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Performance Evaluation of Binary Modulations through Wireless Body Area Network Channel

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ABSTRACT
The error rate link performance has been evaluated and compared for efficient Rake receiver structures in low data rate WBAN (Wireless Body Area Network) channel. Rayleigh and Weibull distributions have been used for generating fading power profiles. This model is based on extensive measurements inside or on the surface of human body. The power profiles for WBAN channel have been generated. The bit error rate has been obtained by using different modulation schemes i.e. BPSK (Binary Phase Shift Keying), 2-PAM (Pulse Amplitude Modulation) and 2-BOK (Bi-orthogonal Keying). With the aid of these graphs, bit error rate performance evaluation of Rake receivers has been done. Through simulative investigations of Bit Error Rate (BER), it has been found from these three binary modulations; 2-PAM is suitable for WBAN channel. It has been observed that the performance of selective rake receiver (for optimum number of fingers) is better than partial rake receiver for all modulation schemes.

General Terms
WBAN channel Model, BPSK, 802.15.6.

Keywords
Wireless Body Area Network, Fading Power profile, Bi-Orthogonal Keying, Pulse Amplitude Modulation.

1. INTRODUCTION
Wireless communications will be one of the key components for the so called information society. Increasing demand for wireless services and applications in scenarios as “On the Road”, “at Home”, “at Work”, “in the Car”, “Anywhere”; will ask for new solutions with more capacity and flexibility [4]. Moreover recent technological advances in integrated circuits, wireless communications, and physiological sensing allow miniature, lightweight, ultra-low power, intelligent monitoring devices. A number of these devices can be integrated into a WBAN, a new enabling technology for health monitoring. WBAN appear to be a particularly appealing solution to provide information about the health status of a patient in medical environments such as hospitals or medical centres[6]. Wireless body area network (WBAN) was first presented by T. G. Zimmerman in 1996. At beginning, he calls these body networks as wireless personal area network (WPAN). Later, WPAN was redefined to be, cable replacement for up to 10 meters (e.g., Bluetooth) and the name WBAN for distances up to 3 meters. Up to day there is no standard specifically intended for WBAN. The closest standard that can be used for is the Bluetooth IEEE 802.15.4 [4]. In order to design and develop a competent and reliable system suitable for WBAN, a knowledge of a radio propagation channel as well as a simple and generic channel model are inevitably required. So in April 2009, IEEE P802.15 working group for wireless personal area networks (WPANs) has developed a channel model (IEEE 802.15.6) for WBAN which is for medical and non-medical devices that could be placed inside or on the surface of human body[5]. In this, fading power profile is generated in terms of received power with respect to transmit power, which is based on NICTA’s (National Information and Communication Technology Australia) measurement results at 820 MHz [1].

This paper is organized as follows. In the next section, brief description of WBAN channel model along with related parameters has been given. Subsequently, the Simulation methodology to generate fading power profiles in WBAN channel scenarios has been described. In Section 4, sub-optimum reduced complexity Partial Rake (P-Rake), Selective Rake (S-Rake) receiver architectures have described along with ideal All Rake (A-Rake) employing Maximal Ratio Combining (MRC). Error rate investigations have also been presented in terms of BER in section-5, wherein we conclude the paper.

2. WBAN CHANNEL MODEL
In the WBAN, radio propagations from devices that are close to or inside the human body are complex and distinctive comparing to the other environments as the human body has a complex shape consisting of different tissues having their own permittivity and conductivity. Therefore, the channel models for WBAN are different from the ones in the other environments. Transmitter and Receiver are the integral part of the WBAN channel. The static path loss and impulse response models for the wearable and implantable WBAN including miniature antennas are presented in [3]. These models are already contributed to IEEE 802.15.6.This model is a statistical model and uses all the measurements carried out by NICTA at 820 MHz. This paper uses the fading power profile of WBAN channel which includes fading and path losses. In the body area network communications, propagation paths can experience fading due to different reasons, such as energy absorption, reflection, diffraction, shadowing by body, and body posture. The other possible reason for fading is multipath due to the environment around the body. Fading can be small scale or large scale. Small scale fading refers to the rapid changes of the amplitude and phase of the received signal within a small local area due to small changes in location of the on-body device or body positions, in a given short period of time. Whereas large scale fading refers to the fading due to motion over large areas; this is referring to the distance between antenna positions on the body and external node (home, office, or hospital). Second affect is pathloss which is both distance and frequency dependent. The pathloss model in dB between the transmitting and the receiving antennas as a function of the distance d based on the Friis formula in free space is described by equation 1 as follows:

$$PL(d) = PL_0 + 10n\, log_{10}\left(\frac{d}{d_0}\right) \qquad (1)$$

Where PL_0 is the path loss at a reference distance d_0, and n is the path-loss exponent.

Third affect is shadowing which is due to the variation in the environment surrounding of body or even movement of the body parts, path loss will be different from the mean value for a given distance as shown in equation (1).This phenomenon is called shadowing, and it reflects the path loss variation around the mean. The shadowing should be considered for stationary and non-stationary position of body. When considering shadowing, the total path loss i.e. PL can be expressed by equation 2 [1].

$$PL = PL_0 + S \qquad (2)$$

3. SIMULATION METHODOLOGY

It is not possible to model every parameter of human body channel through commonly used formulas in other wireless channels because of its complex tissue structure. Also measurement of various human body parameters is not easy task. So it is necessary to design channel model using some standard measurements and in this channel model all measurements, i.e sample rate , spreading bandwidth etc, are taken from NICTA channel measurements. Since the performance analysis of the WBAN receiver is based on statistical model of the channel [9]. The simulation model used here to statistically generate the fading power profile of WBAN channel. In order to generate an initial signal, that matches the desired fading statistics using order statistics, the following steps are being used.

Step1: A set of Weibull distributed random numbers are generated according to best fit to signal statistical distribution around mean from NICTA's measurements.

Step2: Rayleigh fading power is generated by using Jake’s model with an appropriate rate of fading.

Step3: Based on Weibull distributed random numbers, Weibull fading power profile is generated according to the ordering of the Rayleigh power profile.

After generation of initial signal it is manipulated by in such a way to make its fade depth statistics match those found in NICTA's measurements. The signal is treated in portions each portion being a fade followed by a non-fade (a contiguous portion of the signal above the mean power). All the signal portions are compared with the desired fade depth statistics. The current signal portion is manipulated depending on this comparison in one of three ways.

Step 4: If generated signal (step 3) is best matches to desired fade depth statics (dfds), the current signal portion is kept as it is and it is inserted into the output signal.

Step 5: If generated signal (step 3) is highly attenuated to desired fade depth statics then the parts of signal having too much attenuation are discarded and rest of the signal is inserted into output.

Step 6: If generated signal (step 3) do not match with the desired fade depth statics then the whole signal is discarded.

Step 7 Adjust the final signal so its mean is equal to the mean specified by the user.

All parameters used in the above simulation model are taken from NICTA measurements. Some of them are given in table1.

Table1. NICTA specifications for WBAN

Parameter	**NICTA Specification**	**Allowed Range**
Carrier Frequency (fc)	820 MHz	420--2500 MHz
Sample Rate	1 KHz	0.75 -- 15 kHz
Velocity	1.5 -- 5.5 km/h	1.5 -- 20 km/h

Also there is a possibility that user can change some parameters. One of those parameters is time. One can change the number of multipath components by changing time. Below given flow chart shows the process that how signals is being generated using WBAN channel.

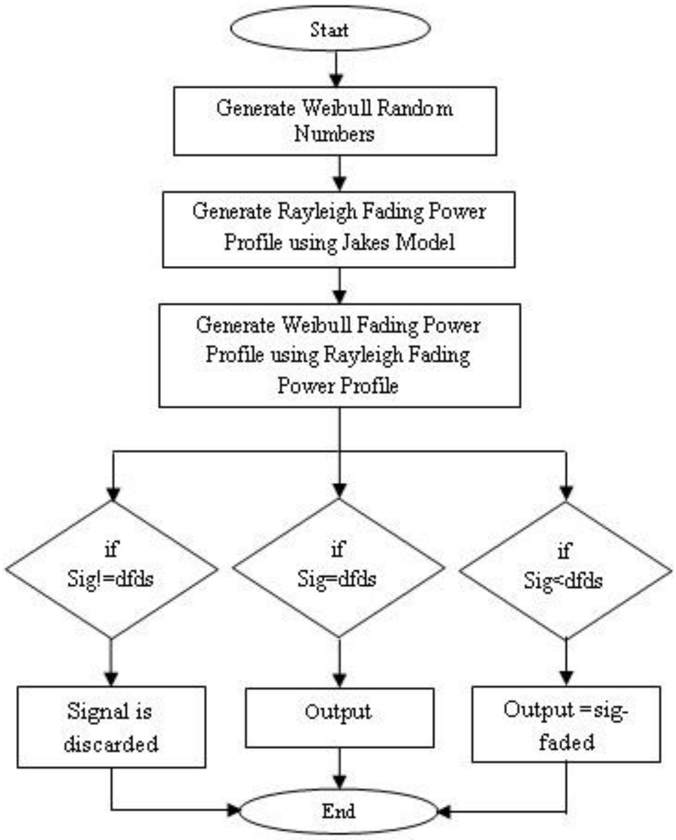

Figure 1. Flow chart for generation of fading power profile

4. RECEIVER STRUCTURE

All In the given WBAN channel, different multipath components (MPCs) of the same transmitted pulse are being generated. Number of multipath components depends upon time on which signal is generated. WBAN receiver can take advantage of diversity by using Rake combiner to improve performance of the system. The basic version of the Rake receiver consists of multiple correlators (fingers) where each of the fingers can detect/extract the signal from one of the multipath components provided by the channel. The outputs of the fingers are appropriately weighted and combined to reap the benefits of multipath temporal diversity. Different strategies for exploiting this temporal diversity include Selection Diversity, Partial Diversity. The A-Rake (All rake) structure used here to indicate the receiver with unlimited resources (fingers or correlators) and instant adaptability, so that it can combine all of the resolved MPCs. In All Rake number of receivers required is $T_d * f_s$ where T_d the time duration of impulse is and f_s is sample rate of signal. Since the number of resolvable multipath components increases with the spreading bandwidth, the number of correlators required for the A-Rake receiver may become quite large for WBAN channels up to 20,000. Two sub-optimum reduced complexity rake structures i.e., S-Rake (Selective rake) and P-Rake (Partial rake) have been proposed here for performance evaluation. The upper limit of achievable performance obtained with A-Rake receiver will act as benchmark for relative performance comparison. The S-Rake selects the best 16/32 taps (a subset of the available resolved multipath components) and P-Rake selects the first 16/32 taps (which are not necessarily the best) then combines the selected subset using MRC. The combiner produces a decision variable at its output which is then processed by a detector. Thus, the detector performance can be considered to be based on this equivalent channel created by the cascade of the radio channel and MRC rake structures [2].

To calculate BER in WBAN channel, binary modulations are used. Binary modulation is the technique in which only one bit is transmitted per symbol. So only two symbols can be transmitted in the given bandwidth. In binary PAM where two signals are arbitrary pulse that is non zero in the interval $0 \le t \le T_b$ and zero elsewhere. Since two binary signals i.e. $S_1(t) = -S_2(t)$ are said to be antipodal. If two signals are equally likely and signal $S_1(t)$ is transmitted, then received signal from demodulator is

$$r = s_1 + n = \sqrt{\varepsilon_b} + n \quad (3)$$

Where n represents the additive white Gaussian noise component with zero mean variance$\sigma_n^2 = (0.5)N_o$. The conditional PDF's (Probability distribution function) of r if symbols $S_1(t)$ and $S_2(t)$ are transmitted [7].

$$p(r|s_1) = \frac{1}{\sqrt{\pi N_0}} e^{-(r-\sqrt{\varepsilon_b})^2/N_0} \quad (4)$$

$$p(r|s_2) = \frac{1}{\sqrt{\pi N_0}} e^{-(r+\sqrt{\varepsilon_b})^2/N_0} \quad (5)$$

Let symbol $S_1(t)$ is transmitted the probability of error is simply the probability that r<0, i.e.

$$p(e|s_1) = \int_{-\infty}^{0} p(r|s_1)dr = Q\left(\sqrt{\frac{2\varepsilon_b}{N_0}}\right) \quad (6)$$

For Bi-orthogonal Keying (BOK) has been evaluated (M=2 for binary modulation) for rake structures. It is not only modulation scheme; it's the combination of modulation and coding. So it is an efficient coding/modulation method that can be easily applied to WBAN system is 2-BOK (where M=2) and its conditional BER can be given as in equation (7) [9].

$$P_e(E/\gamma) = \frac{M}{2(M-1)}\left(1 - \frac{1}{\sqrt{2\pi}}\right) \times \int_{-\infty}^{\infty}\left(1 - \frac{1}{2}erfc\left(\left(x + \sqrt{\frac{2M\gamma log2(M)}{M-1}}\right)\sqrt{\frac{1}{\sqrt{2}}}\right)\right)^{M-1} e^{-x^2/2} \quad (7)$$

5. RESULTS AND DISCUSSIONS

From the description of the simulation model given in the previous section, fading power profile of WBAN channel for number of simulations can be shows in figure 1.Where x-axis shows time delay (in seconds), y-axis shows number of simulations and z-shows fading power profile. Figure 2 shows the BER performance of BPSK, figure 3 shows the BER performance of 2-PAM and figure 4 shows the performance of 2-BOK in WBAN channel. In this paper fading power profile is simulated 300 times with 0.5 seconds delay, which produced 500 delay bins. These delay bins (multipath components) can be increased as delay time increases and this delay time can be increases up to 20 seconds which will generate 20,000 samples.

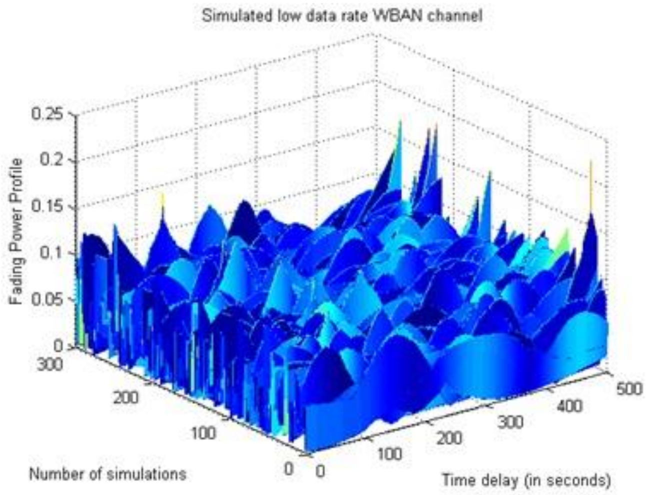

Figure 2. Simulated low data rate WBAN channel

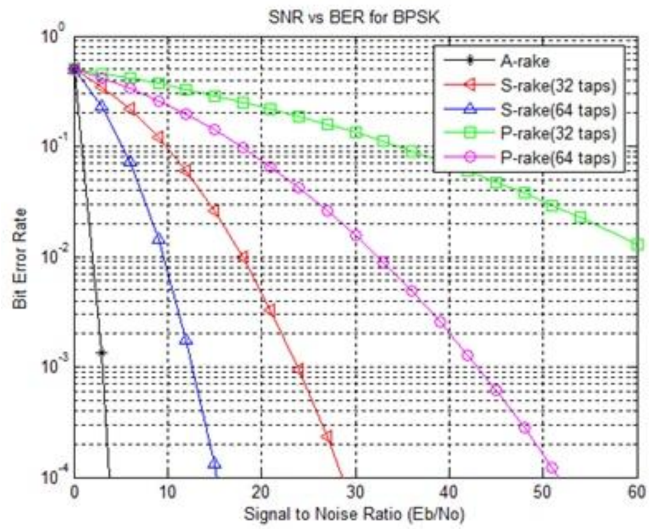

Figure 3. BER performance of BPSK in WBAN channel

From various figures we can say that the performance of selective rake is better than partial rake. The BER performance degrades as the number of fingers reduces. It can also be concluded that the performance of 2-BOK is comparable to BPSK. Still 2-PAM is better. So it can be concluded that from binary modulations 2-PAM shows better performance.

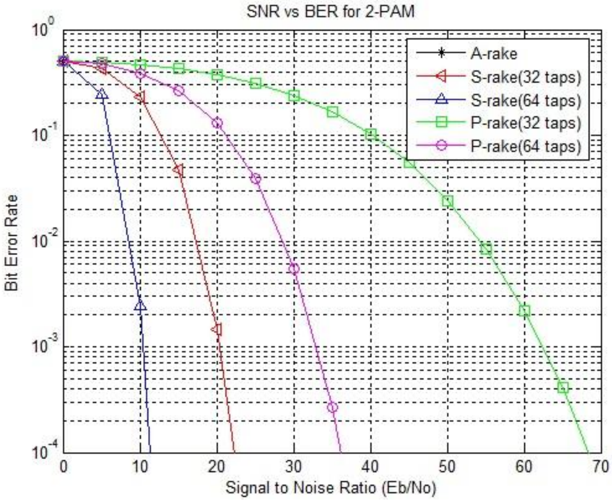

Figure 4. BER performance of 2-PAM in WBAN

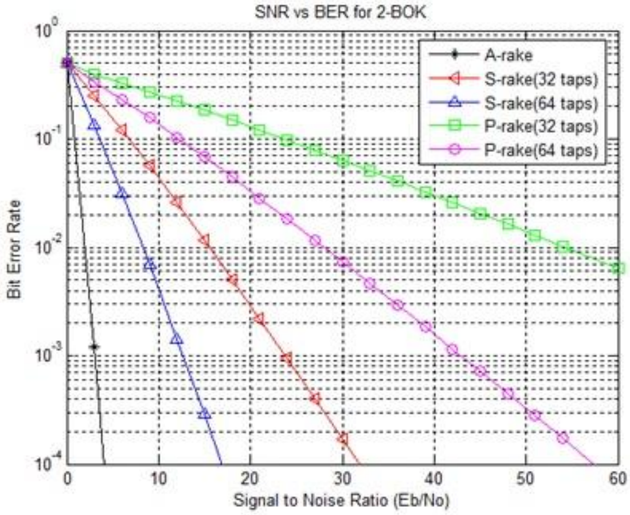

Figure 5. BER performance of 2-BOK in WBAN

Table 2. Comparison of BER for binary modulations

Taps	Target BER	BPSK			2PAM			2BOK		
		ARake	SRake	PRake	ARake	SRake	PRake	ARake	SRake	PRake
64	10^{-2}	2 dB	9 dB	33 dB	0.5 dB	4-5 dB	16dB	2 dB	8 dB	28dB
32	10^{-2}	2 dB	18 dB	>60 dB	0.5 dB	9 dB	33dB	2 dB	15dB	54 dB
64	10^{-4}	4dB	13dB	52dB	1dB	8dB	22dB	4dB	17dB	57dB
32	10^{-4}	4dB	28dB	>100dB	1dB	13dB	43dB	4dB	32dB	130dB

It has been also observed from above table as the number of fingers doubled, required SNR (Signal to Noise Ratio) is reduced by factor ½ to achieve same BER. In BPSK, partial rake shows worst performance as compared to other modulations whereas partial rake performance of 2PAM is acceptable to some extent. All rake performance of BPSK is 50% of 2-PAM. Now we can say 2-PAM is better for WBAN. But it may not be true for higher level modulations when number of symbols got increased. Higher level modulation (for example M-ary techniques) can be used to save bandwidth and to design efficient system. Also coding schemes can be used to improve BER performance.

6. CONCLUSIONS

The Performance evaluation of binary modulations is done by using low data rate WBAN channel model. Fading power profile has been generated for number of simulations. The performance of various rake receivers has been evaluated and compared for optimum number of fingers. In this, we have used SRake, PRake and ARake structures. Performance of SRake is better than PRake but it has more complexity as well as it needs channel estimation. P-rake has less complex structure and shows satisfactory performance in case of 2-PAM. Thus, on evaluating the performance, it is evident that the SRake structure can be employed in any binary modulation with optimally selected fingers, whereas PRake can only be employed in binary PAM.

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