*Proceedings of the 12th International Conference “Reliability and Statistics in Transportation and Communication” (RelStat’12), 17–20 October 2012, Riga, Latvia, p. 195–203. ISBN 978-9984-818-49-8*
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# MODELLING OF VEHICULAR NETWORK FOR SHORT RANGE

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This paper presents the analytical model of two layer and cyclic network for wireless communication in vehicular environment. In fact, we present a vehicular V2I network simulator built to study the behavior of network traffic in Short range environments.

The performance of wireless mobile networks can be affected by different parameters, such as a number of clients in wireless network range and vehicle speed. These parameters have been analyzed with Buzen’s algorithm in Matlab. For evolution of wireless network performance has been used wireless access point model as queuing system with real goodput measurements data. In networks, goodput is the application level throughput.

As a result of the experiment, the mathematical models for cyclic wireless networks have been selected as ones which are to be used for choosing an optimal method for goodput evaluation of Short range communication Vehicular network.

**Keywords:** Two layer network model, cyclic network model, Matlab

## 1. Introduction

For the sake of a simpler mathematical model, let’s make the following assumptions. First, the processed tasks are homogeneous. A homogeneous task flow is a common characteristic for network systems controlling technological processes in real time. Second, the processing moment for every task is accidental and is exponentially distributed with a mean value corresponding by element. Third, elements and tasks being processed are mutually independent.

Vehicular network can be deployed by network operators and service providers or through integration between operators, providers, and a governmental authority. Recent advances in wireless technologies and the current and advancing trends in ad hoc network scenarios allow a number of deployment architectures for vehicular networks, in highway, rural, and city environments.

The standard IEEE802.11p enables a wireless access to vehicular environment. 802.11p functions in the 5.9 GHz range; this technology permits access to navigational options, multimedia information and also telemetry. For design of a wireless network that would work by 802.11p standard, more expensive equipment is required than for other IEEE wireless network standards like IEEE802.11n. The significant improvement of 802.11n standards comparing to previous standards is the raw data rate of the wireless channel up to 600 Mbps – more than twenty-fold improvement over 27 Mbps of IEEE802.11p maximum data speed.

Goodput is the application level throughput, delivered by the network to a certain destination, per unit of time. The amount of data considered excludes protocol overhead bits as well as retransmitted data packets.

## 2. Closed Cyclic Network System

The terminal count in each vehicular wireless network is usually high. It is possible to replace conveyor transfer of files with a consistent transfer on evaluation of bandwidth.

Following the obtained practical results we will calculate the base station performance at variable client count. In our case the 200 meters long base station operational zone of is divided to 5 zones, 40 meters each, the third zone being the most adjacent to the base station, as shows Fig. 1.

We assume that N vehicles enter the operational zone of the base station, starting at the speed of zero. Then velocity increases exponentially.

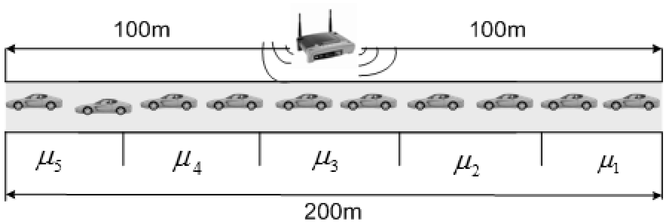


*Figure 1.* A 200 meter segment consisting of 5 zones, 40 meters each, N = 10

Let's investigate a closed network consisting of M independent nodes with N incoming queries. Distribution is exponential with the parameter $\mu_i$ According to this research the speed of vehicle movement on highway is characterized by density. The placement of vehicles per meter [1]:

$$\vartheta = \vartheta_0 \left(1 - \frac{k}{k_C}\right), \quad (1)$$

where, maximal permissible flow rate, and $\vartheta_0$ – initial vehicular movement flow rate. Let's assume that the area of interaction between vehicles and base station can be divided into M intervals. Let's provide a number of trespassing vehicles per second for each interval according to query intensity and processing. If the interval length equals $S_i$, and vehicle movement speed equals $\vartheta_i$, then the intensity of vehicle service by road interval equals [2], [4]:

$$\mu_i = \frac{\vartheta_i}{S_i}. \quad (2)$$

According to (1) the intensity of vehicle service will be depending both on initial vehicle flow rate into the road interval and on density of vehicle location on the road interval.

Such system can be described in a form of a closed cyclic mass service system network with M service devices, N queries and exponentially distributed service time [5]. Query service intensity in the *i*-th interval equals $\mu_i$.

In fact, there has been made an experiment to determine how to grow the speed of vehicle, as Fig. 2 shows.

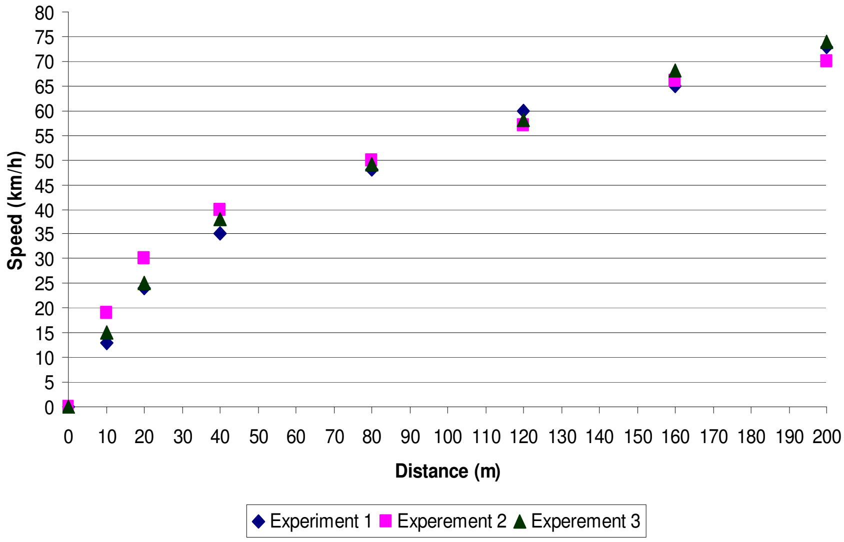


*Figure 2.* Speed of vehicle

The Table 1 shows the technical data of the car that was used in the experiment. The speed grow can be dependent on the vehicle data.

**Table 1.** Vehicle data

| | |
|---|---|
| Car brand | VW PASSAT |
| Capacity | 1.8 litre |
| Max power | 90 PS (66kW) |
| Gearbox | 5 speed manual |
| Weight | 1600 kg |

Vehicle speeds in various zones are presented in Table 2:

**Table 2.** Vehicle speed

| **Zone number *i*** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Distance (m) | 40 | 80 | 120 | 160 | 200 |
| Velocity $\vartheta_i$ (km/h) | 38 | 49 | 59 | 67 | 74 |
| Intensity $\mu_i$ | 0,264 | 0,34 | 0,41 | 0,465 | 0,514 |

Here $x_i$ is estimated by the system of equations:

$$\mu_i x_i = \sum_{i=1}^{M} \mu_i x_i p_{ij} . \tag{3}$$

Due to the periodic nature of this model $x_1 = 1$ the next step is calculated as follows:

$$x_2 = \frac{\mu_1}{\mu_2}, x_3 = \frac{\mu_1}{\mu_3}, ..., x_M = \frac{\mu_1}{\mu_M} . \tag{4}$$

Buzen's algorithm is among the most effective methods for closed network analysis, as shown in Table 3. Buzen's matrix, at the row i and column j can be calculated using the formula:

$$g(i, j) = g(i, j-1) + g(i-1, j)xj . \tag{5}$$

**Table 3.** Buzen's matrix

| **Nr.** | **1** | **0.776** | **0.644** | **0.568** | **0.514** |
|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 1 | 1 |
| … | … | … | … | … | … |
| 9 | 1 | 4,111 | 10,630 | 22,535 | 42.284 |
| 10 | 1 | 4,190 | 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 |

Utilization of segment being occupied:

$$P\{n_i \geq 1\} = x_i \frac{G(N-1)}{G(N)} . \tag{6}$$

Then probability of query (vehicle) distribution among service devices (road intervals) [3], [4]:

$$P_{n_1,...,n_M} = \frac{1}{G(N)} \cdot \frac{\mu_1^{N-n_1}}{\mu_2^{n_2} \cdot \mu_s^{n_S} ... \mu_M^{n_M}} , \tag{7}$$

where G(N) is a normalizing constant, resulted either from adding up and equating to one all probabilities either by Buzen's method [6]. 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:

$$E[n_i] = \sum_{K=1}^{M} (x_i)^K \cdot \frac{G(N-k)}{G(N)} . \tag{8}$$

The model (Fig. 3) has been created in the graphical Simulink environment of MATLAB package. The blokset SimEvents [7] has been used as a source of source blocks..

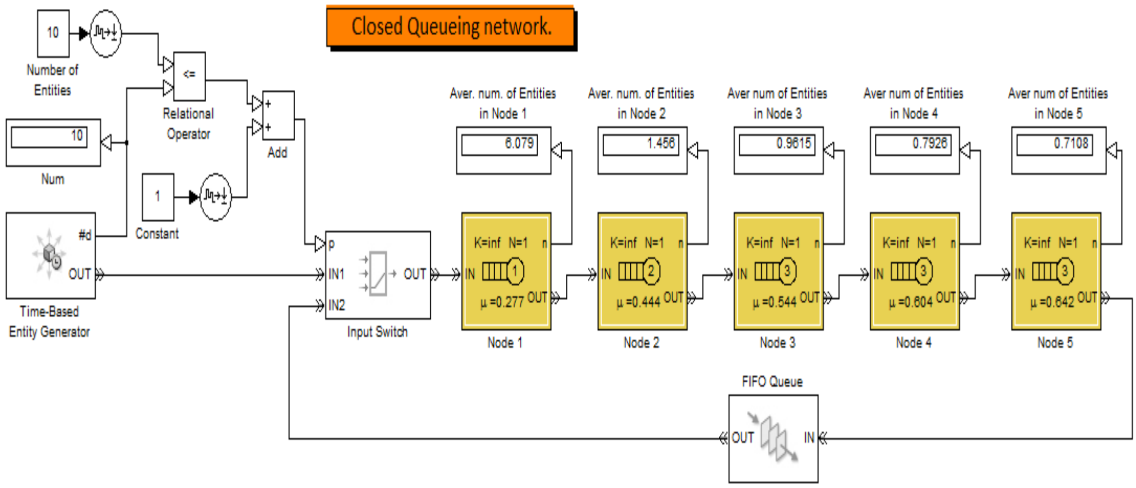


*Figure 3.* Closed model in Matlab

The scheme consists of 5 nodes (Node k, where k = 1…5), offered in [8] which contain more convenient interface for the introduction of parameters as well as more pictorial.

Nodes consist of block of waiting line and server unit with a random-number generator. The last generates the random-number sequence for the organization of service time in the server, as Fig. 4 shows. If there is a Poisson flow at the entrance of the node then the given node can be presented as a model of MMNK system as the service time is distributed in accordance with the exponential law.

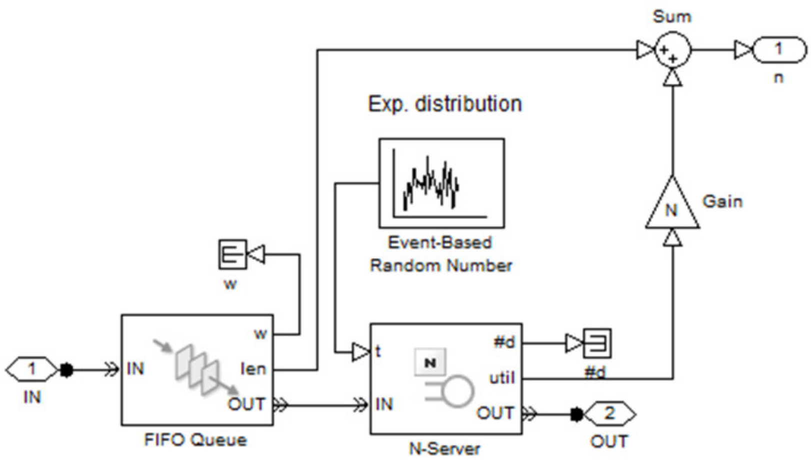


*Figure 4.* The scheme of node

On the basis of the previous calculation in the model for each Node K has chosen the following parameters:

- Queue length K = ∞;
- The number of servers N = 1;
- The service rate for each node: $\mu_1 = 0.277$, $\mu_2 = 0.444$, $\mu_3 = 0.544$, $\mu_4 = 0.604$ and $\mu_5 = 0.642$.

The model also contains the standard generator Time-Based Entity Generator and scheme running the call-off quantity of queries (demands, packets, automobiles) in the closed-loop system. Quantity of queries is set manually with the help of block Number of Entities.

Starting up the system at 200 000 cycles of the simulation time have been obtained the values of the average number of the queries in each node E(n). The theoretical calculation of these values is necessary to verify the obtained data. As the system is closed and the maintenance of each server is distributed exponentially then for the theoretical calculations of the average number of queries we use a known algorithm of Buzena [9], implemented in the MATLAB package. The data, obtained during the simulation with the theoretical values and relative errors, are shown in Table 4.

**Table 4.** Results of average number

| **Number of node** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **E(n)** theory | 6.0665 | 1.4605 | 0.9614 | 0.7953 | 0.7163 |
| **E(n)** Simulation | 6.079 | 1.456 | 0.9615 | 0.7926 | 0.7108 |
| $\delta$,% | 0.2053 | 0.3077 | 0.009 | 0.3366 | 0.7636 |

As Table 4 shows the error is less than 0.8 %!

Depending on the vehicles proximity to base station data processing rate and data processing intensity in base station are different [8], [9]. For file transfer the common packet length is 1500 bytes. Then we estimate the base stations performance $\beta_i$, for a car separated from the base station with a distance of r, by the chart at Fig. 5 [8], [9].

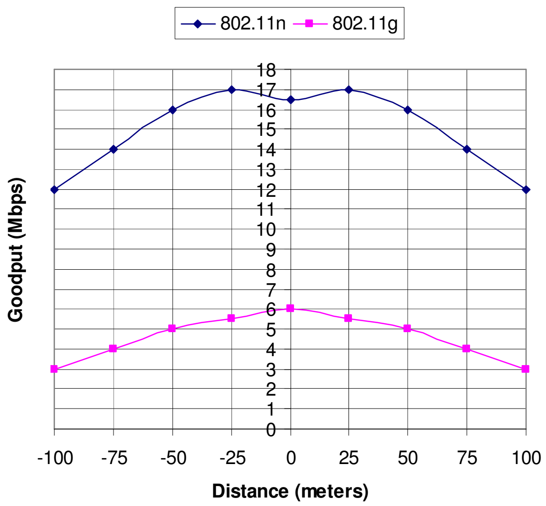


*Figure 5.* Goodput in a wireless network with one router depending on distance for 802.11n and 802.11g

Goodput of a station providing service for the region $i$ can be obtained from this formula and can be seen in Fig. 6:

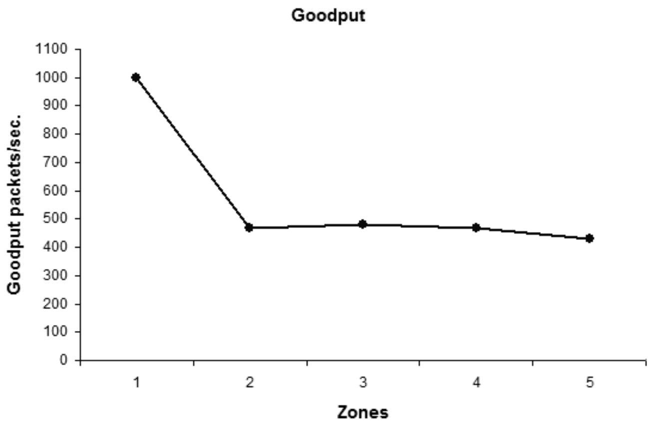


*Figure 6.* Goodput for moving with 10 vehicles

$$\eta_i = (1 - P_0(i))\beta_i . \quad (9)$$

Summary goodput for 802.11n at N = 10 is:

$$\eta = \sum \eta_i = 3244 \frac{packets}{\text{sec.}} .$$

This way the goodput of base station is revealed to be connected with traffic parameters as well as with the characteristics of the base station to vehicle data transfer system.

## 3. Two Layer Network System

The wireless network is reviewed as an object of the research providing the transmission of he data between the movable objects and remote server. The situation of the file transfer is reviewed from the movable objects using FTP protocol and a dependent node on the TCP architecture in IP.

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 802.11 g/n. However, the distance from the AP object should not exceed 300 meters. Further from the AP the data is transmitted to the remote base station on the protocol 802.16 (WiMax). This variant provides the data transmission at the distance up to several kilometres. 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. Null node stimulates the data transmission from a movable object with the intensity of the data transmission $\mu_0$. 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 $\mu_1$.

In its turn AP connects with the remote base station along the wireless network with the 802.16 standard. The intensity of the data transmission of the second node is to be taken to be equal to $\mu_2$.

We assume that all the time of the data processing i.e. the data transmission is considered to the exponential law $\mu_0$, $\mu_1$, $\mu_2$ parameters are the parameters of an exponential law:

$$f(x) = \mu_i e^{-\mu_i x} . \quad (10)$$

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 spending on the transmission of the data packets, which we denote as $E(t_i)$. The ACK transmission takes less time denoted as $E(t_0)$. Then the average time of the data processing in the first node is:

$$E(t_1) = \frac{E(t_i) + E(t_0)}{2} . \quad (11)$$

If we receive the ACK confirmations on the top of each transmitted packet, in this case the intensity of the processing in the first node is:

$$\mu_1 = \frac{1}{E(t_1)} . \quad (12)$$

Participating in the model of probability: $P_{01} = P_{12} = 0{,}5$ for each transmitted packet. 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 (13) formula. In this formula the parameters $\alpha$ and x are determined by the value from (1). 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 802.11g/n the speed of data transmission depends on the remoteness of the vehicles from AP.

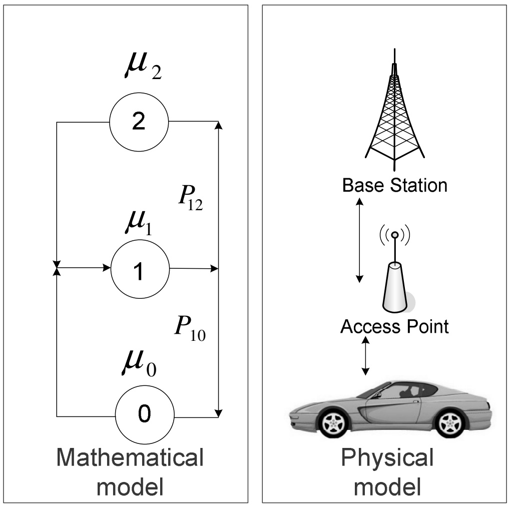


*Figure 7.* Two layer vehicular network model

The terminal count in each vehicular wireless network is usually high [1].
Bandwidth equation for a two layer network:

$$X_1 = \frac{\mu_0}{\mu_1 P_{10}}; \; X_2 = aX_1; \; a = \frac{\mu_1}{\mu_2} P_{12}. \quad (13)$$

The intensity for $\mu_2$:

$$\mu_2 = \frac{1}{t}, \quad (14)$$

$$t = \frac{l_p}{V_f}, \quad (15)$$

where $V_f$ is effective data transfer rate for the IEEE802.16e protocol.

IEEE802.16e protocol is used for the data transmission between the Access Point and the base station , this protocol has the peak transfer rate $V_n$ = 50Mbps.

The packet length is $l_p = 1500 bytes$, but the actual speed is determined in the following way:

$$V_f = \frac{V_n}{2}. \quad (16)$$

The 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 $\overline{n} = (n_1, n_2, n_3)$ is the inquiry count in $i-th$ node. The resulting equation for G(N) calculation looks like this:

$$G(N) = \sum_{\overline{n}} \prod_{i=1}^{3} (X_i)^n i, \quad (17)$$

$$\overline{n} \in \left\{ (n_1, n_2, n_3) / \sum_{i=1}^{3} n_i = N, n_i \geq 0 \forall_i \right\}, \quad (18)$$

where $n$ is a number of vehicles.

Function for the studied two layer vehicular network looks like this:

$$G(N) = \frac{1}{1-a} \sum_{j=0}^{N} X_1^j \left(1 - a^{j+1}\right). \quad (19)$$

Goodput $\eta$ of the two layered network is defined as a count of processed inquiries in a unit of time. The finished task is put out trough the subsystem of input/output, and instantly through it a new task is loaded.

$$\eta = \mu_0 \left(1 - p\{n_0 = 0\}\right). \quad (20)$$

Probability of a lack of inquiries in i-th node:

$$p\{n_i = 0\} = \frac{G(N) - X_i G(N-1)}{G(N)}. \quad (21)$$

By inserting in (20) the variable G(N) from (18) and by moving on to (19), we get the result of:

$$\eta = \frac{\left(1 - X_1^N\right)\left(1 - aX_1\right) - a\left(1 - (aX_1)^N\right)\left(1 - X_1\right)}{\left(1 - X_1^{N+1}\right)\left(1 - aX_1\right) - a\left(1 - (aX_1)^{N+1}\right)\left(1 - X_1\right)} \mu_0. \quad (22)$$

The two layer model has been created in the graphical Simulink environment of MATLAB package, shown in Fig. 8:

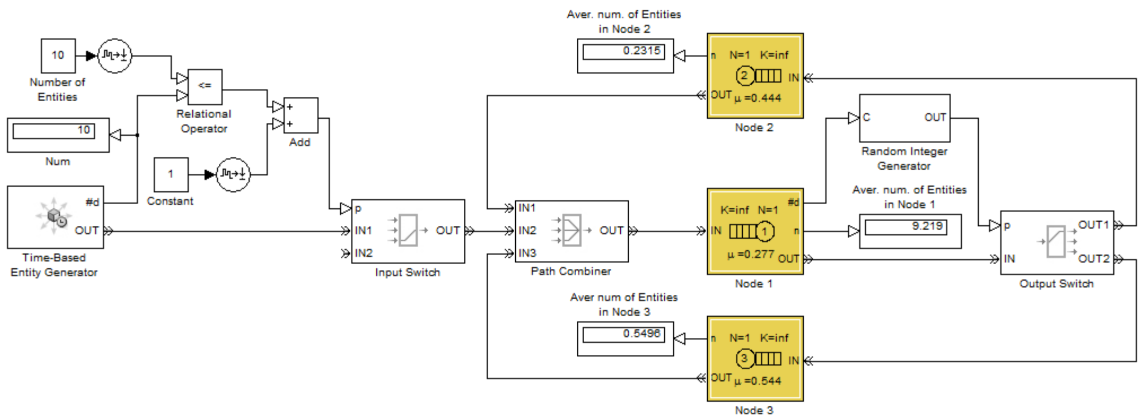


*Figure 8.* Two layer model in Matlab

From the (23) formula we define $\eta$ for the each road section:

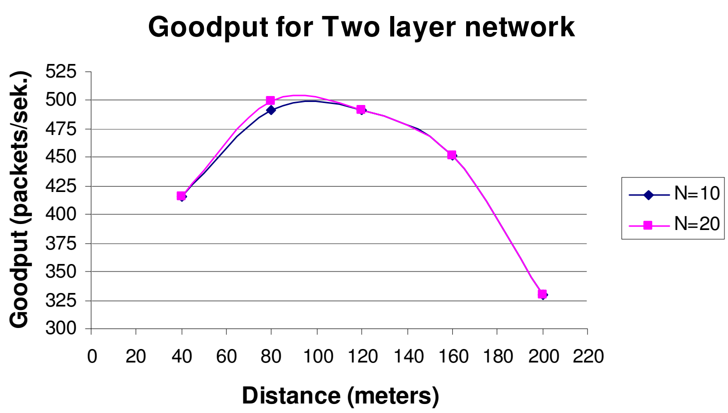


*Figure 9.* Goodput in Two layer wireless network

## Conclusions

The wireless network for mobile users has been created and installed in this experimental work. The wireless network with one access point has been installed. Wireless network throughput has been detected in different modes.

In this research the experimental data about data transfer rate in wireless networks of 802.11.g/n standard connecting moving objects are presented. Basing on the experimental data the mathematical patterns have been developed binding characteristics of vehicular flow with characteristics of data transfer system.

This paper has presented a performance evaluation of the two layer and cyclic network model. A calculation of goodput for each node of two layer network has been explained. Two layer and closed cyclic model for real data transfer rate estimation depending on number N of moving objects located in the wireless network base stations operational zone has been developed. Basing on this research, the real data transfer rate depends on the number and distances from the base station of objects interacting with base station. This work gives a good tool for modeling Vehicular network system.

## References


1. Visnevski, V. M., Lyahov, A. I., Portnoy, S. L., Shahnovoch, I. V. (2005). *Wire broadbands of information transfer*. Tehnosphere. 592 p.
2. Shortle, G. J., Thompson, J., Harris, C. (2008). *Fundamentals of Queuering Theory*. Willy. 500 p.
3. Haverkort, B. R. (1999). *Performance of Computer Communication Systems*. A Model-Based Approach. John Wiley & Sons Ltd. 495 p.
4. Kleinrock, L. (1975). *Queuing Systems*, John Wiley & Sons Ltd. 600 p.
5. Ipatovs, A., Petersons, E. (2006). Performance Evaluation Of WLAN Depending on Number of Workstations and Protocols. *Electronics and Electrical Engineering,* No. 3(67). Kaunas: Technologija.
6. Ipatovs, A., Petersons, E. (2006). Performance Evaluation of WLAN depending on number of Workstations and Protocols. In Electrical and Control Techologies, pp. 266–270. ISSN 9955-25054-2.
7. SimEvents Documentation in Internet http://www.mathworks.se/help/toolbox/simevents/
8. Kazakovs, P. (2012). Planning of the Dator networks in the SIMULINK environment. Bachelor's Paper.
9. Gunter Belch, Stefan Greiner, Hermann de Meer, and Kishor S. Trivedi. (1998). *Queuing Networks and Markov Chains Modeling and Performance Evaluation with Computer Science Applications.* J. Wiley & Sons. Ltd.