URSI GASS 2021, Rome, Italy; 24 Aug. - 4 Sep. 2021

Performance of wireless body area networks for health: ETSI SmartBAN or Bluetooth?

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Abstract

This paper deals with a comparative analysis of the performances of two different communications standards for wireless body area networks (WBAN): ETSI SmartBAN and Bluetooth low energy (BLE). The performance comparison is carried out in additive white Gaussian noise (AWGN) channel as well as in multipath fading channel. Aggregate interference is also taken into account to show which technology tolerates interference better. Both SmartBAN and BLE are possible wireless solutions to implement services like delivering individual's health-related data. The results show that the SmartBAN can outperform BLE in both AWGN and fading channel, in particular, when interference is present, since SmartBAN can take advantage of BCH and repetition features.

1 Introduction

The utilization of wireless body area networks (WBAN) is one solution to circulate humans vital sign data. This method is a cutting-edge path towards customized medical services and remote wellbeing checking. If a patient can be remotely observed, and the wellbeing related data is conceivable to pervasively access by medical professionals, patients can be, e.g., released prior from clinics, thus lessening medics tasks and decrease costs of healthcare services.

In 2013, the European Telecommunications Standards Institute (ETSI) started a work towards smart body area network (SmartBAN) under the dedicated technical committee (TC). The focus of TC SmartBAN is to build up a low-power technology to be utilized in remote monitoring with wearable and implantable sensors. The SmartBAN usage areas include wellbeing and health, personalized care, and security applications [1].

The goal of this paper is to compare the performance of SmartBAN with another technology, highly used in many wireless applications, i.e., Bluetooth low energy (BLE) standard [10]. Both SmartBAN and BLE have low energy utilization and operate at the 2.4 GHz ISM (Industrial, Science and Medical) band. An overview of the ETSI SmartBAN system can be found from [1] and [16].

2 System model and simulation setting

The ETSI SmartBAN PHY model is based on the overall system description set out in [4], while the physical layer definition is described in [2][5]. The radio channel model used in the study is based on the IEEE on-body channel model CM3 [6]. Co-channel interference, based on the measurements as implemented in [3][7], is also used in the simulations. The efficiency of the SmartBAN system in the interfered fading channel is described in [8],[9], but the comparative study between SmartBAN and other rival technologies still requires investigation. This paper partially fills the gap by comparing the efficiency of SmartBAN and BLE in terms of bit-error-rate (BER) in additive white Gaussian noise (AWGN) and fading channels.

A SmartBAN simulator has been specifically designed and implemented in the Simulink ® [12]. The overall simulator is illustrated in Fig. 1. The data bits are encoded with the encoder BCH (127,113) followed by the GFSK modulator with modulation index h=0.5 and the bandwidth-time product BT=0.5. The PHY Layer Protocol Data Unit (PPDU) is repeated one, two or four times as specified in [2]. The received signal $r(t)$ can be thus be written as

$$r(t)=s(t)*h(t)+i(t)+n(t), \qquad (1)$$

where (*) denotes the convolutional operator, $h(t)$ is the fading channel's impulse response, $i(t)$ is the interference process and $n(t)$ is the AWGN with zero mean and standard deviation σ_n. In the simulator, we have implemented three different interference models as described in [12]. These interference models are based on the measurement campaigns carrier out in the real hospital environment [3]. The received PPDUs are combined by using the equal gain combining (EGC) method. The demodulator applies a correlator followed by a maximum-likelihood sequence detector (MLSD). A single system simulator using Matlab ® and Simulink ® has been developed for a fair comparison between SmartBAN and BLE. The PHY simulation models are shown in Fig. 2 and 3.

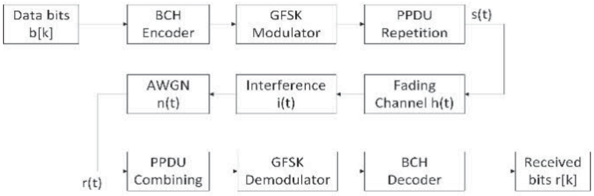

Figure 1. SmartBAN simulator blocks.

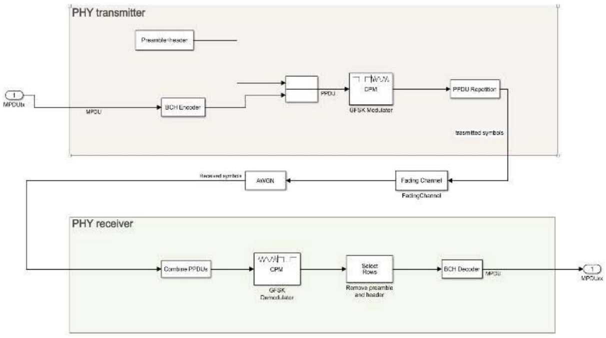

Figure 2. Physical layer implementation of SmartBAN.

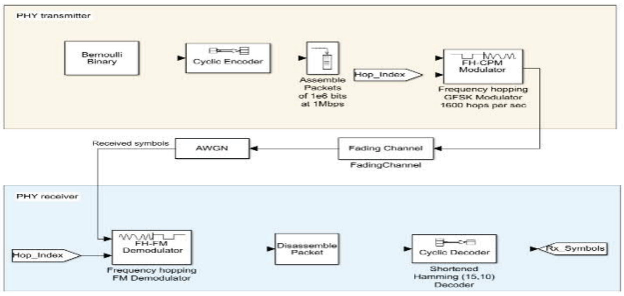

Figure 3. Physical layer of the Bluetooth low energy.

The BLE PHY transmitter in Fig. 3 is designed to send 62500-bit packets at a speed of 1 Mbps. Frequency hopping is utilized in transmitting the GFSK modulated signal, i.e., the signal hops 1600 times per second between all channels using the random pattern. The GFSK modulator uses h=0.5, BT=0.5, 100 samples per symbol and a pulse frequency of 1 bit per symbol. A fundamental part of the PHY in the BLE simulator is the frequency hopping process, where the frequency is changed by a random pattern to minimize interference. The radio channel set consists of 40 different channel realizations. A random data channel is chosen so that there is no overlapping signal. The hop rate is 1600 Hz.

The modulated signal passes through the fading channel and the AWGN blocks. The obtained signal is demodulated in an FH-FM demodulator with a frequency range of 10 Hz and 100 samples per symbol. A performance comparison with the theoretical GFSK curve was made for the validation of the designed BLE PHY in the simulator. The GFSK modulator parameters are *BT*=0.5 and *h*=0.5 for fair comparison. The results are shown in Fig. 4. As expected, the performance of the simulated BLE is slightly worse than the theoretical one. The distance between the BER curves is appropriate and the result validates the configuration of the BLE PHY, which will be used for comparison with the SmartBAN in this paper.

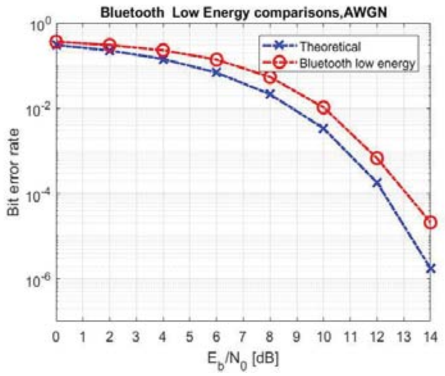

Figure 4. Comparison between BLE and the theoretical curve with GFSK with AWGN channel.

A summary of the main PHY parameters is presented in Table 1. The main difference between SmartBAN and BLE is that the former implements PPDU repetition while the BLE does not. In both cases, the modulated signals pass through the fading and AWGN channels. The fading channel configuration used in the study is the IEEE 802.15.6 body surface to body surface interface CM3 (Scenario S4 & S5) for 2.4 GHz [11]. The measurements for the fading channel modeling were carried out in a hospital and primarily modelling the links between the coordinator located in the middle of the human torso and different locations on the body. The channel model for flat small fading follows a Ricean distribution with parameters described in [8].

TABLE 1. SMARTBAN AND BLE 2.4 GHz PHYS

PARAMETER	**SmartBAN**	**BLE**
Operating frequency [MHz]	2401-2481	2402-2480
Channel bandwidth [MHz]	2	2
Number of channels	40	40
Repetition/spreading	2x or 4x, Entire PPDU	No repetition
Modulation	GFSK (*BT*=0.5, *h*=0.5)	GFSK (*BT*=0.5, *h*=0.5)
Symbol rate[Mbps]	1	1
Receiver type	coherent	non-coherent

3 Simulation parameters and results

The comparative study between SmartBAN and BLE v4.0 was analyzed under the ETSI Specialist Task Force (STF511) initiative. The disturbance, conceived as a channel occupancy of the 2.4 GHz frequency band and reported in [13], was applied in the SmartBAN simulator, and the system performances as a function of BER and frame error rate (FER) were evaluated.

The stochastic interference models used in the studies were based on several one-week measurements in different environments at the Oulu University Hospital, Oulu, Finland and the hospital in Florence, Italy. Within one-week, electromagnetic (EM) spectrum samples were collected every 22 ms using the Agilent E4440a spectrum analyzer. Such studies provided a good and statistically accurate description of the EM properties within the frequency band of interest. Reference [13] reports the models in more details.

The SmartBAN simulator is introduced in [14]. From its conclusion, it can be summarized that a repetition coding of either 2 or 4 would be required when operating in the interfered environment. The corresponding performance evaluation of the SmartBAN system is carried out in [15], taking into account interference, as well as the applicable radio channel model taken from the literature. The key topological distinction comes from the coming support for smart relays, which separates SmartBAN from BLE and IEEE 802.15.6, which are traditional one-hub star-topology-based networks. It should be noted, however, that there is also support for relay capabilities in IEEE 802.15.6 and since Bluetooth v.5.0, BLE supports mesh topology.

A. Simulation parameters

The parameters used in the SmartBAN and BLE simulations are summarized in Table 2 and Table 3, respectively. More details about the SmartBAN simulator can be found in [8]. Performance is evaluated using the BER as well as FER. BER represents the number of bit errors divided by the total number of bits transmitted. The FER is the number of corrupted frames divided by the total number of frames sent.

TABLE 2. SMARTBAN SIMULATION PARAMETERS

Parameter	**Value(s)**
PPDU repetition	1
Retransmission	no
MAC frame body	50, 250, 500, 1000
Samples for GFSK symbol	20
Pulse length of GFSK	1
Traceback depth of GFSK demodulator	10
Distance [cm]	45

TABLE 3. BLE SIMULATION PARAMETERS

Parameter	**Value(s)**
Repetition	Not present
Retransmission	Not available
Sample for GFSK symbol	100
Pulse length of GFSK	1
Traceback depth of GFSK demodulator	10
Distance [cm]	45

B. Results in AWGN channel

The first approach to test the performances of BLE and SmartBAN was made in AWGN channel to see how the BER is affected by the spectral noise density ratio (E_b/N_0) with different energy values per bit. The results of the comparison of the BERs of these two technologies are shown in Fig. 5. The SmartBAN curve is drawn using the PPDU repeat of 1, which is the worst BER curve in the study, as seen in the previous SmartBAN analysis in [8].

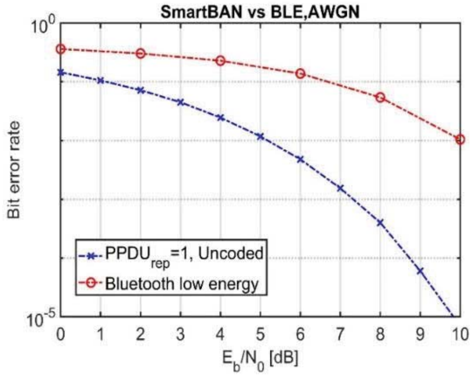

Figure 5. BER performance in the AWGN channel for SmartBAN and BLE.

The SmartBAN always show a better performance in terms of BER. BLE starts with 0.364 and the SmartBAN at 0.18 at E_b/N_0 = 0 dB. Increasing E_b/N_0, the performance of the SmartBAN increases drastically reaching a BER of 10^{-3} with Eb/N0=7.5 dB, 10^{-5} with Eb/N0=9.8 dB. BLE requires much higher E_b/N_0 for the same performance.

C. Results in fading channel with low/high interference

FER comparison as a function of E_b/N_0 between SmartBAN and BLE is reported in this section. The experiments were using the model referred in the above sections. The simulation parameters are as follows: frame size=50 bytes; signal-to-interference ratio (SIR) = 0, 3, 9 dB; repetition coding with PPDU=2; retransmission=On. Low- and high-interferences are considered. The interference model used here is taken from [13]. The model takes into account the typical aggregate interference and the fading characteristics of a hospital environment.

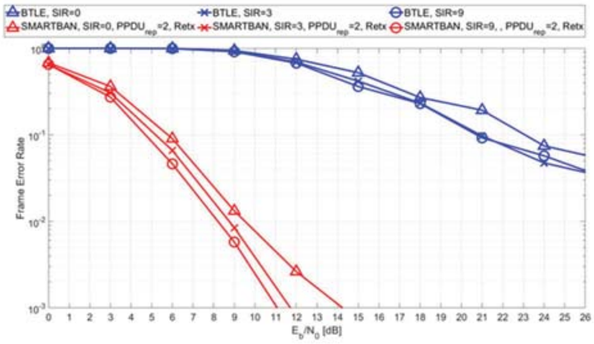

Figure 6. FER comparison, low interference.

Figs. 6 and 7 show the FER performance comparison of SmartBAN and BLE v.4.2 when the retransmission is ON and the interference scenario changes from LOW (Fig. 6) to HIGH (Fig. 7). These results show how much the repetition and retransmission capabilities are able to improve the FER of SmartBAN, even in high interference scenario. The gain of SmartBAN is about 15 dB over BLE at FER=10^{-1}.

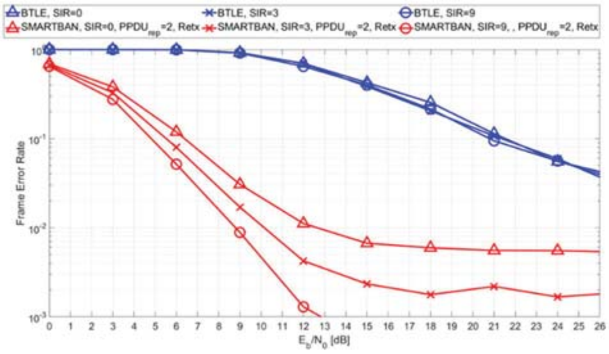

Figure 7. FER comparison, high interference.

4 Conclusion

This paper provided simulation based comparative analysis between SmartBAN and BLE technologies. A simulation environment using MATLAB was developed. It is possible to determine the performance of SmartBAN and BLE by evaluating the effects of BER and FER. In the case of SmartBAN, the worst-case scenario picked from the previously published studies was chosen. The BLE standard does not include encoding and repetition, which deviates these two technologies. As far as BER is concerned, there is no question that the SmartBAN norm for healthcare applications works better than BLE. Furthermore, similar difference between the two systems is seen when comparing their performance in terms of FER.

Our future work will include a comparison with the latest BLE versions, which addresses encoding and a comparison between technologies, taking into account also the intrusion models used in the SmartBAN specification.

5 Acknowledgements

This research has been financially supported in part by the European Union's Horizon 2020 programme under the Marie Skłodowska-Curie grant agreement No. 872752 and Academy of Finland 6Genesis Flagship (grant 318927). We would also like to give big thanks to the whole ETSI TC SmartBAN colleagues involved in the process.

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