Theoretical Evaluation of UMTS/GSM Electromagnetic Fields on Neuronal Network Response

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Abstract – **Understanding the modalities of interaction of electromagnetic (EM) fields with the biological material is a key point in the identification of possible induced effects. In the past authors proposed an integrated approach to model electromagnetic fields interaction with biological systems, in which the final biological target is a neuronal network. In this paper authors investigate the possible effects of EM signals related to UMTS and GSM standards on the neuronal network model.**

I. INTRODUCTION

Understanding the modalities of interaction of electromagnetic (EM) fields with the biological material is a key point in the identification of possible induced effects. Since the beginnings of bioelectromagnetic studies, cellular membrane has been addressed as a primary site of interaction, leading to different models proposed in literature [1]. In particular an analysis of this biological system seemed to be the only effective way to understand interactions between EM fields and biological systems, in order to explain effects at tissue level [1, 2]. This approach is quite in accordance with a basic observation: the biophysical and biochemical physiological equilibria are managed at cell and cell-membrane level. However the cell membrane is not the basic biological unit for a biosystem, in fact some other elementary structures exist with defined tasks and functional modalities. This leads to the determination of a biological scale of complexity that grows from the low bio-physical level of ion-transport across cell membrane, to the biological one of cellular cycles or signalling pathways. The structures present in each level, because of their polar (or multipolar) nature, are intrinsically sensitive to EM fields.

Authors recently proposed an integrated approach to model electromagnetic fields interaction with a particular biological system: the neuronal one [2]. This methodology implements the cited biological scale of complexity, evaluating the effects induced by the electromagnetic field on each component of the model up to neuronal network level. In the present paper authors extended investigation to the possible effects of EM signals related to UMTS and GSM standard on this neuronal network model.

In the next two years the new mobile telecommunication standard UMTS is going to establish itself as the third generation technology, and services based on this standard will coexist with the current use of GSM second generation technology. Second and third generation wireless systems greatly differ with respect to their EM signal patterns (TDMA vs CDMA). Due to such differences in frequencies and patterns used, it seems interesting to evaluate how these wireless RF fields can interact with biological systems and how the differences in the signals eventually modify physiological conditions.

II. METHODS

A. The neuronal network model

A quasi-realistic neuronal network, has been used in order to investigate possible modifications in the electrical responses under electromagnetic exposure.

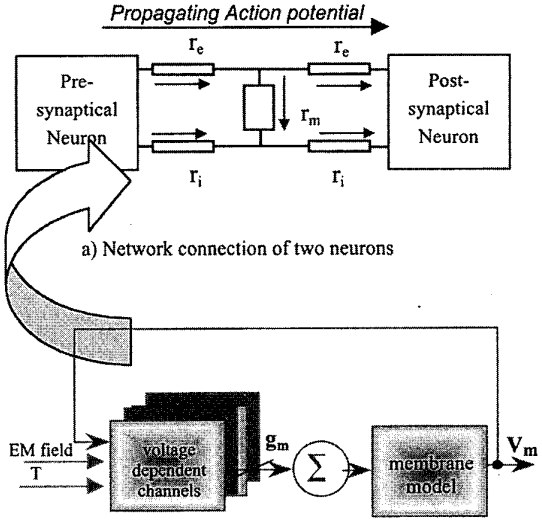

Fig. 1. Interconnection of neuronal models

We mainly consider, as macroscopic observables of the metabolic changes within the neuron, the pattern of action potentials and back propagating action potentials: in particular inter-spike intervals (ISI), spike coincidence and synchronisation of firing neurons.

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In [2] we resolved the task of connecting neuronal models approaching the problem of signal propagation inside the axon thanks to the core-conductor model [3]. The axon length can vary in a range between 1 and 50 mm. The overall effect of the neuronal axon can be taken into account by considering a pre-axon transmembrane voltage Vpre, a post-axon voltage Vpost, linked by the following relationship:

$$V_{post} = V_{pre} \exp(-x/\lambda) \qquad (1)$$

where x is the axon length, and λ is determined referring to the resistive and dielectric characteristics of the axon. More specifically, referring to Fig. 1a, r_i is the core resistance per unit length, r_e the resistance of extracellular fluid per unit length, and r_m the resistance across a unit length of passive membrane [3].

The neuron model can be considered as a black-box, reproducing the physiological behaviour of an isolated the neuronal cell, and taking into account the contribution of the activated synapses. In [2] we investigated a neuronal network exposed to ELF EM fields using as the neuron model a lumped-element circuit [4] able to simulate the behaviour of silent and firing neuronal membranes. Such model cannot properly be used in the RF range due to the presence of an internal short-circuiting capacitance.

In the same paper [2] we presented our integrated methodology applied to a single neuron and we showed how such "integrated model" is able to respond to RF fields, in the following the basic idea will be shortly recalled. Some elements of the circuit can be characterised thanks to a molecular level modelling. In particular voltage-dependent channels (Calcium, Potassium and Sodium) are considered using a Markov-Model approach. The overall result is a membrane model of a typical neuronal cell with its own pattern of receptors and signalling transduction systems, that addresses the effects of the exposure on the action potential frequency pattern [2]. The final result is a neuron composed by cascading protein channels and lumped elements circuital membrane model as sketched in Fig. 1b.

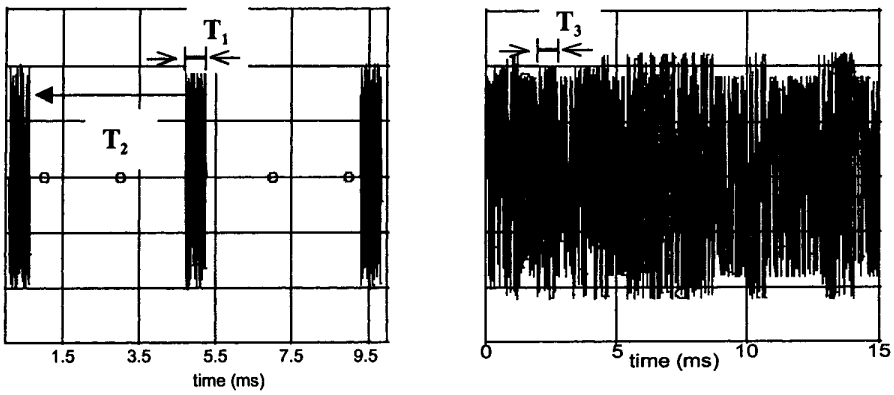
In the present paper, in order to investigate response of the neuronal network to high frequency fields like UMTS and GSM signals, we introduced the "integrated neuron" in the network model (Fig. 1a and 1b).

B. The EM signal

Authors described the GSM standard and the related signal used in their simulations in [2], here an example of such signal is reported in Fig. 2a.

Focussing the attention on UMTS standard, as reported in [5], the uplink (link from the mobile to the base station) physical radio channel can be represented as follows. The uplink direction uses I-Q/code multiplexing for user data and physical layer control information. The physical layer control information is carried by the Dedicated Physical Control Channel (DPCCH). The higher layer information (user data) is carried on one or more Dedicated Physical Channels (DPDCHs).

In this study only the DPDCH has been considered with a characterisation based on two parameters: the frequency allocation and the transmitting power. In particular, in order to take into account a single transmitting channel during each slot a signal with a central frequency of 1940 MHz and with a bandwidth of 5 MHz is simulated. Inside each slot the power is considered constant, while moving from one slot to another the power is considered varying in a range of ±1dB, in order to take into account the mechanism of power control.



a) GSM signal b) UMTS signal

Fig. 2. Example of GSM and UMTS signals used for simulations, a) T_1 is 0.546 ms (carrier on) and T_2 is 4.6 ms, frequency carrier value is 900MHz b) T_3 is 0.66 ms, in each timeslot power varies randomly of 1dB and frequency varies of 5 MHz over 1940 M Hz.

The resulting simulated signal is characterised by a pseudo-noise behaviour as evidenced in fig 2b.

III. RESULTS

As explained in [2] EM field is considered in the model as a value superimposed to membrane voltage resting state. In the following simulations such voltage was fixed at the additive value of 20 μV, which seems to be a good value to evidence the protein channel response. UMTS signals can be considered as a pseudorandom process: this implies statistical evaluation of the biological effects.

In Table I a way to organise the output variables observed for the single biological levels is reported.

TABLE I

OUTPUT VARIABLES FOR THE DIFFERENT MODELS

Biological level	Output variable
Ionic channels	Statistical evaluation of ionic current
Cell membrane	Statistical evaluation of ISI
Cell network	Statistical evaluation of ISI and cell synchronisation

In Fig. 3 results of three seconds exposure for the potassium channel are reported as percent effect on the mean value of the ionic current flowing trough the channel itself for GSM and UMTS signal.

From the figure it is possible to observe that the effect is very light on the mean current value and there is not much difference between the two EM signals at different membrane voltage values.

Similar results can be obtained for Calcium and Sodium channels.

Regarding neuronal network two kinds of results will be proposed: in physiological condition, varying the distance between the neurons, and in exposed conditions.

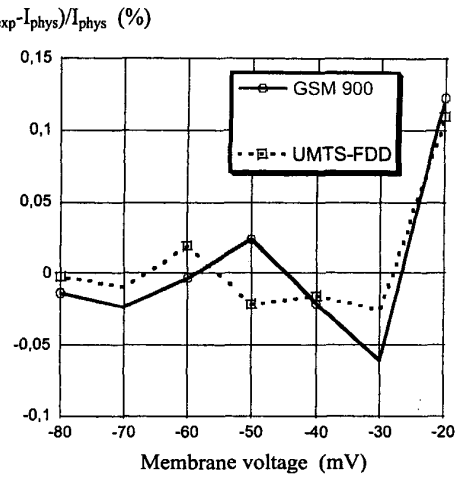


Fig. 3. Potassium channel exposed to GSM and UMTS.

We considered three neurons with connection length d and observed membrane voltage on the central one for 3 seconds. In Table II mean values of ISI and V_T (the threshold activation voltage of the neuronal spike) are reported for different value of d.

It is possible to observe that for longer length d the spikes are more frequent approaching the isolated situation. This means that for greater distances the reciprocal influence among neurons is less decisive on their behaviour.

TABLE II

MEAN ISI AND V_T FOR DIFFERENT VALUES OF CONNECTION LENGTH d

	<ISI> (ms)	$<V_T>$ (mV)
Isolated Neuron	330	-52.1
d=1 mm	394	-57
d=5 mm	366	-58.2
d=10 mm	360	-57.7
d=50 mm	354	-57.3

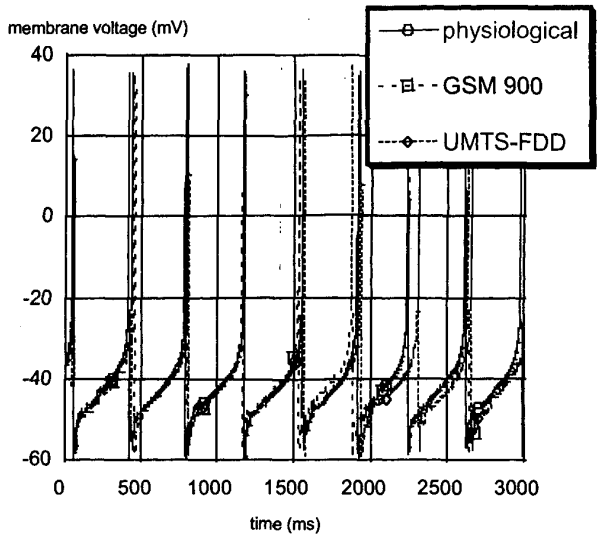


Fig. 4. Membrane voltage of a interconnected neuron in physiological and exposure conditions.

In exposure conditions the temporal evolution of membrane voltage in the central neuron has been observed as well, leading to a behaviour as the one reported in Fig. 4. Differences on effects are really slight as well (few percent) observing the mean value of the ISI.

In Table III a comparison among the effects at the three levels is reported. Alteration of open probability of single Potassium channel (related to ionic current by mean of channel conductance) at V_m equal to 40 mV substantially are not relevant. A synthetic view of ISI mean value shows a lighter effect on the interconnected neuron in comparison with the isolated one.

It is interesting that if one observe not only the mean values but also the standard deviations the difference among the physiological and the two exposure conditions (UMTS and GSM) become more evident as reported in Table III.

TABLE III
MEAN AND STD DEV OF OUTPUT VALUES

	Single channel		*Isolated neuron*		*Interconnected Neurons (3)*	
	$<p_{op}>$	σ_{pop}	<ISI> (ms)	σ_{ISI}	<ISI> (ms)	σ_{ISI}
Phys.	0.41912	7.8E-4	330	26.4	364	18
GSM	0.41968	8.8E-4	318	17.9	365	16.4
UMTS	0.41903	8.8E-4	319	18.6	373	15.7

It is possible to observe that interconnection reduces the value of standard deviation of ISI in physiological conditions (reduction of about 30%) which can be interpreted in a synchronisation of the neuron electrical behaviour. In exposed conditions a reduction can be observed as well, both in isolated and interconnected neurons, 30% and 40% respectively in comparison with the not exposed isolated one. A first sight to these data can suggests that UMTS and GSM exposure induces a kind of synchronisation in the neuron firing activity.

IV. CONCLUSIONS

This approach allows a quantitative evaluation of the effects at neuronal network level induced by mobile signals, and can be a useful instrument for comparing different signal patterns and their impact on living systems. First results suggested a possible synchronisation effect of EM exposure on the neuronal activity without evidencing a different impact of UMTS with respect to GSM.

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