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Joint VMIMO and LDPC Decoders for IR-UWB Wireless Body Area Network

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ABSTRACT A complete impulse radio-ultra wide band (IR-UWB) system is proposed to mitigate the impairments concerning on-body to off-body Wireless Body Area Networks (WBAN). The proposed system maintains the practical communication link between on-body sensors to the fusion center or the monitoring device held by the medical representative. Also, these sensors are assigned a recently proposed pulse shaping to mitigate the noise that existed in the IR-UWB WBAN channel. Furthermore, virtual multiple-input multiple-output (VMIMO) is proposed to perform spatial multiplexing between various sensors transmitted data. Moreover, low complex low density parity check (LDPC) encoding/decoding algorithms, including a new low complex hybrid LDPC decoding algorithm, are proposed to reduce the complexity and to enhance the bit error rate of the on-body sensors. Interestingly, low energy consumption at every sensor participating in the on-body to off-body WBAN was achieved by adopting the combination between LDPC decoders and VMIMO technique. According to simulation results, the new system enhanced the BER performance and reduced the complexity of the on-body to off-body IR-UWB communication system effectively.

INDEX TERMS Low density parity check codes, wireless body area network, forward error correction, turbo codes, hybrid decoding, IR-UWB, virtual MIMO.

I. INTRODUCTION

Impulse Radio-Ultra Wide Band (IR-UWB) communication is recommended for Wireless Body Area Networks (WBANs) in case of medical applications that require high bit rate, low transmission power to save battery life, and minimum hardware complexity [1]. IR-UWB involves pulse shaping in the range of nano seconds resulting in ultra wide frequency band to obtain accurate medical measurements of vital signs for patients. The proposed system by IEEE WBAN 802.15.6 standard involves pulse shaping adopting second derivative Gaussian pulse that has a width of nano seconds. Various published studies [2], [3] proposed alternative pulse shaping using Hermite pulses instead of second derivative Gaussian pulse to achieve higher spectral efficiency and better mitigating channel impairments in UWB WBAN.

Virtual Multiple Input Multiple Output (VMIMO) is the latest technique used for Wireless Sensor Networks (WSNs) cooperation [4], [5]. It was reported in [6] that IR-UWB WBANs consist of on-body multi-sensors transmitting medical information. It also keeps the benefits of MIMO systems such as mitigating Rayleigh fading and differentiates between transmitted medical data from on-body sensors. In [6], VMIMO is proposed for WBAN as it results in recovery of sensors's data of on-body sensors for transmitting medical data effectively. In addition, the authors proposed VMIMO for enhancing diversity gain of operating sensors. Ding *et al.* [6] consider network layer in their study and they did not study the physical layer. Neither the performance evaluation for each sensor participating in the WBAN nor the effect of channel coding techniques were evaluated. In addition they built their system for evaluating VMIMO using the recommended components by IEEE standard only.

Some papers in literature introduced the usage of error control techniques for WBANs. Jeong and Sunwoo [7] and Ahmed and Kohno [12] proposed a BCH coding technique for WBAN. Also, Kaythry *et al.* [13] proposed Raptor codes for WBAN. In [8], they proposed a fountain channel coding technique for WBAN channel. These techniques are characterized by high complexity compared to LDPC decoding algorithms. In addition, experimental results in [9] and [10] proved that LDPC codes are able to fulfill WSN applications performance requirements due to their high coding gain compared to Reed Solomon (RS) codes, Convolutional codes and Turbo codes.

Low Density Parity Check (LDPC) encoding/decoding algorithms proved that it will be the best error control for IR-UWB WBAN [10]. The most challenging aspect in LDPC is its decoding algorithms. LDPC decoding algorithms are divided into three categories: hard decision, soft decision and hybrid decision. LDPC encoding and decoding algorithms completely depend on using sparse matrices to reduce the decoding time, the required power and the hardware complexity [15]. An adaptive Belief Propagation (BP) LDPC decoding algorithm proposed in [16] is classified as soft decision algorithm to save the drained energy by the decoder in WBAN sensors.

A new low complexity hybrid LDPC decoding algorithm named Modified Bootstrapped Modified Implementation Efficient Weighted Bit Filliping (MBMIERRWBF) is proposed in [11] for WBAN characterized by good BER performance and low complexity. It operates in MICS band of WBAN with frequency band 402 to 405 *MHz*. Besides, it only considers SISO case i.e, the connection between implant to implant with low bit rate medical applications. In contrast to the previous work in [11] that dealt with implant to implant communications, this work deals with on-body to off-body wireless communication channel as seen in Figure 1. In this case, the path loss and shadowing parameters are modified to the standard paramters in [1]. In addition we take into consideration the Rayleigh fading effect. To the extent of our knowledge, there is no attempt to implement IR-UWB WBAN system using virtual MIMO technique to multiplex the data of the sensors including the pulse shaping using Hermite pulse combined with LDPC decoding algorithms.

In this paper, the main contributions are: (1) Proposing Virtual MIMO for IR-UWB WBAN system to perform spatial multiplexing for on-body sensors. (2) Evaluating the system using a recent proposed pulse shaping for each sensor participates in IR-UWB WBAN to enhance mitigation of noise. (3) Proposing BPSK as a modulation technique for IR-UWB system. (4) Comparing low complex LDPC decoding algorithms for the proposed system. (5) Proposing a new low complex hybrid LDPC decoding algorithm for more enhancement in BER performance besides lowering the complexity of the whole system.

The rest of the paper is organized as follows: Section II discusses the on-body to off-body IR-UWB WBAN channel model. Section III illustrates briefly the low complexity LDPC encoding and decoding algorithms. Furthermore, it presents a new hybrid LDPC decoding algorithm. Section IV discusses the pulse shaping for IR-UWB WBAN. Section V presents the Virtual MIMO technique. Section VI delineated the complete proposed system. Finally, sections VII and VIII display the simulation results and conclusion.

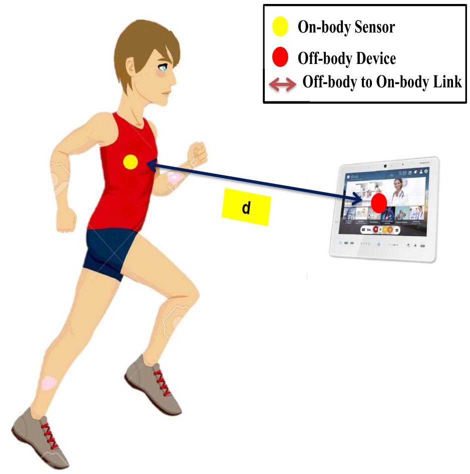

FIGURE 1. WBAN sensors for on-body to off-body communication link with separation distance (d).

II. ON-BODY TO OFF-BODY CHANNEL MODEL

On-body sensors to off-body fusion center link used in WBANs is described in the IEEE WBAN 802.15.6 standard [1]. It is composed of path loss combined with log-normal shadowing due to the continuous movement and change in postures of the body, leading to an excessive fading of the transmitted signal power, in addition to Rayleigh fading due to separate sensors placed on body to sense and measure vital signs of the patient.

IEEE standard reports that the on-body to off-body communication channel can be expressed as follows [1], [17], [18]:

$$PL = PL_o + 10\, n\, log_{10} \frac{d}{d_o} + S \tag{1}$$

where PL and PL_o are the path loss at distance d and reference distance d_o in dB as d is the separation distance between on-body sensor, and off-body sink or fusion center, n is the path loss exponent and S represents the log normal shadow fading in dB with normal distribution having mean (μ) equal to zero and standard deviation (σ_{dB}) [17], [18].

In this paper, the on-body to off-body sensors are classified according to their transmission direction and their position on the body [1].

III. LDPC ENCODING AND DECODING ALGORITHMS

LDPC is a distinguishing channel coding technique that has impressive performance approaching the Shannon limit. It was proposed by Gallager [15] in 1960. It gained high attention and became extremely competitive to turbo codes [19]. It has been selected by some distinctive digital communication standards as an error control coding technique, such as in DVB-S2 [20], DVB-T2 [21], IEEE 802.16 [22] and IEEE 802.11 [23].

LDPC codes are generated by their parity check matrices only with sparse property. Therefore, an adequate encoding procedure using parity check matrix (**H**) will be performed instead of converting a parity check matrix to its generator matrix, which leads to loose the sparseness property belonging to $\mathbf{H}$ matrix which leads to extra complexity [24]. The encoding procedure maintained in the simulations is motivated by [24].

Decoding proceeds by using $M \times N$ parity check matrix $\mathbf{H}$ to obtain a $1 \times M$ syndrome vector bits which can be elucidated as [15]:

$$\mathbf{s} = \mathbf{z}\,\mathbf{H}^T \tag{2}$$

where $\mathbf{z}$ are the hard (binary) values extracted from soft vector $\mathbf{y}$ which is the received vector from the channel. The syndrome is used to check if the received code word is decoded successfully or if it needs further processing.

LDPC decoding algorithms are iterative techniques, using a predetermined number of iterations to reach either zero syndrome (no error exists) or an enhanced version of code word sent by the transmitter with fewer number of errors. Decoding algorithms are classified into three classes: Hard decision, Soft decision and Hybrid decision [15]. Hard decision algorithms depend on hard (binary) information about receiving code word in both detecting and correcting errors, while in soft decision, it depends on soft values (raw values) received from channel to result in either successful detection or correction of errors. Hard decision algorithms are characterized by very low hardware complexity as reported in [25]. The overall complexity of all iterations for these algorithms equals $O((M\rho + N\gamma) \times N_h)$ where ρ is the number of ones per row, γ represents the number of ones per column in $\mathbf{H}$ and N_h is the number of hard descision iterations. The Soft ones are characterized by impressive performance plus high hardware decoding complexity in all iterations which equals $O((2M\rho + 4N\gamma) \times N_s)$ where N_s is the number of soft descision iterations [25]. Hybrid decision algorithms are introduced to compromise between complexity and BER performance of hard and soft decision algorithms. It has hardware decoding complexity of $O((2M'\rho + 4N'\gamma) + (M\rho + N\gamma) \times N_h)$ where $M' < M$, $N' < N$ and $N_s = 1$. The M' and N' are unrealible check nodes and variable nodes predetermined by bootstrap step [27] and modified bootstrap step [11]. As illustrated, the hardware decoding commplexity is divided in two parts. First part is the bootstrap step which is inspired by the soft descion algorithms while, it is only processed on unrealible variable nodes. The second part will be for the hard decision algorithm represented by MIERRWBF algorithm. Thus, the latest variant of Bit-Flipping (BF) algorithms is the Modified Implementation Efficient Reliability Ratio Weighted Bit-Flipping (MIERRWBF) algorithm was illustrated in [26]. It is characterized by low complexity plus fast decoding procedure. Bootstrapped Modified Implementation Efficient Reliability Ratio Weighted Bit Flipping (BMIERRWBF) [27] and Modified Bootstrapped Modified Implementation Efficient Reliability Ratio Weighted Bit Flipping (MBMIERRWBF) [11] algorithms are the most recent hybrid LDPC decoding algorithms. These algorithms combine between very good BER performance of soft decision algorithms represented by bootstrap step and low complexity of hard decision algorithms by maintaining MIERRWBF algorithm. Soft decision algorithms are derived from original Belief Propagation (BP) algorithm proposed in [15]. There are many variants of BP algorithm that have been proposed in literatures [28]–[30]. All these algorithms have very good BER performance while they suffer from high hardware complexity, leading to drain the available power and wasting the sensor's battery life.

Some low complexity decoding algorithms can be derived from the sum product algorithm that could acheive the requirements of WBANs, as it has the lower complexity compared to other soft decision algorithms [25]. One of the most distinguished low complexity soft decision algorithms is min-sum algorithm. It is extracted from sum product algorithm as stated in [25].

PROPOSED LDPC DECODING ALGORITHM (NEW MBMIERRWBF)

The MBMIERRWBF algorithm proposed in [11] solves the problem of offline calculation of threshold β to differentiate between unreliable and reliable messages. It uses a bootstrap step based on min-sum algorithm which needs more improvement to enhance the whole algorithm. The procedure of MBMIERRWBF algorithm initiated by extracting unreliable check nodes by applying (2). Then, obtaining indexes of non-zero syndrome elements s_m which are equivalent to unreliable check nodes. After that extracting $\mathcal{N}(m)$ which represents variable nodes linked to each unreliable check node. Calculation of the lowest variable node belonging to every unreliable check node using $[\bar{n}, y_{\bar{n}}] = \{\min \mid y_n \mid : n \in \mathcal{N}(m)\}$ where $\bar{n}$ represent the index of the variable node with minimum received value $y_{\bar{n}}$. Update all extracted unreliable variable nodes using bootstrap step with new more reliable soft values using eq. (3). Finally, MIERRWBF algorithm procedures is applied.

$$y'_{\bar{n}} = y_{\bar{n}} + \sum_{m \in \mathcal{M}(n)} \prod_{k \in \mathcal{N}(m)\backslash \bar{n}} sgn(y_k).\min_{i \in \mathcal{N}(m)\backslash \bar{n}} \mid y_i \mid \tag{3}$$

where $\mathcal{M}(n)$ is the unreliable check nodes connected to variable node n and $\mathcal{N}(m)\backslash \bar{n}$ are unreliable variable nodes connected to the unreliable check node m except the variable node $\bar{n}$.

A new bootstrap is proposed to improve the one in [11]. The new bootstrap will be:

$$y'_{\bar{n}} = y_{\bar{n}} + \sum_{m \in \mathcal{M}(n)} 2\tanh^{-1}\left(\prod_{k \in \mathcal{N}(m)\backslash \bar{n}} \tanh \frac{y_k}{2}\right) \tag{4}$$

The complete procedure of the proposed algorithm is illustrated by the flow chart in Figure 2. The main difference between the algorithm in [11] and the proposed one in this paper is maintaining the bootstrap step which is completely changed. The bootstrap step maintained in [11] used a bootstrap step with "**signum**" function while in the new algorithm presented in this paper, we are using another function

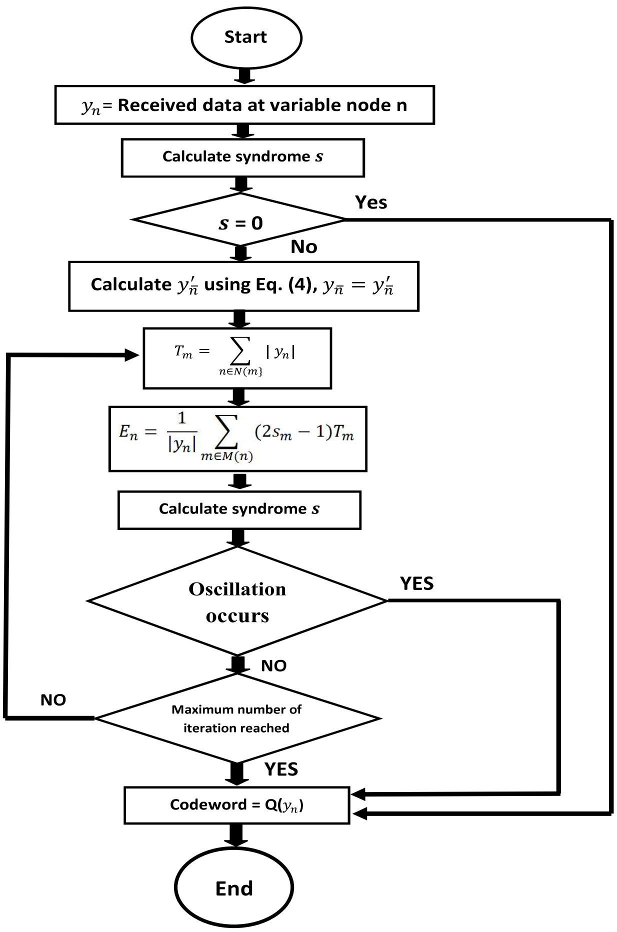

FIGURE 2. Proposed algorithm flow chart.

which is the "**Tanh**" function. This modification according to simulation results enhanced the algorithm at all maintained parameters.

The codeword at the final stage will be extracted in its hard values which is presented by $Q(y_n)$.

IV. UWB PULSE SHAPING

In IR-UWB WBAN, the recommended pulse shape is the Gaussian pulse [31] and its time domain representation can be expressed as follows:

$$w(t) = e^{(-2\pi \frac{t^2}{2t_p^2})} \tag{5}$$

where t_p is the pulse width. The second derivative of Gaussian pulse is plotted in Figure 3 and expressed by:

$$v(t) = \sqrt{\frac{8}{3}}\left(1 - 4\pi(\frac{t}{t_p})^2\right)e^{\left(-2\pi(\frac{t}{t_p})^2\right)} \tag{6}$$

Gaussian pulse and its derivative are used due to their homogeneity in implementation within short interval [31]. It is able to spread the energy of the signal from near DC to a few GHz. Moreover, it efficiently complies with Federal Communications Commission (FCC) regulations, whereas Laplacian and cubic monopolies do not exhilarate the FCC

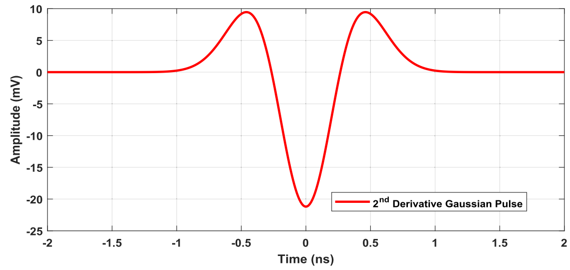

FIGURE 3. Second order derivative Gaussian pulse.

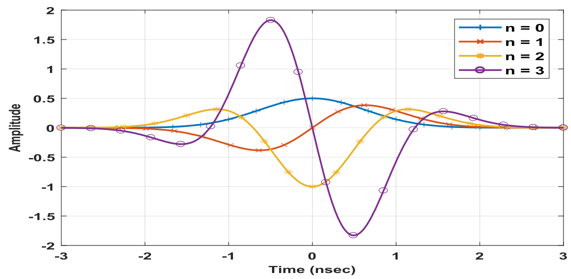

FIGURE 4. n^{th} order derivative of Hermite pulse.

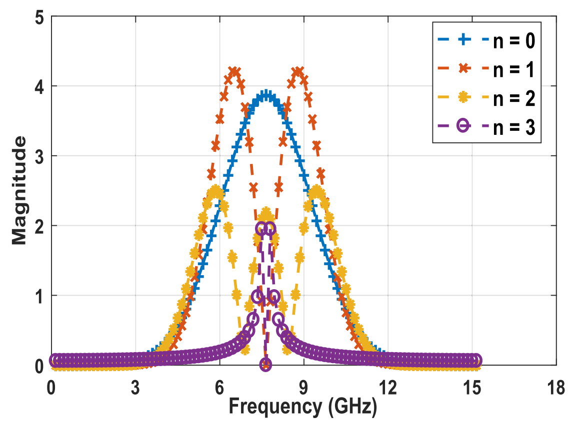

FIGURE 5. Spectrum of n^{th} order derivative of Hermite pulse.

spectral mask without the carrier signal. Generating B-spline pulses are rather complex. Moreover, its baseband signal is not appropriate with FCC mask [31]. Therefore, the second derivative Gaussian pulse as seen in Figure 3 is a commonly used pulse for UWB communication [31].

Hermite polynomials were proposed by Charles Hermite (1822-1901). Hermite pulses are a set of orthogonal polynomials that occur over a domain (-∞,∞).

Hermite polynomial can be expressed by the Rodrige's formula as:

$$h_n(t) = (-\tau)^n e^{\frac{t^2}{2\tau^2}} \frac{d^n}{dt^n}\left(e^{-\frac{t^2}{2\tau^2}}\right) \tag{7}$$

where $n = 0, 1, 2, 3, ...$ and $\frac{d^n}{dt^n}$ is the n^{th} derivative. The parameter τ is the time scaling factor. Thus, according to the study performed in [2] and [3], the Hermite pulse proved its superiority in reducing noise compared to by the second derivative Gaussian pulse.

In Figures 4 and 5, the time domain and the spectrum concerning Hermite pulse are exhibited. The orthogonality of all derivatives reside Hermite pulses is presented in Figure 4 and it occupies the required UWB bandwidth by center frequency approximately equal to 7 GHz as delighted in Figure 5. For the new proposed system utilizing Hermite pulses as its pulse shaping, it will be more robust against Rayleigh fading combined with shadowing to gain a boost in its performance over the recommended pulse by IEEE WBAN 802.15.6 standard for UWB communication represented by second derivative Gaussian pulse.

V. VIRTUAL MIMO IN IR-UWB WBAN

Multi-Input Multi-Output (MIMO) is one of the imperative advances for the wireless communication systems to increase channel capacity under fading conditions. Presently, the time comes to make sense of its utility in WSN to get energy efficient network. MIMO implementation requires more transmit and receive antennas. In normal WSN, a sensor node has just a single transmit antenna system which naturally represents Single Input Single Output (SISO) communication. In the transmitter side of WSN every transmit antenna must be put adequately far separated by $\frac{\lambda}{2}$ where λ is the wavelength of transmitted signal, to get uncorrelated signals [34]. For a tiny sensor node due to space impediment and to minimize circuit complexity, a new proposed concept termed Virtual MIMO (VMIMO) is proposed for WSN in [5]. In VMIMO, numerous sensor nodes are utilized to work cooperatively to accomplish multiple transmitting antenna systems, hence called a virtual antenna array. Thus, in a group of sensor nodes and cluster head there ought to be cooperative nodes.

The VMIMO technique is expected to limit the energy consumption of a sensor network as opposed to centering in minimization of energy consumption of individual nodes. In WSN for a successful full transmission and reception of information, WSN has both a transmitter and a receiver circuits. For short range communication in a sensor network circuitry, energy utilization is ruling the transmission energy consumption [35]. Under VMIMO with a higher order modulation scheme, it can be ready to transmit information in smaller time, besides it makes the circuit off for additional time. As, a result, we can save the sensor node energy and increment the lifetime of a WSN.

The only attempt to implement VMIMO for IR-UWB WBAN is in [6]. They perform comparison between SISO and MIMO modes by attaining BER performance of the network in both cases. According to [6] the pulse shaping used in IR-UWB system is the second derivative Gaussian pulse. In addition, the channel model maintained in [6] is the Rayleigh fading only without taking into account the shadowing exists in IR-UWB WBAN links. The study in [6] concentrates on proving the contribution imposed by using VMIMO by analyzing network layer parameters only with no consideration of the influence of its physical layer parameters. Even their obtained results do not show the VMIMO effect on the performance at each sensor participating in the VMIMO scheme. In addition Ding *et al.* [6] proposed VMIMO to improve only the diversity gain of the sensors in the WBAN.

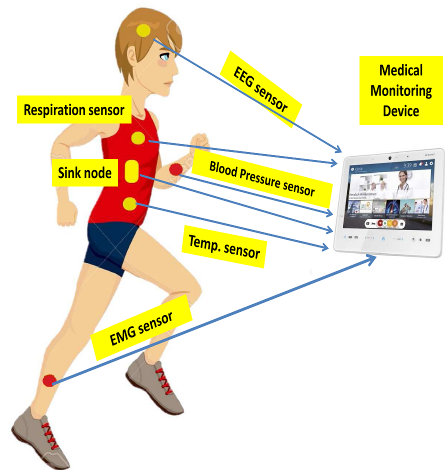

FIGURE 6. Proposed system body model with unequal seperation distance between sensors and monitoring device.

Thus in this paper, VMIMO is maintained in LDPC coded system using new pulse shaping. Additionally, VMIMO is proposed to perform spatial multiplexing for all sensors operating On-body. All simulation results illuminate the effect of LDPC coded VMIMO system especially on all sensors participated in WBAN.

As VMIMO implemented for the on-body sensors it requires an efficient receiver to manage these various medical information. Layered space time (LST) codes are proposed to distinguish between on-body sensors or hub transmissions successfully. LST perform differentiation using Minimum Mean Square Error (MMSE) decoder for the various received medical information all over the body. The decoder function is illustrated as follows:

$$\mathbf{W} = [\mathbf{H}^H\mathbf{H} + \frac{1}{E_b/N_o}\mathbf{I}_{M\times N}]^{-1}\mathbf{H}^H \tag{8}$$

where $\mathbf{I}_{M\times N}$ and $\mathbf{H}$ are identity matrix and channel matrix with size of $M \times N$. MMSE decoder is used in IR-UWB VMIMO system for WBANs to mitigate Rayleigh fading imposed by various on-body sensors.

Combining VMIMO with new pulse shaping portrayed by Hermite pulses, results in remarkable mitigation for noise of transmitting medical data. Each sensor is assigned a particular n^{th} derivative Hermite pulse. Thus, Hermite pulses have orthogonality property between its n^{th} derivatives.

VI. PROPOSED IR-UWB WBAN SYSTEM

As per our Knowledge, no attempt to implement IR-UWB WBAN using the later discussed elements of the physical layer of WBAN sensors. This work proposes a system for IR-UWB WBAN maintaining the later components concerning the physical layer of the sensors or hubs to enhance the performance of the one proposed in [6] which used the recommended components by IEEE WBAN 802.15.6 [31].

As demonstrated in Figure 6, different applications of WBAN sensors are presented by unequal communication

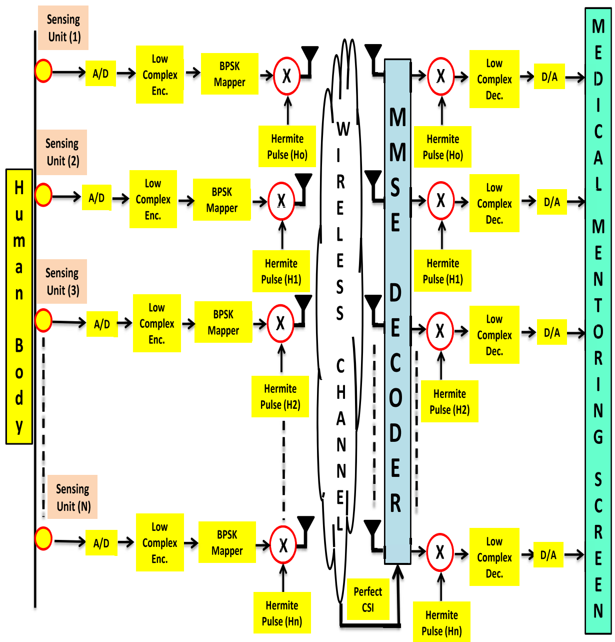

FIGURE 7. Proposed VMIMO IR-UWB WBAN system.

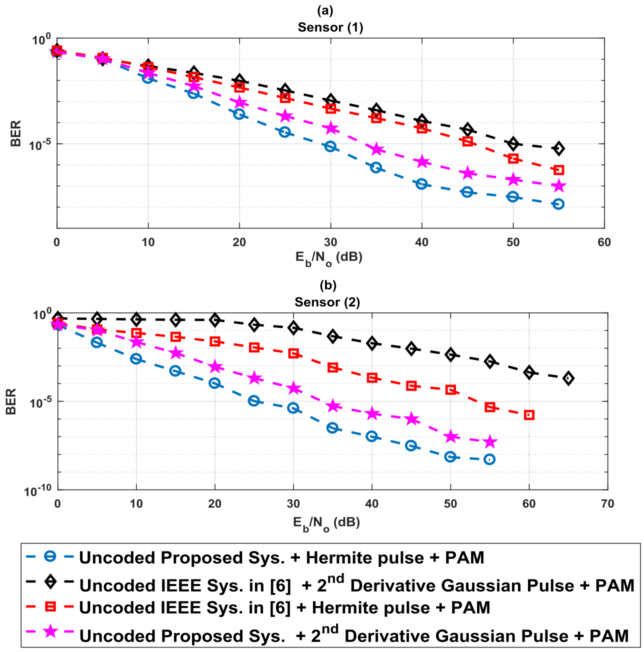

FIGURE 8. BER Comparision between proposed system and IEEE system in [6] employing PAM for different pulse shaping.

separation distances. In the proposed IR-UWB WBAN system, as shown in Figure 7, each component in its physical layer is enhanced by improved one as illustrated in the later sections. This system in Figure 7 presents the proposed physical layer for each sensor starting from new modulation/demodulation, new pulse shaping, VMIMO, low complexity LDPC encoding algorithm and new low complexity hybrid LDPC decoding algorithm. The new system maintains a realistic situation of IR-UWB WBAN by wavering the separation distance between on-body sensors or hubs and the device or fusion center held by medical representative.

VII. SIMULATION RESULTS

The selected channel model for the new LDPC coded VMIMO IR-UWB WBAN system consists of path loss and shadowing as reported in [1] representing Electroencephalogram (EEG), Electromyogram (EMG) and other medical measurements require high data rate information. From the point of view of biological safety, the highest transmitting power level is 0.55 mW or −2.55 dBm [1]. The 2 × 2 VMIMO case was chosen to prove the proposed idea and can be extended to higher number of transmitting sensors. The path loss of the maintained sensors in simulations is $PL_o = 43$ dB, $n = 3.75$ and $\sigma_{dB} = 7.5$ dB plus Rayleigh fading representing the radiating sensed data by unequal separation distance between sensors and the fusion center. The machine capabilities used for simulations are 2.7 GHz Intel Core i7 with 16 GB random access memory (RAM).

The uncoded system is first evaluated to check the best pulse shaping and modulation over WBAN channel. As delighnated in Figure 8, BER performance comparison for two-level PAM modulation between the proposed system

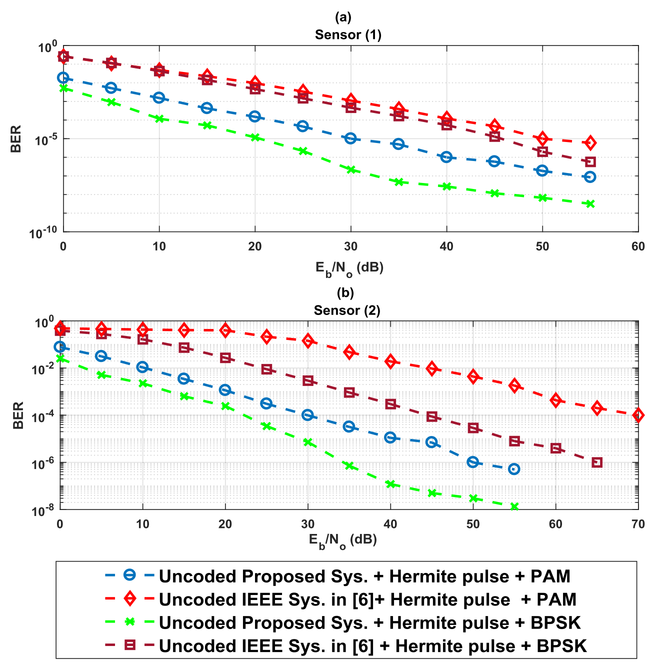

FIGURE 9. BER comparision between proposed system and IEEE system in [6] employing Hermite pulse for different modulation techniques.

employing Hermite pulse and the one in [6] using the second derivative Gaussian pulse (proposed by the IEEE standard of WBANs). The figure shows that Hermite pulse is superior over second derivative Gaussian pulse in mitigating channel impairments imposed in IR-UWB WBAN channel.

As shown in Figure 9, BPSK has better performance than PAM for Hermite pulse. This is because BPSK depends on the phase variations which has better immunity to noise.

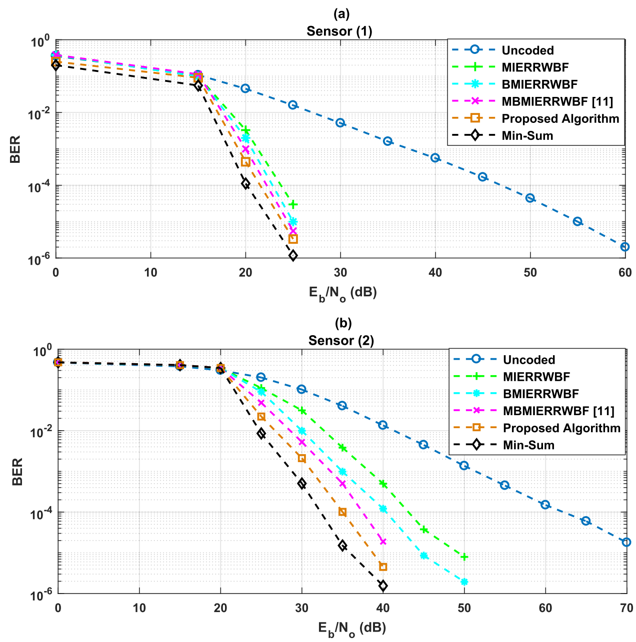

FIGURE 10. BER comparison between uncoded and coded proposed system using LDPC decoders.

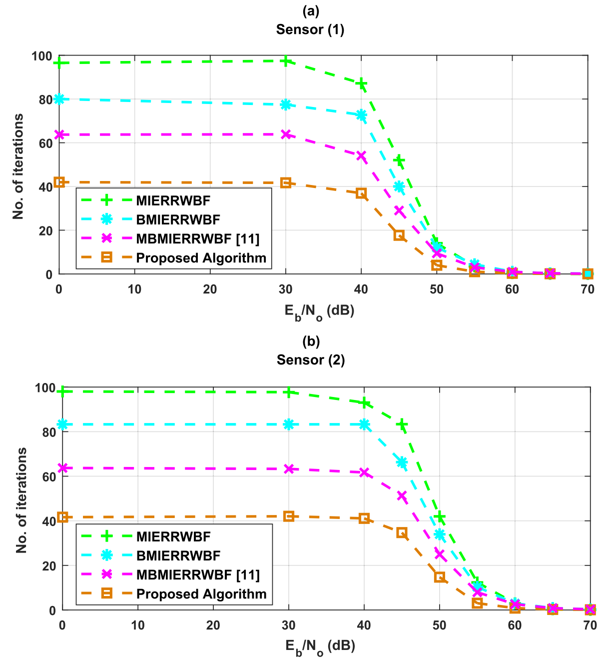

FIGURE 11. Number of consummed iterations comparison between proposed system with LDPC decoders.

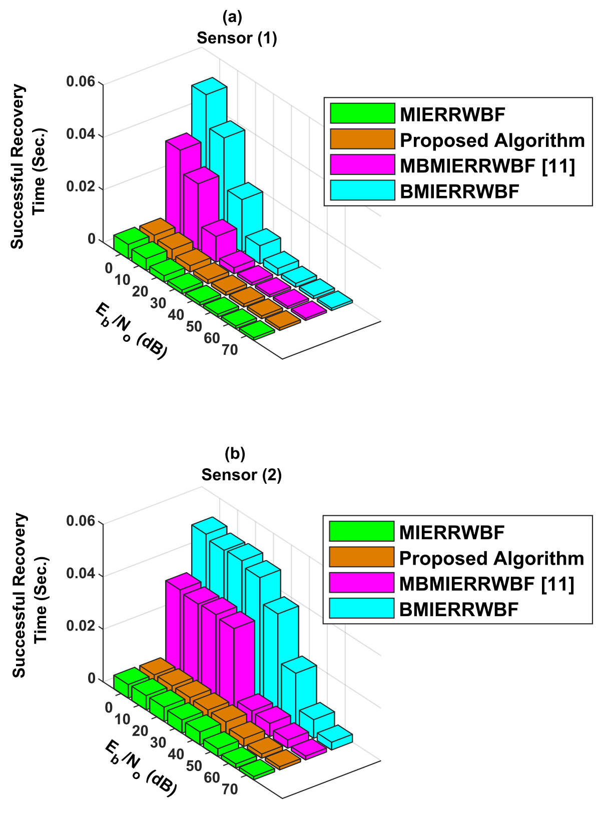

FIGURE 12. Successful recovery time comparison between proposed system with LDPC decoders.

The proposed system is evaluated using LDPC coding and BPSK modulation for on-body to off-body link. The regular PEG LDPC code is utilized with size $N = 504$ columns and $M = 252$ rows [32]. The BER of different LDPC decoders are plotted for both sensors in Figure 10 where the maximum number of iterations equals 600, the separation distance between the fusion center and sensor (1) is set to be 20 cm and sensor (2) is set to be 30 cm. It is observed that the proposed algorithm maintains the lowest BER in hybrid decoders which is close to soft decoder (Min-Sum) in both sensors. Although the min-sum algorithm achieves the lowest level in BER, however it is characterized by its excessive complexity that does not suit WBAN [25]. It is also clear that the BER for sensor (2) is worse than sensor (1), this is because the path loss increases as the distance increases.

Figure 11 shows the number of iterations required by the decoding algorithms for successful decoding. It is observed that the proposed algorithm has the lowest number of iterations in comparison with other algorithms. This is due to the usage of the proposed new bootstrap which enhanced the process of improving the reliability of unreliable received data from the channel.

The successful recovery time for all decoding algorithms in the proposed system is presented in Figure 12. As shown in Figure 12, MIERRWBF algorithm has the lowest successful recovery time where this algorithm is hard decision algorithm. For hybrid algorithms, the proposed one has the lowest successful recovery time due to the usage of the new bootstrap step.

The effect of the separation distance on the successful recovery time is presented in Figure 13 where sensor (1) attained shorter successful recovery time than sensor (2). This is because long separation distances impose sever impairments causing errors on the transmitted medical data and require higher number of iterations for successful recovery.

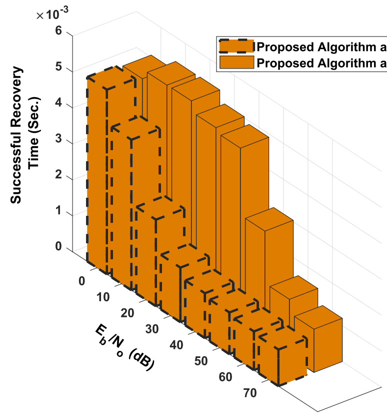

FIGURE 13. Successful recovery time comparison for different sensors located at different distances.

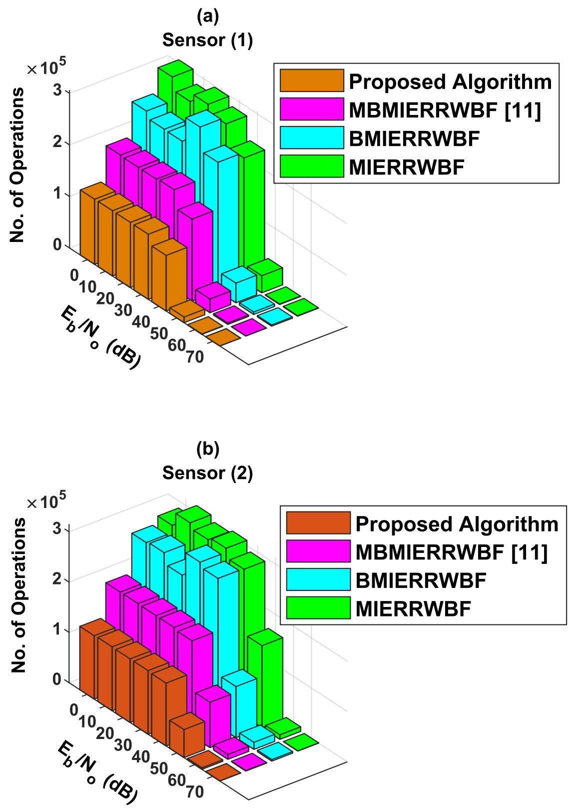

FIGURE 14. Number of operations between proposed system with LDPC decoders.

As shown in Figure 14, the system employing the proposed algorithm occupies the lowest number of operations relative to other algorithms delineated at all E_b/N_os. In addition, the proposed system using MBMIERRWBF algorithm occupies the second lowest place in the number of operations consumed as shown in Figure 14.

Figure 15 presents the throughput of all algorithms. The proposed algorithm achieved the highest level of throughput at both sensors. Thus, according to simulation results, the proposed algorithm proved its ability to operate successfully in sever channel impairments.

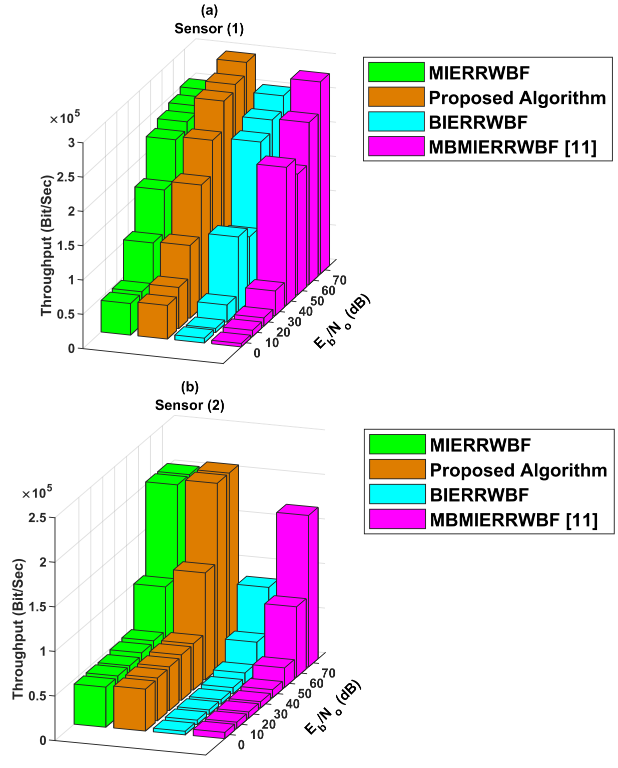

FIGURE 15. Throughput comparison of proposed system with LDPC decoders.

VIII. CONCLUSION

In this paper, new IR-UWB system is proposed for practical situation using low complex LDPC encoding, new hybrid decoding algorithm with pulse shaping. Furthermore, VMIMO technique is utilized to distinctively improve spatial multiplexing between on-body sensors. The proposed system conserves time and energy which are excessively indispensable in WBAN. Furthermore, the proposed system maintaining proposed algorithm has superior BER over all hybrid decision algorithms and approaches to soft decision algorithm. Moreover, it has the lowest number of iterations, successful recovery time, and number of operations and the highest throughput compared to other algorithms. Simulation results demonstrate the superiority of the proposed system over previous one.

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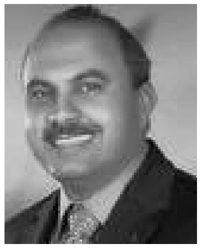

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