The impact of intermodulation interference in superimposed 2G and 3G wireless networks and optimization issues of the provided QoS

[1]G. Paschos, *IEEE member*, S. A. Kotsopoulos, D. A. Zogas, *Student Member*, *IEEE,* and G. K. Karagiannidis, *IEEE member*

Abstract **– This paper investigates the critical parameters that affect the overall operation of the systems that belong to different competing wireless communication consortia. It is anticipated that the competing consortia will operate separate wireless systems (2G and 3G) in the same geographical areas where block allocations of channels are made to facilitate this. Moreover, the generated out-of-band intermodulation interference spectrum by each other is examined and finally, a new frequency planning strategy is introduced in order to optimize the QoS of the 3G wireless system.**

Index Terms **– Intermodulation interference, 2G, 3G, QoS, CDMA capacity.**

[1] G. Paschos, D. A. Zogas and Dr. S. A. Kotsopoulos are with the Laboratory of Wireless Telecommunications, Electrical & Computer Engineering Dept., University of Patras, Rion, 26442 Patras, Greece, Tel +32-610-997301, Fax: +32-610-997302, gpaschos@ee.upatras.gr, zogas@space.noa.gr, kotsop@ee.upatras.gr
Dr. G. K. Karagiannidis is with the Institute for Space Applications & Remote Sensing, National Observatory of Athens, Metaxa & Vas. Pavlou Str., Palea Penteli, 15236 Athens Greece, gkarag@space.noa.gr.

I. INTRODUCTION

THE study of intermodulation interference in the bibliography is rather limited. As a phenomenon, the intermodulation interference is born in coexistence. Naturally, extensive investigation is stirred only when the advent of a new system invades the set RF environment. In [1], an AMPS to CDMA intermodulation interference description can be found. Intermodulation interference has also engaged another kind of research like the development of nonlinear RF circuits with a built-in mechanism of intermodulation rejection [2].

In this analysis the overlapping of 2G and 3G is examined. More specifically, the interaction between the already installed GSM system with the new WCDMA technology of UMTS is showcased. An analysis of interference effects on WCDMA capacity can be found in [3] where the degradation of QoS is illustrated. Finally, in [4] a frequency planning algorithm for 2G systems is described that takes into account the tradeoff between adjacent channel and intermodulation interference. In this study we will propose a new frequency planning logic that optimizes the performance of both GSM and UMTS systems when they coexist in a geographical area.

In the next section the 2G-3G superposition issues are presented, in section III a theoretical background of intermodulation interference is developed. In section IV an estimation of interference power level is found and in section V the impact on WCDMA capacity is explored. Section VI, a GSM1800 - UMTS superposition is simulated, while in section VII the proposed frequency planning is explained and finally in section VIII the paper is concluded.

II. THE SUPERPOSITION OF CELLULAR SYSTEMS

The second generation (2G) systems made their appearance as the first digital systems for mobile telecommunications. The most popular representative is the worldwide spread GSM (Global System for Mobile) which is the one that will be the subject of this analysis. It utilizes hybrid FDMA and TDMA technique with 124 channels of 200KHz bandwidth and 8 timeslots of 576.92ms each. Using GMSK as the modulation method, it manages to serve 9.6kbps throughput. The main applications are speech and short data messages and the connection type is circuit connection. Another interesting aspect is the realization of the infrastructure. As a rule of thumb, GSM cells can have a number of 1 up to 12 base station transceivers (BTS) that are fed to the antenna through a number of adders and combiners. Bandpass filters are also used as it can be seen in figure 1. The frequency allocation of GSM900, GSM1800 and UMTS is shown in figure 2.

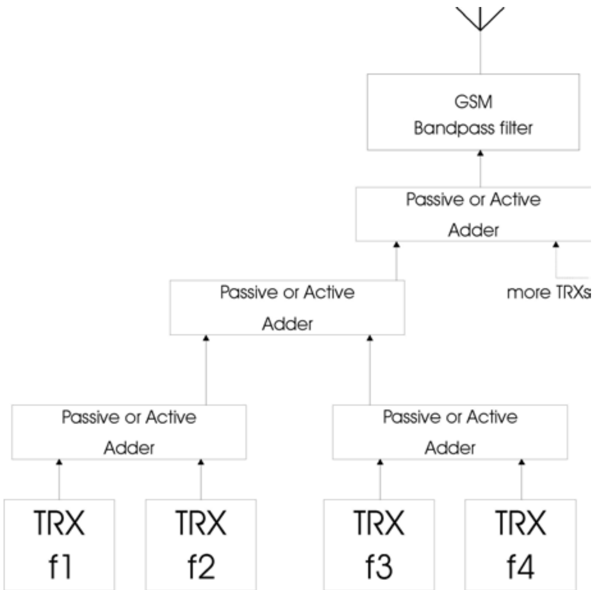


Figure 1: GSM Base Station diagram - Centre frequencies f1, f2, f3, …, fn are arranged in a frequency plan so as to minimize the induced level of intra-system interference (the sum of adjacent, co-channel and intermodulation)

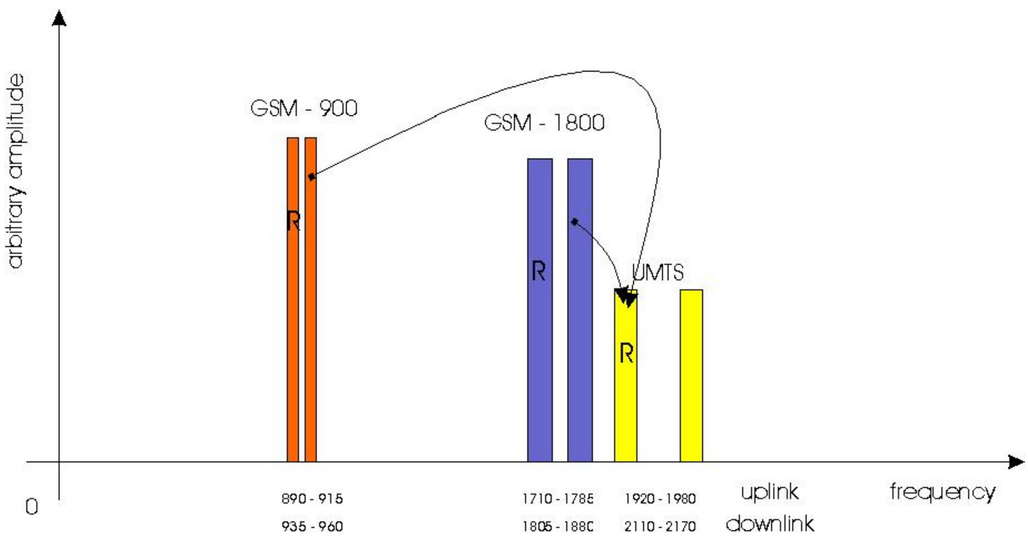


Figure 2: The shape of RF spectrum in a GSM-UMTS coexisting area

The era of third generation (3G) mobile communications has arrived and research is still carried on over the smooth installation of the several new systems. The primary objectives of 3G systems are interoperability, high throughput rates (up to 2Mbps), permanent connection support, transition to packet connection, QoS on demand and full coverage. The main applications will be streaming applications and the internet. Plans are held for multiple QoS standards and the potentiality for data load charge instead of time charge. A characteristic representative of 3G systems is the Universal Mobile Telecommunication System (UMTS).

According to 3GPP standardization, the several possible 3G applications are divided into categories with different QoS requirements. For example, the conversational class requires minimum delay time while the streaming class requires high throughput rates [5]. In any case, the QoS of the system depends on several factors with the physical layer parameters as the most important. High levels of interference and extreme fading can damage the resulting QoS and thus restrict the user to applications with low QoS requirements. The available spectrum for UMTS is shown in figure 2. A UMTS frequency channel may vary from 5MHz to 20MHz. The total number of channels fitting in the 60MHz spectrum will be distributed to several service providers or reserved for future use. One channel with FDD support is adequate for the operation of a UMTS network.

A hot aspect of the installation of these new systems is the interoperability with the existing systems. The efficiency of the whole system and the needs of our society favor the continuation of GSM operation as a service provider system, thus it is necessary for the UMTS system to be able to maintain the desired QoS in this crowdy RF environment. One phenomenon that leads to deterioration of spectrum efficiency is the intermodulation (IM) interference. CDMA techniques, used by 3G systems, are known to be resilient to narrowband interference and multipath fading. However, the degradation can sometimes be notable.

III. INTERMODULATION INTERFERENCE ISSUES

IM interference is a direct result of nonlinearities. When a signal with centre frequency f and bandwidth BW is fed into a nonlinear device with a characteristic function of equation 1, it incites an output that bears a rich spectral content, as shown in figure 3.

$$h(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + ... \quad (1)$$

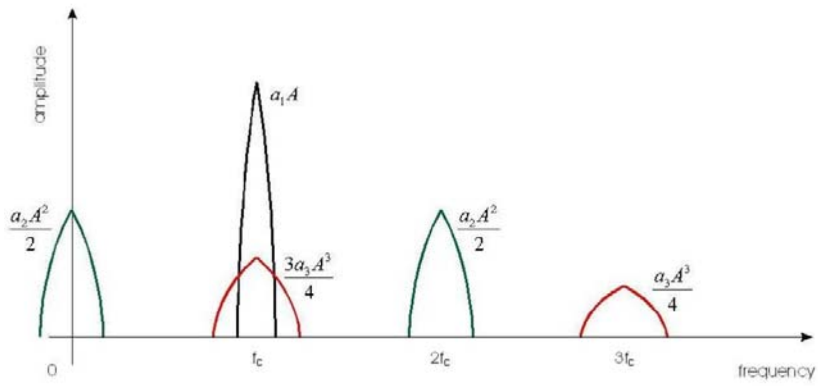


Figure 3: The output of a nonlinear amplifier with x(t)=Acos(2πft) input. 2nd and 3rd order are shown only.

This output signal is in general not desirable in case of transmitters. Sometimes it can be observed as in-band interference, meaning that spurious signals infect the bandwidth of the input signal itself. On the other hand, there are occasions when the intermodulation interference signals (intermods) take up another place in the RF spectrum and are transmitted through the air interface, seen as interference to another operating network. When two or more signals are added in the input of the nonlinear device, the output contains several algebraic sums of the input frequencies. The shape of the signal spectrum is altered as well, since the signal is raised in the nth power. Therefore, a thorough study is needed so as to examine the several cases that the GSM signal can cause interference to UMTS this way.

In this section the several scenarios where a GSM signal can cause IM interference that can damage the performance of a UMTS receiver will be discussed. The inverse case is not of substantial interest because UMTS systems are expected to have very few transmitting frequencies (absence of FDMA). Similarly, it is assumed that the interference caused by the mobile phones is negligible. Since the GSM mobile stations use only one frequency when communicating, according to figure 2, for an in band intermod at least two different frequencies are required to be combined. In addition to that, mobile stations use much less power and only one timeslot out of eight in the GSM frame, facts that reduce the imposed interference of any kind.

Given the aforementioned assumptions, it is clearly understood that our model consists of a GSM base station transmitter and a UMTS receiver that could be a mobile or a base station. Referring to the real existing network, the interference will be caused due to several neighboring base stations that comprise the GSM RF interface of a geographical area. To simplify the problem, we take into account only the 1st tier interferers as the role of the rest interferers is rather small. The position of UMTS base can be exactly on one GSM station (when the provider is the same), or in random position (when belongs to a different service provider or greater transceiver density is required) for which in practice we can assume the gravity centre of three GSM transceivers. The mobile, of course could be anywhere. An example of these scenarios is given in the figure 4, where a UMTS base station and a UMTS mobile station suffer from IM interference caused by the adjacent GSM transmitters.

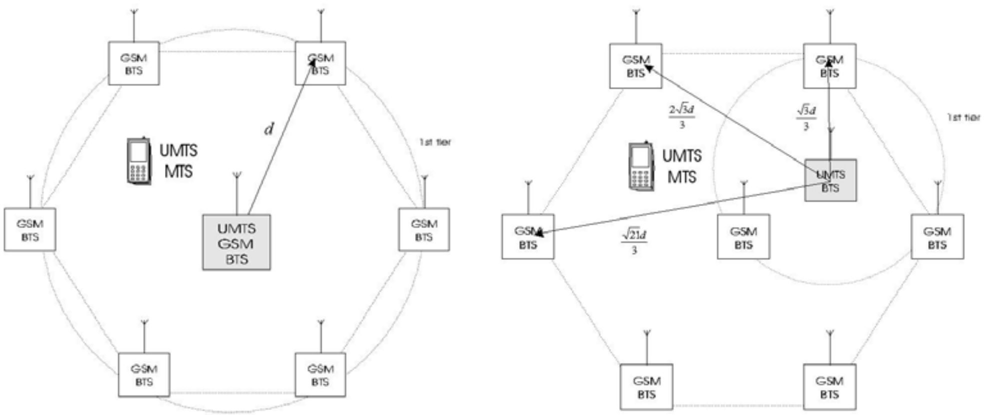


Figure 4: Multiple GSM base station can cause IM interference to UMTS base stations or mobile stations ($d = \sqrt{3} r_{GSM}$)

Apart from the topographical characterization of the interference model, multiple scenarios arise from the number of signal combinations that can result to IM interference. In the following table we have several examples of IM products of two, three or four centre frequency signals fed into a nonlinear device that has a characteristic function with $a_i=0$, $i>4$.

Freq. Input	2nd Output	3rd Output	4th Output
f1	0,2f1	f1,3f1	0,2f1,4f1
f1+f2	0,|f1±f2|,2f1,2f2	f1,f2,2f1±f2,2f2±f1,3f1,3f2	0,2f1,2f2,4f1,4f2,|2f1±2f2|,3f1±f2,3f2±f1
f1+f2+f3	0,2f1,2f2,2f3,|f1±f2|,|f2±f3|,|f3±f1|	f1,3f1,f2,3f2,f3,3f3,2f1±f2,2f1±f3,2f2±f1,2f2±f3,2f3±f1,2f3±f2,|f1±f2±f3|	0,2f1,2f2,2f3,4f1,4f2,4f3,|2f1±2f2|,|2f1±2f3|,|2f2±2f3|,3f1±f2,3f1±f3,3f2±f1,3f2±f3,3f3±f1,3f3±f2,|2f1±f2±f3|,|2f2±f1±f3|,|2f3±f1±f2|
f1+f2+f3+f4	0,2f1,2f2,2f3,2f4,|f1±f2|,|f1±f3|,|f1±f4|,|f2±f3|,|f2±f4|,|f3±f4|	fi,3fi,2fi±fj,2fj±fi,|fi±fj±fk|, where i,j,k all combinations of 1,2,3,4	0,2fi,4fi,|2fi±2fj|,3fi±fj,3fj±fi,|2fi±fj±fk|,|fi±fj±fk±fl|, where i,j,k,l all combinations of 1,2,3,4

Table 1: IM products of frequency sum

The ideal RF spectrum in an area of superimposed 2G and 3G systems would look like figure 2. The known uplink and downlink frequencies are also given in the same figure. It is obvious that only a small fraction of the possible combination of frequencies will give an IM outcome resulting into the UMTS band. In specific, figures 5 and 6 show the possible threatening products from GSM-900 and GSM-1800 in case of two simultaneously transmitted frequencies. Also, more than two frequencies can be combined to give similar result (3 in case of GSM-1800 and 3 or 4 for the GSM-900). However, the results from these scenarios would be a fraction of the shown ones. That is because the in-band products are created by long spaced channels (from a combination of a high and a low channel frequency). Channel frequencies that are not included in the next two diagrams are the intermediate ones. The sums $f_i+f_j-f_k$ and $f_i+f_j+f_l-f_k$ require small f_k and great values for the rest. Thus there is no way to use an intermediate frequency and get closer to UMTS band. This signifies the importance of frequency spacing. Small distances produce adjacent channel interference and great distances favor intermodulation interference. A tradeoff between the two brings the best results.

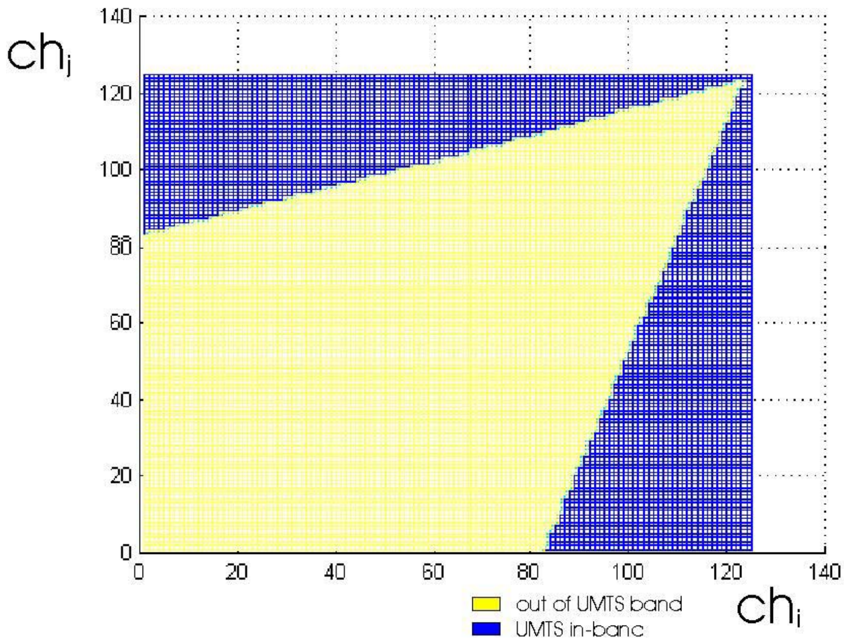


Figure 5: GSM-900 (4th order $\left|3f_i - f_j\right|$) IM products that fall into UMTS band

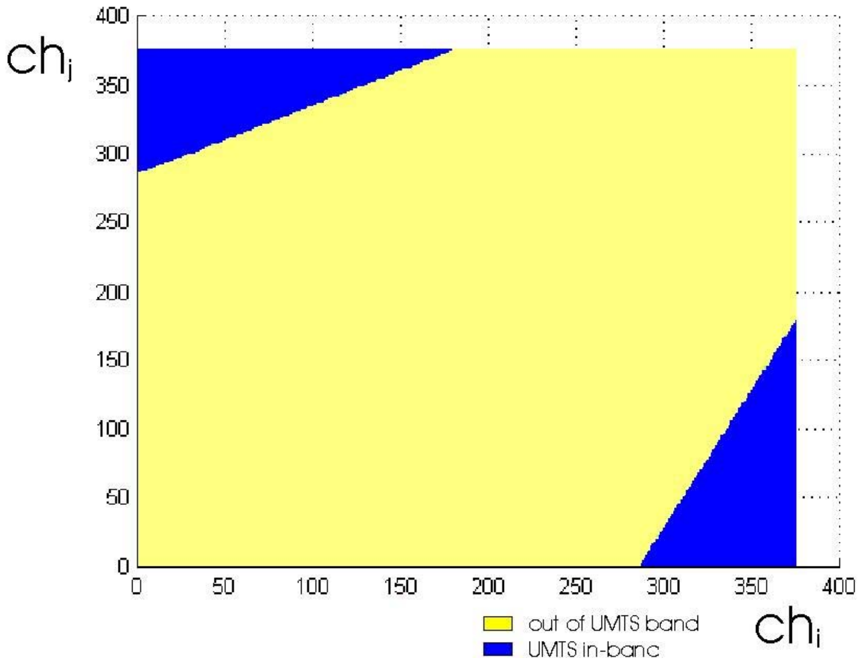


Figure 6 GSM-1800 (3rd order $\left|2f_i - f_j\right|$) channels that can be combined to give UMTS in-band IM products.

Concluding the section, when a GSM base station contains several transmitters that radiate the signal through the same antenna several intermodulation products may be generated depending on the frequency spacing of the operating transmitters.

IV. ESTIMATION OF THE IM INTERFERENCE LEVEL AT THE INPUT OF THE 3G RECEIVER

This section is dedicated to inspecting the whole path that an IM product follows from its creation in the nonlinear device to the UMTS receiver end, where it is presented as interference.

The first thing to look into is the nonlinear device. A typical policy for GSM infrastructure is to maintain multiple transmission stations (BTS) in one transmitting antenna in order to increase the cell capacity. An average number is four BTS and the maximum is twelve. The signal from each transmitter (each transmitter operates in a single frequency with eight timeslots), is mixed in multiple adders and then fed into a bandpass filter and finally into the antenna. Some of these adders are active so as to provide some amplification to the input signals. Active devices tend to be extremely nonlinear. In any case, the adder has a transfer function like equation 1 even though the a_i, $i>1$, coefficients might be very small in some cases. Manufacturers of such products provide information about the second and third order intercept points (SOI and TOI) of the device and using this info enables you to calculate the multiplying coefficients of IM products with respect to the original output signal amplitude. Another way to complete the calculation is to measure the path of intermods and extract the valuable information directly. A way to model the transmission of intermods is to consider these coefficients as signal losses (L_{IM}) with respect to a GSM signal (as a deviation from its original power).

$$L_{IM} = \frac{3P_{op} - 2P_{TOI}}{P_{op}} \quad ,or \quad L_{IM}(dB) = 10\log(3\times 10^{\frac{P_{op}(dB)}{10}} + 2\times 10^{\frac{P_{TOI}(dB)}{10}}) - P_{op}(dBm) \qquad (2)$$

, where P_{op} is the operating power in the input of the nonlinear device and P_{TOI} is the given third order intercept point.

The IM product created in the abovementioned adder, is then transmitted through the filter and the antenna and multiplied by $\left|H(f_i)\right|^2$ and by $1-\left|s_{11}(f_i)\right|^2$, as the filter characteristic function and the SWR of the antenna defines for the certain frequency of the IM product, and by D(φ) as the directivity pattern designates. This mismatch with the antenna, produces a loss we name L_T.

$$L_T = \left|H(f_i)\right|^2 \left(1-\left|s_{11}(f_i)\right|^2\right) D(\varphi) \tag{3}$$

, where f_i is the frequency of the IM product. In order to calculate such losses, extensive measurements of the GSM antenna and transmitter are required.

Finally, the signal reaches a UMTS receiver after traveling through the RF interface and suffering from propagation losses L_p. We choose to apply COST 231 Hata model [9] for this case, as an easy to use, with adequate approximation model [6]. Alternatively we could use a simple $d^{-\gamma}$ model. If we then add all the possible interfering products we get equation 5, which represents all the IM interference at the input of the detector of UMTS receiver. Evaluation of this equation will take place in a following section.

$$L_p = 69.55 + 26.16\log f_i - 13.82\log h_l - a(h_m) + (44.9 - 6.55\log h_1)\log d \tag{4}$$

where: f_i is the frequency of the IM product (GHz), h_l is the effective height of the base station antenna (30-200m), h_m is the height of the receiver antenna (1-10m), d is the distance between two points (km), $a(h_m)=(1.1\log f_i-0.7)h_m-(1.56\log f_i-0.8)$.

$$P_{active} = \sum_{f_i} L_{IM} L_T L_p P_{GSM} \tag{5}$$

P_{active} in the above is the IM interference that is generated in the transmitter or in general in the transmitter end. There exists another mechanism that creates IM products and it is called passive IM or receiver IM. As the name gives away, it stems from the receiver nonlinearities that can be caused even from faded soldering. This IM parameter is difficult to be measured especially when the token receiver is not available. However, theoretical analysis may take place. $P_{passive}$ is given from equation 6 where L_p is the propagation loss in the path from GSM transmitter to UMTS receiver and L_{IM}' is a loss factor that indicates the difference in the level between the GSM signal and the intermods.

$$P_{passive} = \sum_{f_i} L'_{IM} L_p P_{GSM} \tag{6}$$

Finally, the sum of IM interference in the receiver end will be:

$$I_{IM} = P_{active} + P_{passive} \tag{7}$$

V. 3G CAPACITY ISSUES

Capacity in the modern mobile networks is a major concern. Advanced technology is used so that the same available resources can serve more users and provide greater channel bandwidth and bit rate. In this context, capacity is regarded as the number of physical layer connections that take place in a single cell. UMTS and w-CDMA, are widely known as interference limited systems. The signal of every subscriber serves as interference to the others due to the imperfectly orthogonal codes that are used. Capacity and interference compete with each other in a tradeoff between quality of service and availability of service. Having a demand for the rate of communications set, means that the engineers press the system to operate with the minimum acceptable SIR. Greater volume of interference will mean that the receiver will not be able to recover the information sent and less interference will mean less capacity. Both of these two are unacceptable.

It seems that the effort is concentrated in minimizing every other existing interference so as to use the tolerable volume of interference to store more channels into the system. In this context, it is clear that it is desirable to minimize IM interference even though CDMA systems tend to reduce the effect of narrowband interference themselves.

In order to calculate the effect of GSM IM interference on UMTS capacity we should first analyze some UMTS features, like SIR and capacity. We assume that in order to maintain the desirable QoS, probability of error should be constant and below the threshold and as a result, SIR should remain above the desired threshold (usually 5-9dB). Thus the two variables in this analysis are interference and capacity.

SIR is known from bibliography and given by equation 8. In this equation we express the generalized factors. Further analysis of the several factors follows. It is clear that all kinds of narrowband interference are divided by the PG multiplier. This is the mechanism that protects CDMA signals from narrowband interference.

$$SIR = \frac{PG \times S_i}{N_0 + I_{CDMA} + I_{IM}} \quad (8)$$

, where PG is the processing gain (variable in case of UMTS), S_i the power of one UMTS channel, N_0 the background noise and I the several interferences induced. Note that, except IM interference and the one caused from the existence of the rest of the channels, no other kind of interference has been taken into account in this study.

IM interference is given from (5) and CDMA interference is usually given from (9) [8].

$$I_{CDMA} = \sum_{\substack{j=1 \\ j \neq i}}^{N} \alpha(1-\eta)S_j = (N-1)a(1-\eta)\overline{S} \quad (9)$$

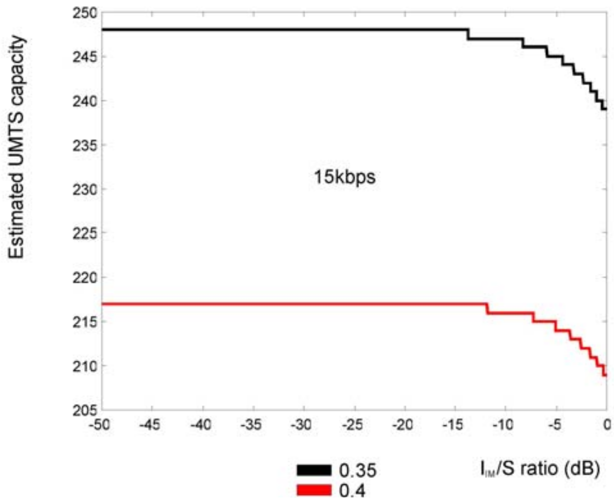
, where α is the voice activity factor (which is approximately 3/8 in real systems or 1 when this technique is not used), η is the average orthogonality factor and $\overline{S}$ the mean value of channel power. If we assume a perfect power control system we get (10) where S is the power of any uplink CDMA channel when the signal reaches the base station receiver. This, of course, is not true for the mobile station receiver.

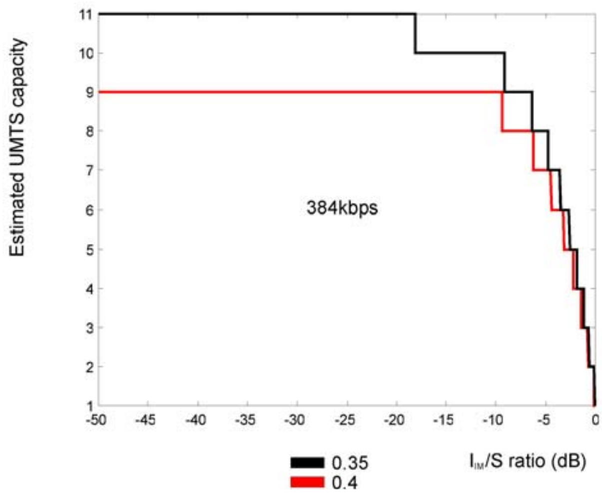
$$S_i = S_j = \overline{S} = S \quad (10)$$

Then, we can extract the formula for capacity in a CDMA system if we solve for N, (11).

$$N = 1 + \frac{PG \times S - SIR(N_0 + I_{IM})}{a(1-\eta)S \times SIR} \quad (11)$$

The above equation clearly shows that, as IM interference rises, the capacity of the system has to be reduced in order to maintain the required SIR and assuming that the other factors of the equation are already tuned. On the other hand, the power of IM interference products is multiplied by SIR/PG (in case of the conversational class this expression is 8/256=1/32) and then compared to S. Therefore, only an important value of I_{IM} can produce serious damage to the capacity of the system. In figure 7 we see an evaluation of the equation 11 for several bit rates.





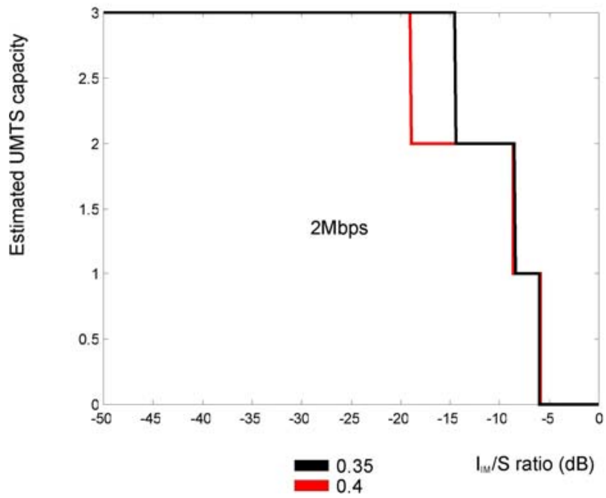


Figure 7: CDMA system capacity dependence from I_{IM}/S ratio with η=0.4 and η=0.35 and the cases of 15kbps, 384kbps and 2Mbps

From figure 7 we draw the conclusion that when the IM product power is at least about -10dB smaller than the original UMTS signal at the receiver it causes reduction in the system capacity. Moreover, we can confirm that high bit rate connection are more fragile because of the much smaller processing gain. In the next section we analyze a case study for a hybrid GSM and UMTS system in order to fully understand the extent of the problem caused by the intermodulation interference.

VI. Evaluation of the GSM and UMTS co-existence interference

This section contains a quantitative analysis of IM interference between two real systems and the conclusions drawn from the results. Passive intermodulation interference is not considered in the following study because it is impossible to simulate it. Instead, we can make the assumption that passive intermodulation will do harm in a small percentage of mobile terminals and will result in deteriorating their performance. In the following, the base station receiver case and the mobile receiver case will be examined separately. Moreover, the GSM-1800 system will be the target of the analysis as the effects are stronger than the GSM-900 case.

Firstly, the induced losses from transmission mismatch have to be taken into account. This issue includes the drop in power level in relation to the original GSM signal. This valuable information can be extracted from the specifications of the GSM transceiver, the TOI of the amplifier, the reject band level of the filter and the SWR of the antenna. Using known values from the references [7],[8] we get the approximation :

$$L_{IM}(db) + L_T(db) = -40db - 110db = -150db \quad (12)$$

The transmitting power of the GSM and UMTS base stations can be set equal to 30dbm and 20dbm respectively since urban transmission is considered. The mobile station power is 10dbm. Due to perfect power control, it can be assumed that the receiving signal in the UMTS node-b will have minimum power, equal to the receiver's sensitivity, regardless of the position of the mobile transmitter. This power level is given by 13.

$$S_{\min} = P_{UMTS} \times L_p(d_{UMTS}) \tag{13}$$

Using the above information and the already described propagation model, a simulation for varying base station positions can be performed. The simulation for several combinations of GSM interferers is showcased in figures 8 and 9. Here, it is assumed that $d_{UMTS}=d_{GSM}$.

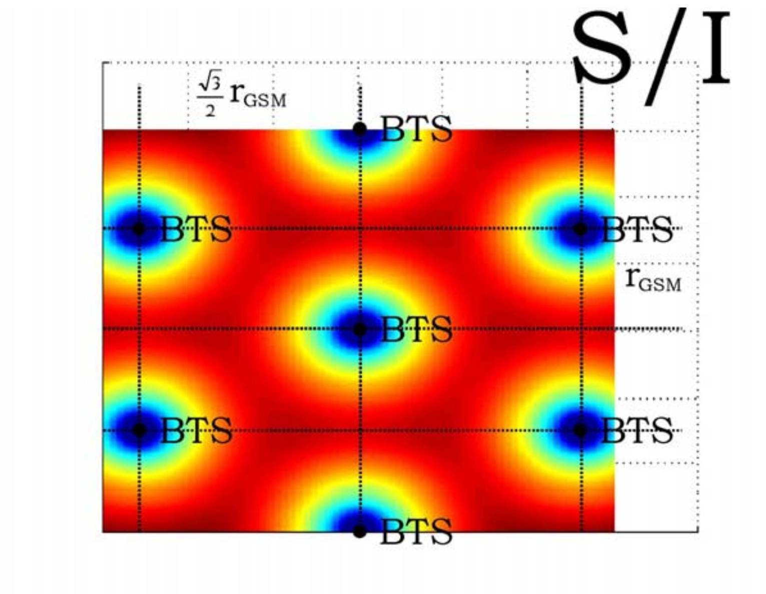


Figure 8: Overview of UMTS signal to GSM IM interference ratio for all the possible locations of node-b. The positions of GSM BTSs are indicated

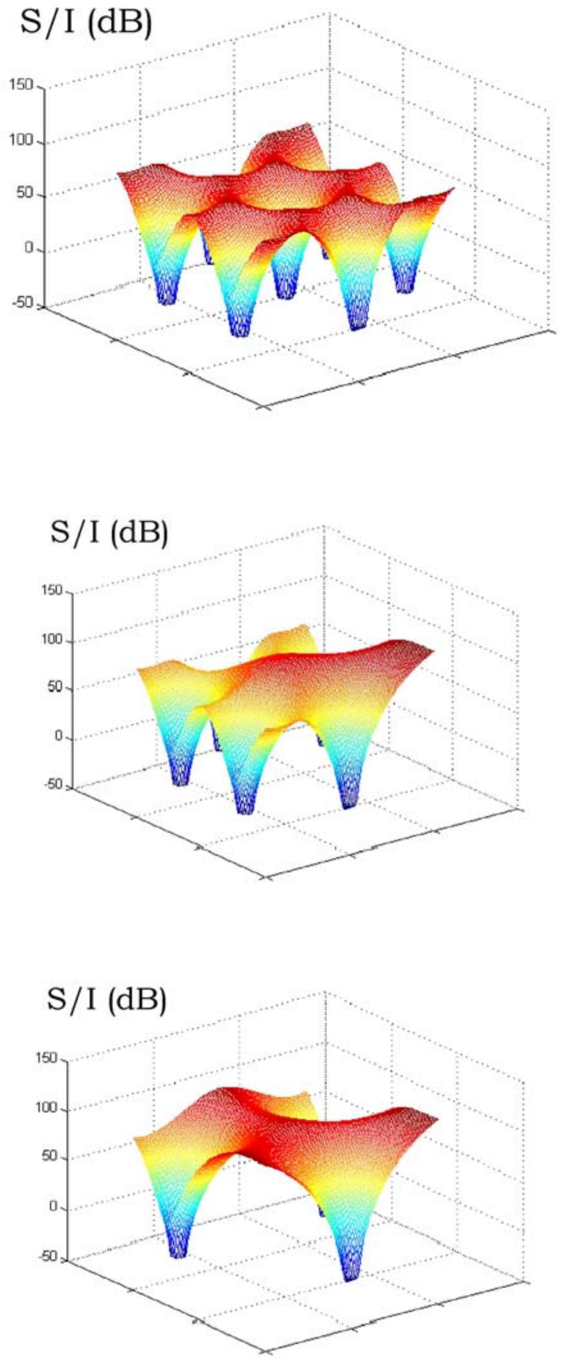


Figure 9: The same SIR chart for 7, 5 and 3 interfering base stations respectively.

A quick mathematical calculation dictates that a UMTS node-b situated d>rGSM/3 away from every GSM interferer will retain its channel capacity untouched. Another conclusion is that the number of actual interfering channels is very important and highly variable. If more than one interfering combinations exist in one BTS the IM interference power will increase accordingly (e.g. +3dB for two combinations). Another point of interest is the occasion when the UMTS node-b and the GSM BTS are co-sited. This situation can not be described by the diagrams correctly. The relative positions of the two antennae and their coupling are important parameters. Proper choice of these can lead to minimization of IM interference.

The number of interfering combinations depends on the channel allocation of GSM and the UMTS channel bandwidth. Channel allocation is usually created adjacent channel interference sensitive. As the reference [4] indicates, the large spacing between the channels in a cell, favors IM interference. As shown in figures 5 and 6, only combinations of distant in frequency channels can cause UMTS in-band interference. The greater the distance, the higher the intermod frequency. This leads to the conclusion that the lower channels of UMTS will suffer the most.

The same analysis applies to the case of the mobile receiver. This time, the signal is the UMTS downlink and its power is increased by +10dB. The frequency is different and so are the combinations of GSM channels that give IM products in this band. However, the passive IM phenomena are expected to be amplified here due to the used RF equipment which is much more compact and of lesser quality. Nonlinearities and rotten soldering are less rare in this case. This hypothesis rests on the assumption the UMTS system will utilize two-way power control. Should the uplink fail to support power control, the small-distance communications will be relieved of interference but the distant ones will suffer dramatically.

VII. Analysis of the new proposed Frequency Planning strategy for GSM

The frequency plan is a major issue of the installation of every cellular system. In this process, the distribution of the available channels is chosen for every tier following a channel spacing rule. Then, the rest of the cells use the rest of the channels as the classical cellular idea demands. The choice of the channel allocation is made frantically so as to achieve minimization of the spurious interference signals. A matter that arises here is that during the installation of the GSM system, the future superposition of UMTS could not have been foreseen. As a matter of fact, in the existing frequency plan, the adjacent cell channels have the greatest spacing possible which leads to minimum adjacent channel interference but maximum IM.

A means of reducing the IM interference is by developing a more insightful frequency plan. In 4, the channel spacing is optimized for better results regarding the tradeoff between the types of interference mentioned. In 3, RF filtering is used for the same reason. Although filtering can reduce the intermods power it cannot battle the passive interference generated in the receiver. In this paper, two different strategies are introduced, the block assignment and the frequency banning.

The first solution is based on figures 5, 6. From these diagrams it can be extracted that there exist block of channels that every combination of them results to out of UMTS band intermods. An example is shown in figure 10. Using the black blocks in a GSM-1800 cluster guarantees that no IM interference will exist at the UMTS node-b. The drawback of this solution is that special treatment is required for the identification of these blocks in every case. Another practical problem is that frequency plans are already made for GSM and it would be uncomfortable to reorganize the base stations of an entire area.

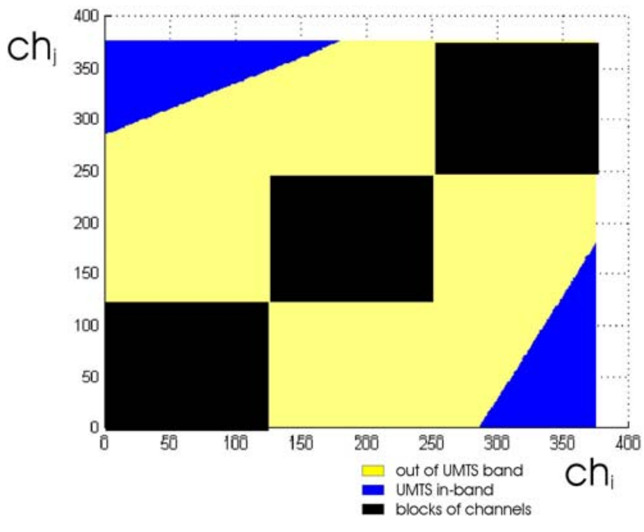


Figure 10: Frequency planning strategy that utilizes free of IM interference blocks of channels

The second proposed solution utilizes the technique of banning frequencies. The first step is to identify the channel combinations that give IM products in every GSM cell. Then in step two, the banning of the most popular channels in the above combinations takes place. By banning the channels at the end of the spectrum it is possible to minimize IM products to an acceptable degree. The third step is the compensation for the loss in the GSM capacity. The frequency hopping technique can be adopted so as to maintain the same number of channels with less transceivers. To sum up, in this proposal, the GSM capacity is compromised in order to give way to high capacity UMTS performance. However, the GSM system can benefit from the spread spectrum techniques which may be used to counter this loss.

The above strategy can be conceived as a tradeoff between GSM and UMTS capacity depending on the needs of each geographical area (e.g. for a high-speed road the GSM capacity might be more important than UMTS high data rates). Another advantage of this technique is that it can easily be applied on an already installed system and that it can completely erase IM products. Moreover, this technique is capable of reducing passive IM interference as well, since there are no in-band combinations allowed.

VIII. CONCLUSIONS

The special characteristics of the air interface necessitate a careful approach. New systems are superimposed with old ones and inter-system interference makes its presence. In this hostile environment a tradeoff between the two systems arises. The high demands of 3G systems may lead to degradation of 2G systems performance but the opposite may as well be the case when the 2G services are valuable. This study demonstrated the existence of this tradeoff and some general rules of the optimization of the systems' co-existence.

IX. References

[1] Khalied Hamied and Gerald Labedz, "AMPS Cell Transmitter Interference to CDMA Mobile Receiver", Vehicular Technology Conference, 1996. Mobile Technology for the Human Race., IEEE 46th , Volume: 3 , 1996.

[2] Greg Agami, Yi-Chiun Chen and C. C. Lee, "Using RF Filtering to Reduce Competitor-Induced Interference", in IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 51, NO. 2, MARCH 2002.

[3] Kari Heiska, Harri Posti, Peter Muszynski, Pauli Aikio, Jussi Numminen, and Miikka Hamalainen, "Capacity Reduction of WCDMA Downlink in the Presence of Interference From Adjacent Narrow-Band System", in IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 51, NO. 1, JANUARY 2002.

[4] Hanwook Jung, *Member, IEEE,* and Ozan K. Tonguz, *Member, IEEE*, "Random Spacing Channel Assignment to Reduce the Nonlinear Intermodulation Distortion in Cellular Mobile Communications", in IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 48, NO. 5, SEPTEMBER 1999.

[5] Harri Holma and Antti Toskala, "WCDMA for UMTS", Second Edition, WILEY.

[6] Ramjee Prasad, "Universal Wireless Personal Communications", Artech House.

[7] SONY Mobile Communication Data book – Technical specifications.

[8] Savo Glisic and Branka Vucetic, "Spread Spectrum CDMA Systems for Wireless Communications", Artech House.

[9] "COST 231, Digital Mobile Radio Towards Future Generation Systems", European Commission, Brussels, Belgium, 1999.