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Simulations and Measurements of the Effect of Beam Sweeping in the EMF level in 5G Communication Systems

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Abstract

The aim of this contribution is to discuss some problems regarding the measurement of the Electromagnetic Field Exposure (EFE) in 5G communication systems, with particular reference to the current 'first' generation of 5G systems. In particular, it will clarify how the smart use of the time/frequency/space resource of the communication channel impacts on the estimation of the EFE. Some approaches for EFE estimations are proposed, and tested on real 5G systems.

1 Introduction

5G will be a core technology for the future society. The advantages of 5G are well discussed, and there is no doubts about the necessity of deployment of faster and more reliable wireless communication systems [1]. On the other hand, the implementation of this new technology is causing an increasing concern over the possible impact on health and safety arising from exposure to radiofrequency electromagnetic radiation arising from 5G. Evaluation of the electromagnetic field level has been object of large attention in the previous generations of cellular systems, and well established protocols are available for Electromagnetic Field Exposure (EFE) measurements [2, 3]. Estimation of the average EMF radiated by 5G base station offers new challenges compared to 4G. In particular, the use of new sophisticated antennas causes a fast and large variation of the field according to the specific antenna beam used by the communication system. This contribution focuses its attention toward this problem and in particular on the impact of the strategy adopted by 5G in the use of the space/frequency/time resource offered by the communication channel on the EMF level measurement. A numerical approach to simulate this effect has been developed in a joint collaboration between the Lazio Regional Agency for Environmental Protection (ARPA Lazio, Italy) and the University of Cassino and Southern Lazio, and compared to measurements carried out by ARPA Lazio.

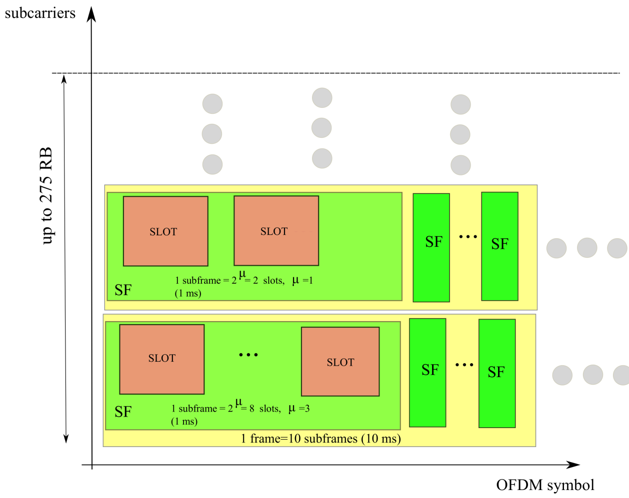

Figure 1. 5G resources in terms of the symbols/subcarriers; each resource block consists of 12 subcarriers.

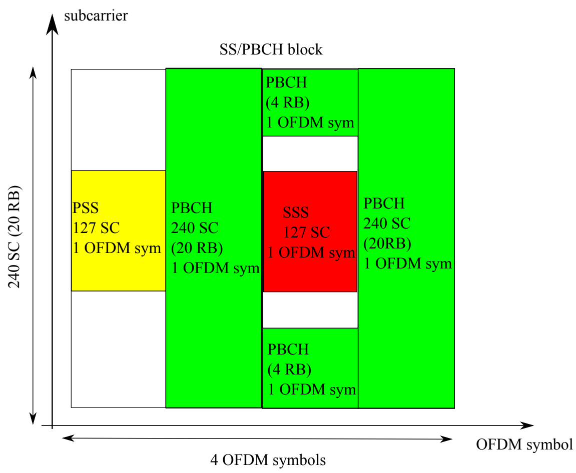

Figure 2. SS/PCBH block.

2 The use of the resources in 5G

As preliminary step before simulating the EMF radiated by 5G, it is important to clarify how the use of the time/frequency/space resources impact the EMF measurement of 5G signals.

5G NR uses CP-OFDM modulation [1, 4] for both the Down Link (DL) and Up Link (UL) NR transmission both in the 450 MHz - 6 MHz Frequencies Range (FR1, commonly referred as "sub-6GHz band") and 24.25 GHz - 52.6 GHz Frequencies Range (FR2, commonly referred as "millimeter wave band"). In 5G NR the term 'resource' is mainly used with reference to the resources made available by the OFDM modulation. Accordingly, the basic resource is represented by 1 subcarrier and 1 OFDM symbol. This is called a *Resource Element* (RE). A Resource Block (RB) consists of 12 consecutive subcarriers. A subframe has a fixed time duration equal to 1 ms. Finally, a frame consists of 10 subframes and has a fixed time duration of 10 ms 1. The available REs considering the available subcarriers and symbols are mapped in the *Resource Grid* (RG). Among the many data structures contained in the RG, the synchronization signal is particularly interesting in the framework of field measurement for EMF Exposure Limits Assessment, since it allows to obtain a number of useful information on the 5G communication parameters. In 5G, Synchronization Signal and Physical Broadcast Channel (PBCH) are packed as a single block (see Fig. 2). More specifically, the Synchronization Signal / Physical Broadcast Channel (SS/PBCH), also called synchronization signal block" or "SS block" (SSB), consists of a block of 240 subcarriers and 4 OFDM symbols containing the Primary synchronization signal (PSS), the Secondary synchronization signal (SSS), the Physical broadcast channel (PBCH) and the PBCH demodulation reference signal (PBCH DM-RS). SS blocks in dowlink frame are transmitted towards UEs at regular intervals based on periodicity set. There are 5 block patterns which have different subcarrier spacings and are applicable for different carrier frequencies: Case A (15 kHz subspace spacing), Case B (30 kHz subspace spacing), Case C (30 kHz subspace spacing), case D (120 kHz subspace spacing) and Case E (240 kHz subspace spacing). The SS blocks are grouped in SS bursts. The maximum number of SS blocks in single burst is frequency dependent, being 4 or 8 in FR1 and 64 in FR2.

From the point of view of EMF measurement, it is important to analyze how the resources at 'subcarrier-symbol level' are mapped into the physical resources at 'time-frequency level'. Since time and frequency are conjugate quantities, higher number of bits per unit time gives larger bandwidth. The allowed maximum bandwidth for FR1 is 100 MHz, while the maximum bandwidth for FR2 is 400 MHz. Finally, note that the frequency/time resources are not only shared by the different users, but also by the single user and the base station. There are two main ways to share the time/frequency resource between the base sta-

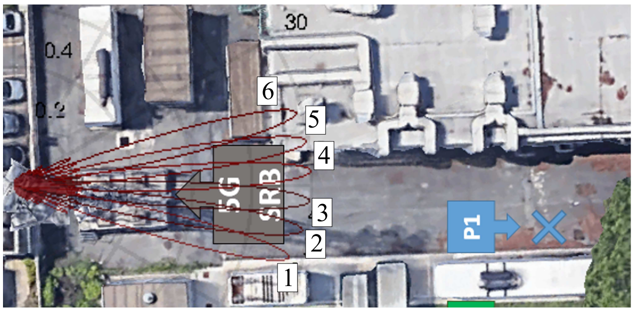

Figure 3. The figure shows the position of the 5G Base Station antenna, the position of the measurement point (P1) and the set of simulated antenna beams (beams numbered from 0 to 5).

tion and the user: sharing the available frequency band, or sharing the available time slot. The first solution is used in Frequency Division Duplexing (FDD), while the second one is used in Time Division Duplexing (TDD). The use of TDD is advantageous when beamforming or sophisticated Spatial Division Multiple Access (SDMA) techniques like Massive MIMO are used, and is the only one used in FR2.

Besides space/frequency, 5G introduces a number of new possibility for an efficient use of the space resource, taking advantage of the spatial distribution of the electromagnetic field in the space. A discussion on the use of the electromagnetic field as a spatial resource in communication system is beyond the scope of this paper. For more details on this topic the interested reader can refer to [6, 5, 7]. It is important to stress that 5G supports the use of advanced antennas by means of a number of dedicated signaling procedures, including SS-B bursts for antenna beam selection, Reference Signal Received Power (RSRP) for dynamic beamforming, and Sounding Reference Signals (SRS) for massive multi-user MIMO . In beam-sweeping (or beam-switched) technique different beams (i.e. beams with maxima pointing in different angular direction) are associated to different SS blocks of a SS burst. The beam associated to the SS block received with highest power is selected, allowing a higher SNR compared to standard fixed-beam antennas. It is worth noting that the effect of such a beam sweeping is a variation of the SS-Blocks power level received by the user. The way in which the space resource is actually used is a choice of the vendor, and multiple beams as well MU-MIMO solutions can be adopted, making the estimation of the average EMF level a not easy task.

3 Simulation and experimental measurement of an on-air 5G signal in the FR1 band

In this Section simulation of a FR1 band signal is discussed, and compared to a measure signal. The geometry of the problem is shown in Fig 3,where the Base Station antenna is placed on the right, while the point where the field was measured is shown as P1 on the right of the figure. In the

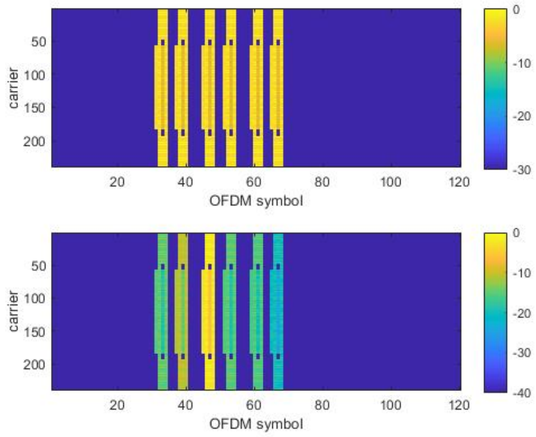

Figure 4. Simulated noise-free received SS Burst in the subcarrier/OFDM symbol representation; upper figure: SS Burst in absence of beam sweeping; lower figure: SS Burst considering the beam sweeping.

same figure the simulated 6 patterns of the antenna are also drawn in red. The patters are numbered from 0 to 5. The simulation process follows the steps described in the previous Section. As first step, the subcarrier/OFDM symbol representation ins considered. In the specific case we suppose that no 'paying' traffic data are present, obtaining the result shown in Fig. 4 (upper figure). The 6 SSB/PBCH blocks organized in a Case C burst are clearly shown. Then, the blocks are mapped on the time/frequency/space domain. The impact of the antenna sweeping on the carrier/OFDM symbols representation is shown in lower part of the Fig. 4, where false colors are in dB scale. Finally the time domain signal in the P1 position is evaluated. The result of the simulation is shown in Fig. 5.

One of the main problems in the simulation of 5G for EMF applications is the lack of experimental data to check the results. Recently the first 5G telecommunication sites were recently built in Italy and ARPA Lazio is currently actively involved in the development of techniques to measure the EMF level of 5G signals. This activity allowed to collect a number of interesting data on 5G communication systems. In this contribution only time-domain analysis is shown, even if much more broad investigation on measurement techniques of 5G signals is currently carried out both time FR1 and FR2 band [8]. The time analysis was carried out using a Vector Signal Analyzer set in span zero and max-hold mode in case of no traffic signal. The signal was measured by means of a Vector Netwok Analyzer Keysight MXA N9020A (Keysight) connected to a Rohde & Schwarz HL050 antenna using a phase-stable cable. The relevant data of the signal, obtained during the measurement session, are: Access mode: TDD; Center frequency = 3680.01 MHz; Bandwidth = 100 MHz: $\mu = 1$ numerology; SS-Block center frequency = 3679.83 MHz; 6 SS-Block per SS-Burst; TDD periodicity = 5 ms. In the following only the result of the time domain measurement obtained

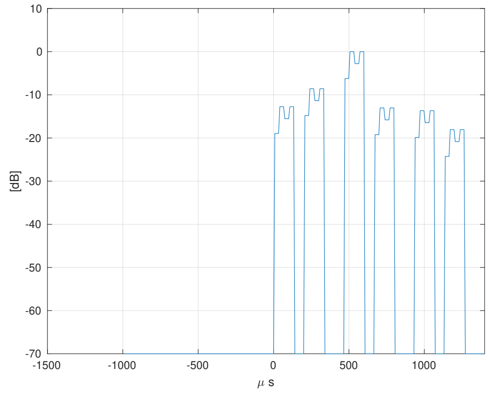

Figure 5. Simulated noise-free received signal

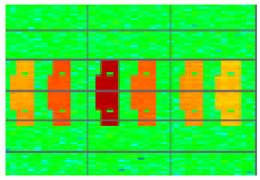

Figure 6. SS Burst from experimental data in the subcarrier/OFDM symbol representation

using span-zero mode, is shown. Fig 6 shows the measure SS Burst configuration of the 5G signal in the subcarrier/OFDM representation, while Fig. 7 shows the SS blocks of a single SS burst in the time domain. The large variability in the detected power of the SS blocks is a clear indication of the use of a beam sweeping technique by the communication system. The measurement result shown in Fig. 7 must be compared with the numerical simulation shown in Fig. 5. Generally, we can note a good agreement. There is a slight overestimation of the outer SS Block levels (0, 4, 5 beams). This is probably caused by a not perfect simulation of the sidelobe level of the patterns due to the absence of information on the antenna required to accurately reconstruct the sidelobes. Numerical and experimental data clearly shown that beam sweeping therefore implies that field level is strongly related to the specific beam direction with respect to the position of the receiver antenna. In particular, it is possible to quantify the effect of beam sweeping on the SS-Block detected power level as $R = \langle P_{SSB} \rangle / \max P_{SSB}$ wherein $\langle P_{SSB} \rangle$ is the average detected power of all the SS-Blocks in a burst and $\max P_{SSB}$ is the power of the strongest SS-Block in the burst. In the example reported in this paper, the R turns out to be $R = 21\%$ in case of simulated signal and 19.5% in case of numerical simulation As noted before, there is a slight overestimation due to the absence of information on the exact shape of the antenna pattern, that however gives a relatively low error since it involves the sidelobes of the simulation.

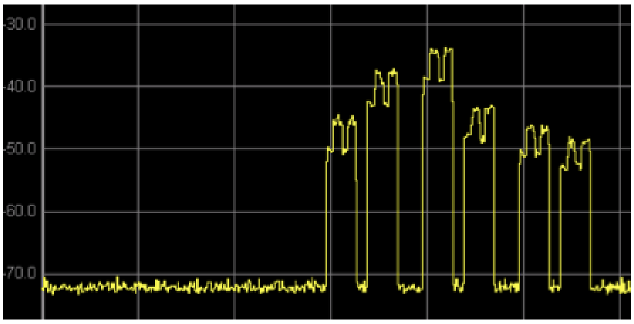

Figure 7. Received signal measured in zero-span mode.

4 Conclusion

5G offers new challenges in EMF measurement. In this contribution the role of beam sweeping is discussed, and its effect on EMF measurement is shown using numerical and experimental data. The numerical procedure outlined in this contribution well matches with the experimental data, and could be useful to investigate the effect of antenna beams in the EMF level.

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