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***Abstract*—The paper investigates the Radio Frequency (RF) coverage and electromagnetic interference (EMI) effect on the performance of the e-healthcare platform CareStore. The hardware part is constituted by the Common Recognition and Identification Platform (CRIP) which operates with Bluetooth in order to detect and receive data from medical devices. To assess the CRIP board performance against the EMIs, the symbol-error-rate (SER) is evaluated in function of the signal-interference-noise-ratio (SINR) and with various digital data modulation techniques. As expected, the SER increases with the SINR and decreases with the number of bits/symbols. Furthermore, the RF link budgets and the unintentional EMIs were analyzed based on Matlab computations by considering an equivalent transmitter source placed in a multiwall floor environment with dimensions of hundreds square meters. The received signal strength coverage cartographies were established for ideal sources placed at different locations. The proposed method benefits from its simplicity and high computation speed compared to the ray tracing or full wave approaches.**

Keywords—multiwall indoor environment, wireless device, electromagnetic interference (EMI), RF coverage cartography.

I. INTRODUCTION

The emerging public demands on data communication services constitute one of the technological development key factors. The major trends are to facilitate the public and private services data exchanges to meet constant progress and keep applications data needs served. Due to this, several applications for short-range wireless devices have been commercialized, knowing a notable expansion with the concept of the Internet of Things (IoT). Nowadays, further research work was made on the development of domesticated homecare services that can be integrated in handset devices such as smartphones. Indeed, the domestication of those communication devices modifies continuously our daily life including the different services in hospital environments [1-4]. This tendency and the progress in the modern numerical and telecommunication technologies, change deeply the nature of healthcare delivery [1-2]. The health care industry is capitalizing new medical technologies that will both considerably improve care and lower cost [1].

Currently, the application and use of wireless medical devices are growing to control body functions and to measure physiological parameters [3-4]. The CareStore project was initiated for this new wave of medical engineering [5]. Similar to all communication devices, this innovative platform is constituted by software and hardware systems.

In this article, CRIP is used as an example of an electronic device that can be used in healthcare applications. The platform was aimed to operate in the ISM band around 2.4GHz and should be suited to indoor communication in the medical rooms with dimensions of some hundreds square meters. Based on the use of wireless sensors, the base stations that will monitor and collect data about the patients are equipped with wireless digital communication interfaces using WLAN, WPAN, etc. In order to meet the 802.xx family standards, the RF digital terminals should operate with minimum Quality of Service (QoS) [6-7]. Therefore, the application environment side effects on the electromagnetic interferences (EMIs) should be minimized. So far, basic theoretical and empirical approaches were forwarded by taking into account those undesirable EM effects based on the various phenomena as path losses, multipath fading, shadowing and interferences with neighboring communicating systems [8-9]. The methods of distribution are the most popular fading channel models of EM propagation environment [6-10]. The usual basic digital communication performance metric is determined with the bit- or symbol- or packet- error rates (BER, SER, PER) for the indoor communications [10].

This article is focused on the RF signal coverage modelling and EM interference (EMI) influence on the CRIP [5][11]. After a brief description of the functioning principles, the assessment of the SER in different zones of the floor due to the signal-to-interference-noise-ratio (SINR) will be discussed. Then, the RF communication performance in a multiwall indoor environment with hundred square meters will be examined. Final synthesis discussions are addressed in the conclusion.

II. DESCRIPTION OF THE CARESTORE PLATFORM

The main objective of the CareStore project is to provide a common European technical solution for automatically and seamlessly identifying medical devices and users in a secure manner by using RFID and biometric technologies [4-5][11]. The platform aims to increase homecare efficiency, reduce costs, improve the living standards of the elder and people with special needs, all with a higher degree of flexibility for the users.

As depicted in Fig. 1, the CareStore platform consists of three subsystems: i) an open source platform and user interface for home use named Common Ambient Assisted Living Home Platform (CAALHP); ii) a hardware subsystem containing Near Field Communication (NFC), Bluetooth and biometrics interfaces for users and devices recognition, named CRIP; and iii) a cloud based platform that offers the flexibility of coupling users identities with devices and upload device's drivers and user's healthcare applications, named CareStore's Marketplace.

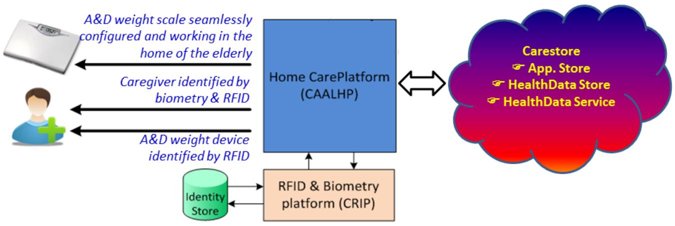

Fig. 1. Overview of CareStore platform configuration [4-5].

A. Description of the CRIP Base Station

The CRIP subsystem will monitor and collect data from users, either citizens or caregivers, and is equipped with standardized electronic board terminal that communicates with the wireless devices and a biometric secured connection as illustrated in Fig. 1. The CRIP module is the component responsible for users' identification and recognizing wireless medical devices. It allows to combine is a unique and secure device, staff and inhabitant identification technology based on the combination of RFID/NFC and biometrics. It offers the capacity to interface with medical devices that comply with the most recent standards, namely devices equipped with Bluetooth and identification technologies like RFID/NFC [5][11].

B. Description of the CRIP NFC Module

The NFC module enables a short-range contactless communication with respect to the ISO/IEC18092 standard; it is intended to operate with low transmitting power. As described, this can be used to identify the caregivers and citizens, plus medical devices on the CareStore platform. Table I summarizes the technical characteristics of the NFC module used on the CRIP.

During the full operation, the CRIP will continuously listen for a NFC tag. When it is identified, the recognition process will be performed. Otherwise, the NFC code should be recorded in the caregiver or patient folder according to the login code.

TABLE I. CHARACTERISTICS OF THE NFC MODULE.

Brand Name	Model Name	Power Supply	Frequency Range	LOS Range
NXP	PN532/C1	2.7V-5.5V	13.56MHz	Few cm

C. Description of the CRIP Bluetooth Module

To transmit the vital data from the medical devices, the CRIP uses the Bluetooth communication module with parameters specified in Table II. This module was chosen for the CareStore platform due to the possibility its offers of optimized energy consumption with acceptable coverage range for a typical multi-room environment. The module operates in the 2.4 GHz IEEE 802.15.1 WPAN bandwidth and uses frequency-hopping with 79 channels of 1MHz each (40 channels in v4). The RF EM coverage in presence of interference (SINR) is evaluated in the next section as a function of the modulation technique (and therefore transmission speed). These calculations use Effective Isotropic Radiated Power (EIRP) and receiver sensitivity values from Table II.

TABLE II. CHARACTERISTICS OF THE BLUEGIGA BLUETOOTH MODULE.

Model Name	Power Supply	Frequency Range	Transmitter EIRP	Receiver sensitivity	Line-of-sight range
BLE112 v4.0	2.3V-5.7V	2402-2480MHz	8dBm	-89dBm	<100m

III. ANALYSIS OF THE CRIP MODULE EMISSION IN MULTIWALL INDOOR ENVIRONMENT

To optimize the CRIP module wireless communication performance in the multiwall indoor environments, the RF coverage quality and the undesirable effects due to EMIs and technological constraints must be taken into account. A computational approach based on the ITU-model will be considered in this section. The analysis of the different parameters of the digital signal communication by considering the SINR and the modulation techniques (PSK, FSK, QAM) will be proposed. Then, a global assessment of the received signal power in an example of multiwall indoor environment with very fast computational method is provided.

A. Scenario of the CRIP Module Indoor Environment

From the RF point of view, the CRIP WPAN module can be assumed as a transceiver system with the possibility of detect/identify and receive data from medical devices. The basic propagation environment represented by the scenario is illustrated in Fig. 2 can be considered. In this test room (assumed with geometrical size $x \times y$), the medical device and the CRIP are placed at a distance d_1. The data transmission quality can be undesirably degraded by the EMIs when other EM radiating sources are placed in the same room or in the proximity of both reception and transmission points. The sensitivity of the communication channel to external interference depends on modulation type and coding techniques. The level of degradation depends on the signal-to-interference-noise-ratio (SINR) at the receiver, i.e. on the power levels and distances between the radiating devices.

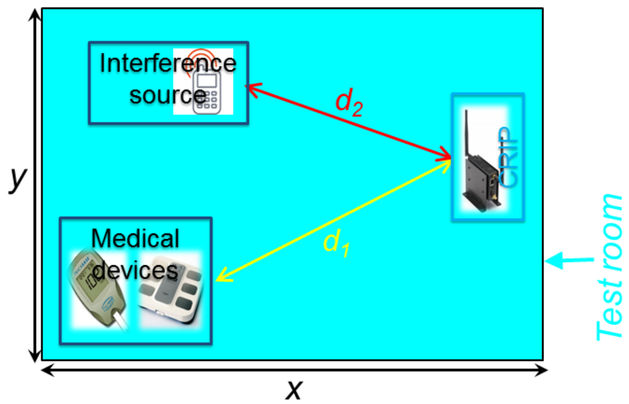

Fig. 2. Top view illustration of the RF communication scenario with CRIP placed in $x \times y$ size test room.

In order to predict effect of interference on the CRIP communication link, an analytical computational routine has been developed using the ITU indoor pathloss model. This enables to determine rapidly the link budgets and the overall RF coverage corresponding to the wireless terminal system presented in Fig. 2. In particular, it can be calculated for each distance, d_1, between the medical device and the CRIP, the critical distance to interferer, d_2, at which the interferer's power starts to exceed the noise margin (signal power minus sensitivity) of the receiver.

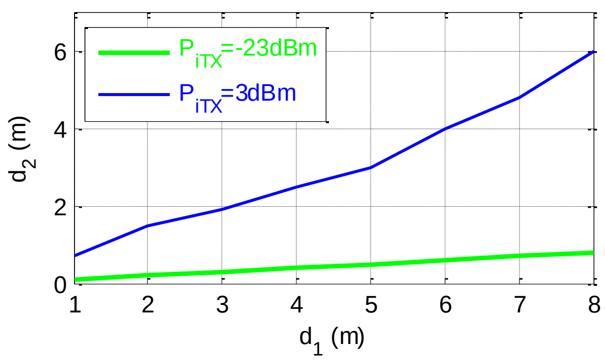

Fig. 3. Relation between the distances d_1 and d_2 for different transmitted interferer signal powers, P_{iTX}.

The relation between the distances d_1 (medical device to CRIP) and d_2 (interference device to CRIP) for the given Bluetooth board sensitivity and EIRP is shown in Fig. 3 for two levels of the interferer device transmitted EIRP, P_{iTX}. For example, for P_{iTX}=3dBm and d_1=6m, the perturbation device generating intereference has to be at least d_2=4m away. For smaller intererer's power P_{iTX}=-23dBm and the same d_1=6m, the distance to interferer can be much shorter at d_2=0.6m. In general, the safe area for the system to operate is above the critical lines in Fig. 3.

B. SER vs SINR and the Modulation Techniques

The receiver sensitivity in Table II corresponds to the lowest and most robust modulation level used in Bluetooth, GFSK (Gaussian Frequency-Shift Keying). This gives data rate of 1 Mbps. The other modulation types currently used by Bluetooth are π/4-DQPSK (Differential Quadrature Phase Shift Keying) and 8DPSK (8-level Differential Phase Shift Keying), with the corresponding raw data rates of 2 and 3 Mbps. However, higher speed is achieved with higher requirements for SINR (Shannon law). Assuming that both noise and interference can be treated as white Gaussian noise (AWGN), we can estimate the minimum SINR for the required channel capacity C with the operating frequency bandwidth Δf from the inverse Shannon-Harley relation:

$$SINR = 2^{\frac{C}{\Delta f}} - 1\,, \tag{1}$$

The actual SINR ratio for the given modulation level (number of bits per symbol), k, energy per bit to noise power spectral density ratio (E_b/N_0), and the interference level I, can be calculated from [6-7]:

$$SINR_{dB} = 10\log(\frac{E_b}{N_0}) + 3 + 10\log(k) + I\,, \tag{2}$$

Then, using the methodology described in [6-7], SER can be determined for different modulation types. Fig. 4 shows 2D representation of these results for multilevel M-ary signaling in M-PSK, M-FSK and M-QAM modulations. The results approximately applicable to Bluetooth are for 2-FSK (k=1), 4-PSK (k=2), and 8-PSK (k=3).

As expected, the SER level is increasing when the number of bits-per-symbol is increased and the SINR is lower. It is also interesting to note, that under the same conditions M-FSK (Fig. 4(b)) and M-QAM (Fig. 4(c)) techniques give lower level of SER than M-PSK.

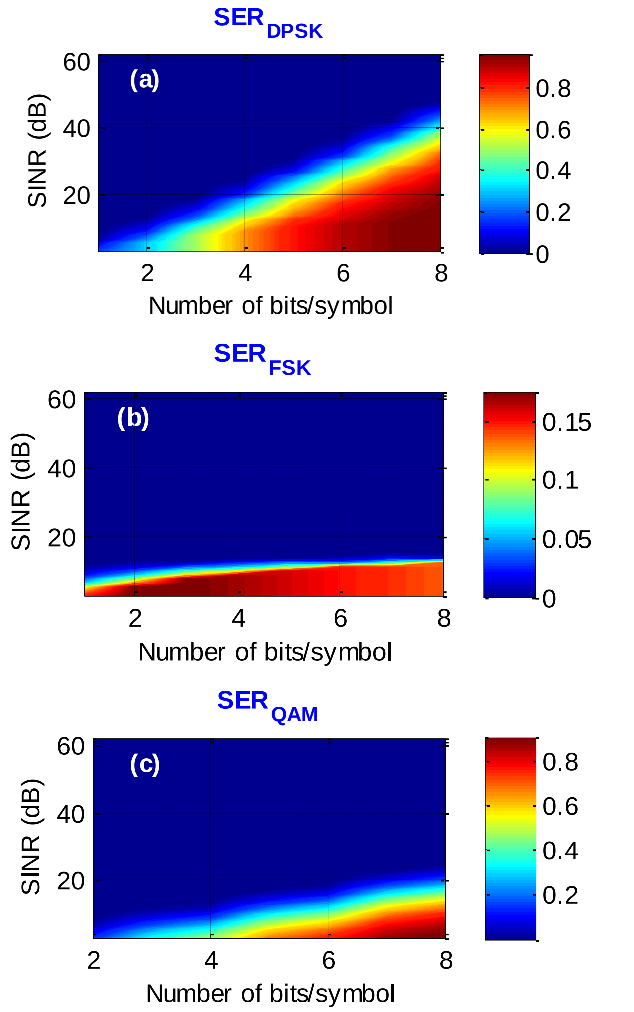

Fig. 4. SER vs (SINR, number of bits/symbol) with communication based on the (a) M-PSK, (b) M-FSK and (c) M-QAM modulations.

C. Application Result Analyses

An indoor environment with rectangular floor of the dimension $x \times y$ = 10m×20m and with wood and concrete walls containing five rooms has been considered as application example. In Matlab computations, the walls separating the test floor rooms were assigned with the empirical penetration losses shown in Table III [12].

TABLE III. PENETRATION LOSSES THROUGH DIFFERENT WALLS VS TX POWER REFERENCE [12].

Reference (dBm)	-30	-20	-10
Glass door (dB)	16.33	36.33	56.30
Wood door (dB)	17.67	37.72	57.61
Wall (dB)	11.44	31.58	51.42

The RF link budget computation the receiver (RX) signal power, including the multi-wall with concrete material shadowing effect, was performed with the isotropic transmitters (TXs) represented by three access point sources placed at TX_1(8m,1m), TX_2(7m,9m) and TX_3(17m,9m). The operation frequency was assumed 2.45GHz and the ideal EIRP of 0dBm. For standard ambient temperature of 290°K and the channel bandwidth of 1MHz, the thermal noise power is analytically equal to -114dBm. After the numerical computations based on the ITU model, the transmitted power coverage cartographies in the horizontal planes situated at 1.5m-height above the ground plane. With single sources placed at TX_1 and TX_2, it can be observed in Fig. 5(a) and Fig. 5(b) that the RF signal is considerably attenuated by the walls which are traced in bold black solid lines. These results illustrate the shadowing aspect susceptible to occur in this test floor.

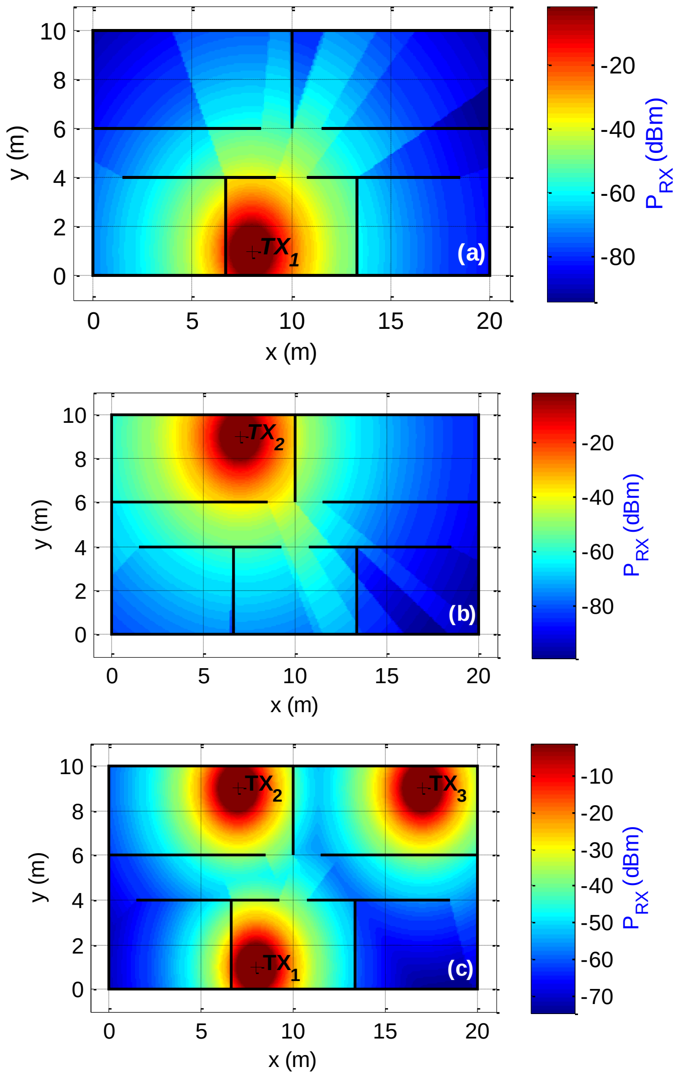

Fig. 5. Maps of RF signal power coverage in a multiwall floor with five rooms with the source (a) TX_1, (b) TX_2 and (c) with three simulaneous TX sources (TX_1, TX_2 and TX_3).

Moreover, by using the basic scenario of three sources (TX1, TX2 and TX3), the main coverage zones of each source in this floor can be predicted as displayed in Fig. 5(c). This preliminary result predicts the CRIP communication performances according to this illustrative scenario with a five room floor. Due to the multiple wall attenuation, the radiated signal radiation powers are significantly decreased in the other rooms without TXs. However, due to the multiple reflections, the utile signals can be affected by the signal interference and AWGNs.

With surface plane discretized with 200×100 sampling points, the computation run time with a PC equipped by windows 7 having Intel® CPU @ 2.3GHz-2Go-RAM was of about ten seconds. The proposed model is applicable for RF coverage analyses in indoor environment with multiple rooms and multiple floors and very highly reduced computational time. However, the proposed computational approach is limited for the time-domain analyses as cases of transient EMIs.

Further computaitons were made when the sources TX_4 and TX_5 are placed in the hallway are added in Fig. 6. This result illustrate clearly the differences between the signal propagation through one and several walls.

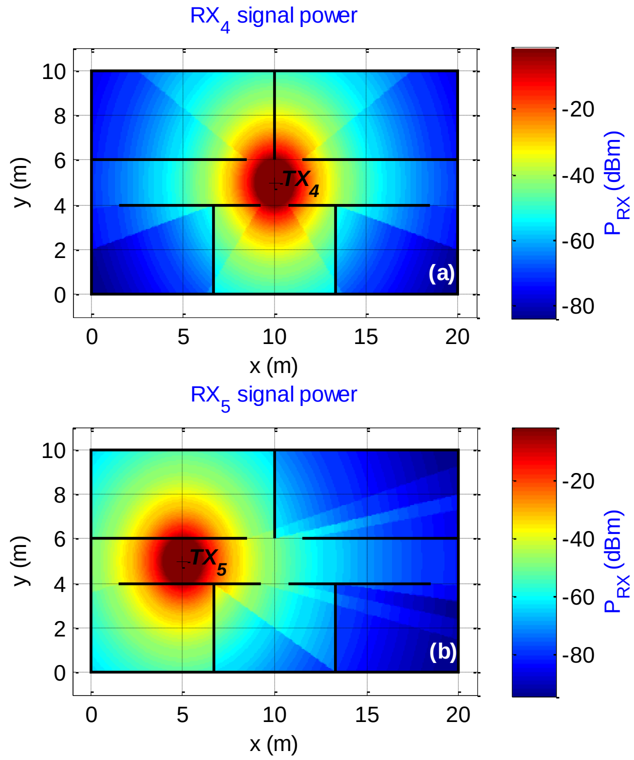

Fig. 6. Maps of RF signal power coverage in a multiwall floor with five rooms with the source (a) TX_4 and (b) TX_5.

The presented here computational method does not require extensive environment layout data and is much faster than the ray tracing method used for more accurate propagation modelling.

IV. Conclusion

Easy to use equipment with potential to meet the most popular health care standard was suggested in the CareStore project [5]. The medical equipment must comply with the standards in order to be legally marketable [11]. The innovative CRIP interface platform is comprised of NFC/RFID reader, biometrics sensor, and Bluetooth module to wirelessly interface with the medical devices. However, owing to popular 2.4GHz ISM band used by Bluetooth, it was shown that the CRIP digital communication performance can be affected by the indoor communication environment and unintentional EMIs. Due to indoor propagation losses and SINR, there are critical zones where the QoS can be degraded, dependent on the transmitter placement. A fast and simple computational method for assessing the RF performance of the CRIP communication link in a multiple room area with many walls has been developed. The method uses ITU indoor propagation model and includes multipath and shadowing effects.

As further study, an indoor extended model in residential, office and open spaces buildings, including furniture, movement and human body effects will be conducted. In addition, the CRIP interface qualification test with respect to the European medical devices European directive 93/42/EEC is in progress. According to standard IEC/EN60601-1-2, the radiated EM compatibility test will be performed with EM aggression level up-to-10V/m over the frequency range from 80MHz-to-2.5GHz.

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