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Traffic Analysis for Exposure Assessment in Mobile Telephony

Zaher Mahfouz^{*,+}, Azeddine Gati^{*}, David Lautru⁺, Joe Wiart^{*,#} and Victor Fouad HANNA⁺
^{*}France Télécom Division R&D RESA: FACE 38-40, rue Général Leclerc 92794 Issy Les Moulineaux, France
[#]Whist Lab: Orange Labs & Institut Telecom Common Lab
{zaher.mahfouz;azeddine.gati;joe.wiart}@orange-ftgroup.com
⁺UPMC Univ Paris 06, UR2, L2E F-75005, Paris, France
{david.lautru ;victor.fouad_hanna}@upmc.fr

Abstract— In this paper, the general public daily exposure to mobile telephony signals, namely GSM900, GSM1800, UMTS2100 and HSDPA, is investigated. Temporal variations and traffic distribution during a day at different sites are presented. The goal is to characterize the ratio between daily maximum realistic values and maximum theoretical values. Relations between the mean values over 24h, the maximum realistic values (at 99%) and the maximum theoretical values are presented. The traffic is expressed in terms of a ratio between the total received power and the power allocated to the pilot channels. The traffic variation and especially the active power over a day are given without and with a sliding time average of 6min applied on the measurements. A general mask is also given for underlining the maximum active traffic depending on the measurement period during the day.

I. INTRODUCTION

The public is permanently exposed to radiofrequency electromagnetic (EM) fields emitted by different EM sources like mobile telephony antennas. Scientists and government are conducting research on possible effects from radio waves emitted from these sources and to define the limits such as those given by the International Commission on Non Ionizing Radiation Protection (ICNIRP) [1]. Standards have also been developed to check the compliance to safety limits like those from IEEE [2], FCC [3] and CENELEC [4].

Humans are exposed to various types of radio emissions. Each signal has its proper behaviour (transmitted power, modulations, bandwidth, power control, data rate, transmission...) and its access mode like Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Frequency Division Duplex (FDD) and Time Division Duplex (TDD).

More recently, the comprehensive characterization of the real human exposure as a function of the time variation of emissions has been investigated. In [5], it has been shown that the fields emitted from GSM900 systems are higher during daytime than at night because of the traffic demand, which induces a high variation of GSM900 signals compared to broadcasting ones like the FM signal. The time variation is of prime interest as the exposure is closely related to the incoming power flux and to the way by which the exposure to

those systems is varying and it depends also on the usage as well as on the propagating conditions.

In this paper, the human exposure to telephony base stations during a day at different sites in urban and rural zones is presented.

The purpose of this paper is to analyse the evaluated real exposure in a realistic environment and to characterize statically the maximum and daily exposures in real conditions induced by operating networks. Also, the margin between the maximum theoretical and the live exposure are investigated to define realistic maximum values which would be more appropriated when defining public exposure limits.

This study will help legal authorities for establishing extrapolation factors for assessing the exposure during a day based on real measured samples more than on theoretical considerations.

II. REAL TRAFFIC IN CELLULAR NETWORK

A. Overview

The exposure is closely related to the time average of the incoming power flux which depends on the traffic variations. Telephony networks like GSM or UMTS involves signals which are composed basically of two parts: the pilot signals and the traffic signals. Of course other signals exist like the synchronization ones, but we will represent the traffic variation by a ratio between the total received power (called P_r) and the pilot power (called P_{Pilot}).

$$P_r = N_{\text{Traffic}} \cdot P_{\text{Pilot}}$$

The pilot signals are the Broadcast Control Channel (BCCH) and the Common Pilot Channel (CPICH) for GSM and UMTS respectively. BCCH and CPICH are continuously transmitted over the day, they represent the signalization. The numbers of equivalent traffic evaluated for GSM and UMTS are expressed by N_{TRX} and N_{CPICH} respectively.

B. Traffic Distribution

Automatic measurements of all bands and all operators (three operators in France) have been performed using special software developed in FT Orange Labs.

20 measurements in urban areas while 6 measurements in rural ones in different locations have been performed every 10s (time sampling) for each signal over a day.

So far, in [6], it has been shown that GSM900 fit a three Gaussian distribution model constructed using the Expectation Maximization algorithm. The first Gaussian represents the traffic during the night (from 1am to 6am), the second one represents the traffic during the working day and the last Gaussian corresponds to a maximum traffic load mostly during the rush hours (12am-2pm and 5pm-9pm). Therefore, the traffic variation follows a Gaussian mixture decomposition corresponding to three different usages: Low-Traffic (LT), Working Day (WD) and Rush Hours (RH) (see Fig. 1, distribution of NTRX).

The percentage of occupation of the different Gaussians is the following: 27% (6.4 hours) for LT, 30% (7.2h) for WD, 24% (5.7h) for RH and 8% (2h) for BCCH (only broadcasting channels are emitted).

The model with a mixture of three Gaussians was also explored for GSM1800, UMTS and High Speed Downlink Packet Access (HSDPA).

The results show that the ratio between Gaussian distribution models in rural zone for GSM900 is higher than that in urban zone due to high power transmission in rural and because of the propagation path loss. This Ratio in rural zone is smaller than that in urban zone for GSM1800 and UMTS due to the coverage and also due to the number of sites deployed in the rural sites. In urban zone, this ratio for GSM1800 is bigger than that in GSM900 due to the capacity allocated resources which are higher in GSM1800 system. The capacity is higher in GSM1800 since this system is used as a reinforcement network to the GSM900 network for high traffic demand areas.

C. Real Traffic in Cellular Networks

In practice, an instantaneous measurement should be extrapolated to a predefined “worst-case” in order to check the compliance to safety limits. For example, for GSM900 and GSM1800, the extrapolation is based on the measurement of the BCCH (Broadcast Control Channel) (noted P_{BCCH}), on the number of TRX (NTRX) which corresponds to the broadcasting channel emitted continuously over the day, and to the number of traffic amplifiers which hold the traffic and for which the power can never exceed the BCCH level respectively.

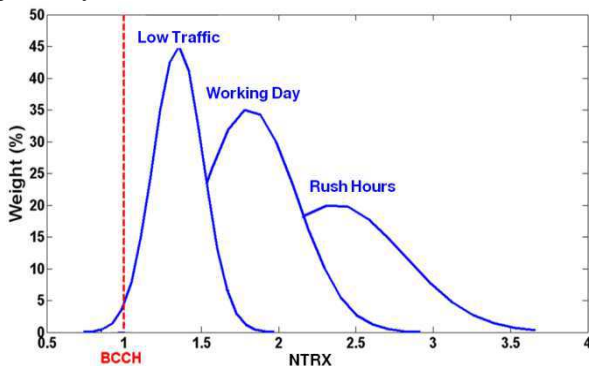


Fig. 1 GSM900 distribution model

The maximum received power (P_r) in GSM and UMTS Networks are given by:

$$P_r(\text{GSM}) = N_{\text{TRX}} \cdot P_{\text{BCCH}} \quad (1)$$

$$P_r(\text{UMTS}) = N_{\text{CPICH}} \cdot P_{\text{CPICH}} \quad (2)$$

Some countries have assumed a maximum number of TRXs and CPICHs depending on the public density. For example, in France in 2002, the ANFR (National Frequency Agency) have given the values of 6, 8 and 10 in GSM900, GSM1800 and UMTS Networks respectively which are the maximum deployed TRXs and CPICHs by operators. Those values are considered as the maximal theoretical ones and are used for extrapolation to the worst case situation as given in international standards. There is no value assumed for HSDPA systems as it was not yet deployed in 2002 when ANFR gave the theoretical values for the different signals.

The real determined exposure evaluation is compared to the maximum theoretical values. Therefore, the study is focused on the determination of the real equivalent number TRXs (N_{TRX}) and CPICHs (N_{CPICH}) that is active over one day.

The measurements show that during the night we have a weak traffic. The average traffic occupation during night is about 35% to 50% of one equivalent TRX for GSM900 and GSM1800 respectively.

GSM900 and GSM1800 have a three mixture Gaussian distribution model. A Metropolis Hasting algorithm, which is a powerful Markov chain method has been employed to simulate multivariate distributions for GSM900 and GSM1800 using their probability density function.

Fig. 2 shows the cumulative distribution function (CDF) for both GSM900 and GSM1800 models in urban areas.

The results show that the power received in GSM900 doesn't exceed $4 \cdot P_{\text{BCCH}}$ contrary to GSM1800 for which it could exceed $5 \cdot P_{\text{BCCH}}$ (with a percentage of 0.02%). This result confirms that the number of TRX in GSM1800 Network is larger than in GSM900 Network. This was expected as the GSM1800 network is used as a reinforcement network to increase the GSM900 capacity.

The results for different configurations are given in Table I. The different measurements prove that the maximal equivalent TRX in a realistic environment is 3 for GSM900 and 4 for GSM1800 in urban zone and 4 for GSM900 and 3 for GSM1800 in rural zone.

The NTRX maximal in GSM1800 is smaller in rural zone than in urban. This was also expected as GSM900 is preferred due to the propagation performances of the 900MHz carrier in rural zone.

These values are smaller compared to the maximum theoretical values. In reality, a full traffic situation is never reached. A maximum number of TRXs can be activated but very shortly to manage an atypical traffic demand like for example near stadiums during football matches.

The extrapolated values correspond to a maximum theoretical full traffic situation and largely overestimate the real exposure even during rush hours.

The average equivalent NTRX is around 1.5 in the Night, 2 in the Working Day and 3 in the Rush Hours.

The same study has been done for UMTS and HSDPA Network in urban zones. The results show that the maximal N_{CPICH} in a realistic environment is about 5 for a UMTS Network and 14 for an HSDPA Network in urban zones. Therefore, the theoretical value ($N_{CPICH} = 10$) given by the ANFR and in many other countries in Europe and in the world overestimates also the real exposure in UMTS Network. We observe that the variation of HSDPA is very high compared to UMTS. In fact, in HSDPA systems, all the power is affected to a single User Equipment (UE) at each time.

All the measurements have been performed every 10s as mentioned above. We have done the same study by taking a sliding time average of 6min for all the measurements to give a better alignment to exposure standards (ICNIRP). The values of the realistic maximal are given in Table I.

We represent in Fig. 3 the variation of the NTRX for the different day periods given in Table I. An important limiting mask for GSM system can be used to determine whether the measurement is performed during the Low Traffic Hours (Night), the Working Day hours or the Rush Hours (12am-2pm and 5pm-9pm). The NTRX are also presented in the figure for these different

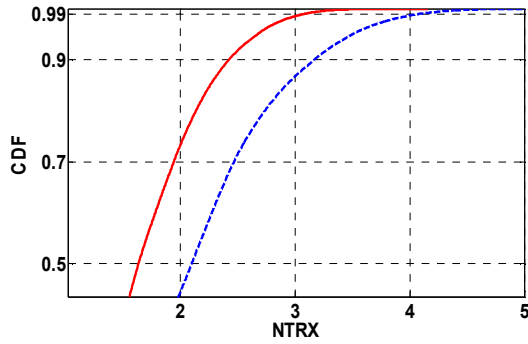


Fig. 2 CDF for NTRX of GSM900 (red line) and GSM1800 (dotted blue line) in Urban

Table I

Number of Equivalent TRX (N_{TRX}) for GSM900, GSM1800, UMTS and HSDPA for Different Configurations

| | NTRX GSM900 | NTRX GSM1800 | N_{CPICH} UMTS2100 | N_{CPICH} HSDPA |
|---|----------------|-----------------|-------------------------|----------------------|
| Theoretical Max (France-ANFR 2002) | 6 | 8 | 10 | - |
| Realistic Max (Urban) | 3 (2.36)* | 4 (2.70)* | 5 (4.38)* | 14(10.21)* |
| Realistic Max (Rural) | 4 | 3 | - | - |
| Night (Low Traffic) | 1.3 | 1.5 | 2.5 | 3 |
| Working Day | 2 | 2.2 | 3 | 4.5 |
| Rush Hours | 2.5 | 3 | 4 | 9 |

(x)* = value with a sliding time average of 6min

periods of the day in order to obtain the maximal received power (1) by performing measurements only for BCCH any time over the day. As mentioned above, the different measurements demonstrate that the maximal equivalent N_{TRX} (at 99%) in a realistic environment is 4 for GSM system, this maximal equivalent NTRX is equal to 1.5 and 3 in Low Traffic Hours and Rush Hours respectively.

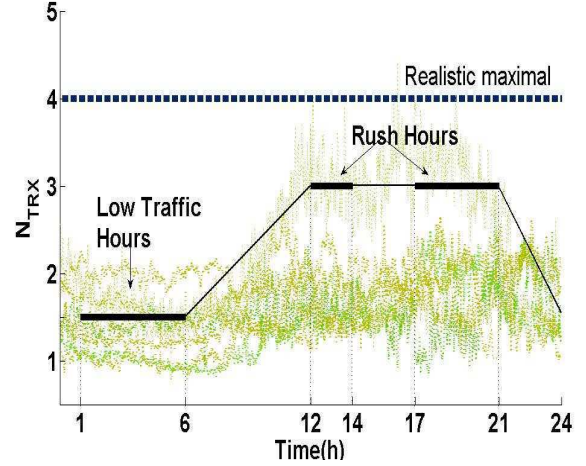


Fig. 3 E^2_{GSM900} : Different measurements for GSM900 and GSM1800 (dotted line), and N_{TRX} limits for LTH, RH and the Realistic Max

D. Relation Between the 24 hour Mean and the Maximal values

We give in Table II the relations between the mean over 24h and either the realistic maximal (at 99%) or the maximal theoretical values (ANFR) for GSM900, GSM1800, UMTS and HSDPA systems. These values correspond to the real measurement without applying a sliding time average of 6min. These ratios can be used to find the mean over 24h as well as the maximal real value from the maximal theoretical value and vice versa. We can also use these values in conjunction with the values given in Table I and the equation (1) and (2) to find the P_{BCCH} , P_{LTH} , P_{WD} , P_{RH} .

Table II

Ratios between Mean Value over 24h and the Maximal Value

| RATIO | GSM900 | GSM1800 | UMTS | HSDPA |
|---------------------------------------|--------|---------|------|-------|
| Mean(24h)/ Max Theoretical | 0,41 | 0,42 | 0.31 | - |
| Mean(24h)/ Max real | 0,62 | 0,64 | 0.63 | 0.35 |

III. CONCLUSIONS

Real live exposure of the general public during a period of one day is investigated in this paper. Traffic conditions cause variations with time of the electric field's amplitude. Each of the systems GSM900, GSM1800, UMTS and HSDPA fits a three Gaussian distribution model.

The main conclusion is that the maximal equivalent N_{TRX} in a realistic environment is 4 for the GSM system and the

maximal equivalent N_{CPICH} is 5 and 14 for UMTS and HSDPA respectively. Furthermore, full traffic situation is never reached in reality.

Results of this work can be very useful for elaborating standards for human exposure based on measurements using actual operating systems and benchmark results coming from different countries which assesses real exposure and give the public a good estimation of exposure in real usage.

ACKNOWLEDGMENT

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