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Two Layer Model for Performance Evolution of V2I Network

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***Abstract*—This research presents data evaluating data transfer rate between a remote object and base station in wireless network standard 802.1g/n. Regularity was observed in data transfer rate dependency from the M number of remote objects. All measurements and conclusions were made under circumstances where objects were positioned stationary relative to base station. As the result of the experiment, the mathematical models for two layer wireless networks and closed cyclic wireless networks were selected as ones who are to be used for choosing an optimal method for performance evaluation of a short range communication vehicular network.**

***Index Terms*—Vehicular network, 2-layer network model, cyclic model, vehicle detection.**

I. INTRODUCTION

Developers of wireless networks for moving objects encounter a series of certain problems. One of such problems is the estimation of the number of moving objects on road depending from their distance to base station. This question is important as it is from the quantity of clients located in base stations operational zone that the useful data transfer rate – the so-called “Goodput” depends from. Estimation of useful data transfer rate while taking the vehicular traffic into account equals another problem of wireless network construction for moving objects. Here, it is the real data transfer rate from the user level of the on-board computer to base station.

II. THE OBJECT DESCRIPTION

The wireless network is reviewed as the object of the research providing the transmission of the 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 the 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 shown in Fig. 1. Null node stimulates the data transmission from a movable object with the intensity of the data transmission μ_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 μ_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 μ_2.

We are assumed that all the time of the data processing i.e. the data transmission is considered to the exponential law μ_0, μ_1, μ_2 parameters are the parameters of an exponential laws

$$f(x) = \mu_i e^{-\mu_i x}. \quad (1)$$

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 denotes it as $E(t_0)$. Then the average time of the data processing in the first node will be

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

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

$$\mu_1 = \frac{1}{E(t_1)}. \quad (3)$$

Participating in the model of probability: $P_{01} = P_{12} = 0{,}5$ for the each transmitted packet. The model participates in

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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 α and x determine 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.

Experimental data of the remoteness influence are presented in Fig.4. This complicates the task as μ_1 will not the constant value, but variable value according to the Fig. 4. And for the system evaluation you have to know the number of vehicles in the AP area and in the AP subarea. Subareas are regarded the road segment that are on the different distances from the AP. In each subarea i corresponds its values $N_i = E(n_i)$. To determine these values n, values $\mu_{(i)}$ is used the closed cyclic model which describes the number of vehicles in the AP active area. This article offers to create a vehicular wireless network using a two layer wireless network model, as show Fig. 1.

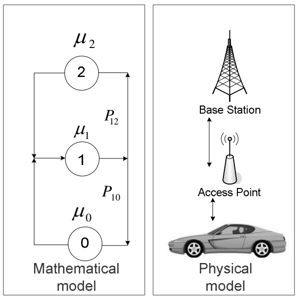

Fig. 1. Two layer vehicular network model.

The terminal count in each vehicular wireless network is usually high [1]–[5].

Bandwidth equation for a two layer network:

$$X_1 = \frac{\mu_0}{\mu_1 P_{10}}, \tag{4}$$

$$X_2 = aX_1, \tag{5}$$

where $a = \frac{\mu_1}{\mu_2} P_{12}$.

The intensity for the μ_2

$$\mu_2 = \frac{1}{t}, \tag{6}$$

where

$$t = \frac{l_p}{V_f}, \tag{7}$$

here V_f – effective data transfer rate for the IEEE802.16e protocol.

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

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

$$V_f = \frac{V_n}{2}. \tag{8}$$

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

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

$$\overline{n} \in \left\{ (n_1, n_2, n_3) / \sum_{i=1}^{3} n_i = N, n_i \geq 0 \forall_i \right\}, \tag{9}$$

where n – number of vehicles.

Function for the studied two layer vehicular network looks like this

$$G(N) = \frac{1}{1-a} \sum_{j=0}^{N} X_1^j \left(1 - a^{j+1}\right) \tag{10}$$

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. The output flow is equal to input flow and from this rule of flow balance it is possible to write

$$\eta = \mu_0 \left(1 - p\{n_0 = 0\}\right). \tag{11}$$

Probability of a lack of inquiries in i-th node

$$p\{n_i = 0\} = \frac{G(N) - X_i G(N-1)}{G(N)}. \tag{12}$$

By inserting in (10) the variable G(N) from (9), we get

$$\eta = \frac{\left(1 - X_1^N\right)\left(1 - aX_1\right) - a\left(1 - (aX_1)^N\right)\left(1 - X_1\right)}{\left(1 - X_1^{N+1}\right)\left(1 - aX_1\right) - a\left(1 - (aX_1)^{N+1}\right)\left(1 - X_1\right)} \mu_0. \tag{13}$$

III. Closed Cyclic Estimation Model for Vehicular Number

This article offers to create a vehicular wireless network using a closed wireless network model.

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

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 is shown Fig. 2.

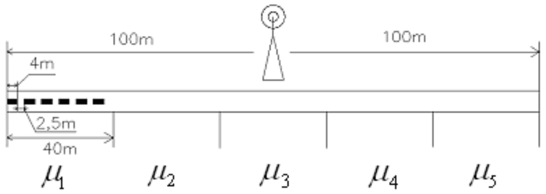

Fig. 2. Vehicle cyclic network system.

Let's investigate a closed network consisting of M independent nodes with N incoming queries. Distribution is exponential with the parameter μ_i According to this research the speed of vehicle movement on highway is characterized by density. If the interval length equals S_i , and vehicle movement speed equals ϑ_i, then the intensity of vehicle service by road interval equals [5]

$$\mu_i = \frac{\vartheta_i}{S_i}. \tag{14}$$

Time of presence on a certain road interval depends from its length and vehicles movement speed. Similarly, in systems of mass service: query service intensity of a single device in an overwhelming majority of observed systems doesn't depend from queue length, while the time of queries presence in the system does.

Such a 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 [2]. Query service intensity in the *i*-th interval equals μ_i .

In fact, to determine how to grow the speed of vehicle was made an experiment, as show Fig. 3.

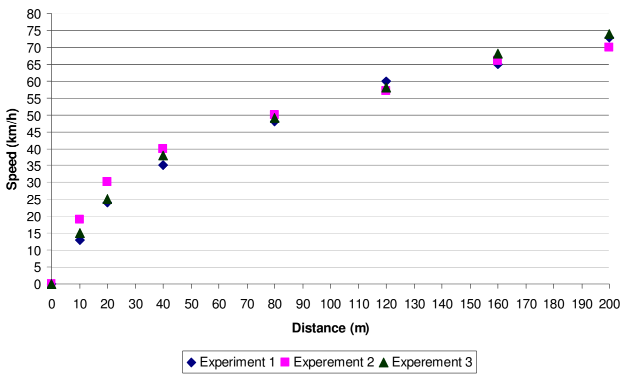

Fig. 3. Speed of vehicle.

Vehicle speeds in various zones are presented in Table I.

TABLE I. VEHICLE SPEED.

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

Here x_i is estimated by the system of equations

$$\mu_i x_i = \sum_{i=1}^{M} \mu_i x_i p_{ij}. \tag{15}$$

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

$$x_2 = \frac{\mu_1}{\mu_2}, x_3 = \frac{\mu_1}{\mu_3}, \ldots, x_M = \frac{\mu_1}{\mu_M}. \tag{16}$$

Buzen's algorithm the most effective methods for closed network analysis, as show in Table II. Buzen's matrix, at the row *i* and column *j* can be calculated using the formula

$$g(i, j) = g(i, j-1) + g(i-1, j)xj. \tag{17}$$

TABLE II. 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

$$P\{n_i \geq 1\} = x_i \frac{G(N-1)}{G(N)}. \tag{18}$$

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

$$P_{n_1,\ldots,n_M} = \frac{1}{G(N)} \cdot \frac{\mu_1^{N-n_1}}{\mu_2^{n_2} \cdot \mu_s^{n_S} \ldots \mu_M^{n_M}}, \tag{19}$$

where G(N) – normalizing constant, resulted from adding up and equating to one all probabilities or by Buzen's method [3]. Naturally, that there are no limitations for the number of vehicles (queries) in the i-th interval, as show Fig. 5.

Average number of queries (vehicles) in *i*-th interval

$$E[n_i] = \sum_{K=1}^{M} (x_i)^K \cdot \frac{G(N-k)}{G(N)}. \tag{20}$$

Table III shows average number of queries:

TABLE III. AVERAGE NUMBER OF VEHICLES.

Zone	**1**	**2**	**3**	**4**	**5**
N=10	6	1	1	1	1
N=20	15	2	1	1	1

Each vehicle in sub-zone i can exchange packets with base station with intensity $\mu_0 < \mu_1$.

Then we know the general form of the equilibrium distribution for $N \leq \min_i m_i$. If the number of stage is sufficiently large and if we assume that $\min_i m_i \geq 1$. As shown in Fig. 2 in the first sub-zone of our segment 6 vehicles can be located. Consequently there won't be more than 6 cars per sub-zone, elsewhere too $m_i \leq m_1 \leq 6$.

There μ for i-th region is obtained from measurement results, illustrated in Fig. 4.

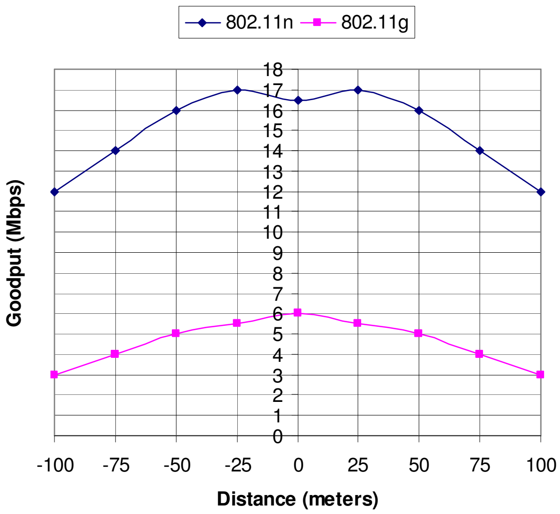

Fig. 4. Goodput in wireless network with one router depending on distance for 802.11n and 802.11g.

From the (13) we define η for the each road section:

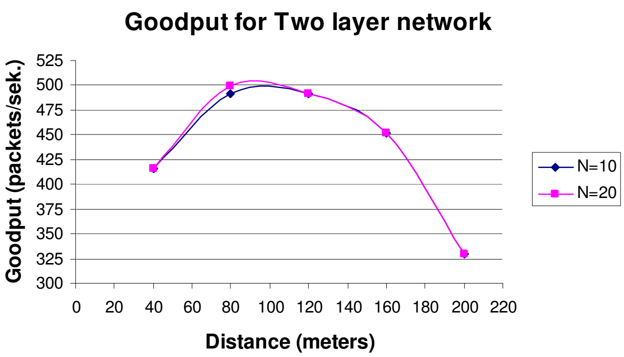

Fig. 5. Goodput in Two layer wireless network for 802.11g.

IV. Conclusions

In this research experimental data is presented, about data transfer rate in wireless networks of 802.11g/n standard connecting moving objects. Based on the experimental data mathematical patterns were developed binding characteristics of vehicular flow with characteristics of data transfer system. Experimental data is presented in this research, concerning data transfer rate in 802.11g/n standard wireless network of moving objects. Based on experimental data two mathematical models were developed, binding the characteristics of vehicular flow and characteristics of data transfer system.

Within the presented research, a model for real data transfer rate estimation depending from number N of moving objects located in the wireless network base stations operational zone was developed. Based on this research, the real data transfer rate depends from the number and distances from base station of objects interacting with base station.

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