Application of High-band UWB Body Area Network to Medical vital Sensing in Hospital

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ABSTRACT

We evaluated a prototype high-band UWB-BAN using several vital information sensors in a hospital. We confirmed by experiments that setting one coordinator near the ceiling or back or forward of the bed and another coordinator under the bed is better solution when the patient lies on a bed. A helical antenna with a high antenna gain along the axial direction, when used in the coordinator showed better radiation performance and less dependence on the direction of the sensor node antenna than a biconical antenna. Next we applied new version of prototype with smaller size of hub and sensor node with more mobility models in a hospital attaching a hub and sensor nodes on the body and confirmed the communication worked well. We also examined the interference by other wireless communication system and medical device and optimized the sequence length to get maximum data rate and satisfying the packet rate and suppressing the interference under multi BAN by numerical analysis.

Keywords

wireless body area network (WBAN), ultra wide band (UWB), interference

1. INTRODUCTION

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The wireless body area network (WBAN) is a technology that provides short range, low power, and reliable wireless communication for use in close proximity to or inside a body. Ultra wide band (UWB) is expected to present low interference andĄ@low effect to body as the power spectrum density is extremely low [1]. Thus, we investigated the advantages and drawbacks of BAN systems using UWB under the IEEE802.15.6 standardization [2] [3]. We used a prototype high-band UWB system that was co-developed with the National Institute of Information and Communications Technology (NICT) and Global Interface Technologies (GIT) in Japan. It is ideal to test under various situations indoors and outdoors, but the UWB system is restricted for use only indoors by Japan domestic law. Many studies have examined the characterization of a UWB channel for the indoor use of BAN. However, most of these studies used a vector or a spectrum network analyzer [4-7]. Recently, a prototype BAN system based on UWB has been evaluated in anechoic chamber [8] or experimental room [3], but not in a real hospital room. So, we applied UWB-BAN in a hospital room where real time vital data information of patients is essential. In Japan, the frequency of UWB that we can use is restricted to low band (3.4-4.8GHz) and high band (7.25-10.25GHz). We reported that commercially available consumer use low-band UWB system did not accommodate another low-band system [9]. And the regulation requests the countermeasures to interference for low band UWB. So we chose high band UWB system for experiments in the hospital. We confirmed almost simultaneous receiving from four vital sensor nodes in the line-of-sight (LOS) situation within 3m distance, but difficult to communicate when patients change posture, especially face down and covering the sensor node. We verified that the most suitable routing to avoid the shadowing problem was to set a coordinator near the ceiling and another coordinator under the bed [9]. In this paper, we present the experimental results of two systems,

Table 1: High-band UWB experimental parameters

Parameter	Value	
	Ver.1	Ver.2
Occupied frequency band	7.25-10.25GHz	
Maximum transmission emission power	-41 dBm/ MHz	
Pulse repetition frequency	50 MHz	
Bit rate	3 Mbps	
Modulation	Pulse density modulation	
MAC	TDMA	TDMA, CSMA/CA

setting the coordinator apart from patient and more mobility model when introducing high band UWB BAN system in hospital. We also present the experimental results of the interference with other communication system and medical equipment in sick room and optimize the sequence length to get maximum data rate, satisfying the packet rate and suppressing the interference under multi Ban by numerical analysis.

2. EXPERIMENTS WITH UWB-BAN SYSTEMS

We evaluated two prototype high-band UWB systems co-developed by the National Institute of Information and Communications Technology (NICT) and the Global Interface Technologies (GIT) in Japan. We used two prototype high-band UWB systems in the Yokohama City University hospital. The study protocol was approved by the ethics committee of the Yokohama City University School of Medicine.

2.1 Prototype UWB-BAN system

The prototype high-band UWB-BAN system comprised of a coordinator (Hub), sensor and a sensor node. Both size of the coordinator (Hub) and the sensor node is 19.5 cm (length) x 16 cm (width) x 12 cm (height) for ver.1. The size of Hub and the sensor node of ver.2 is 12.5cm (length) x8.0 cm (width) x 3.2cm (height) and 8.8cm (length) x4.5cm x2.5cm (width),respectively. Table 1 shows experimental parameters. To prevent interference, the contention-free TDMA protocolĄ@corresponding to the IEEE802.15.6 MAC protocol is adopted. CSMA (Carrier Sense Multiple Access) is also added to ver.2. We prepared four sensors for electrode cardiograph (ECG), percutaneous oxygen saturation (SPO2), acceleration, and body temperature. Packets were transmitted every second. A biconical antenna (23 mm long and 21 mm in diameter) was used for this system. Fig.1 shows a radiation pattern at frequency 8.25GHz. Radiation pattern from 7.25GHZ to 10.25GHz is similar. It is an omni-directional pattern in the horizontal plane and approximately ±60 degree radiation pattern in the vertical plane. The main polarization was vertical .The number of 0,-10,-30 means the antenna gain. We also used a 1.15cm long, 1.15cm diameter and 1cm pitch distance of helical antenna. The shape and radiation pattern of the helical antenna at 8.25 GHz that we used are shown. Radiation pattern from 7.25GHZ to 10.25GHz is similar. It has a high antenna gain along the axial (+Z) direction (Fig.2).

2.2 Experimental condition

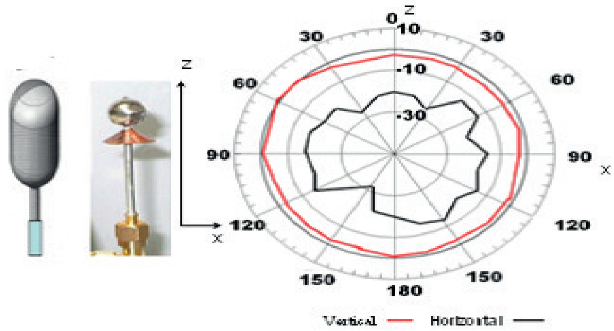

Figure 1: Biconical antenna and radiation pattern

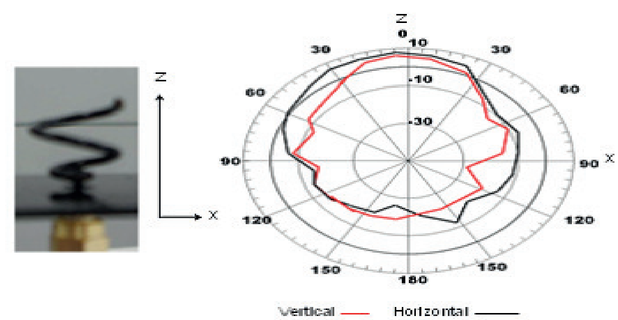

Figure 2: Helical antenna and the radiation pattern

The experiments were conducted in two different hospital rooms: one was a large room [8.6 m Ą 11.0 m Ą 2.7 m (height)], and the other was a smaller private room [2.5 m Ą 2.8 m Ą 2.4 m (height)]. The participant lay on the bed during the measurement. The size of the bed was 2.1 m Ą 0.9 m, and the height from the floor in each room is 0.49 m. The beds had mattress made from the polyester resin of 0.09m thickness.

2.3 Experiment using prototype ver.1 on the bed

The Hub connected to PC was set on the desk of 0.7m height, posterior to the foot of the participant (Fig.3 a, b).The antenna of Fig.3a is biconical antenna and the antenna of Fig.3b is a helical antenna. The distance between the sensor node and the Hub ranged from 3.0 m to 3.2 m in the large sick room and from 2.0 m to 2.2m in the small sick room. We also experimented to set the Hub near ceiling. Four sensor nodes (ECG on the chest, SpO2 on the hand, temperature on the chest, and acceleration near the hip) were attached to the participant (Fig.3c is bucolical antenna vertical and 3d is horizontal). There is a method to attach the Hub to the body, but we first set the Hub apart from body to avoid the burden for the lying patients on the bed using prototype ver.1. One packet is sent every second. The number of packet is shown on the panel of PC. The packet error rate was calculated dividing the number of packet error by communication time(sec). Duty cycle is estimated less than 30%. The experiment was held during ten minutes and repeated twice. Average packet error rate was recorded.

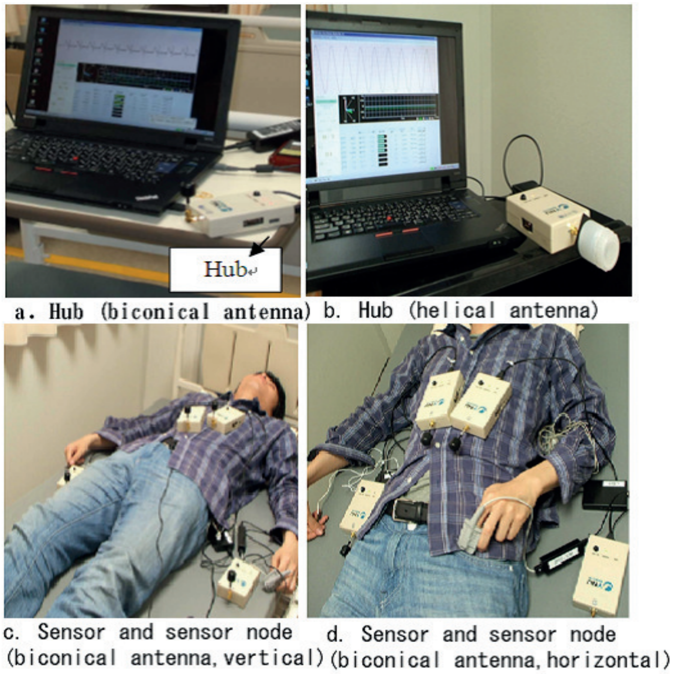

Figure 3: The position of Hub and sensor node

2.4 Experiment using prototype ver.2

The purpose of these experiments is to evaluate the availability of the UWB-BAN system for wireless monitoring with more mobility models and to examine the interference from or to the other wireless communication and medical equipment. The size of Hub and sensor node of prototype ver.2 is smaller than ver.1. So we applied Hub on the body (Fig.4). Hub connected to a tablet type of PC receives the vital data fromĄ@the sensor nodes on the body and transmits it to managing PC by wireless LAN.The system diagram is shown in Fig.5. The distance from Hub to sensor node is about 20-30cm.

3. EXPERIMENTAL RESULTS

3.1 Applying high band UWB BAN system on the bed

Figure 4: Hub and sensor node with antenna on the body

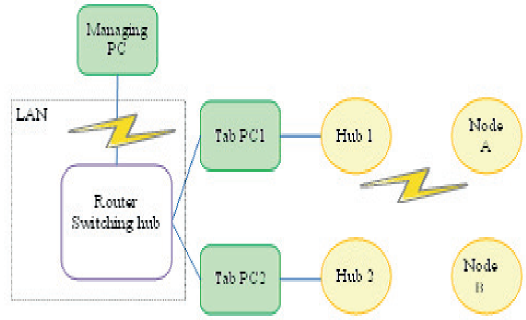

Figure 5: System diagram of ver.2

When a participant lying face up on the bed in a small sick room and both biconical antenna of Hub and sensor node are vertical (Fig.3a, 3c), the packet error rate was 0 in ECG, SpO2 and 0.003 in acceleration and temperature during 10 minutes, but the communication was shut down when the direction of Z axis is horizontal (Fig.3d). When applying a helical antenna to the Hub and directed to+ Z axis to the sensor node (Fig.3b), the communication was successful in any direction of antenna of the sensor node. Next we applied the coordinator near the ceiling above the participant. The antenna of coordinator and sensor node was set + Z axis to the horizontal direction to fit polarization face. The distance between the coordinator and the sensor node on the chest of the participant was 1.75m. Communication was successful when the participantsĄ@was lying face up, however, when he is facing down and covered the sensor node, the communication failed. Humans sometime sleep on their right or left-hand side. Therefore, we examined the PER by varying the body angle of a person with an ECG sensor on his chest on the bed A. The results are shown in Fig.6. The body is shown by a cylinder. The +Z direction of antenna is shown by an arrow. The +Z direction of antenna changes by the angle of human body. The packet loss increased when the participant lies on the right side and the communication was completely shut down when face down. It was confirmed that almost simultaneous reception from four sensor nodes in face up but the communication was partially or completely shut down by the angle of body on the bed in sickroom.

Measures are available to avoid the shadowing problem by multi-hopping using many relay nodes on the body. However, this method suffers from various problems such as the possibility of interference, trouble with the relay nodes, and high cost. We found that the radio waves of the high-band UWB propagated through the bed and reached the floor by setting the coordinator (Hub) on the floor under the bed. The reason that a communication link was established from one side of the bed to the floor under the bed was assumed to be because radio waves propagated through the bed mattresses and the many holes in the metal plate. Fig 7 shows the diagram of angular range blocked by the body on the bed. In this model, Tx indicates the sensor node.Rx1 is a Hub near ceiling and Rx2 is a Hub under the bed. The +z direction of helical antenna directs to bed.

Angle of the human body	Antenna direction on the chest	Coordinator near the ceiling
Face up		0
On the right side		0.388
On the left side		0.0075
Face down		1

Figure 6: Effect of the angle of a human body on the PER

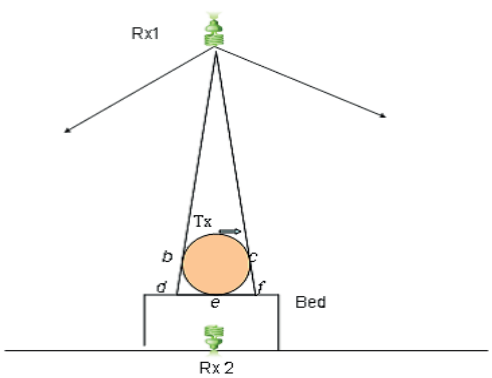

Figure 7: Diagram of angular range blocked by the body on the bed

Figure of patient	Antenna direction on the chest	Coordinator near ceiling	Coordinator under bed
Face up		0	1
On right side		0.003	0
On left side		0	0.085
Face down		1	0

Figure 8: PER for different patient postures and coordinator positions

Figure 9: Received vital data during walking

When the patients lie on their face and cover the sensor node and the communication between the coordinator (Rx1) near the ceiling is disconnected in the part arc bde and cef, the second coordinator (Rx 2) under the bed starts to communicate.The combined information from the two coordinators is sent to the management room such as the nurseĄfs station or the Intensive care Unit (ICU) using a transponder between the BAN and a wired or wireless LAN Fig.8 shows the PER for different patient postures and coordinator positions.

3.2 Applying UWB BAN ver.2 system in hospital

When a participant is walking in a sick room, packet error sometimes happened, but biomedical data was received almost continuously (Fig.9). It was also confirmed on theĄ@bed (Fig.10) and outside the sick room. It is expected Ą@to use in not only sickroom, but also in other places in hospital. In these experiments, the difference of the biconical and helical antenna in Hub was small. The effect of angle of antenna was small. It will owe to a short distance between a Hub and the sensor nodes.

3.3 Interference

We examined the effect from and to UWB-BAN system when operating by other wireless communication and medical equipment such ascommercialized bedside monitor,SpO2, ECG, Defibrillator andĄ@12 lead cardiograph. We confirmed that UWB high band prototype ver.2 did not affect

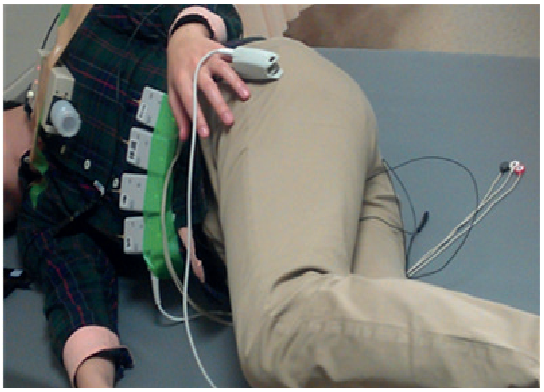

Figure 10: Lying on the bed on right side

Table 2: Test results of interference

Equipment	Communication frequency	Results
Bedside monitor BSM-2401 (Nihon Kohden co)	428MHz	No problem (15 min)
SpO2 (Advanced Medical co)	2.48GHz	No problem (10 min)
ECG (Iryou Denshi)	Bluetooth (2.4GHz)	No problem (10 min)
Defibrillator TEC7631(Nihon Kohden co)		No problem (1 min)
12 lead ECG		No problem (1 min)
Same types of UWB-BAN 5 set	7.25-10.25GHz	No problem (10 min)

to these communication system and medical device and also had no affect from these one as is shown in Table 2.

We also confirmed that that communication worked well when five participants wore this UWB system. It is estimated that TDMA and CSMA worked well.

4. SUPRESSING INTERFERENCE WITH CHANNEL ESTIMATION FOR UWB

We also describe the interference reduction in the multi-BAN environment ,when there is no MAC discernment.

4.1 Multi-BAN Interference(MBI)

In this research, the communication method assumes DS-UWB. Moreover, we assumed that pulse width is not concerned with series length because the chip rate is constant. Supposing N series of BANs are communicating now, the interference from other BANs which i-th BAN receives can be denoted by the following formula using Gaussian approximation.

$$MBI = N_i \sum_{k=1,k\neq i}^{N} P_k \tag{1}$$

Where N_i is the series length of i-th BAN, and P_k is the signal power per chip of k-th BAN. So SINR concerning i-th BAN from formula

$$SINR = \frac{(N_i m_p)^2}{MBI + \sigma_{rec}} \tag{2}$$

(3)

where σ_{recis} are noise components and m_p is the correlation output value per pulse. Therefore, BER of i-th BAN is denoted by the following formula.

$$BER = \frac{1}{2}erfc(\sqrt{\frac{SINR}{2}}) \tag{4}$$

$$= \frac{1}{2}erfc(\sqrt{\frac{\frac{(N_i m_p)^2}{N_i \sum_{k=1,k\neq i}^{N} P_k + \sigma_{rec}}}{2}}) \tag{5}$$

Moreover,the following formula can define Packet Error Rate (PER) about i-th BAN.

$$PER_i = 1 - (1 - BER_i)^{SFDsize} \tag{6}$$

Where SFD size is the number of bits of start-of-frame delimiter which tells the start of a data frame.

4.2 The proposal for assuring PER

PER can be calculated from the numbers of other BANs and SNR under the AWGN environment. However, while PER is more improved if series length is long, a data rate falls because the chip rate is set constant. So we propose that the method which change series length adaptively. In other words, we propose the method which change series length to maximize data rate, filling desired PER using the following constraints.

$$MAX : Data\ Rate = (1x + \frac{1}{3}y + \frac{1}{7}z + \frac{1}{15}w)/packet \tag{7}$$

$$mini : Electricity\ Consumption = (1x + 3y + 7z + 15w)/packet \tag{8}$$

$$subject\ to \begin{cases} x + y + z + w = packet \\ PER \leq PER_{desired} \end{cases} \tag{9}$$

x, y, z, and w are the series length of 1, 3, 7, and 15, respectively. $PER_{desired}$ is the requested PER. Thus, a data rate can be made into the maximum, filling desired PER with optimizing series length according to the number of BANs and SNR.

4.3 Numerical analysis

Table 3 shows the parameter for numerical analysis. The performance of the proposal method and existing method has been analyzed by numerical analysis. In this research, we assume that we can find the information of number of BANs and SNR regularly .

Fig.11 and 12 show PER and the data rate under the AWGN environment respectively.We compared both from a viewpoint of a PER and data rate, as is shown in Fig.8, In the existing method, PER gets worse by increase of number of BANs.This is because that MBI increases by increase of number of BANs. On the other hand, in the proposed method, PER is constant because the series length changed according to the number of BANs and SNR .Also, as is shown in Fig.11, In the proposed method, the data rate is improved filling the desired PER(0.01) because the series length is optimized .

Table 3: Parameter for numerical analysis

Parameter	Value (current)	Value (proporsal)
Number of BAN	1-4	
D/U	1	
SFD size(bit)	64	
transmission emission power (dBm/MHz)	-41.2	
Frequency(GHz)	7 .25-10.25GHz	
Modulation	direct sequence	
Series length	constant (1,3,7,15)	variable (1,3,7,15)

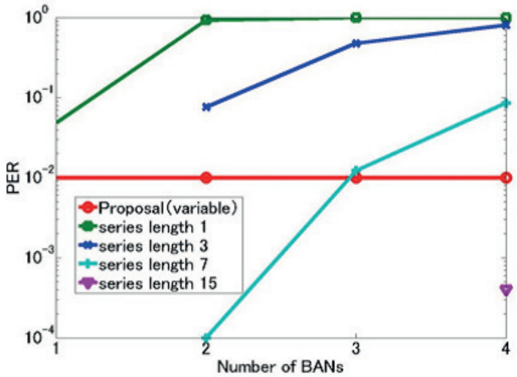

Figure 11: Number of BANs vs PER

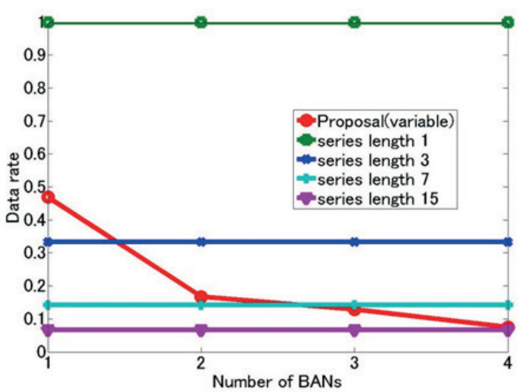

Figure 12: Number of BANs vs Data rate

5. CONCLUSION

In this paper, two prototype of a high-band UWB-BAN that we co-produced was examined for a bed in a hospital sickroom. r. We confirmed by experiments that setting one coordinator near the ceiling or back or forward of the bed and another coordinator under the bed is better solution when the patient wearing vital sensor and sensor node lies on a bed and changing his posture. A helical antenna with a high antenna gain along the axial direction showed better radiation performance and less dependence on the direction of the sensor node antenna than a biconical antenna, when used in the coordinator.New version of prototype with smaller size of hub and sensor node with more mobility models in a hospital attaching a hub and sensor nodes on the body worked well. We also examined the interference from and to other wireless communication system and medical device and other high band UWB system. We confirmed that high band UWB prototype under the IEEE802.15.6 standard performed well in communication and preventing interference. In addition, we proposed the new method by selecting the series length to make more tough for the multiple interference. Future tasks are to make the smaller Hub and combined sensor node and sensor. To confirm the safety for the human and to confirm the interference to another medical device and multiple interference by applying new proposed method.

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