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Standardization for Body Area Networks

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SUMMARY Body Area Networks (BAN) can provide a wide range of applications including medical support, healthcare monitoring, and consumer electronics with increased convenience or comfort. To harmonize with the strong demands from both medical and healthcare societies, and information and communications technology (ICT) industries, IEEE 802.15.6 task group (TG6) was set up to develop an IEEE wireless standard on BAN. This paper presents a general guidance to TG6. Some pre-works to set up TG6 are reviewed. The objectives, main topics, current status are described in details.

key words: *IEEE 802.15, body area networks (BAN), medical and healthcare services, wearable BAN, implant BAN*

1. Introduction

Chronic diseases are becoming main threats that endanger human health. Increase of aging population asks for more efficient healthcare management. The state-of-the-art technologies, including electronics, mechanic, semi-conductor and networks, can provide assistance in different aspects. Among these technologies, information and communication technology (ICT) is of potential capabilities in supporting medical and healthcare services. In recent years, ICT has played more and more important roles in supporting medical and healthcare services. One example is the electrical patient record (EPR) system. This system provides a common platform among diagnosing, nursing, and dosing and improves the efficiency at a whole. However, more active and direct roles of ICT are expected. What and how can ICT do in a more active and direct way in supporting medical and healthcare services? As an effort from the ICT industries, Continua Health Alliance [1] was set up to provide appropriate device and system solutions for medical and healthcare support.

As an emerging ICT technology, body area networks (BAN) have caught significant attention in recent years. BAN operates in close vicinity to, on, or inside body, and is expected to be able to provide distinct solutions in supporting medical and healthcare services. IEEE 802 standardization committee is an international organization that develops international standards on wireless communication. As one of the working groups under IEEE 802, IEEE 802.15 (WG15) concentrates on wireless personal area networks (WPAN) [2]. WG15 had created a number of wireless standards. Examples include IEEE 802.15.1 which is also known as Bluetooth, IEEE 802.15.4 [3] which defines the physical layer (PHY) for low-rate WPAN and is applied for Zigbee, IEEE 802.15.4a which defines an alternative PHY for IEEE 802.15.4 using ultra-wideband (UWB) technology [4], [5], etc. There are also several under-developing standards. Some of them are IEEE 802.15.3c for high-rate WPAN using millimeter wave, IEEE 802.15.4c for Chinese WPAN, IEEE 802.15.4d for Japanese WPAN, and IEEE 802.15.4e for MAC improvement for IEEE 802.15.4.

To harmonize with the strong demands from both medical and healthcare societies, and ICT industries, WG15 formally set up a Task Group 6 (TG 6), which is aimed to work out an international standard for BAN. In this paper we review major issues which need to be addressed by TG6. Early on the TG6 invited representatives from industry to present applications which require body area networks. We then developed an application matrix, which lately has been summarized into a single document which we plan to issue to potential proposers. The other issue facing TG6 was to have a detail understanding of available frequencies for BANs. And finally we need at an accurate model of the channel in this case being the human body. We knew from experience that this channel model will be more difficult to measure and correctly model than air, and would probably take longer than other task groups had to face, previously.

The rest of this paper is organized to review these issues in turn. Section 2 gives the definition of BAN and a short history of TG15.6. Main issues addressed in TG15.6 are presented in Sect. 3. A preliminary study on BAN channel model is shown in Sect. 4. Section 5 foresees the activities of TG 15.6 which is followed by a brief conclusion in Sect. 6.

2. BAN and TG 15.6

2.1 BAN Definition

Definition of BAN is given in the project authorization request (PAR) [6]*.

This is a standard for short range, wireless communication in the vicinity of, or inside, a human body (but

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*All references with an IEEE serial number, started with 15-xx, can be found on the IEEE 802.15 document server, https://mentor.ieee.org/802.15/documents.

not limited to humans). It can use existing ISM bands as well as frequency bands approved by national medical and/or regulatory authorities. Support for Quality of Service (QoS), extremely low power, and data rates up to 10 Mbps is required while simultaneously complying with strict non-interference guidelines where needed. This standard considers effects on portable antennas due to the presence of a person (varying with male, female, skinny, heavy, etc.), radiation pattern shaping to minimize SAR† into the body, and changes in characteristics as a result of the user motions.

It can be seen because that BAN operates in vicinity, on, or inside human body, it has much different channel models compared to other IEEE standards. Safety to human body has a higher priority than the other wireless systems. As a result, parameters like SAR need to be taken into consideration. As a result, we compare BAN with other IEEE 802 standards in Table 1.

2.2 Track of IEEE 802.15 TG 6 [7]

In January, 2006, a standing committee, referred to as wireless next generation (WNG), was set up within WG15 for the purpose of examining new directions and new topics. The first topic that came to table was BAN. An interest group of BAN (IG-BAN) was formed at Jacksonville meeting, FL, USA, in May 2006.

In July 2007, IG-BAN was formally approved by 802 WG15 as a study group (SG-BAN). SG-BAN continued to develop an applications matrix and listen to technical approaches proposed by its members. The SG-BAN was approved as a task group in November 2007 and had its first meeting as a Task Group 6 (TG 6) under 802.15 in January 2008 in Taipei.

The TG6 issued a call for BAN applications to the industry, which closed in May 2008 and the group members are now compiling all the applications that were submitted into a single document [8]. The other key document which will be created by the TG team will be TG6 Summary of worldwide Regulations describing the frequencies and restrictions ruling them in each regulatory domain around the world [9].

Another concern is the medical authorities' regulations as to amount of SAR into the body.

Many teams also are measuring the body channel to determine what data rates and ranges are possible in the vicinity of, or inside, a human body [10]. This data will be used to construct a body channel model with the requisite MatLab code to enable the waveform design and evaluation of the proposed communication protocols.

Finally the group is developing an optional Technical Requirements document [11] which simplifies the Application summary into a cohesive set of requirements, which the proposed standard should meet as best as it can.

Table 1 Comparison between BAN and other 802 standards.

	Other 802 standards	BAN
Configuration	15.3, 15.4 MAC	Single scalable MAC with reliable delivery
Power consumption	Low power consumption	Extremely low power while communicating to protect human tissue
Power source	Conventional power source	Compatible with body energy scavenge operation
Requirements (QoS)	Low latency	Guaranteed and reliable response to external stimuli
Frequency band	ISM	Regulatory and/or medical authorities approved communication bands for in and around human body
Channel	Air	Air, vicinity of human body, inside human body
Safety for human body	None	Required (e.g. SAR)

3. Major Issues to be Addressed by BAN Standard

In this chapter, the main topics discussed in TG6 are summarized.

3.1 BAN Applications

There are different categorizations for BAN applications and usage models. Figure 1 shows a categorization given by the authors. They are (I) healthcare services, (II) assistance to people with disabilities, and (III) body interaction and entertainment.

There is a wide range of applications for BAN in supporting medical and healthcare services. In general, a BAN device is a BAN transceiver communicating with a life sign sensor or a set of life sign sensors. Some typical examples of life sign or biological signal considered by TG6 are summarized in Table 2. Most of these life sign or biological signal can be detected using simple sensors. Some examples of biological stimulators considered for BAN applications are summarized in Table 3. It should be noted that the examples given in Tables 2 and 3 only correspond to the categories (I) and (II) in Fig. 1. There is also plenty of examples for category (III) such as wireless headphone, video streaming, game controller, and so on. Because that category (III) is

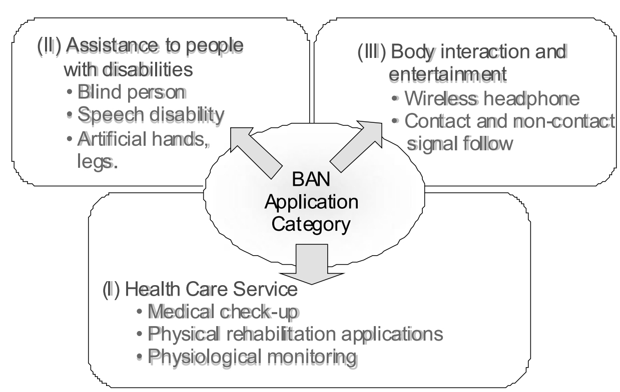


Fig. 1 BAN application categorization.

†SAR (Specific Absorption Rate) measured in (W/kg) = (J/kg/s). SAR is regulated, with limits for local exposure (Head) of: in US: 1.6 W/kg in 1 gram and in EU: 2 W/kg in 10 gram. This limits the transmit (TX) power in US < 1.6 mW and in EU < 20 mW.

Table 2 Examples of life sign or biological signal.

Temperature monitor
Blood pressure sensor
Mechanical motion sensors
Respiratory monitor
Breathing monitor
Saturation of Peripheral Oxygen (SpO_2) -pulse oximeter
Heart rate monitor
Cardiac arrhythmia monitor/recorder
Electro Cardiogram (ECG)
pH value sensor
Glucose sensor
Electro Encephalography (EEG)
Electromyography (EMG) (muscular)
Brain liquid pressure sensor
Fertility Monitor
Endoscope (gastrointestinal)

Table 3 Examples of BAN stimulators.

Deep brain stimulator
Cortical stimulator
Visual neuro-stimulator
Audio neuro stimulator
Parkinson's disease
Epilepsy Stimulator
Brain-computer interface
Wireless capsule for drug delivery

out of the scope of this paper, we don't go into further detail for this category.

3.2 Wearable BAN and Implant BAN

BAN can be divided into wearable BAN and implant BAN according to its location in or on the body where it operates. Wearable BAN may suffer from multipath channel and shadowing, while implant BAN mainly undergoes severe signal decay during transmission. The following differences exist between a wearable BAN and an implant BAN.

- Different requirements on frequencies due to different operating environment on and in body or air channels.
- Battery powered implant BAN devices are generally more power limited and sometimes requires smaller or specific shape form factor due to their location in a body (e.g. hearing aid or a pacemaker).
- Both need to consider tissue protection (e.g., SAR transmit power restriction), while wearable BAN has the freedom of choosing an antenna pattern which is pointed away from sensitive parts of the body.

3.3 Frequency Regulation

Frequencies available for use in BANs are regulated by communication authorities in different countries or regions. TG6 has formed and operated a Regulatory Subcommittee which has been investigating and collecting the information about the available frequencies [9].

A short summary of the bands is shown in Fig. 2. Some available frequency bands are as follows:

- **Medical Implant Communications System (MICS) bands**: 402–405 MHz, USA, Europe, Japan, Australia, Korea, etc. 10 channels of 300 kHz, adaptive frequency agility and 25 μW EIRP.
- **Med Radio**: FCC proposed band 401–402 MHz and 405–406 MHz. In Europe, there is regulation to use these bands for medical applications (EN 302 537).
- **Wireless Medical Telemetry Service (WMTS) Bands**: Three bands are allocated by FCC. I.e., 608–614 MHz (TV channel 37), 1395–1400 MHz, and 1427–1432 MHz. Two bands, 420–429 MHz and 440–449 MHz, are allocated in Japan. There are also available frequency bands in Australia and Europe (433–435 MHz and 868–870 MHz) as can be seen in Fig. 2. However, they are defined for short range devices (SRD).
- **Industrial, Scientific & Medical (ISM) Bands**: 868/915 MHz, 2.4 GHz, 5.8 GHz.
- **UWB Bands**: Both UWB low band (3.1–4.9 GHz) and high band (6.0–10.6 GHz) are available. However, there are different regional regulations for UWB bands.

Some other frequency bands may be considered are:

- **ISM and Short Range Device Telemetry and Telecommand usage** links: 135 kHz, 6.78 MHz, 13.56 MHz, 27.15 MHz (ERC Rec 70-03).
- **Inductive** Link band: 9–315 kHz (ECC Report 12).
- **Capacitive** carrier-less baseband transmission.

It should be noted that frequency bands for MICS in most countries are selected from 401–406 MHz. A common problem for WMTS and MICS is that bandwidth of a single channel is usually narrow in current regulations. That limits high data rate applications. ISM band at 2.4 GHz is available world wide. However, there are many wireless systems operate at ISM band including WLAN on IEEE 802.11b, Bluetooth on 802.15.1, and Zigbee on IEEE 802.15.4. Coexistence among different systems needs to be carefully considered.

3.4 BAN Technology

As a result of nearby or inside body operation, low emission power is one of the fundamental requirements of BAN in order to protect human tissues. Low emission power can also reduce possible interfere to other wireless systems. Other major fundamental requirements include low power consumption, high QoS and high reliability, low cost, small form size, high security, etc.

From the low emission power point of view, potential technologies to implement BAN should be short range communication technologies. A number of technologies have been proposed and discussed in TG6. For implant BAN, narrow band technologies show priorities from a point of

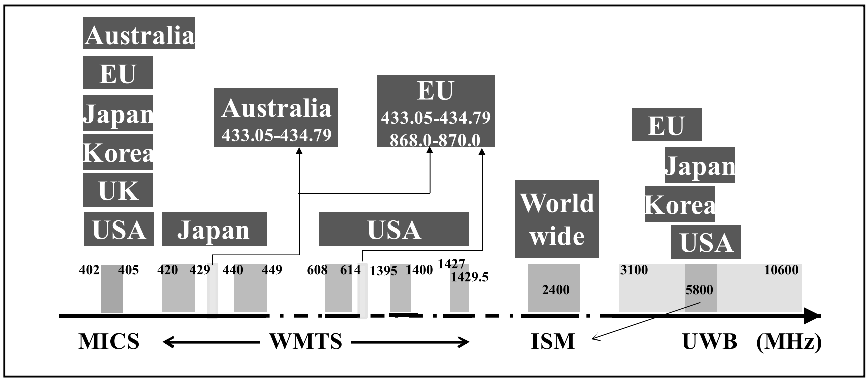


Fig. 2 Available frequency bands for BAN.

view of current available frequency spectrum. Technologies that provide high data rate within limited bandwidth are solicited. Moreover, extremely low power operation is crucial for implant BAN. For wearable BAN, both wideband and narrow band solutions have been discussed. It is asked that not only TG6 must present its uniqueness when compared to other IEEE 802 standards, but also it needs to verify coexistence ability with others. Consensus is formed that it is difficult to have a single PHY to meet all requirements directed to BAN. A practical solution is to allow multiple PHYs with each of them presenting different emphases [12]. However, a common MAC should be created to coordinate between different PHYs.

4. BAN Channel Model

Many teams also are measuring the body channel to determine what data rates and ranges are possible in the vicinity of, or inside, a human body. TG6 has formed and operated a Channel model Subcommittee which has been investigating and collecting the information about channel model measurements. This data will be used to construct a body channel model with the requisite MatLab code to enable the waveform design and evaluation of the proposed communication protocols. Many body area technologies were reviewed by the team working on BAN. In order to aid development of standard proposals, the TG6 requested channel models for body area networks. This information will be invaluable in determining the best choice of transmission in and around the body.

4.1 Measurements of Body Channel at 13.5 MHz

As an example this section describes measurements of body channel taken at 13.56 MHz frequency. This frequency band is one of the ISM band for Short Range Device Telemetry and Telecommand usage. The interest in this band was caused by BAN very low data rates requirements for some fundamental applications. These were to transmit rarely a few bits of relatively high importance.

Although the bandwidths there are relatively small, there are requirements for BAN, where good propagation in the body may be traded off against available low data bit rates.

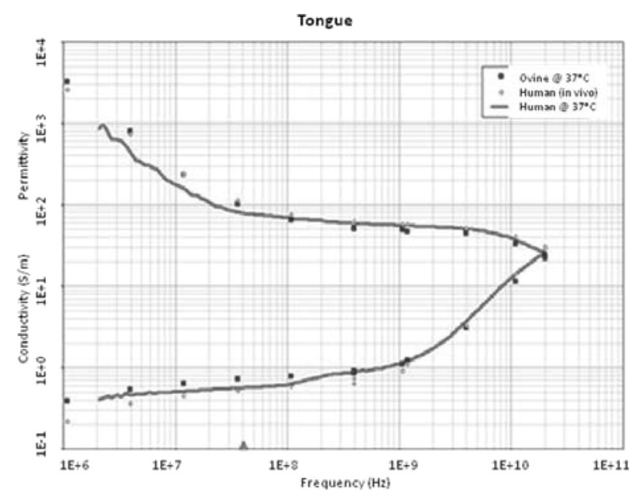


Fig. 3 Body tissue conductivity give in Ref. [14].

One such requirement is to transmit one bit reliably to signal an emergency condition that the BAN node detected. In medical applications this might be BAN sensor detection of heart beat stoppage, excessively low or high blood pressure or temperature, excessively low or high blood glucose level in a diabetic patient, etc.

Another requirement is to transmit reliably a "Wake up" signal to a sleeping BAN node to wake it up, in order to transmit and receive more data. What one hopes to achieve is a considerably lower power consumption of monitoring for the wake up signal, orders of magnitude lower than the normal transceiver operation power.

Finally, it is desirable to be able to recharge a BAN node via an RF signal. This requires a low-loss link through the body channel for power delivery. Because the body tissue conductivity at 13 MHz is between 0.1 and 1 S/m as can be seen in Fig. 3, there is concern with high loss which would require a high power levels, which in turn is detrimental to the meeting the requirements of SAR standards. SAR is a measure of the rate at which radio frequency energy is absorbed by the body when exposed to an electro-

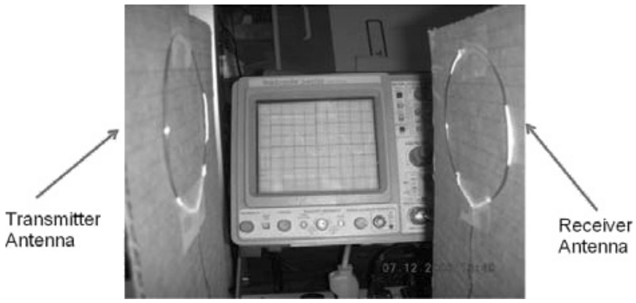
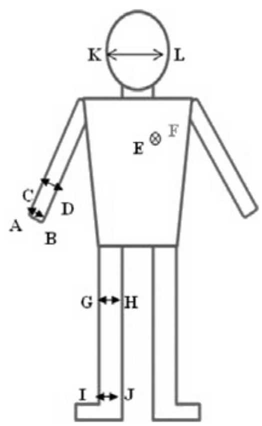


Fig. 4 Transmitter and receiver setup.



Link	Description
A - B	Through the hand
C - D	Through the wrist
E - F	Torso, front to back
G - H	Through the thigh
I - J	Through the ankle
K - L	Left ear to right ear

Fig. 5 Body channel setting.

magnetic field. Due to concerns with body tissue absorption and ionizing radiation the loop antenna was used.

4.2 Measurement Setup

The transmitter and receiver antenna setting is shown in Fig. 4. Transmitter antenna and receiver antenna were pointed at each other and the transmitter was set to transmit 13.56 MHz CW signal. The received signal was measured and the system was calibrated in the air.

The measurements were taken on a live human body of a volunteer (the author) at the locations shown in Fig. 5. The body link descriptions are shown at the bottom of the figure.

Since the measurements indicate that the difference between the "air channel" and "BAN channel" as shown in Table 4 is very minimal and for all practical purposes there is no difference between the "air" channel and "body" channel. Therefore, the measured data are combined results of air transmission and body influence.

Hence, the path loss between the point inside a body and the point outside a body is the same as the path loss

Table 4 Signal amplitude reduction.

Link	Description	Signal amplitude reduction	dB loss in relation to air
A - B	Through the hand	3.3%	-0.15
C - D	Through the wrist	2.8%	-0.12
E - F	Torso, front to back	3.4%	-0.15
G - H	Through the thigh	1.9%	-0.08
I - J	Through the ankle	2.8%	-0.12
K - L	Left ear to right ear	2.0%	-0.09
K - L	Left ear to right ear, wearing metal glasses	1.5%	-0.07

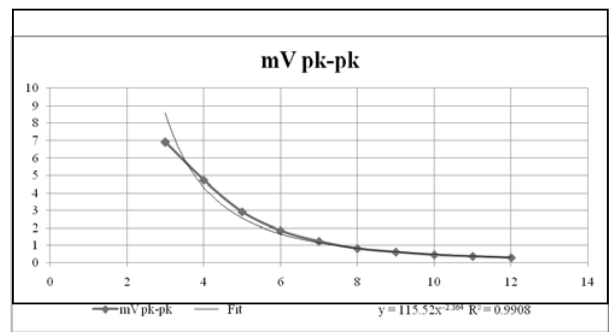


Fig. 6 Exponent fitting of measured data.

measurements among two points outside the body. So to predict or model the path loss between the points inside and outside a body explicitly from the explained measurements we can use the above formula for path loss.

4.3 Results

The results of measured signal amplitude and its related loss compared to air channel are shown in Table 4. It can be seen, the signal amplitude reduction by human tissues is relative low at 13.5 MHz. The maximum reduction measured is 3.4% when the signal is transmitted from front to back through torso.

Signal variation as a function of distance was also measured. The results are given in Fig. 6 to extract the link exponent. The measured data is plotted and fitted to x^n, where x is the distance between transmitter and receiver (in cm), this gives Received Signal (in mV) $\approx 115.52\, x^{-2.364}$ with $R^2 = 0.9908$. This leads to an estimate of the link exponent of 2.4. R^2 here is an indicator of the goodness of fit of a model. In this curve fitting, the R^2 is a statistical measure of how well the curve approximates the real data points. An R^2 of 1.0 would indicate that the regression curve fits perfectly the data.

The formula for R^2 is:

$$R^2 = 1 - \frac{SSE}{SST}$$

where

$$SSE = \sum (Y_1 - \hat{Y}_A)^2$$

and

$$SST = \left(\sum Y_1^2\right) - \frac{\left(\sum Y_A\right)^2}{n}$$

It can be seen that the body channel at 13.56 MHz has a link loss nearly that of the air and so it is well suited for body area network. However the available bandwidth is relatively small, so can only be used for data rates up to few kbps. For example, for BPSK modulation with 1 bps per Hz, with 10 channels in the band, one could get up to 2 kbps data links in a channel. This is adequate to signal an emergency condition or to transmit reliably a "Wake up" signal to a sleeping BAN node.

It must be noted that although we showed the channel measurement results at 13.56 MHz, this does not mean that this frequency band has any priority in TG6. In fact, a number of channel measurement campaigns are being conducted by different teams for various frequency bands shown in Fig. 2. Based on those measurement results, channel model for TG6 will be established and the results will be submitted in the channel model document [10].

5. Current Status and Schedules

Since the first meeting in January 2008 as a task group, a lot of work has already been done in TG6. Call for indication (CFI) of intent to propose [13] was issued in March 2008. CFI was closed in July 2008 and 71 responses were received. Some responders are given below.

- Astrin Radio
- CSEM (Center Suisse d'Electronique et de Microtechnique)
- France Telecom
- Fujitsu ltd.
- GE Healthcare
- IMEC (Inter-University Microelectronics center)
- Korpa (Korea Radio Promotion Agency)
- LG Electronics
- Lund University
- MAGET Beyond
- NICT
- Philips
- Qualcomm
- Samsung
- Texas Instruments
- Toumaz Technologies
- Zarlink Semiconductor

However, there is still a lot of work left, ahead of TG6. Currently, TG6 are working at several documents including (1) application matrix, (2) technical requirement, (3) regulation report, and (4) channel models. The first three documents are expected to be finished in September 2008. Call for proposals (CFP) will be issued also in the same period. The channel model document is expected to be finished in October 2008. After the review of proposals the TG6 plans to reduce them to a baseline proposal in the first half of 2009.

The technical editors will then review the document and correct it until they receive the approval to go to the sponsor ballot. Once all the editorial and technical issues are resolved the standard will go to letter ballot and may become an IEEE standard in early 2010.

6. Conclusion

Body area network (BAN) will play an important role in supporting a wide range of applications with BAN devices being operated in the vicinity, on, or inside body. In response to the strong demands from both medical community and the ICT industry, TG6 was set up to make a BAN standard. TG6 has been attracting a plenty of participations from world wide. In this paper, we summarized some major issues which need to be addressed by the TG6.

TG 6 is now working on some formal documents to smooth the standardization procedure. Proposals and discussion in the group are at the preliminary stage. It is not clear which technology will become dominant. However, a standard with multiple PHYs seems to be able to fit various requirements directed to BAN.

Acknowledgments

The authors would like to thank the members of TG6.

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