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Network Coding for Energy Efficient Transmission in Wireless Body Area Networks

Sadaf Talha^a, Rizwan Ahmad^a, Adnan K. Kiani^a, Muhammad Mahtab Alam^{b*}

^a*School of Electrical Engineering & Computer Science, National University of Sciences & Technology, Islamabad, Pakistan*

^b*Thomas Johann Seebeck Department of Electronics, School of Information Technology, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia*

Abstract

Wireless Body Area Networks (WBANs) is a technology that has revolutionized the health-care industry by allowing remote monitoring, early detection and prevention of diseases. Patients can be remotely monitored thanks to implant devices in the body or by placing nodes on different parts of the body. Often the deployed sensor nodes are constraint by limited battery sources and are required to continuously collect the data and transfer it to the sink node, thus requiring energy efficient communication schemes. In addition, in poor channel conditions, this data collection and transfer results in retransmission thus wasting useful energy. This work presents a cooperative network coding based transmission technique for spectrum and energy efficiency in WBANs. The bit error rate (BER) of the network coded path in comparison to direct communication approach is explored. The effect of WBAN path loss due to different node positions is also discussed. It is observed that node position greatly affects path loss and received power which in turn affect the BERs. Simulation results show that network coded cooperative communication strategy in WBAN channel with and without combining outperforms as compared to direct communication.

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Keywords: Wireless Body Area Networks; Cooperative Communication, Networks Coding; Energy Efficiency

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: muhammad.alam@ttu.ee

1. Introduction

Continuous improvements and developments have been seen in Wireless Body Area Networks (WBANs) during last decade. Remote monitoring of sick and elderly patients helps to examine them by using implant and wearable wireless devices. This provides comfort and ease to patients particularly the elderly patients enabling them to keep track of their health while at the same time reducing visits to the hospitals¹.

WBANs consist of multiple battery driven nodes placed either inside or on the human body. One of the major challenges in WBANs is to design a communication mechanism between these nodes in such a way that energy is efficiently utilized and network lifetime is maximized. This results in maximum life time of nodes as replacing them frequently is not desirable².

To overcome this challenge, on one hand, WBAN nodes tend to operate at ultra-low power, which is desirable due to short communication range and also to avoid un-necessary interference among co-located BANs. On the other hand, very low transmission power results in high Packet Error Rates (PER) which means more re-transmission and low Packet Delivery Ratio (PDR)³⁻⁴. In addition, under realistic time-varying propagation conditions (i.e. channel fading and body shadowing), the performance further degrades. Therefore, it is important to have the right balance between transmission power and PDR performance. In WBAN specific standard (i.e. IEEE 802.15.6) channel models are classified as CM1-CM4. They are basically segregated according to the location of nodes. CM1 addresses the communication of in body nodes whereas; CM2 is for in body to on body nodes communication. CM3 is linked to the communication of on body nodes and CM4 is for OFF body node transmission. There is a big challenge in designing an energy efficient transmission strategy for CM1 and CM2 as human body has a complex structure consisting of tissues and cells.

In order to cater above- mentioned challenges of WBANs, cooperative communication is considered as the best strategy as it addresses simultaneously the issues of link reliability and energy efficiency of nodes⁵. Cooperative Communication is more energy efficient than direct communication. Cooperative communications via Network coding is an active research area in WBANs as it improves the network throughput and provides energy efficient transmission⁶⁻⁷.

The main contribution of this paper is application of Network Coding in a cooperative WBAN scenario. The Decode and Forward (DF) relay decodes the source signal, adds its own data in it and re-encodes into a single data stream before forwarding to the destination. Finally, selection combining is employed at the destination to minimize the number of transmissions and overall delay in data forwarding. Typically, in WBANs, nodes are placed on different parts of the body (i.e., in-body or on-body). It is shown that network coding in a cooperative communication significantly improves the performance in comparison to the direct communication. This paper is organized as follows: Detailed system model and scenario are presented in the next section. This is followed by performance analysis and simulation results in section 3. Conclusions are presented in section 4.

2. Cooperative Communication Scenario and System Model

In this paper, a cooperative transmission technique is presented that effectively transmits the data of source and relay in a WBAN. We consider a cooperative scenario comprising of a source node (S), a relay node (R) and a destination (D), where network coding is employed in WBAN channel. The transmission is executed in two phases; in phase 1, source will broadcast the data using a simple BPSK modulation which will be received by destination and relay. In phase 2, relay upon receiving the data will first decode the received data. It then adds its own data in it by a simple exclusive OR (XOR) operation and transmits this as a single data stream to the destination. This approach will help in effectively utilizing the spectrum and energy.

Figure 1, shows the placement of sensor nodes for intra-body communication. Destination node also known as the Sink is the central coordinator having maximum power and lifetime as compared to rest of the nodes. It controls and coordinate the communication of all the other nodes placed on the body. The remaining nodes have equal power and data rates. Their responsibility is to carry the data from child nodes to Sink.

For illustration purpose, this paper focuses on three nodes placed on right arm using cooperative communication scenario as shown in Figure 1. We assume that all the nodes are capable of using cooperative communication. Network coding is

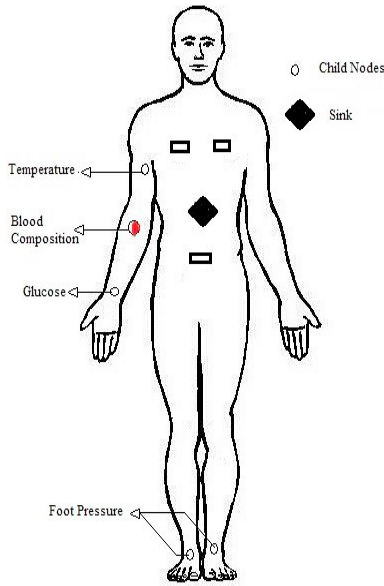


Figure. 1. Nodes Deployment for Cooperative Scenario in Wireless Body Area Network.

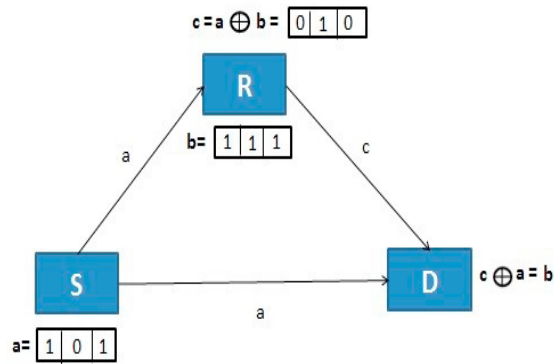


Figure. 2. Cooperative Communication Scenario.

used at the relay to integrate relay’s data with the source data and importantly the destination is capable of applying combining techniques on the received data. This process is shown in Figure 2. Below a simple illustration is presented to explain the application of the network coding in a WBAN in an ideal channel conditions.

In phase 1, S broadcasts the signal $a=101$ which will be received by R and D. It is important to note that here R is not a mere repeater but it has its data $b = 111$ to forward as well. Therefore, it first decodes the source data then xor its own data with it. Consequently, the new signal becomes $c = 010$. This combined signal is forwarded to D, which then, by using both direct and cooperative transmission, decodes both S and R data. In this way, twice the data will be transmitted in single transmission thanks to cooperative communication¹³⁻¹⁴. The network coding can provide significant gain in terms of bandwidth utilizations and throughput over conventional non-cooperative communication as explained in⁸⁻¹².

3. Performance Analysis and Simulation Results

Let $h_{s,r}, h_{r,d}, h_{s,d}$ be the complex Gaussian gain, $n_{s,r}, n_{r,d}, n_{s,d}$ be the Gaussian noise, $\gamma_{s,r}, \gamma_{r,d}, \gamma_{s,d}$ be the SNR and $P_{s,r}, P_{r,d}, P_{s,d}$ be the path loss from source to relay, relay to destination and source to destination. The effect of path loss by changing nodes positions on human body are also added in the analysis. Let ‘x’ be the source data symbol. The received signal after broadcast at the relay is:

$$y_{s,r} = h_{s,r} * x * P_{s,r} + n_{s,r} \tag{1}$$

Relay upon receiving y_{sr} first decodes the data. It then apply simple xor operations on received data and its own data ‘x1’. Let the new signal be $x\sim = x \oplus x1$ after performing xor on both data. It, re-encode and forwards the single data stream to D. The transmitted single data stream from R-D is given by

$$y_{r,d} = h_{r,d} * x\sim * P_{r,d} + n_{r,d} \tag{2}$$

In the same way, transmitted signal via direct link is:

$$y_{s,d} = h_{s,d} * x * P_{s,d} + n_{s,d} \tag{3}$$

The path loss between the transmitting and receiving nodes is given by log normal distribution as1:

$$PL(d) = PL(d_0) + 10n\log_{10}(d/d_0) + \sigma_s \tag{4}$$

Here, d_0 is the reference distance, $PL(d_0)$ is the path loss at reference distance, σ_s is the standard deviation and n is the path loss exponent [9]. Generally, the value of path loss depends upon frequency as well as distance and is

expressed as, $PL=20\log_{10}(4\pi df/c)$. The path loss variations against varying distances are shown in Figure 3 for implant-to-implant communication.

Let us consider the distance between source to relay is d_1 , relay to destination is d_2 and source to destination is represented as d_3 . An arm length d_3 is taken as approximately 45 cm in each scenario. Values of d_1 and d_2 are varied to observe the impact of relay placement.

For simulation purpose, we have considered two different scenarios: 1) Symmetric placement of nodes and 2) Asymmetric placement of nodes. In first case, R is supposed to be exactly in the center of S i.e. $d_1=d_2$. In second scenario, position of R is varied between S and D. It is pertinent to mention that D node is considered as fixed. For different positions as distance between nodes changes, its path loss also varies accordingly.

Figure 4, shows the Symmetric link scenario where R is placed exactly between S and D i.e. $d_1=d_2=22.01$ cm and the gains of all links are kept same. BER results show that the network coded signal performs better as compared to direct transmission. In addition to source data, relay's data is also received and generally the BER of relay signal is better than S data. At low SNR both relay and network coded source signal (NCSS) nearly achieve same

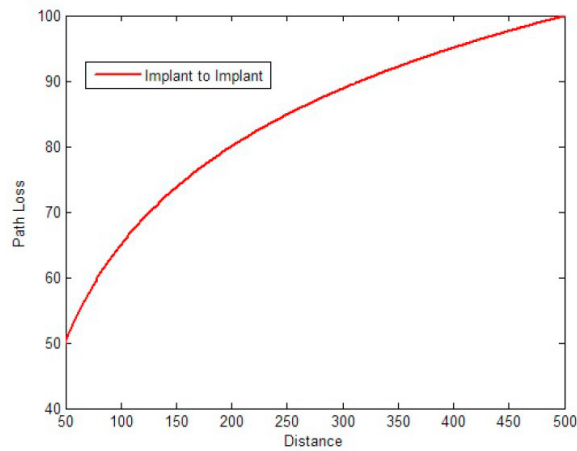


Figure 3. Path loss (dB) vs distance (mm) for implant to implant nodes.

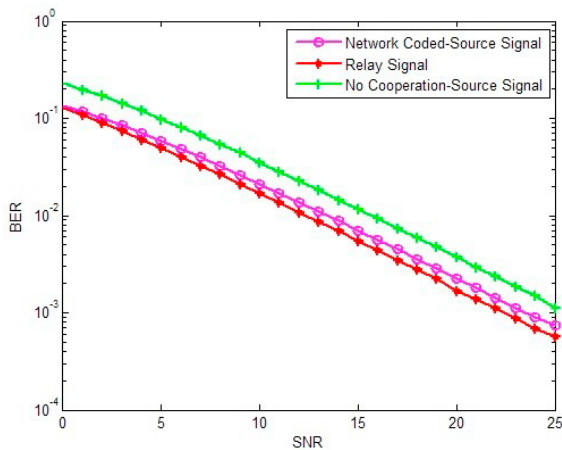


Figure 4. BER vs SNR for Symmetric links.

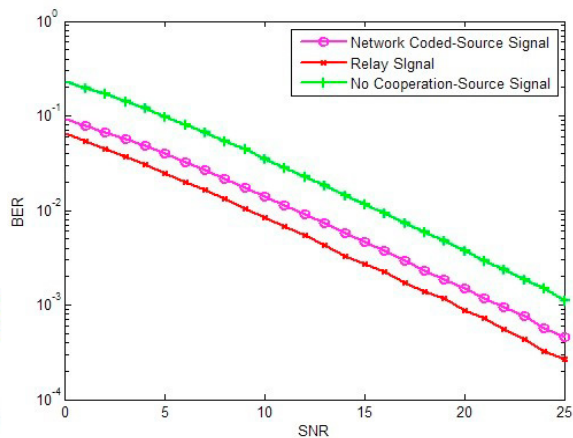


Figure 5: BER vs SNR for Asymmetric links when $\gamma_{s,r} = \gamma_{r,d} = \gamma_{s,d}$.

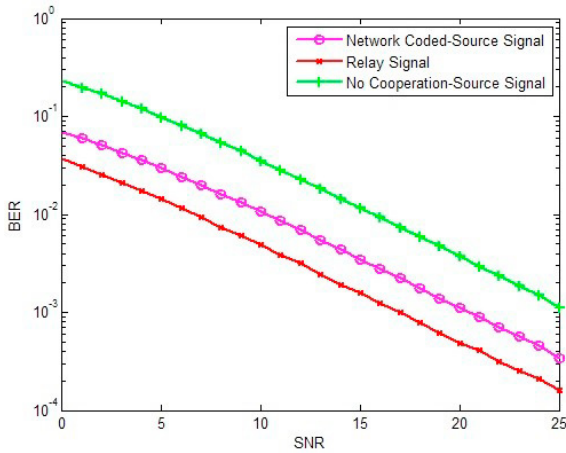


Figure 6: BER vs SNR for Asymmetric links when $\gamma_{s,r}$ and $\gamma_{r,d}$ are 10 dB higher than $\gamma_{s,d}$.

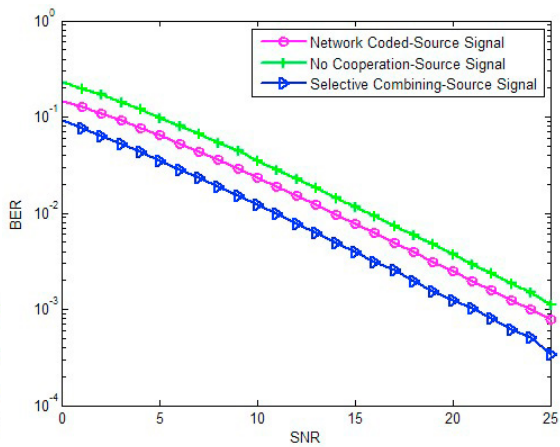


Figure 7: Comparison of BER vs SNR for Source signal when $\gamma_{s,r} = \gamma_{r,d} = \gamma_{s,d}$.

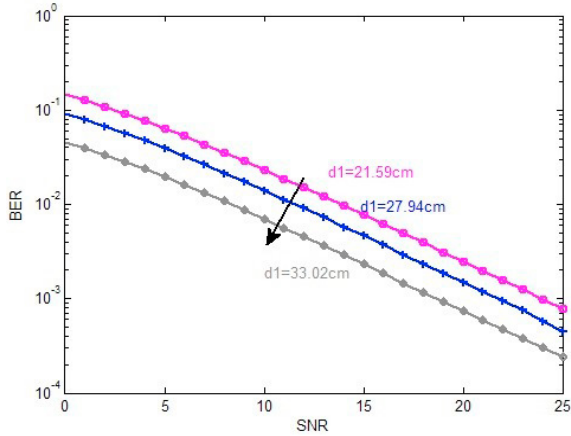


Figure 8: BER vs SNR for different values of d_1 .

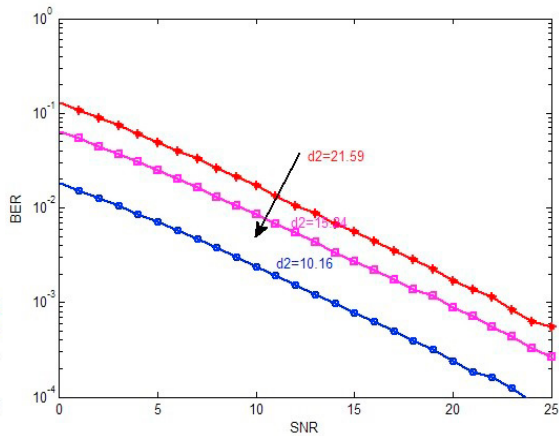


Figure 9: BER vs SNR for different values of d_2 .

performance, however, as SNR increases the relay signal achieve better performance. For example, at SNR of 15 dB, BER of network coded S data is 9% better as compared to S data via direct transmission.

Figure 5 shows an asymmetric link scenario where $d_1=27.94$ cm and $d_2=15.24$ cm. In this case, channel gains of links are kept same; however, path loss is different due to different distances. The gain achieved by the relay transmission is much better than NCSS even at low SNR values. Whereas, in Figure 6, $\gamma_{s,r}$ and $\gamma_{r,d}$ are 10 dB higher than $\gamma_{s,d}$. Results for both NCSS and relay signal show significant improvement in BER when the channel gain is increased by 10 dB. Finally, in Figure. 7, impact of using selective combining on source data is shown. It depicts the comparison of source data for direct path, network coded path and lastly when selection combining is used. The results are for symmetric case where SNR of all three links is kept same. It can be seen that the selection combining approach results in an overall improvement in terms of BER for the source data. Results show that at SNR of 10 dB, data received via selective combining is almost 45% better as compared to network coding path and 65% better than the direct transmission data.

Figure 8 and Figure 9, shows the affect of different values of distances on BER respectively. In Figure 8, arrow shows increasing value of d_1 and Figure 9 decreasing values of d_2 . Here S data via network coding scenario is shown

in Figure 8 and in Figure 9, BER of R's data via network coding is shown. There is no impact on the results of BER of direct transmission in both these cases and therefore, it is not presented. For each distance, its corresponding path loss value is incorporated in the simulations. Results shows that better BER can be achieved as the R approaches closer to D. There is almost 39% increase in BER when d_1 value increase from 21.59 cm to 27.94 cm. This is because the cooperative end-to-end transmission mainly depends upon the second path. Hence, greater value of d_1 and lower the value of d_2 results in better performance.

4. Conclusion

Network coding provides a spectrum and energy efficient technique to transmit multiple user data streams in single end-to-end cooperative transmission in WBAN. Initial investigation of the scheme shows improved BER for the first user in addition to the second user data. Availability of two copies of the same data through diverse paths creates scope for simple combining techniques. The BER results of selection combining shows significant improvement. The paper concludes by showing the effect of path loss on different node positions. It is evident from the results that moving relay closer to the destination can result in improved BERs. In future, it is possible to include more complex combining techniques keeping the WBAN energy and complexity constraints and devise efficient relay selection strategies.

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