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Optimization of Common Voice and Data Channel Resources in GSM/GPRS Network

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Introduction

A GPRS system was introduced using the present GSM infrastructure. The same radio resources are used for transmission of packed data and circuit switched voice. Management of common voice and data channel resources depends upon many factors, such as the number of data and voice users, usage behavior, radio channel resources and internal management rules.

In this paper a mathematical model of common GSM/GPRS resources and a simulation model created in Matlab Simulink are presented. The model connects two systems: a CS (Circuit Switched) voice – GSM system, and a packet date transfer – GPRS system. Peculiarities of interaction of GSM and GPRS users are investigated. During the modeling common channel utilization, the number of served users, user data throughput as well as blocking probabilities of voice and data users' are analyzed. Suggestions for optimization of common data and voice channel resources are formulated.

Initial input parameters of the model are measured in a real GSM/GPRS network using TEMS drive testing tools and network statistics.

To confirm modeling results and model adequacy, measurements of characteristics of a real system in a commercial GSM/GPRS network are done.

Controlling resources of a GSM/GPRS network radio connection

A radio connection (Um) is set between a Mobile Station (MS) and a Base Transmitter Station (BTS). FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) radio channels are used to create a connection between the MS and the BTS. Resources of a single frequency channel in the GSM/GPRS system are presented in Fig. 1.

CS (Circuit Switched) channels are dedicated for voice transmission. R (Reserved) channels are dedicated for packet data transmission. SW (Switchable) channels are common channels that could be switched from PD (packet data) channels to voice channels depending on the number of data and voice users. In SW channels voice users have higher priority than data users. Therefore, when all voice resources are used, voice users can preempt SW channels.

Rules of channel switching, as used by majority of network equipment manufacturers, are described in [4].

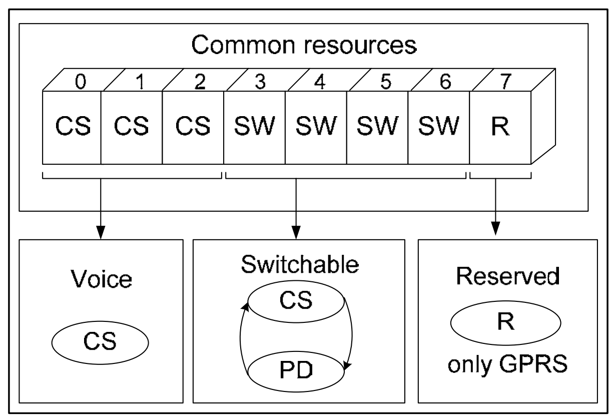

Fig. 1. Resources of a physical GSM/GPRS channel

In the GPRS network capacity of the cell for packet data transmission depends not only on dedicated data resources but also upon the number of voice requests and their time slots (TS). Packet data resources are assigned to all data users served in one cell. If the amount of voice users does not exceed the number of TS dedicated for voice, the number of time slots assigned to one data user (N_T) can be estimated this way:

$$N_T = \frac{C_R + C_{SW}}{N_D} . \qquad (1)$$

It is valid, if $N_{CS} \le C_{CS}$. Here: C_R – the amount of reserved PD TS, C_{SW} – the amount of switchable TS, N_D – the number of data users, N_{CS} – the number of voice users, C_{CS} – the number of TS assigned to voice users.

Mathematic model of common GSM/GPRS resources

Processes, that take place while dividing common data and voice resources, were thoroughly analyzed on purpose to create a mathematical model of a common GSM/GPRS channel. Background for the modeling is taken from [1] and [2]. However, we expand and develop the model, presented in [2], by adding SW TS transformation hysteresis, a possibility of one TS to allocate up to 4 MS and a possibility to use up to 8 TS for data transmission per carrier.
System capacity is the total number of allocated TS: $C_{\Sigma}=C_R+C_{CS}+C_{SW}$. The arrivals of CS voice call requests and GPRS Temporary block flows (TBF) form a Poisson process with a mean rate of λ_b and λ_d. The service time of voice calls and TBF sessions is assumed to be exponentially distributed with a mean of μ_b and μ_d.

Any state of the system may be described using a probability of three variables:

$$P_{i,j,k} = F(i,j,k),$$

where

i – the number of TS, engaged with voice;
j – the number of TS, engaged with data;
k – the number of TBF data sessions.

1 TS may include up to 4 TBF. A new voice call will be blocked, if (at its arrival) there are no available voice channels. In this case, the amount of voice channels in the system will be: $C_B=C_{CS}+C_{SW}$. A data session (TBF) will be blocked, when, creating a new TBF, all data time slots are engaged already: $C_D=C_R+C_{SW}$, and every data TS will include maximum 4 TBF sessions. Range of $P_{i,j,k}$ probability states is:

$$S = \left\{ \begin{array}{l} (i,j,k) \big| 0 \le i + j \le C_{\Sigma} \;,0 \le i \le C_{CS} + C_{SW}, \\ 0 \le j \le C_R + C_{SW}, 0 \le k \le (j \cdot 4), \\ C_{\Sigma} = C_R + C_{CS} + C_{SW} \end{array} \right\} \tag{2}$$

The diagram of range of possible $P_{i,j,k}$ probability states is shown in Fig. 2.

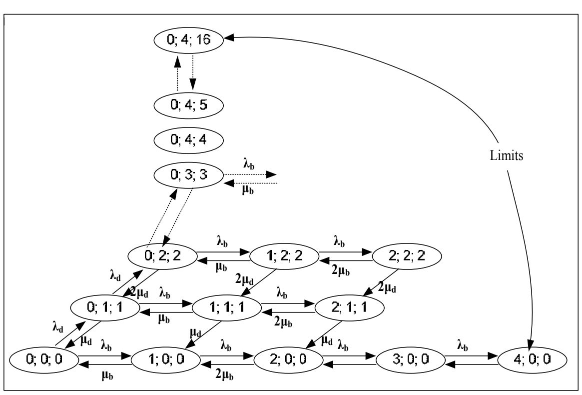

Fig. 2. Range of possible $P_{i,j,k}$ probability states

One mobile phone can maximally use up to 4 data channels (TS) at the same time.

The possibility of call blocking is equal to multiplication of probability, that all $i=C_{CS}+C_{SW}$ voice channels are engaged, by probability of arrival of a new voice call:

$$P_{CS} = P_{i=C_{CS}+C_{SW}} \cdot P_{CS,new}. \tag{3}$$

Probability, that all voice channels are engaged, equals the sum of all probabilities of conditions of the system, when $i = C_{CS} + C_{SW}$:

$$P_{i=C_{CS}+C_{SW}} = \sum_{i=C_{CS}+C_{SW}} P(i,j,k), \tag{4}$$

$$P_{CS,new} = \lambda_b \cdot \varphi(i+1,j,k), \tag{5}$$

where $\varphi(i+1,j,k)$ is a function that equals one, when *i* variable increases by one (*j* and *k* do not change) and it equals zero in all other cases.

The probability of blocking of a data session is equal to multiplication of probability, that every data TS includes 4 TBF, by probability of arrival of a new data or voice session:

$$P_D = P_{k=C_D \cdot 4} \cdot P_{TBFnew}, \tag{6}$$

where

$$P_{TBF,new} = \lambda_d \cdot \varphi(i,j,k+1), \tag{7}$$

$$P_{k=C_D \cdot 4} = \sum_{i=C_D \cdot 4} P(i,j,k), \tag{8}$$

where

$$C_D = C_R + C_{SW} - n(i, C_{CS}, C_{SW}). \tag{9}$$

The amount of SW TS reserved for data transmission depends on the amount of calls *i*, that take place at the particular moment.

$$n(i, C_{CS}, C_{SW}) = \begin{bmatrix} 0 & ,if\ i < C_{CS} \\ 1 & ,if\ i = C_{CS} \\ 2 & if\ i = C_{CS}+1 \\ C_{SW}, & if\ i = C_{CS}+C_{SW} \end{bmatrix} \tag{10}$$

If the maximum possible amount of voice calls $i = C_{CS} + C_{SW}$ is reached, only reserved channels C_R will be left for data transmission.

The probability of blocking of TBF sessions depends not only on the amount of the number of data users but also upon the number of voice sessions. Channel usage, that is estimated dividing useful work time of the transmitter by all work time, not estimating transformation time of SW channels, is:

$$U = \frac{\sum_{(i,j,k)\in S} (i+j) \cdot P_{i,j,k}}{C_{\Sigma}}. \tag{11}$$

Time of transformation of a SW channel (t_{TR}) includes time, needed to preempt the channel t_h, and time, needed to assign the channel for a new user (t_p).

$$t_{TR} = t_h + t_p. \tag{12}$$

Creating a model in Matlab - Simulink

We will analyze the case, when common recourses include one TS reserved for data (R), three TS reserved for voice (CS) and four common SW TS. In SW TS voice transmission takes priority over data transmission. Therefore, when a voice request arrives, a SW channel will be transformed into a CS under the rules, described in [4]. The general structure of the model is presented in Fig 3.

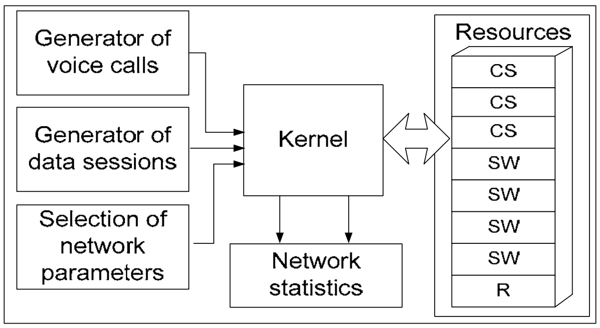

Fig. 3. General structure of the model

The algorithm of control of data resources is shown in Fig. 4.

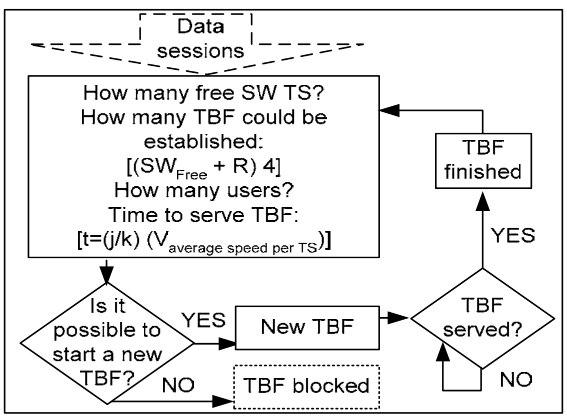

Fig. 4. The algorithm of control of data transmission resources

Controlled parameters are: a transformation index, time of arriving and serving of voice requests and data packets. Time of transformation of a SW channel (t_{TR}) is also estimated while modeling.

The amount of voice requests, their serving time and the transformation parameter directly determine the amount of free SW channels. The less SW channels are assigned to data transmission, the less data users are served and data transition speed is reduced accordingly.

The algorithm of data transmission is much more complicated than voice transmission. When a new data request arrives the speed of data transmission and the time of data transmission are estimated. During the modeling they are continuously tuned depending on the data load, the number of data users and the amount of free SW channels.

Estimation of model input data

A Motorola mobile phone with an expanded menu, that allows observing the amount of transmitted data and used time slots, was chosen for the research. The mobile phone was connected to a personal computer. The "DuMeter" program was used to measure the average and maximum speed of data transmission, the amount of incoming and outgoing data and time required for transmission of data packets. Measurements were done in natural environment of the GPRS/GSM network.

Table 1. Measurement of data speed and transmitted data

	WAP	WWW	FTP
The average speed of data transmission in 1 TS, kb/s	12	13	15
The average amount of transmitted data per one TBF, kb	10	1000	3000
Usage %	60	30	10

After evaluating the usage of every kind of service using a weight coefficient, the average amount of transmitted data is estimated:

$$N_{\sum} = N_1 \cdot k_1 + N_2 \cdot k_2 + N_3 \cdot k_3 ; \qquad (13)$$

$$N_{\sum} = 606 \text{ [kb]}.$$

The estimated average amount of transmitted data and the average speed of data transmitting are used to set initial input parameters of the model.

Modeling

We set that during the modeling maximum voice call blocking rate could be 1.5% and maximum allowed blocking rate of data packets could be up to 10-20%. Data interchange is controlled by a PCU (Packet Control Unit) [1] and dropped data packets are automatically retransmitted. Therefore, the system can accept packet blocking rate up to ten times higher than voice blocking rate. Additional initial parameters of the model are presented in Table 2.

Table 2. Initial parameters of the model

Parameter	Value
The average time for serving a voice request, s	40
The average time for transforming a SW TS, s	4
The average speed of data transmission per 1 TS, kb/s	15
The average amount of transferred data per a TBF, kb	606
Time of modeling, s	3600
Value of the transformation index	1

The transformation index indicates how many SW TS should be preempted end transformed to voice TS before the arrival of a new voice call when all TS, dedicated to voice, are already used.

Dependency of blocking rate and data transmission speed on the load of voice calls is presented in Fig. 5.

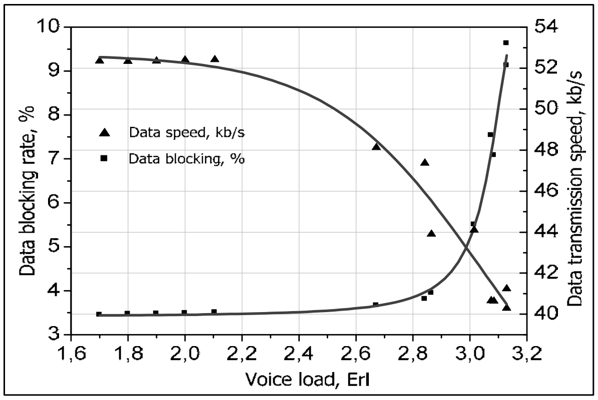

Fig. 5. Dependency of blocking rate and data transmission speed on the load of voice calls

From Fig. 5 we can notice that the average data transmission speed and probability of blocking of data packets in the GSM/GPRS system depends not only on the data load, but upon the voice load as well. The reason for this is that the growing load of voice requests reduces the amount of SW channels, assigned to data transmission. When the voice load grows, initially we can note only reduction of data transmission speed. However, when the voice load becomes very high (more than 3Erl), blocking probability of data packets increases very fast.

Dependency of utilization of common resources of the GSM/GPRS system on the common load of equivalent voice and data requests is presented in Fig. 6.

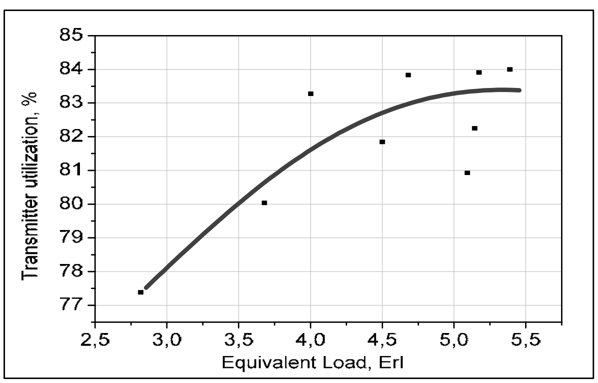

Fig. 6. Dependency of GSM/GPRS transmitter utilization on the common equivalent load of voice and data

We observe that maximum utilization of GSM/GPRS transmitters reaches 83%. During the modeling voice blocking probability is not allowed to reach 1.5 % and blocking probability of data requests is not allowed to reach 10%.

Optimization of common data and voice channel resources in mobile networks

This chapter deals with recommendations to optimization of use of common data and voice resources. The purpose of the modeling is to find an optimal index of transformation under certain determined conditions. When an optimal index is chosen, possibility of blocking a voice request can not exceed 1.5% and possibility of blocking data requests must not exceed 15%. The allowable voice blocking probability is up to 10 times lower than blocking probability of data.

Voice blocking probability, that is higher than 1.5%, can cause discomfort and dissatisfaction of mobile users. It could form a negative opinion about the mobile network operator.

Blocking probability of data packets could be higher. From measurement results it was obtained that 10% packet blocking probability does not considerably reduce perceived service quality of the GPRS end user. In that case only a short speed reduction occurs.

From Fig. 7 it could be noted that, when the transformation index equals 0, voice blocking is 1.6%, whereas when the index is from 1 to 5, blocking does not reach 0.7%. Blocking probability of data packets is within acceptable limits only when the transformation index is 0 and 1. If the transformation index increases, blocking probability of data packets increases rapidly as well and exceeds the acceptable level. When the transformation index is increased, the number of data transfer channels and the average speed of data transition decreases.

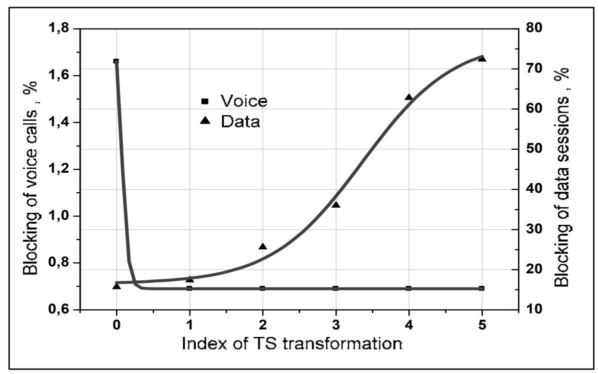

Fig. 7. Dependency of blocking probability of data sessions and voice calls on the TS transformation index

Utilization of a common GSM/GPRS transmitter with the transformation index equal to 0 and 1 is approximately 87%. If the transformation index further increases, utilization significantly decreases, because more and more resources become unused.

When data and voice load peeks occur at the same time, usually the capacity of a base station is expanded and high blocking of data packet requests is avoided. During the research this critical situation is modeled in order to investigate system processes when the maximum load is reached.

After evaluation of measured system parameters and their influence on perceived service quality of the end user, it is recommended to set the transformation index equal to 1.

The investigation of the most critical situation was done (when both data and voice request loads are the highest simultaneously). The voice load is approximately 2.5 Erl and the equivalent data load is approximately 2 – 4 Erl, depending on the amount of SW channels.

Dependency of blocking probability of data requests and the average speed dedicated for one user on the number of SW channels is presented in Fig. 8.

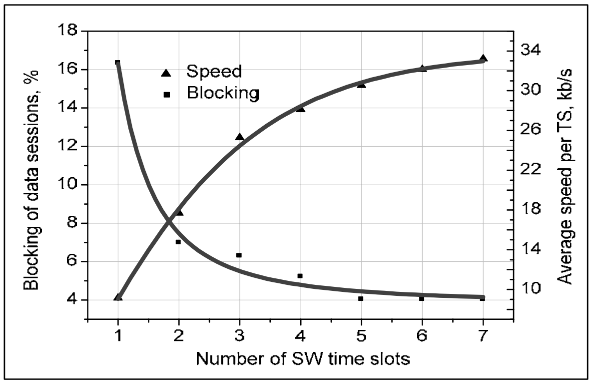

Fig. 8. Dependency of blocking probability of data requests and the average speed dedicated for one user on the number of SW channels

From Fig. 8 it could be noted that user data speed considerably increases when the amount of SW channels is increased. Blocking probability of data packets decreases quickly when the second and the third SW TS are added. So minimally 3 – 4 SW channels are needed for normal operation. However, optimal system operation will be reached only using 6 – 7 SW channels.

The average data transfer speed and data blocking probability in the GSM/GPRS system are determined not only by data, but also by the voice load. When the voice load increases significantly, data blocking increases as well. In that case data transfer speed decreases.

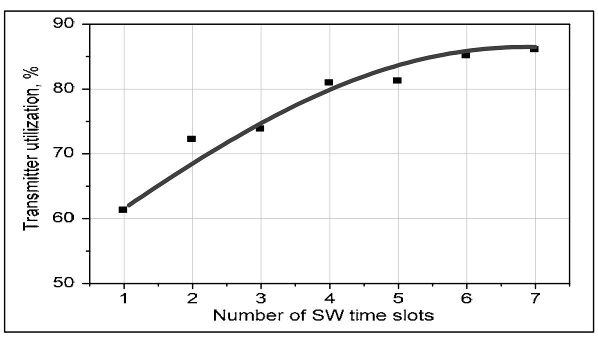

Fig. 9. Transmitter utilization dependency on the number of SW channels (Modeling results)

From Fig. 9 it could be noted that transmitter utilization depends a lot on the number of SW channels and varies from 60 to 87%. This utilization increase is conditioned by fast reuse of SW channels for data transition after the end of a voice call.

Results of the practical research of GSM/GPRS systems

An experimental research was done in a test base station with this configuration: R=1TS; SW= from 1TS to 7TS; CS= from 7TS to 1TS. In total: R+SW+CS = 8TS.

The most critical case, when both data and voice request loads are the highest at the same time, was investigated. During the experiment SW TS were changed from 1 to 7. The average and maximum voice and data loads were measured as well.

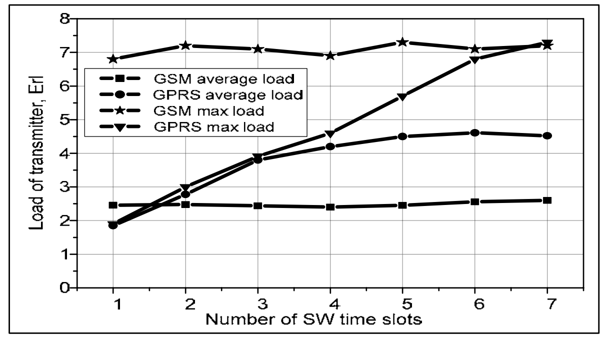

Fig. 10. The measured average and maximum voice and data load dependency on the number of SW channels

From results of experiments it could be noted that the average load was around 2,48 Erl. The equivalent data load, when the number of SW TS was increasing, was growing from 1,85 till 4,61 Erl. Furthermore, the maximum possible peek data load was increasing as well.

While the data load was increasing voice blocking probability was constant, data blocking was decreasing and the average data transmitting speed was growing.

The measured transmitter utilization dependency on the number of SW channels is shown in Fig. 11.

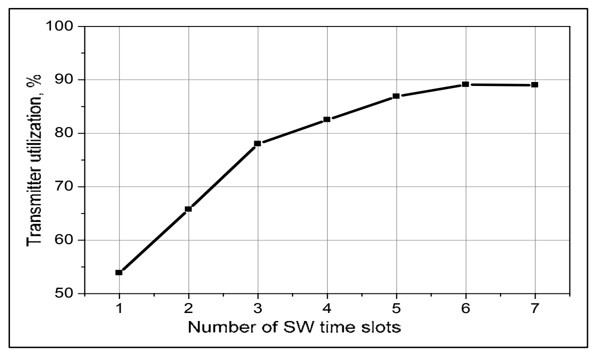

Fig. 11. Transmitter utilization dependency on the number of SW channels (Real system measurement results)

Measurement results show, that a bigger amount of SW channels allows to increase data throughput for the end user and to increase utilization of common GSM/GPRS resources. This is possible, because channels, not used for voice transfer, are dynamically switched to data transfer. When a new voice call arrives, for data assigned channels are dynamically preempted and without blocking the voice call are switched to voice transfer. In this case (for data transfer) not only for data dedicated resources, but also all other transmitter resources (not used for voice transfer) are used.

Conclusions

Use of the system adequate simulation models allows evaluation of varying needs of users and calculation of optimal system parameters before introducing any changes into a live commercial GSM/GPRS network.

We expand and develop the model, presented in [2], by adding SW TS transformation hysteresis, a possibility of one TS to allocate up to 4 MS and a possibility to use up to 8 TS for data transmission.

Referring to modeling and measurement results we could recommend that it is enough to set the TS transformation index equal to one in high loaded cells. This kind of transformation hysteresis stops discontinuous TS transformations and reduces blocking probability of voice and data packets.

In any cell, used for voice and data transmission, it is better to set the maximum possible number of SW TS. For example, if all 7 voice TS are configured as SW TS, the speed of data transmission for the end user, the possible number of data users and utilization of transmitters increase while voice blocking probability does not change. This is possible, because channels, not used for voice transfer, are dynamically switched to data transfer and utilize spare capacity between voice calls.

When 1 for data reserved TS and 7 SW TS are used in the transmitter, GSM/GPRS transmitter utilization reaches 90%, while blocking probabilities of voice and data requests do not exceed 1% and 10%.

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V. Batkauskas, D. Balčiūnas. Оптимизация обшего канального ресурса, используемого для передачи данных и голоса в GSM/GPRS сетях // Электроника и электротехника. – Каунас : Технология , 2006. - № 5(69). – С. 67–72.

Использование моделей, адекватных системе, дает возможность оперативно и точно оценить переменчивые нужды потребителей и вычислить параметры системы, перед тем как делать изменения на сети коммерческого предназначения. Описана математическая модель общего GSM/GPRS ресурса и создана компьютерная модель в среде Matlab Simulink. Во время моделирования исследуется использование общего GSM и GPRS канала, счет обслуженных потребителей, скорость передачи данных на одного потребителя и вероятность блокирования запросов данных и голоса. Сформулированы предложения связи с оптимизацией общей системы передачи данных и голоса. Начальные параметры модели измеряемы в реальной сети, используя измерители TEMS и статистики сети. Для проверки результатов моделирования исследуется реальная GSM/GPRS станция, работающая в условиях аналогичных моделей. Руководствуясь результатами моделирования и измерений, можно рекомендовать при большой нагрузке станции индекс трансформации TS установить на единицу. Такой гистерезис трансформации уменьшает лишние трансформации TS, а таким образом уменьшается блокирование запросов на голос и передачу данных. На станциях передачи данных и голоса лучше всего установить максимально возможный счет SW TS. Ил. 11, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Batkauskas, D. Balčiūnas. Bendrų duomenų ir balso išteklių naudojimo optimizavimas GSM/GPRS tinkluose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 5(69). – P. 67–72.

Naudojant sistemai adekvačius modelius, galima operatyviai ir tiksliai įvertinti kintančius vartotojų poreikius ir apskaičiuoti sistemos parametrus prieš darant pakeitimus komerciniame GSM/GPRS tinkle. Aprašomas sudarytas bendrų GSM/GPRS išteklių matematinis modelis ir Matlab Simulink terpėje sukurtas kompiuterinis modelis. Modeliavimo metu tiriamas GSM ir GPRS bendro kanalo panaudojimas, aptarnautų vartotojų skaičius, vienam vartotojui tenkanti duomenų perdavimo sparta ir balso bei duomenų blokavimo tikimybės. Pateikiama pasiūlymų dėl bendros balso ir duomenų perdavimo sistemos optimizavimo. Pradiniai modelio parametrai išmatuojami realiame GSM/GPRS tinkle, naudojant TEMS matavimo įrangą ir tinklo statistikas. Modeliavimo rezultatams patikrinti atliekami realios ląstelės, dirbančios panašiomis į modeliuojamą sąlygomis, tyrimai. Remiantis modeliavimo ir matavimo rezultatais, galima teigti, kad TS transformavimo indeksą labai apkrautose ląstelėse užtenka nustatyti lygų vienam. Tokia transformavimo histerizė sumažina nereikalingų TS transformacijų skaičių. Šitaip sumažėja ir balso bei duomenų užklausų blokavimas. Balsui ir duomenims perduoti naudojamose ląstelėse yra geriausia sudaryti maksimalų galimą SW TS skaičių. Il. 11, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių kalbomis).