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Determining Threshold Distance Providing Less Interference for Wireless Medical Implant Communication Systems in Coexisting Environments under Shadow Fading Conditions

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Link budget calculations,
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Monitoring threshold power,
Shadow fading conditions,
Wireless IMD communications

Abstract: Important interference problems will be able to be encountered especially close areas to the hospitals where wireless implantable medical systems' communication traffic occurs heavily in near future. It is possible that these interferences could cause wireless implant devices to malfunction and harmful effects on patients. In this study, it is proposed to determine threshold distance in order to get less interference for wireless implantable medical systems under shadow fading conditions where MICS band and MetAids band users coexist intensely simultaneously. In this method, threshold power according to the [1] is pulled down by adding extra distance margin in order to minimize the interference effects to the MICS systems using confidence interval calculations. Because received signal strength just below the monitoring threshold power according to the [1] brings about much more interferences for the MICS systems even if listen-before-talk technique is applied.

Gölge Sönümlenmesi Koşulları Altında Aynı Anda Olunan Ortamda Kablosuz Medikal Implant Haberleşme Sistemleri için Daha Az Girişim Oluşturan Eşik Uzaklık Belirleme

Anahtar Kelimeler
Bağlantı bütçesi hesaplama,
MetAids band,
MICS band,
İzleme eşik gücü,
Gölge sönümlenme koşulları,
Kablosuz IMC haberleşmesi

Özet: İleride, özellikle kablosuz medikal haberleşme trafiğinin çok yoğun olduğu hastanelere yakın bölgelerde, önemli girişim problemleri ile fazlaca karşılaşılabilecektir. Bu girişimlerin, kablosuz implant cihazlarının hatalı işlev yerine getirerek hastalara zarar vermesi olasıdır. Bu çalışmada, MICS ve MetAids kullanıcılarının aynı yerde aynı anda yoğun olarak bulunması durumunda, kablosuz medikal implant kullanıcılarına daha az girişim oluşturmak maksadıyla, gölge sönümlenmesi koşulları altında kablosuz medikal implant haberleşme sistemleri için eşik uzaklık belirleme yöntemi önerilmiştir. Bu yöntemde, MICS sistemlere olan girişim etkilerini minimize etmek için güvenlik aralığı hesaplamaları kullanılarak, [1]'e göre olan eşik gücü, fazladan uzaklık payı konarak aşağıya çekilir. Çünkü [1]'e göre olan eşik gücünün hemen altındaki alınan sinyal gücü, "konuşmadan önce dinle" tekniği uygulansa bile MICS sistemleri için çok daha fazla girişime neden olmaktadır.

1. Introduction

Wireless communication has been taking part in health care domain extensively. Communication of implantable medical devices (IMD)s is also performed wirelessly, so they are named wireless IMDs. There are several wireless IMDs that are used in some disorder treatments i.e. deep brain neorostimulators (DBS)s, cochlear implants, implantable cardiac defibrillators (ICD)/pacemakers, gastric stimulators, insulin pumps [2–6]. But different wireless IMDs for the different disorder treatments will be possible in the future. Therefore, number of IMDs is supposed to be too much in the near future [7, 8].

Federal commnunication comission (FCC) has allocated a frequency band named medical implant communication service (MICS) band between 402 MHz and 405 MHz for the communication of IMD systems [1]. Because this frequency range is appropriate for propagating of the signals in human body with the international acceptability [9]. Therefore, communications between IMDs and base stations (external devices) known as programmers through this band have been performed in a short range by holding transmission power less than 25μW (-16 dBm) according to the standard [1].

MICS band has ten equal channels, each of whom has 300 kHz bandwidth. Multiple devices close each other can use different channels at the same time without distorting each other by performing listen-before-talk (LBT) and adaptive frequency agility (AFA) procedures. These procedures provide interference reduction for both meteorological aids service (MetAids) systems and MICS systems on the

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same frequency band, since MetAids and MICS systems can coexist at the same frequency band [1, 9–11].

According to the LBT and AFA procedures, programmers have capability of monitoring the MICS frequency channel(s). In order to minimize the interference effects before initiating the communication or throughout continuing session, the communication channel will be replaced between the programmer and IMD by the programmer if the detected signal strength is more than monitoring threshold power [1, 9].

Coexistence between the MICS and MetAids systems in the band 402-405 MHz and the interferences to the MetAids systems have taken part in [12]. Coarse separation distance calculations are given in order to protect the MetAids systems from interference effects of MICS systems according to the given link budget parameters and these average distances are also evaluated in accordance with patient's indoor or outdoor position. But these separation distances are not defined under shadow fading conditions and low probability of interferences.

In [13], link budgets for the downlink to the implant and uplink to the programmer have been given in order to obtain signal to noise ratio (SNR) values and bit error ratio (BER) performances according to these SNRs with frequency shift keying (FSK) or quadrature phase shift keying (QPSK) modulations have been presented.

In [14], an interference effects of low power low duty cycle implants to the LBT implants have been discussed where high density of IMDs are available. It is mentioned that most of the power consumed in an LBT session occurs while performing a clear channel assessment and synchronizing the IMD with the programmer/controller. It is also emphasized that excessive LBT and AFA procedures wastes energy, so enough distances should contribute less power consumption and less interference.

In this paper, it is proposed to determine threshold distance in order to get low probability of interference for wireless implantable medical systems under shadow fading where MICS band and MetAids band users coexist intensely simultaneously. In this method, power threshold according to the [1] is pulled down by adding extra distance margin in order to minimize the interference effects to the MICS systems using confidence interval calculations. Because an amount of detected signal strength expressed strong interference zone just below the monitoring power threshold according to the [1] brings about much more interferences for the MICS systems even if LBT procedure is applied. Since both MetAids and MICS systems are allowed to do transmissions simultaneously, according to the LBT procedure under these conditions.

The remaining of the paper is organized as follows. Link budget characterization is carried out and proposed method is explained in Section 2. Section 3 provides the numerical results of the proposed method and conclusions are given in Section 4.

2. Material and Method

2.1. Characterization of link budget for the monitoring system

Programmer considered as a receiver has spectrum monitoring capability and can receive interference signals come from MetAids (radiosonde or rocketsonde) systems as in Figure 1. Therefore, link budget calculations are performed for the programmer according to the structures in [9] and [15]. Required MICS and MetAids system parameters are given in Table 1.

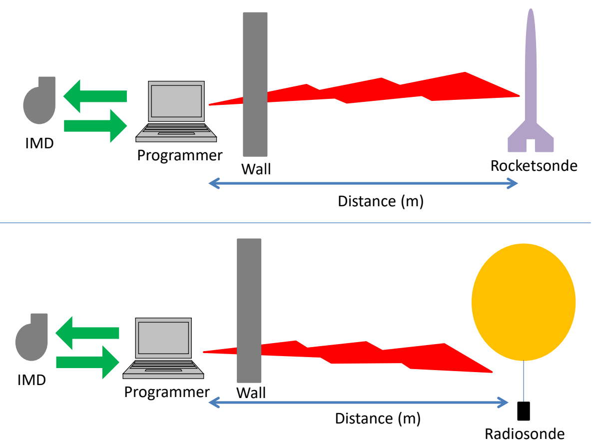

Figure 1. Interferences of MetAids systems to the MICS systems

Table 1. MetAids and MICS system parameters [9, 12, 15]

Parameters	
Transmitter power of MetAids system	24 dBm
Transmitter antenna gain of MetAids system	2 dBi
Fade margin (with diversity)	- 10 dB
Excess loss (polarization, etc.)	- 15 dB
Receiver antenna gain of programmer	2 dBi
Wall attenuation	12 dB

Based on this parameters, received power at programmer can be calculated using [9, 12, 15] as

$$P_{rx}^{(P)}\,[\text{dBm}] = P_{tx}^{(M)} + G_{tx}^{(M)}\,[\text{dBi}] - PL(d) - L_f - L_e + G_{rx}^{(P)}\,[\text{dBi}] - L_w \qquad (1)$$

where $P_{tx}^{(M)}$ is transmitter power of MetAids system, $G_{tx}^{(M)}$ is transmitter antenna gain of MetAids system in dBi, $PL(d)$ is mean path loss, L_f is fade margin, L_e is excess loss, $G_{rx}^{(P)}$ is receiver antenna gain of programmer in dBi and L_w is wall attenuation including building attenuations.

Mean (free space) path loss can be calculated as in [16] as

$$\begin{aligned} PL(d)\,[\text{dB}] &= 20log(4*pi*d/\lambda) \\ &= 20log(4*pi*d/(c/f_c)) \\ &= 20log(4*pi*d*f_c/c) \\ &= 20log(40*pi/3) + 20log(f_c) + 20log(d) \\ &= 32.4 + 20log(f_c) + 20log(d_0) + 20log(d/d_0) \end{aligned} \qquad (2)$$

where f_c is carrier frequency in MHz, d_0 is reference distance taken 1 m, d is distance between programmer and transmitter.

Mean path loss exponent is 2 in free-space propagation, while for indoor or outdoor propagation except free space, mean path loss exponent would be different. With the different mean path loss exponent, mean path loss is expressed as

$$PL(d)\,[\text{dB}] = 32.4 + 20log(f_c) + 20log(d_0) + 10\eta log(d/d_0) \quad (3)$$

where η is mean path loss exponent.

As in [1], monitoring threshold power can be calculated as

$$P_{th}^{(\text{P})}\,[\text{dBm}] = 10log(B) + 150 + G_{rx}^{(\text{P})}\,[\text{dBi}] \quad (4)$$

where B is bandwidth and $G_{rx}^{(\text{P})}$ is receiver antenna gain of programmer in dBi.

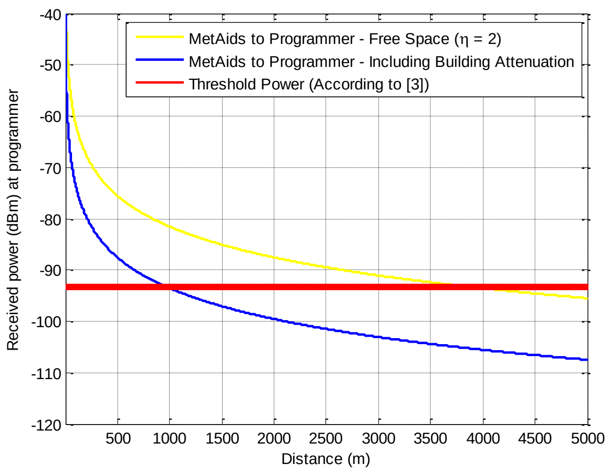

Figure 2. Received power at programmer vs. distance between programmer and MetAids transmitter

In Figure 2, it is illustrated mean received power at the programmer over the distance between programmer and MetAids transmitters. Mean path loss exponent can be chosen 2 for outdoor case and outdoor case is decreased 12 dB as in [12] for indoor case including wall attenuation. Indoor case has many more obstructions between MetAids transmitter and MICS programmer and it is seen in Figure 2 that the received power value at programmer stays below threshold power after the distance 970 m.

2.2. Proposed method

The actual path-loss model is the log-distance model mentioned in [16], Eq. 3 will then be

$$PL(d)\,[\text{dB}] = 32.4 + 20log(f_c) + 20log(d_0) + 10\eta log(d/d_0) + X_\sigma \quad (5)$$

where X_σ (in dB) is the shadowing factor and Gaussian random variable with zero mean and variance (σ^2) causes log-normal-fading or log-normal-shadowing. This variable is random scatter around the mean path loss and used only when there is a shadowing effect. If shadowing (large scale fading) effect is not observed, then this variable is zero.

Proposed method especially takes account of shadow fading conditions and this approach defines the new threshold distance between the programmer and interferer under shadow fading conditions. These interference signals come from MetAids (radiosonde or rocketsonde) as in Figure 1.

Monitoring power threshold according to the [1] has been given in equation 4. Even if the channel is occupied by MetAids systems, this channel can also be selected and used by the programmer when detected signal power just below this monitoring threshold according to LBT procedure in [1] standard. The zone just below this monitoring threshold probably causes more interference to the programmer as in Figure 3 and is named strong interference zone. Because the channel are not only used by the programmer but also used by the interferer simultaneously in this case. Therefore, interference level can be decreased by putting extra distance margin between them. This extra distance margin is determined according to the shadowing effect. If shadowing factor (σ) is known, it is possible to determine new calculated threshold power.

Firstly, the crossing point which mean received power according to logarithm of distance line with the monitoring threshold power line according to the [1] is determined. This point is defined as upper limit of strong interference zone. If this point is accepted a mean (power) of a Gaussian random variable, this Gaussian random variable's standard deviation equals to the shadowing factor (σ). According to the probability density function of this Gaussian random variable, lower limit of strong interference zone is determined according to the random value of power which provides 1% tail probability just below the strong interference zone.

If we have a Gaussian variable $X \sim N(\mu, \sigma^2)$, the probability that $X > x$ is

$$P(X > x) = Q(\frac{x-\mu}{\sigma}) \quad (6)$$

$$P(X < x) = 1 - Q(\frac{x-\mu}{\sigma}) = Q(\frac{\mu - x}{\sigma}) \quad (7)$$

where μ is mean value of X Gaussian variable and σ is standard deviation of X random variable. Lower limit of strong interference zone is then calculated using Q function

$$P(X < P_{th}^{(\text{LL})}) = 1 - Q(\frac{P_{th}^{(\text{LL})} - P_{th}^{(\text{UL})}}{\sigma}) = Q(\frac{P_{th}^{(\text{UL})} - P_{th}^{(\text{LL})}}{\sigma}) = 0,01 = Q(2,3) \quad (8)$$

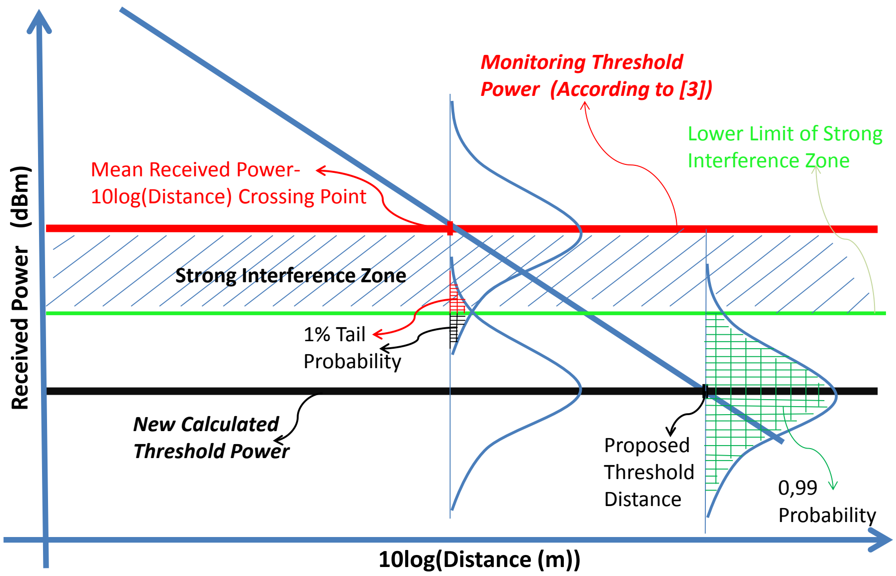

Figure 3. Determining distance threshold according to the proposed method

$$\frac{P_{th}^{(UL)} - P_{th}^{(LL)}}{\sigma} = 2,3 \quad (9)$$

$$P_{th}^{(LL)} = P_{th}^{(UL)} - 2,3\sigma \quad (10)$$

where $P_{th}^{(UL)}$ is upper limit of strong interference zone (power threshold according to the [1]) and $P_{th}^{(LL)}$ is lower limit of strong interference zone.

Strong interference zone stays between these upper and lower thresholds and difference between them results 2,3σ. The region with the 1% tail probability just falls into down below the strong interference zone. If we want a region with the 99% probability just falls into down below the strong interference zone, the mean of this variable gives us the new calculated power threshold. It is understood that this new calculated power threshold stays 4,6σ below upper limit of strong interference zone (threshold power according to the [1]). The crossing point which mean received power according to logarithm of distance line with the new calculated power threshold will then be proposed distance threshold.

$$P_{th}^{(new)} = P_{th}^{(UL)} - 2(2,3\sigma) \quad (11)$$

3. Results

In this section, performance results of proposed method are provided. Similar to the Figure 3, Figure 5 shows us received power at the programmer vs. logarithm of distance between programmer and MetAids transmitter due to log normal shadowing. It is understood from Figure 2 and Figure 4 that the received power value at programmer stays below threshold power after the distance 970 m. However, we want MetAids system's interference to the MICS systems with very low probability and too much weak. Therefore, we should put extra distance between them. Because it is possible that powerful interferences could cause wireless implant devices to malfunction and harmful effects on patients. According to the proposed method, the distance between them should be 13685 m seen also in Figure 4, if shadowing factor σ is 5.

4. Discussion and Conclusion

IMD systems are supposed to be in larger numbers in the near future. Consequently, usage density in MICS band will also increase and interference effects will also be observed too much in this band. In this study, it is proposed to determine threshold distances in order to get less interference for wireless implantable medical devices under shadow fading conditions where MICS band and MetAids band users coexist intensely. In this method, threshold power according to the [1] is pulled down in order to minimize the interference effects to the MICS users using confidence interval calculations when channel is occupied by MetAids and MICS systems simultaneously. Because received signal strength just below the threshold power according to the [1] brings about much more interferences when listen before talk technique is taken into account.

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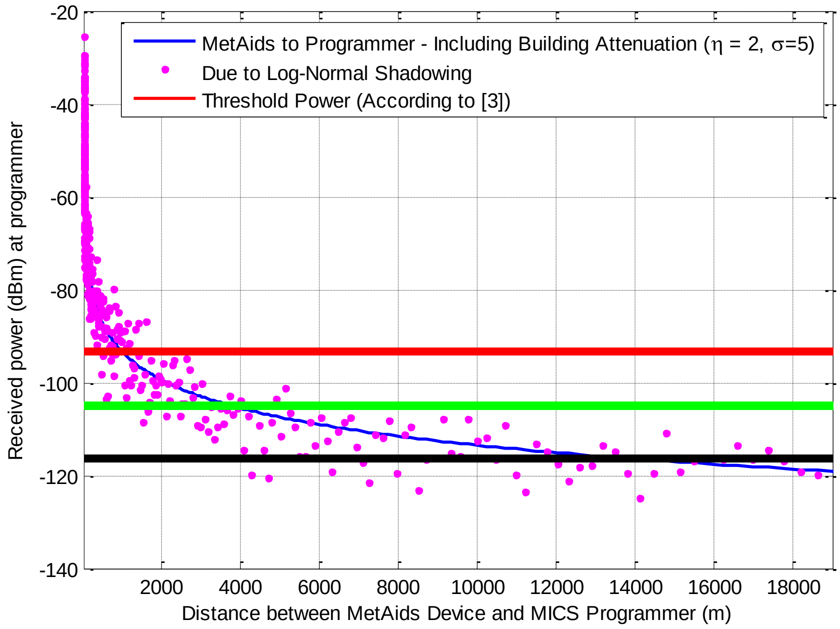

Figure 4. Received power at programmer vs. distance between programmer and MetAids transmitter due to log normal shadowing

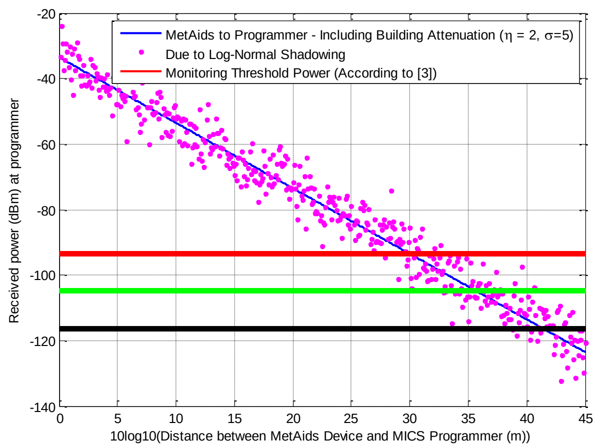

Figure 5. Received power at programmer vs. logarithm of distance between programmer and MetAids transmitter due to log normal shadowing

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