Path loss and interference shadowing model for a real city hospital

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ABSTRACT
Estimating propagation path loss is required in order to predict the performance of a wireless system in its working environment. Hospital, and in particular the emergency ward, is a harsh environment for wireless communications. The information over the air in a hospital are normally very important. The increasing number of wireless medical devices, personal/body sensor networks, etc. make the ISM (Industrial, Scientific and Medical) band particularly crowded. In this paper we propose a modified path loss model based on real measurements carried out in the emergency ward of a modern city hospital. The measurements are used to derive the main parameters of the path loss in such environment, as well as to give a model of the aggregate interference. The probe signal used for the experiments accomplishes the IEEE802.15.4a standard.

Keywords
Path loss, interference modelling, real measurements, hospital, wireless ecg, IEEE802.15.4a, chirp spread spectrum

1. INTRODUCTION
Most wireless application designers are commonly interested in basic questions like which is the maximum distance for which the wireless channel is going to work or where are the best locations in the environment to put the access points (transmitters). Unfortunately, answering these questions is not as easy as asking them. The simplest approach towards answering the above questions is by comparing two things: a) the dynamic range of the system in hand, and b) the electromagnetic waves propagation loss. The dynamic range is a characteristic of the system that is well known to the designer. It determines the maximum power loss that is allowed throughout the communication channel (between transmitter and receiver), while still maintaining the communication link. The main characteristics that determine the dynamic range are the transmission power and receiver sensitivity. Although the theoretical laws of physics describe very accurately the different aspects of electromagnetic wave propagation, it is vital to understand that the complexity of practical life makes the actual propagation loss very difficult to predict. Most applications in today short range RF scene operate in environments that are far different from the ideal free-space scenario. In particular, modern city hospitals are a very harsh environment for wireless communications. Nowadays the wireless devices which make use of the ISM (Industrial, Scientific and Medical) band ($B_s = [2.399, 2.485]$ GHz) are very frequent. This increasing number of ISM devices, together with the extremely large spread of Wi-Fi devices, can lead to a high level of interference in a typical modern city hospital. This interference can be either constructive or destructive, resulting in an increase or decrease of the received power compared to the ideal free-space propagation.

First attempt to characterize the electromagnetic environment in hospitals was more than 30 years ago. In [1] the electromagnetic environment from 14 kHz up to 1 GHz of a hospital was assessed. In this paper, first emission limits for narrowband and broadband emissions are recommended for devices that are used in hospitals. In 1997, the first 24-hours measurements showing temporal dependencies of the measured fields within a hospital for frequencies up to 1 GHz were described in [2]. In 2003 the electromagnetic fields within the ISM band ($[2.40 - 2.4835]$ GHz) were evaluated [3]. Only the electromagnetic emissions were collected. In [4] both short-term and long-term field strength measurements were carried out in the frequency range from 9 kHz up to 10 GHz. Only electromagnetic emissions were collected in these fields experiments.

In order to better define the performance of wireless medical devices operating into hospitals, we carried on real measurements in a typical city hospital in order to model both the path loss and the interference for those kind of environments. The signal and the interference power levels have been taken in several locations of the emergency ward of the city Hospital "San Giuseppe" in Empoli, a medium-size town 20 km west of Florence, Italy. The main parameters to characterize the mathematical model of the path loss and of the interference fluctuations (shadowing) are here proposed, based on those measurements. For the path loss modelling we transmitted a known probe signal and then collect the received power samples in different locations of the emergency ward

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of the hospital. The emergency ward can be seen as a "worst case" of the hospital environments, since typically it includes many medical devices radiating in the ISM band. For modelling the interference we collected the receiving samples by using a spectrum analyzer held in different rooms of the emergency ward of the hospital. No probe signal was sent for the measurements of the interference levels.

The transmission module is based on a IEEE 802.15.4a chirp spread spectrum standard [8]. We used a signal spread over the whole ISM band for the transmission, since it revealed lower interference and better propagation coverage for vital signs real-time monitoring [9][10][11][12][13][14].

2. EXPERIMENTS SET UP

The field trials have been carried out in the emergency ward of a modern city hospital, specifically the Hospital "San Giuseppe" in Empoli, a medium-size town 20 km west of Florence, Italy. All the measurements were taken during the most busy time of the day; personnel and patients are moving around in the structure. The emergency ward can be seen as a "worst case" of the hospital, since it normally includes all the medical devices which can radiate. The measurements campaign aims to collect data for modelling the path loss and for modelling the interference. The main parameters to characterize the path loss are derived by the measurements with a known probe signal. The interference is evaluated by collecting data without probe signal, in the corridors and in the rooms (Fig. 1). The path loss is evaluated only using the corridors measures (LOS condition) because inside a room (NLOS condition) the probe signal cannot be received with enough power to overcome the interference and noise level.

The transmitter module was set up to send a known probe signal over the entire ISM band, specifically the band $B_s = [2.399, 2.4835]$ GHz. Measurements with probe signal have been taken in 3 different environments of the emergency ward: the corridors 1, 2 and 3 (Fig. 1). The measurements are made in LOS condition by putting the transmitter at the beginning of the corridor and moving away the receiver. The distances evaluated are $\{1, 5, 10, 15, 20\}$ m.

The interference is evaluated by putting the spectrum analyzer (without any probe signal) in the corridors as described above and into the rooms of each corresponding corridor. In corridor 1 are present ambulatories of different kinds. The corridor 2 is used for bedridden patients, from acute health problems to low-risk health issues. Corridor 3 is dedicated to any kind of radiological analysis: X-ray, tomography, MRI, ultrasound, etc. In corridor 3 is also present the "red room", for the extreme urgent operations (intensive care and surgeries).

A wireless prototype following the IEEE802.15.4a standard is used for transmitting the probe signal. The prototype was originally designed as wearable wireless system to remotely send the vital signs sensed by body sensors [13]. A portable spectrum analyzer is used to collect the samples of the received signal. The prototype uses a chirp spread spectrum (CSS) technique at physical layer. The CSS is a spread spectrum technique that uses wideband linear frequency modulated chirp pulses to encode information [8].

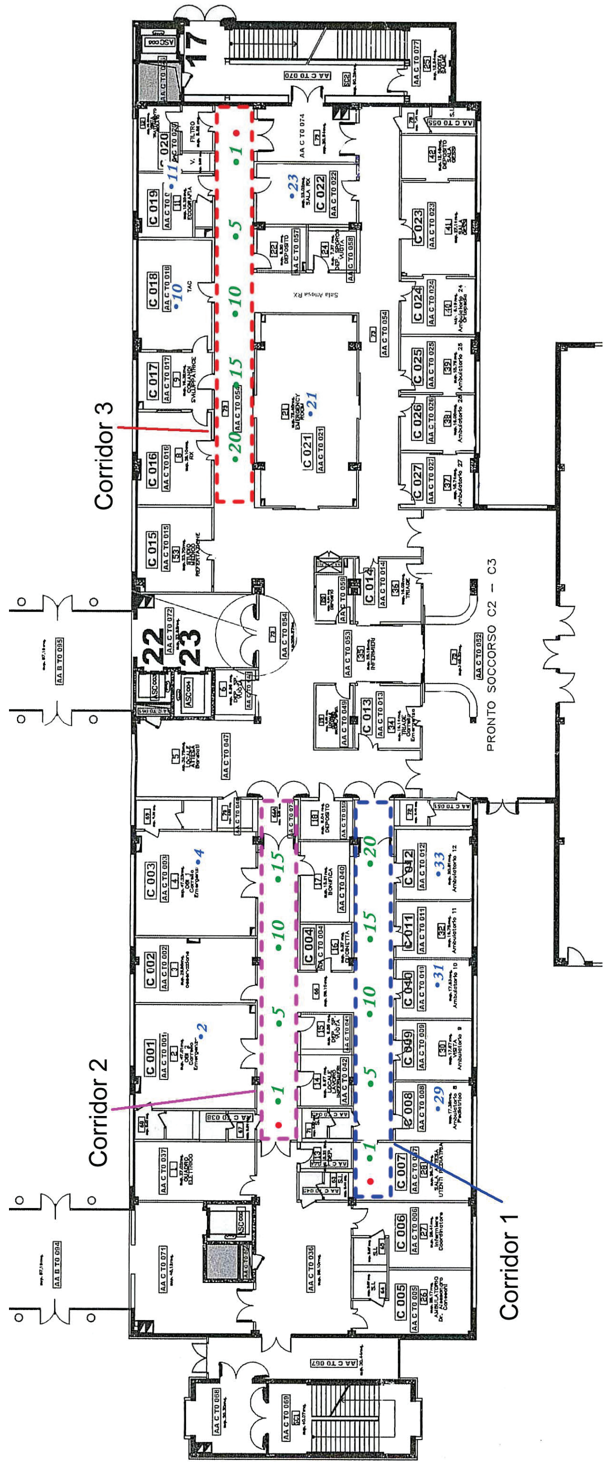

Figure 1: The map of the emergency ward of the hospital. The corridor are highlighted by dashed lines. The red points represent the locations of the transmitter. The green and blue points represents where the measurements were taken.

A chirp is a sinusoidal signal whose frequency increases or decreases over time (often with a polynomial expression for the relationship between time and frequency). Chirp spread spectrum is ideal for applications requiring low power usage and needing relatively low data rates (less than 1 Mbps). In particular, IEEE 802.15.4a specifies CSS as a technique for use in Low-Rate Wireless Personal Area Networks (LR-WPAN). The CSS can be also used for accurate ranging and thus allowing real-time localization capability to the system. The CSS is spread also over the time, which means that the chirp energy is spread in time and therefore chirp signals can maintain low power. The representation of a typical linear chirp waveform is given as

$$s(t) = \begin{cases} a(t)\cos\left(2\pi f_0 t + \frac{\mu t^2}{2}\right), & -T/2 < t < T/2 \\ 0, & elsewhere \end{cases} \quad (1)$$

where T, $a(t)$, f_0, μ are chirp duration, envelope, center frequency and chirp rate, respectively. The parameter μ indicates the rate of change of instantaneous frequency. A chirp with positive μ, is an up-chirp, otherwise a down-chirp.

In particular, the proposed CSS module has the following operating parameters:

- Coverage: 300 m (free space)
- Bandwidth: 80 MHz
- Ranging accuracy: ± 1 m
- Modulation: DPSK
- Data rate: 250 kbps
- Tx power: 7 dBm

3. PATH LOSS AND INTERFERENCE MODELLING

3.1 Path loss model

The first experiment consists of transmitting a known probe signal and collecting the received power levels in the emergency ward of the Hospital. Fig. 1 shows the planimetry of the emergency ward of the hospital where the experiment was conducted. The green numbers in the planimetry indicate the locations where the received power level have been measured by using a portable spectrum analyzer. For each location the received power samples have been collected for 5 minutes. The transmitter module follows the IEEE802.15.4a standard and generates a known probe chirp signal spread over the entire ISM band, specifically the band $B_s = [2.399, 2.4835]$ GHz.

The attenuation (dBm) in the three corridors is shown in Fig. 2, while the n-index of the path loss is reported in Fig. 3.

We took into account the following path loss model

$$L_{dB} = L_{dB}(d_0) + 10n\log(d/d_0) \quad (2)$$

where d_0 is the reference distance (1 m), d is the distance between transmitter and receiver.

The measurement campaign allowed us to derived the parameter n of the path loss in a modern hospital.

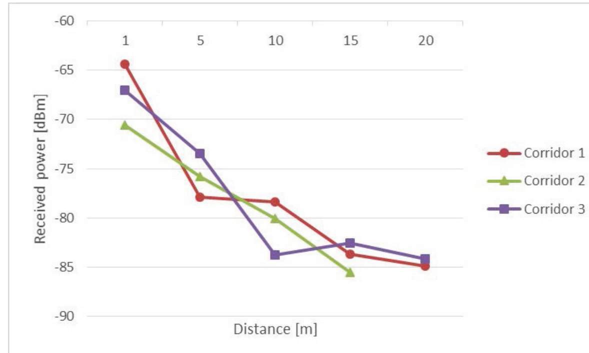

Figure 2: Received power level (dBm) in the corridors of the emergency ward (see Fig.1).

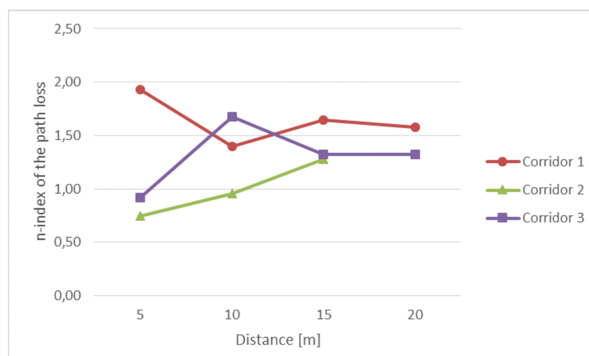

Figure 3: n-index of the path loss in the corridors of the emergency ward (see Fig.1).

3.2 Interference model

The second experiment consists of several measurements of the interference levels sensed in the emergency ward of the Hospital. Fig. 1 shows the planimetry of the emergency ward of the hospital where the experiment was conducted. The green and blue numbers in the planimetry indicate the locations where the interference power level have been measured by using a portable spectrum analyzer. For each location the interference received power samples have been collected for 5 minutes.

Table 4 shows the mean and the standard deviation values of the received power samples in several locations of the emergency ward are shown. The location numbers are reported in Fig. 1. The probe signal is not present in this case.

3.3 Modified path loss model

For all the above results in Sec. 3.1 and 3.2, we can characterize the path loss model as follows

$$L_{dB} = L_{dB}(d_0) + 10n\log(d/d_0) + \nu_{dB} \tag{3}$$

where d_0 is the reference distance (1 m), d is the distance between transmitter and receiver and ν is a Gaussian distributed random variable with zero mean and variance σ^2 which models the effect of the interference (shadowing).

The measurement campaign allowed us to derived the parameter n of the path loss (Fig. 3) as well as the standard deviation σ of the shadowing (Table 4) in a modern hospital.

This model allows to simulate the effect of path loss and interference shadowing inside a city hospital. Figs. 5-7 show the modified path loss model for the corridors 1, 2 and 3.

4. CONCLUSION

The main contribution of the paper is the description of two experimental measurements: one aiming to derive the main parameters to characterize the path loss in the band $B_s = [2.399, 2.485]$ GHz in a modern city hospital, the second aiming to model the aggregate interference power on a system which uses a IEEE802.15.4a chirp spread spectrum transmission (in the whole ISM band). The main parameters of the path-loss model are then derived taking into account the effect of the interference in a typical city modern hospital.

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		μ (dBm)	σ (dBm)			μ (dBm)	σ (dBm)			μ (dBm)	σ (dBm)
Corridor 1	1	-91,11	3,15	Corridor 2	1	-91,41	3,27	Corridor 3	1	-91,32	3,08
	5	-91,67	3,34		5	-91,66	3,21		5	-91,74	3,05
	10	-91,54	3,62		10	-91,66	3,31		10	-92,13	3,11
	15	-92,01	3,28		15	-91,94	3,52		15	-92,11	3,12
	20	-92	3,18						20	-92,33	3,18
	Room 29	-92,16	3,33		Room 2	-92,26	3,11		Room 10	-92,33	2,99
	Room 31	-92,15	3,53		Room 4	-92,23	3,28		Room 11	-92,3	3,04
	Room 33	-92,26	3,22						Room 21	-92,36	3,04
									Room 23	-92,25	3

Figure 4: Mean and standard deviation of the received power in different locations of the emergency ward (see Fig. 1). No probe signal is present.

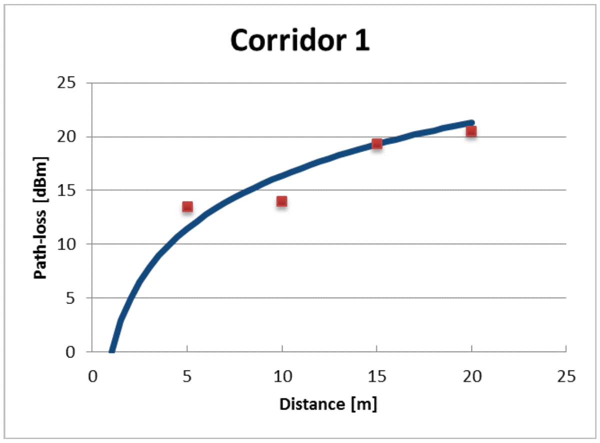

Figure 5: Modified path loss behaviour in corridor 1. The red square points are the measured values.

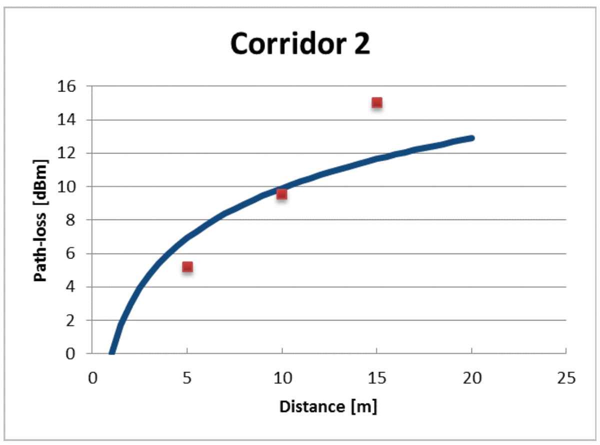

Figure 6: Modified path loss behaviour in corridor 2. The red square points are the measured values.

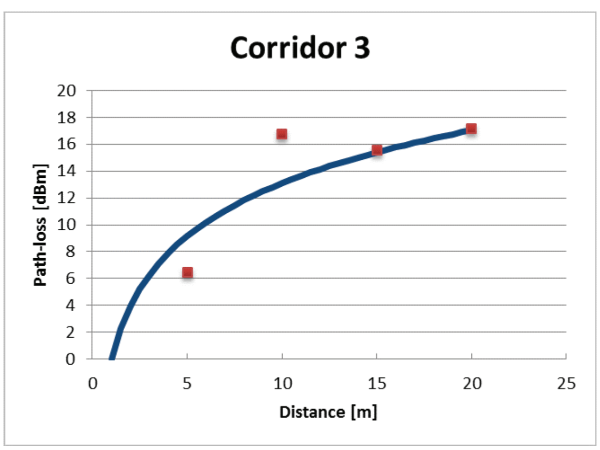

Figure 7: Modified path loss behaviour in corridor 3. The red square points are the measured values.

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