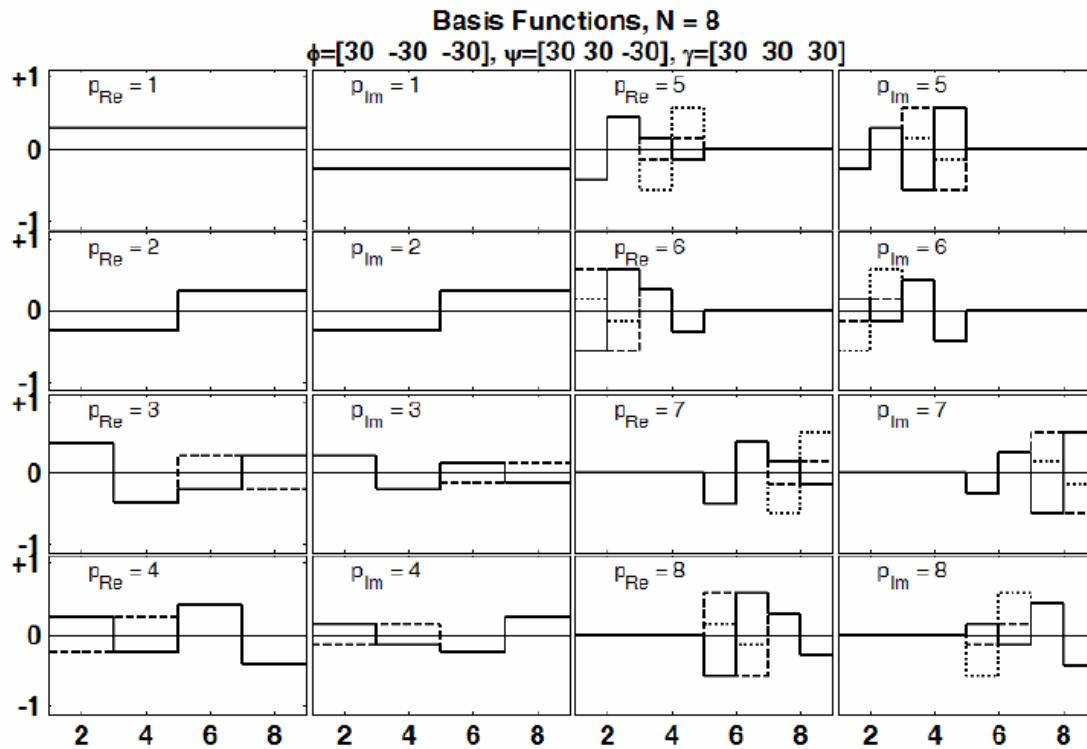


Figure 5.1 Parametriskās Hāra funkcijas ar nulles vidējo vērtību

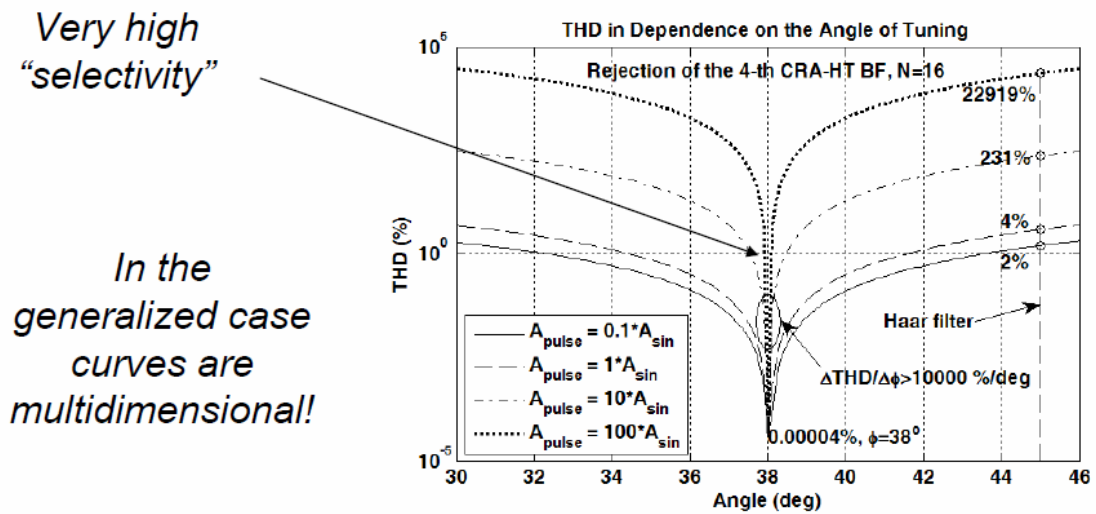


Figure 5.2 DeReFiltering of single BF “Shape resonance”

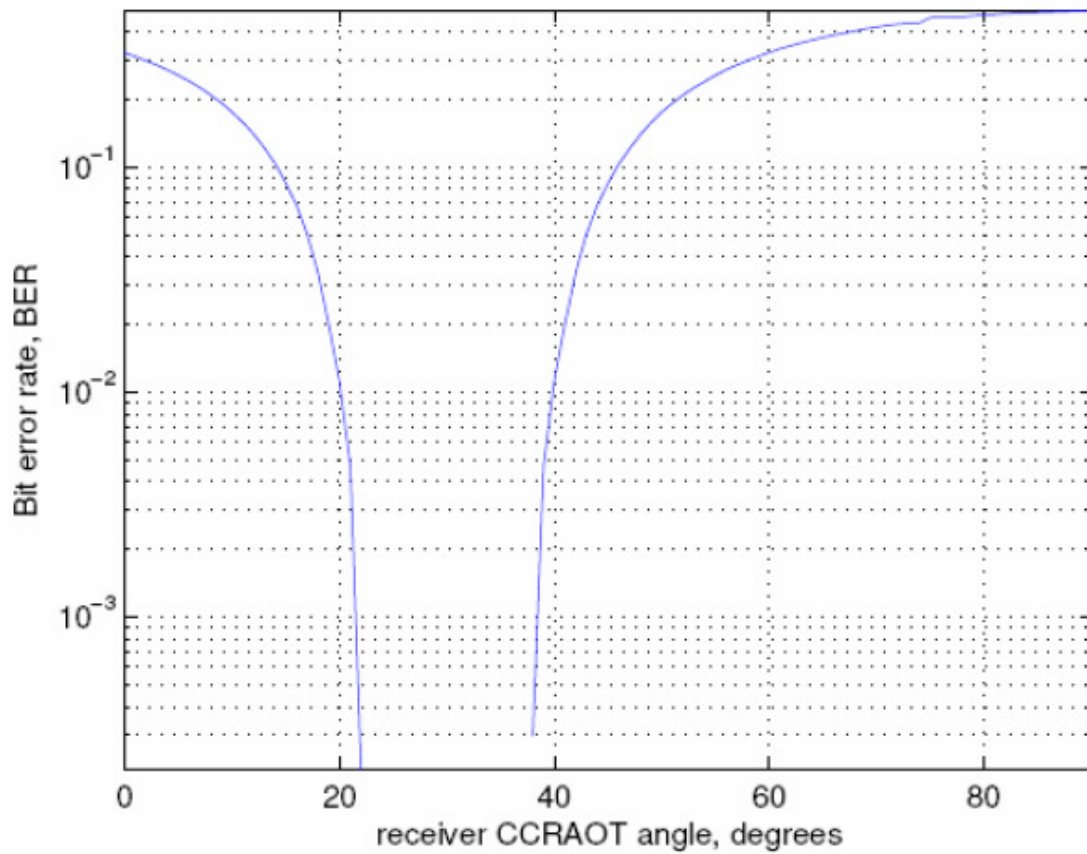


Figure 5.3 Leņķiskā rezonanse 30° VUR sakaru sistēmā

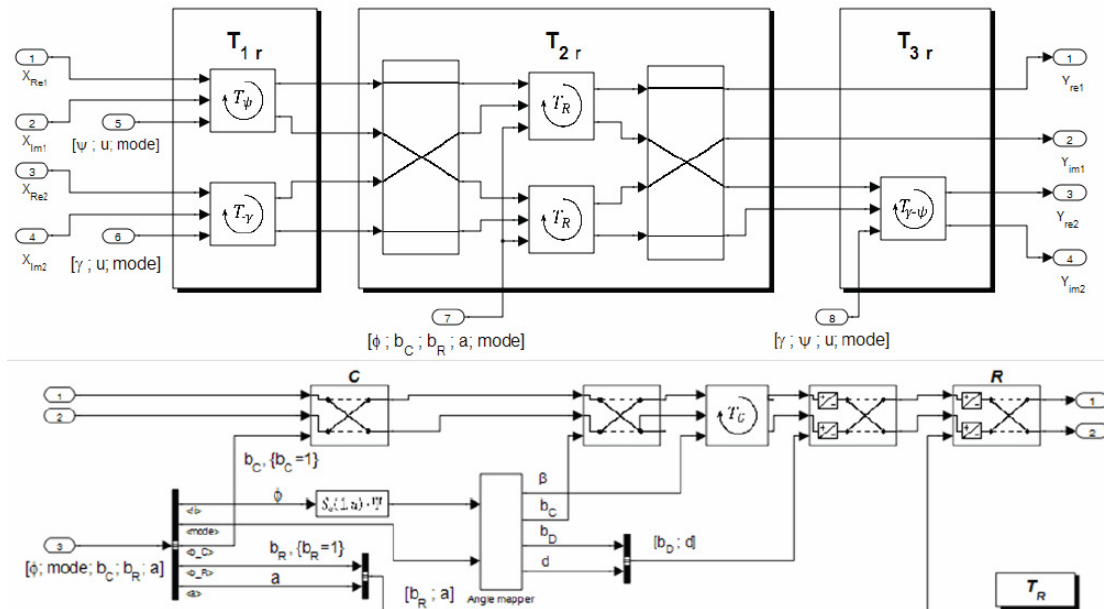


Figure 5.4 Generalized Jacobi rotator

5.1.2. Today and in the future: Some directions of the work

- Unified approach to complex fast orthogonal transforms(“theory”);

- unified approach to real fast orthogonal transforms;
- digital signal processing of acoustical signals (speech, biomedical, research of materials);
- parametrical orthogonal filters;
- wavelets and phi-functions;
- prototypes of generalized data transmission systems (like IEEE 802.11);
- implementation of (prototypes of phi-devices) into FPGA.

5.1.3. Perspektīvas

- Nepārtrauktu signālu rekonstrukcija (vispārinātā, “rotācijas leņķubalstīta” diskretizācijas teorēma);
- uz rotācijas leņķiem balstīta 1-D signālu kompresija;
- uz rotācijas leņķiem balstīta attēlu (kompresija, filtrācija etc.);
- uz VUR balstītu sakaru sistēmas.

5.1.4. References

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6. Elastīgas antenas izstaroto signālu parametru novērtēšana

The results obtained in the period:

- Estimation of the antenna capabilities (Section 6.1).
- Estimation of the shielding capabilities (Section 6.2).

6.1. *Estimation of the antenna capabilities*

6.1.1. *Introduction*

The object of the research of a topic is a textile antenna for protective clothing. The antenna is assigned for microwave power transmitter on a frequency 870 MHz in the ISM band. Remote control monitoring of temperature and voltage is provided by transmitter.

The most popular antennas, which are used in remote sensing are $\frac{1}{4}$ monopole, folded dipole, ceramic antennas. These conventional antennas are not effective enough, in case, when a human body is located in the antenna near zone. The significant part of output power is absorbed by the body. The microstrip patch antenna resolves this problem. The chapter contains description of the most popular portable and textile antennas, modern e-textile materials, transmitter technical data, schematics, calculation methods that are needed to design rectangular patch antenna.

The practical part of the work contains patch antenna design solutions. The target of work there is to develop patch antenna design algorithm, which can be used to produce textile antennas for clothing and remote sensing. To achieve the goal the following methods are used: antenna calculations, modelling with HFSS software, parametric analyzing, optimization, antenna prototype building, S11 measurements, tuning, antenna test with transmitter and receiver, results analyzing.

The 2.45 GHz ISM band is very popular for low power wireless communications. This band has some advantages and disadvantages. The advantages are a short wave length (12 cm), small antennas and universality of the band. The disadvantages are the spectral pollution of the band and poor propagation through the buildings. A lot of wearable textile antennas were designed for this band. For example antenna for fire fighter garments [6.12] [6.13], eight-element e-textile antenna array for body-worn communication and navigation [6.14] and other textile antennas for 2.45 GHz band [6.15]. A lot of these systems were tested in anechoic chambers and the authors get a good efficiency of the communication. But in real life this band can be polluted by high power signals from Wi-Fi, Bluetooth transmitters and microwave ovens. This results in a sudden decrease of communication efficiency. But it cannot be allowed for emergency or rescue workers. The alternative way is using the 868 MHz band which is allowed in Europe. This band is less polluted and the wave has the better propagation in towns. The radio-frequency identification RFID tags also use this band, and some flexible antennas are designed for RFID purposes [6.1] [6.2] [6.3]. A wearable textile antennas for 868 MHz band communications in not distributed widely. We decided to make an antenna for this band using the new conductive pigment technology.

The conductive inks became very popular today. It widely use for ISM band antennas [6.4] [6.5]. A paper or polymer films are used as substrate. The inks with nano-silver particles were used for creation of the conductive layer. The Dimatix DMP 2800 printer usually was used for printing of conductive layer. Also, the conventional ink-jet printer Epson C90 can be used for printing of the conductive layer [6.3]. A lot of print is needed to achieve good conductivity. This technology is more suitable for antennas with thin conductors, for example dipole. But we are focused on the microstrip patch antenna, because it is directional antenna. The ISM band 868 MHz patch antenna has a large radiator and ground. The dimensions of the radiator are 170x115 mm. The dimensions of the ground plane are 200x270 mm. It can be smaller if the substrate has higher dielectric constant of the substrate. The simple rectangular 868 MHz band patch antenna doesn't need a very high precision and the pigment can be drawn manually without special printer. Textile materials can be used as antenna substrate. The common use substrates for flexible antennas are a polyester, cotton, felt, aramid or combinations of these materials. The dielectric constant of the materials is 1.3 – 2.0 and loss tangent 0.0004 – 0.04 [6.6] [6.7]. A lot of measurement methods are available for characterization of the dielectric properties. The most popular is ring resonator [6.2], dielectric loaded waveguide cavity method [6.6], microstrip patch radiator [6.7], matrix-pencil two-line method [6.8]. For the material and patch antenna characterization we use a full sheet resonance method which is described in [6.9] [6.10] and standard IPC-TM-650 2.5.5.6. Also this method is recommended for the tests of materials for circuit boards for example Rogers RO4000, but it is suited well for any structure which forms a planar resonator.

6.1.2. Geometry and materials of the antenna

The rectangular patch antenna was created on the cotton substrate. The thickness of the cotton is 0.3 mm. The dimensions of the antenna are 170x115 mm. The antenna matched with 0.25λ transformer which width is 1.0 mm. The photo of antenna and ground plane is demonstrated on the “Fig. 6.1”.

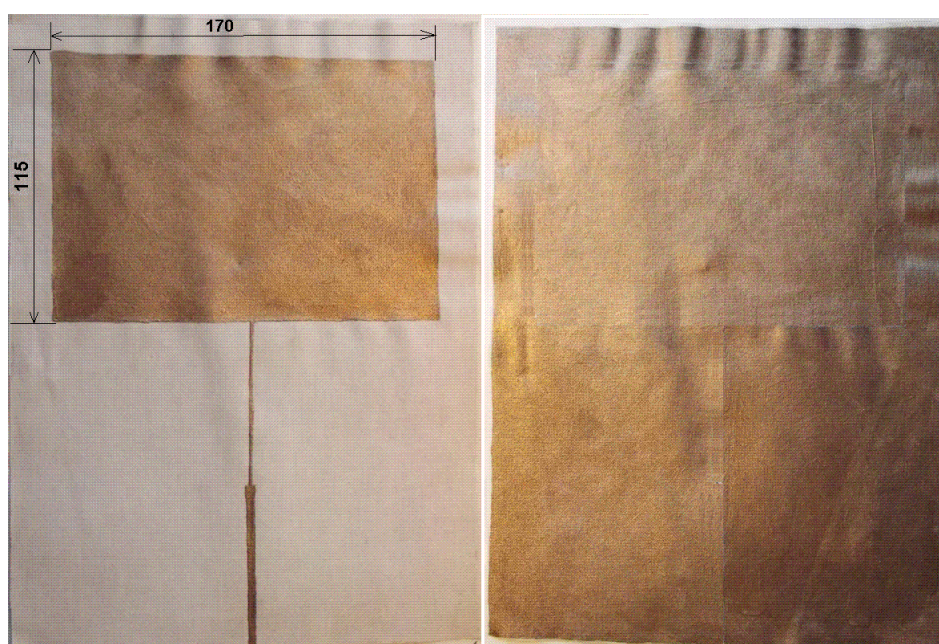


Figure 6.1 Patch resonator and ground plane

The antenna is flexible. It can be roll up in pipe with diameter 15 mm without deformation or degradation of the conductive layer. The conductive layer is quite strong. The “Fig. 6.2” demonstrates the flexibility of the antenna.



Figure 6.2 Rolled antenna

6.1.3. Tests of the antenna

6.1.3.1. Resonance properties

The resonance properties of the antenna were tested by full sheet resonance method. We used the sweep generator X1-43 with frequency range 0.5 – 1250 MHz. The amplitude-frequency response (AFR) was observed. The “Fig. 6.3” shows the test circuit. Patch resonator was connected to generator by using loose electromagnetic coupling on the corners. The coupling can’t influence significant to current distribution of the resonator. The “Fig. 6.4” shows the test conditions. There were prepared two tests. The patch resonator with conductive pigment was tested first. After that the patch resonator with aluminum foil was tested. The dimensions of the aluminum patch resonator are the same as of the pigment resonator. The substrate of the aluminum resonator is fiberglass.

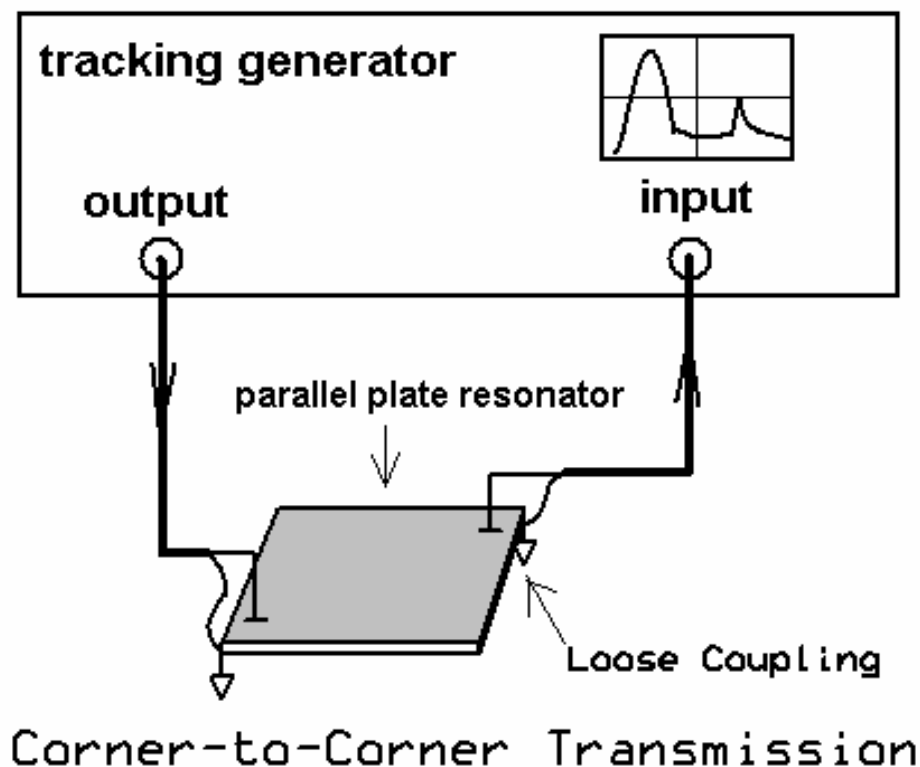


Figure 6.3 Measurements of resonance response of the resonator

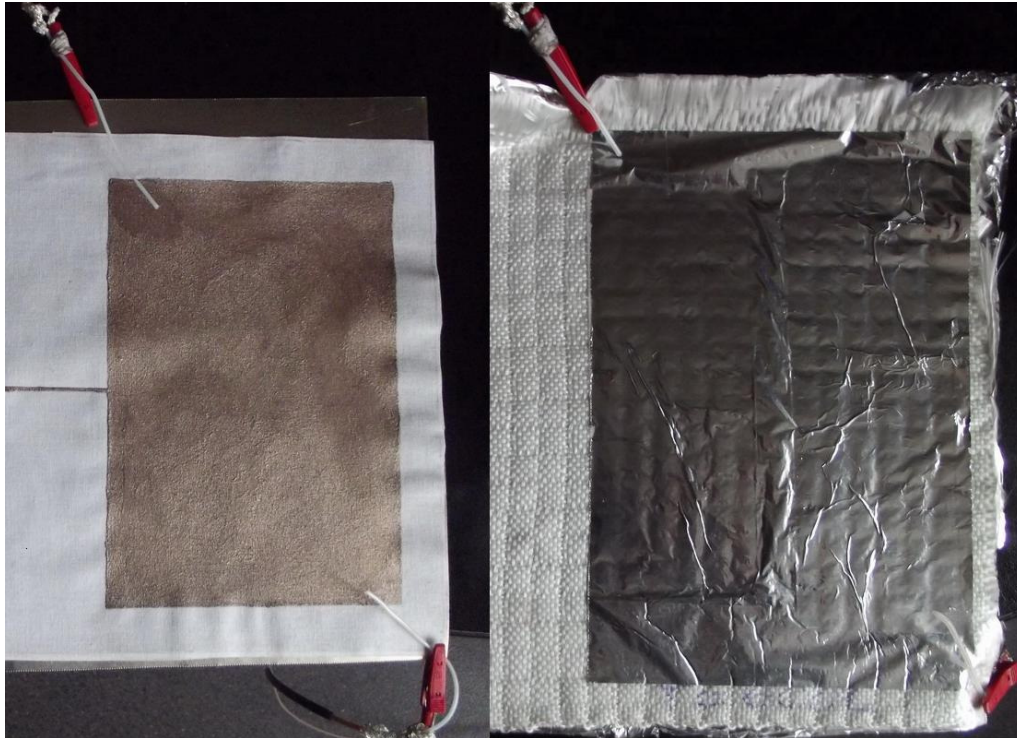


Figure 6.4 Patch resonators. Left – with conductive pigment. Right – with aluminum foil.

The AFR of the both resonators is shown on “Fig.6.5” widely. The resonator with conductive pigment has not significant peaks on the display. It means that it has low Q factor or high losses. The same structure with foil has significant signal amplification in two frequencies. The resonance frequencies are 723 MHz and 992 MHz. The result demonstrates that the resonance frequencies of the patch antenna can be found simply by using the full sheet resonance method. This method gives the opportunity to compare different materials for the antenna and estimate electrical losses in the working frequency. The test shows that the aluminum foil and fiberglass structure is more efficient than conductive pigments and cotton structure.



Figure 6.5 AFR of the rectangular patch resonators. Left – with conductive pigment. Right – with aluminum foil.

6.1.3.2. Resistance and capacitance of the structure

The surface resistance of the pigment was measured with ESCORT ELC-3131D equipment on two frequencies 120 Hz and 1 kHz. The results on both frequencies are the same. The test results are presented on Table 1. The resistance is not uniform and it is not stable enough. The line between points 5 and 7 is a 0.25λ transformer. It has too high resistance and the transformation of the impedance is not expressive enough. In some papers are described the impact of the resistance to effectiveness of the antenna. For example a carbon conductive layer for microstrip patch antenna was researched in [6.11]. There was described that the conductivity of the radiator must be better than 10^5 (S/m), otherwise the effectiveness of the antenna will be too low.

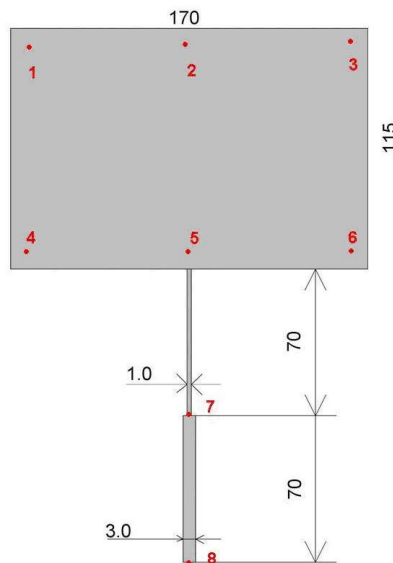


Figure 6.6 Resistance measurement points of the antenna

Table 1

Resistance between control points

Points	1-6	3-4	2-5	7-8	5-7
R, Ω	4	5	3	4	20

The patch resonator has the capacitive properties on the low frequencies. The capacitance of the structure was measured in order to find parameters of the dielectric. But the results were controversial. The tests equipments cannot show the capacitance value correctly because of high loss tangent.

6.1.4. Measurements of resonance of the textile Bi-Quad antenna

The Bi-Quad directional antenna was produced and tested. This antenna consists of two loops. The loops are connected in parallel. The loops can be rectangular or circle. The length of elements of the antenna is equal to wave length which is 32 cm. This antenna is very popular on wireless internet devices, Wi-Fi 2.45 GHz.

The input impedance of the antenna was tested with high frequency (HF) bridge. On resonance mode the antenna input resistance is pure active. The best case is then antenna input resistance is active and equals to $50\ \Omega$. This is the matched load mode. When the antenna is in matched mode, then antenna receives all power of the transmitter. Amplitude of the current in the elements of the antenna is higher in matched mode. The higher current generates more powerful electromagnetic (EM) field. If the antenna is unmatched (reactive load or $\neq 50\ \Omega$) than a part of energy are reflected from antenna input. The reflected power absorbs in the output stage of the transmitter, as a result the antenna radiates less power. The transmitting distance was reduced due to this absorption. The HF bridge compares the impedance of the antenna with etalon $50\ \Omega$ load. If the antenna impedance is $50\ \Omega$ than output voltage of the HF bridge is 0V. The predicted resonance frequency is 800 – 900 MHz. The textile antenna doesn't have expressed resonance on all frequency range. It works like a resistor. The same antenna on FR4 substrate was tested. The test of FR4 antenna shows the expressive rising edge on the 820 MHz frequency. It means that antenna impedance is active and close to $50\ \Omega$. The results of tests are shown on „Fig. 6.9”.

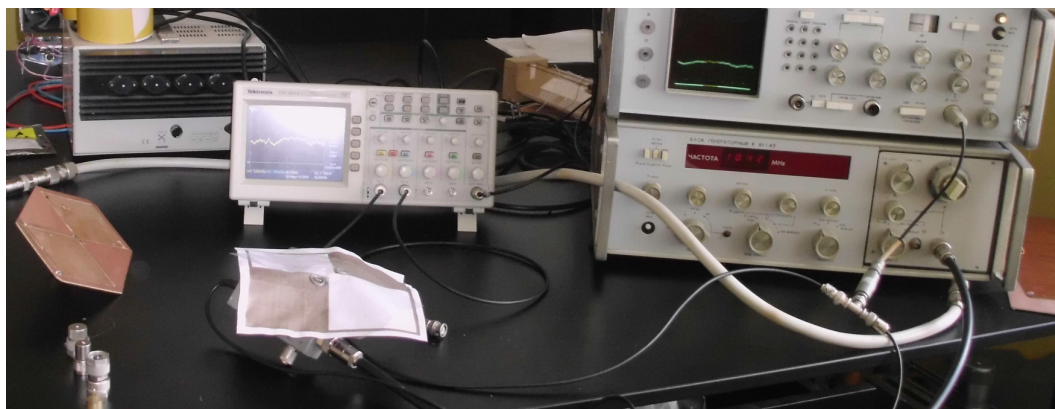


Figure 6.7 Test of textile BiQuad with HF bridge

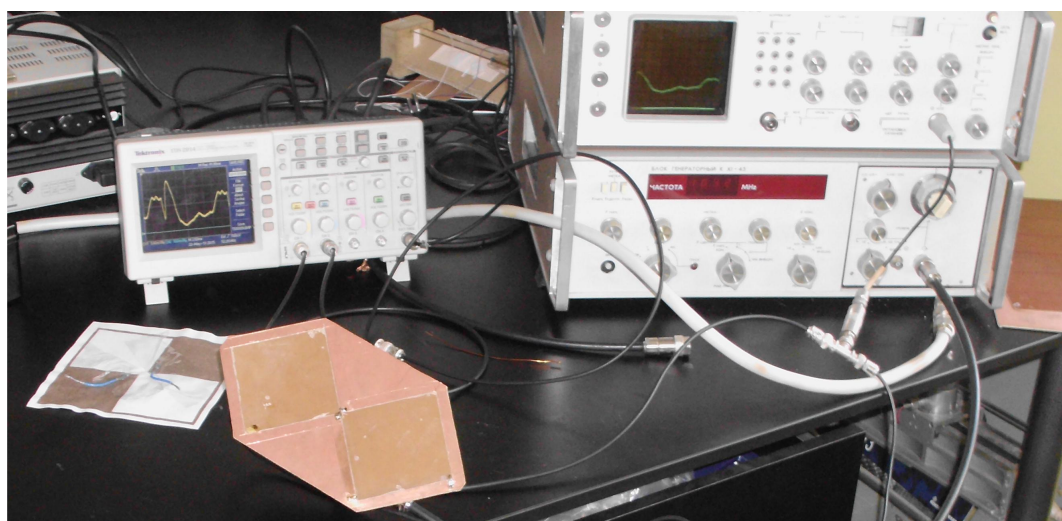


Figure 6.8 Test of FR4 BiQuad with HF bridge

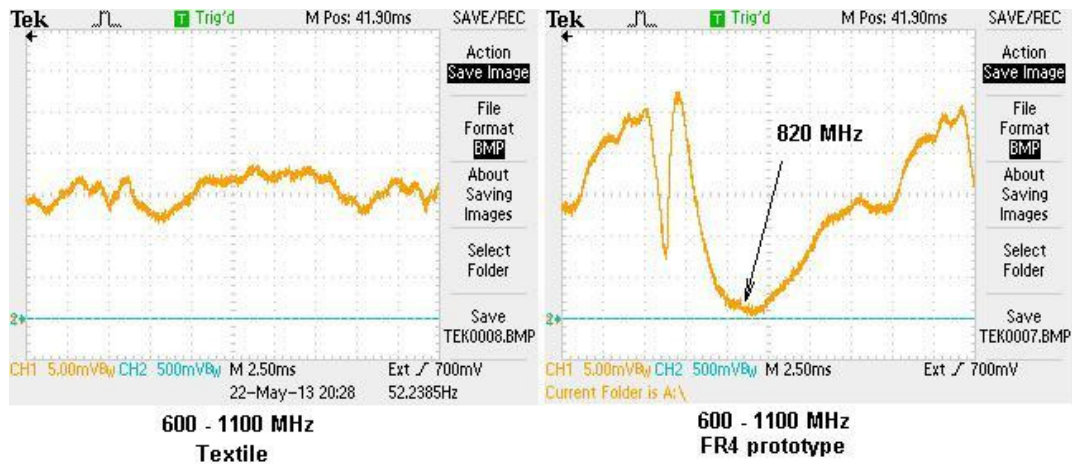


Figure 6.9 Comparison of two antennas

6.2. Estimation of the shielding capabilities

6.2.1. Microwave transition and reflection

The transition and reflection coefficients of microwave were measured. The microwave frequency is 10 GHz. The waveguide method was used. The test circuit is demonstrated at “Fig. 6.10”. The photo of test shows “Fig. 6.11”. Microwaves propagate in waveguide with dimensions 23x10 cm. The load was connected in the end of the waveguide. The load parameters are known. The material of the antenna was located between waveguide output and the load input. The microwave field was distorted by the antenna material. The amplitude and phase differences of the field were observed by using the slotted line.

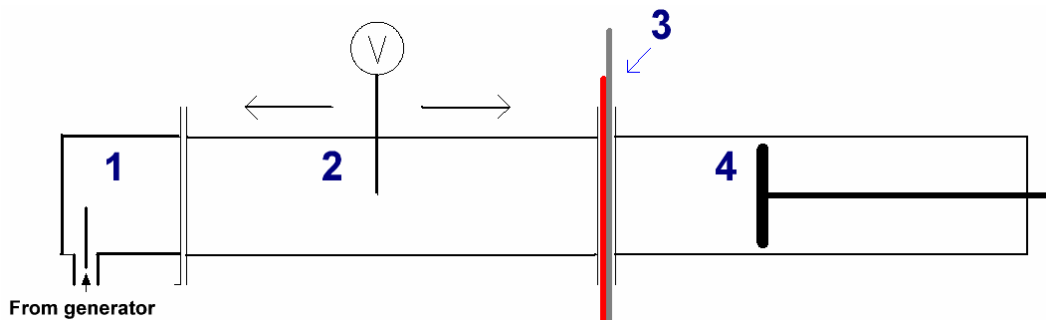


Figure 6.10 Measurements of microwave transition, schematics.

1 - Coaxial to waveguide adaptor, 2 - slotted line, 3 - investigated material, 4 – reactive load

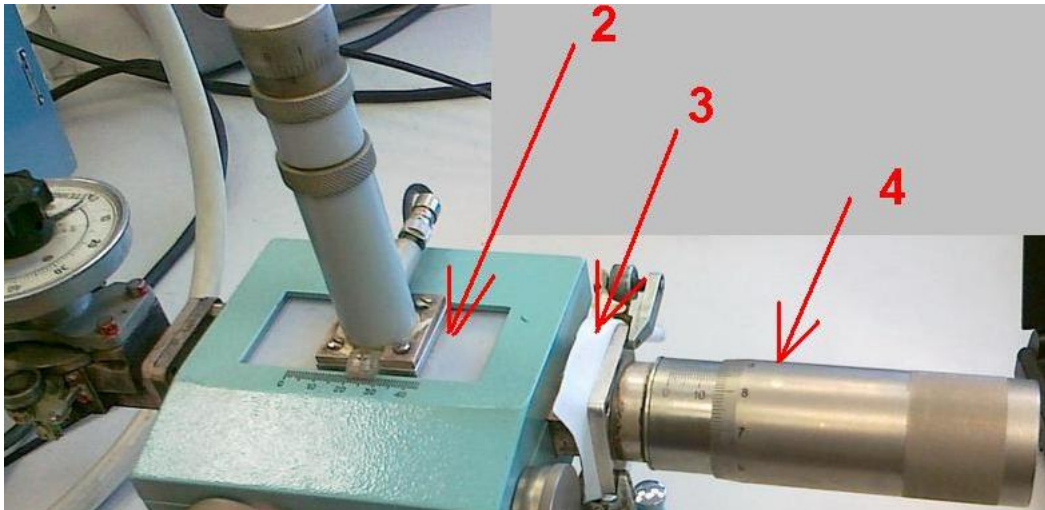


Figure 6.11 Measurements of microwave transition, image.
1 - Coaxial to waveguide adaptor, 2 - slotted line, 3 - investigated material, 4 – reactive load

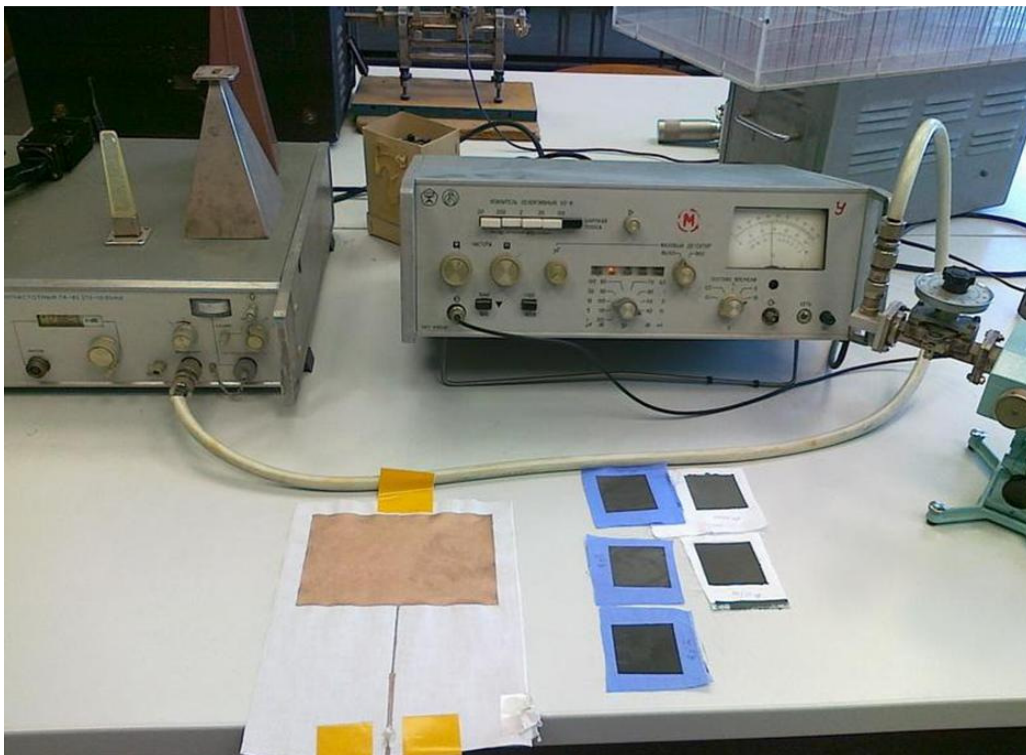


Figure 6.12 Measurements of microwave transition.
Comparison of conductive pigment and graphite coating

The phase and amplitude differences were plotted on the Smith charts which are demonstrated on “Fig. 6.13”.

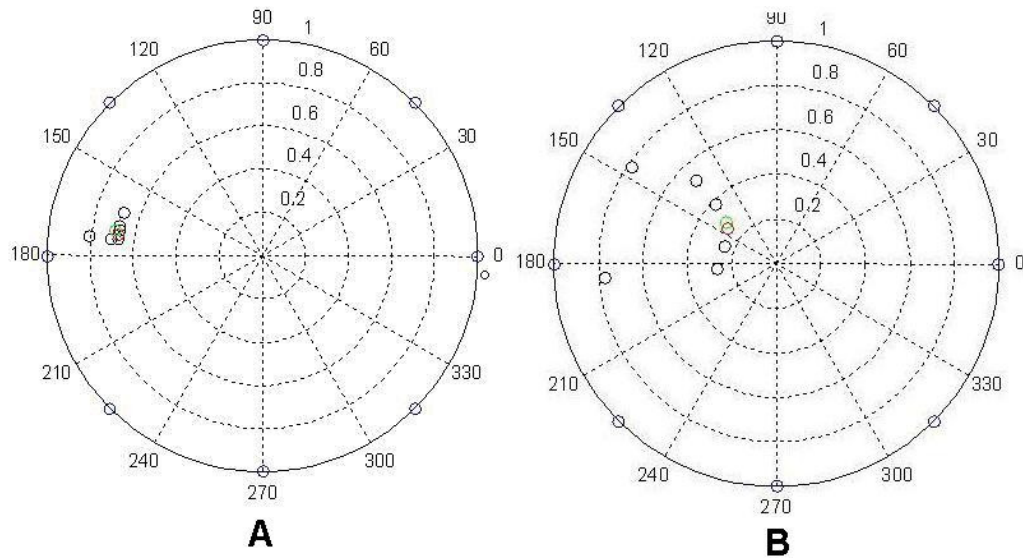


Figure 6.13 The Smith chart of complex impedance. A – textile antenna , B – graphite layer

The complex impedance of the antenna material was found. The transmission and reflection properties (S_{12} , S_{11} , S_{22}) can be extracted from the complex impedance. The textile antenna material was compared with graphite layer. The surface resistance of the graphite layer is $500 \Omega/\square$. Data are collected in Table 2. The physical meaning of these parameters is explained below on “Fig. 6.14” S_{12} – transition of the microwave through antenna material, S_{11} – reflection if the wave propagates from metal side to textile side, S_{22} – reflection if the wave propagates from textile to metal side.

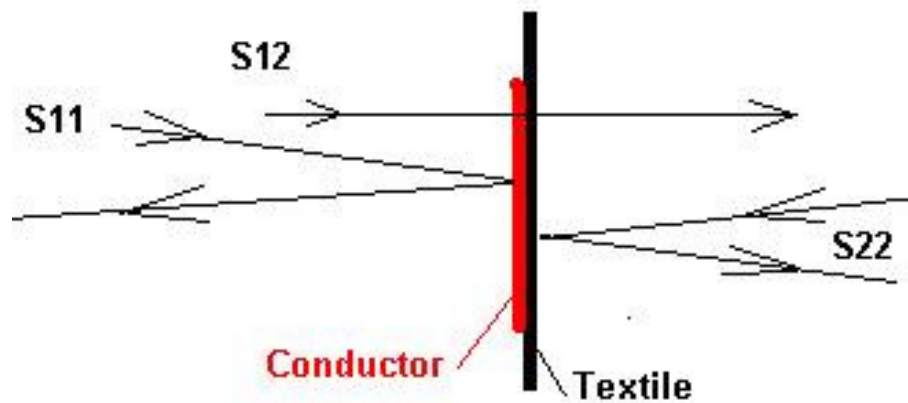


Figure 6.14 Description of the S parameters

Table 2

Transmission and reflection coefficients

	$ S_{12} $ Transmission	$ S_{11} $ reflection	$ S_{22} $ reflection	Absorption $1-(S_{12} + S_{11})$
Pigment	0.20	0.70	0.77	0.10
Graphite	0.46	0.40	0.56	0.14

6.3. Conclusion

The analysis of the result show, that the resistance of the hand-covered conductive pigment is too high for using it for antenna or resonator. The effect of resonance was not very expressive, because the surface resistance of the conductive layer is not uniform enough. The high frequency (HF) field concentrates on places with better conductivity and distribution of the HF field was distorted.

The microwave transition test shows that the pigments are more effective as shielding material than graphite layer. The pigment layer can be used as grounding of the static charge in the electronic devices which has a plastic case. Sometimes an additional shielding is needed in the electrical devices. The conductive pigment layer can be used for additional microwave absorber.

The resistance of the pigment layer should be reduced in order, to use the pigment for antenna design. The microstrip patch antenna is very sensible to resistance and thickness uniformity. The best way is to use automatic conductor covering, which is able provide better uniformity of resistance and thickness. The thicker substrate (1.5 – 5 mm) is needed for patch antenna design. Not only textile can be used for antenna substrate. For example, a rubber or flexible composites can be used as antenna substrate.

6.4. Acknowledgment

The authors would like to thank Peter Wissling from ECKART GmbH for providing the samples of the conductive pigments.

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7. Komunikācijas sistēmas prototipa aprobācija reāliem apstākļiem pietuvinātos scenārijos, kas saistīti ar mobilo objektu vietas noteikšanu ar augstu precizitāti, kā arī bezvadu datu apmaiņu starp kustīgiem objektiem un attālinātiem serveriem

7.1. *Performance Calculation of Two layer Communication Vehicular Network*

Our goal is to demonstrate the performance of IEEE802.11g in the mobile environment. The similar studies estimate the realistic scenarios of the urban traffic with the WLAN performance at very low speeds. They varied the module schemes and analyzed bandwidth throughput. The obtained results of the research are important for the multimedia and for the other real-time applications.

The idea of using IEEE802.11g standard of the automobile scenario is quite unusual. In our research we try to prove that IEEE802.11g standard can be much more accessible and simple in the implementation.

We are interested in the real traffic situations in order to calculate the maximum capacity of IEEE802.11g standard.

7.1.1. *Distribution of the vehicle in the coverage area of the base station*

Base station throughput depends on vehicular (client) number in coverage zone. It is clear, the large client number reduce base station throughput. Throughput in vehicular networks is estimated as goodput. In networks, goodput is the application level throughput. Base station goodput is varied with distance between BS and client.

The 200 meters long base station operational zone of is divided into 5 zones, 40 meters each, the third zone being the most adjacent to the base station (Fig.7.1). We will assume that vehicles enter the operational zone of the base station, starting at the speed of zero. Then the velocity increases exponentially.

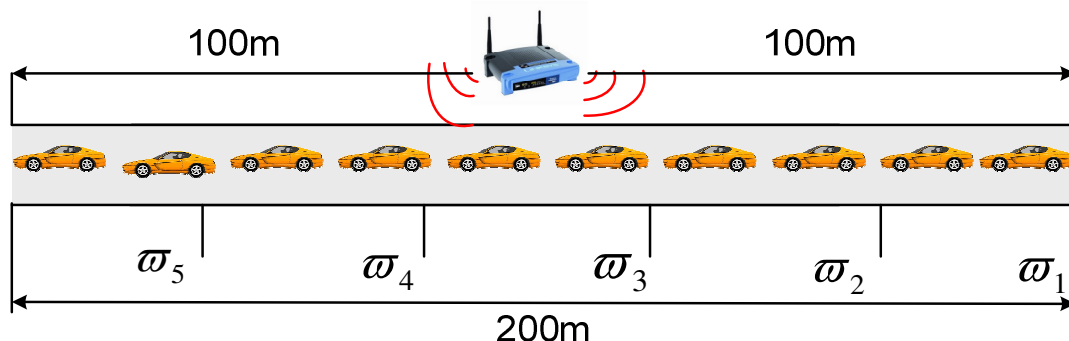


Figure 7.1 Vehicle cyclic network

Besides that the actual speed of data transmission will be depend on the number of objects, which are in the coverage area of the station. Supposing that the average length of the automobile is 5 meters, and the necessary distance on the road between automobiles is 5 meters.

Then, in the length of the road of 600 meters the maximum automobiles that can fit in are 60 automobiles. The road section of 600 meters we divide into 12 subareas in 50 meters, then $0 \leq m_i \leq 5$. Where m_i - length of the distance (50 meters).

For vehicles number investigate a closed network consisting of M independent nodes with N incoming customer. We assume that the parameter ϖ_i according to the highway speed on the movement on highway is characterized by density. Customer service intensity ϖ_i in zone i is related with length of zone and vehicle (customer) velocity in zone [7.1.1].

If the zone length equals S_i , and vehicle movement speed equals $\mathcal{G}_i$, then the intensity of vehicle service by road interval equals:

$$\varpi_i = \mathcal{G}_i / S_i. \quad (7.1)$$

According to (7.1) the intensity of vehicle service is depended on from initial vehicle flow rate into the road interval as from the density of vehicle location on the road interval.

In fact, to determine how to grow the speed of the vehicle was made an experiment. Results are presented in Fig. 7.2.

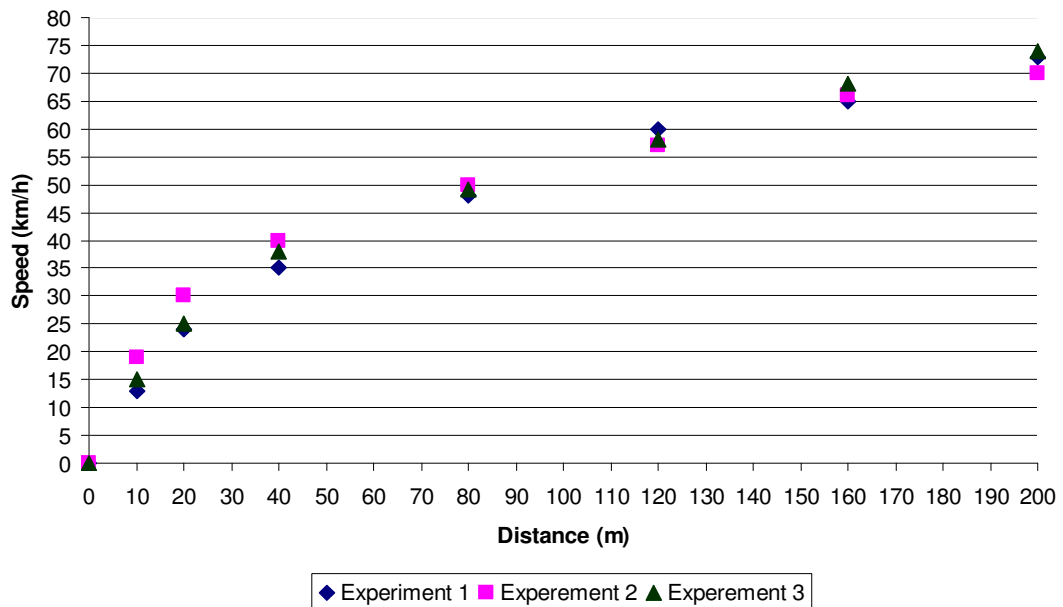


Figure 7.2 Speed of vehicle $\mathcal{G}_0$

The speed of movement of vehicles on the highways is characterized by the density of placement of vehicles on the road section. For the calculation of the average speed of automobiles on the certain road section there is an expression:

$$g_i = g_0 \left(1 - \frac{k}{k_c} \right). \quad (7.2)$$

Where, k_c - is the maximum allowable flux density, g_0 - the speed of the free movement of the flow (the maximum allowable) Fig. 7.2, k - the number of vehicles.

The speed grow can be depending on the vehicle technical parameters. Vehicle speeds in the various zones are presented in Table 7.1:

Table 7.1 The vehicle speed.

Zone number i	1	2	3	4	5
Distance (m)	40	80	120	160	200
Velocity g_i (km/h)	38	49	59	67	74
Intensity ϖ_i	0.264	0.34	0.41	0.465	0.514

For presented closed querying model out coming some variable have been involved in model. First of all variable x_i ($i=1,M$) are needed.

x_i is estimated by the system of equations[4]:

$$\varpi_i x_i = \sum_{i=1}^M \varpi_i x_i p_{ij}. \quad (7.3)$$

From nature of model we may calculate that $x_1 = 1$ and the next step is calculated as follows:

$$x_2 = \frac{\varpi_1}{\varpi_2}, x_3 = \frac{\varpi_1}{\varpi_3}, \dots, x_M = \frac{\varpi_1}{\varpi_M}. \quad (7.4)$$

Using Buzen's matrix is developed for closed network analysis, as shown in Table 7.2:

Table 7.2 Buzen's matrix.

No.	1	2	3	4	5
0	1	1	1	1	1
...	...	...	...	...	...
9	1	4.111	10.63	22.535	42.284
10	1	4.19	11.038	23.835	45.569
...	...	...	...	...	...
19	1	4.443	12.377	28.432	57.991
20	1	4.447	12.414	28.562	58.370

Probability that i – zone is occupied:

$$P\{n_i \geq 1\} = x_i \frac{G(N-1)}{G(N)}. \quad (7.5)$$

Where $G(N)$ – normalizing constant, resulted from equalizing to one all probabilities of system states. Naturally, there are no limitations for the number of vehicles (queries) in the i -th interval.

Average number of queries (vehicles) in i -th interval as shown in Table 7.3:

$$E[n_i] = \sum_{K=1}^M (x_i)^K \cdot \frac{G(N-K)}{G(N)}. \quad (7.6)$$

Table 7.3 Average number of queries.

Vehicle (N)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
10	5.81	1.03	0.92	0.76	0.69
20	15.69	1.65	1.04	0.85	0.76

7.1.2. Two Layer Vehicular Network

The physical sphere for the transmission is the wireless network. At the first stage the data is transmitted from the mobile object to the nearest Access Point along the protocol IEEE 802.11 g. However, the distance from the AP object should not exceed 200 meters. Further from the AP the data are transmitted to the remote base station on the protocol IEEE 802.16 (WiMax). This variant provides the data transmission at the distance up to the several kilometers. Thus, the object of the research represents the two-level system of the wireless networks. This object can be represented by the two-level network model, as it is shown in Fig. 7.3. Null node stimulates the data transmission from a movable object with the intensity of the data transmission μ_0 .

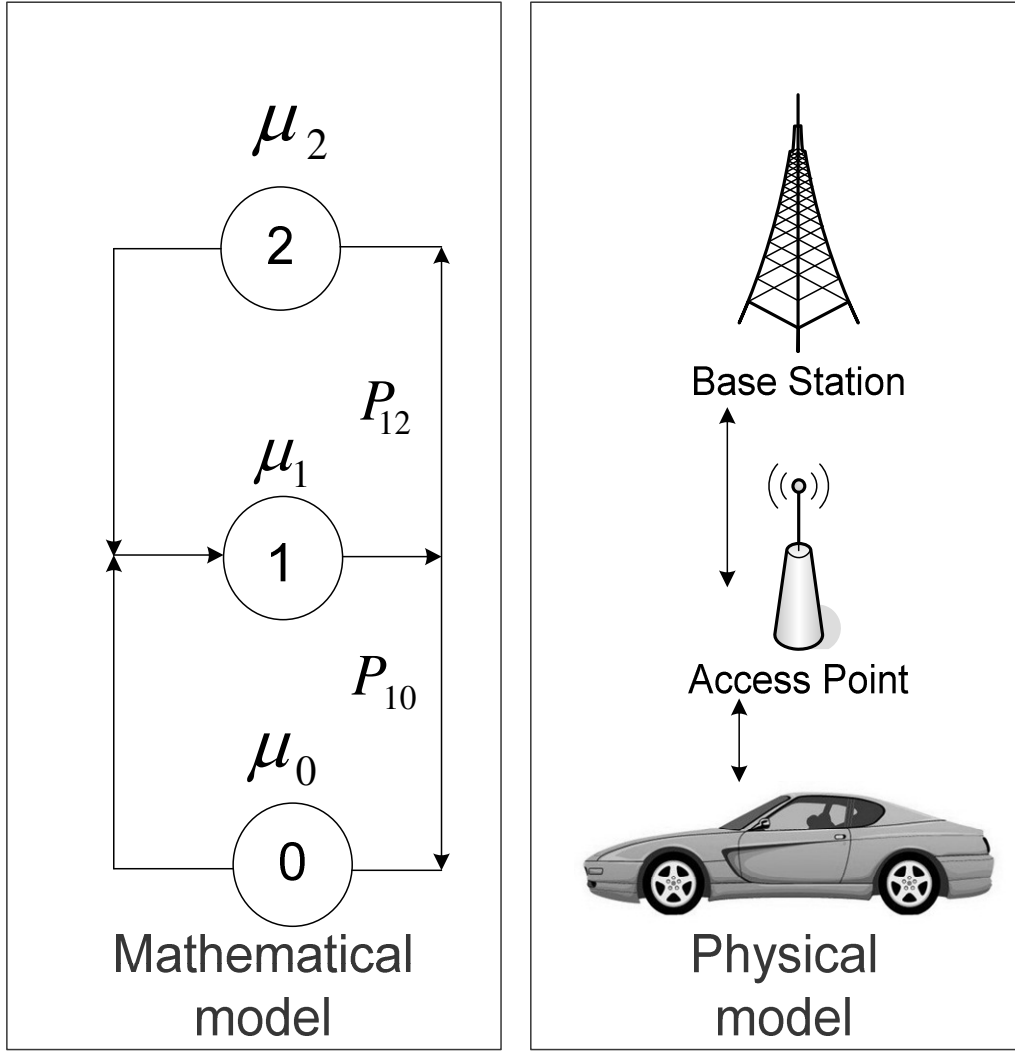


Figure 7.3 Two layers vehicular network model

The second node stimulates the AP wireless network providing the data reception and transmission from the mobile objects of the null node. The intensity of the data processing is equal to μ_1 .

$$\mu_1 = \beta_i . \quad (7.7)$$

Where β_i - is the data – transmission rate in the wireless network IEEE 802.11g depending on the distance to the base station as is shown in the Fig. 7.3 [7.1.2].

Depending from the vehicle's proximity to base station data processing rate and data processing intensity in base station will be different. For file transfer the common packet length is 1500 bytes. Then we will estimate base stations goodput β_i , by the chart at Fig.7.4.

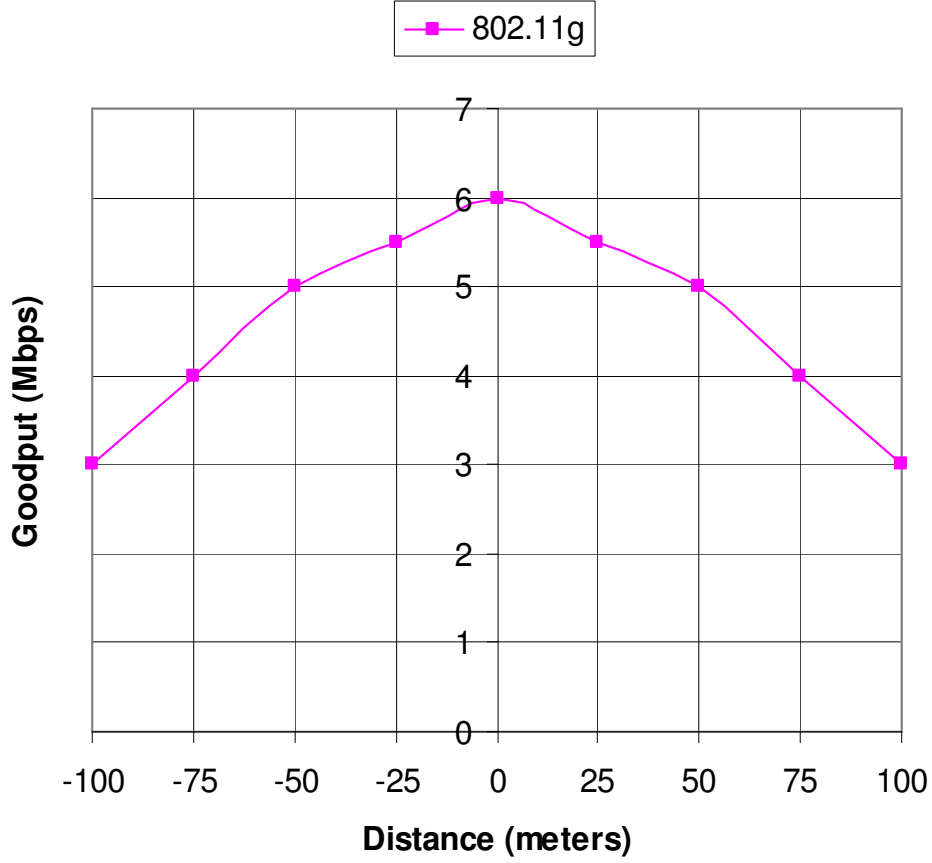


Figure 7.4 Goodput in wireless network with one router depending on distance for IEEE 802.11g

In its turn AP connects with the remote base station along the wireless network with the IEEE 802.16 standard. The intensity of the data transmission of the second node is to be taken to be equal to μ_2 .

The route of the data transmission keeps the track from the null node to the first node and then to the second, if the file transfer is considered from the car to the BS. From the BS is transmitted the ACK confirmations on the packet's transmission. In this case the average time for the transmission will be varying: more time is spent on the transmission of the data packets, which we denote as $E(t_i)$. The ACK transmission takes less time denotes it as $E(t_0)$. Then the average time of the data processing in the first node will be:

$$E(t_1) = E(t_i) + E(t_0) / 2 . \quad (7.8)$$

If on the top of each transmitted packet we receive the ACK confirmations. In this case the intensity of the processing in the first node will be:

$$\mu_0 = 1 / E(t_1) . \quad (7.9)$$

The model participates in the parameter N determining the number of data transmission initiators, which compete for the resource sharing of the 1 and 2 nodes. In our case this is the number of automobiles in the AP coverage area. Then three-node and two-level model of the goodput can be expressed by the (7.17) formula. In this formula the parameters α , X_1 and X_2 determine by the value from (7.10). The valuation problem of the goodput provided by the model consists of the determination of the value N – the number of cars in the AP coverage area. Moreover, in the wireless network standard IEEE 802.11g the speed of data transmission depends on the remoteness of the vehicles from AP.

The terminal count in each vehicular wireless network is usually high.

Bandwidth equation for a two layer network:

$$X_1 = \frac{\mu_0}{\mu_1 P_{10}}; \quad X_2 = a X_1; \quad a = \frac{\mu_1}{\mu_2} P_{12}. \quad (7.10)$$

The intensity of the μ_2 :

$$\mu_2 = 1 / t . \quad (7.11)$$

$$t = l_p / V_f . \quad (7.12)$$

Where V_f - effective data transfer rate for the IEEE 802.16e protocol. For the data transmission between the Access Point and the base station is used IEEE 802.16e protocol, this protocol will have the peak transfer rate $V_n = 50\text{Mbps}$.

The packet length will be $l_p = 1500\text{bytes}$, but the actual speed is determined in the following way:

$$V_f = V_n / 2 . \quad (7.13)$$

Starting point for the calculation is the normalizing function $G(N)$, that is chosen from the principle of the sum of probabilities being one. $p(n_0, n_1, n_2)$, where n_i in vector $\vec{n} = (n_1, n_2, n_3)$ is the inquiry count in i -th node. The resulting equation for $G(N)$ calculation looks like this:

$$G(N) = \sum_{\bar{n}} \prod_{i=1}^3 (X_i)^{n_i} i, \quad \bar{n} \in \left\{ (n_1, n_2, n_3) / \sum_{i=1}^3 n_i = N, n_i \geq 0 \forall_i \right\}. \quad (7.14)$$

Where n - number of vehicles.

The function of the studied two layer vehicular network looks like this:

$$G(N) = \frac{1}{1-a} \sum_{j=0}^N X_1^j (1-a^{j+1}). \quad (7.15)$$

Goodput η of the two layered network is defined as the count of processed inquiries in a unit of time. The finished task is put out trough the subsystem of input/output, and instantly trough it a new task is loaded. Probability of a lack of inquiries in i-th node:

$$p\{n_i = 0\} = [G(N) - X_i G(N-1)] / G(N). \quad (7.16)$$

We get the result of:

$$\eta = P_{10} \mu_1 (1 - p\{n_i = 0\}). \quad (7.17)$$

From equation (7.17) we can calculate η for each segment. On the network performance influences the probability of transmission of the confirmation ACK, as increases ACK, increases the number of packages per unit time.

If the probability will be $P_{10}=0.999$ $P_{12}=0.001$ then the goodput with $N=10$ and $N=20$ will be (Fig.7.5):

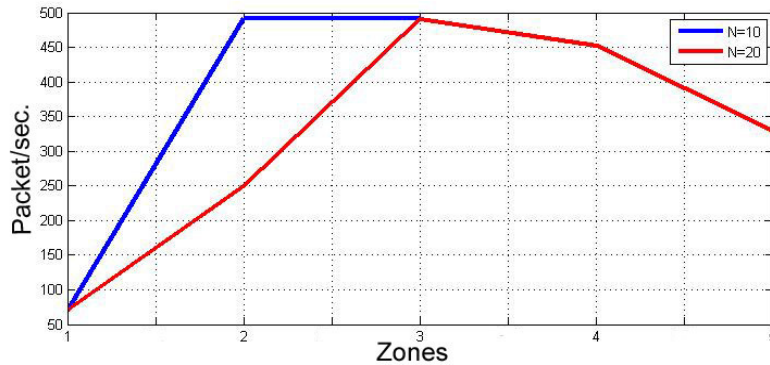


Figure 7.5 Goodput for a Two layer Network model with $P_{10}=0.999$ $P_{12}=0.001$ for IEEE 802.11g and IEEE 802.16e

Goodput with the probability $P_{10}=0.99$ $P_{12}=0.01$ for $N=10$ and $N=20$ will be (Fig.7.6):

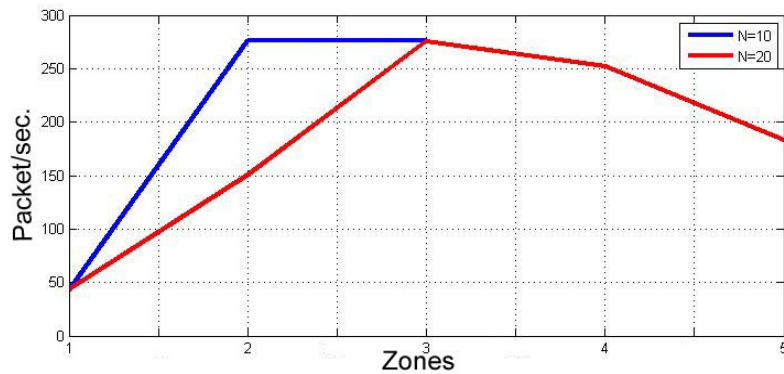


Figure 7.6 Goodput for a Two layer Network model with $P_{10}=0.99$ $P_{12}=0.01$ for IEEE 802.11g and IEEE 802.16e

As a result the goodput of the base station is connected both with the traffic parameters of the moving and data transmission features base station – transport vehicle. [7.1.3]

7.1.3. Opnet Simulation of Two Layer Network Model

OPNET is a research oriented network simulation tool that directly uses real-life applications and protocol stack to generate high-fidelity simulation results. Figure 7.7 shows two layer network model with WiFi and WiMAX:

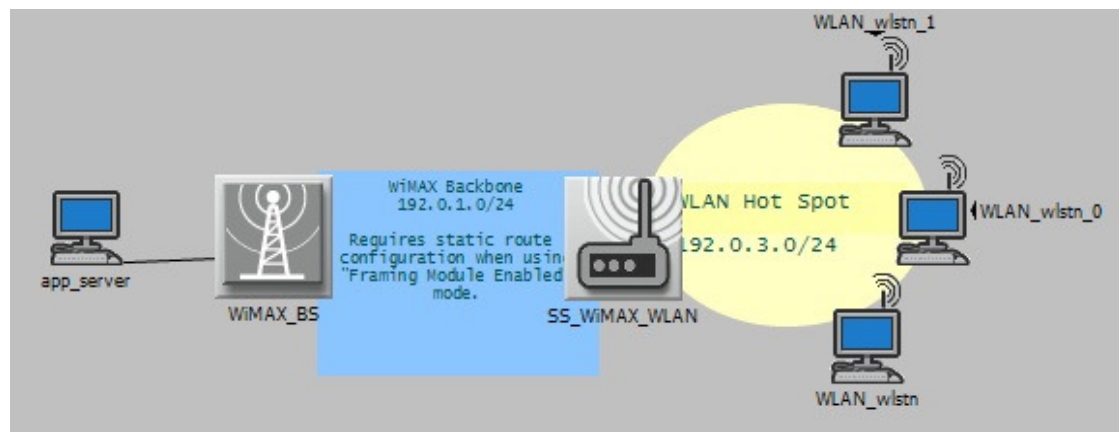


Figure 7.7 Snapshot of IEEE 802.11g and IEEE 802.16e scenario

We used OPNET Modeler 15.0 to simulate IEEE 802.11 and IEEE 802.16e. OPNET provides high-fidelity modeling, simulation, and analysis of wireless networks such as interference, transmitter/receiver characteristics, including MAC, routing, higher layer protocols, and applications. [7.1.2]. Goodput for a simple scenario with one access point (Wifi) and one workstation, present in Figure 7.8.

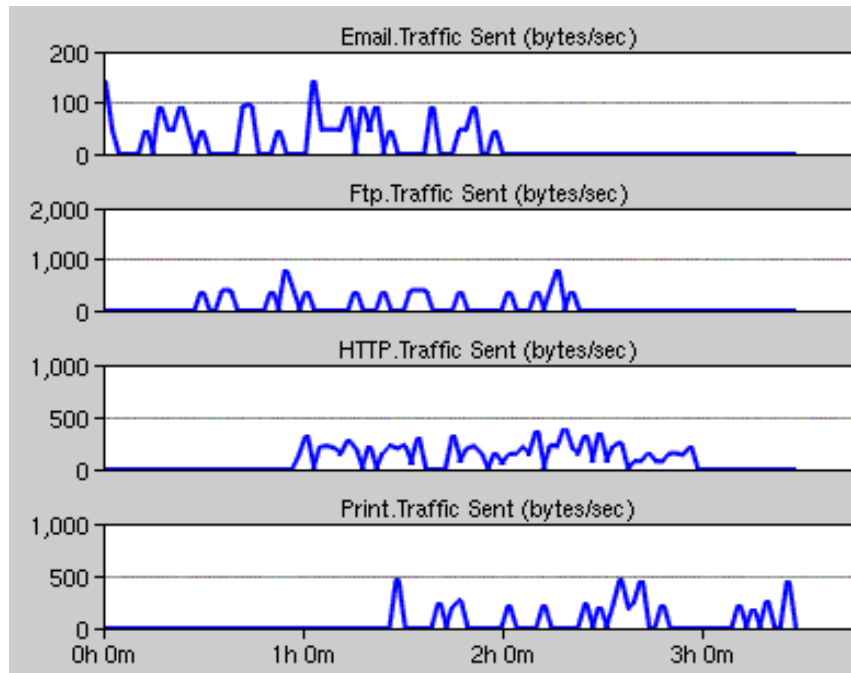


Figure 7.8 Goodput for Application

Figure 7.8 shows that for different network traffic corresponds own goodput. Opnet has the ability to incorporate node mobility and interconnect wire line vehicular networks. The following Table 7.4 will resumes the network setting for our scenario:

Table 7.4 Network setting for Opnet

<i>Parameter</i>	<i>Base station (WiMax)</i>	<i>Work station (Wifi)</i>
Antenna gain	15dB	1dB
Transmited power	38W	0.5W
PHU profile	Wireless OFDMA 20MHz	Wireless OFDMA 20MHz

OPNET modeler can give us the result as graphs form a relation between the studied metric and simulation times or other effected factor like number of users. HTTP is the foundation of data communication for the World Wide Web (WWW). Figure 7.9 shows the HTTP traffic sent by the server.

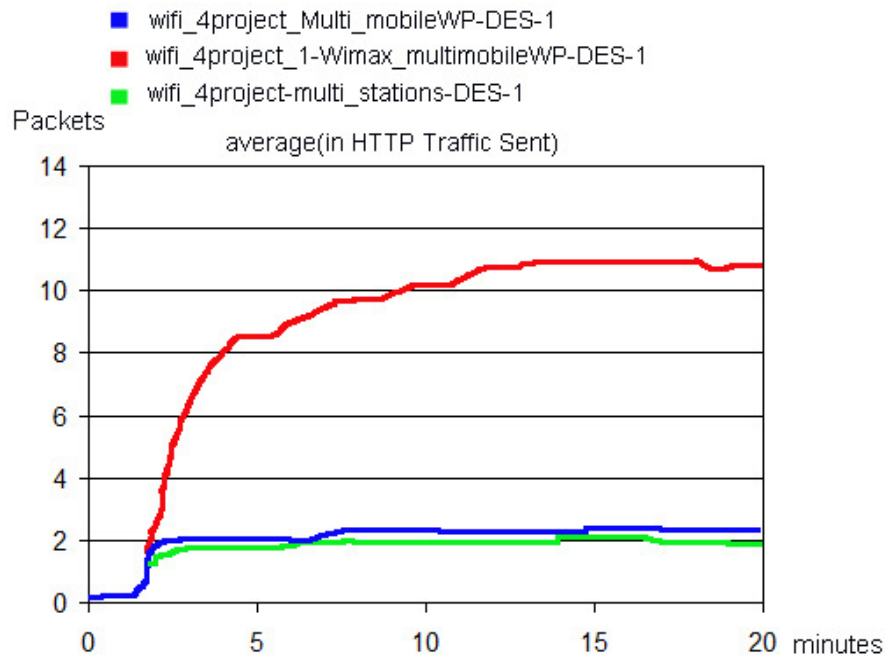


Figure 7.9 HTTP traffic sent by the server

File Transfer Protocol (FTP) is designed for transferring files and offers faster overall throughput. In Figure 7.10 we present average FTP traffic sent by the server:

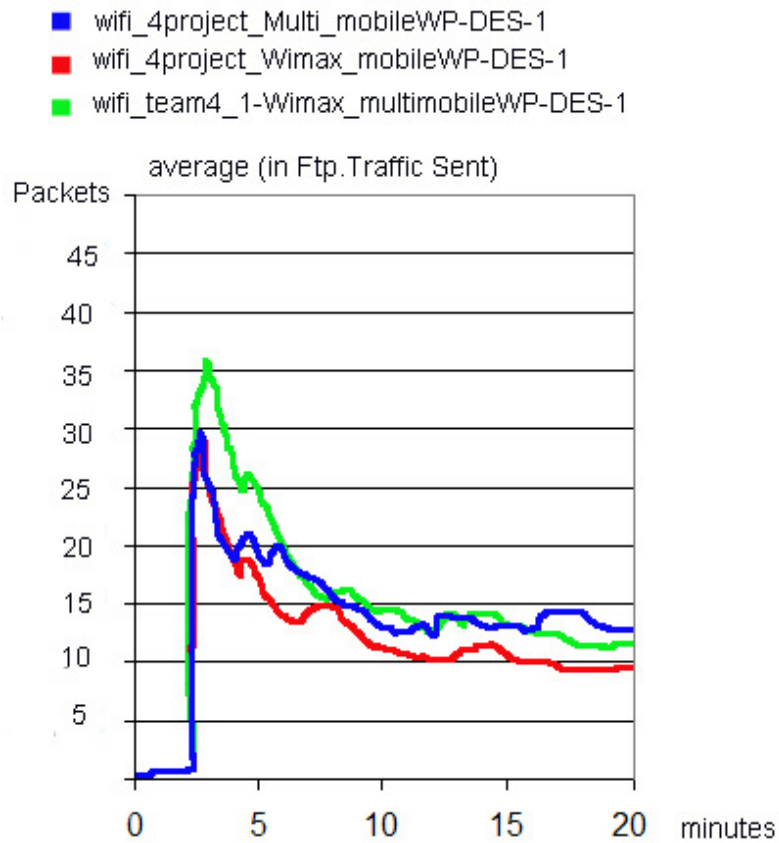


Figure 7.10 FTP traffic sent by the server

On average throughput increases approximately in the same order as the number of users increase. The WLAN throughput is shown in Figure 7. 11.

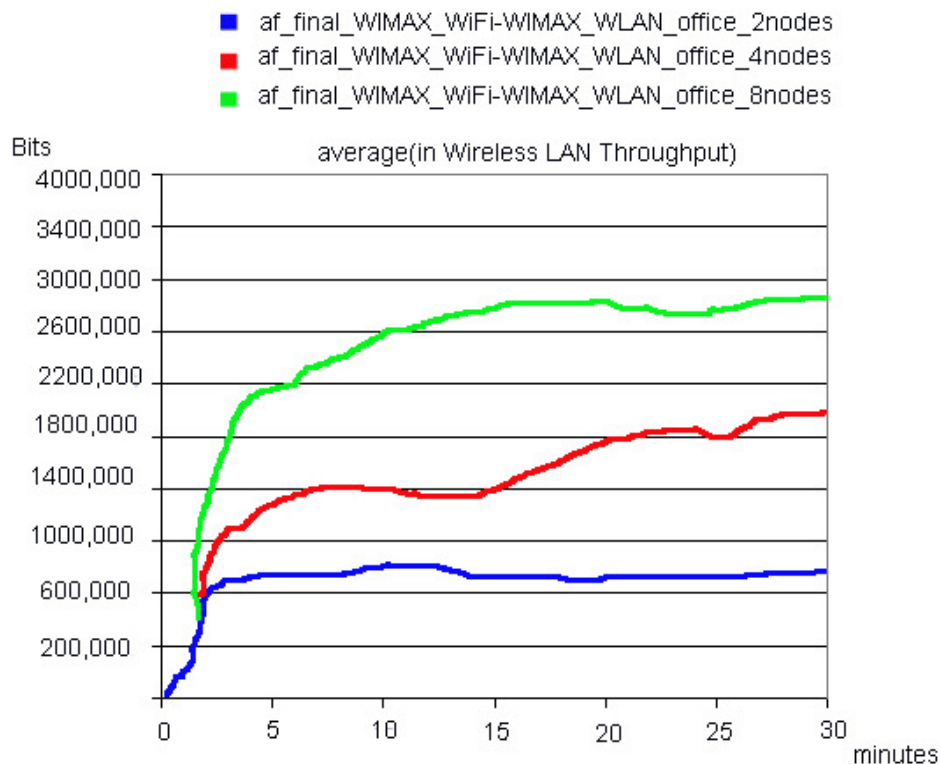


Figure 7.11 Throughput for 2, 4, and 8 WLAN users

In this work we have simulated many different scenarios with one AP and one work station; two layer network model with IEEE 802.11 and IEEE 802.16e. From the simulation result, WiFi access points were compared and the delay in WiFi router was higher than the delay in the WiMAX base station. From this scenario we see that Goodput in access point and base station dependent on the amount of traffic [7.1.4].

7.1.4. Experimental estimation of vehicular network

7.1.4.1. Experimental Estimation of IEEE802.11n for Short Range Vehicular Network

The estimation was made by the means of IxChariot software. The main feature is the fact of speed measurement of the data transmission depending on the remoteness of the mobile object from the base station and its moving speed. The base stations are connected with the primary station, using WDS (Wireless Distribution System) connection Figure 7.12.

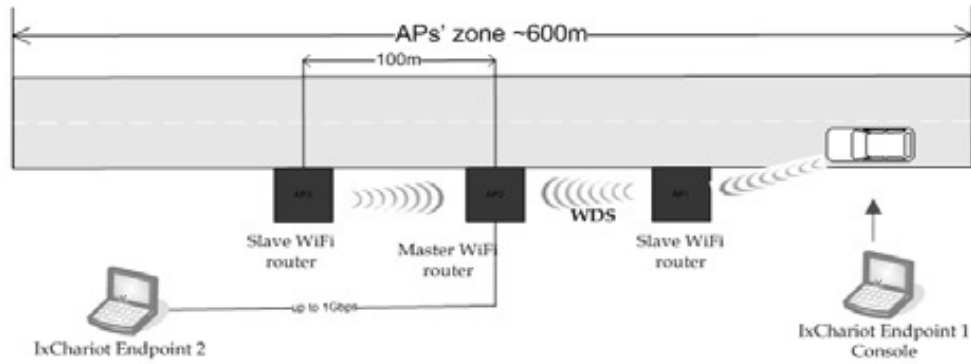


Figure 7.12 Measurement setup using IEEE 802.11n devices

Data transfer rate as a function of location of the mobile object, during its movement at speeds of 20km/h is shown in Fig.7.13. Data transfer rate as a function of location of the mobile object, during its movement at speeds of 40km/h is shown in Fig.7.14. Data transfer rate as a function of location of the mobile object, during its movement at speeds of 60km/h is shown in Fig. 7.15. Data transfer rate as a function of location of the mobile object, during its movement at speeds of 100km/h is shown in Fig.7.16.

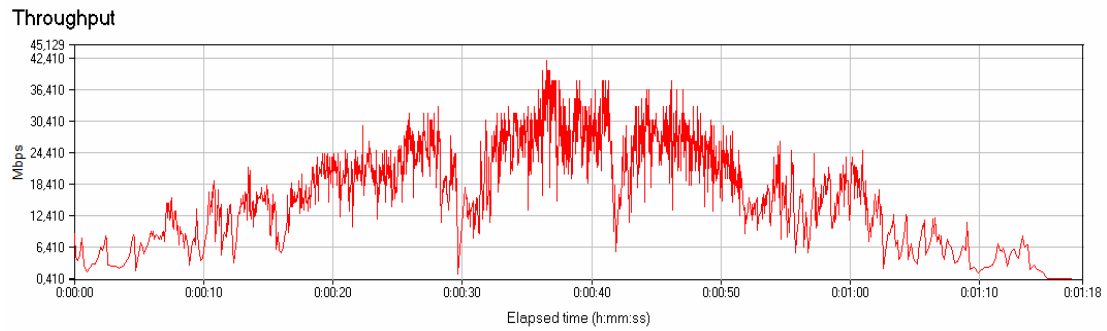


Figure 7.13 Data transfer rate as a function of location of the mobile object, during its movement at speeds of 20km/h

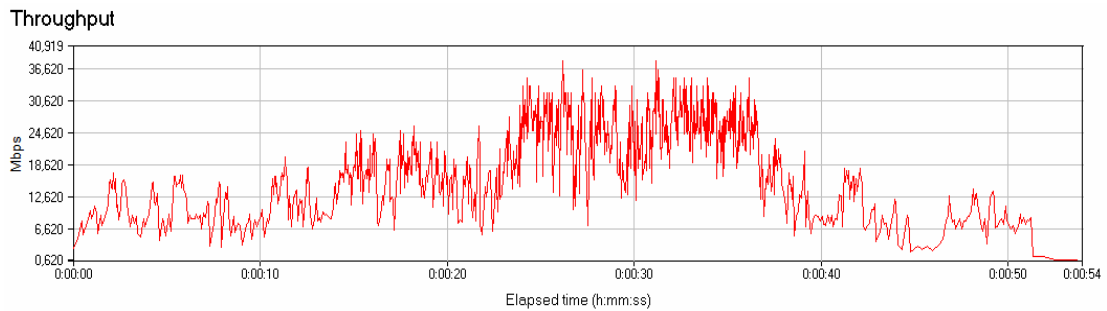


Figure 7.14 Data transfer rate as a function of location of the mobile object, during its movement at speeds of 40km/h

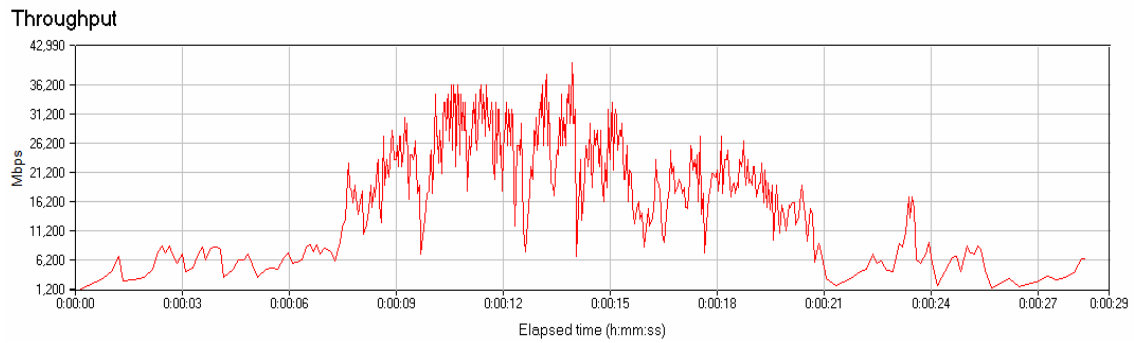


Figure 7.15 Data transfer rate as a function of location of the mobile object, during its movement at speeds of 60km/h

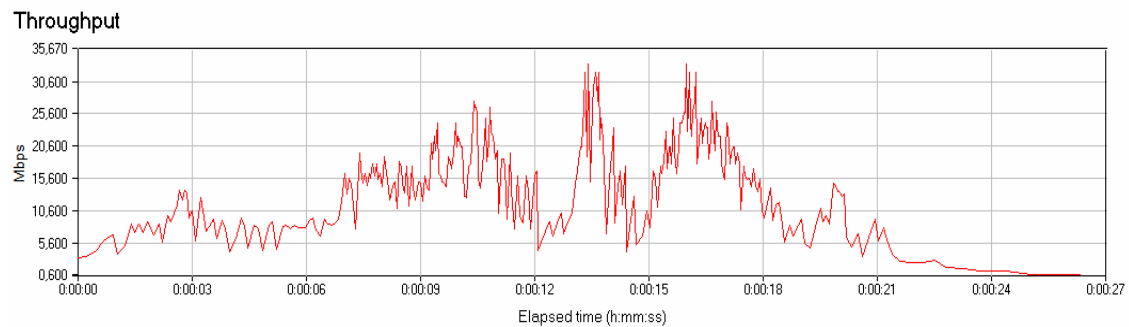


Figure 7.16 Data transfer rate as a function of location of the mobile object, during its movement at speeds of 100km/h

7.1.4.2. Experimental Estimation of IEEE802.11n and 3G for Two-stage Network

The results from previous studies, presented in this article, were continued in the direction of the creation of the analytical model for performance assessment of not only the mobile unit - Access point, but also further from the Access point to the remote server.

The adequate model in this case can be a closed network model of queuing systems, consisting of two nodes. The experiments took place in Rumbula, Riga, research polygon (Fig. 7.17).

The initial node simulates terminals of the mobile units; it is directly connected to AP models with the controller and the router that connects AP to a remote server, which simulates the third node of the network model.

In order to determine the model parameters, such as the intensity of the processing in the nodes and probability of transitions, it is necessary to evaluate the physical parameters of the prototype. In order to create such a prototype, the Cisco equipment has been used.

This prototype presents a “test-bed” for the study of the dependence of goodput on the speed of the car. While the measurement of the effective data transfer rate covers not only the first range of the system “mobile unit – AP”, but also the data transfer channels from AP to a remote server of the user.



Figure 7.17 Rumbula, Riga, research polygon

It is obvious that the goodput will be largely dependent on the data transfer rate from AP to the server, i.e. from the data transfer characteristics. For such studies the router CISCO C819 M2M with two output channels has been used. One channel provides data transfer in GPRS mode. The second channel, being characterized by a high data transfer rate, uses LTE mode – the mode of the next generation of mobile communications. Scheme “test-bed” is presented below (Figure 7.18):

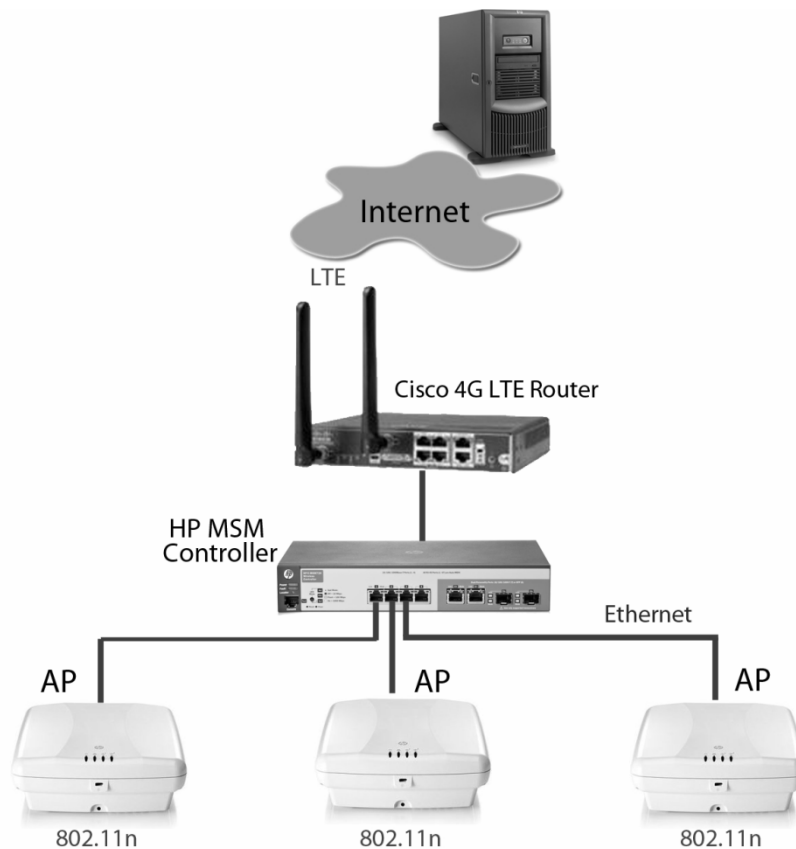


Figure 7.18 Two range network model

The first study showed that the data transfer rate may differ significantly from the data, which were obtained earlier and are covering the first range of the system “mobile unit - AP”. This can be explained by the fact of the delay in the second range of the network to the server. As expected, goodput has a higher value at the transfer to the LTE channel.

The results of goodput are presented in several graphs:

1. 3G goodput at the steady mode is shown in Fig.7.19.
2. Two stage goodput with 3G and 802.11n at speeds of 20km/h is shown in Fig. 7.20.
3. Two stage goodput with 3G and 802.11n at speeds of 40km/h is shown in Fig. 7.21.
4. Two stage goodput with 3G and 802.11n at speeds of 70km/h is shown in Fig.7.22.

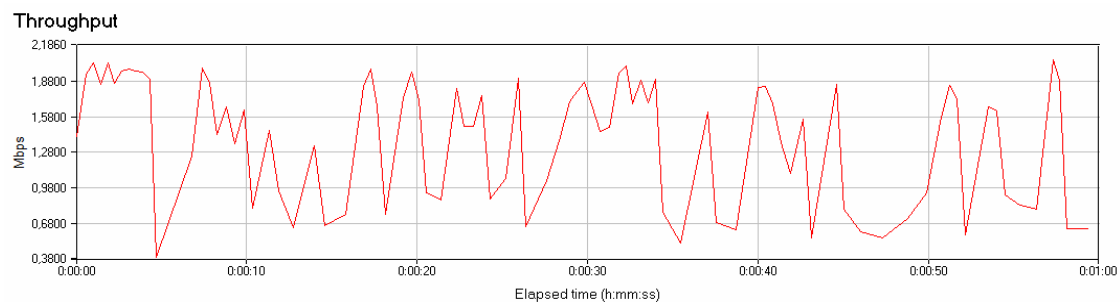


Figure 7.19 3G goodput at the steady mode

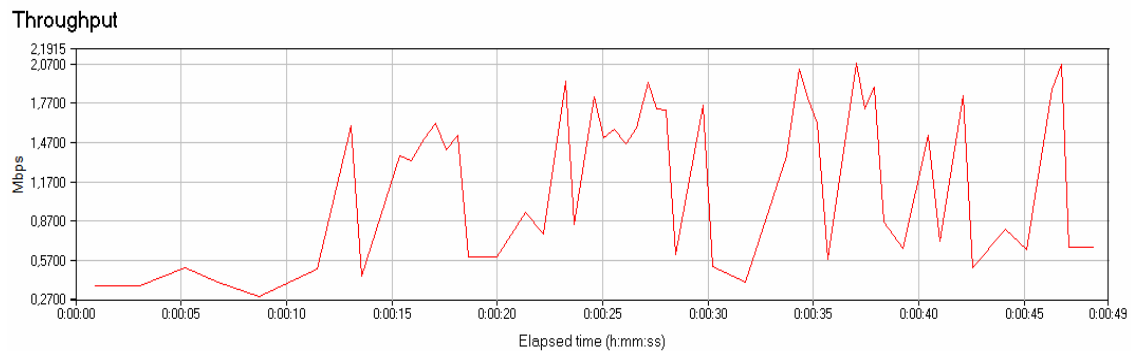


Figure 7.20 Two stage goodput with 3G and 802.11n at speeds of 20km/h

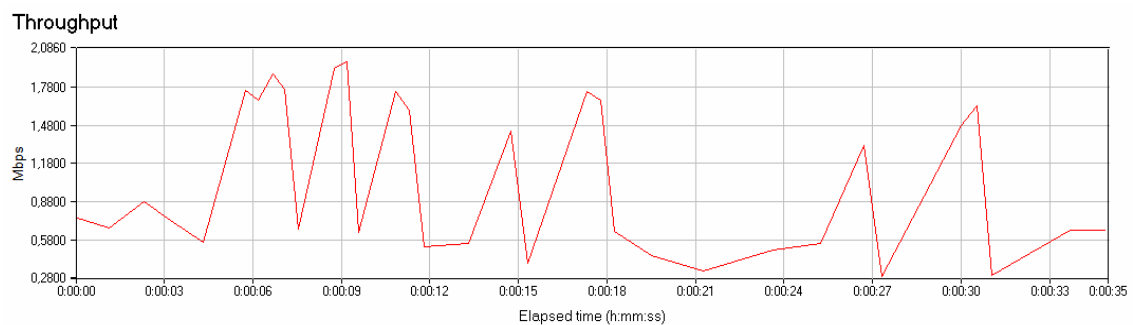


Figure 7.21 Two stage goodput with 3G and 802.11n at speeds of 40km/h

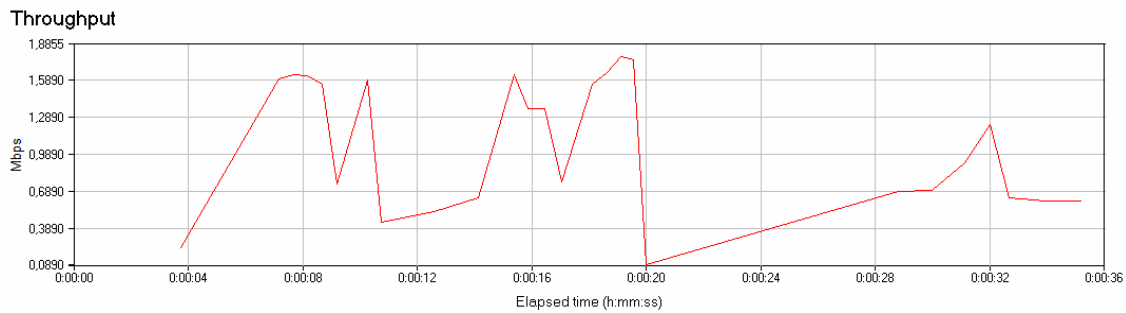


Figure 7.22 Two stage goodput with 3G and 802.11n at speeds of 70km/h

7.1.4.3. Experimental Estimation of IEEE802.11n and 4G for Two-stage Network

This experiment was carried out due to the growing demand for the Internet and its services. Information base is being used to provide good services, the latest wireless networks and corresponding standards to dedicated short-range communications. Considering this part, the wireless base stations can be set up along the priority roads, which will provide communication to the vehicles independently from the network infrastructure.

At the setting up of wireless network, the certain problems occurred with for moving objects, which are required to be solved by the manufacturers. One of the problems is the amount of vehicles on priority roads in respect to the amount of base stations along the priority roads. The certain problem is significant as the certain amount of the customers is located in the coverage of the base station with the recommended data transmission speed, which is called “goodput”. The data transmission speed depends on the traffic intensity. The second problem is the presence of the neighbouring wireless networks.

The main task in this experiment is the approximate data transmission speed in accordance with the distance to the base station, as well as the second task should be resolved, when the Internet speed should be fixed in accordance with the N moving objects, which are located in the coverage of the wireless network base station.

In order to carry out such study, the program Chariot should be used. Over the FTP protocol the file is being sent via base stations from the computer to the remote server moving along the base station. FTP protocol is being used to transfer large amounts of data. During the experiment, the actual speed Goodput will be measured (the recommended data transmission speed) in the program over ftp protocol in order to determine the data transmission speed at the speed of the certain vehicle.

This graph in Fig. 7.23 shows theoretical parameters of the applied access point in our experiment. Each access point has the transferring coverage distance up to 100m radius from the device.

There are mathematical formulas to calculate the amount of packet transfer per second, as well as the possibility of obtain the curves which will show the optimal speed for the moving object in order to receive more packages.

The very first experiment was carried out with the use of access point in each direction at the distance of 60 meters from the controller in accordance with the

principle as shown in the scheme. This means that the access points are located at the distance of 120 m from one another, we use 3 access points and the client was moving with a speed of 30 km/h. It should be mentioned that these experiments have no authority controllers. Throughput - permeability and Elapsed time are denoting the experimental measurement time. Mbps - Mbit/s (Figure 7.23).

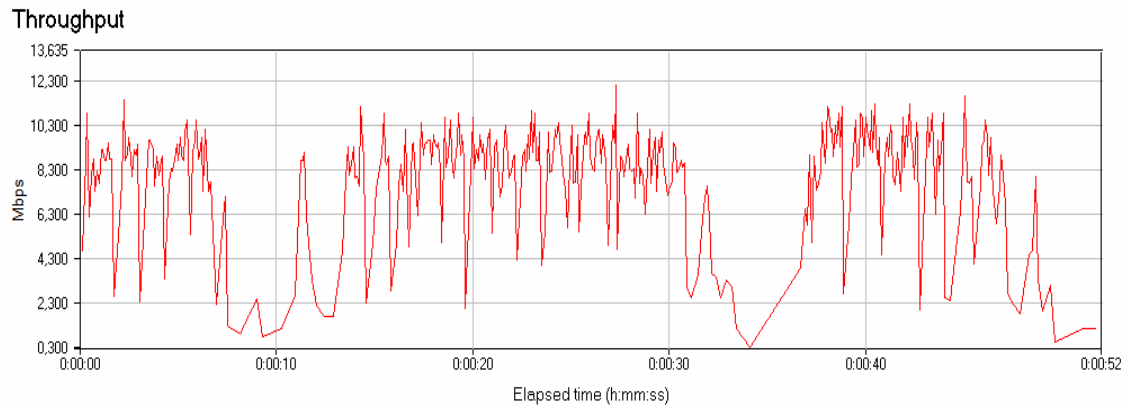


Figure 7.23 Throughput graph at the client travel speed of 30 km/h along the access points

After studying of the graph we can see that the secured speed is a bit lower than expected but this reflects the real internet speed to the server. In accordance with IxChariot program indexes, the average internet speed attained only 5,909 Mbit/s., by using LTE (4G) network the speed should be greater. In this experiment the maximum internet speed was 12.121 Mbit/s. while the minimum rate was 0.311 Mbit/s. The lowest speed is explained by the fact that at that time was switching from one access point to another, so for a short time the data transmission speed is reduced. Response time from the device, seconds and Elapsed time are denoting the experimental measurement time (Figure 7.24).

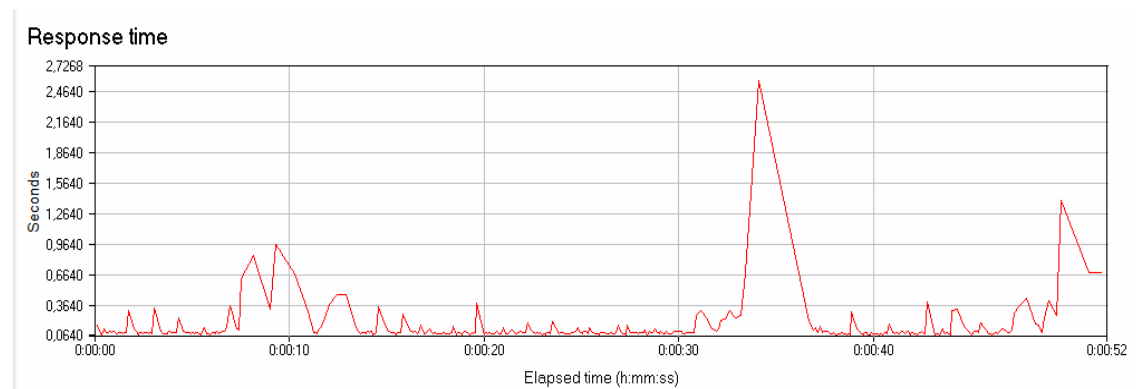


Figure 7.24 Response time graph at the client travel speed of 30 km/h along the access points

Upon comparing of this graph and the previous graph, we can see association that the response time of the client depends on the speed at that moment or the action. When the client switches from one access point to another with a very low Internet covering, he moves for several meters with almost no internet.

The average response time for this attempt was 0.135 seconds, while a very good index is the minimum response time of 0.066 seconds or 66 ms. Response time graph shows that at this time much less data packages are being transferred than with the

lower response time. So, within 51.398 seconds 38.200.000 bytes were transferred or 382 transmissions took places. This means that one single transmission included 100.000 bytes or 0.1 MB and in total 38.2 MB were sent, which is generally a good index during the transmission of information.

The next experiment was carried out at the speed of 60 km/h, traveling down the road along the access points.

But now we used only two access points to see precisely at the switching moment. The distance between the access points is 120 meters (Figure 7.25 and Figure 7.26).

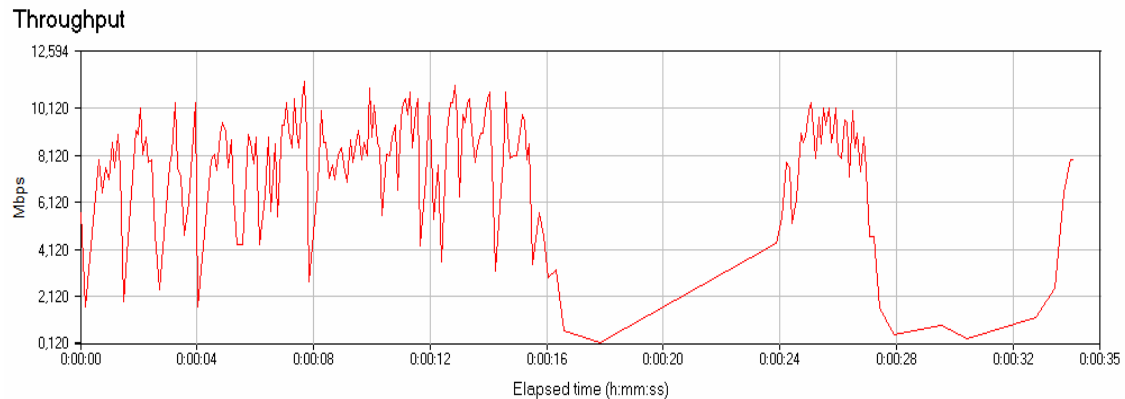


Figure 7.25 Throughput graph for the client at the travel speed of 50 km/h along the access points

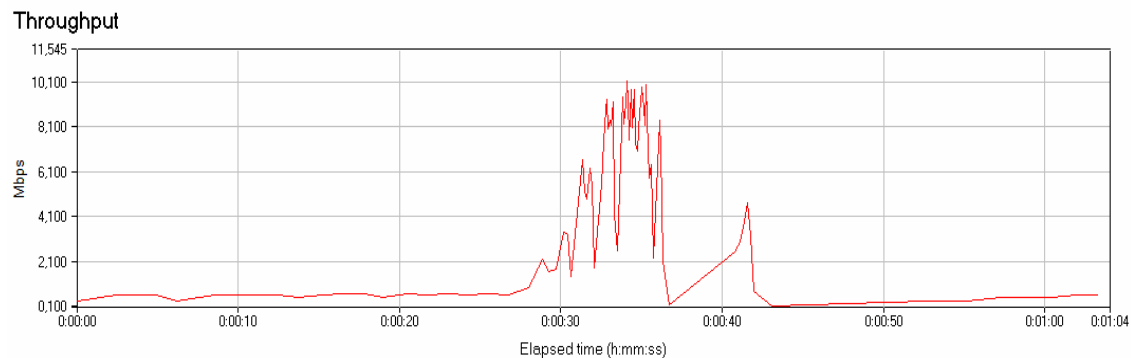


Figure 7.26 Throughput graph for the client at the travel speed of 90 km/h along the access points

Having investigated the graph, we can see that the connection is not lost even during the switchover, as the minimal Internet speed is 0.132 Mbit/s. The average speed for this experiment made only 4.412 Mbit/s, and the maximum internet speed made 11.268 Mbit/s, which is quite a good speed for the vehicle. While making this measurement, 188 transmissions of 100000 bytes took place. The total transferred data amount reached 18.8 MB only at the distance of 240 meters, which is a very good index (Figure 7.27).

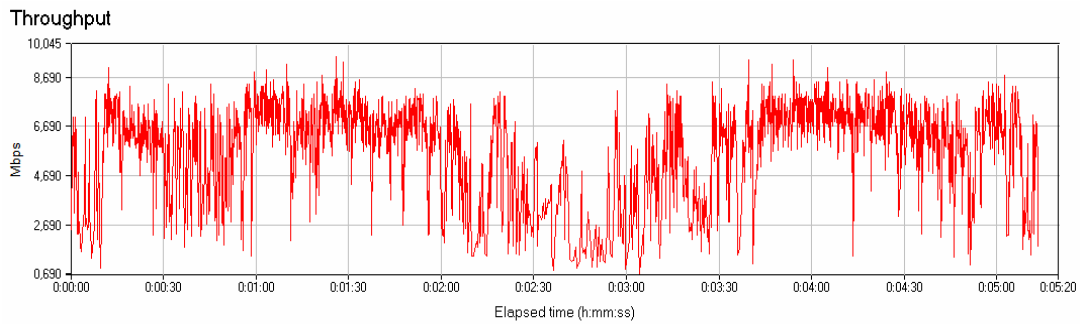


Figure 7.27 4G LTE goodput at the steady mode

7.1.5. Conclusion

From the made models can be seen that the performance of the wireless network depends on the number of customers as well as on the transmission type of traffic (HTTP or FTP). In the given piece of work was developed the model for defining the real speed of the data transmission depending on the number N of the moving objects which were in the coverage area of the base station of the wireless network. On the basis of this piece of work the real speed of the data transmission will depend on the number of the objects interacting with the base station and their remoteness from it. On the basis of the experimental data were developed the mathematical model, the connecting number of vehicle and data transmission feature. In this paper were developed the model to determine the actual speed of data transmission depending on the number of mobile objects which are in the coverage area of the base station of the wireless network. In fact, we have derived practical analytical models for the distribution of the number of packets that a vehicle can download from a two layer network system with access point and base station. It can be concluded that the performance of a base station depends on the number of vehicle and speed. For our calculations we assumed that the rate increases exponentially.

7.2. Multiple Frequencies Precise GNSS RTK System Research in Dynamic Mode

The rapid motor transport development, in terms of both quality and quantity, has generated quite a few problems in the sphere of road traffic safety. Modernization of the existing road infrastructure and creation of new state-of-the-art systems, especially in communication, are aimed at reducing the number of road traffic accidents. [7.2.1]. Given results work presents the possibilities to use GNSS system with phase measurements and real time data correction to establish location of dynamic objects. Test was done by using specially equipped vehicle, which was equipped with high-precision two systems (GPS and GLONASS) phase meter Topcon GRS-1 and a real-time correction system, which used GSM GPRS data transfer format [7.2.2].

7.2.1. Devices used in the research

Structure of the used satellite system devices presented in Fig.7.28. Receiver antenna W1 was installed on the roof of vehicle. For control purposes, in the car was installed a simple satellite signal receiver Holux BU-353 with a proven ability to work at high speeds of movement, but with the lower accuracy.

Correction stations are part of EUPOS-Riga system, consisting of five stations near Riga. In some researches also were used LATPOS correction stations, covering all Latvia territory. For research without satellite system, there were also two types of inertial sensors installed, to autonomously determine the movement of the vehicle in restricted satellite visibility conditions.

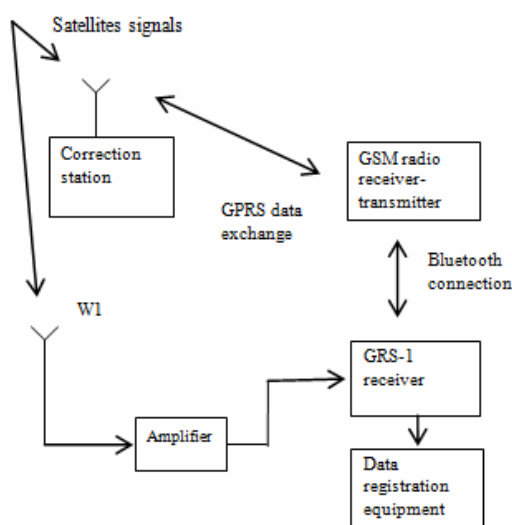


Figure 7.28 Structure of satellite system devices

One of the inertial sensors was MEMS acceleration sensor STEVAL-MKI024V1, another - acceleration and position sensor Xsens MTI-G with built in receiver without correction (Fig. 7.29). Inertial sensors were placed on the roof of the vehicle, next to the satellite receiver antenna, but the sensor output signals were transmitted to the recorder hardware, that was in the car.



Figure 7.29 Installation of devices

7.2.2. TOPCON GRS-1 GNSS Receiver Testing in Dynamic Mode

The testing results of TOPCON GRS-1 gave us good precision evaluation in static mode. The first experiment purpose was to determine the influence of environment (trees and buildings on either side of the road) on the number of satellites available for GRS-1 device and the respective precision errors. The path that contains different type of environment on either side of the road (trees and buildings) was chosen (Fig.7.30).

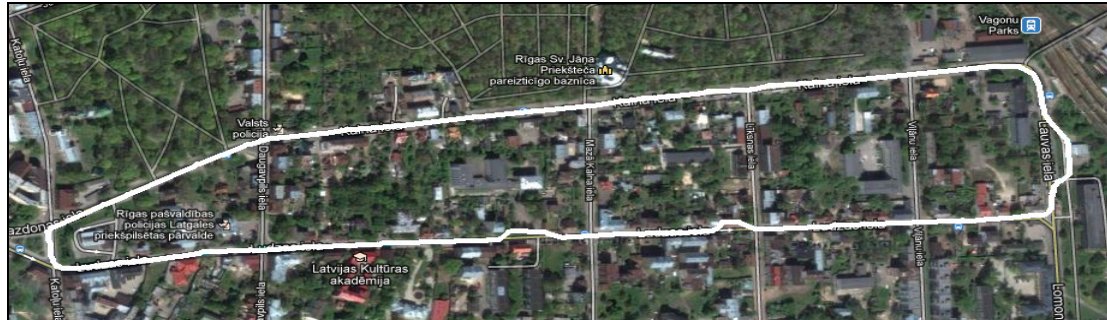


Figure 7.30 The first experiment trajectory on the Google aerial map

After traveling the chosen path the navigation data from GRS-1 was processed and marked on the map. Fig.7.31 illustrates the RMS (that is accuracy) dependence on the number of satellites available for every measured position along the path.

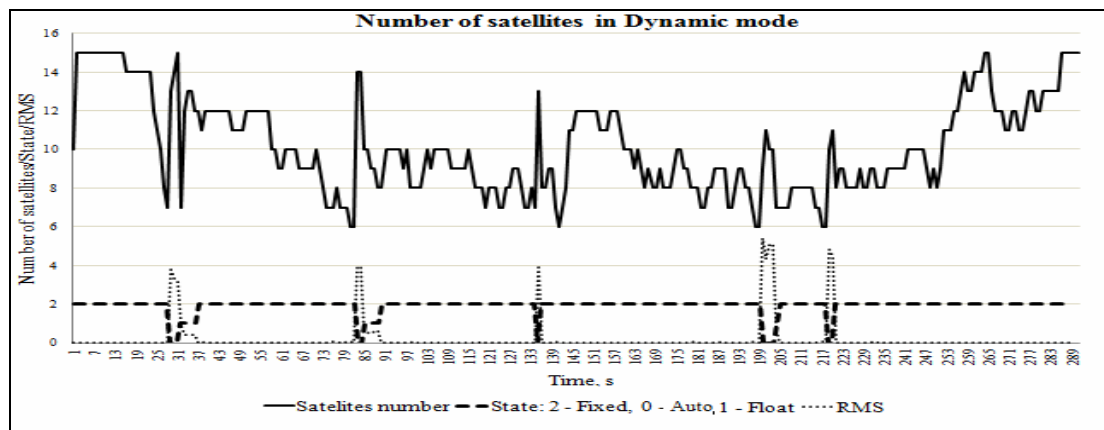


Figure 7.31 RMS dependence on the number of the satellites

TopSURV software provides several types of the position calculation methods: fixed – positions are computed by RTK engine, the carrier phase measurements from a base station and receiver. Integer ambiguities are fixed; autonomous – differential corrections are not available; float - integer ambiguities are not fixed.

The purpose of next experiment was to test GRS-1 receiver at different velocities. The problem was to find a simple way to calculate velocity of the vehicle based on the data provided by GRS-1 receiver. It was impossible to obtain the velocity data directly from the receiver

During the experiment, measurements were carried out for certain vehicle velocity parameters. Vehicle begins moving with acceleration, reaching top velocity – 40 kilometers per hour. Vehicle moves at the top velocity, and then begins to slow down.

The route for the experiment was selected at the straight stretch of the road. Using GRS-1 in static mode the road has been marked in two points: “start” and “finish”. By GRS-1 calculation, the distance between these two points is 182.3728 meters (Fig. 7.32).



Figure 7.32 Orthophoto of the road

The vehicle moves specified distance at the given velocity parameters, while the GRS-1 measures position every second. As a result, we have obtained the samples of coordinates along the entire route with an interval of one second.

Unfortunately, GRS-1 does not support the calculation of the object’s velocity; it measures only coordinates of the position along the route. But GRS-1 has the ability to export the location data in meters (X – for the longitude and Y – for the latitude). Getting X and Y for each point of the route in meters and knowing the time intervals between measurements, we can easily calculate the velocity values for each point of the route draw a complete velocity graph.

We use simple relation in among the sides of a right-angled triangle to calculate distance between two points of the way (7.18).

$$D_i = \sqrt{(X_{i-1} - X_i)^2 + (Y_{i-1} - Y_i)^2}, \quad (7.18)$$

where D_i is the distance between two points, at the beginning it will be the first measured point (X_{i-1}, Y_{i-1}) and the second measured point (X_i, Y_i) . X_{i-1} and X_i are the corresponding values of longitude in meters of the first and the second measured point, and Y_{i-1} and Y_i are the values of latitude in meters of the first and the second measured point, accordingly.

We know that the distance between two points is traveled in one second time interval; therefore we can calculate velocity for every point of the route and then convert values to kilometers per hour according to (7.19).

$$V_i = \frac{D_i}{1000} \times 3600, \quad (7.19)$$

where V_i is a velocity at the (X_i, Y_i) point of the route.

We can calculate directions for the start and finish points and for every point along the route by using the point’s values in meters. We use (7.20) to calculate direction.

$$\varphi_i = \arctg\left(\frac{X_{i-1} - X_i}{Y_{i-1} - Y_i}\right) \quad (7.20)$$

Fig.7.33 shows the results of velocity calculation by using the algorithm described above. The graph shows the typical velocity increase when the vehicle begins to move, then velocity remains relatively constant for some time interval, and then it decreases.

Fig.7.34 shows the comparison of “point to point” direction related to the straight-way route “start to finish” direction. "Start to finish" direction is 317.0687° relative to the north and marked with solid line. "Point to point" direction is also relative to the north and is marked with dashed line.

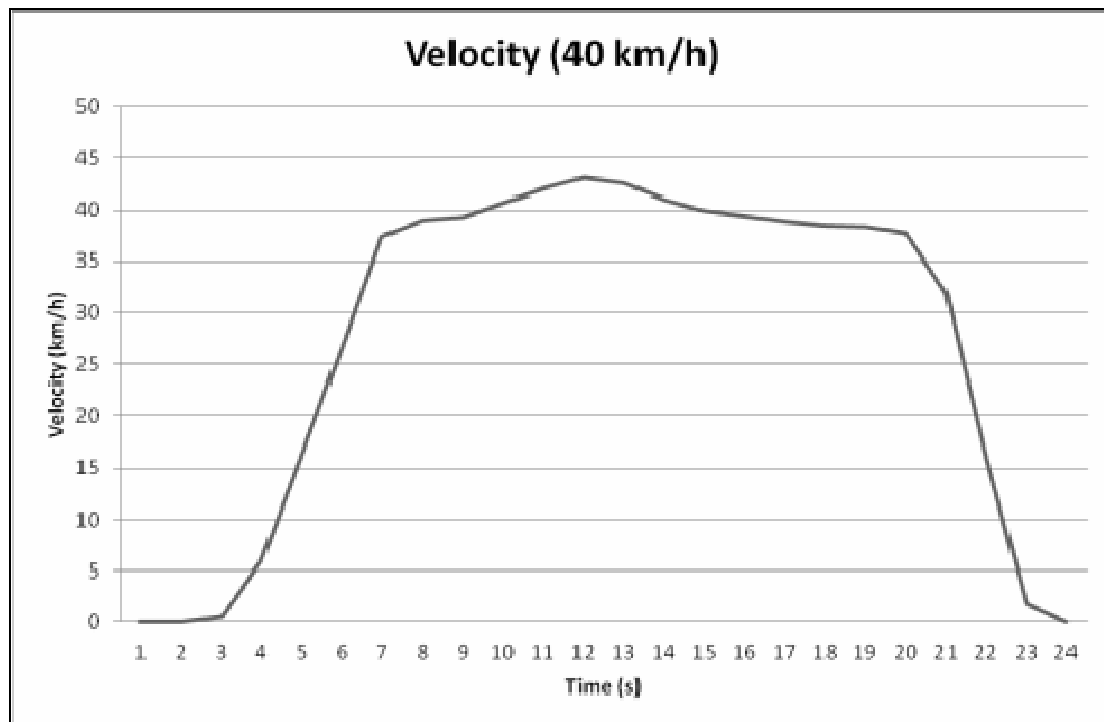


Figure 7.33 Vehicle velocity reaching 40km/h

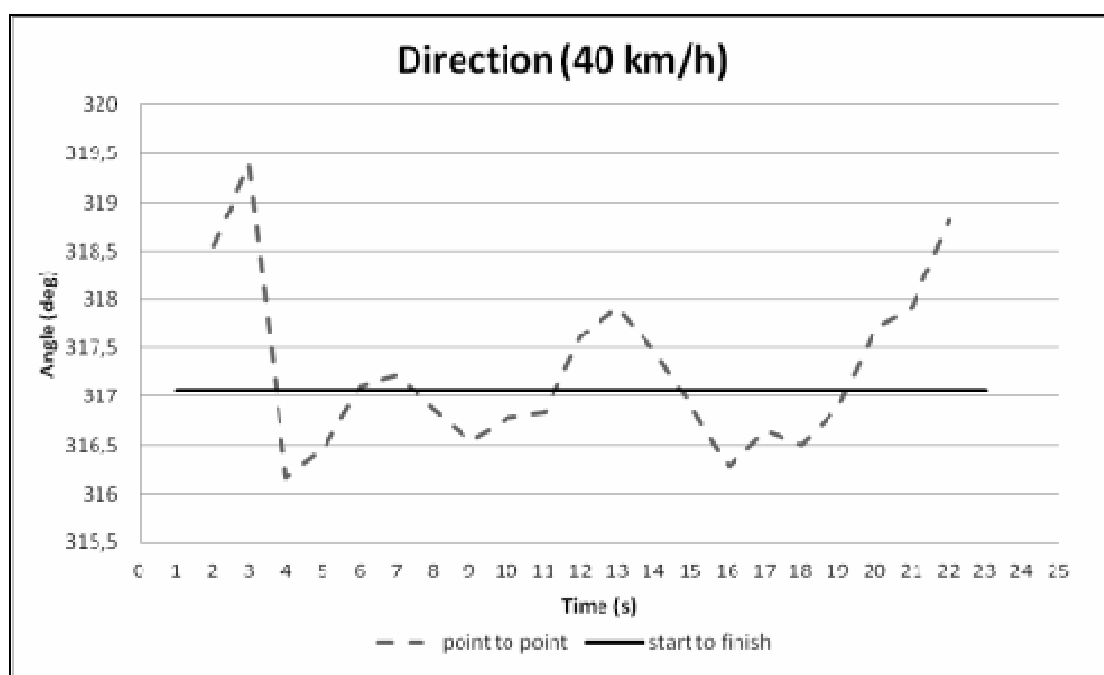


Figure 7.34 Direction comparison for velocity 40km/h

For next experiment route with a much straight stretches of road was chosen in order to reach speed up to 100 km/h (Fig.7.35).



Figure 7.35 Route of the experiment

Experiment results at maximum speed are presented in Fig.7.36.

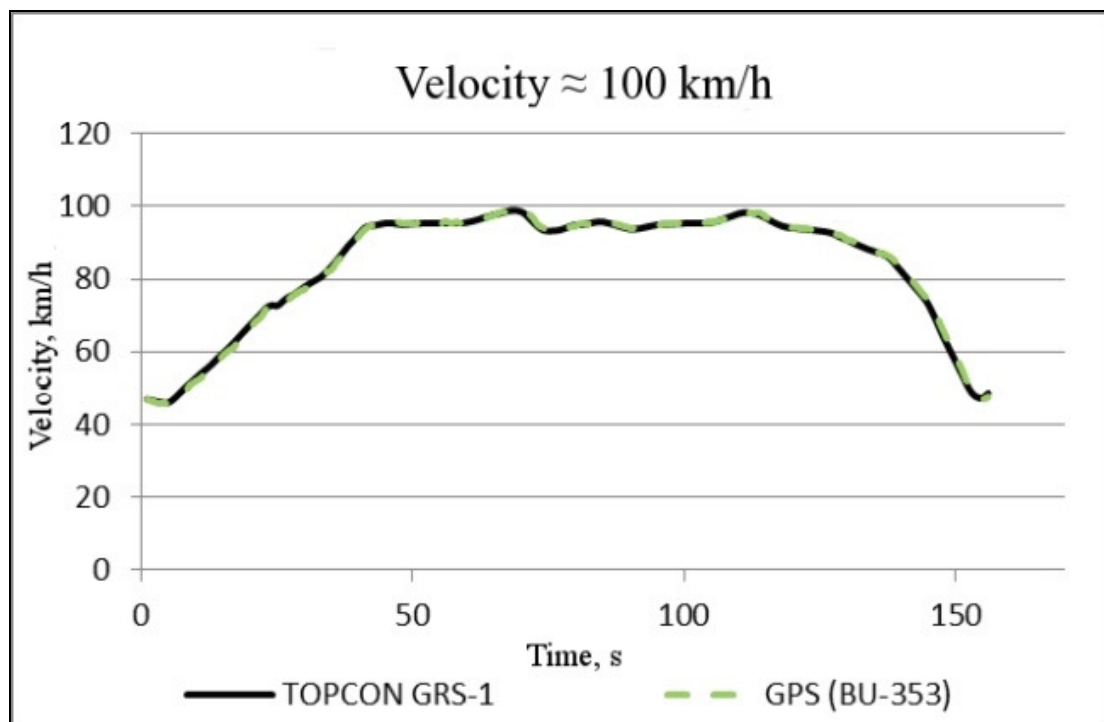


Figure 7.36 Velocity determination with satellite systems devices, $V \approx 100 \text{ km/h}$

As can be seen from presented results, at maximum speed measurements of mobile object location obtained with phase meter and real-time correction (Topcon GRS-1) was very similar, if compared with high dynamic receiver BU-353rd position measurements. In order to compare the correction stations networks EUPOS-Riga and LatPos, measurements by using these networks were carried out. Results are presented in Fig. 7.37 and 7.38.

The results show the possibility of position measure in dynamic mode, using both real-time correction systems.

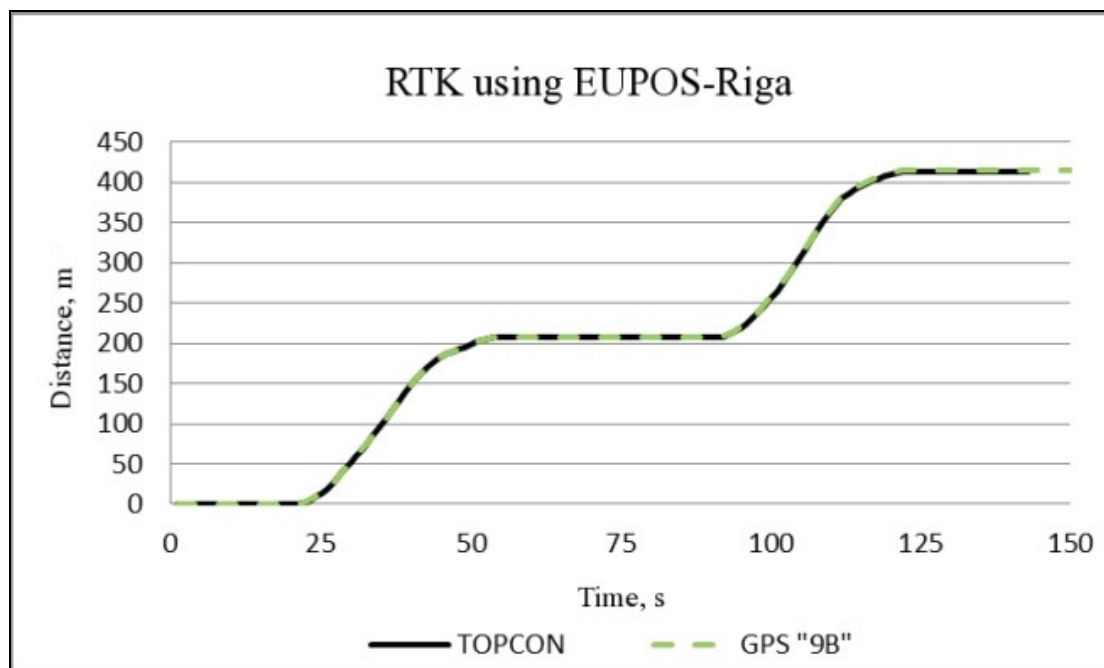


Figure 7.37 Changes in travelled distance using correction from EUPOS-Riga

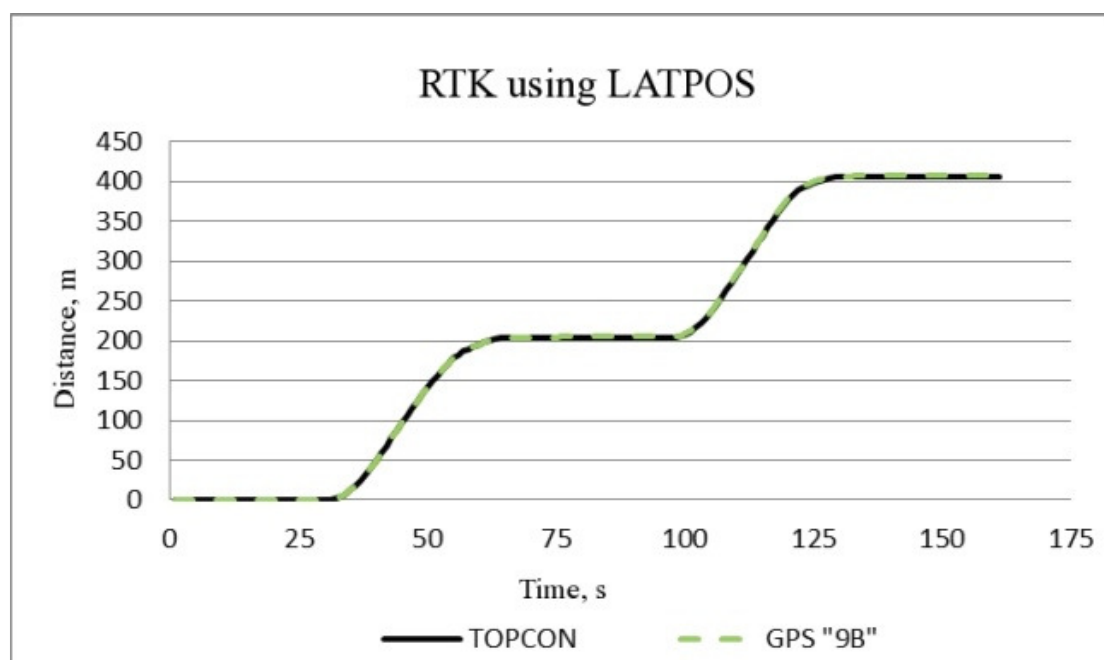


Figure 7.38 Changes in travelled distance using correction from LATPOS system

If from previous figures looks like precise system GRS-1 and non precise system works similar, then now let's take a look at more detailed systems research results (Fig.7.39 and 7.40).



Figure 7.39 Comparison of satellite systems with and without RTK - GRS-1 measurements



Figure 7.40 Comparison of satellite systems with and without RTK - Xsens built in GPS receiver measurements without correction

As we can see from shown measurements results, phase measurements with RTK have much higher accuracy and there is no variation in measurements, as for receivers without correction.

7.2.3. Research of complex system

Location determination experiments with high-precision satellite systems in dynamic mode, even using all available GPS and GLONASS system satellites showed, that in both urban and rural forest massifs are possible disruptions of satellite signal reception. To avoid position measurement loss, incurred during the capture of satellite signals, inertial acceleration sensors were used for automotive sharp lines: x - longitudinal, y - lateral direction.

At the beginning, when satellite device GRS-1 provides positioning, received measurements are used to calculate longitudinal acceleration (x axis) and lateral (y axis) acceleration values. Calculated acceleration is used to evaluate inertial sensors acceleration bias:

$$a_{nx} = a_{ix} - a_{sx} \quad (7.21)$$

$$a_{ny} = a_{iy} - a_{sy} \quad (7.22)$$

where a_{nx} and a_{ny} - acceleration bias in the respective x and y accelerometer axes, a_{ix} and a_{iy} - inertial acceleration meter values in the respective axes, a_{sx} and a_{sy} - acceleration in the respective axes, calculated from satellite device data.

It is important to note, that acceleration bias will not be constant thought the trip, but will fluctuate, respective the accelerometer data noise and error values, mainly caused by vehicle vibration and tilting during the trip. So we made conclusion, that it is necessary for obtained acceleration bias values to apply filtering algorithms. The simplest filter model was selected for this purpose: low - pass filter, which can be described by the following equation:

$$x_{iz_i} = x_{iz_{i-1}} + \frac{1}{k} \cdot (x_{ie_i} - x_{iz_{i-1}}) \quad (7.23)$$

where x_{iz_i} - filter output value in the current time moment, $x_{iz_{i-1}}$ - filter output value in the previous time moment, k - filtration coefficient, x_{ie_i} - filter input value, in our case, acceleration value in the current time moment.

In the case, if navigation signal is lost during the trip, processing algorithm will use accelerometer measurement results to determinate position and movement parameters, by using obtained filtered acceleration bias value for accelerometer measurements correction. For navigation data obtained during the experiment were simulated 20-second interval, when navigation data were not available and the position was

determined by using only accelerometer data. Results obtained without filtering are shown in Fig.7.41.



Figure 7.41 Straight line movement without filtration

With  green arrows are marked vehicle movement and position, when navigation signal was available. With  red arrows are marked vehicle movement and position, for section, when we simulate navigation signal lost, and parameters were obtained by using only inertial sensor measurements. With  yellow arrows are marked determined vehicle movement and position, in case, if navigation signal lost isn't simulated.

Results obtained by using acceleration bias filtration for the same road section are shown in Fig.7.42. As can be seen in this case, we obtain accurate trajectory without using satellite measurements.



Figure 7.42 Position determination by using inertial sensors data with bias filtration

For acceleration filtration also can be used variable window method or Kalman. Variable window method can be described by the following equation:

$$x_{avg} = \frac{1}{k} \sum_{i=n-k}^n x_i \quad (7.24)$$

where x_{avg} - filter output value, k - window length, n - count of input values, x_i - filter input value.

Let's look at the experiment results acquired by using data processing with window method. As we can see from Fig.7.43, filtration with optimal window length (20 cycles) give results very similar to those described above. And it can be concluded, that in principle, we can acquire same results with different processing methods, but in autonomous mode error is most affected by motion unevenness.

Accelerometer results are good enough to determinate position and movement parameters of vehicle when moving in straight direction. But in case when complex movement is made, previously acquired bias value can change and calculated movement trajectory can be different than actual, as that shown in Fig.7.44.



Figure 7.43 Filtration with optimal window length (20 cycles)

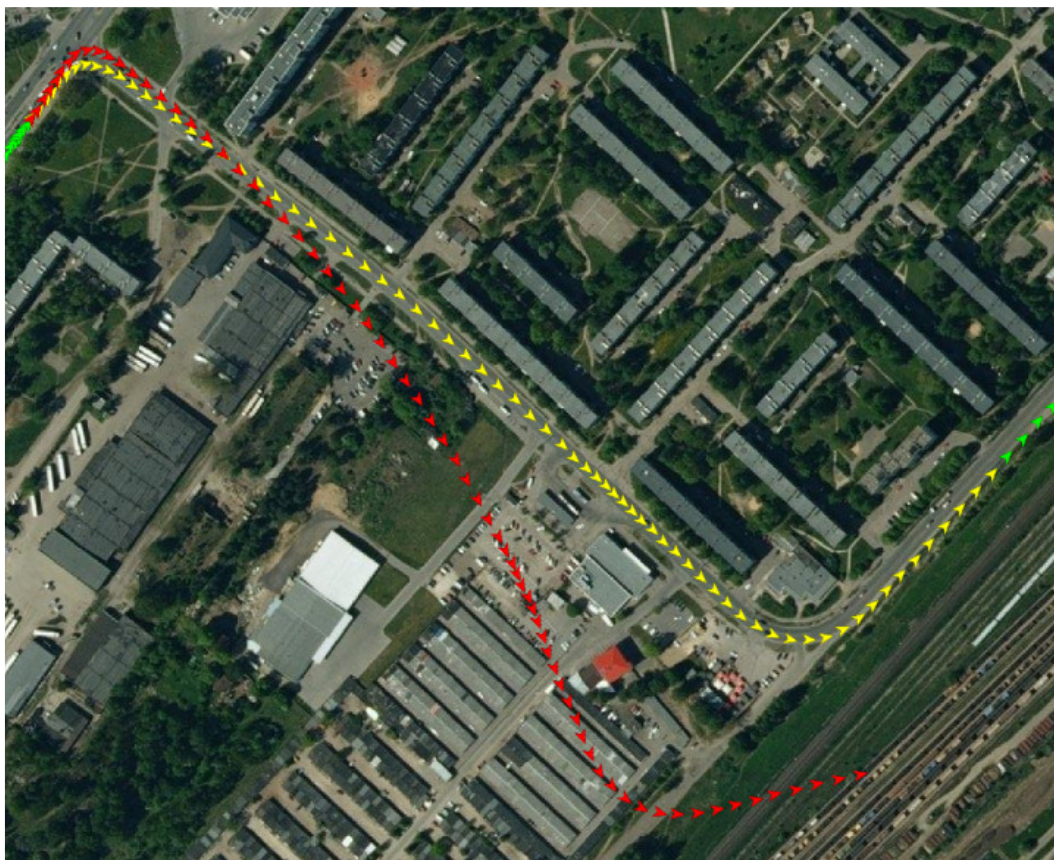


Figure 7.44 Trajectory by accelerometer in complex movement, filtration with optimal window length (70 cycles)

To improve determination of vehicle movement trajectory, instead of accelerometer can be used gyroscope. Gyroscope measure direction change and are more stable in specific axis against vibrations. Some bias still can affect the measurement, but it is possible to compensate it with the mentioned filtering techniques. Example of result is shown in Fig.7.45.

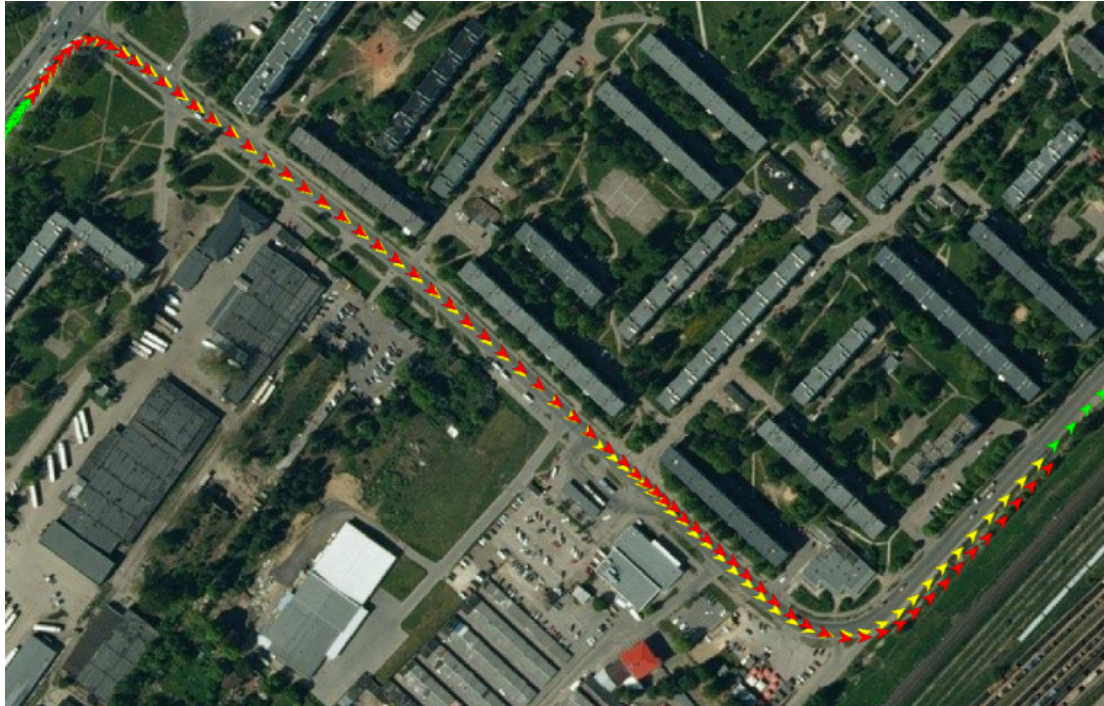


Figure 7.45 Trajectory by Gyroscope in complex movement, filtration with optimal window length (70 cycles)

7.2.4. Conclusions

Results of our experiments for TOPCON GRS-1 show, that GRS-1 receiver has much higher accuracy parameters than other GPS receivers. The accuracy of GRS-1 receiver is affected by the road environment and the number of active satellites in spite of the corrections provided by the base station. GRS-1 can be used for the different velocities, and it is possible to test this receiver in dynamic mode, which will be our future GRS-1 testing aim. Position parameters can be estimated by using the accelerometer offset filtering, when satellite signal is temporarily unavailable. High-precision phase system satellite receivers with real-time data correction can be used for dynamic object location and motion parameters determination up to speed 100 - 110 km/h. To ensure uninterrupted determination of mobile object location in poor visibility conditions, it's required to use additional inertial sensors and simplest complex signal processing with a data comparison and filtration. Complex system with high precision phase satellite receiver modeling and experimental results show that straight road section error is less than 2.5 m, 400 s after satellite signal is lost.

7.3. Appraisal of Feasibility of Using Vehicle-to-Vehicle Communications for Safe Passage of Unsignalled Road Intersection under Varying Conditions

The rapid motor transport development, in terms of both quality and quantity, has generated quite a few problems in the sphere of road traffic safety. Modernization of the existing road infrastructure and creation of new state-of-the-art systems, especially in communication, are aimed at reducing the number of road traffic accidents [7.2.1].

7.3.1. Algorithm application feasibility

One of the prerequisites of passing an intersection safely is the presence of only one vehicle at the intersection. So, on receipt of a possible collision warning signal, the driver must be able to bring his car to a halt before crossing the traffic lanes. Assuming proper operation of the brakes on the vehicle, the minimum stopping distance for a vehicle is determined by the effective coefficient of friction between the tires and the road, the driver's reaction time in a braking situation and the brake system's reaction time. The friction force of the road must reduce vehicle's speed to zero as shown in Fig. 7.46.

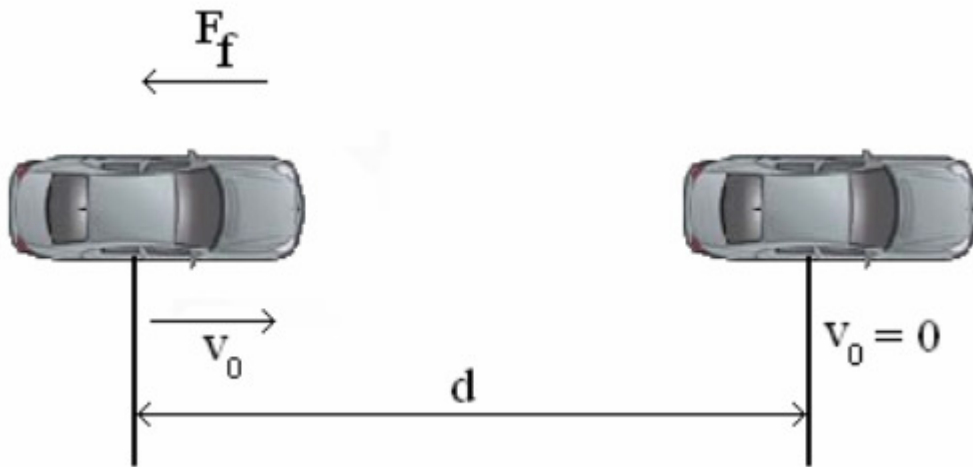


Figure 7.46 Vehicle stopping distance

In order to stop a car, the kinetic energy must be reduced to zero or the kinetic energy must equal the energy given by the friction force as shown in (7.25):

$$F_f d = \frac{mv^2}{2} = \mu mgd, \quad (7.25)$$

here F_f - friction force; m - vehicle's mass;

v_0 - vehicle's initial speed; d - stopping distance;
 $g = .8 \text{ m / s}^2$; μ - coefficient of friction between the tires and the road.

For calculating minimum stopping distance, a value of 0.8 is a nominal value for the coefficient of static friction between good tires and a good road surface. Almost always, coefficients of kinetic friction are less, and are dramatically less for wet, icy, slick, sandy, dirty very smooth or oily surfaces. It can be 0.7 or 0.6 for a vehicle with normally driven and worn tires. Poor condition tires might yield 0.5 or 0.4 for a closer representation of friction.

Therefore, the distance covered by a transport vehicle to standstill may be expressed as (7.26):

$$d = (t_{dr} + t_{br})v_0 + \frac{v_0^2}{2\mu} \quad (7.26)$$

where t_{dr} - driver's reaction time;
 t_{br} - braking system's

The Graphs in Fig. 7.47 show the distance covered by a vehicle to a full halt versus the initial speed of the vehicle for various values of coefficient of friction between the tire tread and the road surface. For this purpose, the average time of driver's reaction to the brake actuation is assumed to be 1.2 sec, and the braking system's reaction time – 0.2 sec.

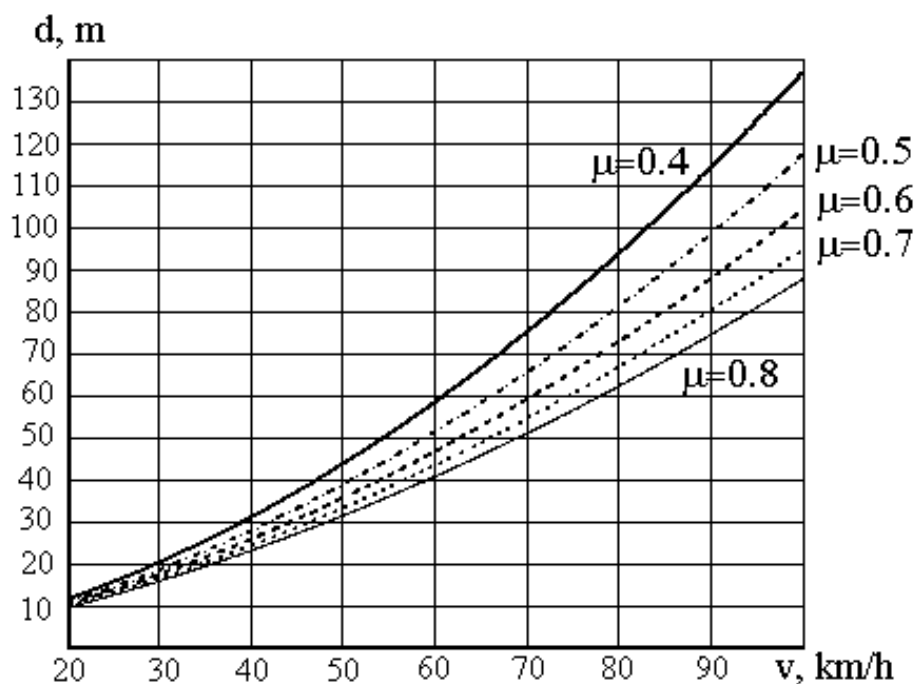


Figure 7.47 Stopping distance/initial speed relationship for different μ values

It is obvious, that within the boundaries of a populated area, given the maximum allowed speed of 50 km/h, the minimum distance covered by a vehicle to a standstill under the worst conditions will be 44 m. Outside the boundaries of populated areas, given the maximum allowed speed of 90 km/h, the aforesaid parameter will increase to 114 m.

7.3.2. Vehicle equipment configuration

Two motor cars were used for test purposes; each of them was equipped with a system, whose structural scheme is given in Fig. 7.48.

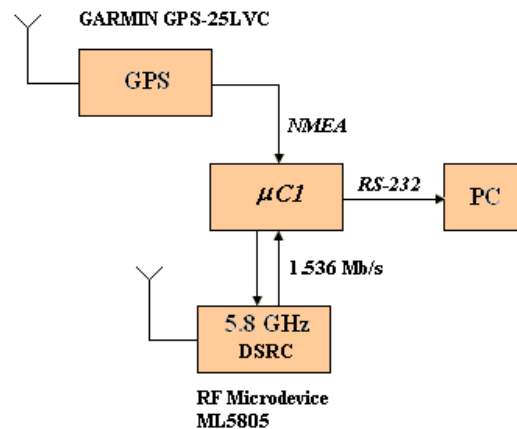


Figure 7.48 Structural flowchart of vehicle onboard equipment

A GPS receiver GARMIN GPS-25LVC with an output in the NMEA 0183 format provides the system with information about the current location, heading and speed of the car.

A 5.8 GHz DSRC transceiver shown in Fig. 7.49, based on a ML5805 microchip, enables the exchange of the obtained information with another transport vehicle.



Figure 7.49 Onboard 5.8 GHz equipment

The device has an omnidirectional, rooftop-mounted antenna as shown in Fig. 7.50. To exclude cable losses, the antenna must be connected directly to the high-frequency part of the transceiver.



Figure 7.50 Car with onboard equipment

As a result, the transmission via a low bit rate port of a microcontroller to PC contains a time marker and information about the position, speed and heading angle of the two tested vehicles. Coordinates conversion and mathematical implementation of the algorithm of possible collision warning at an intersection are performed by a personal computer (PC).

7.3.3. Tests results

The performed tests resulted in determination of the maximum possible ranges of reliable-service distances for various terrains, which confirms the feasibility of the use of the given algorithm for safe passage of a road intersection.

Test drives were held in an urban territory with various types of buildings. Test drive Nr. 1 was conducted within line-of- sight between the transmitter and the receiver without any obstacles on the radio signal path.

The results of Test drives 2 and 3 demonstrate the possibility of V2V communication in the area with two-three-storey buildings around the road intersection and with a low development density of the area as shown in Fig.7.51.



Figure 7.51 Road intersection with low-rise urban structures

Test drives 4 and 5 were conducted in the area of multi-storey buildings with extreme development density as shown in Fig.7.52.

During the test drive, one of the tested vehicles was in static position at various distances to a road intersection, while the second car was moving towards the intersection by crossing course.



Figure 7.52 Road intersection with multi-storied urban structures

The data obtained as a result of the performed tests are shown in Table 7.5:

Table 7.5 Tests results

Test Nr.	d1, m	d2, m	D, m	q, %
1	350	350	495	93
2	80	140	161	85
3	80	180	197	87
4	60	26	65	63
5	15	83	85	75

Where d1 is the distance between the first (static) motor vehicle and the intersection, d2 – maximum distance between the second vehicle and the intersection, at the moment of receipt of the first data set, D – real maximum radio range as shown in Fig. 7.53.

The q parameter estimates the ratio of the correctly received data sets number to the total number of data sets transmitted during the communications period. The number of data sets transmitted during the communications period is determined using time markers and the known transmission periodicity of 1s. The validity of the received data set is confirmed by a checksum.

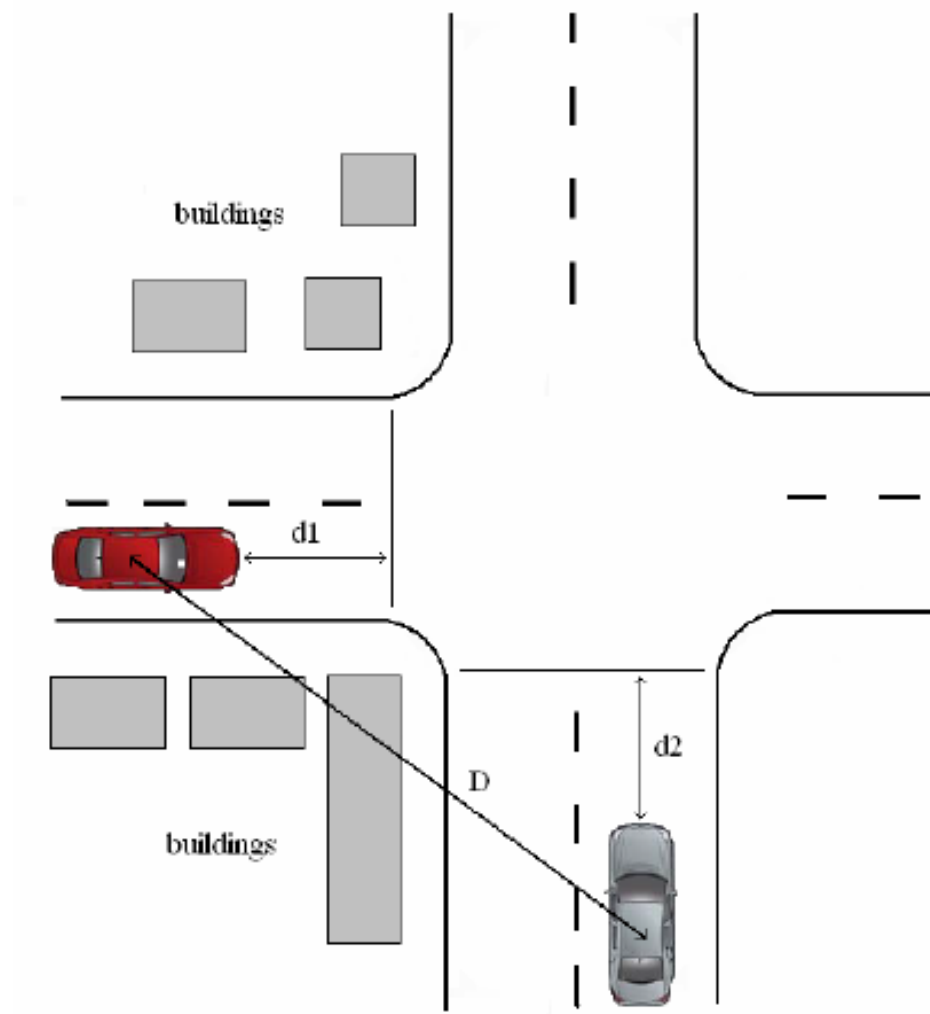


Figure 7.53 Scheme of road intersection

In conditions of direct visibility (test Nr.1) – absence of any constructions – the maximum distance between cars enabling information exchange is 495 m, which is equivalent to the distance of about 350 m to the intersection. In the given case, therefore, the use of the vehicle-to-vehicle communications system for safe crossroad passing will be possible even at the speed of 90 km/h, i.e. outside populated areas.

In conditions of low-rise urban structures (up to 3 storeys high), the maximum possible operable distance of the system is significantly lower, as shown in Table 1, tests Nr. 2 and Nr.3. That can be explained by the different conditions of radio-wave propagation, re-reflection and the low altitude of location of the transceiver antenna.

Nevertheless, the maximum distance from an intersection enabling information exchange is in the range of 80-180 m, which significantly exceeds the established criterion for an urban environment, i.e. 44 m.

In such a case, the number of correctly received data packets falls within the range of 87-93%, which, in view of the slow response of the motor vehicle, does not affect the system operability.

The worst conditions for application of the given kind of vehicle-to-vehicle communications are observed in urban areas with multi-storied structures as shown in Table 1, tests Nr. 4 and Nr. 5.

In such cases, sustained exchange of information is only possible at 15-25 m to the intersection, which is insufficient according to the chosen speed criterion of 50 km/h. It is obviously impossible to apply the algorithm for safety passing of an intersection under the said conditions on the basis of vehicle-to-vehicle communications alone.

The accomplished tests have shown that the presence of buildings and other obstacles significantly reduces the V2V communication rate in comparison with the estimated rate for free space.

When comparing the test drive results with the aforesaid criteria, it becomes evident that the use of the proposed algorithm for safe passage of an unsignalled intersection is feasible under the conditions of line-of-sight and low-storey development.

In conditions of multi-storey urban development, it is impossible to use vehicle-to-vehicle communication alone for intersection passage safety purposes. In the given case, it is worthwhile applying algorithms based on an integrated use of the V2V and V2I communication systems.

7.3.4. Conclusions

The present work provides the feasibility criteria for the application of the algorithm for safe passage of an unsignalled intersection using the vehicle-to-vehicle communication system only.

On the basis of the results of the performed tests, we have assessed the system feasibility and made conclusions on the system applicability under varying conditions both within and outside the boundaries of a populated area.

Further possibility research of applying of the algorithm provide for tests for moving cars, as well as increasing the vehicles involved in the tests.

7.4. References

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8. Viedo radio tīklu sistēmas modeļa izveide un aprobācija reāliem apstākļiem pietuvinātos scenārijos, kas saistīti ar efektīvu daudzu ceļu video datplūsmu pārraidi mobilos bezvadu ad-hoc tīklos, t.sk., izmantojot viedas antenas savstarpējo traucējumu samazināšanai

Pētījuma mērķi:

- Izstrādāt analītisku metodi daudzu ceļu datu pārraides veiktspējas noteikšanai bezvadu ad-hoc tīkla sistēmas modelim ar virzienu darbību un bez tās (Nodaļa 8.3);
- Integrēt bezvadu ad-hoc tīklu sistēmas modeli Matlab rīkā, kas ļautu statistiski izvērtēt daudzus gadījuma rakstura tīkla scenārijus (Nodaļa 8.4);
- Ar imitācijas rīka palīdzību gūt priekšstatu par dažādu tīkla un ceļu izvēles raksturlielumu ietekmi uz daudz-ceļu pārraides efektivitāti un izstrādāt kritērijus ceļu izvēlei (Nodaļa 8.5);
- Izmantot imitācijas rīku lai pētītu daudzu plūsmu pārraidi ad-hoc tīklam ar viedajām antenām, novērtējot optimālo ceļu skaitu, starp-ceļu attāluma, antenu masīva elementu skaita un adaptīvu algoritmu ietekmi uz veiktspēju (Nodaļa 8.6).

8.1. *levads*

Datu pārraide vienlaicīgi pa vairākiem ceļiem tiek piedāvāta kā risinājums augstākas caurlaides spējas sasniegšanai bezvadu ad-hoc tīklos [8.1] [8.2] [8.3]. Pieaugums tiek panākts, nevis palielinot viena kanāla caurlaides spēju, bet izmantojot telpu vairākām vienlaicīgām pārraidēm. Šī pieeja liekas ļoti piemērota video pārraidei, kurai ir augstas prasības pret caurlaides spēju, aizturi, kā arī pakešu zudumiem. Tomēr iepriekšējie pētījumi [8.1] [8.3] arī parāda, ja ceļi ir izvēlēti nepareizi, paralēlas plūsmas rada savstarpējus traucējumus, un gaidīto pieaugumu var arī nerasniegt. Tāpat ir svarīgi novērtēt ceļu caurlaides spēju, jo, kā novērots [8.4], pētot video datu pārraidi, ja apakšplūsmu bitu ātrums pārsniedz noteiktu sliekšni, video kvalitāte strauji krītas.

Traucējumi, kas noved pie datu ātruma samazinājuma, rodas galvenokārt kanāla piekļuves protokola nepilnību dēļ. Bezvadu ad-hoc tīklos tiek izmantots CSMA/CA piekļuves protokols. Tas bloķē vienlaicīgu datu pārraidi starp jebkuriem mezglu pāriem, ja tas varētu radīt savstarpējus traucējumus, bet atļauj raidīt, ja raidošo mezglu pāri atrodas „drošā” attālumā viens no otra, t.i. nerada savstarpējus traucējumus. Šie apstākļi – konkurence uz kanālu un vienlaicīga raidīšana kanālā – ir divi galvenie kanāla caurlaides spējas samazināšanās cēloņi. Papildus ietekmi atstāj slēptie (*hidden*) un pakļautie (*exposed*) mezgli.

Pārraidot video pa vairākiem ceļiem, minētās problēmas vēl vairāk aktualizējas - parādās vairāk vienlaicīgā datu pārraidē iesaistīto mezglu pāru, kopīgie gala punkti (sūtītājs, saņēmējs) rada grūtības izveidot nošķirtus ceļus, mēģinājumi ceļus attālināt

novēd pie papildus mezglu iesaistīšanas un pretēji gaidītajam nedod ieguvumu, intensīvas datu plūsmas tīklu piesātina. Tādēļ viena no galvenajām problēmām, ar kuru jāsaskaras daudz-ceļu pārraidē, ir ceļu savstarpējie traucējumi. Šī pētījuma mērķis ir padziļināta analīze par ietekmi, ko traucējumi atstāj uz daudzu ceļu pārraides efektivitāti, kā arī veidiem to mazināšanai.

Izvirzot par mērķi traucējumu ietekmes samazināšanu, ir divas iespējas: cīnīties ar traucējumu cēloņiem jau ceļu izvēles fāzē, vai mazināt sekas pēc tam. Vispirms, izvēloties optimālu ceļu skaitu un tādus ceļus, kas rada mazākus savstarpējos traucējumus, var mēģināt sasniegt lielāku agregēto tīkla caurlaides spēju. Lai to veiktu, ir jābūt skaidram priekšstatam par tīkla un ceļu raksturlielumiem, kuri var ietekmēt caurlaides spēju. Kā mēs parādījām iepriekšējā darbā [8.5], tīkla caurlaides spēju ietekmē ļoti daudzi savstarpēji saistīti tīkla parametri kombinācijā ar ceļu izvēles algoritmu, padarot optimizācijas uzdevumu ļoti sarežģītu. Pētījumā tiks novērtēta ar tīkla struktūru (mezglu skaits, izvietojums) un ceļu izvēli saistītu raksturlielumu ietekme uz starp-ceļu traucējumiem un attiecīgi caurlaides spēju. Tiks meklēts optimālais ceļu skaits pie dažādiem sūtītāja-saņēmēja attālumiem, kā arī pārbaudīta starp-ceļu attāluma (ceļu nošķirtības) ietekme uz caurlaides spēju, kurai, kā novērots [8.1] [8.3], ir noteicoša loma.

Otra iespēja ir pielietot paņēmienus starp-mezglu un starp-ceļu traucējumu mazināšanai jau izvēlētiem ceļiem. Kā viens no efektīviem, bet, diemžēl, bezvadu ad-hoc tīklos sarežģīti realizējamiem, ir virziendarbība [8.6], realizēta ar digitālo staru kūļa formēšanu (BF). Šādas antenas virtuāli ļauj pavērst antenas diagrammas galveno staru konkrētā virzienā, tādējādi mazinot traucējumus uz citām (vai no citām) vienlaicīgi notiekošām pārraidēm. Papildus pielietojot nevēlamo virzienu nospiešanas (*zero-forced*) BF paņēmienus uztvērējā, var tikt mazināti traucējumi no nevēlamiem virzieniem. Darbā tiks pārbaudīti dažādi ar virziendarbību saistīti jautājumi (virziendarbības *carrier sense*, *zero forced* BF algoritmi) un to ietekme uz daudz-ceļu pārraides efektivitāti.

Bezvadu ad-hoc tīkla darbības imitēšanai šajā darbā tiks uzlabota analītiska metode [8.7], uz kuru balstoties izstrādāts arī ad-hoc tīkla modelis un MATLAB rīks tā pētīšanai. Tas tiks pielietots statistiskai sasniedzamās caurlaides spējas novērtēšanai daudziem gadījuma rakstura scenārijiem. Mūsu pienesums oriģinālajai metodei ir precīzāka *Physical Carrier sense* mehānisma ieviešana un papildināšana ar daudzceļu pārraides iespējām gan ar virziendarbību, gan bez tās (*omni-directional*). Lai arī metode balstās uz ideāla pārraižu plānošanas (*scheduling*) algoritma esamību un iegūtais ātrums reālā dzīvē ir nesasniedzams, tas katram scenārijam ļaus iegūt labāko sasniedzamo rādītāju, uz kuru tiekties. Ievāktā statistiskā informācija sniegs atbildes uz pamatjautājumiem, saistītiem ar daudz-ceļu maršrutēšanas efektivitāti kopumā, kā arī ļaus definēt metrikas *interference-aware* ceļu izvēles algoritmiem.

Nodaļā 8.2 tiks veikta literatūras analīze par citiem mēģinājumiem novērtēt ad-hoc tīklu un daudzceļu pārraides caurlaides spēju. Nodaļā 8.3 izklāstīsim analītisko metodi, uz kuru tiks balstīti pētījumi. Nodaļā 8.4 tiks aprakstīts izstrādātais MATLAB rīks, kā arī apstiprināta rezultātu pareizība, salīdzinot ar specializētu tīklu modelēšanas programmu. Nodaļā 8.5 metode tiks pielietota, lai novērtētu caurlaides spēju pie dažādiem izvēlēto ceļu parametriem. Pēdējā nodaļā tiks pierādīta virziendarbības efektivitāte ad-hoc tīklos.

8.2. Literatūras pārskats

Jau kopš IEEE802.11 standarta pieņemšanas 90to gadu beigās ir bijuši daudzi mēģinājumi izstrādāt analītiskus modeļus un metodes bezvadu ad-hoc tīklu caurlaides spējas novērtēšanai [8.3] [8.7] [8.8] [8.9]. Kopīga iezīme šīm metodēm, kas tās idealizē, ir centrāla koordinatora esamība, kas regulē kanāla piekļuvi, kā arī trafiku piešķirtajā laika slotā. Neraugoties uz to, rezultāti var tikt izmantoti kā labākais scenārijs uz kuru tiekties.

Viens no autoritatīviem rakstiem [8.8] piedāvā teorētiskos limitus bezvadu ad-hoc tīklu veikspējai. Tiek atsevišķi noteikta sasniedzamā caurlaides spēja:

- protokola līmenī, darbojoties gadījuma piekļuvei ar drošības attālumu kolīziju mazināšanai (piemēram, CS apgabals);
- fiziskajā līmenī, kur traucējumu apstākļos jānodrošina SNIR attiecība, lielāka par kādu sliekšni, kas nepieciešams veiksmīgai pārraidei.

Protokola modelim tiek pierādīts, ka ātrums, ar kādu var sazināties divi mezgli gadījuma rakstura tīklā (mezglu izvietojumus un trafika raksturs ir gadījuma), krītas asimptotiski kā $\frac{W}{\sqrt{n \log n}}$, kur W ir mezglu pārraides ātrums, n ir mezglu skaits.

Vislabākajā gadījumā, kad mezglu novietojums, trafiks, raidīšanas attālums katrai pārraidei ir optimāli izvēlēti, tas nevar pārsniegt $\frac{W}{\sqrt{n}}$. Interesanti, ka noteiktās robežas paliek spēkā arī fizikālam modelim, kur uzstādījums ir nodrošināt SNIR līmeni virs noteikta sliekšņa. Atrastās sakarības parāda bezvadu ad-hoc tīklu protokolu „globālas” problēmas un ierobežojumus. Atšķirībā no [8.8] tālāk apskatītie darbi [8.3] [8.7] [8.9], kā arī mūsu pētījums ir orientēts nevis uz teorētiskām tīkla veikspējas robežām, bet uz reālu tīkla topoloģiju analīzi, kuru veikspēja būs zem teorētiskā limita. Šajos darbos tiek piedāvā metodoloģijas caurlaides spējas noteikšanai.

Darba [8.9] autori piedāvā vispārīgu metodoloģiju, balstītu uz konfliktu grafiem, ar mērķi maksimizēt datu plūsmu starp vienu sūtītājs-saņēmējs pāri, izmantojot vienu vai vairākus ceļus. Vienkāršākajā gadījumā, neņemot vērā traucējumus, problēma tiek formulēta kā lineāra programma, kur tiek maksimizēta plūsma no avota (zināma kā *max flow* metode). Lai aprakstītu kanāla konkurenci un traucējumus, vienādojumu sistēma tiek papildināta ar nosacījumiem no konfliktu grafa. Konfliktu grafs apraksta vienlaicīgi pieļaujamus aktīvo mezglu pārus (linkus) tīklā. Grafs tiek zīmēts tādējādi, ka grafa virsotnes ir linki, savukārt tā malas vai savienojumi apzīmē vienlaicīgi neiespējamus linkus. Būtībā šie grafi ļauj sastādīt neatkarīgus linku komplektus (*independent sets*) – tādus, kas var vienlaicīgi būt aktīvi. Ar grafu palīdzību tiek uzlikti papildus nosacījumi *max flow* lineārai programmai optimālās plūsmas un tai atbilstošā laika *schedule* atrašanai.

Lai uzzīmētu konfliktu grafus, līdzīgi kā [8.8] tiek atsevišķi izdalīts protokola un fizikālais modelis. Protokola modelī vienlaicīgi ir jāizpildās nosacījumiem:

$$d_{ij} \leq R_i \quad (1)$$

Neviens cits mezgls n_k , kura attālums $d_{kj} \leq R'_k$, neraida.

Traucējumu ietekme starp diviem vienlaicīgi raidošiem mezglu pāriem fizikālajā modelī tiek novērtēta:

$$\omega_{ij}^{pq} = \frac{P_{pj}}{\frac{P_{ij}}{SINR_T} - N_a} \quad (2)$$

Reāli tā ir uztvertā traucējumu jauda pret pieļaujamo (nosaka SNIR sliekšnis). Jo mazāks būs w , jo lielāks būs iespējamais datu ātrums.

Kā atzīst arī paši autori, šie modeļi neatbilst precīzai IEEE802.11 darbībai. Pirmkārt, protokola modelī traucējumi tiek novērtēti tikai no uztvērēja puses, bet ne raidītāja. Reālā tīklā gan CS mehānisms raidītājā, gan SNIR sliekšnis uztvērējā noteiks, vai linki ir pieļaujami aktīvi vienlaicīgi. Šī apstākļa ignorēšana neļauj precīzi novērtēt *Carrier Sense Threshold* (CST) ietekmi uz caurlaides spēju. Savā darbā mēs cenšamies precīzāk implementēt CSMA/CA mehānismu, veicot CS pārbaudi tieši raidītāja pusē. Tas ļauj novērtēt arī CS sliekšņa ietekmi uz caurlaides spēju. Otrkārt, papildus neprecizitāti protokola modelī ienes apstākļi, ka netiek ņemts vērā summārais traucējums, ko var radīt divi vai vairāk traucētāji. Traucējumu apgabals R_k^i palielināsies, traucējošo mezglu skaitam augot. Šajā gadījumā nevar operēt ar attālumiem, bet ir jāpāriet uz uztvertās jaudas sliekšni.

Darbā [8.9] tiek apskatīta arī ar skaitļošanu saistīta problēma - atrast visus linku komplektus, kas ir aktuāla arī mūsu darbā. Atšķirībā no mūsu darba, tai skaitā arī [8.3] [8.8], autori apskata arī scenārijus, kad mezgli nav noslogoti visu laiku (*brusty traffic*) – vidējais trafiks ir zemāks par maksimālo. Tiek atrasts, ka šādā gadījumā vairs nav spēkā sakarības [8.8], kur caurlaides spēja samazinās, mezglu skaitam pieaugot.

[8.9] konfliktu grafu metode tiek pielietota un tālāk attīstīta [8.3], kurš veltīts tieši daudzceļu pārraides pētīšanai. Darbā [8.3] tiek meklēta caurlaides spējas atkarība un izvēlēto ceļu nošķirtības (*radio-disjointness*), un līdz ar to atšķirībā no [8.9] parādās konkrētas ceļu kombinācijas (komplekti). Tiek meklēts ceļu pāris, kurš nodrošina visaugstāko plūsmas ātrumu protokola un fizikālo traucējumu apstākļos. Pie tam, atšķirībā no citiem darbiem, tiek ņemti vērā arī fona trafika (BTL) radītie traucējumi.

Lai atrastu neatkarīgas pāru kopas, tiek sastādīti konfliktu grafi. Tas tiek veikts, atrodot ω_{ij}^{pq} (2) starp katriem diviem pāriem. Netiek vērtēti tie pāri, kur vienlaicīgu pārraidi nepieļauj CS vai kopīgs mezgls, daļēji tas risina [8.9] problēmu, kur konfliktu grafs tiek sastādīts tikai no uztvērēja perspektīvas, neņemot vērā CS. Tomēr saglabājas otra problēma, jo CS sliekšni nosaka attālums, nevis jaudas līmenis. Par traucējošiem linkiem tiek uzskatīti tādi, kur vienlaicīgi pārraide pārsniegs SNIR sliekšni (gadījumā $w > 1$), un attiecīgi tie nevar atrasties vienā linku komplektā. Netraucējoši ir tādi, kur ir pieļaujama vienlaicīga pārraide - tādējādi tiek iegūta sasniedzamā pārraides spēja dažādiem ceļu komplektiem. Metodes tiek pārbaudītas ar OPNET modelēšanas palīdzību.

Tiek salīdzināta topoloģija ar vienu ceļu un trīs topoloģijas ar diviem ceļiem - pilnībā *radio-disjoint*, daļēji *radio-disjoint* un traucējoši, un, kā jau bija sagaidāms, vislabākos rezultātus uzrādīja otrā topoloģija. Visas *multi-path* topoloģijas tika pārbaudītas pie vienāda ceļu garuma, tikai mainoties attālumam starp ceļiem. Te netika ņemts vērā, ka reālā dzīvē, lai ceļus attālinātu, var būt nepieciešams vairāk

lēcienu, un attiecīgi - iesaistīto mezglu. Kā mēs tālāk parādīsim šajā darbā, tad garāki ceļi var arī nedod gaidīto efektu, īpaši, ja linki tiek maksimāli noslogoti.

[8.7] ievieš jēdzienu tīkla kapacitātes reģioni, kuri raksturo iespējamās caurlaides spēju kombinācijas visiem tīkla linkiem, pie tam, darbojoties kādai pārraides stratēģijai, kā, piemēram, mainīga ātruma pārraide, viena lēciena vai daudz-lēcīnu maršrutēšana, jaudas kontrole, interferences mazināšana. Vienlaicīgi pieļaujami raidošie mezglu pāri tiek sadalīti pārraides shēmas, kurām tiek variēts aktīvais laiks, veidojot tīkla kapacitātes reģionu. Metode ir pietiekami universāla un pārraides shēmas var tikt balstītas gan uz protokola, gan fizikālo modeli, gan arī citiem nosacījumiem. Pārraides shēmu kopums ir analogija ar konfliktu grafu iepriekš apskatītajos darbos, savukārt pati pārraides shēma ir *independent set*. Optimālās veikspējas raksturošanai tiek piedāvāts jēdziens – *uniform capacity* – kas raksturo maksimālu ātrumu, vienmērīgu pa visu tīklu, kuru var sasniegt, darbojoties kādam kanāla piekļuves protokolam, pie optimāla *scheduling* datu pārraidēm. Vairāk par šo metodi nodaļā 8.3, jo tā tiks izmantota par pamatu tālākiem pētījumiem. Oriģinālā metode tiks pielāgota vairāku ceļu apstākļiem kā arī tiks papildināta ar CSMA/CA protokola darbības mehānismu un virziendarbības iespēju.

8.3. Analītiskā metode

Analītisko tīkla veikspējas aprēķinu pamatā ir „veikspējas reģionu” metode, kuru savos pētījumos pielieto *Toupin* un *Goldsmith* [8.7]. Mūsu pētījumos interesē pielietot šo metodi, lai meklētu 802.11 ad-hoc tīkla caurlaides spēju, pārraidot datus pa vairākiem paralēliem ceļiem vienlaicīgi starp vienu sūtītāja un saņēmēja pāri. Ievācot statistiskus datus par daudzām gadījuma rakstura topoloģijām, izpētīt dažādu parametru ietekmi uz ceļu kvalitāti un attiecīgi izstrādāt kritērijus ceļu izvēlei. Papildus tā tika pielietota, lai novērtētu virziendarbības efektivitāti starpceļu traucējumu mazināšanai.

8.3.1. Teorētiskie pamati

Ceļa caurlaides spēju nosaka atsevišķu tā linku caurlaides spēja, darbojoties konkurences apstākļos ar citiem linkiem. Ātrumu, ar kādu var sazināties divi mezgli, nosaka uztveršanas apstākļi un izmantotā bezvadu tehnoloģija. Lielāki ātrumi ir sasniedzami ar „sarežģītākām” modulācijām, bet tādu pielietošana uzliek augstākas prasības arī kanāla apstākļiem. Lai saņemtie dati būtu atkodējami, kļūdu skaits (BER) nedrīkst pārsniegt noteiktu līmeni.

Uztveršanas apstākļi var tikt raksturoti ar signāls-troksnis-attiecību (SNIR). Tas tiek aprēķināts kā derīgā signāla jauda pret trokšņu un traucējošo raidītāju jaudu summu.

$$SNIR = \frac{P_{Rx}}{N_{Rx} \cdot B + \sum P_i} \quad (3)$$

Mezgļi sazināsies ar tādu ātrumu, kuri pie SNIR uztvērēja ieejā spēs apmierināt BER prasības. Tas tiek realizēts, izvēloties vienkāršāku vai sarežģītāku nesēja modulācijas veidu.

8.3.1.1. SNIR aprēķins

SNIR formula balstās uz to, ka ir zināma gan uztvertā derīgā signāla jauda, gan katra atsevišķa traucētāja jauda. Šīs jaudas var aprēķināt, izmantojot radio viļņu izplatīšanās modeļus. Brīvai telpai:

$$P_{Rx}(d) = \frac{P_{Tx} G_{Tx} G_{Rx} \lambda^2}{(4\pi)^2 d^2} \quad (4)$$

Kanāla vājinājums (*path loss*) būtu izsakāms kā:

$$G = \frac{\lambda^2}{(4\pi)^2 d^2} \quad (5)$$

Visam tīklam ir iespējams sastādīt $N \times N$ kanāla vājinājuma matricu G , kuru veido n mezglu savstarpējie vājinājumi:

$$\begin{aligned} G &= [G_{ij}], \text{ kur } i = 1 \dots n; j = 1 \dots n, \\ G_{ij} &= 0, \text{ kad } i = j \end{aligned} \quad (6)$$

Attiecīgi jauda, ko mezgls j uztver no raidītāja i :

$$P_j = P_i \cdot G_{ij} \cdot G_i \cdot G_j \quad (7)$$

Pie virziendarbības G_i un G_j būs raidītāju un uztvērēja antenu pastiprinājuma koeficienti virzienā virzienā vienam uz otru. *Omni-directional* gadījumā $G_i = G_j = 1$.

8.3.1.2. Datu pārraides ātruma noteikšana

Zinot SNIR līmeni, var iegūt pārraides ātrumu vairākos veidos:

a) pēc *Shannon Theorem* pārraides ātruma limitu starp diviem mezgliem nosaka:

$$C = B \cdot \log_2(1 + SNIR) \quad [\text{biti/s}] \quad (8)$$

b) empīriski noteiktus pārraides ātruma līmeņus. Pētījumos izmantotas NS2 802.11 fizikālā modeļa vērtības:

Modulācija	SNIR	Datu ātrums (20 MHz kanāls)
BPSK	2.5	6 Mbps
QPSK	5	12 Mbps
QAM16	15.8	24 Mbps
QAM64	100	54 Mbps

c) izmantojot konkrēta uztvērēja BER līknes. Šis paņēmieni tālākā pētījumā netiek apskatīts.

8.3.2. Metode tīkla veiktspējas novērtēšanai

Tīklā konkrētā laika momentā notiekošo aktivitāti var raksturot ar pārraides shēmu. Šī shēma atainos datu pārraides starp visiem tajā brīdī aktīvajiem (raidošiem-uztverošiem) mezglu pāriem. Tās būs visas vienlaicīgās pārraides, kuras pieļauj tīkla protokols, piemēram, CSMA. Var sastādīt galīgu skaitu iespējamo pārraides shēmu, kuras veidos dažādas pāru kombinācijas. Secīgi pārejot no vienas shēmas pie nākamās, var realizēt pilno datu pārraidi kādā laika intervālā. Tiek pieņemts, ka katrai datu paketei tikai viens konkrēts mērķis (nav *multicast/broadcast*).

Apskatīsim scenāriju ar četriem mezgliem, kur n1 sūta datus uz n4, bet n4 uz n1 (8.1. att.). Tā kā pa vidu ir kāds šķērslis tad tas tiek izpildīts ar diviem lēcieniem.



Figure 8.1 Scenārijs ar četriem mezgliem un šķērslis

8.2.a. attēlā pirmais solis, kad vienlaicīgi ir aktīvi divi mezglu pāri. To var aprakstīt ar pārraides shēmu:

$$\begin{bmatrix} n_1 & \rightarrow & n_2 \\ n_4 & \rightarrow & n_3 \end{bmatrix}$$

Ja pieņem, ka mezgls vienlaicīgi nevar uztvert un raidīt, tad citi aktīvi pāri šajā shēmā nav iespējami. Nākošā laika momentā, kad pakete (dati) starp pirmajiem pāriem ir pārsūtīta, aktīvi būs nākamie divi (8.2.b att.), kuras aprakstīs shēma:

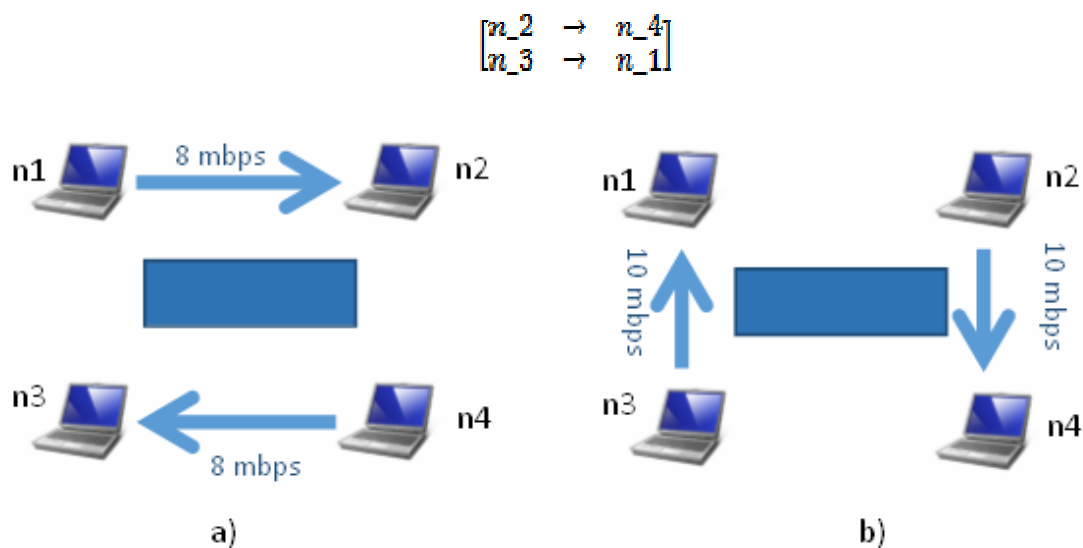


Figure 8.2 Divi pārraides soļi

Konkrētajam tīklam ir iespējamas arī citas shēmas. No visa kopuma var tikt atlasītas tādas, kuras nodrošinātu maksimālu veikspēju un efektivitāti. Pārraides shēmu kopums ir analogija ar *conflict graph* un pati pārraides shēma ir *independent sets* citos darbos [Kamal Jain, Kuladinithi].

Tā kā aprēķinos tiek operēts ar datu ātrumiem, tad no pārraides shēmām notiek pāreja uz datu ātrumu matricām. Datu ātrumi tiek noteikti ar iepriekš apskatītajiem paņēmieniem, balstoties uz SNIR un radio viļņu izplatīšanās modeļiem. Šīs matricas sevī ietvers ne tikai aktīvos mezglus un ātrumu, bet arī datu avotu un saņēmēju. 8.2.attēla scenāriju var raksturot ar šādām datu ātruma matricām:

$$R_1 = \begin{bmatrix} -8 & 8 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & -8 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & -10 & 0 & 10 \\ 10 & 0 & -10 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Rinda raksturo mezglu, kurš ir sūtītājs, piemēram, R1 pirmā rinda – mezgls n1 sūta ar ātrumu 8 mbps, ceturtā rinda mezglu n2. Kolonnas raksturo mezglu, kurš ir datu avots un saņēmējs, attiecīgi avotu rakstot ar negatīvu zīmi, bet saņēmēju ar pozitīvu. Reizinot datu ātrumu matricas ar svāra koeficientiem, kas raksturo shēmas darbības ilgumu kā daļu no kopējā laika, un tās summējot, iegūst pilno pārraides ātrumu matricu:

$$\frac{3}{4} \begin{bmatrix} -8 & 8 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & -8 \end{bmatrix} + \frac{1}{4} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & -10 & 0 & 10 \\ 10 & 0 & -10 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} -6 & 6 & 0 & 0 \\ 0 & -2.5 & 0 & 2.5 \\ 2.5 & 0 & -2.5 & 0 \\ 0 & 0 & 6 & -6 \end{bmatrix}$$

Atlasot tādas datu ātruma matricas, kas nes pienesumu tīkla veiktspējai, kā arī variējot katras matricas darbības ilgumu no 0 līdz 1, var iegūt visas iespējamās caurlaides spēju vērtības. Autori to sauc par veiktspējas reģionu un matemātiski to apraksta *convex hull* visam matricu kopumam. Praktiski tiek realizēts, risinot lineāru vienādojumu sistēmu. Mūs interesē tāds laika sadalījums, kurš nodrošina maksimālu, pa visu tīklu vienmērīgu ātrumu (*uniform capacity*). Datu ātruma matricas jāpārveido par kolonnu vektoriem, kuri tālāk tiks izmantoti, lai sastādītu lineāru vienādojumu sistēmu:

	R1	R2
n1 → n2	8	-
n1 → n3	-	-
n1 → n4	-	-
n2 → n1	-	-
n2 → n3	-	-
n2 → n4	-	10
n3 → n1	-	10
n3 → n2	-	-
n3 → n4	-	-
n4 → n1	-	-
n4 → n2	-	-
n4 → n3	8	-

Tālāk var sastādīt vienādojumu sistēmu un tās nosacījumus:

$$\begin{cases} t_1 \cdot 8 + t_2 \cdot 0 \geq C \\ t_1 \cdot 0 + t_2 \cdot 10 \geq C \\ t_1 \cdot 0 + t_2 \cdot 10 \geq C \\ t_1 \cdot 8 + t_2 \cdot 0 \geq C \end{cases} \quad (9)$$

$$\max(t_1 + t_2)$$

$$0 \leq t_1, t_2 \leq 1$$

$$t_1 + t_2 \leq 1$$

Pakāpeniski samazinot C vērtību, tiek atrasts tāds skaitlis, kurš spēj apmierināt šo vienādojumu sistēmu ar nosacījumu, ka laiku t_1 un t_2 summa tiecas uz 1. Maksimāli iespējamo vienmērīgu caurlaides spēju $C_{\max}$ atrod:

$$C_{\max} = \frac{C}{(t_1 + t_2)} \quad (10)$$

8.3.3. Sākotnējās metodes pielāgošana daudzu ceļu pārraides pētījumiem

Ja oriģinālajā pētījumā [8.7] autorus interesēja atrast pilnīgi visas pārraides shēmas starp visiem mezgliem, tad mūs interesēs tikai tie mezgli, kuri veido pārraides ceļus. 8.3. attēlā divus ceļus veido pieci mezgli - n15, n7, n8, n10, n4. Shēmas netiks veidotas kā visas kombinācijas starp šiem mezgliem, bet pāri būs tikai kaimiņi, kuri viens otru var sasniegt ar kādu noteiktu jaudas līmeni. Dzīvē to noteiks uztvērēja jutība.

Šobrīd pieņemam, ka maršrutēšanas protokols ir atradis 2 ceļus starp n1 un n6, kurus veido četri pāri: n11 → n2; 2 → 3; 3 → 6; 11 → 9; 9 → 8; 8 → 6. Citi savienojumi šo divu ceļu ietvarā nav iespējami. Tas mums ļauj izdarīt vēl vienu vienkāršojumu oriģinālajai metodei – atteikties no datu *forwarding* un uzskatīt, ka datu avots ir katrā pāri.

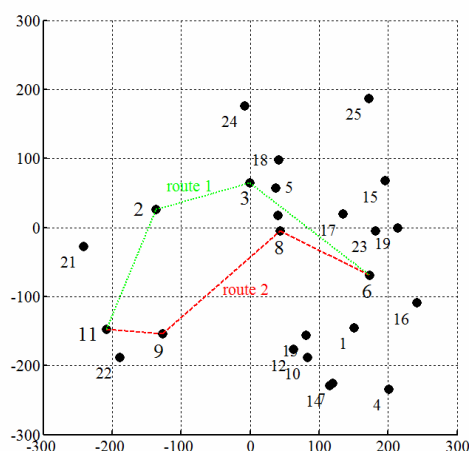


Figure 8.3 Divi pārraides ceļi

Ja mēs pieņemam, ka tīklā darbojas kāda gadījuma kanāla piekļuves sistēma, kur vienīgais nosacījums ir, ka mezgls vienlaicīgi nevar raidīt un uztvert, tad var sastādīt 5 iespējamās pārraides shēmas:

2 → 3	8 → 6	3 → 6	3 → 6	2 → 3
8 → 6	11 → 2	9 → 8	11 → 9	9 → 8
11 → 9		11 → 2		

Netiek apskatītas daļējas shēmas, kad, piemēram, 2 → 3 raida un tanī laikā citas pārraides nenotiek. Tāda situācija pie nepārtrauktām datu plūsmām nav paredzama, jo gadījuma kanāla piekļuvē pāris mēģinās tikt pie kanāla, kolīdz tam būs ko sūtīt.

Viens no pieņēmumiem tālākajiem pētījumiem ir - pietiek atrast tādu laika sadalījumu starp pārraides shēmām, pie kura visos linkos (arī starp vairākiem ceļiem) ir vienmērīga caurlaides spēja C . Vienlaicīgi tā būs katra ceļa maksimālā caurlaides spēja. Šādam pieņēmumam ir vairāki iemesli:

- tikai vienmērīga plūsma visos viena ceļa ietvaros nodrošina to, ka kāds mezgls *multi-hop* apstākļos neraida vairāk datu, kā saņem no kaimiņa;
- vienmērīga plūsmas meklēšana visos ceļos ir saprātīga, jo tas ir pietiekami biežs scenārijs daudzu ceļu pārraidē (piemēram, MDC video);
- izmantotajai metodei ir ierobežojumi, kas to neļauj pielietot, ja visos ceļos plūsma nav vienmērīga.

Šāda pieeja mums ļauj kopēju visu ceļu caurlaides spēju iegūt kā:

$$C_{agr} = C \times routes \quad (11)$$

Sarežģījums rodas, ja kāds no linkiem ir koplietots starp diviem ceļiem. Tādā gadījumā šī formula vairs nav spēkā. Lai to apietu, shēmas tiek papildinātas ar linka piederību ceļam. Šajā gadījumā koplietotais links tiek sadalīts divos virtuālos linkos, kur mezgli ir vieni un tie paši, bet piederība ceļam cita. Šāda pieeja ir korekta, jo katrai no konkurējošajām plūsmām koplietotajā ceļā nepieciešams laiks datu pārraidei. Kamēr tiks pārraidīta vienas plūsmas paka, otras plūsmas pakai ir jāgaida.

Šāds scenārijs ir attēlots 8.4. attēlā un apakšā ir dotas iespējamās shēmas ar pievienotu ceļa marķējumu iekavās.

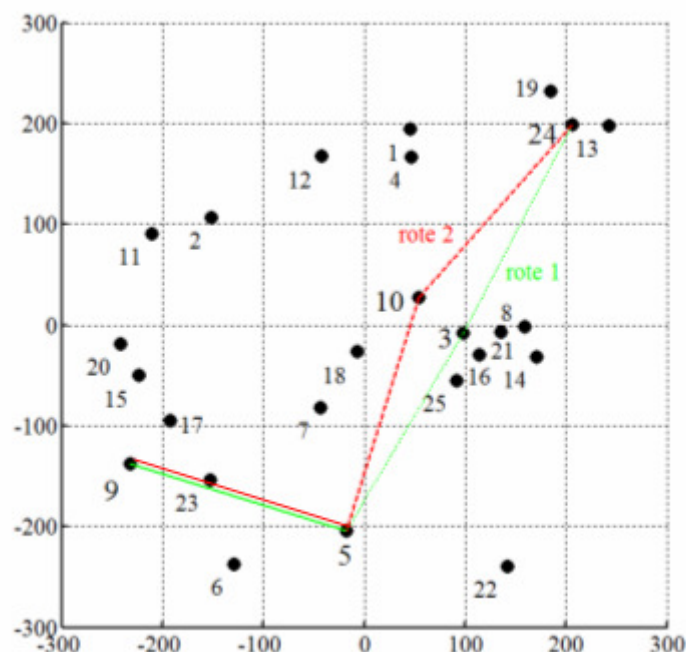


Figure 8.4 Divi pārraides ceļi ar koplietotu linku

5 → 10 (2)	9 → 5 (1)	3 → 24 (1)	5 → 3 (1)	9 → 5 (2)	3 → 24 (1)
3 → 24 (1)	10 → 24 (2)	9 → 5 (1)	10 → 24 (2)	10 → 24 (2)	9 → 5 (2)

Pārejot uz datu ātrumu matricām, tiek iekļautas papildus rindas katram ceļam.

8.3.4. Pārraides shēmu atrašana, balstoties uz CSMA/CA protokola darbību

Pārraides shēmas tiks meklētas tikai protokola līmenī. Tas nozīmē, ka vienīgais ierobežojums mezglu pāriem atrasties vienā shēmā tiks balstīts uz CS mehānismu raidītājā. Rezultātā tiks pieļautas visas pārraides, kurs nav ierobežojis CS, pat ja SNIR līmenis $\rightarrow 0$.

IEEE802.11 kanāla piekļuve tiek nodrošināta ar CSMA/CA protokolu. Tas paredz, ka mezgli piekļūst kanālam nejaušā veidā, bet ar mehānismiem kolīziju iespējamības mazināšanai. Tas tiek īstenots vispirms mezglam, kuram ir ko raidīt, klausoties kanālu. Ja uztvertā jauda ir zemāka par noteiktu sliekšni P_{CST} , tiek sākota atskaite no kāda gadījuma skaitļa, kuru lielumu nosaka *contention window* min un max vērtības. Ja vairāki mezgli vienlaicīgi konkurē uz kanālu, tad pirmais pie tā tiks tas, kuram izvēlētais gadījuma skaitlis būs mazāks. Kanāla klausīšanās tiek veikta ar mērķi novērst, ka uztvērējā nonāk 2 vai vairāk vienlaicīgi signāli ar samērojamu jaudas līmeni

Lai veikspējas reģionu metodes ietvaros varētu realizēt CSMA/CA darbību ad-hoc tīklā, ir nepieciešams izmantot P_{CST} sliekšņa vērtību (RTS/CTS tiks pieņemts kā izslēgts). P_{CST} sliekšnis noteiks, kuri mezglu pāri var atrasties vienā pārraides shēmā

– nodrošināt vienlaicīgas pārraides. Papildus tiek ievērots, ka mezgls nevar vienlaicīgi sūtīt un saņemt datus. Pārraides shēmas veidos visas iespējamās mezglu kombinācijas, sastādītas tā, ka traucējumu jauda P_{CS} , ko jūt katrs no shēmā ietvertajiem raidītājiem, ir mazāka par P_{CST} , pie tam ņemot vērā arī savu paštroksni.

$$P_{CS} + P_{\text{paštroksnis}} < P_{CST} \quad (12)$$

Te ir jāņem arī vērā, ja $P_{\text{paštroksnis}}$ būs lielāks par P_{CST} , šāda situācija reālā tīklā nav pieļaujama, jo mezgls nepārtraukti jūtīs aizņemtu kanālu, un līdz ar to nekad netiks pie raidīšanas.

Pie tam katrā shēmā ir jāiekļauj pilnīgi visi iespējamie pāri, lai arī reālajā dzīvē shēma var realizēties arī nepilnīga. Mums jāreķinās ar pašu sliktāko scenāriju, kura iespējamība ir diezgan augsta, ņemot vērā, ka datu plūsmas video straumēšanas gadījumā ir nepārtrauktas – tālād nebloķētie mezgli nestāv dīkstāvē.

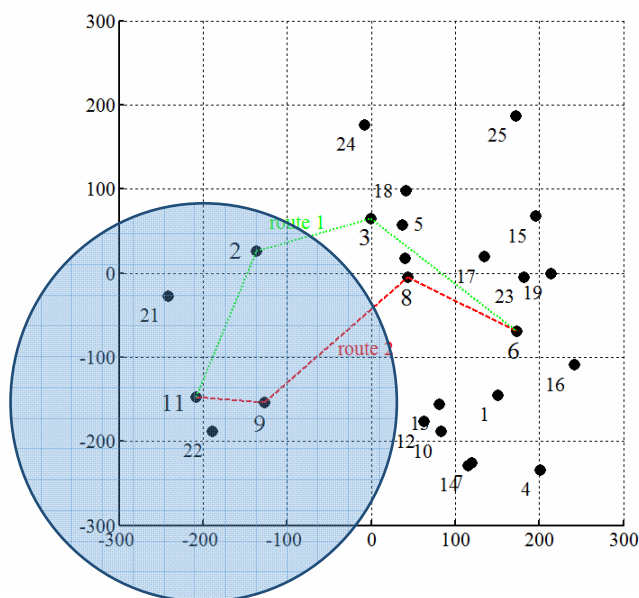


Figure 8.5 *Carrier Sense* attāluma ietekme

8.5. attēlā parādīts, kā P_{CST} ietekmē pārraides shēmas atrašanu. Ja izsakām P_{CST} kā attālumu, kādā nosacīti tas var just traucējumus no viena cita pāra (zila aplis), tad iepriekš šim scenārijam apskatīta pārraides shēma [2 → 3; 8 → 6; 11 → 9] nebūs iespējama. Pārraide 2 → 3 rada pietiekami traucējumu, lai mezgls 11 justu aizņemta kanāla statusu un līdz ar to atliktu pārraidi.

8.3.5. Metodes ierobežojumi

Aprēķinātā maksimāli iespējamā vienmērīgā caurlaides spēja ir iespējama tikai teorētiski pie optimāla laika sadalījuma starp pārraides shēmām (*scheduling*), kuru var nodrošināt tikai centrāli vadāms kanāla piekļuves protokols. CSMA/CA piekļuve

kanālam ir ar gadījuma raksturu, kuru ietekmē savstarpējā mezglu konkurence un mehānismi kolīziju novēršanai (*backoff time*), tādējādi caurlaides spēja var būt zemāka. Neraugoties uz to, ka reālā ad-hoc tīklā *scheduling* nav optimāls, metode dod rezultātu, uz kuru tiekties. Salīdzinot savā starpā dažādu izvēlēto ceļu komplektu caurlaides spēju, sagaidāms, ka labāks teorētiskais rezultāts norādīs uz labāku rezultātu arī reālā tīklā.

Tiek pieņemts, ka *scheduler* piešķirtajā laika slotā mezgli raida nepārtraukti ar vienmērīgās plūsmas ātrumu. Tas nozīmē, tiem buferī vienmēr ir dati, ko raidīt, un tie bez vilcināšanās pārsūta tālāk. Tas nav pretrunā ar daudzu ceļu video pārraidi, kur tiek izmantota visa kanāla kapacitāte, un plūsmai visā ceļā ir jābūt ar vienu ātrumu. Ierobežoti ir pētījumi situācijās, kad vienā ceļā plūsma ir ar zemāku ātrumu kā otrā, vai arī parādās kāda *background* trafika noslodze.

Tālākajās nodaļās tiks pierādīti gadījumi, kad metodi var pielietot 802.11 ad-hoc tīklu analīzei, un kad tās sniegtie rezultāti atšķiras no NS2 tīklu stimulatora rezultātiem.

8.3.6. Virziendarbības izmantošana ad-hoc tīklā

Virzienu darbības izmantošana ad-hoc tīklos tiek atzīts kā efektīvs veids kā mazināt mezglu savstarpējos traucējumus [Ramanathan]. Pavisam maz ir veikti pētījumi, kur virzienu darbība tiek apskatīta kontekstā ar daudzu ceļu pārraidi.

Šajā darbā apskatītā metode ir pietiekami universāla, lai atrastu caurlaides spēju daudzu ceļu pārraidei ar virziendarbības antenām.

8.3.6.1. Virziendarbības pamati

Virzienu darbība var tikt īstenota ar antenu masīviem un digitālās signālapstrādes paņēmieniem, apstrādājot no vairākiem antenas elementiem saņemto signālu. Šāda pieeja tiek saukta arī par *digital beamforming* (DBF). Tā kā antenas elementi ir izvietoti telpā ar intervāliem d , tad zem leņķa θ krītošs signāls katrā no tiem nonāks dažādos laikos (8.6.att.).

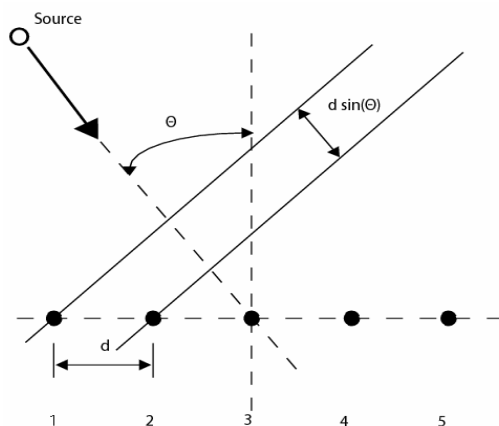


Figure 8.6 Krītošs stars uz antenu masīvu

Nemot 1. elementu kā atskaites punktu, laika aizture uz n-to elementu būs:

$$\tau_k = \frac{(n-1) \cdot d \cdot \sin \theta}{c}, \quad (13)$$

kur c ir gaismas ātrums. Lineāru antenas masīvu ar N elementiem var pierakstīt ar reakcijas vektoru:

$$\alpha(\theta) = \begin{pmatrix} 1 \\ e^{-j d \cdot \sin \theta / c} \\ e^{-j 2 \cdot d \cdot \sin \theta / c} \\ \vdots \\ e^{-j (N-1) \cdot d \cdot \sin \theta / c} \end{pmatrix} \quad (14)$$

Piemērojot svāra koeficientus katram no elementiem, var tikt panākta masīva stūrēšana. Svāra koeficienti var ietekmēt gan fāzi, gan amplitūdu. Ja ω ir antenas svāra koeficientu vektors, tad signālu $y(k)$ uztvērēja izejā var iegūt:

$$y(k) = \omega^H \cdot x(k) \quad (15)$$

$$x(k) = \alpha(\theta) \cdot s(k), \quad (16)$$

kur $\omega^H = [\omega_1 \quad \omega_2 \quad \dots \quad \omega_N]$ svāra koeficientu vektors, $s(k)$ - krītošais signāls

Detalizētāki DBF principi ir izskaidroti [8.10].

8.3.6.2. Antenas virzienu diagrammu iegūšana

Ar signālapstrādes metodēm tiek meklēti svāra koeficienti, lai iegūtu vēlamu antenas vērsuma diagrammu. Ad-hoc tīklā *beamforming* var īstenot:

- virtuāli pavēršot antenas diagrammas maksimumu pret derīgo virzienu;
- vienlaicīgi vēršot galvenā lapas virzienu pret derīgo signālu un nospiežot nevēlamos virzienus (*zero-forced beamforming*).

8.3.6.3. ZF-BF

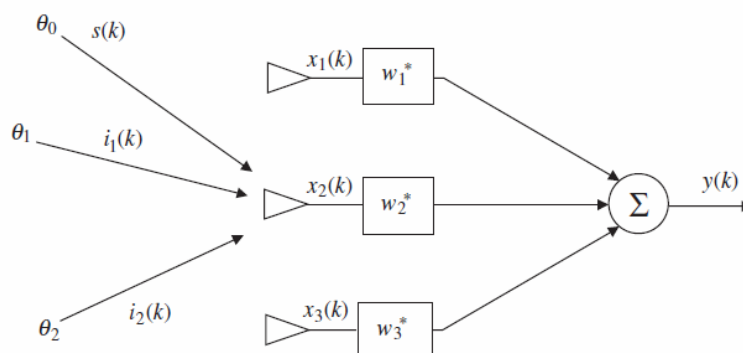


Figure 8.7 Uztvērējs un dažādiem virzieniem ienākoši signāli

Uztvērējā no dažādiem virzieniem pienāk derīgais signāls $s(k)$ un traucējošie signāli $i_1(k), i_2(k) \dots$ (8.7.att). Pēc [8.2] aprakstītās „Maksimāla signāls - traucētājs attiecība” metodes svara koeficientu atrašanai, var sastādīt vienādojumu – derīgā signāla jauda pret traucējošo signālu jaudu:

$$SIR = \frac{E[|\bar{\omega}^H \cdot \bar{x}_s|^2]}{E[|\bar{\omega}^H \cdot (\bar{x}_i + \bar{n}(k))|^2]} = \frac{\bar{\omega}^H \cdot \bar{R}_{ss} \cdot \bar{\omega}}{\bar{\omega}^H \cdot \bar{R}_{uu} \cdot \bar{\omega}} \quad (17)$$

kur $\bar{x}_s$ ir derīgā signāla vektors, $\bar{x}_i$ ir traucējošā signāla vektors, $\bar{n}(k)$ troksnis antenas ieejā. Kā parādīts iepriekš (xx), reizinot šos vektorus ar antenas svara koeficientiem, tiek iegūts derīgais un traucējošais signāls izejā. $E[|\bar{\omega} \cdot \bar{x}|^2]$ ir signāla vidējā jauda antenu masīva izejā. $\bar{R}_{ss}$ un $\bar{R}_{uu}$ ir signāla un trokšņu korelācijas matricas, kas veidojas, reizinot attiecīgi signāla un trokšņa vektorus pašus ar sevi.

Jāatrod tādi antenas elementu svara koeficienti $\bar{\omega}$, lai signāls-traucētājs attiecība būtu maksimāli liela. Tāda ir iespējama tad, ja pret derīgo signālu būs vērsts antenas diagrammas maksimums, bet pret traucējošajiem nulles. Vienādojumu (xx) ar nelieliem pārveidojumiem var pārrakstīt šādi:

$$\bar{R}_{uu}^{-1} \cdot \bar{R}_{ss} \cdot \bar{\omega} = SIR \cdot \bar{\omega} \quad (18)$$

Iegūtais vienādojums ir īpašvektora vienādojums, kur SIR ir īpašvērtības. Maksimāls SIR ir vienāds ar lielāko īpašvērtību matricai $\bar{R}_{ii}^{-1} \cdot \bar{R}_{ss}$ un $\bar{\omega}$ būs tai atbilstošais īpašvektors.

Ierobežojumi, izmantojot šo metodi ad-hoc tīklā:

- mezglam ir jāspēj noteikt virziens no kura nāk derīgais signāls;
- to, cik traucētājus ir iespējams „nospiest”, nosaka antenas elementu skaits (brīvības pakāpes). Tā kā pie lielāka ceļu skaita traucētāju skaits palielinās, tad mazam antenu skaitam zf-bf var būt neefektīvs.

Papildus ir iespējams veikt traucējumu slāpēšanu tikai uz spēcīgākajiem (tuvākajiem) traucētājiem, tādējādi nepārsniedzot brīvības pakāpes. Šāds mehānisms arī tiks apskatīts eksperimentālajā daļā.

8.3.6.4. Uztvertās jaudas aprēķins virziendarbības gadījumā

Ja divi mezgli, kuri sazinās ar virzienu darbību, zina viens otra atrašanās vietu (leņķi), tad matemātiski var aprēķināt jaudu uztvērējā:

$$P_{rx} = R_{\theta_{rx}} \cdot R_{\theta_{tx}} \cdot G \cdot P_{tx}, \quad (19)$$

kur $R_{\theta_{rx}}$ - uztvērēja pastiprināšanas koeficients virzienā uz raidītāju, $R_{\theta_{tx}}$ - raidītāja pastiprināšanas koeficients virzienā uz uztvērēju, G – kanāla vājinājums starp uztvērēju un raidītāju, P_{tx} – raidīšanas jauda.

Līdzīgi kā derīgajam signālam, arī uztvertā traucējumu jauda ir aprēķināma pēc šīs pašas formulas. Te ir jāņem vērā, ka uztvērēja un traucētāja antenu vērsumu diagrammas nebūs noskaņotas vienam uz otru.

$$P_I = R_{\theta_{rx}} \cdot R_{\theta_{tx}} \cdot G \cdot P_{tx}, \quad (20)$$

Analizējot *omni-directional* scenārijus $R_{\theta_{rx}}, R_{\theta_{tx}} = 1$.

Virzienu darbības ietekme parādās divos etapos:

- Pārraidē shēmu atrašana CSMA/CA apstākļos. Saglabājot CSMA/CA protokola darbību arī virziendarbības apstākļos, jāņem vērā, ka antenas diagramma ietekmēs kanāla jušanu. Protokola efektivitāte šādos apstākļos tiks analizēta praktiskajā daļā.
- Nosakot SNIR, lai atrastu datu pārraidē ātrumus katrā no shēmām. Tā kā SNIR ir atkarīgs no derīgās un traucētāju jaudas, tad antenas pastiprināšanas koeficientiem var būt liela ietekme uz SNIR vērtībām.

8.4. MATLAB rīks daudzu ceļu caurlaides spējas noteikšanai

Balstoties uz iepriekš aprakstīto metodi, ir izstrādāts Matlab rīks, kas ietver sevī bezvadu ad-hoc tīkla, daudzu ceļu maršrutēšanas, CSMA/CA un datu pārraidē modeļus, un ļauj noteikt caurlaides spēju.

Izstrādātais rīks ļauj pārbaudīt lielu skaitu *random* scenāriju pie dažādiem ieejas parametriem, tādējādi ļaujot statistiski novērot dažādas sakarības un izdarīt

secinājumus par protokolu un metožu efektivitāti. Nākamajā 8.8. attēlā rīka struktūrshēma.

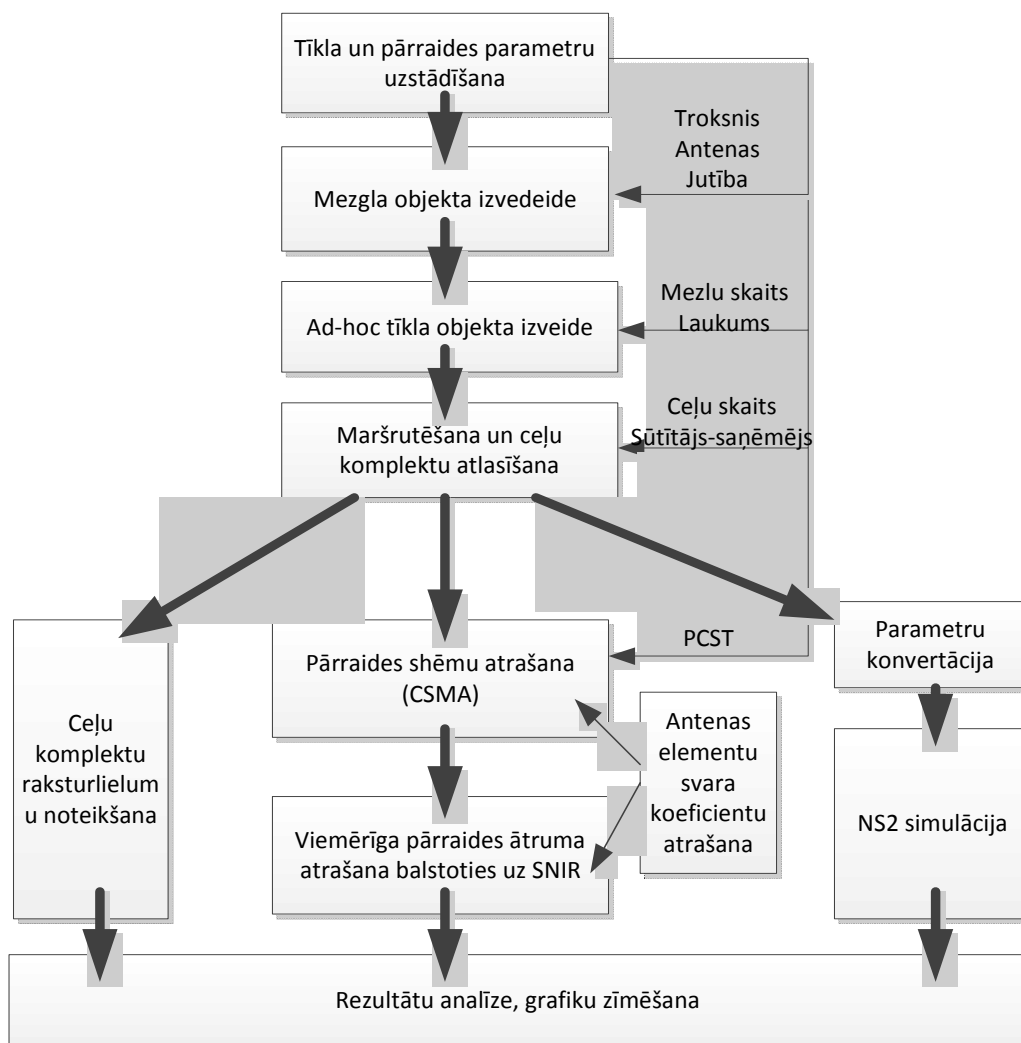


Figure 8.8 Matlab rīka blokshēma

Shēma rāda secīgi izpildāmus programmas blokus, ejot no augšas uz apakšu, kas tiek veikti, lai noteiktu vairāku ceļu pārraides caurlaides spēju, balstoties uz iepriekš izklāstīto metodi. Paralēli tiek veikta arī NS2 simulācija, lai pārbaudītu skaitlisko rezultātu (tikai *omni* gadījumā).

8.4.1. Bloku paskaidrojums

8.4.1.1. Tīkla un pārraides parametru uzstādīšana

Simulācijas sākumā tiek uzstādīti galvenie parametri:

- raidīšanas parametri - uztvērēja antenas paštroksnis, kas ietekmēs SNIR aprēķinu, kā arī nesēja jūšanu CSMA/CA protokola darbības simulācijā, raidīšanas attālums, *Physical carrier sense* sliekšnis (PCST);
- tīkla struktūras parametri – laukums, mezglu skaits.

8.4.1.2. Mezglu un tīkla objekta izveide

Tiek veidotas MATLAB struktūras, kuras ietver visu nepieciešamo informāciju un funkcionalitāti. Mezglu koordinātes var tikt izvēlētas, izvietojot tos regulārā režģī, *random* vai vienā līnijā. Mezgli tiek izvietoti planāri (2D). Mezgli ir nekustīgi. Pēc koordinātēm un izvēlētajā radio viļņu izplatīšanās modeļa tiek aprēķināta tīkla vājinājuma matrica G . Tiek izmantots viens *uplink/downlink* kanāls.

8.4.1.3. Maršrutēšana

Tiek izvēlēts sūtītāja un saņēmēja mezgls pēc gadījuma principa, tomēr nodrošinot, ka tie atrodas ne tuvāk par iepriekš noteiktu attālumu.

Tiek veikta ceļu meklēšana starp šiem diviem mezgliem. Šo daļu krietni atvieglo tas, ka ir zināmas visu mezglu atrašanās vietas. Vispirms tiek noteikti katra mezgla kaimiņu mezgli. Lai arī teorētiski minimālu ātrumu (piemēram, ar BPSK modulāciju) var nodrošināt lielākā attālumā, attālums, kādā tiek veidoti savienojumi ar kaimiņu mezgliem, tiek noteikts 250 m, kas nodrošina stabilu pārraidi. Tiek meklēti visi iespējamie ceļi starp sūtītāju un saņēmēju.

Analizējot dažādas ceļu kombinācijas, tiek izveidoti ceļu komplekti, kas apmierina iepriekš noteiktus kritērijus: ceļu skaits, lēcienu skaita atšķirība starp ceļiem, krustojšanās vietu skaits, koplietoti linki.

Ja neizdodas atrast ceļu nepieciešamo routu skaitu, mezglu skaits tiek palielināts par 1.

8.4.1.4. Ceļu komplektu raksturlielumu iegūšana

Tiek noteikti interesējošie ceļu komplektu raksturlielumi: vidējais lēcienu skaits, starpceļu attālums u.c., kas pēc tam varēs tikt izmantoti, analizējot īpašību ietekmi uz caurlaides spēju.

8.4.1.5. Pārraides shēmu atrašana

Balstoties uz zināmo informāciju par izvēlēto ceļu komplektu, tiek meklētas pārraides shēmas ceļus saturošajiem mezgliem. Tiek izmantots iepriekš aprakstītais CSMA/CA darbības princips. Pārraides shēmu meklēšana notiek pēc šāda algoritma:

1. Tiek ņemts pēc kārtas viens raidītājs-uztvērējs pāris, kuru ievieto tukšā pārraides shēmā.
2. Nākamais pāris tiek nejauši izraudzīts no atlikušajiem (tādiem, ar kuriem nav kopīgs mezgls). Ja abpusēji netiek pārsniegts Cs līmenis, pāris tiek pievienots pārraides shēmai.
3. Otrais punkts tiek atkārtots, līdz vairs neviens pāris nevar tikt pievienots shēmai, dēļ apstākļa, ka traucējumu jaudas summa kādā no iepriekš izvēlēto pāru uztvērējiem pārsniedz Cs sliekšni.

4. Ja izveidotā pārraides shēma ir unikāla (nesakrīt ar kādu iepriekš izveidotu), tā tiek saglabāta.

5. Process tiek atkārtots, vairākkārt izejot cauri visiem mezglu pāriem.

Liela mezglu skaita gadījumā, varbūtība galīgā laikā atrast pilnīgi visas pārraides shēmas samazinās. Precizitāti nosaka iterāciju skaits.

8.4.1.6. Viemērīga pārraides ātruma atrašana

No pārraides shēmām sastādot vienādojumu sistēmu (9), kuru risinot tiek meklēts tāds laika sadalījums starp shēmām, kas nodrošina maksimālu vienkāršu pārraides ātrumu visos linkos.

8.4.1.7. Antenas elementu svāra koeficientu atrašana

Papildus bloks, kurš darbojas kopā ar iepriekšējiem diviem. Tiek meklēta antenas diagramma katras pārraides shēmas ietvaros. Tiek izmantots lineārs antenas masīvs (vektors), mainot elementu skaitu no 1-64. Ja elementu skaits ir $N=1$ (*omni-directional*), tad bloks atgriež pastiprinājuma koeficientu 1 visos virzienos.

ZF-BF metode tiek pielietota tikai uztvērēja pusē.

8.4.1.8. Parametru konvertācija uz NS2 un simulācija

Tiek veikta, lai katru MATLAB scenāriju pārbaudītu arī ar NS2 tīkla stimulatoru, un novērotu, vai saglabājas tās pašas tendences. Tiek izmantots NS2 *PhyExt* un *MACExt* modeļi, kas ļauj modelēt IEEE 802.11g tīklus.

Caurlaides spēja tiek vērtēta ar CBR trafiku, atrodot maksimāli pieļaujamo - nerada tīklā sastrēgumu (*congestion*), kas noved pie pakešu zudumiem. Plūsmas tiek pakāpeniski palielinātas, nosakot pazaudēto pakešu (trafika) apjomu katrā sekundē pēc formulas:

$$losses(t) = \frac{pk_{sent}(t) - pk_{received}(t)}{pk_{sent}(t)} \quad (21)$$

$$CBR_{max} = C(losses < 2\%) \quad (22)$$

Noslēdzošajā posmā tiek analizēti no MATLAB un NS2 iegūtie dati.

8.4.2. Rīka validācija salīdzinot rezultātus ar NS2

Lai novērtētu analītiskās metodes un tās MATLAB modeļu pareizību, rezultāti

tiek salīdzināti ar NS2 - viens un tas pats scenārijs tiek pārbaudīts gan analītiski MATLAB, gan simulatorā. Atšķirība būt pieļaujama tikai absolūtajos caurlaides spējas skaitļos, bet ne kopējās tendencēs. Atšķirības var radīt jau iepriekš minētie aspekti:

- ir centrāli vadāms - ideāls - *scheduling* kanāla piekļuvei;
- tiek pielietota *Shanon* kapacitātes limita formula linka caurlaides spējai, līdz ar to netiek ņemts vērā arī virstēriņš protokolā.

Attēlā 8.9 dots Matlab-NS2 sniegto vērtību salīdzinājums (korelācija). Analītiskās caurlaides spējas vērtības visiem scenārijiem ir sašķirotas no mazākās uz lielāko, un atliktas uz x ass (tumšā līkne), attiecīgi katram scenārijam ir atlikta arī NS2 vērtība (gaišā līkne). Rezultāti ir iegūti atsevišķi pie dažādām paštrokšņa un PCST sliekšņa vērtībām.

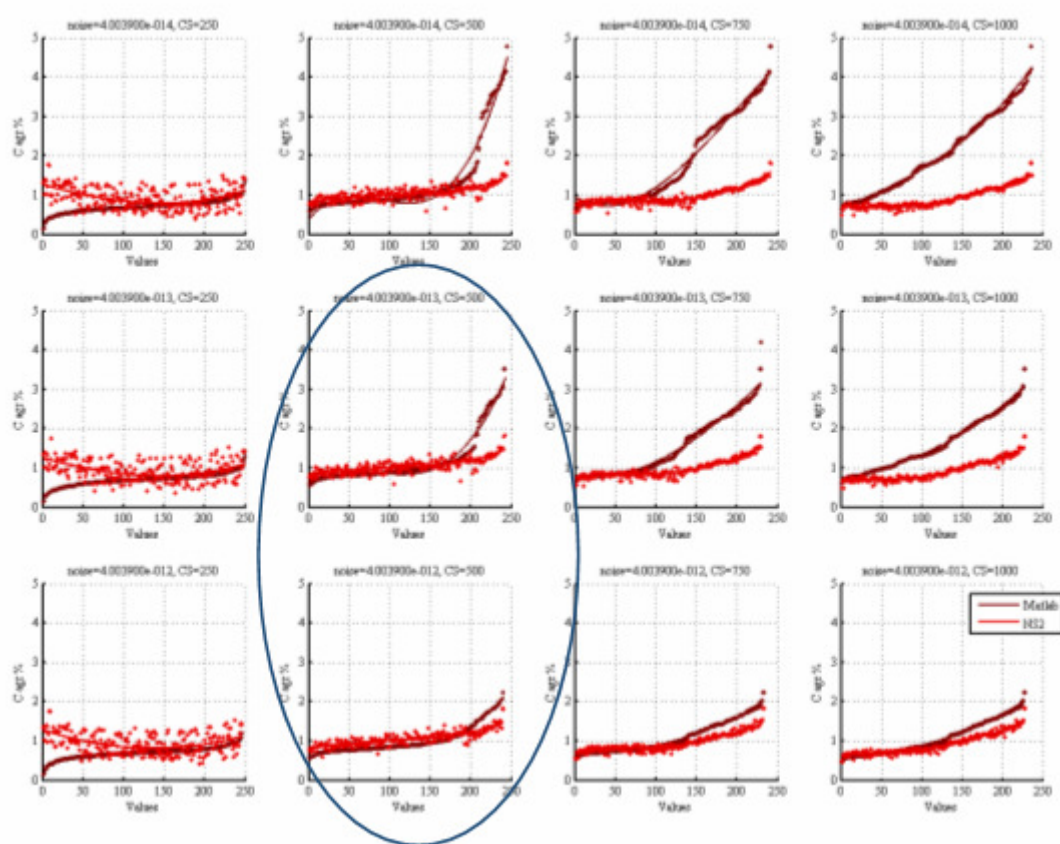


Figure 8.9 Matlab un NS2 rezultātu salīdzinājums

Vislabāko sakritību varam novērot pie CS=500 un augstāka trokšņa līmeņa, kuru varam izvēlēties par optimālajiem nosacījumiem šim modelim. Jāatzīmē, ja CS tieksies uz bezgalību, tad reālā tīklā pārraide nenotiks vispār. Tāpat arī, ja CS tieksies uz 0, jo SNIR būs zem SNIR *threshold* veiksmīgai pārraidei ar vismazāko datu ātrumu.

Nākamajā grafikā (8.10. att.) dots rezultātu salīdzinājums, pārbaudot sūtītāja-saņēmēja attāluma ietekmi uz modeļa precizitāti (CS=500, $P_{\text{noise}}=4e-013$).

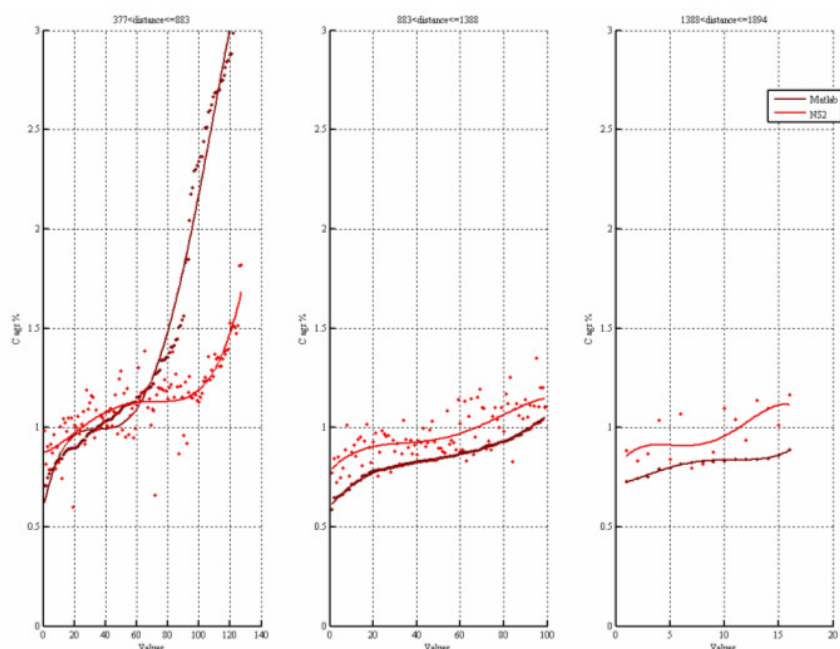


Figure 8.10 Matlab un NS2 rezultātu salīdzinājums

Lai arī visos trīs grafikos tendences ir līdzīgas, labāki rezultāti, kad sūtītājs-saņēmējs attālums ir lielāks. Lielā atšķirība pie maza starpmezglu attāluma izskaidrojama ar situāciju, kad katrā pārraides shēmā ir tikai viens raidītājs un tīkls darbojas „beztraucējumu” apstākļos. Šis pats efekts bija novērojams iepriekšējā grafikā. No tā varam secināt - Matlab modelī attālumam starp sūtītāju un saņēmēju mezgliem jābūt krietni lielākam par CS, lai efektīvi izpaustos *spatial reuse*. Tādēļ turpmākajos pētījumos šis attālums tiks izvēlēts > CS apgabala rādiuss.

8.5. Vairāku ceļu pārraides efektivitāte

Šī nodaļa pievēršas jautājumam par optimālo ceļu skaitu daudzu ceļu pārraidē (neizmantojot virziendarbību). Tabulā 8.1 doti modelēšanas parametri.

Tabula 8.1 Modelēšanas parametri

Analizētie ceļu komplekti	1 ceļam	79
	2 ceļiem	74
	3 ceļiem	71
	4 ceļiem	31
Laukuma izmērs		1000x1000m -2200x2200m
Mezglu skaits		45 - 248
P_{tx}		0.1 W
P_{PCST}		3.8e-011 W (~500 m)
$P_{paštroksnis}$		1.6e-13 W
Radio viļņu modelis		Brīva telpa
uztveršanas sliekšnis		1.5171e-010 W (250 m)
Koplietoti linki		0

8.5.1. Caurlaides spējas atkarība no ceļu skaita vienmērīgām plūsmām

Grafikā (8.11. att.) tiek attēlota kopējās (agregētās) caurlaides spējas atkarība no ceļu skaita. Atsevišķi līknes pie dažāda sūtītājs-saņēmējs attāluma.

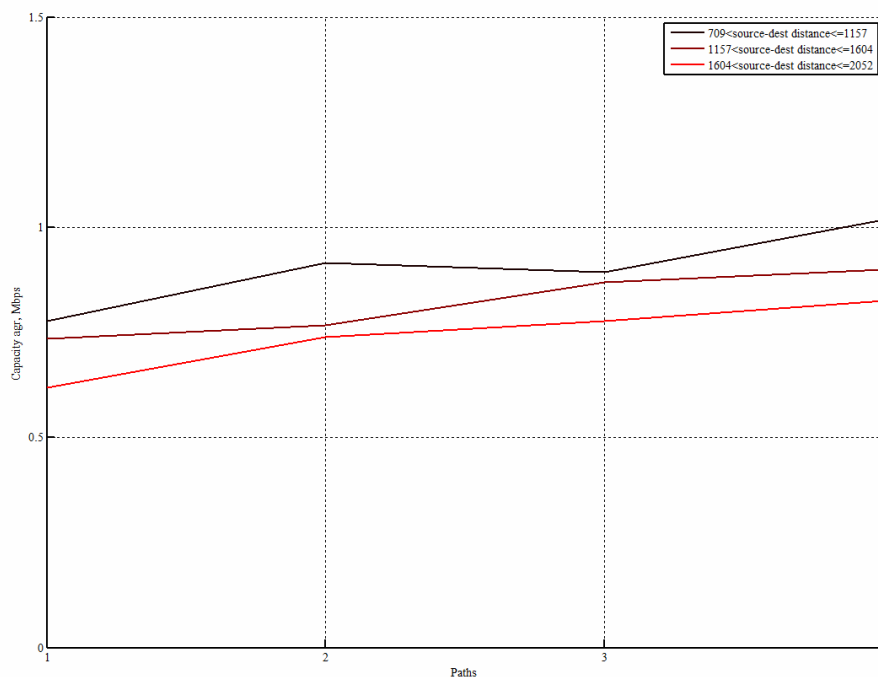


Figure 8.11 Kopējās caurlaides spējas atkarība no ceļu skaita

Kā redzams, tad pieaugums ir neliels (30 % robežās pret vienu ceļu), neraugoties uz to ka ceļu skaits tiek četrkāršots. Tas nozīmē, ka spēcīgi izpaužas starpceļu traucējumi, pie kam, kā mēs sīkāk analizēsim nākamajā nodaļā, darbojas *Gupta-Kumar* modeļa sakarība, kur tīkla caurlaides spējas robežas atkarīgas no mezglu skaita.

Pārbaudot pieņēmumu, ka caurlaides spēju var ietekmēt arī sūtītāja-saņēmēja attālums, kā bija sagaidāms, tad lielāku caurlaides spēju sasniedzam, kad sūtītājs-saņēmējs ir tuvāk. Tas izskaidrojas ar mazāku mezglu un lēcienu skaitu visos ceļos.

Caurlaides spēju nevienmērīgu plūsmu gadījumā 8.2. nodaļā minētā metode neļauj pētīt situācijās, kad plūsma abos ceļos nav vienmērīga. Tas būtu pretrunā ar pieņēmumu, ka mezgli savā laika slotā raida nepārtraukti (**tiem viemēr buferī ir dati, ko raidīt, un tie bez vilcināšanās pārsūta tālāk**). Situācijā, kad vienā pārraides shēmā būtu mezglu pāri no diviem ceļiem, kur viens pāris neraida pilnu atvēlēto laiku, modelī nav iespējama.

Šādu scenāriju ļāva pārbaudīt NS2 modelēšanas programma. Rezultāti 8.12. attēlā.

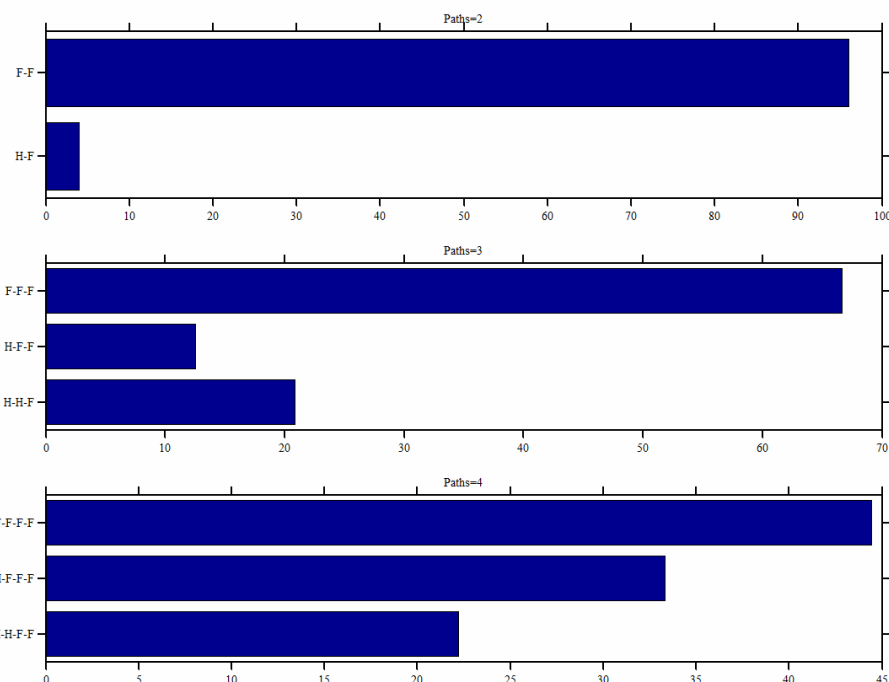


Figure 8.12 Scenāriju biežums

Ar F apzīmēta pilna plūsma, ar H - 50% no pilnas, piemēram, HHFF nozīmē, ka 4 ceļu gadījumā divos ceļos ir bijusi nepilna plūsma, bet divos pilna. Grafiki parāda, cik procentos gadījumu katrs plūsmu sadalījums ir bijis vispiemērotākais. Nevienmērīga plūsma tika uzskatīta par labāku, ja tās agregētā caurlaides spēja bija vismaz par 5% augstāka, nekā vienmērīgai. Redzams, ka 2 un 3 ceļu gadījumā nevienmērīga plūsma reti dod efektu. Tikai 4 ceļu gadījumā ir vērts apskatīt šādu iespēju.

8.5.2. Ceļu raksturlielumi un to ietekme uz caurlaides spēju

Rakstā [8.5] mēs piedāvājam shēmu, kura raksturo dažādas tīkla parametru savstarpējās atkarības. Kā viens no noteicošajiem faktoriem tikai izvirzīts ceļu izvēle. Izstrādātais modelis ļauj daļēji īstenot shēmas savstarpējo atkarības, lai noskaidrotu caurlaides spēju un tās atkarību no ceļu izvēles kritērijiem (8.13. att.).

Ar dzeltenu ir iekrāsoti bloki, kuri ir realizēti Matlab rīkā. Tiek ņemti vērā tīklu *Ietekmējoši faktori*:

- *Protocols deployed*: CSMA/CA priekš kanāla piekļuves;
- *Radio Channel*: paštroksnis, radio viļņu izplatīšanās modelis, uztvērēja jutība;
- *Network structure*: laukuma izmērs, mezglu skaits, sūtītāja un saņēmēja atrašanās vieta.

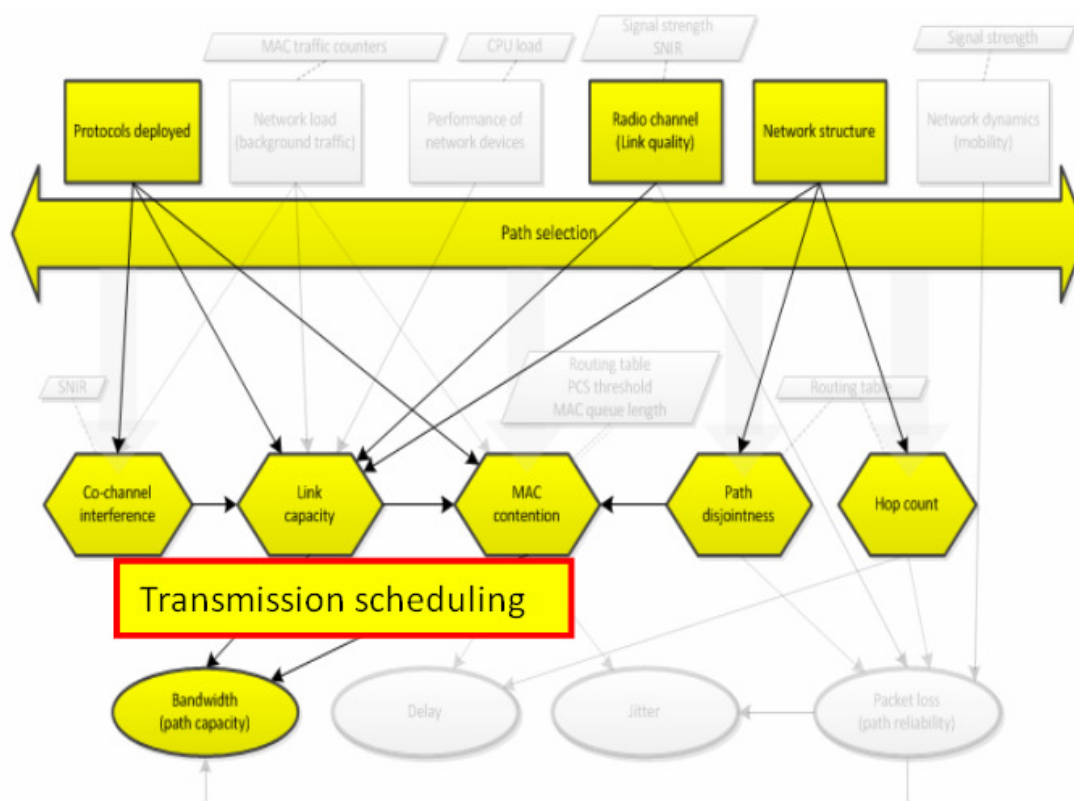


Figure 8.13 Tīkla raksturlielumu atkarību shēma

Tīkla raksturlielumi, kuri tiek ietekmēti, ir kanāla konkurence, linka caurlaides spēja, savstarpējie traucējumi, ceļu nošķirtība, lēcienu skaits. Izvēloties dažādus ceļu komplektus (*Path selection*) tiek noteikta to *caurlaides spēja*. Tomēr jāatceras, ka minētā caurlaides spēja tiek mērīta pie ideālas pārraižu plānošanas.

Kā viens no ietekmes faktoriem, kas kombinācijā ar ceļu izvēli tiks analizēts šajā darbā, ir tīkla struktūra. Rakstos [8.1] [8.2] [8.3] ir izteikta hipotēze - lielāku caurlaides spēju var sasniegt, izvēloties nošķirtus (*radio-disjoint*) ceļus. Parasti tas ir saistīts ar lielāku starp-ceļu attālumu. Tālāk šajā nodaļā tiks pārbaudīts, cik šādi apgalvojumi ir pamatoti.

Pirmā problēma, kura jāatrisina – kā novērtēt starp-ceļu attālumu. Šajā darbā par starpceļu attāluma raksturojumu tiks izmantots laukums, kuru aizņem ceļu komplekts. Tas būs laukums, kuru iegūst, savienojot ar līnijām visus ārējos mezglus. Matemātiski tas ir *convex hull* no mezglu koordinātēm. 8.14. attēlā parādīti divi dažādi starpceļu attālumi.

Diemžēl šī pieeja neatrisina jautājumu par attālumu starp iekšējiem ceļiem. Sākotnējie pētījumi tiks veikti tikai pie divu ceļu scenārijiem, jo tie visprecīzāk var tikt aprakstīti ar *convex-hull* laukumu.

Modelēšanas parametri apkopoti tabulā 8.2.

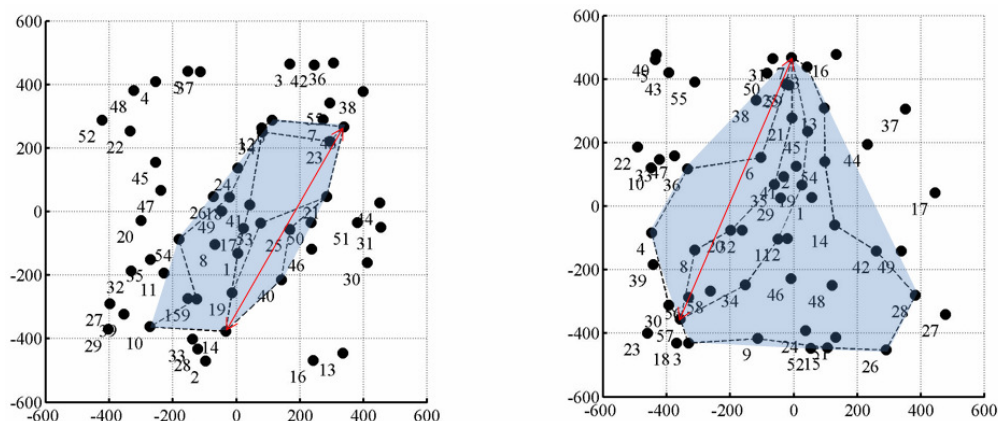


Figure 8.14 Starpceļu attālumi izteikti kā *convex hull*

Tabula 8.2 Modelēšanas parametri

Field size	1000x1000m - 2500x2500m
Number of scenarios	3168
Number of nodes in network	45 – 301
P_{tx}	0.1 W
P_{PCST}	3.8e-011 W (~500 m)
P_{noise}	1.6e-13 W
Radio propagation model	Free space
Transmission distance	250 m
Carrier frequency	2.45 Ghz

Attēlā 8.15 ir parādīts, kā mainās caurlaides spēja atkarībā no starp-ceļu attāluma (izteikts kā ceļu ietvertais apgabals). *Convex-hull* laukums ir atkarīgs arī no attāluma starp gala punktiem (bultu nogrieznis 8.14. att.), tādēļ atsevišķi dota vidējā veikspēja pie dažāda sūtītājs-saņēmējs attāluma diapazona. Lai novilktu līknes, atbilstošas izkliedētajiem datiem (punkti grafikā), tika pielietota lineārā regresija. Katrs punkts ataino veikspēju kādam scenārijam. Papildus rezultātu drošības intervāls ir dots katrai līknei (raustītās līnijas).

Šī eksperimenta galvenais secinājums - nav izteikta caurlaides spējas pieauguma, palielinoties attālumam starp ceļiem, kas ir pretrunā ar sākotnēji izvirzītajiem apgalvojumiem. Tikai pie liela starpmezglu attāluma ir novērojams caurlaides spējas pieaugums, kas varētu tikt skaidrots ar efektīvāku telpas izmantošanu (*spatial reuse*). Viena no hipotēzēm necīgajam pieaugumam ir tāda, ka, lai nodrošinātu lielāku starpceļu attālumu, ir jāizmanto vairāk mezgli, kas savukārt nozīmē caurlaides spējas kritumu. Darbā [8.8] piedāvātajā modelī jau tika pierādīts, ka caurlaides spēja asimptotiski seko sakarībai $\frac{W}{\sqrt{n \log n}}$. Lai to pārbaudītu uz šiem pašiem rezultātiem, 8.16.att. ir parādīta vienmērīgas veikspējas atkarība no iesaistīto mezglu skaita. Papildus tiek pielikta teorētiskā līkne (nepārtraukta līnija) no *Gupta-Kumar* modeļa

[8.8] . Redzams, ka punkti diezgan precīzi atkārto sakarību. Tas vēlreiz apstiprina, ka ļoti svarīgs faktors ir mezglu skaits un, ja lielāks starpceļu attālums prasa lielāku mezglu skaitu, tad **caurlaides spēju veidos abu kombinācija**.

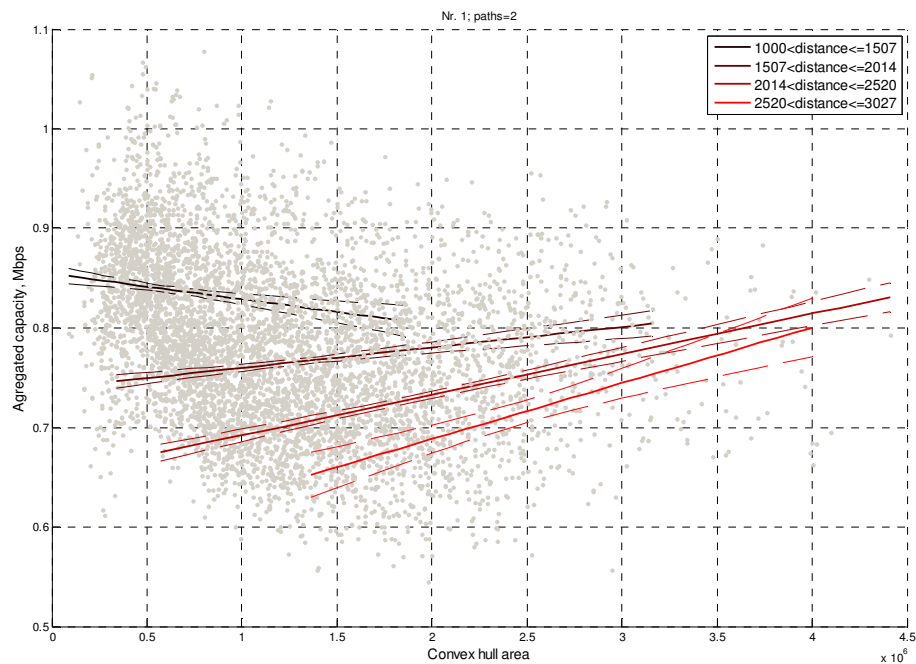


Figure 8.15 Starpceļu attāluma ietekme uz caurlaides spēju

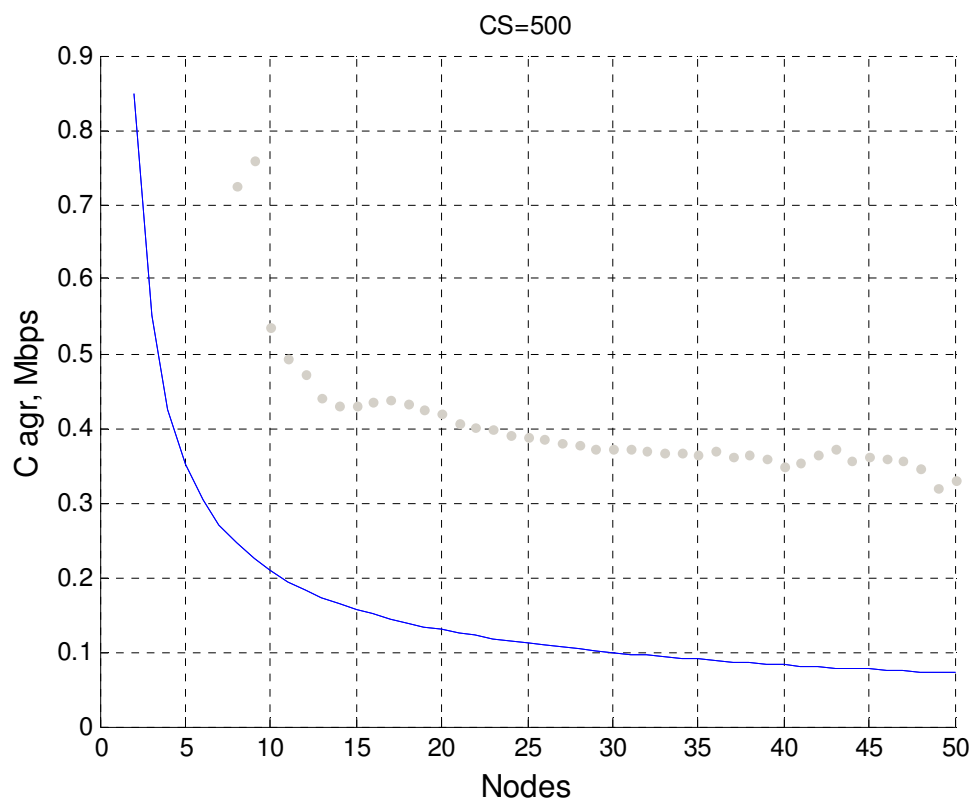


Figure 8.16 Gupta-Kumar modeļa [8.8] likne

To apstiprina arī nākamais attēls (8.17.att), kur atsevišķi apskatīta caurlaides spēja atkarībā no starpceļu attāluma pie līdzīga mezglu skaita. Novērojams izteiktāks pieaugums. Tāpat kā 8.15 attēlā, saskatāma tendence ātrumam samazināties, palielinoties starpceļu attālumam.

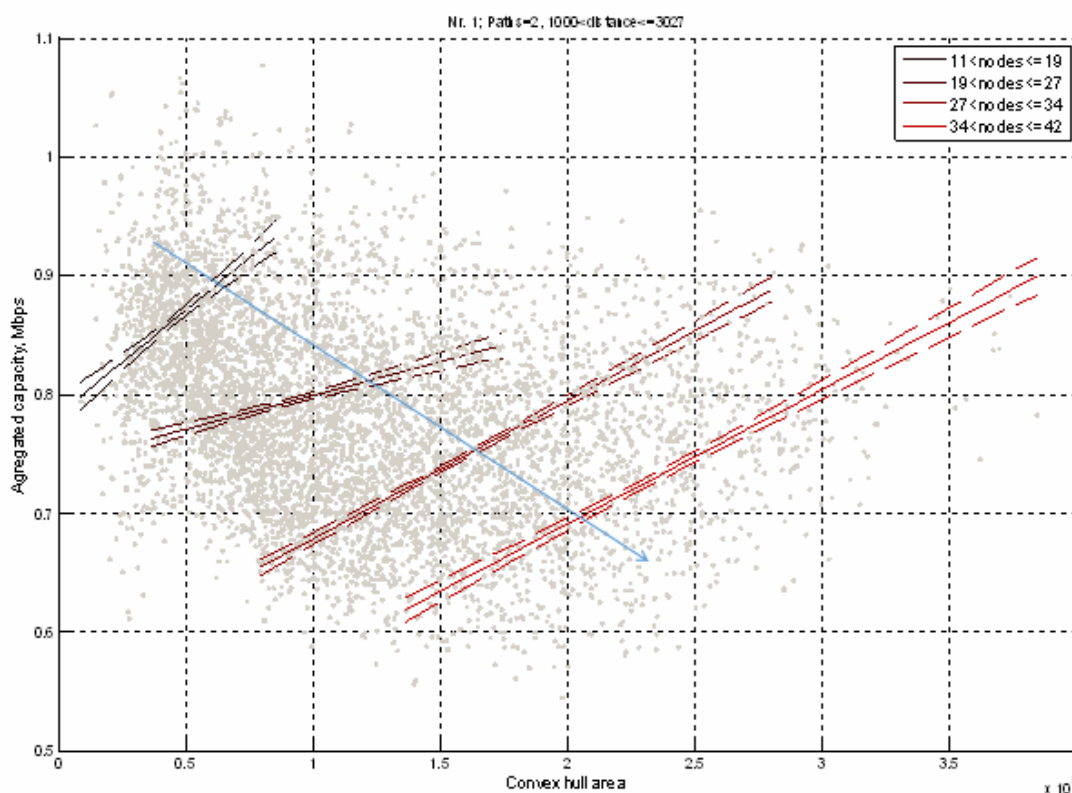


Figure 8.17 Starpceļu attāluma ietekme pie līdzīga mezglu skaita

8.6. Virziendarbības antenu efektivitāte

Iegūto rezultātu sakritība ar NS2 *omni-directional* antenu gadījumā (Nodaļā 8.4.2) ļauj pieņemt, ka metode var tikt pielietota arī virziendarbības pētīšanai.

Šajā nodaļā tiks pārbaudītas virzienu darbības antenas kā veids traucējumu mazināšanai daudzu ceļu pārraidē. Lai novērtētu efektivitāti, agregētā caurlaides spēja var tikt izteikta procentuāli:

$$C_{agr\%} = \frac{C_{agr}}{C_{\max(1\ path - omni)}}$$

un rāda, kāds būtu uzlabojums, izmantojot daudzceļu pārraidi ar virziendarbību traucējumu mazināšanai, salīdzinājumā pret pārraidi ideālos apstākļos (bez traucējumiem) pa vienu ceļu.

Vispirms tiks pārbaudīta CSMA/CA mehānisma efektivitāte pie virzienu darbības

(8.18. att.) ar mērķi noteikt tās izmantošanas lietderību. Papildus tas tiks pētīts kombinācijā ar ZF-BF (Nodaļa 8.3.6) trīs veidos (3 grafiki):

- bez ZF-BF;
- ZF-BF, slāpējot traucējumus pret visiem mezgliem;
- ZF-BF (*close ZF-BF*), slāpējot traucējumus tikai pret tuvākajiem (N-1) mezgliem; jāņem vērā, šis variants prasa papildus informāciju par traucētāju signāla stiprumu (attālumu).

Katrā no grafikiem tiek piedāvāti trīs CSMA/CA režīmi:

- bez CS;
- CS tiek veikts ar virzienudarbību;
- CS tiek veikts klasiski ar *omni-directional*, bet pārraide ir *directional*.

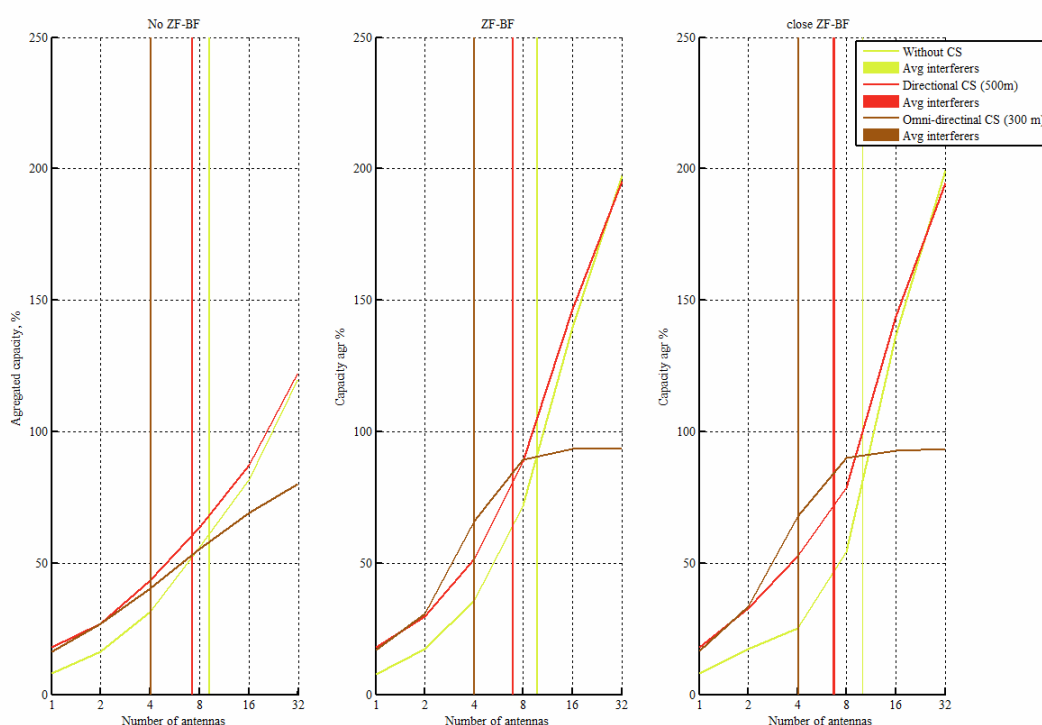


Figure 8.18 CSMA/CA mehānisma efektivitāte pie virzienu darbības

CS izmantošana (abi - *omni* un *directional*) uzrāda krietni labākus rezultātus pie maza antenas elementu skaita. *Omni-directional* CS gadījumā tas skaidrojams ar iespēju novērst slēptos mezglus. Pie liela elementu skaita (>8) parādās piesātinājums dēļ nevajadzīgi pakļautiem mezgliem. Tā neļauj izpausties vienai no virziendarbības priekšrocībām – slāpēt traucējumus pie daudziem vienlaicīgi raidošiem mezgliem.

Ar vertikālu līniju - vidējais traucētāju skaits katram mezglam, pret kuriem ir nepieciešams vērst diagrammas minimumu ZF-BF gadījumā. Bez CS gadījumā tas ir vislielākais, jo pārraides shēmas satur maksimālu skatu mezglu pārus. Lai efektīvi varētu slāpēt visus traucētājus ar ZF-BF metodi, antenas elementu skaitam jābūt lielākam par traucētāju skaitu. To var novērot arī grafikā pēc straujākas caurlaides spējas uzlabojuma, pārsniedzot šo robežu (īpaši izteikti pie ZF-BF).

Nākamajā grafikā (8.19.att.) tiek salīdzināta daudzu ceļu pārraides efektivitāte pie dažāda antenas elementu skaita, atsevišķi izdalot ar un bez ZF-BF, kā arī attālumu starp sūtītāja un saņēmēja mezglu.

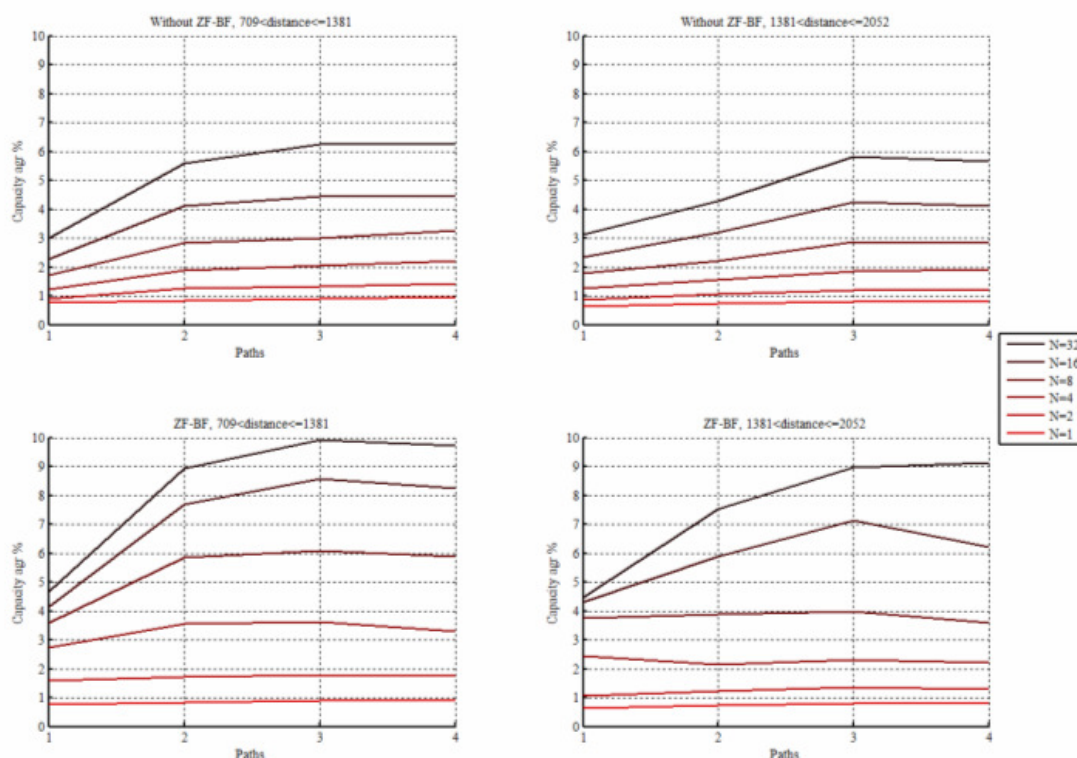


Figure 8.19 Daudzu ceļu pārraides efektivitāte pie dažāda antenas elementu skaita

Galvenie novērojumi, uz kuriem jāvērs uzmanība:

- ZF-BF režīmā pie $N=4$ un $N=8$ novērojams caurlaides spējas kritums, palielinot ceļu skaitu. Izskaidrojums: traucētāju skaits kļūst lielāks kā antenas brīvības pakāpes. Pie liela antenu skaita šāds kritums nav novērojams, bet pie maza N traucētāju skaits visu laiku pārsniegs brīvības pakāpes un ZF-BF nebūs efektīvs;
- Pie maza attāluma starp sūtītāju un saņēmēju tiek sasniegti labāki rādītāji caurlaides spējai. Skaidrojams ar mazāku iesaistīto mezglu skaitu, līdz ar to vieglāk nospiest traucējumus;
- Virziendarbība var ievērojami palielināt caurlaides spēju, pārraidot datus pa vairākiem paralēliem ceļiem, jo veiksmīgi ļauj izvairīties no traucējumiem. Tas novērojams gan ar, gan bez ZF-BF;
- Izmantojot CS, izpaužas virzienu-darbības slēptās stacijas problēma, kura ir minēta arī [8.6]. Īpaši tā ir novērojama $N=2$ gadījumā, kad caurlaides spējas ieguvums ir niecīgs, vai pat novērojams kritums salīdzinājumā ar $N=1$. Izskaidrojams ar specifisko antenas diagrammas formu, kur galvenā lapa vērsta uz abām pusēm.

Slēptas stacijas problēma ir attēlota 8.20. attēlā. Mezglis n_1 , aprīkots ar divu elementu antenu, vēlas sākt pārraidi uz n_4 . Tiek veikts *carrier sensing*, lai pārbaudītu vai kāds nerada traucējumus n_4 . Diemžēl tas, ka n_2 raida n_4 virzienā, nav dzirdams, un pārraide tiek atļauta. Divu antenas elementu gadījumā antenas

diagrammas galvenās lapas ir vērstas abos virzienos, līdz ar to slēptās stacijas risks palielinās, jo kolīzija notiks, n2 raidot gan n3, gan n5. Šo problēmu daļēji atrisinātu *RTS/CTS handshake*, jo minētajā situācija n_4 neatbildētu ar *clear-to-send* mezglam n1.

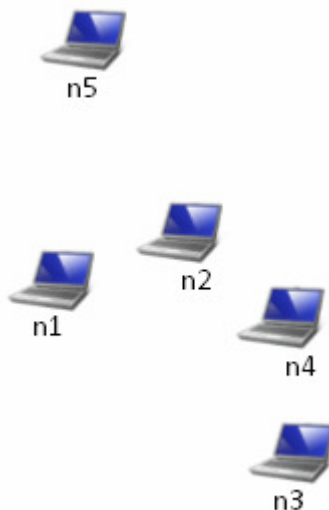


Figure 8.20 Virziendarbības slēptās stacijas problēma

8.7. Secinājumi

Uzlabota analītiskā metode daudz-ceļu pārraides caurlaides spējas novērtēšanai, darbojoties CSMA/CA protokolam. Neraugoties uz daudzu sarežģītu procesu vienkāršotiem modeļiem (idealizāciju), tā ir pielietojama, lai gūtu pamatpriekšstatus par optimālu ceļu izvēli.

Intensīvu datu plūsmu gadījumā, daudzceļu pārraide nesniedz būtisku caurlaides spējas pieaugumu, neizmantojot paņēmienus traucējumu mazināšanai.

Caurlaides spēja veidojas kā mezglu skaita un starp-ceļu attāluma kombinācija. Palielinot starp-ceļu attālumu, gandrīz automātiski palielinās arī iesaistīto mezglu skaits. Uzlabojums ir novērojams, ja palielinot starp-ceļu attālumu, mezglu skaits mainās nelielās robežās.

Virziendarbība ievērojami palielina caurlaides spēju daudzu ceļu pārraidē un straujš uzlabojums ir panākams, palielinot antenas elementu skaitu N virs 2. ZF-BF sniedz papildus pieaugumu, tomēr efektivitāte saistīta ar antenas masīva spēju nospiest traucējošos virzienus, kas, palielinoties mezglu skaitam, ir komplicēti pie neliela antenas elementu skaita. CS klasiskā izpildījumā pie virzienu darbības nav efektīvs - liela N gadījumā mezgli tiek nevajadzīgi pakļauti.

Nepieciešami tālāki pētījumi ar citiem radio viļņu izplatīšanās modeļiem, kā arī 2D antenu masīviem. Papildus pētījumi par optimālas ceļu izvēles kombinēšanu ar traucējumu mazināšanas paņēmieniem.

8.8. *Atsauces*

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Pielikums #1



Eventech SIA

Reģ.nr.: 40103495910

PVN reģ.nr.: LV40103495910

Jur.adrese: Dzērbenes iela 14

Rīga, LV-1006

Rīgā

2013.gada 8.oktobrī

Nr.1-6

Elektronikas un datorzinātņu institūtam

Atsauksme par taimešanas tehnoloģijas aprobāciju

Ar šo vēstuli vēlamies apliecināt SIA „Eventech” līdzšinējo veiksmīgo sadarbību ar Elektronikas un datorzinātņu institūtu (EDI). 2012.gadā SIA „Eventech” parakstīja licences un sadarbības līgumu ar EDI par „Tehnoloģija notikumu taimera A033-ET ražošanai” ekskluzīvu licencēšanu un komercializēšanu. Tā rezultātā SIA „Eventech” ieguva ekskluzīvas tiesības ražot un izplatīt EDI ražotās ierīces – pikosekunžu diapazona laika mērītājus A033-ET (turpmāk tekstā A033-ET).

Tai pat laikā tika likts pamats veiksmīgai savstarpējai sadarbībai gan tehnoloģiskajā, gan zinātniskajā jomā, jo SIA „Eventech” regulāri konsultējas ar EDI Laika mērīšanas laboratorijas zinātniekiem, risinot dažādus tehniskus jautājumus. Jaunie tehniskie risinājumi un uzlabojumi, saistītie ar laika mērītāju precizitātes un mērīšanas ātrumu palielināšanu un izstrādātie Valsts pētījumu programmas „INOVATĪVO DAUDZFUNKCIONĀLO MATERIĀLU, SIGNĀLAPSTRĀDES UN INFORMĀTIKAS TEHNOLOĢIJU IZSTRĀDE KONKURĒTSPĒJĪGIEM ZINĀTŅU IETILPĪGIEM PRODUKTIEM”, Projekta Nr. 2 „Inovatīvas signālapstrādes tehnoloģijas viedu un efektīvu elektronisko sistēmu radīšanai” ietvaros veiksmīgi aprobēti reālos komercproduktos, jo SIA „Eventech” turpina cieši sadarboties ar EDI pasūtot jaunu produktu testēšanas un kalibrēšanas darbus.

Kopš sadarbības sākuma SIA „Eventech” ir pārdevusi 14 gab. A033-ET tādiem klientiem kā *Finnish Geodetic Institute* (Somija), *XI'AN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS* (Ķīna), *HARBIN ENGINEERING UNIVERSITY* (Ķīna), *Cybioms Corporation* (ASV), *Shimosato Hydrographic Observatory of Japan Coast Guard* (Japāna), *NPK SPP* (Krievija), *NATIONAL TIME SERVICE CENTER CAS* (Ķīna) un *Institute of Geodesy & Geophysics CAS* (Ķīna).

Iepriekš minētie klienti strādā ne tikai satelītu lāzerlokācijas jomā, bet arī ģeodēzijas un metroloģijas jomās un no viņiem ir saņemtas tikai pozitīvas atsauksmes par A033-ET darbību un viņu plānos ietilpst iegādāties SIA „Eventech” ražotās ierīces arī turpmāk.

SIA „Eventech” plāno attīstīt A033-ET ražošanu, meklējot jaunus pielietojumu gravimetrijas, fluorescences spektroskopijas un virszemes apsekojumu jomās, aktīvi sadarbojoties ar EDI jaunu produktu izstrādē vai esošo produktu pielāgošanā, kā arī meklējot finansējuma avotus šo ieceru realizēšanai.

Ar cieņu,
Nikolajs Adamovičs
SIA „Eventech”
Valdes loceklis

G.Ozoliņš
26522982

Pielikums #2



Piņķos

2013. gada 28. oktobrī

Atsauksme par superplatjoslas impulsu tuvdarbības radara sistēmas tehnoloģijas aprobāciju

SIA „VentEko” apliecina, ka esam veikuši Elektronikas un datorzinātņu institūta Valsts pētījumu programmas „Inovatīvo daudzfunkcionālo materiālu, signālapstrādes un informātikas tehnoloģiju izstrāde konkurētspējīgiem zinātņu ietilpīgiem produktiem”, Projekta Nr. 2 „Inovatīvas signālapstrādes tehnoloģijas viedu un efektīvu elektronisko sistēmu radīšanai” ietvaros izstrādātās tehnoloģijas superplatjoslas impulsu tuvdarbības radara sistēmas prototipa aprobāciju reāliem apstākļiem pietuvinātos scenārijos zemgarozas kartogrāfijā.

Aprobācija tika veikta trīs mēnešu laika posmā no 2013. gada 1. jūlija līdz 1. oktobrim Rumbulā bijušā lidlauka teritorijai pieguļošā aviācijas degvielas uzglabāšanas vietā Rīgā, Maskavas ielā 461. Aprobācijas vide ir no aviācijas degvielas piesārņojuma attīrāms objekts – pļava un grants ceļš, zem kuriem atrodas komunikācijas kabeļi, naftas vadi un attīrīšanas nolūkos instalētas drenāžas caurules.

Ar izstrādātās universālās modulārās radaru sistēmas palīdzību spējam noteikt mūs interesējošos zemgarozas objektus un veikt to kartēšanu. Darba gaitā iepazīnāmies ar izstrādātās tehnoloģijas darbības principiem un apzinājām tehnoloģijas iespējas un ierobežojumus.

Aprobācijas laikā, aktīvi sadarbojoties ar Elektronikas un datorzinātņu speciālistiem tehnoloģijas izmantošanā un uzlabošanā, ar konkrētam pielietojumam izstrādātām 500 MHz antenām tika veikta arī zemes dziļākos slāņos esošā naftas vada detektēšana un kartēšana. Salīdzinot izstrādātās tehnoloģijas parametrus ar analogām ģeofizikas iekārtām atbilstošā cenu kategorijā analogus nesaskatām. Īpaši noderīga, mūsu prātā, ir sadarbības veicināšana starp tehnoloģiju izstrādātājiem un to lietotājiem reālas vides apstākļos.

Ņemot vērā aprobācijas rezultātus, uzskatām, ka superplatjoslas impulsu tuvdarbības radara sistēmai ir potenciāls pielietojums ātrākā un precīzākā zemgarozas slāņu un objektu kartēšanā, tādējādi dodot ieguldījumu zemkopības, vides aizsardzības un ģeoloģijas jomās. Uzskatām, ka šīs tehnoloģijas attīstīšana un konkrētu produktu prototipu izstrāde ar tālāku mērķi komerciāliem pielietojumiem dos ieguldījumu tautsaimniecības attīstībā.

Izpildedirektors
Māris Pētersons

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Pielikums #3

Rīgā, 2013.g. 31.oktobrī

Atsauksme par tehnoloģijas „Objektu 3D sekošana izmantojot pasīvo stereo redzi uz mobilas platformas” aprobāciju

Latvijas Auto klubu apvienība (LAKA) apliecina, ka Elektronikas un datorzinātņu institūts (EDI) Valsts pētījumu programmas „Inovatīvo daudzfunkcionālo materiālu, signālapstrādes un informātikas tehnoloģiju izstrāde konkurētspējīgiem zinātņu ietilpīgiem produktiem” projekta Nr.2 „Inovatīvas signālapstrādes tehnoloģijas viedu un efektīvu elektronisko sistēmu radīšanai” ietvaros veicis tehnoloģijas „Objektu 3D sekošana izmantojot pasīvo stereo redzi uz mobilas platformas” aprobāciju reālos apstākļos sadarbībā ar LAKA biedriem – Amerikāņu auto klubu un biedrību „MB Club.lv”.

Aprobācijas laikā sadarbības partneriem tika nodrošināta iespēja veikt testa braucienus ar auto, kurā tika uzstādīta sistēma objektu 3D sekošanai. Izmantojot divas sistēmas sastāvā ietilpstošās kameras, tika iegūti dati par apkārtējās vides objektiem, t.sk. attālums līdz tiem, kā arī ātrums un pārvietošanās virziens. Aprobācijas laikā sistēma parādīja, ka ir spējīga darboties un var tikt izmantota atbalsta sniegšanai transporta līdzekļa vadītājam, taču ir nepieciešami turpmākie pētījumi apkārtējās vides objektu sekošanas optimizēšanai, kā arī atsevišķu sistēmas komponentu apvienošanai vienā kompaktā iekārtā.

Mikus Zelmeņa testa brauciens bija pārsvarā ārpus pilsētas. Subjektīvais vērtējums ir tāds, ka būtu lietderīga sistēmas jūtības palielināšana braucot ar lielāku ātrumu, jo objektu pirmreizējā uztveršana varētu notikt mazliet ātrāk, kā šobrīd (lielākā attālumā), sekošana jau uztvertiem objektiem ir laba, arī objekti ceļa malās tiek labi fiksēti. Braucot pilsētas ātrumā (līdz 50 km/h), objekta pirmreizējās uztveršanas un “pazaudēšanas” attālums šķita pieņemams un netika izjusta tāda attālumu atšķirība, kā ārpus pilsētas. Satiksme ārpus pilsētās nebija intensīva. Braukšana notika pa dienu, tā ka grūti novērtēt iespējamo ieguvumu no sistēmas braukšanai naktī, jo tumsā tās priekšrocības noteikti būtu izteiktākas.

Aprobācijas laikā notika aktīva sadarbība ar EDI speciālistiem, kuri sniedza papildus informāciju par sistēmas darbību. Ņemot vērā aprobācijas rezultātus, uzskatām, ka sistēmai objektu 3D sekošanai ir potenciāls pielietojums atbalsta sniegšanai transporta līdzekļa vadītājam, un, ņemot vērā priekšrocības salīdzinājumā ar RADAR un LIDAR bāzētām sistēmām, tās komercializācija var sniegt ieguldījumu tautsaimniecības attīstībā.

Mikus Zelmenis
Biedrības „MB Club.lv” pārstāvis,
Latvijas Auto klubu apvienības valdes priekšsēdētājs



Pielikums #4



BIEDRĪBA

AMERIKĀŅU AUTO KLUBS

Rīgā, 2013. gada 31. oktobrī

ATSAUKSME

Biedrība "Amerikāņu auto klubs" sistēmu testēja 25. oktobra pēcpusdienā un vakarā, tumšajā vakara daļā, kā arī 28. oktobra dienas vidū.

Automašīnas saņemšanas brīdī tikām informēti par sistēmas pamatprincipiem, jau veiktajiem testiem un to rezultātiem, kā arī ar jau sastaptajām nepilnībām. Pirmo testu veicām Rīgā, sastrēgumu stundās. Sistēma tika iedarbināta autostāvvietā aptuveni 1m attālumā no priekšā stāvoša auto. Jau izbraucot no EDI stāvlaukuma secinājām, ka objektu atpazīstamība ir ļoti nekvalitatīva un nepilnīga. Atpazīts tika retais objekts. Pēc pāris nobrauktiem kilometriem sistēmu izslēdzām.

Nākamo testu veicām jau tumšajā vakara daļā. Sistēmu ieslēdzām klajā automašīnas lukturu izgaismotā laukumā. Uzsākot kustību atkal bija jāsecina, ka detekcija nenotiek. Aptuveni pēc 2 km attēls sāka "raustīties" un "ķerties". Jau gaitā, esot satiksmē, sistēmu restartējām. No šī brīža objektu atpazīšana būtiski uzlabojās. Braucot ar 50km/h auto lukturu izgaismotajā zonā, gan pa kreisi, gan pa labi, gan tieši automašīnas priekšā objektu uztveršana bija ļoti laba.

Palielinot ātrumu līdz 70km/h objektu uztveršana kavējās. Tai pašā laikā izsekošana palika stabila. Noteiktie attālumi līdz objektiem bija būtiski lielāki, kā dabā.

Palielinot ātrumu līdz 90km/h būtiskas izmaiņas netika novērotas.

28. oktobrī testā papildus piesaistījām apsardzes video inženieri, kura pārziņā ir kameras ar objektu atpazīšanu, kā arī speciālistu auto vadības bloku izstrādē un mikroprocesoru programmēšanā. Testu veicām dienas vidū maršrutā no Pārdaugavas uz EDI. Sistēmu ieslēdzām stāvlaukumā, priekšā, 4m attālumā esot konteinerim. Līdzīgi, kā iepriekš, tūlīt pēc ieslēgšanas, objektu uztveršana praktiski nenotika. Gaitā, jau esot satiksmē, restartējām sistēmu, kas, līdzīgi, kā jau iepriekš, atjaunoja vēlamo darbību. Objektus uztvēra labi, tomēr saraustīti.

Salīdzinot testu tumsā un gaismā, secinām, ka tumsā uztver precīzāk un seko noturīgāk. Gaismā uztver daudz vairāk objektus, bet saraustītāk un ne tik noturīgi.

Papildus, lai arī uztver automašīnas, stabus un citus objektus ielas malās, tomēr ļoti vāji vai nemaz neuztver gājējus un velosipēdistus. Tāpat mums šobrīd nav viedokļa par sistēmas reālu pielietojumu, apzinot nepieciešamās tehnikas jaudas un mikrorisinājumu iespējas.

Piezīmes par paša testa procesu. Iesakām nākošajiem testiem izveidot testu procedūras, lai testētāji var koncentrēties uz konkrētām problēmām, kuras censties apzināt, novērst līdz nākamajiem testiem.

Paldies, par iepazīstināšanu ar šo projektu un iespēju piedalīties testos.

Āris Seisums
Biedrība "Amerikāņu auto klubs"

Biedrība "Amerikāņu auto klubs"
Reģ. Nr. 40008079950

AS SWEDBANK
Konta Nr. LV47HABA0551006667242

Putnu iela 15A, Rīga, Latvijas, LV1004
e-pasts: uscars@uscars.lv | WEB: www.uscars.lv

Pielikums #5



RĪGAS DOMES INFORMĀCIJAS TEHNOLOĢIJU CENTRS

Brīvības iela 49/53, Rīga, LV-1010, tālrunis 67037022, fakss 67037023, e-pasts: tc@riga.lv

ATSAUKSME

Rīgā

17.10.2013. Nr. TC-13-441-nd

Iesniegšanai pēc pieprasījuma

Par plaukostas biometrijas tehnoloģijas
aprobāciju

Rīgas domes Informācijas tehnoloģiju centrs (turpmāk – RD ITC) apliecina, ka Elektronikas un datorzinātņu institūts Valsts pētījumu programmas „Inovatīvo daudzfunkcionālo materiālu, signālapstrādes un informātikas tehnoloģiju izstrāde konkurētspējīgiem zinātņu ietilpīgiem produktiem”, Projekta Nr. 2 „Inovatīvas signālapstrādes tehnoloģijas viedu un efektīvu elektronisko sistēmu radīšanai” ietvaros ir veicis izstrādātās plaukostas biometrijas tehnoloģijas aprobāciju reālos apstākļos.

Aprobācijas laikā plaukostas biometrijas sistēma tika pieslēgta pie RD ITC telpu piekļuves kontroles mehānisma. Plaukostas biometrijas sistēma RD ITC darbiniekiem ļāva iekļūt telpās, izmantojot plaukostas asinsvadu biometrijas datus. Aprobācijas laikā sistēma parādīja, ka ir spējīga darboties un varētu tikt izmantota kā piekļuves kontroles iekārta, tomēr ir nepieciešami turpmāki pētījumi precizitātes paaugstināšanai, kā arī ergonomiskuma uzlabošanai.

Aprobācijas laikā Elektronikas un datorzinātņu institūta speciālisti aktīvi sadarbojās ar RD ITC darbiniekiem, lai uzlabotu tehnoloģijas darbību, novērtētu tās precizitāti un veiktu atbilstošas korekcijas.

Ņemot vērā aprobācijas rezultātus, uzskatām, ka plaukostas biometrijas sistēmai ir potenciāls pielietojums telpu piekļuves kontroles nodrošināšanai, un, ņemot vērā virkni priekšrocību salīdzinājumā ar RFID sistēmām, tās komercializācija var sniegt ieguldījumu tautsaimniecības attīstībā.

Centra direktors

Jelnieks 67037780

Ē. Zēgelis

Pielikums #6



SIA "UniHaus"
Brūņinieku 5/25, Rīga, LV-1001
Reģ. Nr. 40003931388
A/S Hansabanka, kods HABALV22
Konts: LV50HABA0551017155701

Atsauksme par sistēmas „AccGrid” eksperimentālā maketa aprobāciju

Esam aprobējuši Elektronikas un datorzinātņu institūta piedāvāto sensoru tīkla sistēmu „AccGrid” stājas monitorēšanas pielietojumam. Aprobācijas mērķis bija novērtēt iekārtas lietderīgumu ortopēdijas un fizioterapijas sfērā. Aprobācija tika veikta reālos apstākļos ārsta klātbūtnē, strādājot ar pusaudžu (13-15) vecuma pacientiem, kuriem ir izteikti stājas traucējumi.

Aprobācijas gaitā tika ieteikti virkne nepieciešamo uzlabojumu, kurus Elektronikas un datorzinātņu institūta darbinieki ņēma vērā, veicot modificēšanu. Piemēram, pēc SIA „UniHaus” speciālistu iniciatīvas sensoru tīkls tika iešūts sporta krekla ar rāvējslēdzēju, lai vizuāli sensori būtu mazāk pamanāmi un neradītu lietotājam psiholoģisku diskomfortu, kā arī, lai nodrošinātu sensoru ciešāku kontaktu ar ķermeni kustību laikā. Lai arī Elektronikas un datorzinātņu institūta izstrādātā lietotne ir parocīga un saprotama, ņemot vērā mūsu komentārus, tika mainīts 3D modeļa noformējums tā, lai tas mūsu jomas lietotājam būtu saprotamāks.

Vēlami atzīmēt, ka Institūta speciālists piedalījās arī fizioterapijas nodarbībās ar pacientiem, kura jau vairākus gadus valkā cieto korseti skoliozes korekcijai. Pēc fizioterapeites Alīnas Šilvānes ieteikumiem lietotnei tika pievienota jauna funkcija - iespēja fizioterapeitam saglabāt pacienta muguras formas attēlu (vai koordinātas) pirms un pēc nodarbības, tādā veidā salīdzinot izmaiņas, kas notiek tieši fizioterapijas nodarbības rezultātā.

Iekārtas potenciālais pielietojums var būt lietošana pacientam mājās patstāvīgi. To var izmantot pacienti, kuriem pēc cietās korsetes valkāšanas perioda ir pašiem, ar savu muskuļu spēku, jāiemācās noturēt mugurkauls pareizā pozīcijā. Kā arī pacientiem, kam muguras deformācija tiek ārstēta bez korsetes, bet uzdevums ir noturēt koriģētu muguras pozīciju.

Cita potenciālo lietotāju grupa ir bērni un jaunieši, kuriem ir novērojamas stājas deformācijas vai stājas vājums. Šī jauniešu grupa ar iekārtas palīdzību var iemācīties noturēt stāju pareizā pozīcijā.

Pasaules praksē pielieto ķermeņa 3D skenerus lai iegūtu muguras telpisku attēlu, tādēļ redzam, ka Elektronikas un datorzinātņu institūta piedāvātā sistēma var kļūt tiem par alternatīvu ar būtiski mazākām izmaksām. Minētā ierīce līdz ar to var tikt pielietota pacientu izmeklēšanā, lai iegūtu muguras formas attēlu/koordinātas, kā arī paveras iespēja pacientam to lietot mājās kā „vingrojumu komplektu”, lai kontrolētu vēlamo ķermeņa pozīciju. Iekārta ir inovatīva un tai ir potenciāls, lai nākotnē sniegtu piensumu Latvijas tautsaimniecībai.



Gundars Rusovs
Ārsts, tehniskais ortopēds
SIA UniHaus
18.10.2013

SIA "UniHaus"
Ārsts - tehniskais ortopēds
Gundars Rusovs
1-040168-12256

SIA "UniHaus"

Reg. Nr. 40003931388; A/S Hansabanka, kods: HABALV22; konts LV50HABA0551017155701
Brūņinieku iela 5/29, Rīga, LV-1001, tālr.: +371 67295272, fakss: 67295294
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Pielikums #7



REHABILITĀCIJAS CENTRS
MĒS ESAM LĪDZĀS
REHABILITATION CENTER

Lēdmanes iela 2, Rīga, LV-1039, Latvija, telefons/fakss (+371) 675 53196, e-pasts: brc@eriga.lv, www.edi.lv/mel

Rīgā, 2013. gada 16. oktobrī

Atsauksme par stājas monitoringa iekārtas „SmartWear” prototipa aprobācijas rezultātiem Rehabilitācijas centrā „Mēs esam līdzās”

Pēc Elektronikas un datorzinātņu institūta lūguma Rehabilitācijas centrs „Mēs esam līdzās” veica Valsts pētījumu programmas projekta Nr. 2 „Inovatīvas signālapstrādes tehnoloģijas viedu un efektīvu elektronisko sistēmu radīšanai” pētījumu rezultātā izveidotās stājas monitoringa eksperimentālās sistēmas „SmartWear” aprobāciju.

Aprobāciju notika reālos apstākļos, strādājot ar Rehabilitācijas centra pacientiem. Iekārta ir universāla tāpēc, ka tā ir iestrādāta ortozē ar izmēra regulēšanas iespējām, kā arī tāpēc, ka var kalibrēt (saglabāt datus) iekārtu katram pacientam individuāli.

Aprobācijas laikā notika aktīva sadarbība ar Elektronikas un datorzinātņu institūta speciālistiem tehnoloģijas uzlabošanā. Balstoties uz mūsu komentāriem, sensori tika pāršūti no testējamā krekla, medicīniskā ortozē. Tika veiktas korekcijas mobilās iekārtas lietojumprogrammā, paplašinot sistēmas iespējas, piemēram, papildus iespējai mobilā telefonā saglabāt informāciju par to, cik ilgi pacients izmanto iekārtu un cik procentus no šī laika perioda viņš atrodas definētajā stājas pozīcijā. Aprobācijas periodā tika izveidots daļējums mazākos diapazonos, veicot procentu aprēķinu katrā laika diapazonā, ar mērķi novērot pacienta progresu.

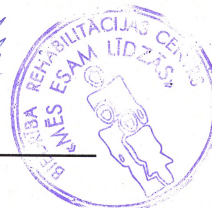
Tā kā Rehabilitācijas centrā ārstējas pacienti ar Cerebrālo Trieku, kuriem ir nepieciešams attīstīt rumpja un augšējo ekstremitāšu stabilitāti un mobilitāti, viņiem tiek piemēroti vingrojumi, kuros ir iesaistītas roku kustības. Sākotnējā variantā sistēma bija pārāk jutīga un sūtīja atgriezenisko saiti, kad pacients kustināja rokas, tāpēc tika veiktas izmaiņas kļūdas aprēķināšanas algoritmā, kā rezultātā kļūdas aprēķinam netiek ņemti dati no plecu daļas sensoriem (pacients var brīvāk kustināt rokas), taču sensoru datu vizualizēšana notiek pilnā mērā. Tika veiktas uzlabojumi arī stājas 3D modeļa attēlošanai. 3D modeļa krāsu diapazons tika pielāgots stājas deformācijām – pacients redz, kura muguras daļa būtu jāiztaisno, jo tā attēlā izmaina krāsu uz sarkanu. Jaunajā lietojumprogrammā ir ērtāk rotēt un pārskatīt 3D modeli.

Aprobācijas laikā sistēma „SmartWear” ir parādījusi, ka tā ir noderīga darbam ar bērniem un jauniešiem, kuriem ir rumpja muskulatūras distonija vai ir novērojami stājas traucējumi. Šāda veida iekārtas potenciāli var tikt izmantotas rehabilitācijas medicīnā neiroloģisku un ortopēdisku saslimšanu gadījumos. Rehabilitācijas centra kolektīvs uzskata, ka ir mērķtiecīgi un lietderīgi turpināt šīs tehnoloģijas attīstību konkrētu produktu prototipu izveidē ar tālāku mērķi komerciāliem pielietojumiem, jo šobrīd medicīnas iekārtu tirgū iekārtai atbilstošā cenu kategorijā analogus nesaskatām.

Ņemot vērā aprobācijas rezultātus, uzskatām, ka stājas monitoringa sistēmai „SmartWear” ir potenciāls pielietojums rehabilitācijas medicīnā, un tās komercializācija dos ieguldījumu tautsaimniecības attīstībā.

Andra Greitāne
Rehabilitācijas centra „Mēs esam līdzās” valdes priekšsēdētāja
Sertificēts ārsts rehabilitologs

Biedrība "Rehabilitācijas centrs *Mēs esam līdzās*" Riekstu iela 12-57, LV-1055, Reg.Nr. 40008006641



Pielikums #8



ATSAUKSME

2013.gada 21.oktobris, Rīga

Mūsu uzņēmums sadarbojās ar RTU Transporta elektronikas un telemātikas katedru komunikācijas sistēmas prototipa aprobācijā reāliem apstākļiem pietuvinātos scenārijos, kas saistīti ar mobilo objektu vietas noteikšanu ar augstu precizitāti, kā arī bezvadu datu apmaiņu starp kustīgiem objektiem un attālinātiem serveriem. Sistēma tika uzstādīta arī uz mūsu uzņēmuma automašīnas un parādīja augstu precizitāti un liela apjoma datu apmaiņas iespējas. Uzskatām, ka Valsts pētījumu programmas „Inovāciju daudzfunkcionālo materiālu, signālapstrādes un informātikas tehnoloģiju izstrāde konkurētspējīgiem zinātņu ietilpīgiem produktiem”, Projekta Nr. 2 „Inovācija signālapstrādes tehnoloģijas viedu un efektīvu elektronisko sistēmu radīšanai” ietvaros izstrādāto tehnoloģiju var izmantot mobilos objektos nosakot to atrašanās vietu ar augstu precizitāti.

SIA APU Genesis
Valdes loceklis



/Aigars Klūga/

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