IF-TH-71

A bioelectromagnetic overview of the Universal Mobile Telecommunication System (UMTS)

Mauro Cappelli*, Luciano Tarricone◇

*D.I.E.I. - University of Perugia, Via G. Duranti, 93, 06125, Perugia, Italy

◇ Dip. Ingegneria dell'Innovazione, University of Lecce, Via Monteroni, 73100, Lecce, Italy

email: tarricone@diei.unipg.it

Abstract— **The large-scale introduction of the Universal Mobile Telecommunication System (UMTS) must be forwarded by a suitable evaluation of possible effects of its radiowave signals on end-users. For this purpose, a rigorous characterization of its radio-signals must be performed from a radioprotection point of view, spectral and power behaviour being among the most important issues. In this paper UMTS radiowave signals are accurately investigated. An algorithm is proposed for the numerical generation of such signals, so that real operating conditions can be accurately simulated, and bioelectromagnetic interactions studied. Results demonstrate the accuracy of the proposed algorithm, as well as the amenability of the attained signals to model the bioelectromagnetic interaction up to cellular scales.**

I. Introduction

The world of wireless technologies is continuously and rapidly changing. One of the next, and relevant, changes, is the so-called *third generation* (3G) of communication systems, including the quite well-known Universal Mobile Telecommunication System (UMTS).

The wide-scale introduction of UMTS, nonetheless, must be forwarded by a suitable and accurate preliminary analysis of the possible bioelectromagnetic impact of such signals on the potential users (or, more generally, on people exposed to the used signals).

Similar analyses have been performed into details for previous systems, such as for the GSM one [1],[2],[3], whilst, as far as we know today, UMTS, or, more generally, CDMA-based systems, have been only shortly outlined in [2].

In this paper a complete, yet simplified, overview of UMTS is given, so that the power, spectrum and time characteristics of the used signals can be focussed. As a practical example, a simple *uplink* connection is studied and the reader is proposed a simple algorithm to generate a numerical UMTS signal. The same signal is used to simulate the biointeraction at membrane channel level, in order to identify possible effects on relevant physiological parameters. Finally, conclusions are drawn and some perspective views proposed.

II. UMTS Radio-interface layer

The physical layer defines all the procedures directly involved in the radio-transmission of signals. Its description is herein based on the WCDMA solution as adopted by the 3GPP Group [4], [5], [6], [7]. In UMTS, two communication standards are adopted: FDD (Frequency Division Duplex) and TDD (Time Division Duplex). In this paper, for the sake of brevity and clarity, we elect the FDD mode as the reference case. In FDD case, the UPLINK is assigned the $1920 - 1980 MHz$ band, and DOWNLINK the $2110 - 2170 MHz$ one.

The WCDMA is a wideband DS CDMA (Direct-sequence Code-Division Multiple-Access). Basic issues for CDMA for bioelectromagnetic purposes are given in [2]. In WCDMA user's bits are spanned (*spreading* phase) over a wider band thanks to the multiplication (or frequency convolution) with suitable quasi-random codes. Symbols attained are called *chips*.

The WCDMA adopted in UMTS can be partitioned into three main steps: spreading, scrambling and modulation, respectively.

The spreading operation (often called *channelization*) turns bits into chips, as previously mentioned, with a consequent user's bandwidth improvement, depending on the spreading factor (SF). Each user occupies a bandwidth equal to:

$$B = \frac{1}{T_b} SF = \frac{1}{T_c} \tag{1}$$

where T_b and T_c are the bit and chip period respectively.

The DS-CDMA technique used in UMTS uses orthogonal spreading codes in conjunction with a different encoding strategy, called *scrambling*. This operation does not correspond to further bandwidth improvement, but brings out important network advantages.

Let us now consider the uplink connection. The following dedicated channels are given: *Dedicated Physical Data Channel* (DPDCH) and *Dedicated Physical Control Channel* (DPCCH).

The signals are structured into 10 ms *frames*, which are themselves partitioned into 15 0.666ms *slots*, each containing 2560 chips. Slots and frames are the shortest time units inside which the transmitting power and speed, respectively, do not change at all.

0-7803-7239-5/02/$10.00 © 2002 IEEE

2002 IEEE MTT-S Digest

A. Spreading, Scrambling and Modulation

The codes used in UMTS for *spreading* are the so-called Walsh's Orthogonal Variable Spreading Factors [8] (OVSF), ranging from 4 to 512. They are sinchronous and orthogonal, guaranteeing a null cross-correlation and a dynamical use of SF. They are generated by using the Walsh-Adamart technique.

Scrambling codes are complex-valued and pseudo-random. They are attained by using Feedback Shift Register generators [9], ensuring an adequately low cross-correlation.

Spreading and scrambling operations over physical DPDCH and DPCCH channels are resumed in Fig. 1, where spreading codes are indicated with C_c (for DPCCH channels) and $C_{d,n}$ (for DPDCH channels).

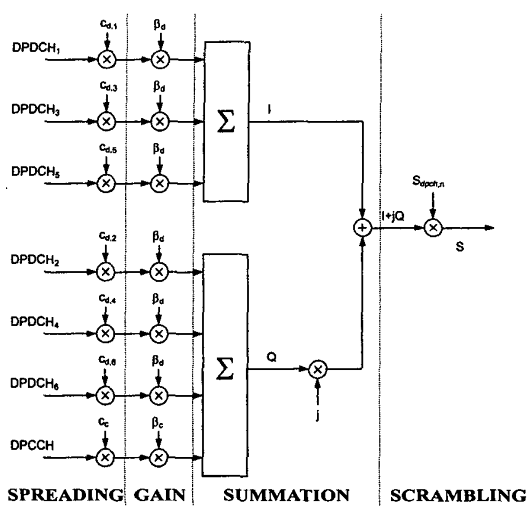

Fig. 1. Spreading and Scrambling codes in uplink.

The modulation scheme is QPSK-based, with carrier frequencies around 2 GHz and bandwidth around 5 MHz. The signal is time-shaped by a *root-raised cosine* pulse $p(t)$, with roll-off factor α of about 0.22, so that possible inter-chip interferences induced by the channel time dispersion can be minimized. The used modulator is proposed in Fig. 2.

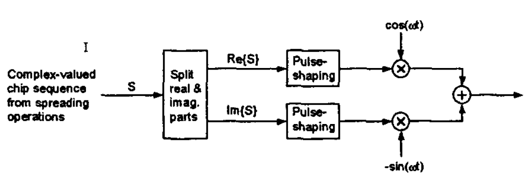

Fig. 2. Basic scheme for a modulator.

B. Power control

As apparent from previous sections, in the WCDMA approach *power* is the shared resource, *frequency* and *time* being its corresponding entities in FDMA and TDMA approaches respectively. Thus, power control is crucial in order to prevent signals from shadowing induced by their neighbours. Should interfering signals be too powerful, the interesting signals could not be detected.

In such a framework, an accurate real-time power control is mandatory. UMTS ensures a power control up to time-slot level (Fast Power Control): power can be adjusted, depending on the several mentioned parameters (pathloss, load, site characteristics, quality-of-service, etc. etc.) up to once per slot (around 1500 times per second).

A further problem related with power is the so-called *Near-Far Problem*: should all the users transmit with the same power, those near the base-station would shadow the remaining signals, because of their minimum pathloss. Consequently, transmitted power is accurately and dynamically tuned according to distance.

III. Results

On the basis of the performed discussion on the physical characteristic of the radio signals adopted in UMTS, we propose now some results. First of all, we suggest a simple procedure to generate synthetic data with all the main spectral and time properties of the real UMTS signal. Later on, we demonstrate how such signals can be fruitfully used in the analysis of the interaction between UMTS signals and cell membranes.

A. UMTS signal generation

A mobile station (MS), fixed or slowly moving, is considered, so that the maximum bit-rate can be assumed during a generical UPLINK connection. It is casted that the MS is the unique transmitting entity in the considered cell (in other words, potential interferences between up and downlink are neglected). An ideal pulse, instead of the previously mentioned *root-raised cosine* pulse, is adopted. One single data channel (DPDCH) and one single control channel (DPCCH) are assumed. This condition, yet minimal, can be considered quite typical, especially in the kick-off phase of UMTS services. The following choices are adopted for the relevant parameters: $\beta_d = 1$ and $\beta_c = 0.33$.

The three main operations of spreading, scrambling and modulation are attacked on the basis of what discussed in sections II-A and II-B, as well as in Fig. 1 and 2.

An important test to verify the appropriateness of the proposed algorithm is the spectral behaviour of the generated signal. More specifically, a simulation interval of 20 chips has been considered, and a frequency carrier of

$1.92 GHz$. Signal transmission has been supposed continuous, that is MS is assumed always on-line.

We report in Fig. 3 the PSD as attained by performing the Fast Fourier Transformation (FFT) of the simulated time signal. The reported bandwidth is of $10 MHz$, about twice the bandwidth of each frequency carrier. Power density levels (reported in dB) have been normalized, so that the reported results do not depend on the effective transmitted power, which is, as previously thoroughly discussed, extremely time-changing.

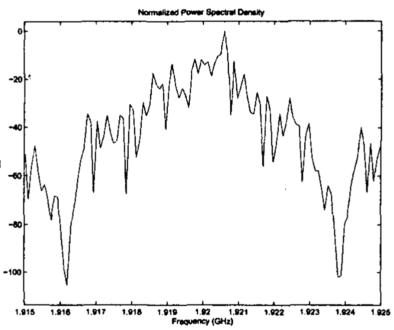

Fig. 3. Normalized Power Spectral Density for the simulated frame (central frequency = 1.92 GHz), as attained after Channelization.

B. Application to signal-membrane channel interaction

We propose now a possible application of the algorithm for UMTS signal generation. The application is based on a modelling approach proposed in previous papers [10],[11],[12], based on Markov models, and quickly resumed here. We assume that this modelling strategy is a viable and appropriate approach to study the bioelectromagnetic interaction between EM signals and biological system at cell membrane level, and jointly use it together with the numerical UMTS signals, in order to evaluate possible biological effects.

The adopted modelling strategy focusses on ionic channels inside cell membranes. We focus in this paper on voltage-dependent ones, i.e. channels whose conducting properties are directly linked with the transmembrane potential V_t. Each channel is considered as a stochastic automaton, with a finite number of states (basically closed and open states, corresponding to a non-conducting or conducting channel), and the channel's kinetical behaviour is described by the *transition rates* regulating transitions among states [13].

A typical two-state Markov model is shown in Fig. 4, where α and β are the transition rates, O is the open state, and C is the closed one.

The physiological behaviour of a voltage-dependent channel can be simulated by generating random processes whose aleatory variable is the dwell-time in each state of the channel.

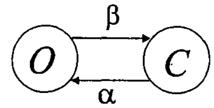

Fig. 4. A two-state Markov model.

The transmembrane voltage V_t modifies the kinetical behaviour of transitions, and consequently the current flow through the channel. In fact, referring to Fig. 4, α and β depend on V_t. Therefore, an external EM field, impinging on the cell membrane, modifies V_t, and perturbes the physiological equilibrium of the channel. More specifically, the probability for the channel to be open at a certain time can be perturbed by an exposure to an external UMTS signal of a given intensity. If we indicate with P_o^{ne} the open probability for a non-exposed channel, and with P_o^e the open probability for an EM-exposed channel, we can quantify the induced bioeletromagnetic effect as

$$\textbf{effect} = \frac{P_o^e - P_o^{ne}}{P_o^{ne}} \qquad (2)$$

Now, by using the UMTS numerically-generated signal, we estimate and discuss the observed effects considering the Potassium voltage-dependent channel, which is appropriately modelled by using a two-state Markov model. Under the assumption of Ohmic behaviour of the channel [10],[11], P_o is generally proportional to the current flowing through the channel.

A variable gain has been considered in the algorithm: the maximum considered power variation is of 10% between adjacent slots, with respect to the average value, thus simulating a dynamical power management similar to that required by the distance variation between MS and BTS.

In Fig. 5 we report the attained results for the Potassium channel exposed to UMTS signals of different amplitudes, and for different clamping transmembrane voltages V_t. Working frequency is the typical $1.92 GHz$ for the uplink connection.

It can be argued that the observed **effect** (as from eq. (4)) is complex and multi-folded. It assumes both positive (increase in P_o) and negative (decrease in P_o) values, depending on the transmembrane clamping voltage and on the stimulating field.

Moreover, very small differences in the stimulating signal's amplitude correspond to substantial changes in the channel response, as frequently observed in many bioelectromagnetic phenomena.

The large number of simulations performed for different stimulating frequencies has also demonstrated an evident frequency sensitivity. For the sake of conciseness, we report here a simple table (Tab. I). For four different stimulating frequencies in the UMTS range, and for

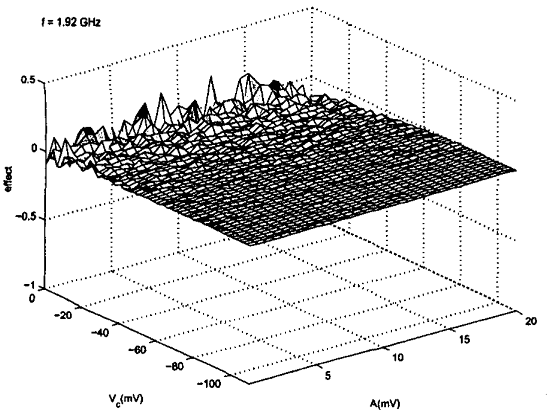

Fig. 5. Potassium channel exposed to a UMTS signal (f=1.92 GHz). Effect is reported as a function of the clamp voltage (V_c) and the amplitude of the external signal (A)

an amplitude equivalent to a transmembrane voltage of 1mV, we report the average value for the observed overall **effect** for a given signal's amplitude, estimated by referring to the following formula:

$$< \mathbf{effect} >= \frac{1}{N_s} \sum_{i=1}^{N_s} |\mathbf{effect}(i)| \qquad (3)$$

where N_s is the number of considered clamping voltages, and **effect**(i) is the observed effect for the i-th stimulating-field amplitude.

On the other hand, the algebraic summation of all the observed effects at each clamping voltage is reported, as estimated by using the following formula:

$$\mathbf{effect} = \sum_{i=1}^{N_s} \mathbf{effect}(i) \qquad (4)$$

with the above reported considerations for N_s and **effect**(i).

	f_1=1.92	f_2=1.94	f_3=1.96	f_4=1.98
Average	0.0114	0.0101	0.0091	0.0119
Overall	-0.222	0.037	-0.191	-0.155

TABLE I

AVERAGE AND OVERALL PERCENTAGE EFFECT FOR A 1MV STIMULATING FIELD AND FOUR DIFFERENT FREQUENCIES (IN GHZ).

IV. CONCLUSIONS

In this paper the main characteristics of radiowave signals adopted by the UMTS standards have been studied from the radioprotection point of view. The forthcoming diffusion of third-generation systems, in fact, compells to a careful evaluation of possible risks. This implies an immediate need of theoretical and experimental skills to model the used radio-signals, as well as the typical operating conditions.

As possible application, the case of an interaction between UMTS signals and cell membranes is addressed, with a specific focus on the use of a modelling technique to represent the response of ionic channels inside cell membranes.

Results attained, both for the generated signals, and for the considered applications, demonstrate the accuracy of the proposed algorithm, and its usability for research and development purposes.

REFERENCES

[1] G. F. Pedersen, "Amplitude Modulated RF Fields Stemming from a GSM/DCS-1800 Phone," *Wireless Networks*, no. 3, pp. 489–498, 1997.
[2] G. F. Pedersen, J. B. Andersen, "RF and ELF Exposure from Cellular Phone Handsets: TDMA and CDMA Systems," *Radiation Protection Dosimetry*, vol. 83, no. 1-2, pp. 131–138, 1999.
[3] F. Apollonio, G. D'Inzeo, L. Tarricone, "Modelling of Neuronal Cell Exposed to RF Fields from Mobile Telecommunication Equipment," *Bioelectrochemistry and Bioenergetics*, vol. 47, pp. 199–205, 1998.
[4] 3GPP, "Spreading and Modulation (FDD) (3G TS 25.213)," *Technical Specification Group Radio Access Network*, 2000.
[5] 3GPP, "Multiplexing and Channel Coding (TDD) (3G TS 25.222)," *Technical Specification Group Radio Access Network*, 1999.
[6] 3GPP, "Physical Layer Procedures (FDD) (3G TS 25.214)," *Technical Specification Group Radio Access Network*, 2000.
[7] 3GPP, "Physical Layer: General Description (3G TS 25.201)," *Technical Specification Group Radio Access Network*, 1999.
[8] F. Adachi, M. Sawahashi, K. Okawa, "Tree-structured Generation of Orthogonal Spreading Codes with Different Lengths for Forward Link of DS-CDMA Mobile," *Electronics Letters*, vol. 33, no. 1, pp. 27–28, 1997.
[9] J.G. Proakis, M. Salehi, *"Communication Systems Engineering"*. Prentice Hall I.E., 1994.
[10] A.L. Hodgkin, A.F. Huxley, "A Quantitative Description of Membrane Current and its Application to Conduction and Excitation in Nerve," *Journal of Physiology*, vol. 117, pp. 500–514, 1952.
[11] L.J. De Felice, J.R. Clay, *"Membrane Current and Membrane Potential from Single-Channel Kinetics" in "Single-Channel Recording"(B. Sakmann and E. Neher eds.)*. Plenum Press, NY,pp. 323-342, 1983.
[12] G. D'Inzeo, S. Pisa, L. Tarricone, "Ionic Channel Gating under Electromagnetic Exposure: a Stochastic Model," *Bioelectrochemistry and Bioenergetics*, vol. 29, pp. 289–304, 1993.
[13] D. Colquhoun, A.G. Hawkes, *"The Principles of the Stochastic Interpretation of Ion-Channel Mechanisms" in "Single-Channel Recording"(B. Sakmann and E. Neher eds.)*. Plenum Press, NY,pp. 135-174, 1983.