Study of Probability-Time Characteristics of GSM Standard Mobile Telecommunication Networks

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Abstract

GSM standard mobile telecommunication networks are analyzed, their simplified physical model and vector models of these networks are developed based on it. Analytical models of these networks and methods for calculating probability-time characteristics is proposed based on the M/M/1 type single-channel mass service system, which includes Poisson flow, exponential service time and unlimited queue. Numerical values of the probability-time characteristics such as the probability of the length of the queue in the system, the average number of requests and its average stay time in the system, the average waiting time of all requests in the queue, as well as the fully normalized average value of the stay time of requests in the system are calculated and analyzed through the conducted experiments.

Keywords: GSM standard mobile telecommunication networks, base station subsystem, switching subsystem, mobile station subsystem, management system, operation-technical service center, vector model.

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GSM standartlı mobil telekommunikasiya şəbəkələrinin ehtimal-zaman xarakteristikalarının tədqiqi

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Xülasə

GSM standartlı mobil telekommunikasiya şəbəkələrinin analizi aparılmış, onların sadələşdirilmiş fiziki modeli və onun əsasında bu şəbəkələrin vektor modelləri işlənmişdir. Özündə Puasson axınını, ekponensial xidmət vaxtını və qeyri məhdud növbəni ehtiva edən M/M/1 növ bir kanallı kütləvi xidmət sistemi əsasında bu şəbəkələrin analitik modelləri və ehtimal-zaman xarakteristikalarının hesablanması metodları təklif olunmuşdur. Aparılalan hesabi eksperimentlər vasitəsilə sistemdə növbənin uzunluq ehtimalı, sorğuların orta sayı və onun sistemdə orta qalma vaxtı, bütün sorğuların növbədəki orta gözləmə vaxtı, eləcə də sorğuların sistemdə qalma vaxtının tam normalaşdırılmış orta qiyməti kimi ehtimal-zaman xarakteristikalarının ədədi qiymətləri hesablanmış və onların analizi aparılmışdır.

Açar sözlər: GSM standartlı mobil telekommunikasiya şəbəkələri,baza stansiya alt sistemi, kommutasiya alt sistemi, mobil stansiya alt sistemi,idarə etmə sistemi,istismar-texniki xidmət mərkəzi, vektor modeli.

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Исследование временно-вероятностных характеристик сетей мобильной связи стандарта GSM

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Аннотация

В этой статье проанализированы сети мобильной связи стандарта GSM, на их основе построены их упрощенная физическая модель и векторные модели этих сетей. Предложены аналитические модели этих сетей и методы расчета вероятностно-временных характеристик на основе одноканальной системы массового обслуживания типа M/M/1, включающей Пуассоновский поток, экспоненциальное время обслуживания и неограниченную очередь. Численные значения вероятностно-временных характеристик, таких как вероятность длины ожиданияв системе, среднее количество заявок и среднее время их пребывания в системе, среднее время ожидания всех заявок в очереди, а также полностью нормализованное среднее значение времени пребывания запросов в системе рассчитано и проанализировано в результате проведенных экспериментов.

Ключевые слова: сети мобильной связи стандарта GSM, подсистема базовых станций, подсистема коммутации, подсистема мобильных станций, система управления, центр эксплуатации и технического обслуживания, векторная модель.

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Hasanov M.H. et al.

Introduction

GSM (Global System for Mobile Communications) standard mobile networks are the most modern and rapidly developing field of telecommunications [1]. In these networks, the area where communication is provided is divided into separate cells, while the subscriber usually receives the same service package in each cell. Thus, when moving from one cell to another cell, subscribers can freely use communication services regardless of the area. During relocation, the connection created by subscribers (voice call, data, etc.) should not be interrupted and its continuity should be ensured, as it is ensured by the so-called "hondever" device. The connection created by the subscribers is captured by the neighboring hives, as if in a relay, and the subscribers continue to exchange information over the Internet.

GSM standard mobile telecommunication networks use time division multiple access(TDMA) method. The structure of the TDMA frame includes 8 time positions in each of 124 carriers. Block and ultra-precise coding is used in order to protect against errors in radio channels during the transmission of informational data on these networks. At the small displacement speed of mobile stations, both increasing the coding efficiency and slow changing of working frequencies with a speed of 217 jumps per second during the communication session are ensured. Gaussian frequency manipulation with minimal frequency shift is used in GSM standard mobile telecommunication networks. Information processing is carried out within the framework of its intermittent transmission process, which ensures that the transmitter is connected only when the information is given, and it is disconnected at the end of the transmission. In the case of the converter device, a pulse excitation long-term and linear prediction codec is used. The speed of information conversion in these networks is 13 kbit/s. Functional interaction of network elements is carried out through a number of interfaces. All functional components of GSM standard mobile telecommunication networks interact according to the 7№ to common channel signaling system CCSS.These networks have advantages such as high-speed and high-quality information transmission (voice call, data, etc.), low cost of equipment and services, small size of user equipment, and the ability of subscribers to use mobile phones when switching to other GSM networks [2, 3]. These advantages make the selection of GSM standard mobile telecommunication networks as a research object even more urgent.

Setting the issue

One of the main features of GSM standard mobile telecommunication networks is that their subscribers are mobile and not "bound" to a specific location, they can move within the entire network area and beyond. When it is done, as a rule, the connection is not interrupted, because the service calls are directed to the neighboring cell that is not busy and has sufficient signal level. The structure of these networks includes more elements and different types of communication channels, which make their structure makes it even more complicated. As a result of this, a large number of physical and probabilistic processes occur during the transmission of information on networks, which seriously affect their characteristics. Therefore, it is necessary to use a mathematical apparatus that takes into account the physical and probability processes occurring in the network during the development of analytical models of these types of networks and methods of calculating probability-time characteristics. For this reason, M/M/1, which includes Poisson flow, exponential service time, and unbounded queuing, allows taking into account the physical and probabilistic processes occurring in the network in order to develop analytical models of GSM standard mobile telecommunication networks and calculation methods of probability-time characteristics. The issue of using 1 type of one-channel mass service system is set.

The purpose of the work

Analysis of GSM standard mobile telecommunication networks, development of their simplified physical and vector models, as well as on the basis of this M/M/1 type single-channel mass service system, which includes Poisson flow, exponential service time and unlimited queue. Proposing methods of calculating analytical models and probability-time characteristics of networks, calculating the numerical values of these characteristics through computational experiments and conducting their numerical analysis.

Physical model of GSM standard mobile telecommunication networks. This model includes five subsystems such as base stations subsystem BSSS, switching subsystem SSS, mobile stations subsystem, network management system and other networks subsystem [4, 5]. The physical model of GSM standard mobile telecommunication networks is shown in figure 1.

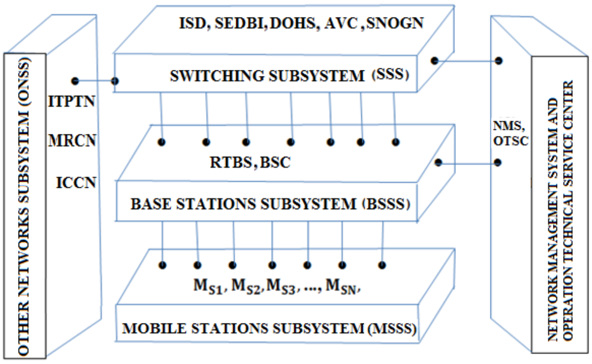


Figure 1 – Physical model of GSM standard mobile telecommunication networks

The switching subsystem SSS performs the function of providing information and includes the authenticity verification center AVC, It includes the subscriber database ISD, the database of "Home" subscribers DOHS, the subscriber equipment database includes SEDBI and the switching nodes of the GSM network SNOGN, which perform the following functions spend [4, 5].

AVC performs verification of the authenticity of subscribers and thus ensures the prevention of unauthorized access to the network. Every time the subscriber opens the phone, makes a voice call, sends an SMS, etc., the authenticity of which is checked through mobile switching based on the information received from the AVC.

In ISD, information is stored about both active subscribers in the service area of the mobile switching center, as well as home subscribers belonging to this mobile switching center and temporarily operating in it, i.e. subscribers of other telecommunication operators or other regions.

In DOHS, both the subscribers belonging to the mobile switching center and the provided services, their status, the location of the subscribers, etc. are stored.

SEDBI stores information about mobile phone identification numbers, which are used to block stolen phones.

SNOGN manages base stations and base station controllers located in the service area of the network. Its main function is to connect network subscribers. Connections between landline telephone and intercity communication networks ICCN, as well as other communication networks are made through this node .

The base station subsystem BSSS performs all the functions related to the radio interface. Within this subsystem, reception/transmission base stations RTBS and base station controllers BSC operate. Its service area is divided and managed into hives, each covered by a RTBS. RTBS mobile stations provide a physical radio interface between CS and BSC. The RTBS includes receiver/transmitter assembly, digital processors and switching equipment of various purposes. The equipment of RTBS is built on the modular principle, which allows to increase the number of radio frequency devices. All important high-frequency equipment, digital devices and power sources work in a structurally autonomous mode. Directional antennas with a horizontal plane radiation pattern width of 120° are used in RTBS. The content of RTBS education includes diagnostic devices that also have an indication of status and operating modes. For testing and tuning RTBS, it is possible to connect it to an external terminal. BSC manages the distribution of several base stations and radio channels, controls the connection between base stations and the switching center of mobile communications, performs connection switching and frequency hopping adjustment, as well as makes decisions about the quality of service of the "relay" transmission based on the information received from RTBS.

The network management system and operation-technical service center is considered the central element of the GSM standard mobile telecommunication network and includes the network management system and the operation-technical center. The management system ensures the management of this network, and the operation and maintenance center performs its operation and maintenance. The operational and technical service center ensures monitoring of network traffic and control of emergency signals occurring in all network elements, depending on the nature of the emergency that may occur in the network and its elimination automatically or with the active intervention of personnel. This system has access to both SSS and BSSS subsystems.

Mobile stations subsystem CS BSSS contains mobile stations CS and they carry out mutual communication of network subscribers.

The other networks subsystem includes the public telephone network ITPTN, the mobile radio communication network MRCN and the intercity communication network ICCN.

Vector model of GSM standard mobile telecommunication networks. In order to expand the physical model of these networks given in figure 1, its basic model can be written with the following vector:

$$W = [K, B, M, D, S],$$

where K, B, M, D and S are subvectors showing the switching subsystem, base stations subsystem, mobile stations subsystem, other networks subsystem, network management system and operation and maintenance center subsystem, respectively.

The K - subvector can be written as:

$$K = [V_{\mathrm{AVC}}, V_{\mathrm{ISD}}, V_{\mathrm{DOHS}}, V_{\mathrm{SEDBI}}, V_{\mathrm{SNOGN}}],$$

where $V_{\mathrm{AVC}}, V_{\mathrm{ISD}}, V_{\mathrm{DOHS}}, V_{\mathrm{SEDBI}}$ and V_{SNOGN} authentication center subsets, subscriber database subsets, "Home" subscriber database subsets, subscriber equipment database subsets, and switching nodes subsets of the GSM network, respectively.

The B- subvector is equal to:

$$B = [V_{RTBS}, V_{BSC}],$$

where V_{RTBS} and V_{BSC} - are receive/transmit base station subsets and base station controller subsets, respectively.

The M-subvector can be written by the following formula:

$$M = [M_1, M_2, M_3, \ldots, M_N],$$

where $M_1, M_2, M_3, \ldots, M_N$ - are subsets of N number of mobile stations.

$$D = [V_{ITPTN}, V_{MRCN}],$$

where V_{ITPTN} are subsets of V_{MRCN} receive/transmit base stations and controller subsets of base stations, respectively.

$$S = [V_{ITPTN}, V_{MRCN}, V_{ICCN}],$$

where n are V_{ITPTN}, V_{MRCN} and V_{ICCN} public telephone network subsets, mobile radio communication network subsets, and long-distance communication network subsets, respectively.

Analytical models of GSM standard mobile telecommunication networks and methods of calculating probability-time characteristics. In order to study these networks, we consider them as single-channel M/M/1 types, which include Poisson flow, exponential service time, and unbounded queuing, let's describe it in the form of a mass service system (figure 2).

Since there is a regular flow of requests in this system, only one request falls into the queue at each time, or one request from the queue is transferred to the service channel, that is, the process of "death and reproduction" takes place in the system [6, 7]. Therefore, the mass service system given in figure 1 is depicted as a transition graph of the "death and reproduction" scheme (figure 3).

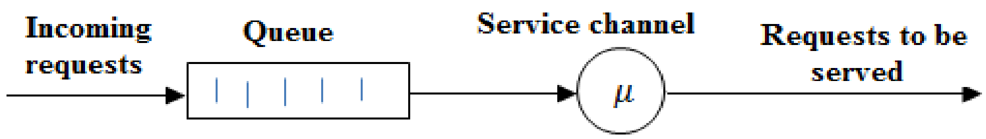


Figure 2 – Description of GSM standard mobile telecommunication networks as M/M/1 type mass

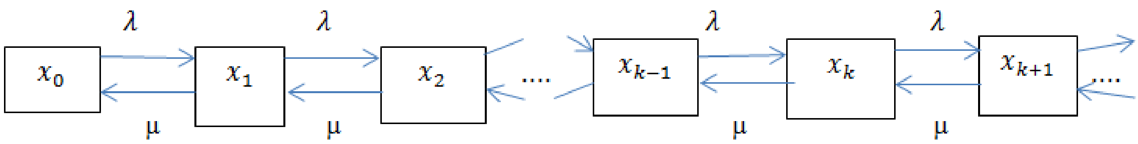


Figure 3 – M/M/1 type mass service system representation as a transition graph of the “death and reproduction” scheme

At this time, the transition states of the system take the following form:

x_0 -the service channel is not busy;

x_1 -the service channel is busy, there is no queue;

x_2 - the service channel is busy, there is only one request in the queue;

x_{k-1} -the service channel is busy, there are $k-2$ requests in the queue;

x_k the service channel is busy, there are $k-1$ requests in the queue,

x_{k+1} -the service channel is busy, there are k number of requests in the queue.

Since the flow of requests to the system is stationary, the transition intensity takes a constant value [6,7], i.e. $\lambda_k = \lambda$, $k = 0,1,2,3,\ldots \mu_k = \mu$, $k = 0,1,2,3,\ldots$

At this time, the probability of having k number of requests in the system in a stationary state is determined by the following formula:

$$P_k = p_0 \prod_{i=0}^{k-1} (\lambda / \mu) = p_0 (\lambda / \mu)^k \qquad (1)$$

Since the series is cumulative in this formula, its initial value can be written as follows:

$$\begin{aligned} p_0 &= 1/\sum_{k=1}^{\infty} (\lambda / \mu)^k = \\ &= 1/(1+(\lambda/\mu)/(1-\lambda/\mu)) = \\ &= 1-(\lambda/\mu) = 1-\rho \end{aligned} \qquad (2)$$

where ρ, k, λ and μ are respectively the load of the system, the number of requests, the intensity of requests entering the system, and the intensity of serving requests.

In this case, the probability of the length of the queue resulting from k number of requests entering the system can be calculated by the following formula:

$$p_k = (1-\rho)\rho^k \qquad (3)$$

Based on the mathematical expectation of k number of discrete random quantities in the considered system [8, 9], the average number of requests in the system and its variance are determined by the following formulas, respectively:

$$\overline{N} = \sum_{k=0}^{\infty} k p_k = (1-\rho) \sum_{k=0}^{\infty} k \rho^k = \rho/(1-\rho),$$

$$\sigma^2 = \sum_{k=0}^{\infty} (k - \overline{N})^2 p_k = \rho/(1-\rho)^2 \qquad (4)$$

where p_k and $\overline{N}$ – are determined by formulas (3) and (4), respectively.

According to Littla's formula, the average time of requests in the system can be determined as follows:

$$\overline{T} = \overline{N}/\lambda \qquad (5)$$

If we take into account the formula (4) and $\lambda = \rho\mu$ in (5) and solve it, we will get the final formula for the average time of requests in the system:

$$\overline{T} = 1/\mu(1-\rho) \qquad (6)$$

The probability that there are at least m number of requests in the system, as well as the probability that there are less than the number of requests in the system are determined by the following formulas [8–10]:

$$P\{k \geq m\} = \sum_{k=m}^{\infty} (1-\rho)\rho^k = \rho^m,$$

$$P\{k < m\} = 1-\rho^m \qquad (7)$$

Now let's look at defining the characteristics of the queue in the system. The average number of requests in the system is equal to the sum of the average number of requests in the service channel and the average number of requests in the queue, that is:

$$\overline{N}_S = \overline{N}_{xk} + \overline{N}_{\text{queue}} \qquad (8)$$

where is $\overline{N}_{xk}$ the average number of requests in the service channel, $\overline{N}_{\text{queue}}$ is the average number of requests in the queue, whichdefined as follows:

$$\overline{N}_{\text{queue}} = \overline{N} - \rho \qquad (9)$$

where $\overline{N}$ - is determined by the formula (4).

Calculation of the average number of requests in the queue if we consider and solve formula (4)-(9).

We get the final formula for

$$\overline{N}_{\text{queue}} = \rho^2 /(1-\rho) \qquad (10)$$

Using Littla's formula [8, 9], the average waiting time of all requests in the queue $\overline{W}_G$ can be determined as follows:

$$\overline{W}_G = \overline{N}_{\text{queue}} / \lambda = (\rho^2 /(1-\rho)) / \lambda \qquad (11)$$

where $\overline{N}_{\text{queue}}$ - is determined by the formula (10).

If we take into account the formula (10) and $\lambda = \rho\mu$ value in (11) and solve it, we will get the final formula for calculating the average waiting time of all requests in the queue:

$$\overline{W}_G = \rho / \mu(1-\rho) \qquad (12)$$

The fully normalized average dwell time of requests in the system indicates how many times the requests exceed the average waiting time in the service channel due to the presence of a queue in the system. In the considered M/M/1 mass service system, the fully normalized average stay time of requests in the system $\overline{T}_{norm}$ is equal to:

$$\overline{T}_{norm} = \overline{T} / \overline{x}, \quad \overline{x} = \rho / \lambda \qquad (13)$$

where $\overline{T}$ - is determined by the formula (5), $\overline{x}$ - is the processing time of requests in the service channel of the system.

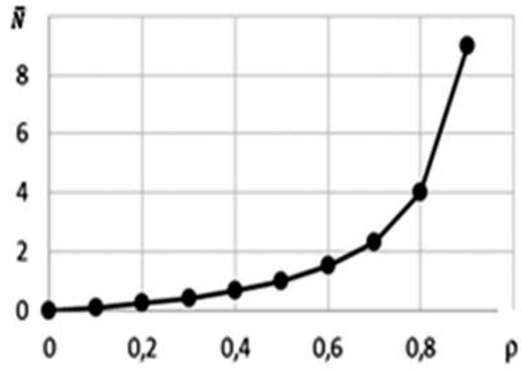
If we consider and solve the formulas (4), (5) in (13), as a result, we will get the final calculation formula for the fully normalized average value of the requests staying time in the system:

$$\overline{T}_{norm} = 1/(1-\rho) \qquad (14)$$

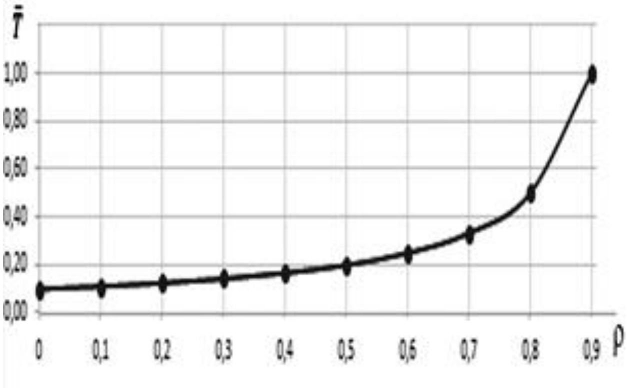
Results of computational experiments and their analysis. In order to determine the EZX numerical values of the probability-time characteristics of GSM standard mobile telecommunication networks, calculation experiments were carried out using Excel software. This time $\rho = 0;0.1;0.2;0.3;0.4;0.5;0.6;0.7;0.8;0.9$ and $\mu = 10$ requests/s/based on formulas (4), (6), (12) and (14) using the initial data, the average number of requests in the system $\overline{N}$, the average waiting time $\overline{T}$, the average waiting time of all requests in the queue and $\overline{W}_G$ the fully normalized average of the requests staying time in the system the numerical values of time $\overline{T}_{norm}$ were set, the obtained results are given in table.

Table – Numerical values of probability-time characteristics of the system

EZX \ ρ	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
$\overline{N}$	0	0.11	0.25	0.43	0.67	1.0	1.5	2.33	4.0	9.0
$\overline{T}$	0.1	0.11	0.13	0.14	0.17	0.2	0.25	0.33	0.5	1.0
$\overline{W}_G$	0	0.007	0.017	0.029	0.044	0.067	0.1	0.156	0.267	0.6
$\overline{T}_{norm.}$	1.0	1.11	1.25	1.43	1.67	2.0	2.5	3.33	5.0	10



a)



b)

Figure 3 – Graphs of the average number of requests in the system: a) and the average stay time b) depending on the system load

Based on the values given in Table 1, the average number $\overline{N}$ of requests in the system and the average stay time $\overline{T}$ graphs of dependence on the load of the system were constructed (fig. 3a, b).

The analysis of the graphs shows that the average number of requests in the system increases with the increase of the system load the dwell time increases as a whole, when the load changes in the rang $\rho = 0 \div 0.5$, both the average number of requests in the system and the values of the average dwell time slowly increase, and when it changes in the range of $\rho = 0.5 \div 0.9$, a jump is observed.

Conclusion

GSM has analyzed standard mobile telecommunication networks as a whole, their provision of high-speed and high-quality voice and data transmission, low cost of equipment and services, small size of user equipment, and the ability of subscribers to use mobile phones when switching to other GSM networks. It is noted that it has such advantages. Information transmission processes in GSM standard mobile telecommunication networks were analyzed, a simplified physical model of these networks and its vector models were proposed in order to expand this model.

In order to study the characteristics of GSM standard mobile telecommunication networks, they are described as a M/M/1 type single-channel mass service system containing Poisson flow, exponential service time, and unlimited queuing. and possible transition states are shown. Based on M/M/1 type mass service system, analytical models of GSM standard mobile telecommunication networks were developed and based on these models, methods for calculating their probability-time characteristics were proposed. Numerical values of the probability - time characteristics such as the probability of the length of the queue resulting from requests in the system, the average number of requests and the average stay time in the system, the average waiting time of all requests in the queue, as well as the fully normalized average value of the stay time of requests in the system, and their numerical value analysis was carried out.

Conflict of Interests

The authors declare there is no conflict of interests related to the publication of this article.

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