

Research of a 2-layer Closed Vehicular Network

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Abstract. In this article, the evaluation of a 2-layer network has been performed. Buzen's method has been applied for the 2-layer closed network performance calculation.

This paper offers a 2-layer model of a wireless vehicular network and presents a bandwidth calculation of each network node. There is also described how the vehicle movement speed and the number of terminals connected to fringe stations influence the bandwidth of a 2-layer wireless vehicular network. Bandwidth calculations of IEEE 802.11g and IEEE 802.16 are demonstrated.

The mathematical models for 2-layer wireless networks have been selected as ones which are to be used for choosing an optimal method for performance evaluation of a short range communication vehicular network.

Keywords: 2-layer network, IEEE 802.11g, IEEE 802.16, vehicular network.

I. INTRODUCTION

Vehicular wireless network is made using the IEEE 802.11p standard. This standard 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, as well as telemetry. For creation of a wireless network that would work by 802.11p standard, more expensive equipment is required than for other IEEE wireless network standards. This article offers to create a vehicular wireless network using a 2-layer wireless network model as show in Fig. 1.

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 [9].

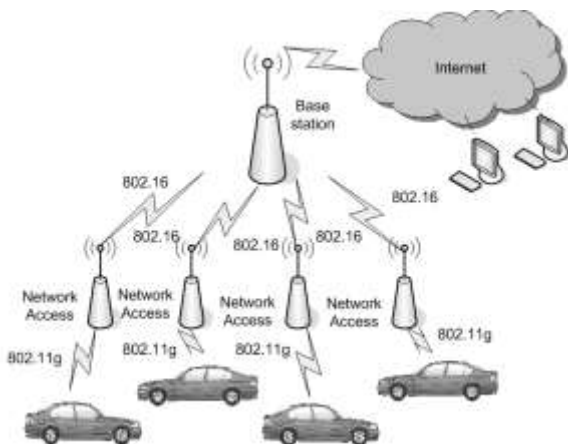


Fig. 1. Vehicular network

II. LAYER WIRELESS VEHICULAR NETWORK

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 $\bar{n} = (n_1, n_2, n_3)$ is the inquiry count in i -th node. The resulting equation for $G(N)$ calculation looks like this (Fig. 2):

$$G(N) = \sum_{\bar{n}} \prod_{i=1}^3 (X_i)^{n_i} \quad (1)$$

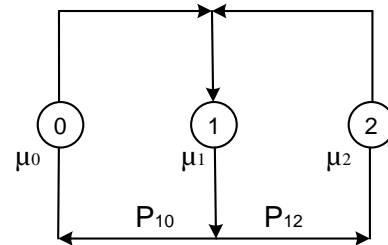


Fig.2. 2-layer network model

Bandwidth equation for a 2-layer network:

$$X_1 = \frac{\mu_0}{\mu_1 P_{10}}; \quad X_2 = a X_1; \quad a = \frac{\mu_1}{\mu_2} P_{12} \quad (2)$$

$$\bar{n} \in \left\{ (n_1, n_2, n_3) / \sum_{i=1}^4 n_i = N, n_i \geq 0 \forall_i \right\} \quad (3)$$

Function for the studied 2-layer vehicular network looks like this:

$$G(N) = \frac{1}{1-a} \sum_{j=0}^N X_1^j (1-a^{j+1}) \quad (4)$$

Performance η of the 2-layered network is defined as the count of processed inquiries per 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:

$$\eta = \mu_0 (1 - p\{n_0 = 0\}) \quad (5)$$

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

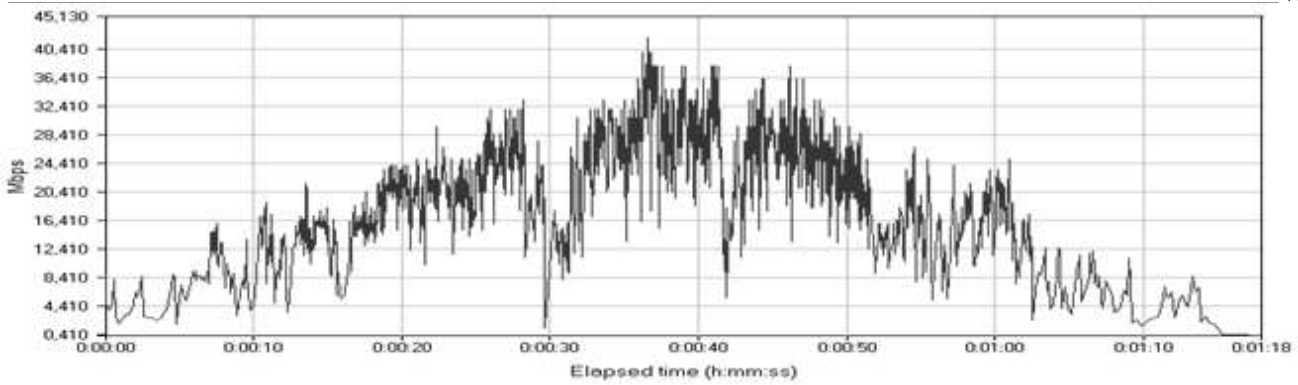


Fig.3. Data transfer rate as a function of location of the mobile object, during its movement at speeds of 20km/h

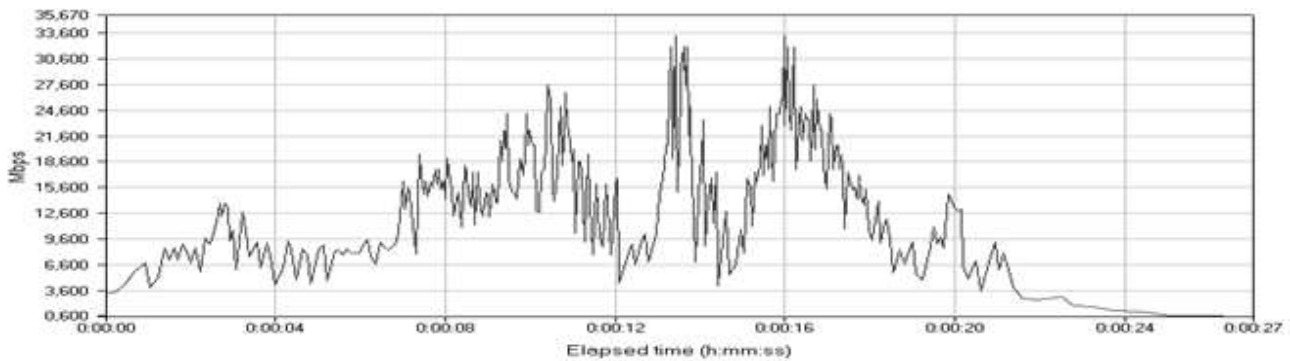


Fig.4. Data transfer rate as a function of location of the mobile object, during its movement at speeds of 100km/h

$$p\{n_i = 0\} = \frac{G(N) - X_i G(N-1)}{G(N)} \quad (6)$$

By inserting the $G(N)$ from (4) in (6) and by moving on to (5), we get the result of:

$$\eta = \frac{(1 - X_i^N)(1 - aX_i) - a(1 - (aX_i)^N)(1 - X_i)}{(1 - X_i^{N+1})(1 - aX_i) - a(1 - (aX_i)^{N+1})(1 - X_i)} \mu_0 \quad (7)$$

Intensity:

$$\mu_1 = \lambda_2 + \frac{1}{\tau}$$

$$X_1 = \mu_0 \tau = p_1$$

$$a = \frac{\lambda_2}{\mu_2} = p_2$$

$$\eta = \frac{(1 - p_1^N)(1 - p_1 p_2) - p_2(1 - (p_1 p_2)^N)(1 - p_1)}{(1 - p_1^{N+1})(1 - p_1 p_2) - p_2(1 - (p_1 p_2)^{N+1})(1 - p_1)} \mu_0 \quad (8)$$

u – arrival time.

$E[n]$ – number of queries in the mass service system.

λ – system incoming flow.

$$u = E[n] / \lambda$$

$$\lambda = \eta$$

$$E[n] = N$$

$$u = \frac{N}{\eta} = \frac{N}{\mu_0}$$

(9)

$$\frac{N}{\mu_0} = \frac{(1 - p_1^{N+1})(1 - p_1 p_2) - p_2(1 - (p_1 p_2)^{N+1})(1 - p_1)}{(1 - p_1^N)(1 - p_1 p_2) - p_2(1 - (p_1 p_2)^N)(1 - p_1)}$$

III. CYCLIC MODEL OF VEHICULAR MOVEMENT

As shown in Fig. 3 and Fig. 4, the speed of processing the inquiries differs in various zones; of course, there will be different performances. For calculation of the general performance of the whole section it is necessary to use the formula (17).

According to this research, the speed of vehicle movement on highway is characterized by density [1][2]. The placement of vehicles per meter:

$$g = g_0 \left(1 - \frac{k}{k_C} \right) \quad (10)$$

where, maximal permissible flow rate⁽⁸⁾, and g_0 - initial vehicular movement flow rate.

Under the assumption that the area of interaction between vehicles and base station can be divided into M intervals, we 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 \mathcal{G}_i , then the intensity of vehicle service by road interval equals:

$$\mu_i = \frac{\mathcal{G}_i}{S_i} \quad (11)$$

According to (10), the intensity of vehicle service will depend both on the initial vehicle flow rate in the road interval and the density of vehicle location on the road interval.

Vehicles pass all M intervals successively, and the total number of vehicles within the range of the base station is N .

Entering the area covered by a base station from the zero state (a lack of connection with the station), the vehicle finds itself in the zero state again. 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. Query service intensity in the i -th interval equals μ_i as show in Fig. 5.

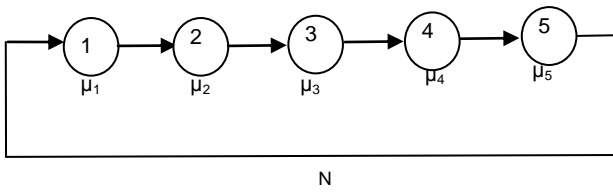


Fig. 5. Cyclic system

Then probability of query (vehicle) distribution among service devices (road intervals):

$$P_{n_1, \dots, n_M} = \frac{1}{G(N)} \cdot \frac{\mu_1^{N-n_1}}{\mu_2^{n_2} \cdot \mu_3^{n_3} \dots \mu_M^{n_M}} \quad (12)$$

Here $G(N)$ – normalizing constant, resulted from adding up and equating to one all probabilities or by Buzen's method.

Naturally, that there are no limitations for the number of vehicles (queries) in the i -th interval.

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

$$E[n_i] = \sum_{k=1}^M (x_i)^k \cdot \frac{G(N-k)}{G(N)} \quad (13)$$

Here x_i is determined by equitation system:

$$\mu_i x_i = \sum_{j=1}^M \mu_j x_j p_{ij} \quad 1 \leq j \leq M \quad (14)$$

Because of the cyclic nature of system:

$$\mu_i x_i = \begin{cases} \mu_{i-1} x_{i-1} & i = 2, 3, \dots, M \\ \mu_M x_M & i = 1 \end{cases} \quad (15)$$

One of x can be equated to one and thus:

$$x_1 = 1, \quad x_2 = \frac{\mu_1}{\mu_2}, \quad x_3 = \frac{\mu_1}{\mu_3}, \dots, x_{M-1} = \frac{\mu_1}{\mu_{M-1}}, \quad (16)$$

$$x_M = \frac{\mu_1}{\mu_M}$$

Performance of cyclic system:

$$\eta_1 \cdot P(n_1) + \eta_2 \cdot P(n_2) + \dots + \eta_M \cdot P(n_M) = \eta \quad (17)$$

An experiment took place, where a 200-meter range of operation of base station was divided into 5 intervals, 40 meters each. The third interval was closer to the base station. In case if there is one car that (Fig. 6):

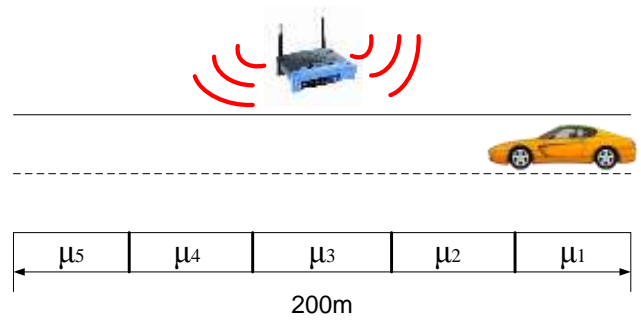


Fig. 6. 200-meter interval divided into intervals with 1 car

Speed of a car in zones (Table 1):

TABLE 1
AUTOMOBILE SPEED PER AREA

i	1	2	3	4	5
M	40	80	120	160	200
\mathcal{G}_i	39.9	63.9	78.3	86.9	92.1
μ_i	0.27	0.44	0.54	0.6	0.64

TABLE 2
BUZEN'S TABLE

Nr.	X_1	X_2	X_3	X_4	X_5
0	1	1	1	1	1
1	1	1.62	2.1	2.59	3

Probability that the first node will not be idle (Table 2):

$$P(n_1 \geq 1) = \frac{G(N-1)}{G(N)} = \frac{1}{3} = 0.333 \quad (18)$$

Probability of this node being idle:

$$1 - P(n_1 \geq 1) = 1 - 0.333 = 0.667 \quad (19)$$

If there are 10 vehicles in a closed cyclic mass service network then (Fig. 7):

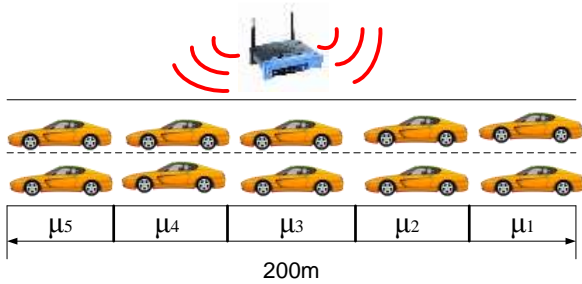


Fig. 7. 200-meter interval divided into intervals with 10 car

Probability that the first node will not be idle (Table 3):

$$P(n_1 \geq 1) = \frac{G(N-1)}{G(N)} = \frac{16.52190141}{16.90699228597} = 0.977 \quad (20)$$

depends on the frequency, for antennas with similar characteristics there is a frequency dependent effect on the reduction in signal strength as measured by two antennas. This effect is commonly referred to as frequency dependent path loss [3].

Coverage is better at 2.4 GHz and fewer access points are needed, lowering the overall system cost. 802.11g access points can also communicate with 802.11b devices as the current 802.11g products show.

As discussed in the previous section, the maximum throughput at the upper layers depends on the overhead of the layers below. The TCP protocol dynamics has a direct impact on the throughput as well. In this paper we do not consider the effects of the TCP protocol on the throughput. The objective is to calculate the maximum throughput of IEEE 802.11 technologies in the medium access control (MAC) layer for different parameters such as data rate, packet size. The maximum throughput in higher layers will be lower due to additional overhead at each layer [8].

The size of data frame is 1536 bits and its transfer speed is 54 Mbps (such data has also been received during the experiment). Knowing that on a physical layer 802.11g uses OFDM technology with 64-QAM modulation, which encodes 216 data symbols in a single OFDM symbol at a speed of $\frac{3}{4}$, we can calculate the number of OFDM symbols for a single data frame. It is equal to ~57 symbols. By multiplying the count of symbols with the transfer time of a single symbol (4 μ s) and adding OFDM preamble time of 20 μ s and signal extension time 6 μ s, mentioned in theoretical part of “ERP-OFDM

TABLE 3
BUZEN’S TABLE

Nr.	$X_1 = 1$	$X_2 = 0.624$	$X_3 = 0.509$	$X_4 = 0.459$	$X_5 = 0.433$
0	1	1	1	1	1
1	1	1.624	2.133	2.592	3.025
2	1	2.013376	3.099073	4.288801	5.598626
3	1	2.256346	3.833774	5.802334	8.2265395
4	1	2.407960	4.359351	7.022623	10.5847147
5	1	2.502567	4.721477	7.9448612	12.5280427
6	1	2.5616019	4.964833	8.6115251	14.03616766
7	1	2.5984396	5.125540	9.0782300	15.15589069
8	1	2.62142632	5.2303262	9.3972338	15.95973448
9	1	2.63577002	5.29800606	9.61133638	16.52190141
10	1	2.64472049248	5.34140557702	9.75300897544	16.90699228597

IV. BANDWIDTH CALCULATIONS OF IEEE 802.11G

The 802.11g standard uses a frequency range of 2.4 GHz, providing a transfer rate of 54 Mbit/s. Because the size of the antennas used to transmit and receive signals

Frame”, we receive that data transfer needs 254 μ s. Data frame is followed by SIFS interval, whose length is 10 μ s and which is needed to separate one frame from another (Fig. 8).

After SIFS interval, in case of a correct reception of data frame, a confirmation frame follows, with a size of 14 bytes, and that is transferred with a speed of 24Mbps (as it also was in the experiment). This frame has also the OFDM preamble and a signal extension (20 μ s and 6 μ s), but unlike a data frame, a 16-QAM modulation at a coding speed of $\frac{1}{2}$ is used for its transfer. This means that a single OFDM symbol (4 μ s) is needed to transfer a single ACK frame. By adding all time intervals together, we conclude that it takes 30 μ s to transfer a confirmation frame.

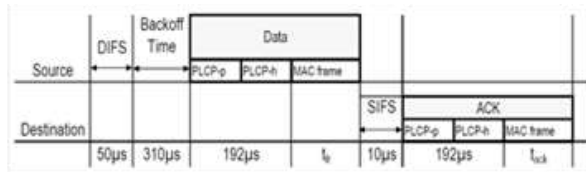


Fig.8. Performance of IEEE 802.11g networks

The theoretical total time of single frame transmission is DIFS time plus data time plus SIFS time plus ACK time and that is equal to 344 μ s [6].

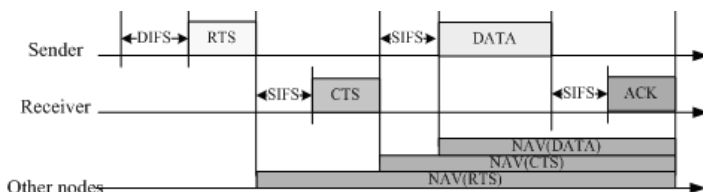


Fig. 9. Distributed Foundation Wireless MAC

We consider the 802.11g based WLAN. We expect a wider deployment of 802.11g WLAN because of its ability to inter-operate along with the widely prevalent 802.11b networks. Our aim is to analyse the 802.11g mechanism at its highest data rate, 54mbps. Also, instead of analysing it in its pure mode, where only 802.11g clients can exist, we would like to observe the legacy mode performance, where 802.11b clients can co-exist along with it. The 802.11 DCF mode uses a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm to mediate access to the shared medium [2].

When a client has to send data, it senses the medium for at least a DCF Inter Frame Space (DIFS) period of time. DCF control functions are the mechanisms of access to the wireless environment used in the 802.11p protocol. As a possible setting over DCF, the PCF central control functions are used (Figure 9). DCF model has a high efficiency, while the network load is low. If the medium is found idle, the frame is transmitted. Otherwise, a backoff time (measured in time slots) is chosen randomly in the interval 0 - CW, where CW is the contention window, calculated as CW_i , where i is the

number of attempts made (including the current one) to transmit the frame, and k is the constant minimum contention window, CW_{min} (Table 4).

TABLE 4
IEEE 802.11g PARAMETERS

Parameters	Value
MAC	34 bytes
ACK	14 bytes
Bandwidth (r)	54 Mbps
CW_{min}	15
CW_{max}	1023
Slot time	20 micro sec
SIFS	10 micro sec
DIFS	50 micro sec
PHY	20 micro sec

The calculation proceeds as follows (time is in microseconds and throughput is in Mbps):

- time taken to send *just* the packet (without calculating ACK, PHY and backoff) is

$$t_{pkt} = \frac{(p + MAC) * 8}{k.r} = \frac{(200 + 34) * 8}{56.623k} = \frac{33.06}{k} \quad (21)$$

where, k is some fraction of the raw available bandwidth(r).

- time taken to send ACK is

$$t_{ack} = \frac{ACK * 8}{k.r} = \frac{14 * 8}{56.623k} = \frac{1.978}{k} \quad (22)$$

- time taken to send a packet + ACK + PHY overhead + backoff is

$$\begin{aligned} t_{total} &= 2 * PHY + SIFS + DIFS + \frac{backoff}{2} * slot + t_{pkt} + t_{ack} \\ &= 100 + 10 * backoff + \frac{33.06}{k} + \frac{1.978}{k} \\ &= 100 + 10 * backoff + \frac{35.038}{k} \end{aligned} \quad (23)$$

Now theoretical throughput is given as,

$$\begin{aligned} T &= \frac{Payload}{t_{total}} \\ &= \frac{p * 8}{100 + 10 * backoff + \frac{35.038}{k}} \\ &= \frac{1600}{100 + 10 * backoff + \frac{35.038}{k}} \end{aligned} \quad (24)$$

The first field, DIFS (DCF Interframe Space), is a fixed interval of 50 μ s. That is the time spent by all stations to hear the medium before assuming that it is free.

The second field, backoff time, is a random value that the stations must wait to access the medium, once they have verified that the channel is free [5].

$$t_{backoff}(i) = \begin{cases} \frac{[2^i \cdot (CW_{min} + 1)] - 1}{2} \cdot SLOT[\mu s] & 0 \leq i < 6 \\ \frac{CW_{max}}{2} \cdot SLOT[\mu s] & i \geq 6 \end{cases} \quad (25)$$

The PLCP-p and PLCP-h fields of the IEEE 802.11g networks last 192 μs (144 μs for the PLCP preamble and 48 μs for the PLCP header) to ensure compatibility with IEEE 802.11 devices, as explained afterwards [7].

The Data field, in addition to physical headings and preambles, consists of 28 control bytes and the MSDU (MAC Service Data Unit), which make up the message's payload. The duration of the Data field depends on the MSDU value, and also on the frame's transmission speed.

$$t_{fr}(\mu s) = \frac{(MSDU + 28) \cdot 8}{R_B(Mbps)} \quad (26)$$

SIFS (Short Interframe Space) is a fixed interval of 10 μs . SIFS is used for the highest priority transmissions enabling stations with this type of information to access the radio link first.

The ACK field is composed of physical headings and 14 control bytes.

$$t_{ack}(\mu s) = \frac{14 \cdot 8}{R_B(Mbps)} \quad (27)$$

V. BANDWIDTH CALCULATIONS OF IEEE 802.16

IEEE 802.16 architecture consists of two kinds of fixed (non-mobile) stations: a subscriber station (SS) and a base station (BS). The BS regulates all the communication in the network.

We assume that there are N SSs in the system, and BS broadcasts a back-off window size B. Since each user will choose between the 1st and Bth reservation slots to send its bandwidth reservation, the probability of choosing a given slot is $p=1/B$. As a result, the probability of a given slot that is not selected by any SS is given by [4]:

$$P_{NS} = (1 - p)^N \quad (28)$$

Probability of a successful broadcast equals the probability that one user will choose the given slot.

Therefore the system performance is calculated by formula [5]:

$$P_{th} = Np(1 - p)^{N-1} \quad (29)$$

To maximize system throughput, we have to get:

$$\frac{dP_{th}}{dp} = N(1 - p)^{N-1} - N(N - 1)p(1 - p)^{N-2} = 0 \quad (30)$$

$$p = \frac{1}{B} = \frac{1}{N} \Rightarrow N = B \quad (31)$$

VI. CONCLUSION

This paper has presented the performance evaluation of the 2-layer network.

The calculation of bandwidth for each node of 2-layer network has been provided. In the article, it has been explained how the vehicle speed influences the bandwidth of a vehicular wireless network. A significant gain in bandwidth by using the 802.11g standard has been demonstrated. This paper has presented a simple scheme to compute the maximum throughput for an IEEE 802.11g network, which is the most popular WLAN standard at the moment.

In the future our laboratory will research a multipath 2-layer network model and a change of signal volume.

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Nikolajs Bogdanovs, Aleksandrs Ipatovs, Jānis Jansons. Divu līmeņu bezvadu transporta tīkla modelis

Šajā rakstā tika veikts divu mezglu tīkla veikspējas novērtējums, vispirms nosakot katru tīkla mezglu joslas platumu. Lai aprēķinātu divu mezglu tīkla veikspēju, tika izmantota Buzena metode. Tika apskatīts slēgts tīkls, kas sastāvēja no M neatkarīgiem centriem, kur adresējas N prasības, kuru sadale notiek pēc eksponenciālā likuma. Dotais tīkls strādā ar fiksētu uzdevumu skaitu N . Bija noteikta regularitāte datu pārraides ātruma izmaiņas no skaitļa M izdzēsto objektu. Demonstrēta iespējamā dažādu ielas iecirkņu slodze atkarībā no bāzes stacijas attāluma un automobiļu ātruma. Ir noteikts, ka atkarībā no transporta līdzekļa attāluma līdz bāzes stacijai, ātruma apstrādes pakete un intensitātes apstrādes pakete bāzes stacijā būs dažāda.

Šajā darbā tiek piedāvāts divu līmeņu bezvadu transporta tīkla modelis. Pētījumā aprakstīta bezvadu tīkla radīšana kustīgiem objektiem. Atrisināta problēma, kā noteikt kustīgu objektu skaitu uz maģistrāles atkarībā no objektu attāluma līdz bāzes stacijai. Tika demonstrēts katru tīkla mezglu caurlaidības aprēķins. Rakstā ir aprakstīta automobiļa kustības ātruma un pie gala stacijām pieslēgto termināļu skaita ietekme uz divu līmeņu bezvadu transporta tīkla caurlaidību. Tika demonstrēti caurlaidības aprēķini standartiem IEEE 802.11g un IEEE 802.16. Izmantojot saņemtos eksperimenta rezultātus, bija izstrādāts modulis, kas tika pielietots, lai noteiktu reālo datu pārraides ātrumu bezvadu transporta tīklā, atkarībā no N skaita kustības objektu, kas pienāk bāzes stacijā.

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В данной статье была сделана оценка производительности двухузловой сети. Для расчета производительности двухузловой замкнутой сети был использован метод Бузена. Рассматривалась замкнутая сеть, состоящая из M независимых центров, в которой обращается N требований, где распределение происходит по экспоненциальному закону. Данная сеть работает с фиксированным числом задач N . Была выявлена закономерность изменения скорости передачи данных от числа M удалённых объектов. Представлена вероятность загрузки разных участков дороги в зависимости от удалённости базовой станции и скорости автомобилей. Выявлено, что в зависимости от удалённости транспортного средства от базовой станции, скорость обработки пакетов и интенсивность обработки пакетов в базовой станции будет различна.

Предложена двухуровневая модель транспортной беспроводной сети. Был представлен расчет пропускной способности каждого узла сети. В статье описывается создание беспроводной сети для подвижных объектов. Решена проблема определения числа подвижных объектов на магистрали в зависимости от удалённости объектов от базовой станции. В статье описано влияние скорости движения автомобиля и количество терминалов, подключенных к станциям на пропускную способность в двухузловой транспортной беспроводной сети. Продемонстрированы расчеты пропускной способности стандарта IEEE 802.11g и IEEE 802.16. На базе реальных данных, полученных в результате экспериментов, была разработана модель, которая была использована для определения реальной скорости передачи данных в беспроводной транспортной сети в зависимости от числа N движущихся объектов, пребывающих в зоне действия базовой станции.