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Error Rate Performance of Digital Modulations Schemes through Body Surface to External Communication in Wireless Body Area Network

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Abstract

The improvement in propagation characteristics of WBAN is required to develop the high quality WBAN system. In this paper, the error rate performance of channel model CM4 of WBAN is evaluated for different modulation schemes for distinct body directions for UWB. The effect of rake receiver structure is also assessed. The bit error rate has been obtained by using BPSK (Binary Phase Shift Keying), M-ary PAM (Pulse Amplitude Modulation) and M-ary BOK (Bi- orthogonal Keying). The evaluation is done by calculating the value of Signal to noise ratio for targeted Bit Error Rate for different body directions using different modulation scheme. The obtained results give an assessment to better understand the effect of modulation schemes selection on error rate performance of the WBAN channel.

***Keywords**: Bit Error Rate (BER), Signal to Noise Ratio (SNR), Ultra wideband (UWB), Wireless Body Area Network (WBAN)*

1. Introduction

The healthcare monitoring industry is in a need of urgent attention. This need is spurred by many factors. The increasing population of the world is a main factor which is hindering the performance of health care industry. In 2013[6], WHO states that the average life expectancy at birth of the global population was 71 years, ranging from 62 years in low-income countries to 79 in high-income countries. The rising aged population of the world is overwhelming the current hospital centric healthcare. Even the increasing death rate due to cancer and heart disease as reported by WHO alarms the healthcare industry to take some urgent action [7]. So the health care industry is in a need of immediate change.

The continuous monitoring and actuating is possible only by implementing Wireless Body Area Network (WBAN). The WBAN system consists of sensors that communicate to sense the physiological signal of body in a very coordinated manner. One of the powerful sensor acts as a coordinator which transmit the signal from the body to the external portable device like smart phone. The external device can further send this information to the doctors via internet and then the treatment procedure can be triggered in return.

The architecture of WBAN seems to be very simple, but to design and develop a competent and affordable system suitable for WBAN, a knowledge of a radio propagation channel as well as a simple and generic channel model are inevitably required. Even the effects of human tissue, body postures and movement, and outside environment on the wireless BAN need to concern first.

WBAN was first referred by Zimmerman in 1996 but he named it as a Wireless Personal Area Network in the beginning [15]. In 2009, IEEE P802.15 working group for WPAN has developed task group IEEE 802.15.6 for wireless body area network which is for medical and non-medical devices that could be placed in or on the surface of the body.

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According to IEEE the communication in WBAN can be classified among four channel models *i.e.*, CM1 (implant to implant nodes), CM2 (implant to on-body nodes), CM3 (on-body to on-body nodes) and CM4 (on-body to off-body nodes).The efficient WBAN system is not possible without the designing of effective models for its channel model. In this paper our focus is to contribute for the channel model CM4 of WBAN system for ultra wideband (UWB).

The UWB wireless technology is used here for the number of advantages provided by it including the data rate ranging from 850kbp to 20Mbp which can be used for monitoring many physiological signals including ECG(electrocardiography), EMG(electromyography) and EEG(electroencephalography) [2],[5]. The large bandwidth of UWB is required for hundreds of sensing channels of WBAN system like the next-generation brain implant which needs hundreds of cortical implant sensors streamed wirelessly to a receiver. Even the ability of UWB to not provide any EMI (electromagnetic interference) risk to other narrow band systems and medical equipment's because of its low transmitted power make it a better choice for WBAN systems. So using a UWB for WBAN channels is more convenient.

The performance of the system is significantly influenced by the modulation schemes used in that system. Changxing FAN and Lina CAO [11] reviewed the capacity of BPSK and QPSK modulation techniques for their excellent anti-interference and strong anti-fading ability and therefore consider them a suitable modulation schemes for body area network. But BPSK and QPSK has the problem of phase ambiguity. Even if we consider the Rayleigh fading channel, the performance of BPSK is inferior [14]. Jordi Agud Ruiz and Shigeru Shimamo (2006)[10] investigate the transmission characteristics of the human body considering high radio frequency signals and suggests the MSK and BPSK as a suitable modulation schemes for IBC(Intra Body Communication). Yue Ping Zhang and Qiang Li [16] observe the UWB on-human-body propagation channel for Pulse Position Modulation (PPM), Phase Shift Keying (PSK) and On-Off Keying (OOK) modulation schemes and analyzed that PPM is more sensitive to rms delay spread because of its time shift nature which need longer chip time and hence cause inter symbol interference. However, PSK performs better with higher rms delay spread cases. Amitava Ghosh *et al.*, (2012) [12], proposes a modulation scheme, viz., DFSK, for ultralow power wireless body area communication which reduces the average energy consumption per bit, compared to the established modulation schemes like MQAM or MFSK. In [13], Rout DK, et al. (2012) proposes an idea of combining properties of continuous phase modulation and pulse position modulation techniques to provide the performance superior to m-ary PSK and m-ary FSK.

Thus so far, only a limited set of published literature investigates the modulation schemes for WBAN and thus only limited results are available which makes it difficult to select best modulation technique for the system. The novelty of this work is to compare the different modulation schemes including BPSK, M-ary PAM and M-ary BOK scheme with varying body directions for channel model CM4 of WBAN so that the best one which improves the performance of the system can be selected. The result of the paper is organized as follow: In the next section, brief description of WBAN system and channel model is followed by the simulation methodology and environment. Subsequently, the simulation results and Discussion are given in next section. The paper is finally concluded in the last section.

2. WBAN System and Channel Model

2.1. Overview

Information propagates as electromagnetic waves in WBAN from devices that are placed around the human body. According to IEEE 802.15.6 BAN model; three types of nodes can be there in WBAN:

- *Implant node*: A node is placed within the human body. This could be immediately below the skin to further deeper inside the body tissue.
- *Body Surface node*: A node is placed on the surface of the human skin or at most 2 centimeters away.
- *External node*: A node that is not in contact with human skin or at a distance of a few centimeters to 5 meters away from the human body.

A list of four channel models (CM1-CM4) and seven scenarios (S1-S7) can be identified in which IEEE802.15.6 devices will be operating. CM1 consider implant–to-implant for medical implant communication services (MICS). CM2 consider implant to body surface (S2) and implant to external link (S3) operating in same frequency band as CM1. CM3 considers body-to-body surface link, while CM4 considers body-to-external link. Both are proposed to operate in various frequency bands, including UWB bands [1].

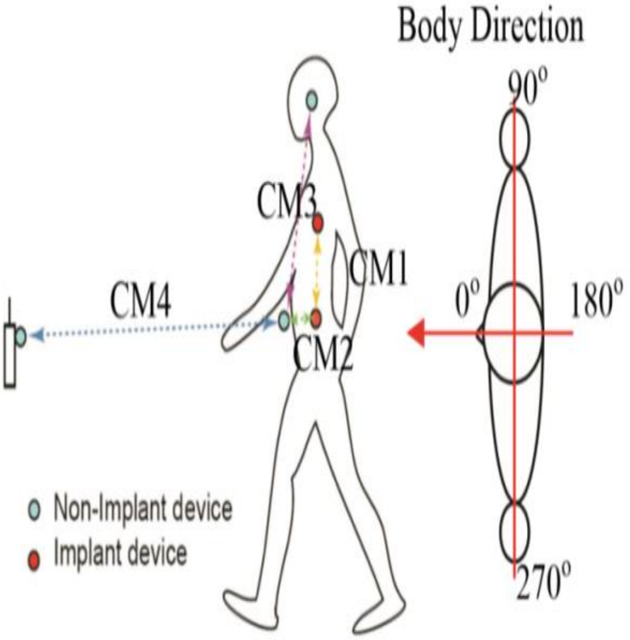

Figure 1. Possible Communication Links and Channel Model [1]

The model presented in this paper is a statistical model based on measurements carried out by NICT for CM4 in UWB band. The CM4 model is based on office environment measurements in which the effect of ground is considered. The channel response is characterized by a power delay profile (PDP) as below

$$h(t) = \sum_{m=0}^{L-1} \alpha_m \, \delta(t - \tau_m) \tag{1}$$

where

$$|\alpha_m|^2 = \Omega_o e^{-\frac{\tau_m}{\Gamma} - k[1-\delta(m)]} \beta \tag{2}$$

$$k = \Delta k \left(\frac{ln10}{10}\right); \; \tau_o = \frac{d}{c}; and \; \beta \sim lognormal(0, \sigma) \tag{3}$$

Where h(t) is complex impulse response; L is the number of arrival paths, modeled as a Poisson random variable with the mean value of 400; α_m is the amplitude of each path; τ_m, m =1,…, L-1, is timing of path arrivals and is modeled as a Poisson random process with the arrival rate λ= 1/(0.501251 ns); k is the K-factor (NLOS); Ω_0 is the path loss; d is the distance between transmitter and receiver; and c is the velocity of light[3].

2.2. Rake Receiver

A rake receiver is a specially designed radio receiver to counter the effect of multipath fading in the system. In the wireless body area communication for the same transmitted signal the number of multipath components (MPC) are generated. The WBAN receiver can take the advantage of diversity by applying the rake structure in the system to improve its performance. The rake structure use several sub-receiver called multipath correlators (fingers or taps), each assigned to different multipath component. Each correlator individually decode single multipath component provided by the channel. The output of the correlators are appropriately weighted and combined in order to make the maximum use of the different transmission characteristics of each transmission path. Selection Diversity, Partial Diversity are different strategies for exploiting the temporal diversity. In optimal manner, the A-Rake (all-rake) receiver collects all the multipath components present in the channel. In A-Rake, the number of correlators required are $T_d * f_s$ where T_d is the time duration of impulse and f_s is the sample rate of signal. So the A-Rake receiver structure needs unlimited resources (correlators or fingers), which even enhance the complexity of the system. Therefore the implementation of the A-Rake receiver is not an easy task. Two sub-optimum reduced complexity Rake structures i.e., S-Rake(selective rake) and P-Rake(partial rake) have been proposed for performance evaluation. The S-Rake structure selects the best N paths(a subset of the resolved multipath components) and P-Rake structure selects the first N paths(that are not necessarily the best one). And the upper limit of achievable performance obtained with A-Rake receiver will act only as a benchmark for relative performance comparison. The combiner produces a decision variable at its output which is then processed by a detector. Thus, the detector performance is based on this equivalent channel created by the cascade of the radio channel and Rake structures [8].Thus for multipath effect caused by body scattering which degrades the Qos of communication in WBAN, we utilize the rake receiver structure.

2.3. Signaling Scheme

In a communication system, signal transfer is generally limited by its channel. All physical medium are continuous time and bit stream to be transfer is inherently discrete in nature; therefore to represent the bit stream as a continuous time signal a process called modulation is performed. There are various possible modulation schemes depending on the application, design specifications and constraints, range, power, capacity requirement, data rate, hardware complexity, and reliability of the channel. Therefore, it is essential to select an accurate modulation scheme for the true purpose [4]. Here we compare different modulation schemes including M-ary modulation technique for WBAN. In these modulations, mapping is generally performed by taking blocks of $k = \log_2 M$ binary digits at a time from sequence $\{a_n\}$ and selecting one of symbols from

$$M = 2^k \tag{4}$$

Where $M \rightarrow Number\ of\ symbol$ and $k \rightarrow Number\ of\ bits\ per\ symbol$

M-PAM: PAM stands for Pulse amplitude modulation in which the amplitude of the modulating signal vary in accordance with the carrier signal. It is a digital modulation scheme in which the carrier signal is in form of pulses which is modulated by digital modulating signal[4]. The probability of symbol error is

$$\mathrm{P_M} = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\left[1-\left(\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{y} e^{-x^2/2}dx\right)^{M-1}\right]\exp\left[\frac{-1}{2}\left(y-\sqrt{\frac{2E_s}{N_o}}\right)^2\right]dy \tag{5}$$

Where $\frac{E_b}{N_o} \rightarrow signal\ to\ noise\ ratio$

The average bit probability error is

$$P_m = \frac{P_M}{M-1} = \frac{P_M}{2^k-1} \tag{6}$$

M-BOK: M-ary Bi-Orthogonal Keying is a modulation technique in which a set of M moderate length ternary codes (−1, 0, +1) is used to represent M symbols. The M-BOK symbols are spaced on M orthogonal axes in the modulation symbol space, so the probability of symbol errors follows that of M-ary bi-orthogonal modulation [4]. The probability of symbol error is

$$P_M = 1 - \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\left(\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{v+\sqrt{\frac{2\gamma M}{M-1}}}\exp\left(\frac{-x^2}{2}\right)\right)^{M-1} d * \exp\left(\frac{-v^2}{2}\right)dv \tag{7}$$

Where $\gamma = \gamma_b \log(M)/\log(2)$ is the SNR per symbol and γ_b is the received SNR per information bit.

The average bit probability error is

$$P_m = P_M \frac{M}{2(M-1)} \tag{8}$$

BPSK: Binary Phase Shift Keying is a popular modulation technique for its smooth power spectrum and low BER. Phase-shift keying (PSK) is a digital modulation scheme that transfer data by modulating the phase of a reference signal. BPSK is the simplest form of PSK. It uses two phases which are separated by 180° and so can also be termed 2-PSK [9].

The probability of bit error rate for BPSK is calculated as

$$P_b = Q\left(\sqrt{\frac{E_b}{N_o}}\right) = \frac{1}{2} erfc \sqrt{\frac{E_b}{N_o}} \tag{9}$$

Where $\frac{E_b}{N_o} \rightarrow signal\ to\ noise\ ratio$

3. Simulation Methodology and Environment

Simulation is the process of developing a model of a real system and then conducting experiment on this model either to understand the behavior of the system or for evaluating various parameters and strategies for the operation of the system. However it is not possible to model every parameter of the human body because of its complexity compares to other wireless channel, but major parameter has been taken into consideration for this model. The channel model is developed by using the standard measurements of NICT's model. Since the performance analysis of WBAN receiver depends on statistical model of the channel. The simulation model is used here to statistically generate the power delay profile of WBAN channel. Then the various digital modulation techniques are used to plot signal to noise ratio versus bit error rate by using the following steps.

Step 1: Generate impulse response ([h,t,n_p]=uwb_hospban_chan_CM4(num_channels, body_direction))

Step 2: Generate power delay profile of CM4.

Step 3: Calculate received SNR of each sample of power delay profile with the help of

transmitted SNR and mean_path_loss.
Step 4: Calculate received signal to noise ratio for various rake taps (all-rake, partial rake, selective rake).
Step 5: (a) Calculate BER for BPSK receiver (A-Rake, P-Rake, S-Rake) at different rake taps (2 and 4).
(b) Calculate BER for M-ary PAM receiver (A-Rake, P-Rake, S-Rake) at different rake taps (2 and 4).
(c) Calculate BER for Mary-BOK receiver (A-Rake, P-Rake, S-Rake) at different rake taps (2 and 4).
Step 6: BER vs. SNR curves are plotted for BPSK, M-ary PAM and M-ary BOK for different body directions.

The measurements are carried for the UWB frequency band of 3.1-10.6 GHz. The On-body antenna characteristics were measured in anechoic chamber, while the channel measurements were carried out in office room. The line-of-sight and non-line-of-sight both situations are considered in this experiment as human body may turn around in real scenario. For this measurement, the transmitting antenna is placed on the wooden stand at a fixed height of 1 m from the ground and receiver antenna is placed on-body at right wrist with 3 m distance from the transmitter [3]. The vertically polarized Omni-directional antennas are used for both transmitter and receiver at UWB frequency band. The transmitting antenna was teardrop type wideband monopole antenna while receiving antenna was Planar UWB antenna (SkyCross SMT-3TO10M-A), since flat type antenna is better for attaching to the body surface [3]. The transmitting antenna was fixed near the wall, and receiving antenna positions were changed in human movement area. In this measurement, human direction was also changed for considering shadowing by human body. The measurements were taken with the test subject facing in four different directions: 0^o, 90^o, 180^o and 270^o. With 0^o representing the subject facing the receive antenna and 90^o representing the subject facing 90^o to the right of the receive antenna. All the parameters of channel model CM4 depends upon the direction of body toward the transmitting antenna and are taken from NICT measurements. Some of them are listed in the Table 1.

Table 1. Parameters of CM4 [3]

Body Directions	Cluster decay factor Γ(ns)	K-factor K(Δk[dB])	Lognormal standard deviation σ(dB)
0^o	44.6346	5.111(22.2)	7.30
90^o	54.2868	4.348(18.8)	7.08
180^o	53.4186	3.638(15.8)	7.03
270^o	83.9635	3.983(17.3)	7.19

4. Simulation Results and Discussion

In this section, the system performance of channel model CM4 has been compared for BPSK, M-ary PAM, and M-ary BOK modulations and the rake reception has been performed over each signalling scheme. The BER performance is evaluated for each body direction i.e. 0^o, 90^o, 180^o and 270^o. The channel realizations are simulated by using the Matlab code enclosed in the appendix of IEEE 802.15.6 channel modeling subcommittee final document [3].

4.1. SNR vs. BER for BPSK

Figure 2 shows the performance of BPSK modulation scheme for varying body directions (*i.e.*, 0^o, 90^o, 180^o and 270^o) of human body for different number(2 and 16) of rake taps (*i.e.*, All rake, Partial rake and Selective rake). The performance curve for the BER for increasing SNR shows significant improvement in case of S-

Rake as compares to P-Rake. The results specifies that the roll-off is more steeper as the number of rake taps increases. However A-Rake shows the best results compares to other rakes. But the A-Rake is the ideal structure which cannot be brought into implementation. So we can take the selective-Rake which shows better result than partial-Rake.

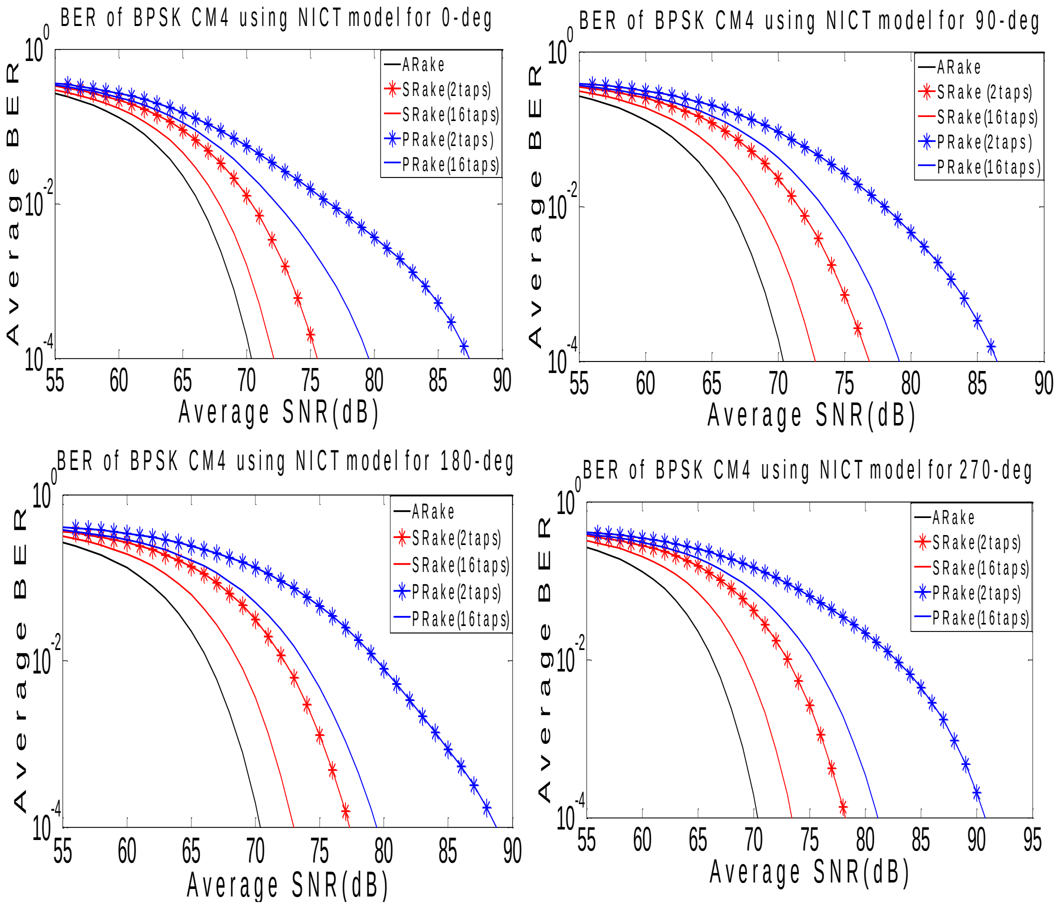

Figure 2. BER Performance of BPSK for CM4 for Four Body Directions

Considering the BPSK, results in Table 2 show that for targeted BER the obtained SNR increases with increase in the angle between the transmitter and receiver from 0^0 to 270^0. At Average SNR of 80 dB(for example) for 2-taps P-Rake structure, the BER for 0^0, 90^0, 180^0 and 270^0 is $10^{-2.43}$, $10^{-2.34}$, $10^{-2.09}$ and $10^{-1.66}$ respectively which shows continues increase.

So it is preferred to use selective rake with lowered angle of the body direction or the subject facing the receiving antenna with higher number of rake taps to improve the performance.

Table 2. BER Analysis for Different Body Directions

Body Direction	**Signal to Noise ratio for BPSK**				
	Target BER	**No. OF TAPS**	**All-RAKE**	**S-RAKE**	**P-RAKE**
0- Degree	10^{-1}	2	**61.13**	**64.52**	**67.3**
		16		**62.56**	**65.47**
	10^{-3}	2	**68.77**	**73.46**	**83.63**
		16		**70.41**	**76.74**
90-Degree	10^{-1}	2	**61.12**	**65.75**	**69.52**
		16		**63.19**	**66.94**
	10^{-3}	2	**68.77**	**74.63**	**83.24**
		16		**71.06**	**76.82**
180- Degree	10^{-1}	2	**61.13**	**66.38**	**71.52**
		16		**63.37**	**67.5**
	10^{-3}	2	**68.77**	**75.25**	**84.69**
		16		**71.24**	**77.09**
270- Degree	10^{-1}	2	**61.13**	**67.05**	**72.46**
		16		**63.77**	**68.65**
	10^{-3}	2	**68.78**	**76.12**	**87.9**
		16		**71.69**	**78.8**

4.2. SNR vs. BER for M-ary PAM

M-ary PAM (Pulse Amplitude Modulation) is a digital modulation scheme considering $M=2^k$, where k represents the number of bits/symbol and M represents the number of symbols. In this modulating scheme, k binary digits are taken at a time for mapping, in which amplitude of the pulse are varied in accordance with the modulating signal.

4.2.1. SNR vs. BER for 2-PAM: Figure 3; show the results for 2-PAM where the number of bits per symbol is 1 and the number of symbols are 2. It compares the 2-PAM modulation scheme for different body directions (0^0, 90^0, 180^0, 270^0) with respect to receiver for different rake structure (A-Rake, S-Rake, and P-Rake). As the number of rake taps increases, the result shows better performance, however the system complexity increases. From the figure, it is clear that the performance of selective rake with higher rake taps shows better results.

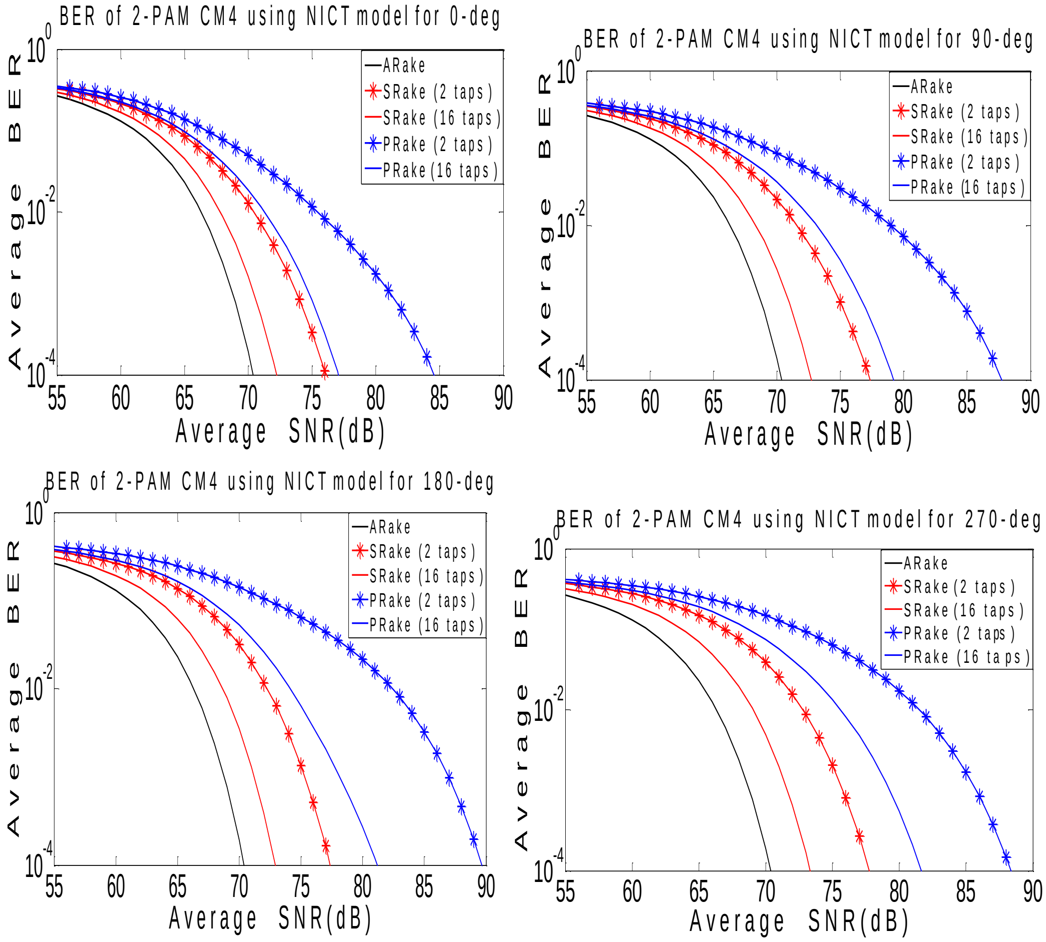

Figure 3. BER Performance of 2-PAM for CM4 for Four Body Directions

Table 2 shows the results of obtained SNR of 2-PAM for targeted BER. An attractive point observed from the table is that the performance of S-Rake is better than P-Rake and the difference in there BER for targeted SNR increases with rising angle of body direction. For example for 2-PAM, at SNR=70dB the difference in BER of S-Rake and P-Rake for 16 taps increases from $10^{-1.77}$ to $10^{-1.16}$ as body direction change from 0^0 to 270^0. So it is more convenient to use 0^0 body direction with S-Rake structure to improve the results.

Table 3. BER Analysis of 2-PAM for Different Body Directions

Body Direction	**Signal to Noise ratio for 2-PAM**				
	Target BER	**No. OF TAPS**	**All-RAKE**	**S-RAKE**	**P-RAKE**
0- Degree	10^{-1}	2	**61.12**	**64.36**	**66.75**
		16		**62.47**	**64.85**
	10^{-3}	2	**68.77**	**63.8**	**81.15**
		16		**70.43**	**74.76**
90-Degree	10^{-1}	2	**61.12**	**65.36**	**69.1**
		16		**63**	**66.29**
	10^{-3}	2	**68.77**	**75.01**	**84.5**
		16		**70.97**	**76.77**
180- Degree	10^{-1}	2	**61.12**	**66.42**	**72.36**
		16		**63.36**	**67.57**
	10^{-3}	2	**68.76**	**75.3**	**86.96**
		16		**71.21**	**77.09**
270- Degree	10^{-1}	2	**61.12**	**66.92**	**75.52**
		16		**63.73**	**68.7**
	10^{-3}	2	**68.77**	**75.76**	**85.73**
		16		**71.61**	**79.28**

4.2.2. SNR vs. BER for 4-PAM: For 4-PAM modulating scheme, the total 4 symbols with 2 bits per symbol are used. In Figure 4, the performance of 4-PAM is compared for various rake taps with different body directions. The figures show better results for selective rake structure with higher number of rake taps. For example, for S-Rake for 0^0 body direction 16-taps shows $10^{-3.3}$ BER while 2-taps shows $10^{-2.15}$ BER for 75dB SNR, which represent a significant increase. So it is preferred to use selective rake with higher number of rake taps.

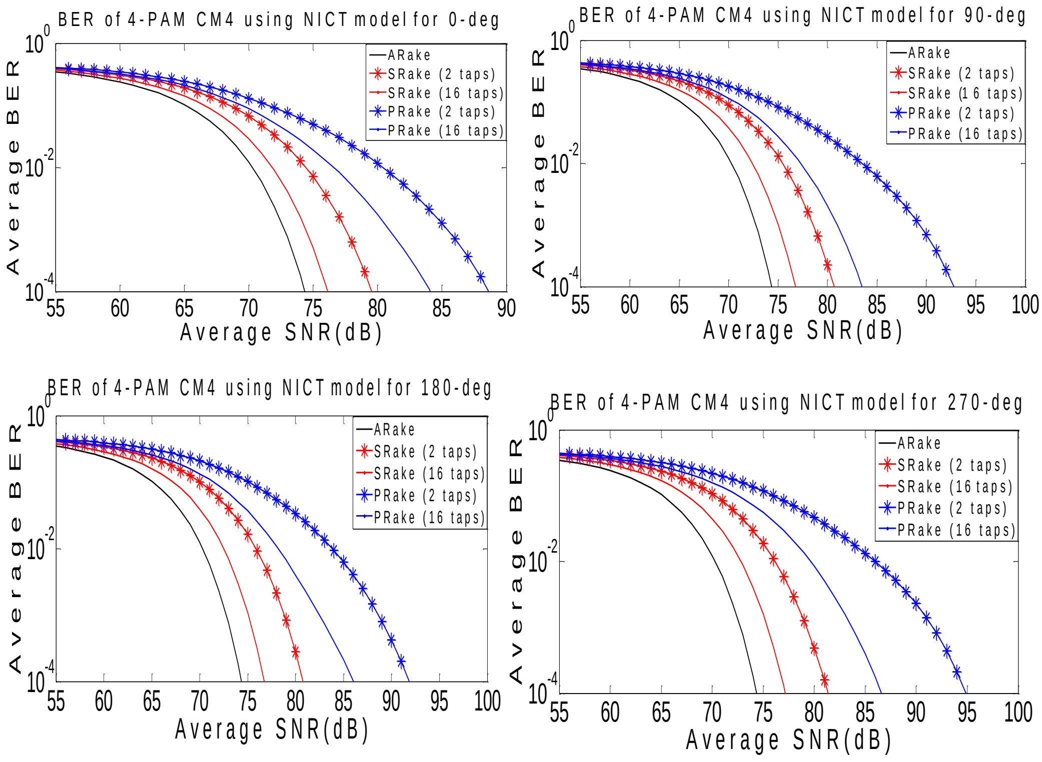

Figure 4. BER Performance of 4-PAM for CM4 for Four Body Directions

Table 4. BER Analysis of 4-PAM for Different Body Directions

Body Direction	**Signal to Noise ratio for 4-PAM**				
	Target BER	**No. OF TAPS**	**All-RAKE**	**S-RAKE**	**P-RAKE**
0- Degree	10^{-1}	2	**65.1**	**68.48**	**71.52**
		16		**66.53**	**69.42**
	10^{-3}	2	**72.75**	**77.5**	**85.39**
		16		**74.4**	**80.9**
90-Degree	10^{-1}	2	**65.1**	**69.5**	**73.97**
		16		**67.07**	**70.64**
	10^{-3}	2	**72.74**	**78.54**	**89.31**
		16		**75.02**	**81**
180- Degree	10^{-1}	2	**65.1**	**70.03**	**75.08**
		16		**67.2**	**71.42**
	10^{-3}	2	**72.73**	**78.81**	**88.62**
		16		**75.07**	**82.48**
270- Degree	10^{-1}	2	**65.11**	**70.22**	**76**
		16		**67.44**	**72.53**
	10^{-3}	2	**72.74**	**79.25**	**91.61**
		16		**75.41**	**83.69**

The results obtained by simulative investigation of CM4 for different body directions in Figure 4 for 4-PAM is computed in Table 4. From Table 4, it is analyzed that for 0-degree body direction the value of BER is least for targeted SNR. At an average SNR of 80dB(for example), the BER obtained for 0^0 is $10^{-1.93}$ while for 90^0, 180^0, 270^0 it is $10^{-1.56}$, $10^{-1.48}$, $10^{-1.33}$ respectively for 2-taps P-Rake receiver structure. So the use of 0-degree angle between transmitting and receiving antenna improves the performance of the WBAN system.

4.2.3. SNR vs. BER for 8-PAM: For 8-PAM modulating scheme, the number of bits/symbol is 3 and the number of symbols are 8. In Figure 5, 8-PAM is compared for various rake taps with varying number of taps and different body directions. The performance of error rate for P-Rake is more degraded than S-Rake as shown in Figure 5. From Figure 5, it can be observed that with the increase in number of taps of Rake receiver, SNR falls to achieve the same BER. Example for targeted BER of 10^{-3} the average SNR for 0-degree body direction for 16-taps S-Rake structure is 78.63dB while for 2-taps S-Rake structure it is 81.64dB. So the performance observed with 16 taps is much better than 2-taps but with increased receiver complexity.

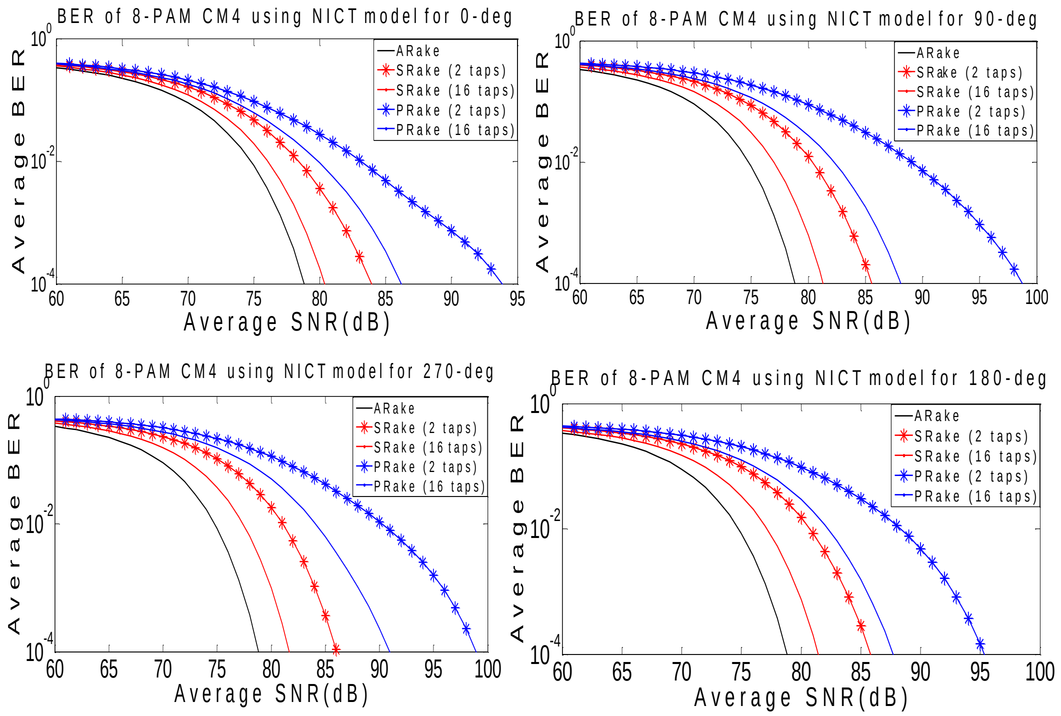

Figure 5. BER Performance of 8-PAM for CM4 for Four Body Directions

From Table 5, it is clear that for 8-PAM, 0-degree body direction shows better result than 90-degree, 180-degree and 270-degree body direction. The performance of WBAN system with 8-PAM, shows the increase in BER (for example) from $10^{-1.7}$ to $10^{-1.43}$ with increase in body direction angle from 0^0 to 270^0 for targeted SNR of 75dB for 16 taps S-Rake receiver structure.

Table 5. BER Analysis of 8-PAM for Different Body Directions

Body Direction	**Signal to Noise ratio for 8-PAM**				
	Target BER	**No. OF TAPS**	**All-RAKE**	**S-RAKE**	**P-RAKE**
0- Degree	10^{-1}	2	**69.56**	**72.38**	**74.68**
		16		**70.76**	**73.15**
	10^{-3}	2	**72.22**	**81.64**	**89.12**
		16		**78.63**	**83.68**
90-Degree	10^{-1}	2	**69.56**	**74.34**	**79.26**
		16		**71.64**	**75.62**
	10^{-3}	2	**77.22**	**83.44**	**94.85**
		16		**79.55**	**85.74**
180- Degree	10^{-1}	2	**69.56**	**74.87**	**79.82**
		16		**71.83**	**76.01**
	10^{-3}	2	**77.22**	**83.77**	**92.69**
		16		**79.72**	**85.5**
270- Degree	10^{-1}	2	**69.58**	**75.15**	**80.74**
		16		**72.07**	**77.31**
	10^{-3}	2	**77.22**	**84.07**	**95.83**
		16		**79.98**	**88.02**

4.3. SNR vs. BER for M-ary BOK

In M-ary BOK, the symbols are spaced on M orthogonal axes in the modulation symbol space such that probability of symbol errors follows the M-ary bi-orthogonal modulation.

4.3.1. SNR vs. BER for 2-BOK: Simulation graphs for 2-BOK (*i.e.*, for total 2 symbols and 1 bits/symbol) are plotted for different rake taps with varying body directions in Figure 6. The performance curve of the BER for S-Rake shows significant improvement as compares to P-Rake with increasing SNR. The roll-off is more steeper as the number of rake taps increases. The all rake structure shows the best results compares to other rake but with increased hardware complexity. So S-Rake with acceptable performance is utilized for WBAN.

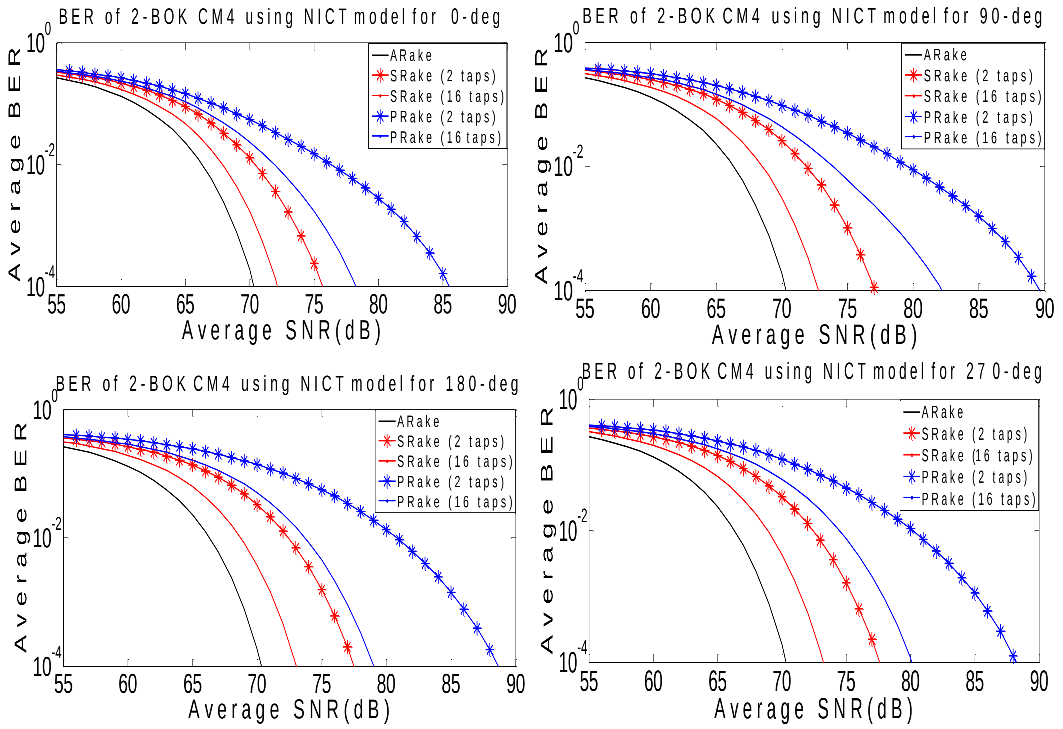

Figure 6. BER Performance of 2-BOK for CM4 for Four Body Directions

The results obtained from simulative investigation of 2-BOK for different body direction are computed in Table 6. The results show the degradation in performance with rising angle of body direction. Example for 16 taps S-Rake structure, with targeted SNR of 70dB the average BER for 0^0, 90^0, 180^0, 270^0 is $10^{-2.77}$, $10^{-2.5}$,$10^{-2.4}$,$10^{-2.36}$ respectively for 2-BOK. The worst performance is shown by 270-degree body direction. Even it can be observed that with the decreasing number of rake taps, the required SNR to obtain the targeted BER is raised.

Table 6. BER Analysis of 2-BOK for Different Body Directions

Body Direction	Signal to Noise ratio for 2-BOK				
	Target BER	**No. OF TAPS**	**All-RAKE**	**S-RAKE**	**P-RAKE**
0-Degree	10^{-1}	2	**61.12**	**64.45**	**67.08**
		16		**62.57**	**65.21**
	10^{-3}	2	**68.76**	**73.56**	**82.23**
		16		**70.46**	**75.71**
90-Degree	10^{-1}	2	**61.12**	**65.85**	**69.79**
		16		**63.19**	**66.86**
	10^{-3}	2	**68.77**	**75.01**	**86**
		16		**71.11**	**78.69**
180- Degree	10^{-1}	2	**61.12**	**66.5**	**72.07**
		16		**63.38**	**67.49**
	10^{-3}	2	**68.77**	**75.46**	**85.56**
		16		**71.31**	**76.88**
270- Degree	10^{-1}	2	**61.12**	**66.42**	**71.05**
		16		**63.53**	**67.99**
	10^{-3}	2	**68.76**	**75.52**	**85.17**
		16		**71.49**	**77.89**

4.3.2. SNR vs. BER for 4-BOK: In Figure 7, simulation graphs for 4-BOK (i.e. for total 4 symbols and 2 bits/symbol) modulation scheme are plotted for different rake taps with different body directions (0^{o}, 90^{o}, 180^{o} and 270^{o}). The figures show better results for selective rake structure with increasing number of rake taps. For example, for S-Rake for 0^{0} body direction 16-taps shows $10^{-3.15}$ BER while 2-taps shows 10^{-2} BER for 70dB SNR, which represent a significant increase. So it is preferred to use selective rake with higher number of rake taps.

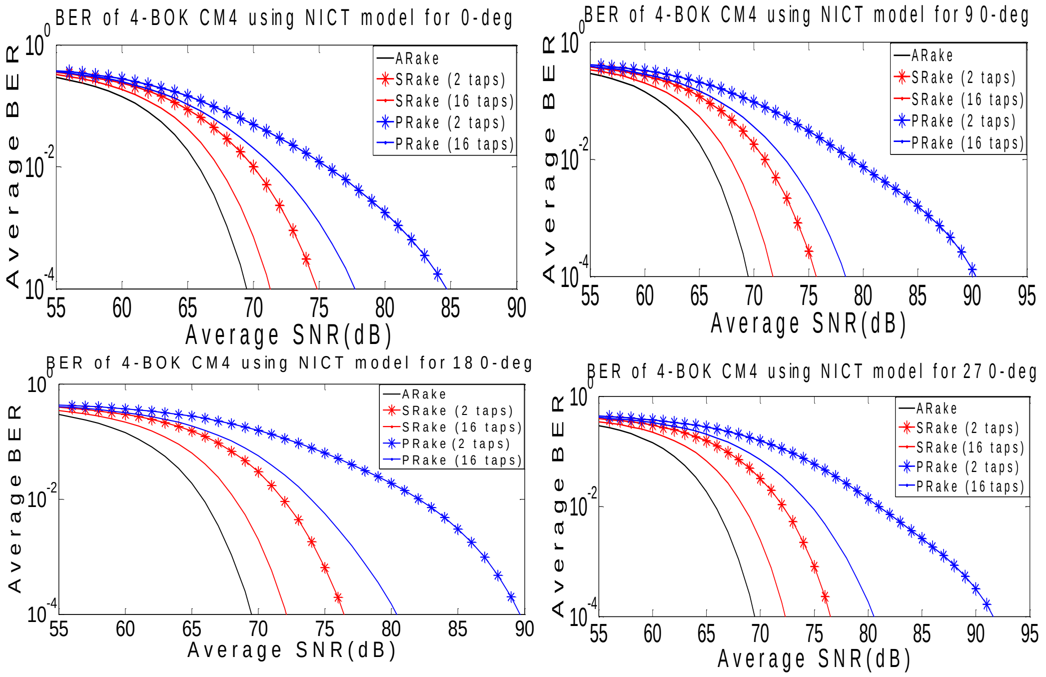

Figure 7. BER Performance of 4-BOK for CM4 for Four Body Directions

From Table 7 it is clear that for 4-BOK, 0-degree body direction shows better result than other body directions *i.e.*, 90, 180 and 270-degree.The performance of

BER(example) for targeted SNR of 70dB for 0^0 is 10^{-2} while for 270^0 it is $10^{-1.49}$ for 2-taps with S-Rake receiver structure. So it can be observed that the rising angle of body direction cause increase in bit error rate and it is preferred to use 0^0 body direction with S-Rake structure.

Table 7. BER Analysis of 4-BOK for Different Body Directions

Body Direction	**Signal to Noise ratio for 4-BOK**				
	Target BER	**No. OF TAPS**	**All-RAKE**	**S-RAKE**	**P-RAKE**
0- Degree	10^{-1}	2	**61.31**	**64.5**	**66.87**
		16		**62.68**	**65.2**
	10^{-3}	2	**68.05**	**72.9**	**81.14**
		16		**69.71**	**75.23**
90-Degree	10^{-1}	2	**61.31**	**65.61**	**69.65**
		16		**63.2**	**66.67**
	10^{-3}	2	**68.05**	**73.79**	**86.24**
		16		**70.2**	**76.15**
180- Degree	10^{-1}	2	**61.31**	**66.72**	**72.61**
		16		**63.61**	**68.02**
	10^{-3}	2	**68.05**	**74.57**	**86.93**
		16		**70.53**	**77.61**
270- Degree	10^{-1}	2	**61.31**	**66.81**	**72.51**
		16		**63.75**	**68.66**
	10^{-3}	2	**68.05**	**74.77**	**87.57**
		16		**70.75**	**78.14**

4.3.3. SNR vs. BER for 8-BOK: Simulation graphs for 8-BOK(*i.e.*, for total 8 symbols and 3 bits/symbol) modulation scheme are plotted for different rake taps with different body directions in Figure 8. The performance curve for the BER for increasing SNR shows significant improvement in case of S-Rake as compares to P-Rake. For example for SNR of 70dB for 16 taps for 0-degree body direction, the S-Rake shows $10^{-3.6}$ BER and P-Rake shows $10^{-1.8}$ BER. So it is observed that P-Rake structure degrades the performance of WBAN.

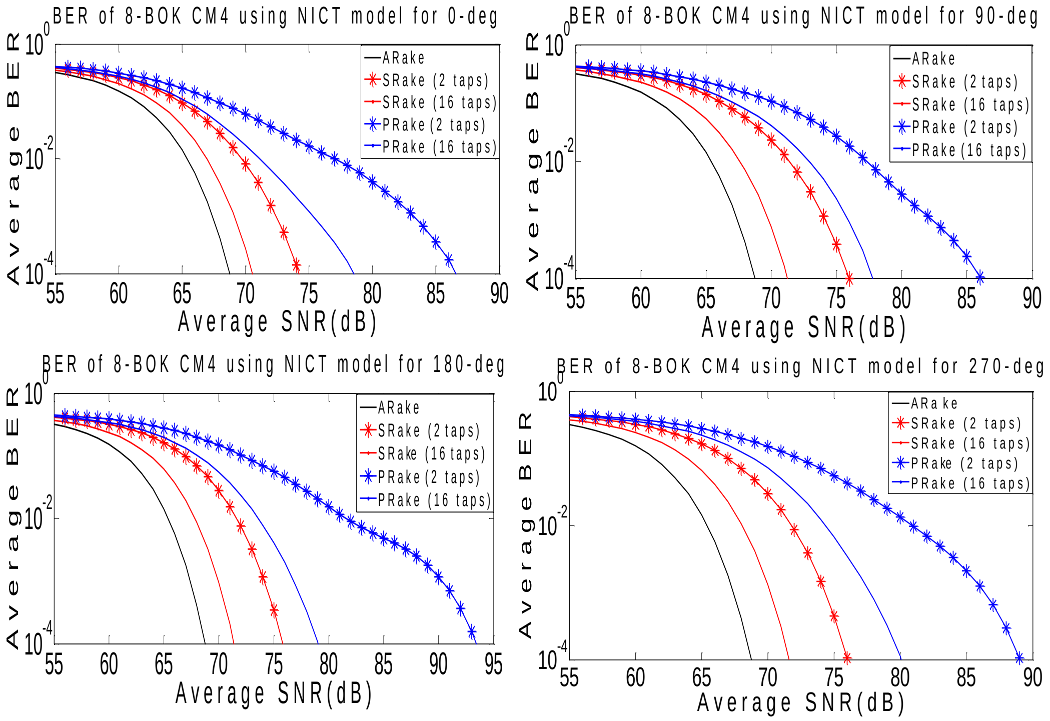

Figure 8. BER Performance of 8-BOK for CM4 for Four Body Directions

The Table 8 computes the SNR for targeted BER for different body directions which shows better results for 0-degree body direction than others. And by increasing the angle of body direction between transmitter and receiver the performance of the system became poor. Example for 2 taps S-Rake, with targeted SNR of 70dB the average BER for 0^0 is 10^{-2} while for 270^0 it is $10^{-1.5}$ for 8-BOK. The worst performance is shown by 270-degree body direction. Even it can be observed that with the decreasing number of rake taps, the required SNR to obtain the targeted BER is raised.

Table 8. BER Analysis of 8-BOK for Different Body Directions

Body Direction	**Signal to Noise ratio for 8-BOK**				
	Target BER	**No. OF TAPS**	**All-RAKE**	**S-RAKE**	**P-RAKE**
0-Degree	10^{-1}	2	**61.39**	**64.76**	**67.71**
		16		**62.79**	**65.53**
	10^{-3}	2	**67.39**	**72.4**	**83.23**
		16		**69.1**	**75.33**
90-Degree	10^{-1}	2	**61.39**	**66.25**	**70.25**
		16		**63.41**	**67.16**
	10^{-3}	2	**67.39**	**74.13**	**82.31**
		16		**69.78**	**75.89**
180- Degree	10^{-1}	2	**61.39**	**66.86**	**72.12**
		16		**63.71**	**68.05**
	10^{-3}	2	**67.39**	**74.12**	**90.03**
		16		**69.95**	**76.81**
270- Degree	10^{-1}	2	**61.39**	**66.93**	**72.26**
		16		**63.87**	**68.85**
	10^{-3}	2	**67.39**	**74.31**	**86.34**
		16		**70.18**	**77.86**

Also from Table 6, Table 7 and Table 8 it can be observed that for M-ary BOK modulation scheme, BER performance of 2-BOK for selective rake is much more effective than 4-BOK and 8-BOK for different body directions for channel model CM4 of WBAN. Example for S-Rake with 0-degree body direction with 16-taps, the BER for 2-BOK is $10^{-2.03}$ while for 4- BOK it is $10^{-2.23}$ and for 8- BOK it is $10^{-1.43}$ at targeted SNR of 68dB. So it is better to use 2-BOK for WBAN at ultra wideband as compares to 4- BOK and 8- BOK.

From results obtained for BPSK, M-ary PAM and M-ary BOK we can conclude that results for BPSK, 2-PAM and 2-BOK are far better than other modulation schemes. The performance curve for the BER with increasing SNR shows significant improvement in case of 2-PAM as compares to BPSK and 2-BOK. As observed from the results(for example) the targeted BER of 10^{-1} for 0^0 body direction for 2 taps S-Rake for BPSK, 2-PAM and 2-BOK is obtained at 64.52dB, 64.36dB and 64.45dB respectively which proves the effective performance of 2-PAM.

5. Conclusion

WBAN seems to be very prominent technology in the near future. However there are list of design challenges ahead of communication engineers to make it a reality. The selection of best modulation technique for implementation of WBAN is required to allow the realization of loss free WBAN channel. In this work extensive simulation has been carried out to compares various modulation schemes for different body directions of channel model CM4 of wireless body area network. The results obtained in this paper shows that the signal transmitted through 0^0 body direction degrades much lesser than the one which travel through 90^0, 180^0 and 270^0 body directions. The error rate performance of 2-PAM shows better results as compares to BPSK and M-ary BOK modulation scheme. The results obtained with rake receiver structure are best in case of All-Rake, but due to complexity and difficulty in realization of All-Rake, S-Rake is considered as a better choice. Even the results obtained with higher number of rake taps shows significant improvement in the channel performance of wireless body area network. So considering the 2-PAM modulation scheme with Selective-Rake structure with efficient number of rake taps can help in designing the effective network structure for WBAN channel.

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