Computers and Electrical Engineering 50 (2016) 111–124

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Multi-relay cooperative body surface communications in ultra-wideband body area networks☆

Deepak Kumar Rout[a,*], Susmita Das[b]

[a] Signal Processing and Communication Lab, Department of Electrical Engineering, National Institute of Technology, Rourkela, India
[b] Department of Electrical Engineering, National Institute of Technology, Rourkela, India

ARTICLE INFO

Article history:
Received 25 October 2015
Revised 8 February 2016
Accepted 8 February 2016

Keywords:
Body area networks
Cooperative communications
UWB
Amplify and forward
Decode and forward
Multiple relays

ABSTRACT

Ultra-wideband (UWB)-based body area networks (BAN) are envisioned to provide health care to patients on the move, and monitor patients' health. Since UWB uses transmit power lower than 1 mW, the link performance degrades due to absorption in body tissues and channel impairments. In BAN, multiple sensor nodes present between the transmitter and the receiver can act as relays to improve the link quality, thereby improving the energy efficiency and reliability.

In this paper, we suggest a novel cooperative communications scenario for BAN and present a comparative bit error rate performance analysis of amplify forward and decode forward strategies using multiple relays. A power performance analysis, and validation of performance by transmitting electrocardiogram signals and magnetic resonance images, and recording the bit error rates, root mean square error and peak signal to noise ratio proves that proposed methods provide better performance compared to direct transmission.

1. Introduction

Technology has led the health care revolution in the world ever since X-ray scanners and other electronics devices like magnetic resonance imaging (MRI) and electrocardiogram (ECG) sensors came to picture. These devices not only help to locate anomalies but also enable early detection of diseases. However, a shortcoming of these methods is that they do not support patient mobility. For patients who have to stay under continuous supervision, the only way is to remain hospitalized. In a much better dimension, the body area networks (BANs) are being developed to collect these data without hampering mobility of the patients. Sensors are mounted on or inside the human body to obtain the different medical signals and transmit it wirelessly to any nearby medical monitoring centre. BAN will facilitate the wireless transmission of the vital health data and enable the monitoring of patients and early detection of diseases. They will replace the existing telemedicine and remote health monitoring systems. The information acquired by the sensors are transmitted to a remote medical monitoring centre which also helps in tracking patients in cases of emergency; so that health services can reach in emergencies [1]. To provide all these facilities, high data rates and reliable communication are needed along with excellent link quality. The communication must be energy efficient so that an implanted sensor will be able to transmit wirelessly throughout its useful lifetime. All these requirements make ultra-wideband (UWB) the most suited candidate for BANs, as it

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. Jia Hu.

* Corresponding author. +91 9692460769.
E-mail address: deepak09@live.com (D.K. Rout).

http://dx.doi.org/10.1016/j.compeleceng.2016.02.006
0045-7906/

uses low power pulses for communication in the 3.1–10.6 GHz band and provides a data rate high enough to carry medical signals and other system data. However, there is a small issue. BAN channels are quite different from the existing wireless channels and involve attenuation due to body tissues. The motion of body parts severely degrades the communication link performance. Losses and degradations can be overcome in conventional UWB communications by increasing the transmit power level, but in BAN this is not a preferable option, since the transmit power must be minimized to save battery life and prevent any damage to human body tissues. Hence, other options should be explored to improve the link performance.

A variety of techniques exists to improve link performance in the conventional wireless communication research archives. The most feasible to the BAN is the use of cooperative communications. In BAN multiple sensor nodes are present between the source and destination nodes which can be used as relays to improve the link quality without increasing the transmitted power.

In [2], Nosratinia et al. investigate the advantages, benefits and the progress in the area of cooperative communications. In [3], Guan et al. propose an AF and DF mixed relay network which improves the availability of relays. In [4], way back in 2004, Laneman et al. suggested low-complexity cooperative diversity for wireless networks. In [5], Khan et al. present a performance analysis of single relay and multiple relay cooperative networks over Nakagami and Rician fading channels. As explained prior, in BAN power consumption is a major issue, as a sensor has to work during its useful lifetime with its only energy source. Similar scenarios are already addressed in context to conventional wireless sensor networks in [6,7] by Sadek et al. and Zhang et al., respectively, where they propose approaches to achieve power control so as to improve system efficiency. In [8], Shirvanimoghaddam et al. propose two rate-less transmission schemes along with their performance analysis. The techniques use both AF and DF-based transmission and provide efficient performance. However, the channels used for the study are flat and block fading channels. Thus, such studies are inapplicable for BANs where the channels are quite dissimilar. In [9,10], Nazir et al. and Arrobo et al. have proposed methods for increasing reliability of BANs. While Nazir et al. propose a cooperative cognitive wireless body area networks (WBAN), Arrobo et al. suggest methods to improve reliability and suggests using cooperative communications. In [11] Smith et al. have suggested cooperative communications for BAN but their work is limited to the 2.36 GHz band, and the BAN channel used is different than the UWB BAN channel recommended by the institute of electrical and electronics engineers (IEEE) 802.15 task group 6 in [12]. In [13], Smith et al. present the performance of DF-based cooperative strategy with maximal ratio combining (MRC) and coherent selection combining (CSC). The study is on several hours of empirical data from measurements involving five subjects; it is again in the 2.36 GHz band. The work present in the research papers [2–12] present concepts for a reliable communication all of them are based on conventional Rayleigh and Rician fading channels or in the 2.36 GHz band. BAN channels are different from these existing wireless channel models. There are differences in pathloss and other channel characteristics between the narrowband (400, 600, 900 MHz and 2.4 GHz) and the wideband (UWB 3.1 to 10.6 GHz) channels. BAN channels are different because the medium varies, anything from wireless and human body scenarios to a combination of both persists. And that is why they are modelled not only by taking into account the losses due to the wireless medium but also the losses due to body tissues, and the movement of body parts with respect to each other.

The existing work mentioned either focuses on the narrowband 2.4 GHz ISM band or does not focus on the BAN channels. While in a few research articles, cooperative communications have been proposed for BANs, it is merely mentioned and no practical analysis or simulation is attempted. Therefore, a thorough analysis and investigation of these cooperative relaying strategies in the UWB band of BAN will be beneficial for further implementation.

It is worthwhile to mention here that while multiple articles have studied the performance of AF and DF relays in several channel conditions [14–16], the performance of these schemes has never been studied for body area network conditions.

Hence, in this paper, we have proposed a novel multi-relay UWB-based BAN system. Both theoretical as well as simulated performance have been studied and simulated on the IEEE 802.15 task group 6 designated CM3 channel model. The work mostly focusses on the performance analysis of AF and DF relaying against and direct transmission for BAN communication in the 3.1–10.6 GHz UWB band. Direct transmission is when there is absence of a relay between the source and the destination.

The paper initially presents a brief overview of the UWB-based BAN system in Section 2. The channel characteristics for body area networks are explored in Section 3. The multi-relay cooperative communication system is discussed and its salient features are presented in Section 4. It is further described that how a multi-relay scenario can be applicable for the BAN system. A theoretical based study is then presented in Section 5 to calculate the bit error rate performances. Simulation results in Section 6 prove the propositions made in the article. In Section 7, we validate the performance of the proposed system by transmitting medical signals and images.

2. A brief overview of UWB-based body area networks

UWB BAN is a variety of wireless sensor networks proposed for remote health monitoring. They provide higher data rates than the other forms of BAN in the 400–2400 MHz range. In BAN tiny sensor nodes implanted on or inside the human body and they collect vital health information in the form of blood pressure, blood sugar, electrocardiogram (ECG), electroencephalograms (EEG) and other critical parameters [1]. The combined medical signals like a combination of ECG, EEG and some medical signals like the MRI images require very high data rates and UWB BAN has the real potential to provide it. And this demand for higher data rates makes UWB the most preferred candidate for BAN.