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# Body Area Networks Interference Performance Analysis Using UWB

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*Abstract*: **The successful realization of a Wireless Body Area Network (WBAN) using Ultra Wideband (UWB) technology supports different medical and consumer electronics (CE) applications but stand in a need for an innovative solution to meet the different requirements of these applications. Previously, we proposed to use adaptive processing gain (PG) to fulfill the different QoS requirements of these WBAN applications. In this paper, interference occurred between two different BANs in a UWB-based system has been analyzed in terms of acceptable ratio of overlapping between these BANs' PG providing the required QoS for each BAN. The first BAN employed for a healthcare device (e.g. EEG, ECG, etc.) with a relatively longer spreading sequence is used and the second customized for entertainment application (e.g. wireless headset, wireless game pad, etc.) where a shorter spreading code is assigned. Considering bandwidth utilization and difference in the employed spreading sequence, the acceptable ratio of overlapping between these BANs should fall between 0.05 and 0.5 in order to optimize the used spreading sequence and in the meantime satisfying the required QoS for these applications.**

*Index Terms:* **Body Area Network, DS-UWB, Overlapping Ratio, Medical Applications, Entertainment Applications.**

## I. Introduction

UWB technology is a useful and safe new technology in the area of wireless body area network (WBAN). There are many advantages of using UWB as a communication standard for biomedical applications. Its interesting features can be summarized in its very low radiated power (−41.3 dBm/MHz), low power consumption, good coexistence with the other existing instruments, robustness to interference and multipath [1]. With its 7.5 GHz of spectrum allocated to the UWB devices by Federal communications Commission (FCC), entertainment applications can be more enjoyable with the wide frequency range which allows the communications to achieve high data rate transmission [2]. These enormous advantages for UWB offer a promising future for this technology for short-range communications. For low power peer-to-peer and multiple access communications, IR-UWB is preferred because of its nanosecond (or less) width pulses which usually combined with some spreading technique to offer low power spectral density across the bandwidth.

Recently, there is a high demand for the body area networks (BANs) devices which supports both medical and entertainment purposes. The coexistence of these applications in one device is a challenging task because of the gap in the required Quality of Service (QoS) for these applications which can be seen as a diversity-multiplexing tradeoff. Medical applications are related to the human health and require high reliability transmission with small power consumption and limited effect on human body, which can be achieved by increasing the diversity order of the transmission system. While the high data rate is the main interest for the entertainment devices with comparatively low error probability, where we should improve the multiplexing order. The BAN network consists of a piconet in star topology [3], where an external controller works as a coordinator to collect the data from the different sensors which can be implanted inside of the body or on the body surface. A typical piconet consists of a hub and up to 256 sensors and up to 10 piconets can be collocated in the same domain.

The coexistence of many BANs in the near vicinity of each other (elevator for example) can lead to interference between these BANs because of the large number of sensors each piconet can have and unpredictable movement of these sensors. In addition, no proper global coordination scheme exists as there is no natural choice of coordinator between piconets. The previous factors cause a considerable degradation in the performance for each interfering piconet in the near vicinity. Generally, co-channel interference between the different piconets in a WBAN, can be mitigated by using multi-access schemes like CDMA. Within a piconet, and the employment of MAC protocol, performance can be optimized. Considering a WBAN with piconets assigning different spreading codes, the situation case will be quite different since the interference occurs between moving piconets. Piconets come into and leave each other's vicinity frequently, and there is no natural choice of piconet to coordinate them [4].

Previously, adaptive transmission scheme using variable-length spreading sequence (VLSS) based on IR-UWB for wireless communication has been proposed [5]. According to the system load, the length of the spreading sequence changes adaptively which proven to be able to reduce the inter-chip interference, inter-symbol interference and multiple-access interference and thus improve the system performance. Also, they show that using RAKE receivers allow the proposed scheme to outperform the conventional system by appropriately allocating the spreading sequences.

Previously, we have proposed to adaptively change the

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spreading sequence code length according to the number of active nodes in the system and the applications these nodes employed for. Motivating with the importance of the acceptable ratio of overlapping between two or more nodes employing different spreading code length, this paper analyze that system assuming a constant chip rate for all nodes as a way to achieve fairness between them.

The analysis of this interference can be used in feedback control systems, system employing channel estimation at transmitter side and finally, on production side, minimizing the used sequence length providing the required performance will be much appreciated.

The rest of this paper is organized as follows: in section II we give a brief introduction and statement for the problem we analyze under the Gaussian environment. Section III presents the impulse response DS-UWB system model. Simulation parameters and numerical results are presented in Section IV. Conclusion and open problem is drawn in Section V.

## II. Problem Statement

As we can see in "Fig. 1," we assume a typical piconet consists of a hub and some sensor nodes organized in a star topology. The hub coordinates the transmission within the piconet. Each piconet employed for different application and hence assigned spreading code length accordingly. We assume that the interference occurs between two sensor nodes belong to different piconets. As we proposed earlier, the medical applications require more reliability even though there is a sacrifice with data rate. Entertainment applications attracted more to high data rate with some condoning to the achieved error rate if necessary.

In this paper, we assume a whole bandwidth $B$ and the number of chips transmitted over this bandwidth is fixed for both piconets, which enable a fair comparison. We consider multirate users with multiple processing gain schemes because it has been reported that multirate modulation schemes have significantly worse performance for high data rate users [6].

We assume $N_m/N_e$ spreading code for medical/entertainment piconet respectively. Each piconet has a predefined code length to spread its data bits.

The length of a code depends mainly on the purpose of this piconet, namely medical or entertainment purposes. Each piconet randomly picks a code from the whole set of Gold sequences generated according to required code length $N_m/N_e$.

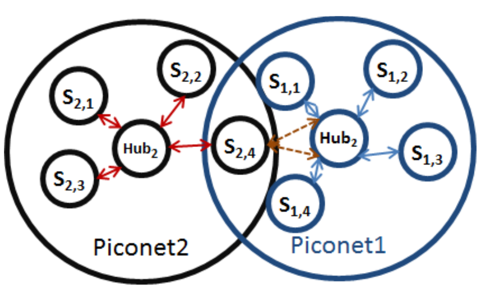


Fig. 1, Interference between adjacent piconets

Each chip occupies the whole band B and has a chip period of $1/B$. We assume that this system is designed such that there is no Inter-Symbol Interference (ISI). Given $B$ and $N_m/N_e$, the symbol period is $N_m/B$ or $N_e/B$. Consider that chip rate is fixed, the difference in code length leads to different data rate.

In this work, we analyze the system to find out the acceptable ratio of overlapping between two users symbols which can satisfy the QoS conditions for medical/entertainment applications concerning the acceptable error probability and minimum data rate.

Also we must fulfill the power emission regulations for Ultra Wideband system which standardized by the Federal Communications Commission (FCC), which we targeting in this paper. In this work, we use the fifth derivative of Gaussian UWB-pulse because it satisfies the FCC regulations.

## III. System Model

We consider a Body Area Network system model employing impulse response DS-UWB transmission technique where the transmitted data from each node $k$ can be represented as:

$$x_k(t) = \sum_{i=-\infty}^{\infty} d_k(i) s_k(t - iT_b)$$

Where $d_k$ is the $k^{th}$ transmitter equiprobable binary bit stream modulated as BPSK and $s_k$ is the normalized spreading spectrum waveform given by

$$s_k(t) = \sqrt{E_b/N} \sum_{j=0}^{N-1} c_k(j) w_{tr}(t - iT_p)$$

Where $c_k(j)$ is a pseudorandom spreading code that takes values {-1,1} and has a period $N = N_m$ in case of medical nodes and $N = N_e$ for entertainment nodes. $w_{tr}(t)$ denotes the UWB pulse, which is normalized to $\int_{-\infty}^{\infty} w_{tr}^2(t) = 1$

$T_b$ denotes the duration of one data bit.

$E_b$ is the energy of one bit.

$T_p$ is the pulse duration of $w_{tr}(t)$ and $N_m/N_e$ copies of $T_p$ gives one medical/entertainment bit duration.

The UWB pulse used for this research is the fifth-order derivative of the Gaussian pulse which can be described as

$$w_{tr}(t) = A\left(\frac{-t^5}{\sqrt{2\pi}\sigma^{11}} + \frac{10t^3}{\sqrt{2\pi}\sigma^9} - \frac{15t}{\sqrt{2\pi}\sigma^7}\right)\exp\left(\frac{-t^2}{2\sigma^2}\right)$$

where the pulse amplitude value $A$ keeps the unity of the pulse energy, $t$ is time, and $\sigma$ is the pulse width control factor. The pulse width in this system is 0.5ns.

We assume that the system is designed such that no inter-symbol interference (ISI) occurs. The signal of the $k^{th}$ transmitter $s_k(t)$ propagates through a white Gaussian noise channel. Ignoring antenna effects on the transmitted pulses, the signal at the input of the receiver is given by

$$r(t) = \sum_{i=0}^{U_m-1} s_i(t) + \sum_{k=0}^{U_e-1} s_k(t) + n(t)$$

where we assume the existence of $U_m$ medical nodes and $U_e$ entertainment nodes. *n(t)* represents the additive white thermal noise at the receiver following the Gaussian distribution with mean equal to zero and variance $\frac{N_0}{2}$.

## IV. Simulation and Discussion

The performance of the DS-UWB system with $U_m = 1$ medical and $U_e = 1$ entertainment nodes has been analyzed by simulation. In all our simulation, we assume that the medical piconet always has relatively longer spreading code in the vicinity of another entertainment piconet with a shorter code. We define the ratio of overlapping between the bit duration for medical and entertainment nodes as Overlapping Factor and denoted as

$$\varrho = \frac{N_e}{N_m}$$

and since $N_m$ is always longer, we get always $0 < \varrho \leq 1$. The system uses a Gold code spreading sequence for both applications as shown previously in "Table 1."

The received data exposed to thermal noise at the receiver assumed to have Gaussian distribution. We assume that all the active users have the same transmission power. During all the simulations in this work the chip rate is fixed at 2 Gchip/sec. Changing the spreading code length lead to a change in transmission data rate as shown in "Table 1."

For sake of simplicity, we use the conventional matched filter receiver to retrieve the transmitted data even though it is considered to be sub-optimal among multiuser detection receivers.

Table 1. Spreading codes and Data rate used for medical and entertainment applications

| SS Med | Data Rate Med (Mbps) | SS Ent | Data Rate Ent (Mbps) |
|---|---|---|---|
| 3 | 666.6 | 3,7,31,63 | 666.6, 285.7,64.5,31.7 |
| 7 | 285.7 | 3,7,31,63 | 666.6, 285.7,64.5,31.7 |
| 31 | 64.5 | 3,7,31,63 | 666.6, 285.7,64.5,31.7 |
| 63 | 31.7 | 3,7,31,63 | 666.6, 285.7,64.5,31.7 |

### A. *One medical and one entertainment node in the system*

We fix the medical spreading code length and change the entertainment one. As shown in "Figs. 3-4," for medical nodes the optimum BER and throughput achieved at $\varrho = 0.4921$ while for entertainment node the best BER occurred at $\varrho = 0.1111$ and optimum throughput at $\varrho$ =0.4921 and start degrading till the lowest value when $\varrho = 1$.

Next, we test the effect of changing the medical node code length in "Figs. 5-6." We find that for medical node the optimum value for BER occurred at $\varrho = 0.1111$ while the optimum throughput at $\varrho = 1$. For entertainment node, the optimum for BER and throughput at $\varrho = 0.0476$ and throughput start to degrade and BER kept almost constant with a small gap to the optimum value.

### B. *Five medical and four entertainment nodes in the system*

We increase the number of nodes interfering in the system to be $U_m = 5$ medical nodes and $U_e = 4$ entertainment nodes. First we target to study and analyze the effect of changing the overlapping factor on both medical and entertainment nodes. To this end, we fix the spreading code length for all medical nodes and increase the spreading code length for the entertainment till the same medical nodes' length.

Since the spreading gain doesn't change for the medical nodes, as shown in "Fig. 7," the optimum value of throughput for entertainment nodes occurred when overlapping factor is very small $\varrho = 0.0236$ accompanied with bad error probability while the optimum value for BER with relatively low throughput for medical nodes occurred when the overlapping factor equals $\varrho = 0.2441$ and decreases to the worst value when the sequences code length is equal.

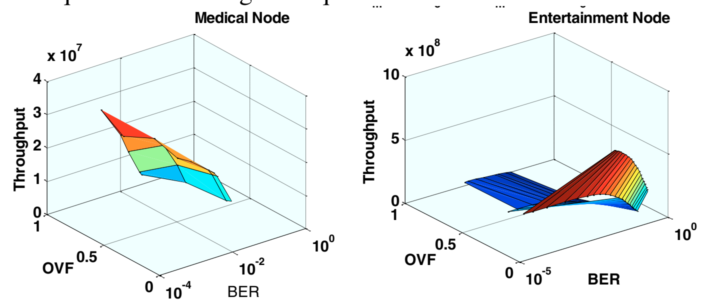


Fig. 3, System average throughput for entertainment node as a function of Overlapping Factor and SNR for Medical node and Entertainment nodes.

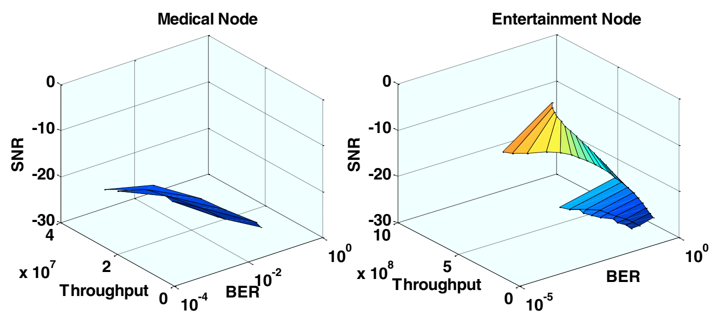


Fig. 4, System average throughput as a function of BER and SNR for medical nodes and for entertainment node. The processing gain for medical node is fixed and for entertainment node changing but shorter than medical one. The system contains one medical nodes and one entertainment nodes

The increase in SNR gave an improvement in throughput as expected. A more clarification can be seen in "Fig. 8," where throughput is represented as a function in BER and SNR.

For medical nodes, "Fig. 7," the throughput start with an optimum value and continue to achieve it till it degraded when the two sequences code length became equal.

Reversing the situation, we fix the spreading code length for all entertainment nodes and increase it for the medical starting from the entertainment nodes' length.

As shown in "Fig. 9," the optimum value of throughput occurred when overlapping factor equals $\varrho = 0.2258$ accompanied with the best error probability while throughput degrade to it lowest value when the sequences code length is equal. The same for medical nodes, we can achieve the best throughput at overlapping factor equals $\varrho = 0.2258$ but the worst value at $\varrho = 0.1111$.

## V. Conclusion

Performance evaluation of DS-UWB for WBAN systems has been evaluated by simulation. We consider the required error probability, bitrate and throughput for two applications (medical and entertainment). It is shown that in the way to achieve every application's requirements, we have to accept some scarification. In case of one medical and one entertainment node, to achieve both medical and entertainment applications goals we can choose the overlapping factor to be $\varrho = 0.05 \sim 0.5$. In case of higher number of users, it has been shown overlapping factor is subject to many factors like number of nodes for every application and length of used spreading code. For future, we need to analyze the system with a full capacity channel utilization and maximum allowed number of users in the different applications.

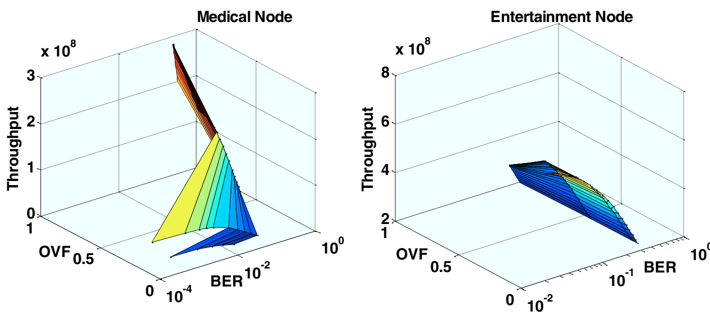


Fig. 5, System average throughput for entertainment node as a function of Overlapping Factor and SNR for Medical node and Entertainment node.

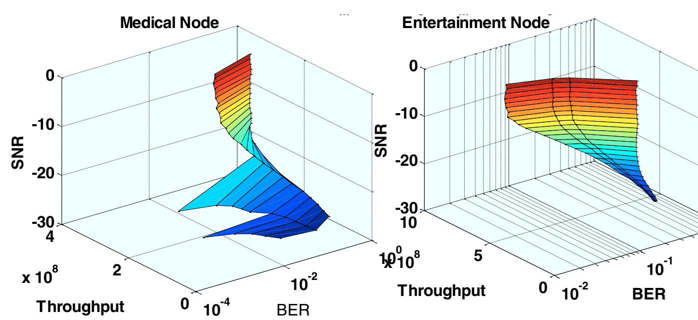


Fig. 6, System average throughput as a function of BER and SNR for medical node and for entertainment node.

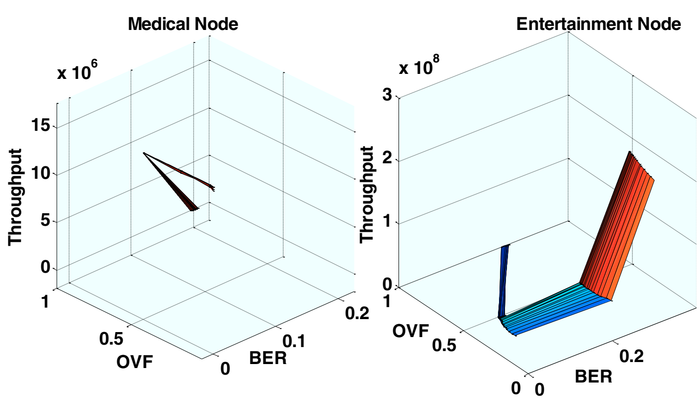


Fig. 7, System average throughput for entertainment node as a function of Overlapping Factor and SNR for Medical nodes and Entertainment nodes.

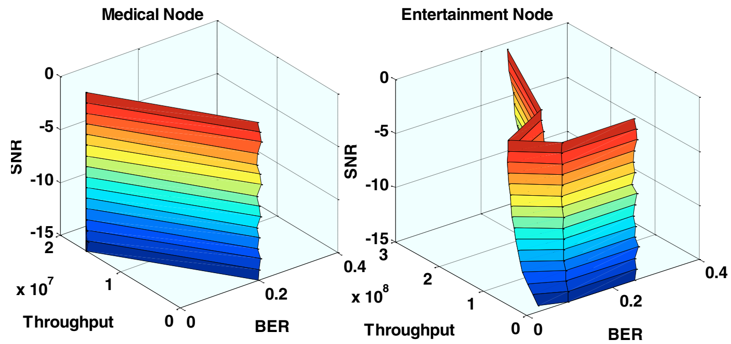


Fig. 8, System average throughput as a function of BER and SNR for medical nodes and for entertainment nodes.

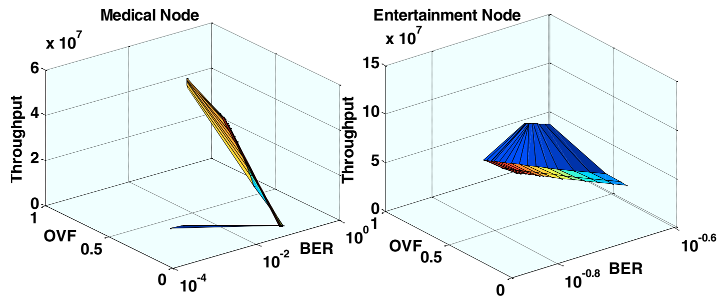


Fig. 9, System average throughput for entertainment node as a function of Overlapping Factor and SNR for Medical nodes and Entertainment nodes.

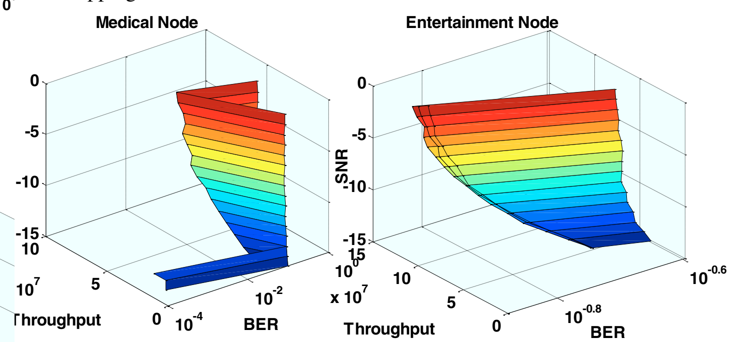


Fig. 10, System average throughput as a function of BER and SNR for medical nodes and for entertainment nodes.

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