RIGA TECHNICAL UNIVERSITY

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EXPERIMENTAL AND ANALYTICAL RESEARCH OF ROAD TRANSPORT MOBILE WIRELESS NETWORK

Summary of the promotion work

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RIGA TECHNICAL UNIVERSITY
Faculty of Electronics and Telecommunications
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PROMOTION WORK
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The promotion work for a doctor's degree of engineering sciences is to be defended publicly at 16:30, on October 10, 2013, at the Faculty of Electronics and Telecommunications of the Riga Technical University, 12 Azenes Str., in the lecture-room No. 210.

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CONFIRMATION

I confirm that the work contained in the Dissertation submitted by me to Riga Technical University for the Doctor's Degree in Engineering is my own original work and has not previously been submitted by me for a degree at this or any other University.

Janis Jansons ……………………………. (Signature)

Date: ………………………

This promotion work is written in the Latvian language. It contains an Introduction, 4 Chapters, Conclusion, and Bibliography, 9 appendices, 50 Figures and illustrations, with the total number of 146 pages in total. The Bibliography has 154 titles.

GENERAL DESCRIPTION OF THE WORK

Topicality of the subject matter

To address globally and locally road traffic growth and its effects, it is necessary to involve the high technology in the auto industry. As a result vehicles networking feasibility studies are up to date, and are considered the new challenges and opportunities in both science and auto industry.

The new initiative's main task is to create an intelligent transportation system (hereinafter - ITS), that using communication and information system solutions will be able to cut the negative impact of road transportation, to increase the transport efficiency and to provide passengers access to Internet resources.

Modern cellular systems theoretical download speed is up to 150Mbps, but in practice the data exchange is ten times lower. The cost of constantly using the communication systems of data exchange service is at least four times higher than the fixed Internet connections. Therefore, it is necessary mobile technology solutions in vehicular environment, which will be widely available as cellular networks, the cost will be fixed Internet connection price range and the throughput will be higher than almost modern cellular systems provide.

For vehicle networking is set up an international standard - IEEE802.11p [2], which is known as Wireless Access in Vehicular Environments. This standard has been created based on IEEE802.11a standard by reducing throughout two times and increasing distance up to four times for the primary be able to send short messages for road traffic safety and efficiency, while secondary to provide Internet access.

Whereas latest wireless local area network technological solutions such as IEEE802.11n[3] can ensure compatibility with previous standards, are widely available and equipment costs are 10-100 times lower than cellular networks. IEEE802.11g/n standard communication solutions theoretically supports up to 600Mbps throughput for both stationary and slow-moving users, but despite this fact, there are no limitations to investigate these standards in a vehicular environment.

The aim and tasks of the work

To research passenger data access quality improvement opportunities and their network infrastructure; to research the existence of maximum throughput of the road transport wireless local area network. To achieve this thesis aims is defined the following tasks:

- To analyse the vehicle networking trends and their impact on road traffic;
- To analyse the number of users depending on vehicle traffic in a wireless LAN area of operation;
- To study the existing road traffic analytical models, selecting a suitable model for further research of a mobile wireless LAN;

- To build up a test bed for a wireless LAN experiment in a vehicular environment;
- To research the wireless LAN behaviour in real time at various user movement speeds;
- Using possibilities of the queuing theory to set up vehicle networking analytical model, which is based on previously obtained approximate data from the vehicle mobility model and experimental research of wireless LAN performance in the small scale vehicular scenario;
- To analyse the vehicle networking computer simulation option to use a suitable simulation tool for further study of the mobile wireless LAN;
- To compare the results of vehicle wireless communications integrated analytical model with the results of computer simulation.

The **object** of research is the latest technologies of wireless LAN for interaction processes with highly mobile users. The research **subject** is vehicle movement parameters, a wireless LAN performance, as well as a solution to build up a low-cost and high-throughput communication network for road transport.

The methodology of research

In the study are used four types of research methods as follows:

- Literary Analysis: The required information was obtained from the IEEE, SCOPUS, Science Direct, ACM databases, as well as from other scientific informational sources like journals and books, conferences and online materials, and summarized textually and classifying in the tables;
- Practical experiments: In the test bed (airfield "Rumbula") was conducted experimental measurements of wireless LAN performance in a vehicular environment;
- Theoretical calculations: Based on the approximation of the practical measurement and the vehicle mobility model results using the queuing theory is created a model of mobile communication solution for road transport;
- Simulation experiments: With the proper computer simulation tool is set up vehicle networking model, the results are compared with theoretical calculations.

The results and scientific novelty of the research

Researching wireless LAN under vehicle moving characteristics is a broad term that includes several objects for studying. This work was carried out several experimental and analytical studies to evaluate wireless local area network basic performance in a vehicular environment. The scientific novelty of the promotion work consists as follows:

- Proved that the use of modern technology and the wide availability and low-cost equipment it is possible to create a mobile wireless LAN for road transport, that allows not only to ensure road transportation safety and effectiveness, but also passengers access to the Internet, mobile office and other services maintaining high quality of service parameters;
- Depending on experimental data, results of the analytical model and simulation tool is a proven fact that there is a wireless network solution that has been linked to the vehicle's movement dynamics and wireless LAN performance parameters, ensuring maximum throughput;
- Not only from promotion work experiments and analytical results, but also from the recent publications have shown that in the mobile wireless LAN exist traffic with high burst and falls;
- Depending on the major recent publications were identified effective analysis tool (i.e.Estinet). The based on this tool was created simulator of the wireless LAN in a vehicular environment, the results are compared with experimental and analytical results;
- A simulation model is created, which can be used in further studies, providing the necessary result of vehicle movement and wireless LAN behaviour of highly mobile users' service.

Practical value of the work

According the aims of the promotion work the practical value is as follows:

- Developed the analytical model of the mobile wireless LAN in a vehicular environment;
- Developed the simulator of the mobile wireless LAN in the vehicle environment that is based on the computer program Estinet for mobile wireless communication network design and feasibility studies;
- Development of the methodology that analysis may effectively and accurately evaluate the performance of the wireless LAN linking it to a specific environment.

The theses to be defended:

- that using commercial off the shelf (COTS) IEEE802.11g/n standard wireless LAN equipment with a wireless distribution system (WDS) shows enough performance in a vehicular environment (V2I), providing passengers access to Internet resources;
- that in an environment with low signal reflections movement of the vehicle caused as a result inter-carrier interference (ICI) IEEE802.11g/n standard used modulation constellation error vector magnitude (EVM) are not exceed the limits imposed by the standard;

- that between the vehicle speed and IEEE802.11g/n standard wireless local area network parameters are derived binding expressions with non-linear nature;
- that of being integrated into the simulation tools with feedback that can provide road mobile network simulation with a single sequence of events EstiNet enables faster and more accurate verification of wireless local area network behaviours vehicular environment (V2I);
- that the wireless LAN user can achieve a maximum throughput value, if the vehicle speed is in the range of movement 70-100km/h, proving the fact by mathematical modelling and practical experiments.

Approbation of the results of the research

The main results of the promotion work are presented at 10 international and local scientific conferences as follows:

1. RTU 50. Student Scientific and Technical Conference, Riga, Latvia, 2009.;
2. Baltic Conference „Advanced Topics in Telecommunication", Rostock, Germany - Tartu, Estonia, 2009.;
3. The 52nd International Scientific Conference of Riga Technical University: Section "Electronics, Telecommunications and eSociety", Riga, Latvia, 2011.;
4. The 15th International Conference ELECTRONICS 2011, Kaunas and Vilnius, Lithuania, 2011.;
5. The 13th Biennial Baltic Electronics Conference (BEC2012), Tallinn, Estonia, 2012.;
6. The 2nd International Conference on Digital Information Processing and Communications (ICDIPC2012), Klaipeda, Lithuania, 2012.;
7. The 2nd Baltic Congress on Future Internet Communications (BCFIC 2012), Vilnius, Lithuania, 2012.;
8. The 7th International Conference on Electrical and Control Technologies, Kaunas, Vilnius, Lithuania, 2012.;
9. The 16th International Conference ELECTRONICS 2012, Palanga, Lithuania, 2012.;
10. The 27th IEEE International Conference on Advanced Information Networking and Applications, Barcelona, Spain, 2013.;
11. The International Conference on Technological Advances in Electrical, Electronics and Computer Engineering, Konya, Turkey, 2013.

The results of the promotion work were used for the realization of two Latvian scientific **research projects**:

1. National research program: INFORMATION TECHNOLOGY RESEARCH BASE 5th project "New electronic communication technologies"
2. National research program: DEVELOPMENT OF INNOVATIVE MULTIFUNCTIONAL MATERIALS, SIGNAL PROCESSING AND INFORMATION TECHNOLOGIES FOR COMPETITIVE KNOWLEDGE INTENSIVE PRODUCTS (IMIS) Project No. 2 “Innovative signal processing technologies for development of intelligent and efficient electronic systems”

The research results of promotion work were shown **7** publications in scientific journals, **9** publications in the full-text conference proceedings and **3** publications in the conference books of abstracts:

1) Jansons J., Ipatovs A., Pētersons E. Estimation of Doppler Shift for IEEE 802.11g Standard // Proceeding of Baltic Conference "Advanced Topics in Telecommunication". - Rostock, Germany: University of Rostock publishing house, 2009. - pp.73-82;
2) Jansons J. IEEE 802.11n Evaluation in Vehicular Communication Systems // Abstracts of the 52nd International Scientific Conference of Riga Technical University: Section "Electronics, Telecommunications and eSociety", Latvia, Riga, 13.-14. October, 2011. - pp.-26;
3) Jansons J., Pētersons E., Ipatovs A. Model for Wireless Base Station Goodput Evaluation in Vehicular Communication Systems // Electronics and Electrical Engineering. Nr.5(111) . - , : Technologija, 2011. – pp.19-22;
4) Bogdanovs N., Jansons J., Ipatovs A. Parameter Estimation for Model of Vehicular Network // 52nd International Scientific Conference of Riga Technical University , Latvija, Riga, 13.-14. October, 2011. - pp.-26;
5) Bogdanovs N., Ipatovs A., Jansons J. Research of a 2-layer Closed Vehicular Network // The Scientific Journal of Riga Technical University. 7th ser., Telecommunications and Electronics. – vol. 11. (2011), - pp. 34-40;
6) Jansons J., Pētersons E., Bogdanovs N. A Measurement Study of WLAN Link Recovery Using WDS in a Vehicular Environment // Proceedings of the 13th Biennial Baltic Electronics Conference (BEC2012), Estonia, Tallinn, 3.-5. October, 2012. - pp.173-174;
7) Jansons J., Barancevs A., Pētersons E., Bogdanovs N. IEEE802.11a Standard Performance in Mobile Environment // International Journal on New Computer Architectures and Their Applications. - Vol.2, No.3. (2012). - pp.497-500;
8) Jansons J., Doriņš T. Analyzing IEEE 802.11n Standard: Outdoor Performance // The Second International Conference on Digital Information Processing and Communications (ICDIPC2012), Lithuania, Klaipeda, 10.-12. July, 2012. - pp.26-30;

9) Jansons J., Doriņš T., Bogdanovs N. Analyzing the Basic Performance of IEEE802.11g/n // International Journal on New Computer Architectures and Their Applications. - Vol.2, No.3. (2012). - pp.465-470;
10) Jansons J. Goodput Analysis in Short Range Vehicle Network depends on Auto Traffic Parameters // The Second International Conference on Digital Information Processing and Communications (ICDIPC2012) Lithuania, Klaipeda, 10.-12. July, 2012. - pp.22-25;
11) Jansons J., Pētersons E., Bogdanovs N. IEEE802.11n Standard's Capability to Support Wireless Device in Vehicular Environment // Electrical and Control Technologies (ECT-2012): Proceeding of the 7th International Conference , Lithuania, Kaunas, 3.-4. May, 2012. - pp. 44-47;
12) Bogdanovs N., Pētersons E., Jansons J. Modeling Results of Vehicular Network for File Transfer // Proceeding of the 7th International Conference on Electrical and Control Technologies, Lithuania, Kaunas, 3.-4. May, 2012. - pp.60-63;
13) Jansons J., Barancevs A. Using Wireless Networking for Vehicular Environment: IEEE 802.11a Standard Performance // The Second International Conference on Digital Information Processing and Communications (ICDIPC2012) , Lithuania, Klaipeda, 10.-12. July, 2012. - pp.5-9;
14) Jansons J., Pētersons E., Bogdanovs N. Vehicle-To-Infrastructure Communication Based on 802.11n Wireless Local Area Network Technology // Proceeding of the 2nd Baltic Congress on Future Internet Communications (BCFIC 2012), Lithuania, Vilnius, 25.-27. April, 2012. - pp. 26-31;
15) Jansons J., Bogdanovs N., Ipatovs A. Vehicle-to-Infrastructure Communication Based on IEEE 802.11g // International Journal of Digital Information and Wireless Communications. - Vol.2, No.1. (2012). - pp.858-862;
16) Jansons, J., Pētersons, E., Bogdanovs, N. Analyses and Evaluation of Wireless Local Area Network in Vehicular Mobility Scenarios. Electronics and Electrical Engineering, 2013, Vol.19, No.2, - pp.97.-100. e-ISSN 20295731. ISSN 13921215;
17) Bogdanovs, N., Pētersons, E., Jansons, J. Two Layer Model for Performance Evolution of V2I Network. ELEKTRONIKA IR ELEKTROTECHNIKA, 2013, Vol.19, No.3, - pp. 98-101. ISSN 13921215;
18) Jansons J., Pētersons E., Bogdanovs N. WiFi for Vehicular Communication Systems // IEEE 27th International Conference on Advanced Information Networking and Applications Workshops, Spānija, Barselona, 25.-28. March, 2013. – pp. 425-430;
19) Bogdanovs, N., Pētersons, E., Jansons, J. Simulation to Evaluate Performance of Two Layer Vehicular Networks. No: The International Conference on Technological Advances in

Electrical, Electronics and Computer Engineering (TAEECE2013), Turkey, Konya, 9.-11. May, 2013. Konya: Mevlana University, 2013, 548.-553.pp. ISBN 9781467356114.

The volume and structure of the work

The volume of the promotion work is 146 pages with appendices. The work consists of six chapters, where the first chapter is an introduction and the sixth chapter is the main conclusion, bibliography and nine appendices. Introduction is substantiated the topicality of the research and identifies the thesis research directions and challenges.

In Chapter 1, the growing problem of traffic flow and the achievements and challenges of intelligent transport system, as well related works and problematic in this research area are analysed. Apart from this chapter formulate the aim and tasks of the promotion work, its scientific novelty, the theses to be defended. In Chapter 2, the characteristics of road traffic are analysed to get in analytical way the number of vehicles to the velocity. In Chapter 3, describe mobile wireless network solutions for vehicular networking and comparison is given, to prove a wireless LAN advantages over other mobile communication solutions. In Chapter 4, outline experimental scenarios, the analytical model and their results are presented to evaluate wireless LAN performance according to the vehicle movement parameters. In Chapter 5, the possibilities of vehicular networking computer simulation are analysed and the simulation results are presented to compare them with experimental and analytical results. In the summary, the main conclusions and recommendations for future research tasks and direction are presented to extend this research.

DETAILED DESCRIPTION OF THE WORK'S CHAPTERS

Chapter 1

Vehicle flow increases continuously, for example between 2000 and 2008 in European countries vehicle flow increased 7% and globally is estimated that up to year 2035 in the world as shown in Figure 1.1., will double the number of cars and will reach 1,7 billion units[7]. This increase has been formed due to fuel price, extension of road infrastructure and weak environmental position.

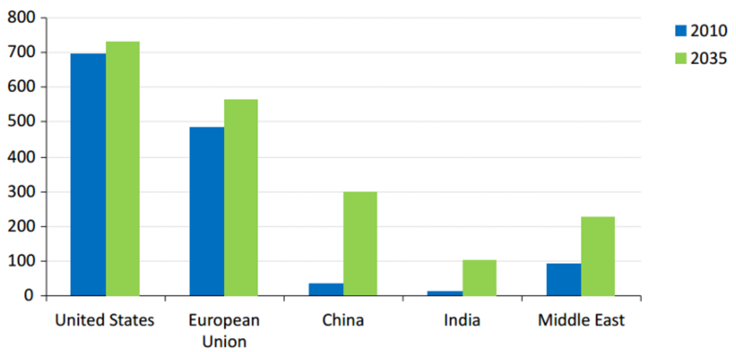

Figure 1.1. Vehicles per 1,000 people[8]

This development trend in vehicle environments increases road congestion and traffic accidents, as well as travel time, transport costs and emissions.

Vehicle use is a daily necessity to get from the place of residence to the workplace. In U.S. daily every person average needs to spend 48.6 minutes to go to work and back[7]. In contrast, Canadian statistics show everyday worker movement to / from the job use an average 63 minutes[8], but due to congestion in the same way employees spend extra 18 days a year [9].

Every year around the world in road traffic accidents die many citizens. European countries in the year 2009 were recorded 34,817 cases of fatalities [10]. Other hand, in the same year in the U.S. from 5.5 million road traffic accidents are 38,808 fatalities [11].

Future road transport system shall not be based only on the road structures and the existing infrastructure, but will also be highly dependent on several integrated technology innovations. This approach will allow the use of existing road capacity at maximum load. Already since 1990 are being developed intellectual transport systems (ITS), which are a broad conceptual solution and by its nature is defined as those systems utilizing synergistic technologies and systems engineering concepts to develop and improve transportation systems of all kinds [13]. ITS allows road traffic to be predictable, dynamic and flexible, that can be adapted to existing conditions. ITS like air traffic control and management systems for road environment will be based on specific network sensors, micro-controllers and wireless mobile communications systems, with the aim of collecting and processing information centrally for road traffic control and management, as well as decentralized response to an immediate change in road traffic dynamics.

The main goal of ITS is the vehicle environment using communication and information systems to establish cooperation among vehicles, pedestrians and road infrastructure to improve road safety, transport efficiency and comfort levels so achieving ecological, social and economic benefits.

Information on road safety, traffic flow, speed of movement, mileage and other service information in the short report format for the amount of 160 characters. For this transfer of information is necessary a safe, secure and stable communication, to be able the vehicle driver to decide within 2-3 seconds. Mobile communication technology solutions that have been created (including a GSM / UMTS) and it is planned to set up (i.e. WAVE), is/shall be able to offer such information exchange.

The increasing need to travel by road passengers will spend more time in vehicles. Need access to data networks increase due passengers will have the desire to spend more appropriate transportation time through the mobile network option to access to the Internet and remote network resources. The passenger is requested for the exchange of information going beyond the information that is exchanged on road safety and effectiveness.

To offer in ITS access to Internet resources, such information exchange in mobile environments with speeds up to 100 km/h and above, is required for mobile communication solutions with throughput that is higher than it is able to provide with existing mobile communications solutions (including GSM / UMTS, WiMax ect.).

Wireless LAN research in vehicular environment is up to date since 2002 and is considered to be a new challenge for science and industry worldwide. Despite the fact that this problem has already realized several years ago, research continues and is generating new theoretical and practical results, which are published in international journals and electronic databases. Authors [26], [31-36] have reported studies on wireless network performance in ad-hoc mode with two and more users, but the wireless access point throughput in infrastructure mode is studied by a mobile user or ad-hoc mode with two vehicles that not sufficient to give a complete picture of wireless LAN performance with multiple mobile users.

Chapter 2

In research of road transport mobile wireless network it is important to be aware of the number of users and their speed at which mobile users move the network node area of operation.

The main tasks in the road transport sector studies are to analyse the interaction between vehicles, their management and road infrastructure. Vehicle dynamics is a complex process determined by human perception and decision-making in different situations on the road.

This chapter will address the vehicle dynamics principles and movement of cars analytical models, identifying critical parameters of vehicle movement and to find the model which represents the closest vehicle movement.

Vehicle dynamics have begun to describe analytically since the last century. Br. Greenshields [50] published the first study, after performing a number of measurements with photographic methodology established correlations between the traffic flow, density and speed:

$$q = \rho \times v \, , \tag{2.1}$$

where q – flow, vehicles / hour;
ρ - density, vehicles / km;
v – speed, km / h.

Greenshields according to the initial assumptions, came to the following linear velocity and density relationships:

$$v(\rho) = v_{max}(1 - \frac{\rho}{\rho_{sa}}), \tag{2.2}$$

where v (ρ) - speed density function, km/h;
v_{max} - maximum speed, km/h;
ρ – density, vehicle units/km;
ρ_{sa}-vehicle density in a traffic jam, vehicles / km.

Based on the above mentioned empirical results, as well as other recent findings [51], the traffic flow is divided into three states - free, synchronous and congestion flow.

Congestion flow falls to zero, you can end up to a maximum density (ρ_{max}) and it depends on the vehicle length (l), the spacing between vehicles (s_0) and observed road segment length (d).The condition that the spacing between the observed vehicles are identical and vehicle dimensions are identical, then the maximum amount of vehicles can be expressed as follows:

$$\rho_{max} = \frac{d}{(s_0 + l)}\,, \tag{2.3}$$

where d - the observed road segment length, m;
s_0 - the gap between vehicles, m;
l - length of vehicle, m.

Taking into account density of the maximum and minimum values Greenshields speed-density relationships were identified basic problems the maximum and minimum speed cannot be achieved at the proper density. To solve this problem, Greenshields expression was extended with a number of conditions and constants, as well as with maximum and minimum values:

$$v(\rho) = \begin{cases} v_{min}\ , ja\ \rho < \rho_{min} \\ v_{min} + (v_{bri} - v_{min})\left(1 - \left(\frac{\rho - \rho_{min}}{\rho_{max} - \rho_{min}}\right)^a\right)^b , ja\ \rho \in [\rho_{min}, \rho_{max}]\ , \\ v_{min}, ja\ \rho > \rho_{max} \end{cases} \tag{2.4}$$

where v_{min} - the minimum speed, km/h;
$v_{bri} = v_{max}$ - the maximum speed, km/h;
ρ_{min} - minimum density, vehicles/km;
ρ_{max} - maximum density, vehicles/km;
a, b - different model parameters.

This basic idea is used in the latest vehicle traffic models, depending on the vehicle motion parameters to simulate realistic vehicle dynamics.

Since the 1950s, researchers have begun to describe the physical changes in the traffic flow on the macroscopic and microscopic model's principle. Several empirical traffic flow models were based on fundamental properties and did not have enough details to completely evaluate the traffic flow phenomena.

Only in 1990 the major scientific breakthroughs due to increased traffic modelling analysis, which was possible based on the better vehicle traffic data and high computing capacity. At present, traffic flow models are widely used to assess the state of traffic to prove expanding the road network architectures as well as ITS system development, testing and optimization.

Traffic flow models to assess the network performance mainly use two models - macroscopic and microscopic. In addition to the distribution patterns may also include mesoscopic models that is depending on the combination of these two models. In this model, each individual vehicle is moving according to the laws of dynamics defined by the macroscopic values [53].

In contrast Krauss and the IDM model results reflect the road traffic, which is more realistic. Compared Krauss model with IDM model - Krauss model simulates the movement of a much more rapid change than the IDM model.

In order to assess the amount of vehicles depending on vehicle speed is further used expression of the IDM author's work [64] as follows:

$$v(\rho) = \min[v_{des}, \frac{\rho_{max}-\rho}{T\rho_{max}\rho}], \tag{2.17}$$

where v_{des} - selected new desirable speed, km / h;
T - safe time gap between vehicles, h;
ρ_{max} - maximum density, vehicles / km;
ρ - the observed density, vehicles/ km.

Under condition, if the vehicle's new desirable speed is constant and is defined as the maximum (v = 120km/h), then depending on the safe velocity and the observed vehicle density changes as illustrated in Figure 2.7. with a dark line is marked change in the average size of the curve, which leads to a closer relationship between the velocity and the number of vehicles. As has been mentioned, the road vehicle travelling at a high speed tends to increase the distance to the vehicle in front. Other hand distance among the cars is reduced at lower speed. Safe time gap to the vehicle in front can be in the range [0.6s <T <3s]. Shorter time of 0.6 seconds, in several European countries is considered as the road traffic offence, but 2-3 seconds is recommended.

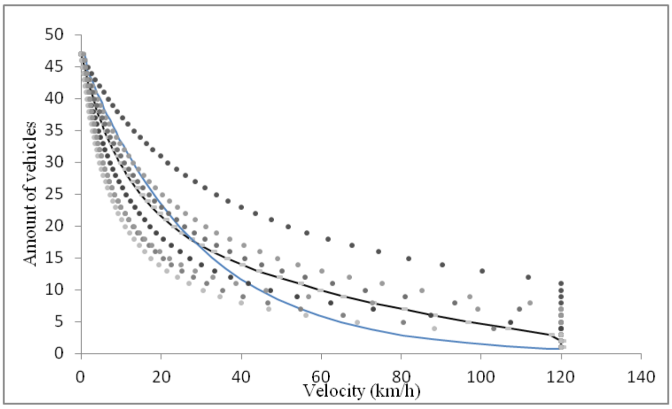

Figure 2.7. Density vs Velocity

The approximation of the IDM model results provided that the distance (d) is 300 m and the maximum speed is 120km/h, the correlation was obtained between the amount of vehicles and the speed, and it is as follows:

$$N(v) \approx \rho_{max} \cdot e^{-0.0349v}, \tag{2.19}$$

where N (v) - depending on the number of vehicle velocity, vehicles / 300m;
ρ_{max} - maximum density, vehicles/ 300m.

Calculate the resulting linear expressions closeness measure of the degree or the correlation coefficient (r) with the following expression:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})\cdot(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\cdot\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}, \quad (2.20)$$

where x_i – x sample the i-th value;
y_i – y sample the i-th value;
n – amount of x,y samples;
$\bar{x}, \bar{y}$ - x,y samples arithmetic mean.

The resulting relationship standard deviation or error (δ) can be expressed as follows:

$$\delta = \frac{1-r^2}{\sqrt{n-1}}, \quad (2.21)$$

where r - the correlation coefficient;
n - number of samples.

The resulting expression(2.19) means square error is 0,00264 and results can be considered reliable (with a probability of 95%), because the correlation coefficient r = 0.990522 is greater than the critical threshold of correlation coefficient $r_{0,05\ 43,}$ according table data [65].

A distance of 300 meters is not chosen randomly, but it is taken as a basis, the average distance can serve a wireless local area network access node.

In this chapter the traffic models have been analysed and compared, leading to the appropriate model for further analysis. From IDM approximate results were obtained easily handled expression, which will make it possible to determine the number of users on the observed road section.

Chapter 3

In this section are considered mobile wireless networks, which are being planned or are being used in ITS systems. Focuses on wireless mobile network technologies, which are compared with a wireless local area network. The question remains why wireless LAN?

One of wireless metropolitan area networks technologies are the standard IEEE 802.16 or WiMax, which is a broadband wireless communication system with packet-switched service for stationary, portable and mobile access. The WiMax base station can provide up to 50 km of coverage and up to 70 Mbps data throughput, but lack of technology is their node cost and low usage because it is not yet integrated into the widely used communications equipment such as mobile phones, tablet computers and portable computers.

Similar to WiMax, cellular networks are able to provide for mobile user permanent communication connection, while the wireless local area networks are being used for temporary connection. But compared with the cost and network throughput, cellular networks, maintenance and modernization require large investments, as well as the cellular network subscriber data service costs are higher than the fixed Internet connections. One GSM and UMTS base station coverage area outside the city can provide up to 15 km, where the antenna is located at least 130 meters in height. With such coverage of cellular network base station can provide access to many users, resulting it is necessary to share network resources among multiple users decreasing for each individual user's internet (data transmission) service quality.

The latest cellular network technology (4G) base stations are to be placed closer (on average 0.6-1.4km) to ensure data throughput (up to 150Mbps), but the practical measurements show a relatively low data rate. According to tab. 3.1. data, the U.S. cellular networks with higher average scores measuring the ability to provide only 6.44 Mbps. Similar results were obtained when measuring at the "Rumbula" airfield, as illustrated in Fig.3.1., where a mobile user can reach 5,307 Mbps average throughput.

Table 3.1.

Measurement results in 13 freely selected U.S. cities[67]

Mobile operators	Average download data rate (Mbps)	Average upload data rate(Mbps)	Latency(ms)
Verizon	6.44	5.00	128
T-Mobile	2.83	0.85	173
AT&T	2.48	1.05	169
Spring	2.15	0.61	214

In contrast, wireless local area networks (WLAN) operating short distance (300 meters), but provides a high throughput of up to 600 Mbps and capable of supporting several hundred active slow moving and stationary users.

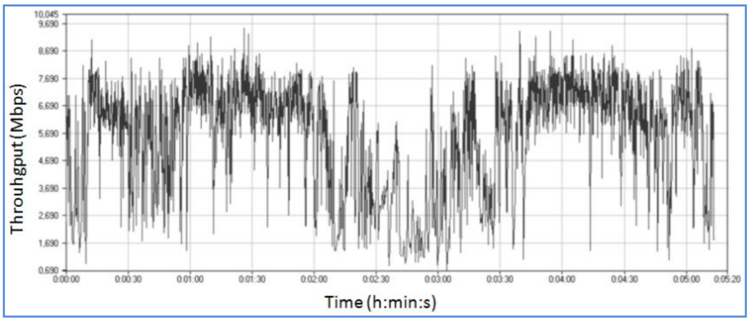

Figure 3.1. 4G network performance test results

In the future, the introduction of any new communication system, there are always a number of issues that are essential to making important decisions. If there is an expressed clear need and determined requirements of the communication system, one of the most pressing issues is the system implementation and maintenance costs.

WLAN costs are known and can be found by visiting the nearest computer store or the Internet, but GSM/UMTS and WiMAX costs are not entirely available.The cost estimation is summarized in table 3.2., taking into account the estimated cost of local publication and other author's work[73-85].

Table 3.2.

GSM/UMTS,WiMAX and WiFi comparison with the cost of one km length of the road section

NAME	ESTIMATED COST (LVL)		
	GSM/UMTS (1xBS)	WiMAX (1xBS)	WiFi (7xAP)
Base station (BS) placement construction	40 000	-	-
BS node/ AP	42 000	30 000	3 150
BS controller	3 500	-	-
Network Management System (30%)	25 650	-	-
Frequency license fees	303 100	17 500	-
Installation costs	5 550	1 600	1 050
Development costs total	416 300	49 100	4 200
Electricity consumption per year (<3%)	2 500	900	126
Maintenance work per year (<5%)	5 000	1 500	210
Equipment disposition rental per year	2 000	1 420	315
Maintenance costs total	9 500	3 820	651
The total cost for one year	425 800	52 920	4 851
The total cost in percentage	100 %	12.4%	1.1%
Theoretical throughput (Mbps)	up to 150	up to 128	up to 600

To develop a mobile wireless network for road transport one kilometre long section of the road with the wireless LAN solution and the one year maintenance, cost will be at least 90 times lower than the GSM/UMTS and 11 times lower than the WiMAX communications solutions, but the wireless LAN network throughput following the technical data is at least four times higher than comparable technologies. According to the analysis advantages of the wireless LAN relative to other widely used mobile technologies are significant to study this mobile communication technology in the vehicle environment.

Chapter 4

Wireless LAN performance analysis in vehicle environment is a complex undertaking. To realize the practical measurements in such an environment is complex and requires the involvement of a large resource (i.e. test area, vehicle, testers, equipments ect). Analysis of individual network characteristics it is possible to obtain an approximation of the results. As well as doing small practical measurements can be initially concluded on the suitability of the wireless network in vehicle environment and the approximated results can be used in analytical models to assess performance of road transport mobile wireless network.

Vehicle environment since the previous analysis is closely related to the speed of the vehicle and traffic flow, which determines the number of customers and potential location or time spent in the operating range of a wireless network access point. Mobility is one of the main reasons for the reduction in the throughput of wireless networks[31], [32], [38], that may result from the communication system resistance to multipath propagation and Doppler effects, as well as design of wireless LAN (i.e. handover, rate adaptation method, the channel resources allocation among users ect).

In this part evaluates the wireless access point performance depending on the vehicle motion parameters which determine the number of mobile terminals within range of wireless access point. Wireless access point throughput evaluation is performed using real measurements from a small-scale road traffic scenario to integrate them into the analytical model of large-scale road traffic scenario.

Practical measurements were made using IEEE802.11g/n wireless LAN standard to further in the RTU TeTk laboratory analyse and evaluate the throughput of wireless LAN, the data rate adaptation depending on the distance, the impact of the Doppler effect and handover effect using a wireless distribution system (WDS) technology. Certain experimental measurements were taken to determine the impact on the overall throughput depending on the amount of stationary user's, as well as assessing network resource sharing among users.

Test bed:

On "Rumbula" airfield was conducted several practical wireless LAN performance measurements in a vehicle environment with one mobile user. As shown in Fig. 4.1. the runway is 1,500 meters long and suitable for practical tests as it situate in a remote area and there is a low-emitting activity in a wireless LAN frequency band. Side of the runway is cleared at least 150 meters in width, and there is not radio signal reflecting objects.

Figure 4.1. Test bed "Rumbula" airfield runway

Test Equipment and Tools:

WLAN equipments were selected based on technical parameters and costs to carry out the measurement under the pre-arranged scenarios. Measurements were used low-cost devices (i.e. LVL 20 range) and software (IxChariot program v.6.7) available for measuring and collecting measurement results. Wireless WLAN studying were used IEEE802.11b/g standard access points Linksys (WRT54GL v.1.1) and IEEE802.11n standard access points ASUS (RT-N16 v.1.0.0.6).

Thanks to the cooperation with Rohde & Schwarz Denmark Latvian company representative was possible to use WLAN high precision signal generator and spectrum and signal analyzer.

The Experimental Scenarios:

For practical WLAN performance measurements were previously prepared scenarios as illustrated Fig. 4.7. to measure goodput (application level throughput) of wireless LAN at different test vehicle speed. The test vehicle was initially placed outside the operational zone of the wireless LAN access point the vehicle has the possibility before entering the zone to reach the required speed.

All three WLAN access points were connected to each other over a wireless network using a wireless distribution system (WDS) technology. This system provides interconnection between access point to expand WLAN range with a wireless solution and at the same time provides a wireless connection to a mobile device. Using this system allows mobile devices to switch from one WLAN access point to another without losing the connection.

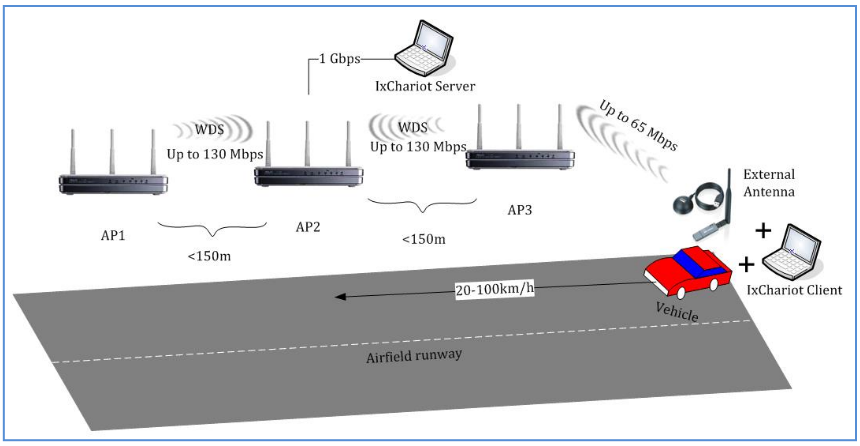

Figure 4.7. IEEE802.11n WLAN experimental scenario

Doppler effect measurements were made using a signal generator SMVBV100A and signal analyzer FSV-K91 as illustrated in Fig. 4.9.

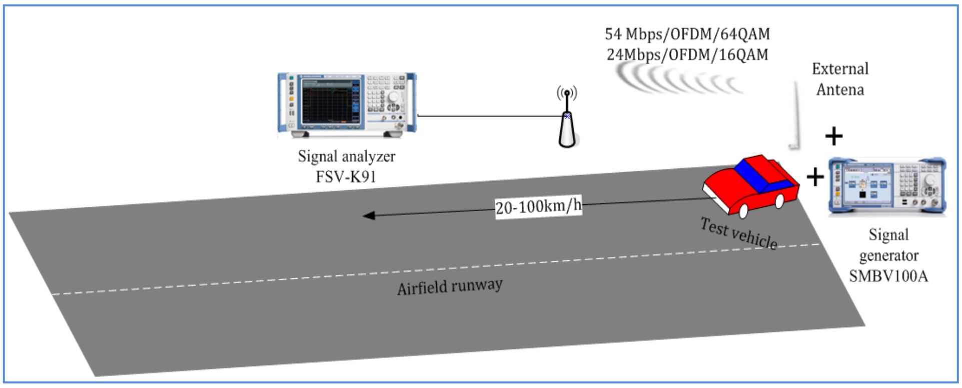

Figure 4.9. Doppler effect measurement scenario

As shown in Fig. 4.10. signal generator was placed in the test vehicle, and the electricity supply was provided by a continuous power supply equipment APC RS1000 VA. Signal Analyzer was deployed in a stationary environment at the edge of the runway and connected through the APC Back-UPS RS 500 to Honda INVERTER EU 20 generator for continuous power supply. Signal analyzer antenna Eusso UWA2610-ID attached to the tripod base and connected to a coaxial cable to the signal analyzer. The receiving antenna height was adapted for transmitting antenna height to the maximum direct vision, and to avoid blocking the signal. The methodology of measurement was made according to generally accepted testing standards [90].

Figure 4.10. Experimental measurement equipment and their location during the tests

As depicted in Figure 4.11., obtained with the experimental results, as well as having other authors' conclusions [29], [31] [32] [38], it can be justified that increased movement speed wireless LAN goodput decreases. Wireless LAN based on IEEE 802.11 g standard goodput decrease average 65% at speed from 20 to 100 km/h, but using the IEEE80.11n standard goodput reductions are 30%.

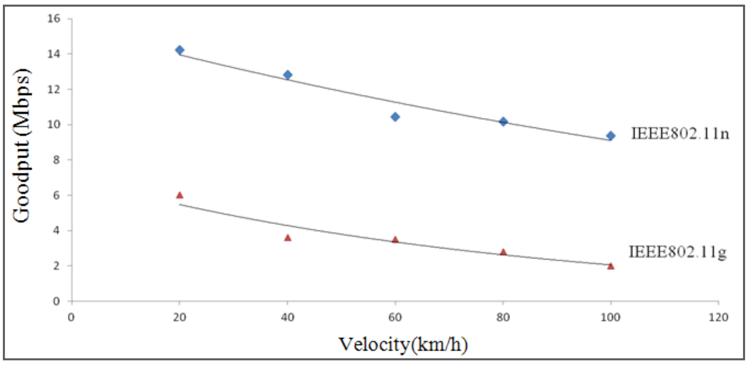

Figure. 4.11. WLAN technology performance comparison in mobile environment

By approximating the results between the WLAN throughput and average vehicle speeds can be obtained easily managed expression:

$$\mu_{IEEE802.11n} = 15{,}524e^{-0{,}005v}, ja\ 20 \leq v \geq 100, \quad (4.1)$$

$$\mu_{IEEE802.11g} = 6{,}9881e^{-0{,}012v}, ja\ 20 \leq v \geq 100, \quad (4.2)$$

where in both cases v - vehicle speed in km/h;
μ - WLAN throughput Mbps.

The calculation of the expression (2.20), the results of approximation of expression have a strong correlation (i.e. 0.7 <| r | <0.99) and can be considered reliable (with a probability of 95%), the correlation coefficient r = 0.9317 is greater than the critical threshold of correlation coefficient [68] $r_{0.05,5}$.

Doppler effect impact on the wireless LAN can be observed when moving at speeds up to 120km/h and can increase the frequency offset error vector magnitude value, which can decrease the goodput. As shown in Fig. 4.13., error vector magnitude value at all velocities are constant, and the average it is 4%. This deviation does not exceed the standard defined error vector magnitude value limit.

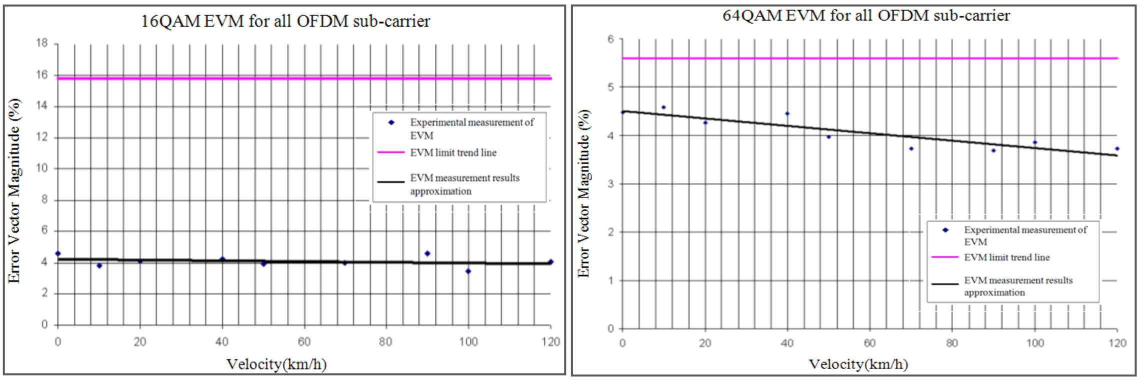

Figure 4.13. Doppler effect results for 16 and 64-QAM modulation

While moving at speeds up to 120 km/h, the classical Doppler shift does not impact on the OFDM [92], and such modulation can also be applied to a higher velocity of movement as such reflected in the experimental results of other authors [93]. As a result, it can be concluded that the Doppler effect on the WLAN performance is minimal.

Using the approximated practical and theoretical results and integrating them into the elements of queuing theory was created an analytical model based on the M/M/1//N queue. The use of such model in the feasibility study of the wireless network performance to give a basic idea of the WLAN throughput changes in vehicle environment is innovative in the academic environment because only a year ago a similar method of analysis the Chinese University researchers [102] reflected in their work.

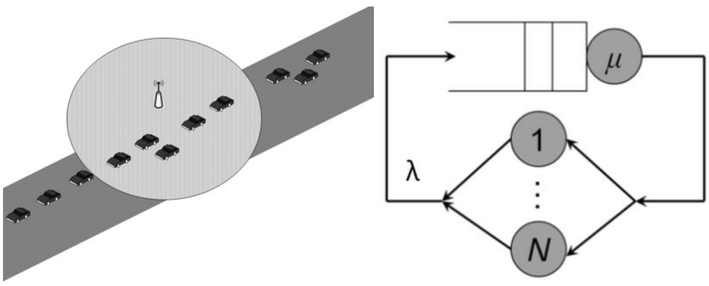

Figure 4.22. Conceptual and analytical model

To compare with the two wireless LAN standard throughputs, experimental results were used (ie, approximations (4.16) and (4.17)). In this analytical model, which is reflected in Figure 4.22., it is assumed that the communication system with one servicing wireless node or server, which has infinitely large buffer memory and is capable of supporting a limited number of users N(v), whose number varies depending on the vehicle velocity (i.e. the approximation (2.17)). Using M/M/1//N(v) queuing model, the average goodput for each individual mobile user can be estimated from the following equation:

$$goodput(v)_N = goodput(v) \cdot (1 - p_0) / N(v) , \tag{4.23}$$

where p_0 is the probability that the servicing system does not have any serviceable mobile user, and it is expressed as follows:

$$p_0 = \left[\sum_{j=0}^{N(v)} \frac{N(v)!}{(N(v) - j)!} \cdot \frac{\lambda}{\mu}^{j} \right]^{-1} , \tag{4.24}$$

where the next number j = 1,2,3 .... N (v);
μ - bit rate at which data transmission is occurring between stationary wireless nodes and individual mobile terminal;
λ - the incoming bit rate in the system.

Under condition that each vehicle is equipped with a wireless mobile wireless nodes by interpretation of the results it can be concluded that at lower vehicle speeds stationary access point services multiple mobile wireless nodes than at higher speeds. This means that network resources are shared among multiple users, which affects goodput of each individual user. With an increasing velocity of movement up to 50 km/h, goodput curve shows, as illustrated in Figure 4.23., that each individual mobile station bit stream doesn’t increase significantly. Such changes in the curve are due to the fact that the increasing velocity of movement decreases the overall throughput of the access point. Continuing to increase the velocity in the system reduce the number of mobile users, as a result at 100 km/h each mobile user's terminal can achieve maximum goodput. After reaching the peak throughput decreases in proportion to the maximum connection speed of the access point.

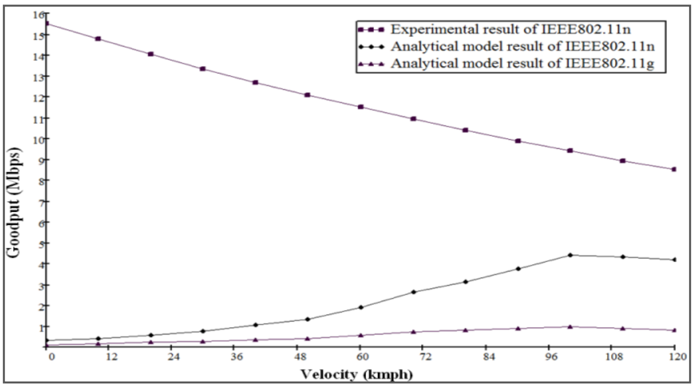

Figure 4.23. Goodput of mobile terminal depending on the velocity of movement

Expanding research can be avoided that there will be situations where not all vehicles will be equipped with wireless network access solutions, as well as the vehicle will be to not use the wireless access. Active mobile wireless terminal number within the total number of vehicles which are equipped with a wireless connection option, can be interpreted as the service penetration rate p. Telecommunication terminal penetration rate is the term commonly used in the telecommunications statistics to describe the number of active terminals (typically as a percentage) within a specific population. In this case, the population is described as the total number of vehicles which varies depending on the velocity of movement in the operation area of wireless access point.

As illustrated Figure 4.24., at low service penetration i.e. if 20% the maximum throughput can be achieved with velocity up to 70 km/h. Other hand increasing the spread of services for a situation that every second vehicle is fitted with an active mobile terminal, the maximum goodput of wireless network is decreasing up to one and half time and it is possible to reach by the moving at a velocity of 90km/h. With maximum penetration service rate the individual user goodput increases proportionally reaching a maximum value by velocity at 100 km/h.

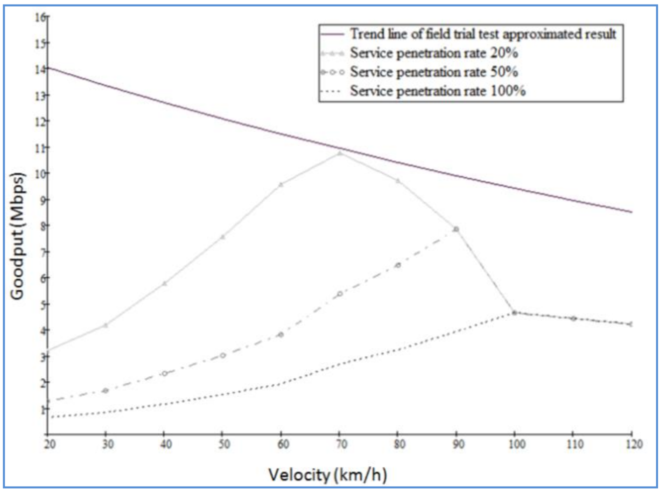

Figure 4.24. Mobile terminal throughput, depending on the velocity distribution and service penetration rate

Chapter 5

The use of simulation tools is relevant to study road transport mobile wireless network performance. Software solutions are different and decades of usage in both industry and academia can provide an idea what kind of solutions are used to obtain the desired results. As shown data in Table 5.1., simulation tools usability for the vehicle networking, published from 2004 to 2013 in the ACM and the IEEE Xplore digital library, is extensive and simulation tools are used to verify the analytical calculations in the simulation environment.

Table 5.1.

Simulation tool usage in scientific research for vehicle networking

Nr.	Name of simulation tool	Number of publications in IEEE Xplore digital library	Number of publications in ACM digital library	Percent	Recent changes (year)
1.	ns-2	51	139	42%	2013
2.	ns-3	20	27	10%	2013
3.	JiST/SWANS	7	28	8%	2005
4.	OMNeT++	10	23	7%	2013
5.	NCTUns	11	13	5%	2013
6.	VISSIM	2	21	5%	2013
7.	OPNET	7	15	5%	2013
8.	GloMoSim	2	14	4%	2000
9.	Veins	2	13	3%	2012
10.	GrooveNet	1	7	2%	2007
11.	citi (t.i. QualNet, Straw, SimITS, ASH, TraCI, TraNS)	9	29	8%	2005-2013

As a result, in the academic environment the simulation tools are used actively. Table 5.1. data shows that the network simulation tools like ns-2 and ns-3 mostly (i.e. 52% of the review scientific articles) are used in research of a vehicle networking which is due to the fact that the simulation tools are available free of charge and the academic environment uses for training and research processes. In contrast, for vehicle networking research some simulation tools utilization trends are based more on the tool the region of origin. OPNET is widely used in the U.S. but NCTUns (Estinet) is being used in Asian countries.

Vehicle networking simulation tools can be divided into two major classes - free and tightly integrated computer software solutions. Free integrated simulation tools combine the separate results from mobility and communication network simulation models. Mobility simulation models generate the movement of vehicles and record the results in separate files. However, to simulate the movement of mobile users, network simulation tools using the pre-generated files. Tightly integrated simulation tools don't use separate files, but are able to combine both simulations in single vehicle network simulation model.

The high performance commercial microscopic mobility or traffic simulation tools have higher accuracy, because they have been validated by the national organization, and the benefits that they are widely used in transportation systems planning. Other hand most commercial tools disadvantages that they are not freely available and their execution are too detailed for evaluation of vehicle networking performance. But non-commercial tools that are being developed at a university or individual laboratories are much more flexible and enables users to utilize any open source options by reducing or increasing any separate parameters and later to import results in network simulation tools like OPNET, QualNet, ns-2/3 or OMNeT++.

Communications simulation tools are used for vehicle networking research, as usage of the road traffic simulation tool is highly dependent on the accessibility, or the open-source system. A number of universities have accumulated a lot of experience actively using the ns network simulation tool to enable practice of students. Such student orientations present a high number of projects and publicity from ns environment. But despite this, ns and the other above-mentioned communication network simulation tools without additional models fail to ensure compatibility with the vehicle traffic simulation tools. Another hand for assuring the bidirectional exchange of information and present wireless local area network simulation in a real vehicle environment requires an integrated solution that combines movement and network models in one simulation tool.

Currently, no standard or highly validated simulation tool to perform analysis of the vehicle networking. More recently, it was designed to tightly integrate simulation tools (Veins, Estinet (NCTUns), TraNS, iTetris etc.) that combine vehicle traffic and network components in one application. Advanced simulation tools are capable of providing bidirectional communication between road traffic and network components to form a feedback between the network and vehicle mobility.

The usage of majority open source simulation tools is needed specialized knowledge and experience to be able to manage and control the compiled simulation to obtain the required results. Stability during simulation time is an open-source simulation tool development challenge. These disadvantages were also identified using the open-source simulation tool NCTUns 6.0, but this tool commercialized version Estinet 7.0 these disadvantages have been eliminated and the results obtained makes it possible to evaluate a mobile wireless network in the vehicle environment.

Analysing the results of the scenario when the vehicle with wireless LAN mobile terminal moves at speed from 20 to 90 km/h, maximum connection speed is set to 54 Mbps, the experimental results presented (i.e. up to 32Mbps) goodput doesn’t reach the maximum connection speed, as depicted in Figure 5.10., exist traffic with high burst and falls. This is due to the fact that useful information is encapsulated in lower-level protocols, creating additional overhead. High burst and falls of traffic related to the quality of the signal and the receiver's ability to restore the bit sequence as a negative result damaged data packet is being requested to retransmit. As shown in Figure 5.10. at the higher speed a mobile terminal to connect wireless LAN access point is needed longer distance, which is related to the speed of movement and time.

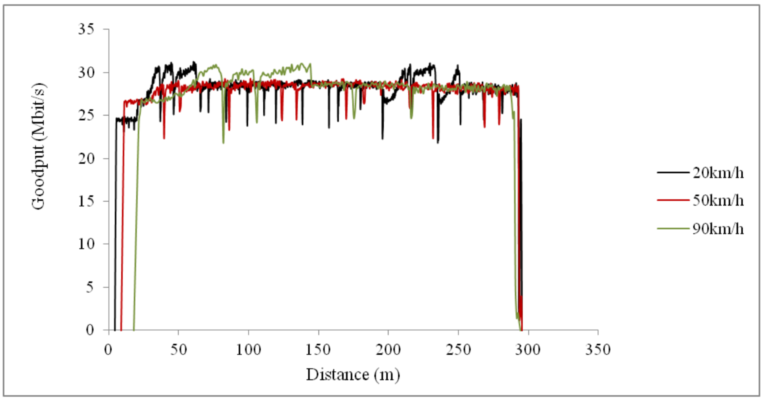

Figure 5.10. Wireless LAN throughput results at various speeds

With the simulation tool is not possible to model the impact of data rate adaptation methods on the wireless LAN goodput, hence, mobile terminal arriving into the WLAN access point coverage are provided with the maximum connection speed. Above mentioned input and output phases of the simulation model presented in the results are not especially strong in particular, as it was identified in the experimental measurements in the test bed.

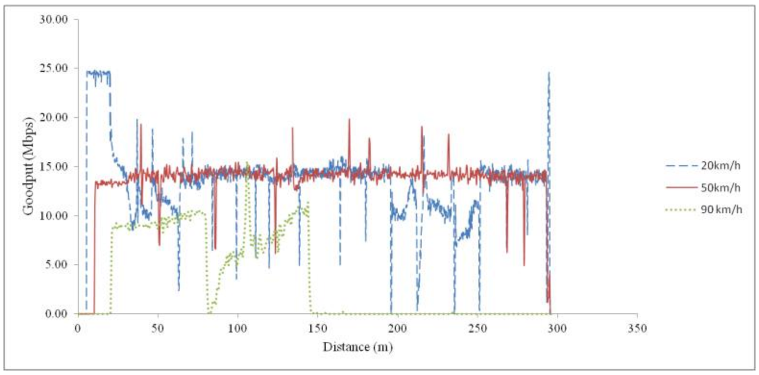

Figure 5.11. Probe vehicle wireless LAN simulation results at various speeds

Probe vehicle WLAN mobile terminal throughput characteristic diagram, as shown in Figure 5.11., is observed that at low speeds, traffic is fluctuated with high burst and falls. Moving with a speed that is characteristic of an urban environment with a low flow of vehicles, traffic fluctuations are smaller. Other hand, as shown in Figure 5.12., by increasing movement speed of the probe vehicle, goodput of wireless LAN mobile terminals decreases.

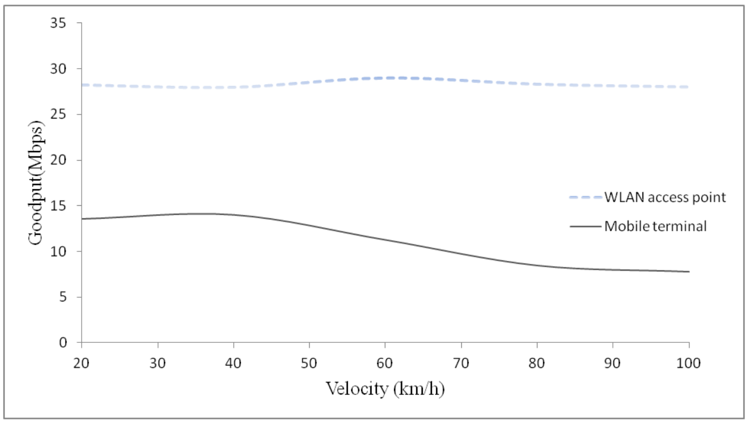

Figure 5.12. Mobile wireless network simulation results

Taking into account road safety recommendations [144] safe transport time to the vehicle in front by good weather is average two seconds. In the second chapter (2.19) equation, the number of road transport is variable and depends on the speed of movement. These parameters were taken into account, creating a near real road transport mobile wireless network. Figure 5.13., shows that a simulation model with extended vehicle mobile wireless LAN architecture was created with the aim of analysing an individual network segments. According to the simulation results it can be concluded that each change in vehicle mobility and data rate affects the overall performance of wireless network.

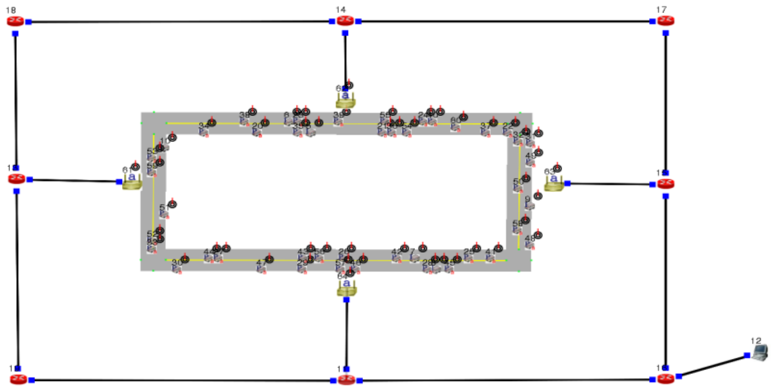

Figure 5.13. Extended vehicle mobile wireless local area network scenario

In situations where the vehicle is moving wireless WLAN switches from one access point to another or take the handover procedure, the network performance is disturbed. As a result, the goodput of mobile terminal decreases which lasts an average of 2-5 seconds while the authentication is done with other network segment.

Figure 5.14., shows that wireless connection simulation results are stated in all cases, irrespective of the allowable velocity change (50 or 100 km/h) or the maximum data rate conversion (24-54Mbps). In contrast, in practical measurements, which were reflected in the fourth chapter, the goodput curves decrease and was dependent on the velocity, but in the handover process goodput curve is more flattened, and the connection is not interrupted.

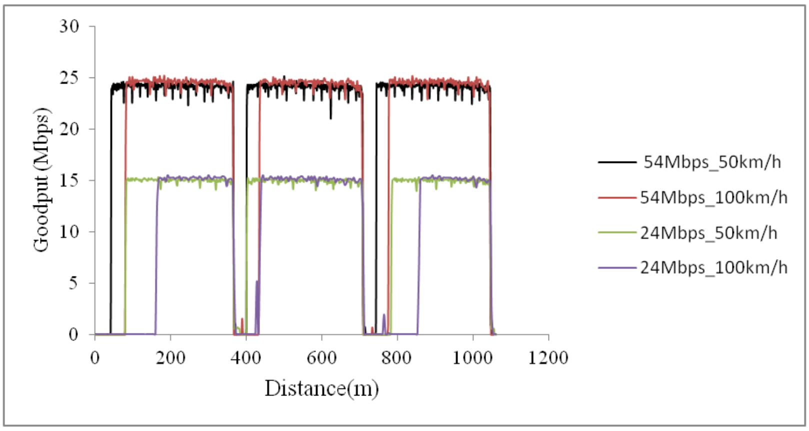

Figure 5.14. Results of four simulation scenarios with two connection data rate and velocities

The wireless distribution system (WDS) model with the selected simulation tools cannot be fully realized. In contrast, using the Mobile IP protocol settings of the simulation tool has been established a model which can help to continue the session without requiring re-transmission of the data.

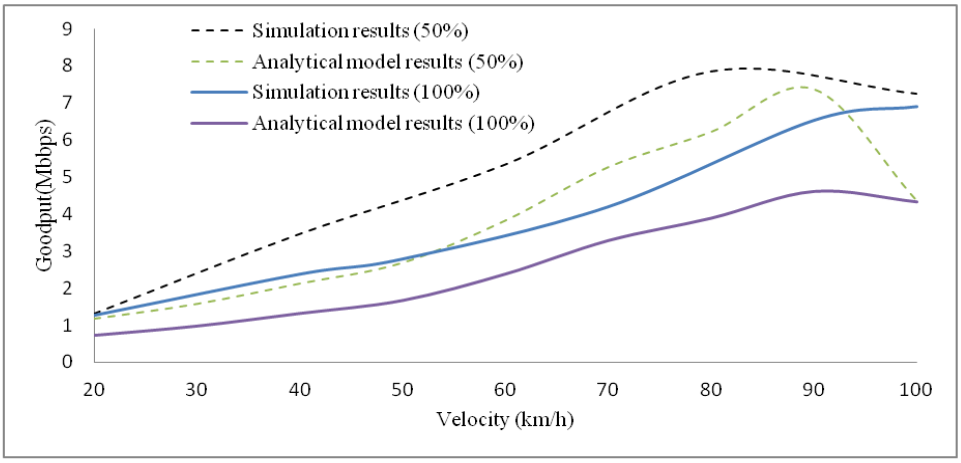

Figure 5.18. Analytical and simulation results comparison

Comparing the simulation results with the work of the fourth chapter the theoretical results can be observed that the wireless LAN throughput curves followed similar patterns. Each individual mobile terminal goodput depending on the speed is variable. The goodput for each individual user depends on the existence of other users in the wireless network and their activities. In this context, the simulation of each individual user or a mobile terminal activity, this was set to be created TCP traffic that is generated is able to maximize efficient use wireless LAN channels or to provide saturated throughput.

Under these conditions close to the real scenario by increasing vehicle speed enhance goodput for each user, which is contrary to the scenario when a WLAN access point allows the exchange of data for one or in the case three of mobile wireless local area network nodes. In contrast, changing the distribution of service or scenario, when the vehicle will vary depending on the maximum or desired speed and only every second vehicle is equipped with a wireless LAN access node, be observed changes in goodput. Figure 5.18., shows that can be identified by the simulation scenario, the service distribution p = 0.5 there has been an increase of goodput for each individual mobile node. This increase is above the theoretical section to analyse the assumption that at the speeds it is possible to achieve maximum throughput. This increase is similar to the previously analysed in the theoretical part that at certain speeds it is possible to achieve maximum goodput. This increase was observed from 50 to 80 km/h, reaching a maximum value of 80 km/h, which is close to the result of a previous theoretical analysis, where the maximum throughput with similar service penetration is 90 km/h. Increasing service penetration rates up to 100%, the throughput increase at 100km/h below the average of the maximum value.

THE MAIN RESULTS OF THE PROMOTION WORK

Research of wireless LAN depending on road traffic characteristics is a broad term which may include several objects for studying. This work was carried out a number of experimental and analytical studies to evaluate the performance of the wireless LAN in vehicle environment and promotion work's conclusion is as follows:

- Road transport networking trends and their impact on the road traffic analysis allowed the identification of increasing road traffic effects as well as the need to develop the intelligent transport system (ITS) and its role in further to reduce road transport usage problems using the wireless mobile network solutions;
- Using modern technology and the wide availability and low cost equipment can create a road transport wireless local area network, which allows not only to ensure road transportation safety and efficiency, but also passengers access to the Internet, mobile office and other services maintaining high quality of service parameters;
- Analysis of the number of users and their dynamics on observed road section, using the vehicle movement dynamics principles and their analytical models, was identified, that not all the used models are capable of reflecting the real road transport dynamic, as well as the velocity of road transport is one of the main parameters characterizing vehicle density;
- Experimentally carried out practical measurement of wireless local area network performance in vehicle environment with a mobile user, was studied the behaviour of wireless local area network in real time at various movement speeds of mobile user, concluding that the wireless local area network goodput is dependent on the user velocity, and it was found that mobility resulting Doppler effect impact on wireless LAN performance is minimal;
- Analyzing the vehicle wireless networking computer simulation options have been identified that not all open source simulation tools able to exchange information between vehicle

mobility and network simulation, models branched development of this tool shows a high publicity while only several solutions provide a fully integrated simulation environment to enable more detailed analysis of road transport mobile wireless local area network performance;

- Putting out major recent publications was identified effective software (i.e. Estinet). On the bases of it was set up the road transport wireless local area network simulator, which results are compared with experimental and analytical results;
- The simulation model is created, which can be used in further studies, for verification of road transport wireless local area network performance characterization parameters;
- Bases on experimental and analytical model and the results of the simulation tool is shown by the fact that there is a network solution that has been linked to the vehicle's movement and wireless local area network performance parameters providing maximum throughput.

The study identified the following unsolved tasks in vehicle mobile wireless network performance analysis depending on the traffic flow characteristics:

- Experimentally with existing equipment failed to evaluate the performance of IEEE802.11n wireless LAN with a maximum connection speed in the vehicle environment;
- Experimentally and analytically did not take into account a mobile user placement and generated traffic impact on wireless LAN performance;
- According to the terms of the Estinet 7.0license, simulation results obtained are not allowed to compare with the simulation tool results (i.e. Wayne, SUMO-TraNS-ns2, iCIS-SUMO-ns3, etc.);
- To reduce the wireless LAN performance influencing factors, was reduced to a minimum synchronization procedure of equipment switching off automatic addressing and security measures.

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