

Evaluation of the Aggregate Interference in Hospital ISM Band

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ABSTRACT

Estimation of the aggregate interference is required in order to predict the performance of a wireless system in its working environment. Body Area Networks (BANs) for healthcare applications are becoming a reality, allowing patients to be monitored continuously without forcing them to stay in bed or in hospital. The increasing number of wireless medical devices makes the ISM (Industrial, Scientific and Medical) band particularly crowded. If new smart BANs have to correctly operate in hospital, coexistence with the existing wireless devices must be accurately investigated, starting with studying the interference in the operating frequency band. In this paper we propose an interference model based on real measurements carried out in the emergency ward of a modern city hospital. The measured data is used to model the probability density function of the aggregate interference as well as the occupancy of the channel.

Keywords

interference modelling, real measurements, wireless communications, ISM band.

1. INTRODUCTION

Wireless communication system designers are commonly interested in basic questions like what is the maximum distance for which the wireless channel is suitable for communications or what are the best locations in the environment for the access points. 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 designers. It determines the maximum power loss that is allowed

between transmitter and receiver, while still maintaining an effective 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 real-life environments makes the actual propagation loss very difficult to predict. Most applications in today's short range RF scene operate in environments that are far 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 common. This increasing number of ISM devices, together with the extremely widespread adoption of Wi-Fi devices, can lead to a high level of interference in a typical modern city hospital [1]-[6]. This interference can be highly destructive, resulting in an alteration of the received power compared to the ideal free-space propagation. Early attempt to characterize the electromagnetic environment in hospitals dates back more than 30 years. In [8] the electromagnetic environment from 14 kHz up to 1 GHz in a hospital was assessed. In this paper, emission limits for narrowband and broadband signals were first recommended for devices used in hospitals. In 1997, the first 24-hour measurements showing temporal dependencies of the measured field within a hospital for frequencies up to 1 GHz were described [9]. In 2003 the electromagnetic field within the ISM band ($[2.40 - 2.4835]$ GHz) was evaluated [10]. In [11] 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 field measurements.

In order to better define the performance of wireless medical devices operating in environments where a hypothetical patient which is monitored by a WBAN uses to stay, we carried out real-life measurements in a typical city hospital in order to model the interference behaviour. Concerning the hospital, the interference power levels have been recorded for 5 hours by using a spectrum analyzer 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.

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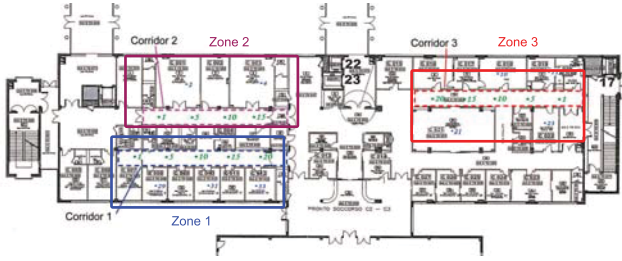


Figure 1: The map of the emergency ward of the hospital. The corridors are highlighted by dashed lines. The green and blue points represent the locations where the measurements were taken.

The main parameters, such as the first and second order statistics, to characterize the probability density function (PDF) of the interference fluctuations are derived based on those measurements.

The evaluation of the amount of interference can give us a hint on how much interference is typical in the most used environments for persons wearing WBANs. This can also give us a hint on whether more cognitive smartness (sense, elaborate and decide/change) is needed in the WBAN terminals or not, in order to face the interference and enhance the quality of transmission of very sensitive data.

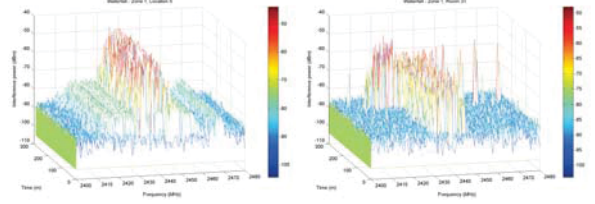
2. MEASUREMENTS SETTINGS

The field trials have been carried out in the emergency ward of a modern city hospital. The hospital ensemble includes four buildings and a surface of 43402 square meters, totally. The hospital has 24 wards, 413 beds, 8 operating rooms and 2 birthing rooms. Each recovery bed has a personal computer with Wi-Fi access for the entertainment of the patient. The hospital has also been equipped with the latest medical devices, most of which make use of wireless connection for transferring of medical data of the patient directly to the server and updating of the health history record.

All the measurements were taken during the busiest time of the day; medics and patients were moving around in the building. 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 interference was evaluated by collecting data without probing signal, in the corridors and in the rooms (Fig. 1), over the entire ISM band, specifically the band $B_s = [2.399, 2.4835]$ GHz. A spectrum analyzer (SA) by RF Explorer [7] was used to measure the received power (in dBm). The main parameters of the SA are the following: freq. range 2350-2700 MHz, 112 freq. measured points, freq. resolution 1 kHz, bandwidth resolution 500 kHz, sweep time 120 ms and amplitude resolution 0.5 dBm.

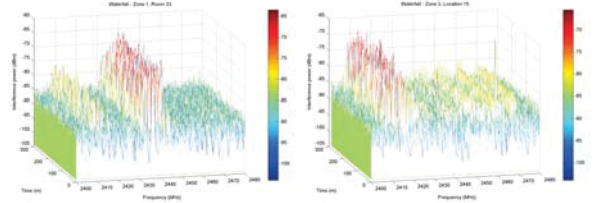
In Fig.1 the map of the emergency ward is shown. The coloured points represent the locations where the interference was measured. The functionalities of the different zones are the following:

- Zone 1 is used for various types of ambulatory care units.



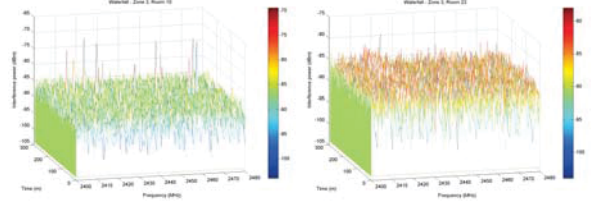
(a) Corridor 1, Location 5

(b) Room 31



(c) Room 33

(d) Corridor 3, Location 15



(e) Room 10

(f) Room 23

Figure 2: Interference power (z-axis, dBm) in the ISM band as a function of time (y-axis, minutes) and frequency (x-axis, MHz) for Zone 1.

- Zone 2 is used for bedridden patients, with various health problems from acute diseases to chronic conditions.
- Zone 3 is used for various radiological analyses: X-ray, tomography, MRI, ultrasound, etc. Note that the room 21 in Zone 3 is for the extremely urgent operations (intensive care and surgery).

3. RESULTS

In this section the results of the test fields will be discussed. The measurement results will be shown for Zones 1 and 3 only, for lack of space. Fig. 2 illustrates the interference power in the ISM band as a function of time and frequency for Zone 1 and Zone 3, respectively. It is evident that the profile of the interference power varies significantly as the receiver location changes, either across different zones or within the same zone.

More specifically, the following observations can be made. First, there is less interference in Rooms 10 and 23 in Fig. 2

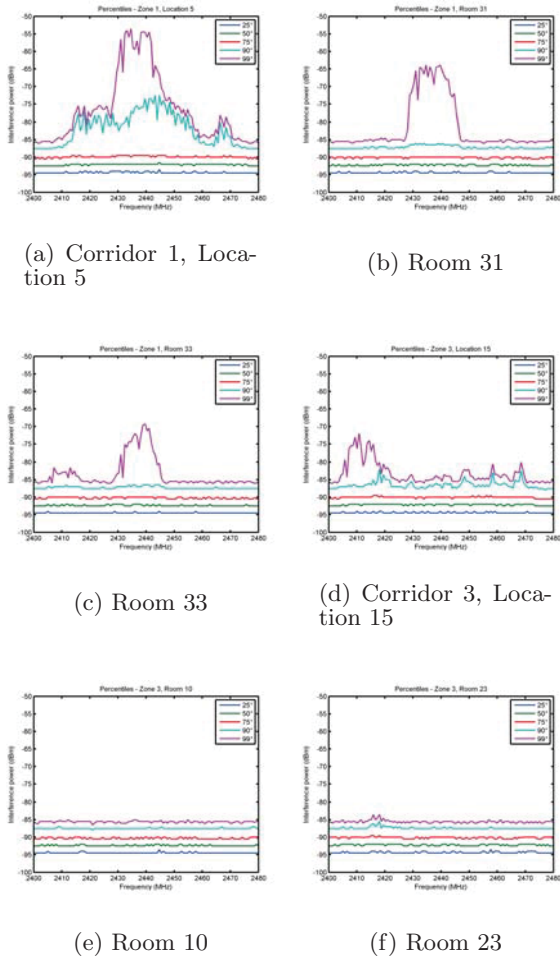


Figure 3: Percentiles of the interference power samples in the ISM band for Zone 1 and 3.

as these are devoted to radiological operations and thus the walls are very thick, blocking electromagnetic waves. Rooms 31 and 33 show more interference, in some sub-bands with “impulsive” behaviour (interference higher than noise level only for a short time). In particular, Rooms 31 and 33 are close to an external door which is remotely controlled by a signal in the ISM band. Corridors of Zone 1 (Location 5) show higher interference compared to Zone 3 (Location 15) but not in all sub-bands. Corridor 3 shows interference more uniformly distributed over the frequencies.

Fig. 3 shows the percentiles of the interference plus noise power in the ISM band over time. A percentile is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations fall. For example, the 20th percentile is the value below which 20 percent of the observations may be found. Focusing on Fig. 3(b) we can see that the 90% of the interference plus noise power samples (over the entire samples collected for 5 hours) fall below -87 dBm. Consequently, only 10% of the total interference samples were higher than -87 dBm. The average noise level (ANL) was measured to be -100 dBm.

The interference behaviour can be very different from one location to another, depending on the type of ward, the type of room, etc. In any case, the percentage of interference samples that exceed, e.g. -90 dBm, is not so high, even in the worst location. In particular, no matter which the location is, maximum amount of interference that exceeds -90 dBm is 25%, i.e., 75% of the time the interference samples have a power below -90 dBm. Thus, we can conclude that wireless body sensors and body area networks can be used without particular mechanisms for interference rejection. The percentiles show that only a small amount of interference power samples can be considered high, e.g., in Room 31 only 1% of the received samples lay over -80 dBm.

Using the measurements we have investigated the best fitting probability distribution function (PDF) of the received power samples. We have tried 16 different distributions for all the locations where we have collected data. In particular, the distributions are: Beta, Birnbaum-Saunders, Exponential, Extreme value, Gamma, Generalized extreme value, Generalized Pareto, Inverse Gaussian, Logistic, Log-logistic, Lognormal, Nakagami, Normal, Rayleigh, Rician, t location-scale and Weibull. The best fitting distribution has been derived by using a specific Matlab script. The Matlab script finds the most fitting distribution by using the *maximum likelihood* criteria. Two exceptions are the normal and log-normal distributions with uncensored data. For the uncensored normal distribution, the estimated value of the sigma parameter (standard deviation) is the square root of the unbiased estimate of the variance. For the uncensored lognormal distribution, the estimated value of the sigma parameter is the square root of the unbiased estimate of the variance of the log of the data.

The results show that when the interference is more prominent like in Zone 1 the best-fit PDF is the t location-scale (TLS), while if the interference is lower like in Zone 3 then the best-fit PDF changes to the *generalized extreme value* (GEV) or *normal* (N).

The t location-scale (TLS) distribution has a density function of

$$p(x|\nu, \mu, \sigma) = \frac{\Gamma(\frac{\nu+1}{2})}{\sigma\sqrt{\pi\nu}\Gamma(\frac{\nu}{2})} \left(\frac{\nu + \frac{x-\mu}{\sigma}}{\nu} \right)^{-\frac{\nu+1}{2}} \quad (1)$$

where $\Gamma(t) = \int_0^\infty x^{t-1}e^{-x}dx$ is the Gamma function, μ is the location parameter, $\sigma > 0$ is the scale parameter and $\nu > 0$ is the shape parameter. If x has a t location-scale distribution, with parameters μ , σ and ν , then $\frac{x-\mu}{\sigma}$ has a Student’s t distribution with ν degrees of freedom. The t location-scale distribution is useful for modeling data distributions with heavier tails (more prone to outliers) than the normal distribution. It approaches the normal (N) distribution as ν approaches infinity, and smaller values of ν yield heavier tails.

The PDF for the generalized extreme value (GEV) distribution with location parameter μ , scale parameter σ , and shape parameter $k \neq 0$ is

$$p(x|k, \mu, \sigma) = \frac{1}{\sigma} e^{-(1+k\frac{x-\mu}{\sigma})^{-\frac{1}{k}}} \left(1+k\frac{x-\mu}{\sigma}\right)^{-1-\frac{1}{k}} \quad (2)$$

for $1 + k \frac{x-\mu}{\sigma} > 0$ and $k > 0$. The case $k > 0$ corresponds to the extreme value Type II distribution, also known as Fréchet distribution, while $k < 0$ corresponds to the Type III, also known as Weibull distribution and $k = 0$ corresponds to the Type I, also known as Gumbel distribution. Similar to the extreme value distribution, the generalized extreme value distribution is often used to model the smallest or largest value among a large set of independent, identically distributed random values representing measurements or observations. The generalized extreme value combines three simpler distributions into a single form, allowing a continuous range of possible shapes that include all the three simpler distributions. Distributions whose tails decrease exponentially, such as the normal, lead to the Type I. Distributions whose tails decrease as a polynomial, such as Student's t , lead to the Type II. Distributions whose tails are finite, such as the beta, lead to the Type III.

The main parameters of each of the best-fit distributions, e.g., (μ, σ, ν) for the t location-scale and (k, μ, σ) for the generalized extreme value, for each frequency of the ISM band and for each location have been derived. Using these parameters it is possible to build the correct distribution of the interference in the specific environment of the hospital. The interference distribution can be used to predict the quality of the received signal and thus design the main parameters of the wireless body area networks for a proper use inside the hospital. As example, Tables 1-2 show the main parameters of the best-fit distributions for each frequency of the ISM band for Zone 1 Location 5 and Room 31.

4. CONCLUSION

In this paper we have presented a measurement campaign aiming to collect the interference power levels in a modern city hospital. The data have been collected in different locations of the emergency ward during a typical busy day. The data has been used to show the typical interference levels in the ISM band. The best fitting distributions have been derived for each frequency and location. For each distribution the main parameters of the best-fit PDF have been derived. Thus the interference behaviour can be reproduced in order to test and design the use of wireless body area networks in the main locations a monitored patient uses to stay. The interference plus noise power has been characterized by means of time-frequency graphics as well as by drawing the percentiles. In particular, the percentiles show that even in the worse locations of the hospital the amount of interference samples that exceed -90 dBm, over the entire duration of the measurement, is less than 25%. This preliminary research led us to a preliminary conclusion: the amount of interference is not dramatic in the hospital to justify an added smartness (and thus complexity) in the transceivers of WBANs.

Acknowledgment

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Table 1: Best fitting distributions and relative parameters of the interference in Zone 1 Location 5.

Frequency	Distribution	Parameters								
		Name	Description	Value	Name	Description	Value	Name	Description	Value
2412	GEV	k	(shape)	-0.205	sigma	(scale)	3197	mu	(location)	-93297
2417	GEV	k	(shape)	-0.050	sigma	(scale)	3359	mu	(location)	-93310
2422	GEV	k	(shape)	0.006	sigma	(scale)	3371	mu	(location)	-93472
2427	GEV	k	(shape)	-0.033	sigma	(scale)	3405	mu	(location)	-93507
2432	GEV	k	(shape)	0.071	sigma	(scale)	3515	mu	(location)	-93478
2437	TLS	mu	(location)	-92302	sigma	(scale)	2600	nu	(deg of freedom)	1796
2442	TLS	mu	(location)	-92303	sigma	(scale)	2501	nu	(deg of freedom)	1727
2447	GEV	k	(shape)	0.071	sigma	(scale)	3590	mu	(location)	-93484
2452	GEV	k	(shape)	0.018	sigma	(scale)	3398	mu	(location)	-93474
2457	GEV	k	(shape)	-0.110	sigma	(scale)	3226	mu	(location)	-93403
2462	GEV	k	(shape)	-0.241	sigma	(scale)	3229	mu	(location)	-93138
2467	GEV	k	(shape)	-0.078	sigma	(scale)	3405	mu	(location)	-93458
2472	GEV	k	(shape)	-0.256	sigma	(scale)	3264	mu	(location)	-93321

Table 2: Best fitting distributions and relative parameters of the interference in Zone 1 Room 31.

Frequency	Distribution	Parameters								
		Name	Description	Value	Name	Description	Value	Name	Description	Value
2412	N	mu	(location)	-92421	sigma	(scale)	2992			
2417	TLS	mu	(location)	-92248	sigma	(scale)	2737	nu	(deg of freedom)	7935
2422	TLS	mu	(location)	-92277	sigma	(scale)	2731	nu	(deg of freedom)	6903
2427	TLS	mu	(location)	-92315	sigma	(scale)	2760	nu	(deg of freedom)	8359
2432	TLS	mu	(location)	-92179	sigma	(scale)	2612	nu	(deg of freedom)	3731
2437	TLS	mu	(location)	-92150	sigma	(scale)	2525	nu	(deg of freedom)	3032
2442	TLS	mu	(location)	-92181	sigma	(scale)	2605	nu	(deg of freedom)	3209
2447	TLS	mu	(location)	-92114	sigma	(scale)	3012	nu	(deg of freedom)	15713
2452	N	mu	(location)	-92241	sigma	(scale)	3008			
2457	TLS	mu	(location)	-92255	sigma	(scale)	2848	nu	(deg of freedom)	32154
2462	N	mu	(location)	-92347	sigma	(scale)	2986			
2467	TLS	mu	(location)	-92268	sigma	(scale)	2873	nu	(deg of freedom)	34058
2472	N	mu	(location)	-92359	sigma	(scale)	2955			