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Estimation of Traffic Influence on Energy Saving at GSM Channels with Reallocation

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Abstract: This paper presents an innovative procedure for base station emission power calculation in the case of traffic channels reallocation implementation in GSM mobile systems. The main idea of active traffic channels reallocation is to place the connections which require higher emission power due to higher mutual distance between base station and mobile station to the first frequency carrier because these channels have to be always in active mode due to the applied discipline of traffic service in GSM mobile systems. The principle of connections reallocation on the base of distance values sequence determination is novelty comparing to the much more applied principle of connections arrangement according to the propagation conditions. Power saving as the result of this method usage is compared to the necessary power when the sequential hunting with homing method of idle channel looking for is applied. Two special cases are analyzed: 1. the case of low offered traffic (when not more than 6 traffic channels are busy on average) and 2. the case when offered traffic is increased. It is proved that the achieved relative energy saving when the offered traffic is increased over 6Erl rapidly grows at first and then begins to fall. It is important that the absolute value of power saving continuously increases when the offered traffic is increased. One typical example of base station emission power save daily profile is presented on the base of the obtained results. All results in the paper are verified by traffic process simulation.

Keywords: energy saving; base station emission power; sequential hunting with homing method of idle channel seizure; channel reallocation; daily traffic profile

Ocena vpliva prometa na varčevanje z energijo v kanalih GSM s prerazporeditvijo

Izvleček: V članku je predstavljen inovativen postopek za izračun emisijske moči bazne postaje v primeru prerazporeditve prometnih kanalov v mobilnih sistemih GSM. Glavna ideja prerazporeditve aktivnih prometnih kanalov je, da se povezave, ki zaradi večje medsebojne razdalje med bazno in mobilno postajo zahtevajo večjo moč oddajanja, prenesejo na prvo nosilno frekvenco, saj morajo biti ti kanali zaradi uporabljene discipline prometnih storitev v mobilnih sistemih GSM vedno v aktivnem načinu. Načelo prerazporeditve povezav na podlagi določitve zaporedja vrednosti razdalj je novost v primerjavi z veliko bolj uporabljenim načelom razporejanja povezav glede na pogoje razširjanja. Prihranek energije zaradi uporabe te metode je primerljiv s potrebno močjo pri uporabi zaporednega lovljenja z metodo iskanja praznega kanala. Analizirana sta dva posebna primera: 1. primer nizkega ponujenega prometa (ko je v povprečju zasedenih največ 6 prometnih kanalov) in primer, ko se ponujeni promet poveča. Dokazano je, da doseženi relativni prihranek energije pri povečanju ponujenega prometa nad 6Erl najprej hitro narašča, nato pa začne padati. Pomembno je, da se absolutna vrednost prihranka energije nenehno povečuje, ko se poveča ponujeni promet. Na podlagi dobljenih rezultatov je predstavljen en tipičen primer dnevnega profila prihranka energije emisij bazne postaje. Vsi rezultati v članku so preverjeni s simulacijo prometnega procesa.

Ključne besede: varčevanje z energijo; oddajna moč bazne postaje; zaporedni lov z metodo iskanja domačega kanala v mirovanju; prerazporeditev kanala; dnevni prometni profil

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1 Introduction

Last five decades are characterised by the rapid development of mobile communications. Starting from the first generation (1G) of mobile systems between 1970s and 1980s, achievable communication rate and data capacities were constantly increased [1]. The first generation systems (also known as Advanced Mobile Phone Systems – AMPS) were used only for analog voice communication and their maximum rate was 2.4kb/s [2]. These performances were improved in the second generation systems (2G) which started in 1990s. The applied digital Global System for Mobile (GSM) technology allowed communication rate of 1Mbps. Although still devoted mainly to voice communication, these systems introduced services as text messages, picture messages and multimedia messages (MMS) [2].

The third generation systems (3G) in Code-Division Multiple Access (CDMA) technology and Universal Mobile Telecommunication System (UMTS) framework further improved communication rate to 2Mbps maximum [2] and allowed services as video calls and conferencing, video with some multimedia, mobile television, Global Positioning System (GPS). 3G technics was first introduced at the beginning of 21st century. The new applied principles are based on packet switching to achieve fast data transmission.

The fourth generation (4G) systems started in 2010. The applied technologies are Long Term Evaluation (LTE) and Worldwide Interoperability for Microwave Access (WiMAX). The communication rate is increased to 60Mbps and even 100Mbps [1], [2]. The new services in 4G systems are mobile web access, gaming, 3D television. The spectral efficiency is approximately doubled comparing to 3G systems [3]. The achieved improvements are based on the combined application of Frequency-Division-Duplex (FDD) and Time-Division-Duplex (TDD) principles [3].

The most modern systems are designated as the fifth generation (5G). The significantly increased data rates comparing to 4G (up to 20Gbps down-link) allow application of services as Internet of Things (IoT), Machine Learning (ML), UltraHD streaming videos, virtual reality media and so on [1]. This technology is at high level of development today.

Energy (power) consumption decrease is one of the primary goals today. It is important to consider possibilities to save power in each system type from 2G to 5G. When speaking about the necessary energy for base station (BTS) operation in GSM systems, traffic channels reallocation is one of the methods. It is proved in [4] that reallocation decreases this objective in two ways: by seizing traffic channels in the first carrier in the beginning and then by allocation of these channels to the users who need the maximum emission power. The price paid for this saving is the reallocation of busy traffic channels in such a way that the channels which require maximum emission power are placed in the first 6 traffic channels (TCH) which have always the maximum emission power [5]. The procedure for channels reallocation is not more complex than the simplest handover. (All channels at the first carrier in all BTSs have the maximum emission power and are used to determine the nearest BTS to some mobile station, MS). It is proved in [4] that energy and power saving depends on the number of carriers, i.e., number of channels, on the environment characteristics and on the users surface distribution in the mobile cell. This paper considers process of power saving in more detail and the accent in this paper is on the traffic analysis for all traffic values. Power saving as the function of the offered traffic is determined in all cases, i.e., also at small traffic values. It is proved that power saving exists even at such low traffic level. The additional value of this paper in relation to [4] is that it considers power saving according to the daily traffic profile. The significant level of relative power saving comparing to the systems without reallocation during the day is proved, because approximately half a day time the offered traffic is not high and may be served by the traffic channels on the first carrier. The modifications in the paper comparing to [4] are related also to some important aspects of simulation process: for example, simulation now supports conclusions making not only on the base of offered traffic but also on the base of instantaneous realized connections number.

The existing methods and solutions for power saving in mobile GSM systems are presented in the section 2. The two models of traffic channels seizure, which are later analyzed in this paper - the sequential hunting model with homing procedure of looking for idle channel and the model with channel reallocation are described in the section 3. All variables used in this paper are also defined in this section. These two models in the case of small traffic, (i.e., when less than 7 connections are realized), are compared in the section 4. The calculation of base station emission power in the case of low offered traffic – (approximately) up to about 7E is presented in the section 5. The section 6 is related to the emission power calculation and, consequently, to the power saving when the second model is applied in the case that the value of offered traffic is increased. The section 7 presents one example of daily traffic profile and base station emission power saving in the case of the second model application. The section 8 gives retrospective view to the number of mobile stations in GSM technology which are still going to be used in the world. The obtained analytical results are verified by traffic process simulation as described in the section 9. The conclusion is, finally, given in the section 10.

2 Existing solutions for power saving in mobile GSM systems

There are three main approaches for energy saving in mobile communications networks. The first one is application of advanced dynamic algorithms for traffic resources reallocation in mobile network. The second one is application of sleep mode on some groups of channels for which there is no need to carry traffic. And, finally, the third one is implementation of more energy-efficient network elements [6]. The first two groups of solutions request only software tools for their realization while changes of hardware elements are necessary to perform modifications according to the third group. Thus this third group is, obviously, more demanding and more expensive and it is not considered in this paper. The solution presented in this paper fall into the first group of approaches and this solution is considered in comparison to some other, existing approaches belonging to the first two groups.

Existing solutions for traffic resources reallocation are mainly related to the connections displacement between different subbands [7]. When considering GSM systems, this is between channels at 900MHz and 1800MHz which exist at the same location. There are three reasons for such reallocation: 1. In the case of lower traffic load when different subbands are only partially busy, it is possible to collect all connections on one (or a less number) frequency carrier and thus to free the other frequency carrier. The idle carrier then may be put to sleep mode to lower total power consumption; 2. Attenuation at 900MHz subbands is less than at 1800MHz, so connections may be realized over channels at 900MHz subbands to allow lower power consumption; 3. The best effect in emission power consumption reduction may be sometimes achieved when traffic over all frequency subbands is equalized.

The second approach which supposes application of sleep mode is the logical consequence of traffic channels release on some frequency carriers after implementing reallocation according to points 1. and 2. in the previous paragraph. Generally, this second approach leads to higher values of power consumption than the solutions from the first approach. The second approach is widely used in all types of mobile systems mainly in the time of low traffic. When implemented in GSM systems, sleep mode supposes that some minimum signal transmission (for example pilot signal, channels on the first carrier) should remain [8]. It means that complete base station power supply turn-off could not be achieved to easily recover to operation mode when the traffic level increases again. The simulation of GSM system with activated sleep mode is presented in [9]. The performed Monte Carlo simulation is based on data collected on real BTS locations. The goal of simulation is to determine the value of total BTS power if sleep mode is applied.

The goal in modern mobile networks is to reduce power consumption of GSM systems by improved methodology for BTS or only frequency carriers' turn-off and turn-on [10]. The threshold parameters for activating and deactivating sleep mode are adjusted by the implementation of machine learning algorithms [11]. Such access additionally decreases the mean number of active frequency carriers and thus reduces power consumption comparing to classical switching parameters control. In the case that GSM base station exist at the same location with some 3G or 4G base station, decreasing power consumption in GSM mobile system may leave more power for 3G or 4G system. It means that reallocation of traffic resources in GSM system thus leads to power consumption reallocation [12] which allows more traffic to be realized over more applied 3G or 4G systems.

3 Models of traffic channels groups, designations and assumptions

Our access in power saving pertain to the first approach according to the division from the previous section. It is based on an innovative principle of traffic channels reallocation according to the distance between the base station and each active user station.

Let us consider the circular GSM cell with the radius R. The number of traffic channels in the cell is $N=6+8\cdot(n-1)$, where n is the number of frequency carriers. The surface user density in the cell is uniform. The number of users in one cell, M, is supposed to be significantly greater than the number of traffic channels. It is also supposed that telephone calls are generated randomly. The emission power in the first 6 traffic channels is maximal and in the remaining channels power control is performed, i.e., it is adjusted according to the user needs. The necessary power mainly depends on the user distance from BTS.

The designation for the power will be w, the mean and the maximum power of one channel will be designated by w_m and w_{max}, respectively. The power of the i^{th} ($i = 1, 2,\ldots, N$) channel will be designated by w_i, the mean and the maximum power of the i^{th} channel will be designated by w_{im} and w_{imax}, respectively. The user distance from BTS, d, affects the necessary emission power according to the law $w=a \cdot d^{\gamma}$, where a is the coefficient of proportionality and γ is the environment attenuation factor [5]. The state when i traffic channels are busy will be designated by {i}. The offered traffic is designated by A and served traffic by Y. The designation P(i, A, N) means the probability that i channels (i = 0, 1,…, N-1, N) are busy in the group of N channels if the offered traffic is A Erl. This probability is called the probability of state {i}. Each call may seize idle channel, so this channel group comes to Erlang model. The probability that all channels are busy is called the probability of traffic loss and designated by E(N, A) = P(N, N, A), the so called Erlang B formula.

Power saving is achieved in two ways: at lower traffic all connections are realized over the channels in the first carrier which always have (maximum) power and at the higher traffic users who need higher power are connected over the TCH of the first carrier. That's why two cell models are going to be analyzed.

The first model (MC1) is the standard one applied in the cells without reallocation. The main property of this model in this paper is the channel selection for the new call. The idle channel for each new call is selected by sequential hunting with homing [13], section 4. This procedure of channel selection for the new call allows that the first 6 channels which have the highest emission power do not remain idle. The first cell model is presented in the Fig. 1 which is taken over from [4].

The second GSM cell model (MC2) satisfies two conditions. The first one is that all connections should be realized over the first 6 traffic channels when the number of connections, i.e., busy channels is less than 7 ($i<7$). The second condition is the following one: if it is $i>6$, six connections which request the higher emission power than the remaining connections should be realized over the first 6 channels. We need to have a ranking list of realized connections with the data about the necessary emission power (i.e., distance BTS - MS) in order to compare this power to the necessary power for the new call.

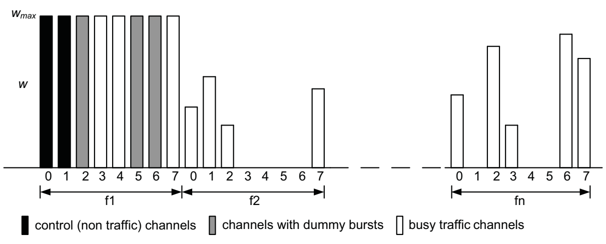

Figure 1: Model MC1: Sequential hunting of idle channel with homing from the first channel on the first carrier (taken over from [4]).

Filling, i.e., seizing of the first 6 traffic channels is performed using the so called channel reallocation which is presented in the Fig. 2 (taken over also from [4]). The necessary power for the channel is symbolically designated by asterisk and for some channel *i* this value is w_i.

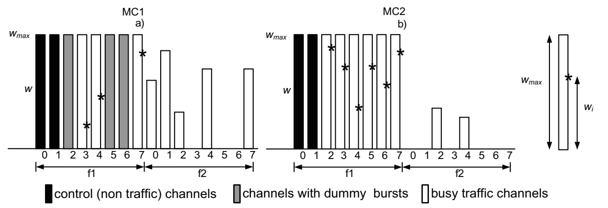

Figure 2: Model MC2: Channel reallocation such that 6 channels with the highest necessary power take traffic channels of the first carrier (taken over from [4]).

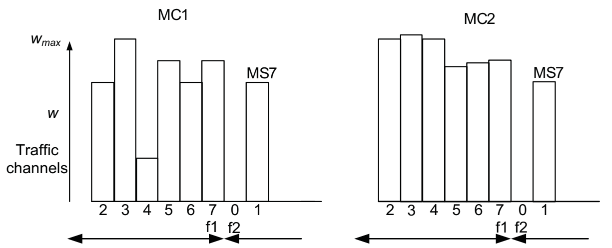

Figure 3: Models MC1 and MC2 in the moment when 7 connections are realized.

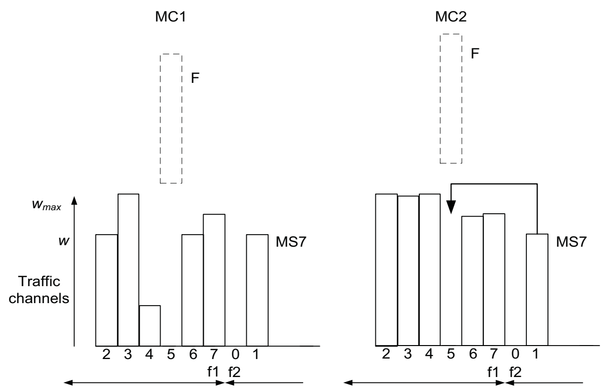

Figure 4: Processes in the models MC1 and MC2 in the moment of finishing one of 7 existing connections (the connection realized on the first carrier).

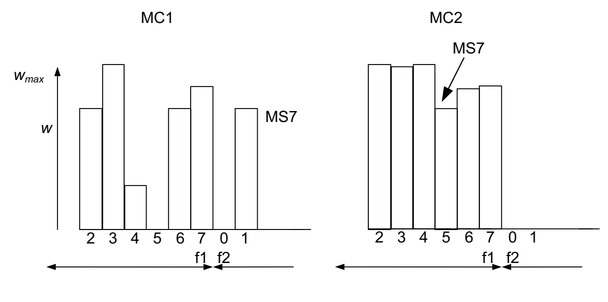

Figure 5: Allocation of 6 remaining channels in the models MC1 and MC2 after the connection end.

4 The characteristics of considered cells at low traffic load

It has been already emphasized that at low traffic load (i<7) when the model MC2 is applied all connections are realized over the first 6 channels while it is not the case when the model MC1 is applied. Let us now consider a simple example with 7 realized connections. All connections except the connection of the seventh user (MS7) are realized over the channels on the first carrier f1. The connection of MS7 is realized in the channel of the second carrier f2, Fig. 3.

Let us suppose that connection over the channel 5 ends in the moment *t1* (connection F) and that this channel releases. In this moment nothing happens in the cell MC1. The channel 5 on the first carrier remains idle until the moment when the new call arrives. Owing to the sequential method of idle channel looking for starting from the first channel, the new call which is initiated in the moment *t2* will seize the channel 5.

The connection reallocation is performed in the cell MC2: the connection of the user MS7 continues over the released channel 5 on the first carrier instead over the channel 1 on the second carrier, figures 3, 4 and 5. It is clear that the power in MC1 equals: $w_{MC1} = 6 \cdot w_{max} + w_m$ where w_m is the mean power in the channel 1 of the second carrier. The emission power in MC2, under the same conditions, equals $w_{MC2} = 6 \cdot w_{max}$. It is obvious that it is

$$w_{\mathrm{MC1}} > w_{\mathrm{MC2}} \tag{1}$$

It may be concluded that at low traffic values, besides emission of maximum power in all 6 TCHs of the first carrier, power is also generated in some other channels when considering MC1 cell. This is impossible in MC2 cell: if the number of connections is less than 7, emission power is the same as if there is no traffic. It has to be noted that an example, presented by the figures 4 and 5, is the simplest one. Similar to this example, it may happen releasing of several channels on the first carrier in the MC1 cell, which even more increases the difference of emission energy in MC1 and MC2, but the probability of such an event is significantly lower.

5 Emission power calculation at low traffic value

Let us consider an example of two cell models when they are in the state *{6}*, i.e., there are 6 connections. The offered traffic is A. The served traffic by channel i is Y_i, (i = 1, 2, 3, 4, 5, 6). According to [13], equation 4.14, when sequential looking for idle channel with homing is applied, the served traffic by the i^{th} channel is

$$Y_{\mathrm{i}} = A \cdot \left(E(i-1, i-1, A) - E(i, i, A)\right) \quad i = 1,2,\ldots,6 \tag{2}$$

for the MC1 cell. It is the part of time when channel i is busy. In other words, it is the difference of overflow traffic on channels *i-1* and *i*.

The characteristic of served traffic on one channel, i, is that it is $Y_i < 1$. That's why the probability that all 6 traffic channels on the first carrier are busy is $Y_1 \cdot Y_2 \cdot Y_3 \cdot Y_4 \cdot Y_5 \cdot Y_6 < 1$. This, further, means that idle channels may exist on the first carrier in the state *{6}* in MC1 cell. The traffic process simulation program for such cell is made to determine probability of idle channel on the first carrier as a function of the offered traffic (see section 8). The obtained results are presented in the Table 1.

The difference 1 - Y_i, (i = 1, 2……6) represents the part of time when the i^{th} channel is idle.

$$S = \sum_{i=1}^{6} \left(1 - Y_{\mathrm{i}}\right) \tag{3}$$

The sum represents the mean number of idle channels in the state *{6}* on the first carrier in the cell. Therefore, there are 6 connections in the state *{6}* and it is clear that this number S will represent the mean number of busy channels in the other carriers.

The dependence of mean number of busy channels in carriers 2, 3,... in the state *{6}* on the offered traffic A in the cell MC1 is presented in the Table 2. The results in the Table 2 are obtained by simulation.

Therefore, the mean number of busy channels on other carriers is S in the state {6} at the offered traffic A and the power is generated in these channels in MC1 and not in MC2. These values are obtained by traffic process simulation in the MC1 cell whereby the total number of traffic channels is N=14. It is clear that possible power saving in the MC2 cell is proportional to the number of channels which are busy on the second carrier in the MC1 cell.

Example: If the offered traffic is A = 5 Erl in the state {6}, nearly all measurements will show that between first 6 channels exists, on average, one idle channel in the MC1 cell, i.e., that one channel is busy in other channels. The higher emission power in MC1 comparing to MC2 is the phenomenon which exists also at low values of offered traffic.

It may be concluded that power saving at lower traffic values is realized only by using the channels of the first carrier.

Table 1: The probability of at least one idle channel existence on the first carrier as a function of offered traffic in the model MC1 when there are 6 realized traffic connections, *N=14*.

Offered traffic (Erl)	2	3	4	5	6	7
Probability $1\text{-}Y_1Y_2Y_3Y_4Y_5Y_6$ that there is an idle cannel on the carrier 1, in the state {6}	0.2957	0.4457	0.5659	0.6505	0.7271	0.7698

Table 2: The number of busy channels on the carriers 2, 3, as a function of offered traffic in the MC1 cell when there are 6 realized connections.

Offered traffic (Erl)	2	3	4	5	6	7
The number of busy channels on the carriers 2, 3,… in the state {6}, N=14	0.3098	0.5586	0.7726	0.9505	1.1475	1.2791

It has to be noted that the Table 2 is related only to the state *{6}* whose probability is changed when offered traffic is changed. The second important fact is that channel seizure in carriers 2, 3,… in MC1 cell happens also in other states.

6 Power saving at traffic increase

Let us consider now the case when the offered traffic increases, i.e., the number of connections is greater than 6. The first 6 traffic channels in the MC1 cell serve user connections which have been initiated in random moments. The other connections, which have also started in random moments, are served in the following channels. The necessary emission power in all channels including the ones outside the first 6 traffic channels is in principle different, but may be considered as equal to the mean channels power. The mean channel power for the uniform user surface density distribution is $w_m = 0.5 \cdot w_{max}$, where it is $w_{max} = a \cdot R^2$ because it is analyzed the case for the value γ = 2 [14].

Sectors, i.e., rings which separate areas with different necessary users' power are presented in the Fig. 6. As an example the situation of mild traffic increase is considered i.e., when the number of connections is 8 and the number of sectors is 16. (According to [15], the power control is realized in 15 steps of 2dB each step, here are considered 16 steps to easier reference explanation supported by examples). The probability that the call is generated in some sector is proportional to the number of traffic sources, i.e., to the number of users in that sector (or, in other words, to the sector area) in relation to the total number of users. (It is clear that the number of users increases when the sector radius increases at uniform distribution of surface users' density. The other reason of sectors' area increase when these sectors are more distant from BTS is that emission power decreases according to the exponential law). The question from this example is: if the total number of connections is 8, from which sectors come 6 connections which request the maximum power? From all sectors (100% of surface, i.e., users) come 8 (100%) calls and 6 (75%) calls are generated from the sectors which represent 75% of surface/users. In our example these are 3 sectors with the maximum radius and their border is at about $R2 \approx 0.5 \cdot R$.

The mean power of active channels is $w_m = 0.5 \cdot w_{max}$. The channels on the first carrier are seized by 6 users and two users seize two channels on the second carrier. The way how these calls are arranged in the channels of MC1 and MC2 cell is presented in the Fig. 6. In the MC1 cell the channels are seized according to the order of their arrivals. Therefore, the connections in the first carrier request power according to the random selection. That's why, besides the mandatory power of the channels on the first carrier (w_{max}), the emission power is in MC1 cell increased by the value of mean power of two channels in the second carrier, i.e., $2 \cdot w_m = w_{max}$.

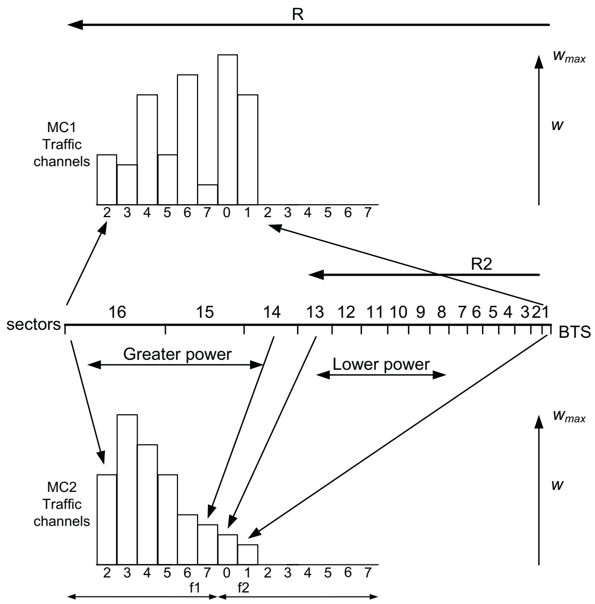

Figure 6: Spatial layout wherefrom calls are initiated on average in models MC1 and MC2 when 8 connections are realized.

The MC2 cell is now considered under the same conditions. Due to reallocation implementation, the first 6 channels are seized by the users who request maximum emission power. The calls of remaining two users originate from 13 sectors which are located nearest to BTS. The mean necessary power of these users is $w_{m2} = 0.5 \cdot w_{max2}$, where w_{max2} is the highest power of one channel in the circle of the radius *R2* which contains 13 sectors nearest to BTS, $R2=(0.5 \cdot R)$, i.e., $w_{max2} = (1/4) \cdot w_{max}$. The mean emission power per a channel of the second carrier in MC2 is $w_{m2} = (1/2) \cdot w_{max2}$. The ratio of emission power per a channel of the second carrier in MC1 and MC2 cell at 8 connections, γ = 2 and uniform distribution of surface users distribution is 4.

The consequence of further offered traffic increase is the increase of the number of calls coming from the greater number of sectors. This process should be presented in the Fig. 6 by the greater number of calls, i.e., busy channels. The users in MC1 would continue to seize channels according to the random principle. In MC2 the first 6 channels would be seized by users from the sectors which are more distant from BTS. The remaining channels would be seized by users from the group of sectors with the radius *R3* which is greater than the one from the Fig. 6, i.e., *R3* > *R2*. That is why the ratio of emission power in MC1 and MC2 decreases with the traffic increase.

Example: Let us suppose that the number of channels is *N*=14, the number of connections is 10, γ = 2 and that distribution of users' surface density is uniform. As in the previous example, the call arrival is proportional to the sector area. We are interested from which sectors come 6 of total 10 instantaneous calls if these 6 calls request maximum power. It is clear that these 6 calls come from the distant sectors from BTS and this is 60% of surface/users. These are, on average, two sectors with the greatest radii. The sectors are limited by the radius *R3* at the distance approximately $R3 \approx 0.63 \cdot R$ from BTS. Each channel of the second carrier in MC1 requests $0.5 \cdot w_{max}$ on average. The mean power of 4 channels in the second carrier of MC2 is determined by the mean power in the part of cell with the radius $0.63 \cdot R$, i.e., it is now $w_{max2} = 0.63^2 \cdot w_{max} = 0.397 \cdot w_{max}$. The ratio of mean emission power in the channels of the second carrier in MC1 and MC2 is $w_m/w_{m2} = 0.5 \cdot w_{max}/0.5 \cdot w_{max2} = 1/0.397 \approx 2.5$.

The ratio of mean power per channel in MC1 and MC2 cells (w_m/w_{m2}) as a function of the number of connections is presented in the Fig. 7. The other data is the same as in the previous two examples.

Figure 7 presents that the relative ratio of emission power per channel in MC1 and MC2 decreases when traffic (i.e., the number of realized connections) is increased. However, the absolute amount of power save is higher for the higher traffic values, because the power is saved on each active channel.

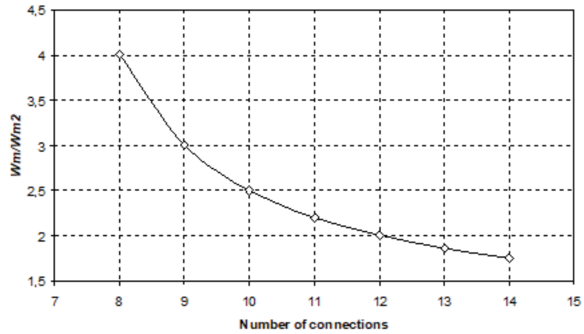

Figure 7: The ratio of mean power per channel at models MC1 and MC2 as a function of the number of connections, *N=14*, γ = 2.

Example: The saved power when 8 connections exist is $2 \cdot w_m - 2 \cdot w_{m2} = w_{max} - 0.25 \cdot w_{max} = 0.75 \cdot w_{max}$. If the number of connections is higher, i.e., 12, the power save on the second carrier is

$$6 \cdot w_m - 6 \cdot w_{m2} = 3 \cdot w_{\max} - \frac{3}{2.11} \cdot w_{\max} = 1.58 \cdot w_{\max} \quad (4)$$

which is the higher saving in absolute values of power.

7 Daily profile of emission power

It is clear that channel reallocation allows emission power saving, but the level of saving depends on the number of busy channels, i.e., on the offered traffic *A*. As the offered traffic is changed during a day according to the so-called daily traffic profile, the level of emission power saving in the cell with reallocation according to MC2 will be also changed. Figure 8 presents daily traffic profile, i.e., the number of connections for the case of a cell with two carriers. After that, daily profile of emission power for the MC1 cells (black line) and for MC2 (red line) is presented in the Fig. 9. The other conditions are: surface user density is uniformly distributed, there are two carriers and environment coefficient γ = 2.

The power unit on the y-axis of the Fig. 9 is the maximum power, i.e., $w_{max}=a \cdot R^2$. It is clear that the difference between the black and red line represents the emission power save in this case and that the similar daily profile of the emitted (and saved) power may be obtained for each specific case.

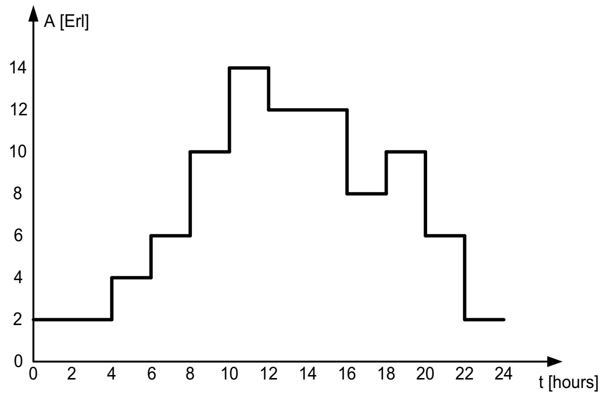

Figure 8: Daily traffic profile (the mean number of connections) in the considered cells according to the models MC1 and MC2.

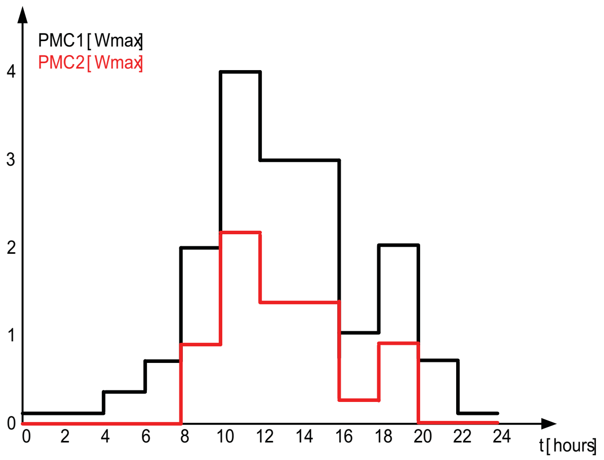

Figure 9: Daily profile of the emission power variation for channels 7, 8, ..., etc., MC1 (black) and MC2 (red) for the supposed daily traffic profile from the Fig. 8.

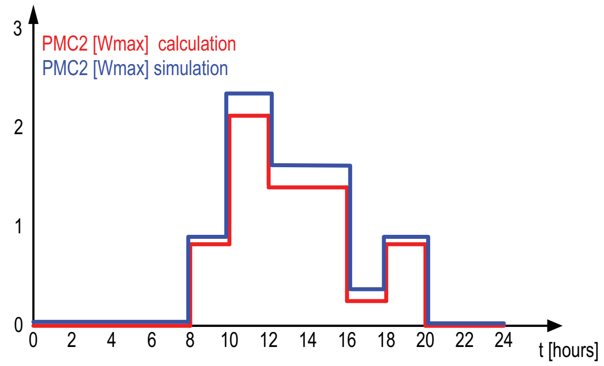

Figure 10: Daily profile of the emission power change for the channels 7, 8, …, etc. in the cell MC2 determined analytically (red) and by simulation (blue) for the supposed daily traffic profile from the Fig. 8.

The total daily power consumption saving when our method is applied comparing to the pure sequential hunting with homing procedure of looking for idle channel may be calculated as the surface value between the black and red line in the Fig. 9. This value is about 21W. This value in absolute sense is not high. But, relatively to the total daily emission power value, the contribution of our solution is about 60%. Namely, the total emission power consumption without our solution implementation, calculated as the surface between the black line and *x*-axis in the Fig. 9, is about 35W. This is important if possible interference to the other system, which perhaps operates in the same frequency band as the considered GSM system, is analyzed. Lower emission power on the GSM system allows that the signal on this other system has better quality.

The value of energy save is verified by simulation and the comparison of calculation and simulation values is presented in the Fig. 10. Quite a small difference of these values results from the difference in computation (the power determined by the sector ordinal number) and simulation (continual power directly dependents on distance).

8 A look at reducing number of GSM users in the world and to the comparison with other approaches for power saving

In this paper it is presented how channel reallocation affects emission power saving in mobile network 2G, i.e., GSM. The question of the relevance of this research and time limitation of the results can with good reason be asked. However, the predictions of the study [16] suggest that hundreds of millions of GSM network users will exist in the world for a long time. This is especially true for some developing countries with many inhabitants where still 99% users use mobile phones in GSM technology [17]. There are even areas where only GSM mobile systems are implemented [11]. Generally speaking, successive suspension of GSM connections is planned in the developed countries (in Italy till 2029. year), but in undeveloped countries such connections will continue to exist after this period [18]. It is the reason why we think that power saving in GSM network could not be neglected.

Comparing to other approaches belonging to the first group of solutions emphasized in the section 2, our method for channels reallocation does not request to have available carriers from both 900MHz and 1800MHz in the same BTS, because power saving is realized on different principles. The necessary software tools in both cases (existing solutions and our method) request the similar software tools: implementation of handover for channels rearrangement.

Comparing to the solutions from the second group which are related to the sleep mode activation, our method for power saving is applied regardless of the traffic value. In the section 7 we have already illustrated its implementation by the daily profile, i.e. during the whole day. On the contrary, sleep mode is implemented only at low traffic values, which usually means at night. The additional problem when turn-on or turn-off of sleep mode is performed is to determine the threshold values for these two actions [10], [11]. In principle, power saving achieved by sleep mode activation is significantly higher than when our method is applied. But, when traffic values are not low (for example during the day time at the great majority of BTSs), sleep mode may not be activated and there is no power consumption decrease due to its application. In such a case the power saving would be achieved only by the implementation of our method, as it is applicable regardless of the traffic value.

The main subject of the paper is to compare the characteristics of our solution for improved power consumption to the power consumption in the classical GSM system with sequential hunting with homing looking for idle channel and the majority results are related to this subject.

9 Simulation

All simulations in this paper are performed in C++/C programming language. It is performed using simple, commercially easily available software packs installed on home-version PC. There is no need for special, expensive software programs or advanced computer systems. The main input parameters in simulation are the number of applied traffic channels (*N*), the offered traffic (*A*) and the environment attenuation factor (γ) which may be in the range 2-5. One more element which is important for simulation is the type of users' distribution (we consider uniform distribution). The main output parameters are the mean values of emission power in the original system with sequential hunting with homing and in the system with reallocation. Traffic loss probability and the values of offered and served traffic are determined in the simulation in order to validate simulation process correctness. Simulation is based on roulette (Monte Carlo) traffic simulations used in classical telephone techniques long ago [19]. These traffic simulations are upgraded in a whole series of papers by a component to determine base station emission power on the base of distance between the base station and the mobile user. This distance is also calculated starting from the randomly generated number [20], [21].

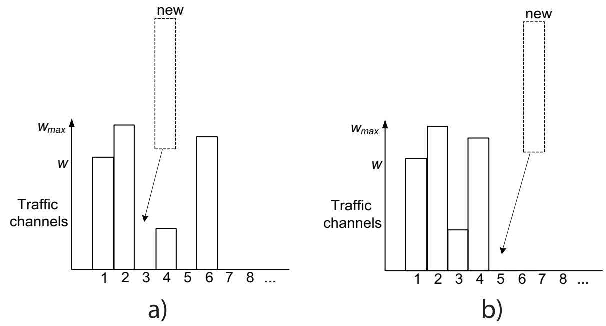

Figure 11: Channel seizure in a homing system: a) earlier seized channels are not one after the other; b) earlier seized channels are one after the other.

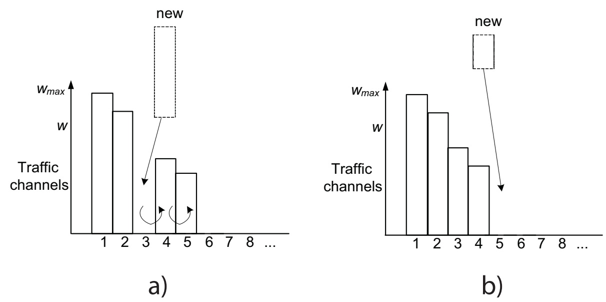

Figure 12: Channel seizure in the system with reallocation: a) earlier seized channels are not one after the other; b) earlier seized channels are one after the other.

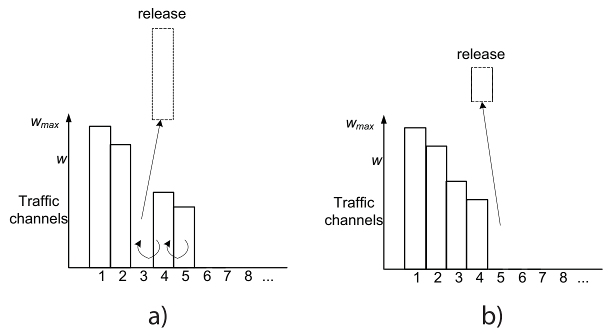

Figure 13: Channel release in the system with reallocation: a) the released channel is not the last in the series of busy channels; b) the released channel is the last in the series of busy channels.

Simulation program from [20] is further upgraded for the analysis purposes. In the part for traffic analysis this upgrade includes specific discipline of traffic channels seizure in the first case of systems with homing procedure for idle channel looking for and in the second case of homing seizure with channel reallocation. The part of upgrade is also the specific procedure of channel release at systems with homing seizure with channel reallocation.

The algorithm of traffic channels seizure at each new connection initialization is based in both cases on homing procedure of idle channel looking for starting from the first traffic channel. The goal is in the case of systems with homing seizure to find the first idle traffic channel, as it is presented in the Fig. 11. It may be, for example, channel number 3 according to the Fig. 11a) given that channels 1 and 2 have been busy from earlier. In the case that all busy channels are sequenced one after the other in the considered moment of new connection initialization, the first channel after them is seized (in an example in the Fig. 11b) channels 1-4 are busy and the new connection will take the channel 5). In the case of systems with reallocation all busy channels are arranged one after the other according to their decreasing necessary power, i.e., decreasing mutual distance between base station and mobile user. The value of necessary emission power for the new connection is compared successively from the first channel for all already realized connections until it is found the connection with the power lower than the necessary power for the new connection. When such a connections is found, the channels for all connections starting from it onwards are shifted for one channel towards the higher ordinal number, and the new connection is placed on the released place (according to the Fig. 12a), the connections on the channels 3 and 4 are shifted to channels 4 and 5, while the new connection takes the channel 3). If all existing connections have the higher power than the new initiated connection, this new connection is placed at the end of the row on the first idle place (in the channel 5 after 4 already realized connections in the example in the Fig. 12b)).

The procedure for channel release in a system with reallocation is presented in the Fig. 13. There are 5 busy channels before release in the Fig. 13a) and the connection at the channel 3 has to be terminated. In this case the channels with the higher ordinal number than the ordinal number of the connection which has to be released are shifted for 1 channel towards the lower channel ordinal number (channels 4 and 5 to the positions 3 and 4), and the channel on the position 5 is released (w=0). If it is necessary to terminate the connection on the last in the series of busy channels, it is only released without reallocation of busy channels (Fig. 13b)).

The principle of base station emission power definition is the same as in [21] for uniform user surface distribution and for $\gamma=2$. The more complicate case of emission power calculation for non-uniform user surface distribution and $\gamma\neq2$ is analyzed in [20].

The simulation program, which is realized according to the described algorithm, is freely available at the address [22]. Besides the program code, also is available the file obtained by the simulation with the data used to verify the analytically defined characteristic in the Fig. 7.

Simulation is very powerful method for systems operation modelling. It allows very fast verification because simulation program execution is significantly less time consuming than measurement in real world operation. The verification is also simpler and cheaper than testing on the polygon. The procedure which is described in this paper is supported by the authors' long year experience in simulation program development [23].

10 Conclusions

It may be concluded from this paper that channel reallocation always contributes to emission power saving. Even at low traffic values power saving (of lower extent) exists as presented in the section 4. When the number of simultaneous connections overcomes 6, relative emission power saving rapidly increases if channel reallocation is applied. Relative power saving slightly decreases with the further traffic increase.

Emission power saving in absolute amount increases with the traffic increase.

Everything that is concluded about the dependence of emission power saving as a function of the type of surface user distribution, number of the users and environment coefficient γ from [4] is valid also here with respect of dependence on traffic value.

The results obtained in this paper are verified by our original simulation program. There is a small difference between the results obtained analytically and by simulation as illustrated in the Fig. 10. The reason has been already explained at the end of the section 7: in reality the BS power is changed in discrete steps according to the ordinal number of the sector where the MS is situated and in simulation this power is varied continually according to the distance between BS and MS. But, difference in the obtained results due to these two approaches is negligible as proved by the Fig. 10.

When considering dependence of emission power saving on the number of connections as a function of γ or number of users (i.e. frequency carriers), the quantitative relations would be established in the future work as the result of simulations after minor modifications of our verified simulation program [22].

The second aim in the future development is to compare in the quantitative sense performances of our solution to the existing solutions from the area of emission power saving in GSM systems. This comparison is related to the traffic analysis and to the necessary power level.

The last and even the most important aim is to study possibilities to adapt our solution for the implementation in newer generation networks – first of all in 4G (LTE) systems. Besides the possible effect to the emission power decrease in LTE systems, such an improvement would decrease interference to "5G under 6GHz" mobile systems (i.e. when they operate in a frequency band about 700MHz where LTE and 5G systems may coexist.

The importance of the study presented in this paper may be summarized in the following several main points according to the whole study presented in this paper: 1. GSM BTS emission power is decreased in absolute and, specially, relative amount; 2. it is possible to decrease this power regardless of the instantaneous emission power value and regardless of the frequency band where GSM system operates; 3. interference to other systems operating in the same frequency band is decreased; 4. for the future, our solution may be adapted for the application in other modern mobile systems, such as LTE.

All results in the paper are verified by traffic process simulation. Unfortunately, we are not able to realize verification of an idea presented in the paper by experimental implementation of real traffic in a live network but we would be glad if some mobile devices supplier or provider accepts to do it. We would like to contribute ourselves in such experimental verification.

11 Conflict of Interest

The authors declare no conflict of interest.

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