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Engineering

ENERGY EFFICIENCY IMPROVEMENT OF COOPERATIVE COMMUNICATIONS IN IEEE802.15.6 IR-UWB WBAN

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ABSTRACT The work presented in this paper scrutinizes the use of cooperative communication scheme with one-relay for improving the energy efficiency of Ultra-wideband based Wireless body area networks. However, various investigations have been performed in the parameters like hop distance and channel error and its influence upon the energy efficiency. Based upon several analytical and simulation results it has been observed that there is an enhanced energy efficiency for cooperative communication than direct communication, for all values of source to destination hop distance. The results also reveal that there is a threshold behaviour exist regarding energy efficiency which separates locations of direct transmission from the locations where cooperative communication will be beneficial. The simulation results depict that if the channel conditions are poor, when the source to destination distance is greater than a threshold value cooperative communication technique gives better energy efficiency when compared with direct communication scheme.

KEYWORDS : Ultra wide band, Wireless body area networks, Energy efficiency.

1. INTRODUCTION

The applications of UWB (large data rate-short distance or low data rate-long distance) to a great extend is restricted by the restrictions on the transmit power (i.e; the power limit is below 0.5mW) .The physical layer signal structure balances the tradeoff of UWB. The reduced transmit power implies that multiple low energy UWB pulses need to be combined to transport 1 bit of information. Higher number of pulses per bit implies lower data rate and hence larger transmission distance can be achieved. The interference created by UWB signals on already prevailing narrow-band radio systems is very low because of its low power spectral density(PSD). The UWB transmitter skips the additional radio frequency mixing stage by producing a very short pulse, which can propagate by itself, and hence the large modules used in the current narrow band systems such as modulator, demodulator and intermediate frequency(IF) stages which are highly expensive are not a required for the UWB transceivers. This ultimately results in the size,cost and weight reduction and reduced power consumption of UWB systems compared to narrowband systems for communication.The RF mixing stage involves the injection of a carrier frequency into a base band signal and thereby transforming the base band into a pass band that has desired propagation characteristics. The ultra high bandwidth of the UWB signal enables it to span over a range of generally used carrier frequencies. The UWB signals can propagate without the need for amplification and additional upconvertion. It is clear that the UWB technology enables to achieve huge data rates and also is a feasible solution for a short range-high data rate communications.

For providing spatial diversity to combat multipath fading, and for improving the link reliability and throughput of wireless sensor networks, various techniques are presently considered for research, of which, cooperative communication proposals are focussed more [1,2]. Cooperative communication uses a relay mechanism to improve the communication link efficiency. The underlying concept is that the systems having relay nodes placed between the transmitter and the receiver are used to amplify or decode and retransmit the signal to the receiver. Cooperative schemes are mainly of two types , amplify and forward (AF) and decode and forward (DF) which could be either adaptive or fixed. The relay amplifies the signal received and retransmits it to the primary receiver in the case of AF relaying scheme. The relay mechanism in DF relaying, decodes the received signal and retransmits it to the receiver. Cooperation can tremendously reduce the BER and thereby enhance the network lifetime compared to direct transmission. The traditional cooperative relaying mechanism causes a wastage of the various channel resources since the relay always forward the signal without taking in to consideration the various channel conditions. Usage of the orthogonal channels for communication, by the relay and the source, causes cost of extra resources even if relaying is not needed due to successful direct communication between the source and destination pair. The conservation of the various channel resources form the main objective of incremental relaying schemes. If the source-to-destination link SNR is sufficiently high, an acknowledgement (ack) from the destination could be used to indicate that there exists a successful direct transmission link and that the technique of relaying is not needed. If the source-to-destination link SNR is not large enough for the transmission successful, a negative acknowledgement (nack) is sent by the receiver to indicate that the relay is needed for data forwarding. Thus an efficient usage of the channel resources can be done, with respect to conventional cooperation scenarios. The incremental relay scheme proposes that the relay forwards only when in times of necessity [2].The conventional schemes necessitate the usage of a very sophisticated combining technique and synchronization for acquiring a spatial diversity benefits among geographycally separated relays. In the case of an incremental relaying technique,the destination operates only a single signal at a time . Therefore, co-phasing and combining can be excluded leads to simplified receiver units. Inorder to compare the consumption of energy between cooperative and non cooperative transmission schemes, we taken into account both transmit circuit energy and receiver circuit energy.

In the present scenario, cooperative and multi-hop communications are treated as effective methods inorder to enhance the energy efficiency of BANS [1-3]. An additional spatial diversity is the result of cooperation by adopting an independent multipath via the relay , can enhances the reliability of transmission in opposition to various channel disorders like fading .In [3] authors investigate about the analysis of energy efficiency of single-hop and single relay based co-operative communications in the context of multipath fading for different channel models . The work in [3] also proposes a model for energy efficiency in 2-hop communication in multipath fading. Adding to that, an optimal packet length to reach the maximum energy efficiency is also investigated. In [4] authors proposed a relay selection procedure for energy efficiency cooperative communication .

The rest of the paper is coordinated in the following manner: Section II describe the system model followed in the work and packet success probabilities. Section III actually provides a detailed analysis of energy efficiency.Section IV focuses on the simulation results and section V concludes the paper.

II. SYSTEM MODEL

An arrangement of remote sensor nodes which speak with the center point hub is being considered. Uplink comprises a communication from sensor nodes to the hub and downlink constitutes communication from hub to the various sensor nodes. According to the standard IEEE 802.15.6 , a hub can handle up to 64 nodes.There are 11 channels are defined for the UWB PHY in the 3.1- 10.6 GHz spectrum band, each with a channel bandwidth of 499.2 MHz.The nodes transmit in the orthogonal time slots . The standard emphasizes upon two modes for IR-UWB PHY: the Default mode and the High QOS (Quality of Service) mode . The default mode is used for nonspecific WBAN demands ,uses an on-off keying signaling (OOK) and BCH (63, 51) code is used for forward error correction, and is being considered in this work. A non-coherent receiver that is suboptimal in nature which is rest on either energy detection (ED) or autocorrelation (AC) is considered because of the demand for the low complexity receivers.

Relay node is to be placed at a distance that measures exactly half of the total distance between the source and destination nodes to provide a maximum energy efficiency. Equal amount of data on both s -d link and the r - d link is considered. The sensor nodes transmit in various orthogonal time slots therefore the multi-access interference effect can be neglected. A half-duplex communication is another assumption and also it is supposed that all the nodes are inside the transmission range of each other [5]. The type of the link between the source and destination nodes in the sensor network is exposed to narrowband Rayleigh fading, propagation path-loss, and Additive White Gaussian Noise (AWGN) is being considered. The channel fades are supposed to be mutually independent for different links. In direct communication scheme, only a direct transmission between the source and the destination nodes is permitted. If the channel between the source and the destination suffers from deep-fading and shadowing, the communication between S-D fails in the case of the first scheme. The WBAN nodes are been around slow fading because of limited mobility, the channel remains in deep-fade for prolonged intervals. Therefore an automatic repeat request (ARQ)protocol would inadequate.

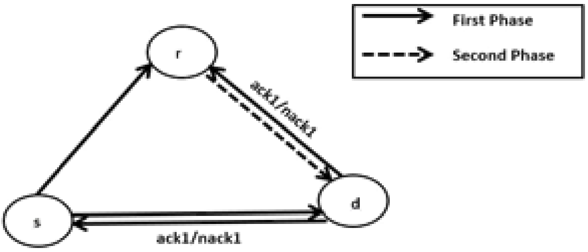

Fig. 1. single-relay incremental cooperative communication model

Two- stage cooperative communication occurs between source and destination, in which both nodes exchange their data using relay[2]. The first stage of the communication, consider the source transmits a packet to the destination which is also overheard by the relay, since the broadcast medium is wireless. In case ,if destination decodes packet properly, it sends ack and relay must continue idle and if destination does not decode packet properly ,it sends nack to source. The relay if it obtains the packet containing the data correctly in the first phase, then it forwards the packet to the destination during the second phase .If the destination is able to decode the packet correctly then destination sends acknowledgment and there exists successful relaying. If destination does not decode the data properly in the second phase, the single - stage relaying fails, thus there is failure in s - d and r - d links. Whereas if relay does not decode the packet properly in first phase the packet is dropped .Hence single - stage relaying fails because of the failure of both s - d and s - r links. A higher layer protocol, by means of time out mechanisms and sequence numbers can effectively manage the dropped packets which are the extensions and are not described in the present analysis.

III. ANALYSIS OF ENERGY EFFICIENCY

This portion describes the energy efficiency models of direct, single stage cooperative communication in detail.The energy resources required by the sensors are limited and also it needs a long operation time. Re-charging the battery of the hub is a suitable task and thus the sensors and hub have dissimilar energy consumption costs. Therefore the uplink energy consumption cost is higher same with the case of the reception on the downlink.

Let E_{enc}=E_{dec} represents the energy needed for data encoding/decoding. Also let $^{E}tx\_ack$ = $^{E}rx\_ack$ denotes the energy needed for the transmission/reception of acknowledgment packets. The various constants Cr_{dl}, Ct_{dl}, Cr_{ul}, Ct_{ul}, and indicates the energy consumption costs for reception and transmission on the downlink and uplink scenarios respectively. Let N_p denotes the number of pulse per symbol. Let *Etx_p* represents the total energy required for the transmission of a pulse (includes the processing energy of the electronic circuit and radiation energy) and *Erx_p* represents the total energy utilized by electronic circuits for the reception of a pulse. *R* represents the coding rate of data payload, indicated as number of bits per symbol, is depends on modulation.

A. DIRECT COMMUNICATION

In [5], energy efficiency model of 1-hop communication for impulse radio based UWB WBAN is proposed.The packet success probability for direct and single relay cooperative communication is derived in [11]. We considered that *l* encoded bits are there in the data packet for transmission from a sensor to the hub.Let $^{E}tx\_d$ stated as the energy needed for transmitting a packet of *l* bits.

Then where E_{enc} is the encoding energy for BCH code rate.

$$^{E}tx\_d = \frac{NpEtx\_pct_{ul}}{R} l + ct_{ul}{}^{E}enc \qquad (1)$$

The energy utilized to receive the data packet could be expressed as,

$$E_{rx\_d} = \frac{NpErx\_pcr_{ul}}{R} l + Cr_{ul}E_{dec} \qquad (2)$$

Where $E_{dec} = (4nt + 10t^2)E_{mul} + (4nt + 6t^2)E_{add} + 3tE_{inv}$ and E_{inv} is the energy consumed for inversion operation. Similarly the energy needed for the acknowledgment reception and transmission is given by,

$$^{E}tx\_ack = \frac{NpEtx\_pct_{ul}}{R} lack \qquad (3)$$

$$E_{rx\_ack} = \frac{NpErx\_pcr_{ul}}{R} lack \qquad (4)$$

Let E_0 is the total overhead energy needed for encoding and decoding and for acknowledgement transmission and reception,

$$E_0 = \bar{E}tx\_ack + Erx\_ack + Ct_{ul}Eenc + Cr_{ul}Edec \qquad (5)$$

Therefore the total energy spend for transfering a data packet of size *l* bits for the direct communication (1-hop) can be expressed as,

$$E_{total}{}^{1hop} = \frac{NpEtx\_pCt_{ul}l}{R} + \frac{NpErx\_pCr_{ul}l}{R} + E_0 \qquad (6)$$

$$= x(N_p l/R) + E_0$$

Where $x = Etx\_p\,Ct_{ul} + Erx\_p\,Cr_{ul}$

Therefore energy efficiency of direct communication can be formalized as the fraction of energy for successful communication of L_{fb} bits to the total consumed energy, it can be written

$$\eta d\,c = \frac{x(\frac{NpLfb}{R})ps}{x\left(\frac{Npl}{R}\right) + E0} \qquad (7)$$

Where *ps* is the packet success probability for direct communication [11].

B. SINGLE-RELAY COOPERATIVE COMMUNICATION

To compute the average total energy consumption per bit of cooperative communication (Etotal1cc) three events are taken into consideration. The first event taken into account is the successful transmission of source to destination link(s-d) in the 1st time slot which consumes energy E_1 with probability $(1\text{-}pe_{sd})$.*E1* can be written as,

$$E1 = {}^{E}tx\_d + 2{}^{E}rx\_d \qquad (8)$$

The second event considered is the transmission failure of source to destination link(s-d) and source to relay link(s-r) in the 1st time slot together, which spend an energy E_2 with probability $pe_{sd}pe_{sr}$. E_2 can be expressed as,

$$^{E}2 = {}^{E}tx\_d + 2{}^{E}rx\_d \qquad (9)$$

The third event considered is the transmission failure of source to destination link, and the successful trans-mission of source to relay link in the 1st time slot in the meantime which expends energy E_3 with probability $pe_{sd}(1\text{-}pe_{sr})$. E_3 can be expressed as,

$$E_3 = 2{}^{E}tx\_d + 3{}^{E}rx\_d \qquad (10)$$

Therefore, total energy expenditure of cooperative communication in average can be expressed as, Etotal1cc $= E_1(1\text{-}pe_{sd}) + E_2pe_{sd}pe_{sr} + E_3pe_{sd}(1\text{-}pe_{sr})$ (11)

The total energy spend for the transmission of acknowledgment packets in cooperative communication can be written as

$$Ecc\text{-}ack1 = ({}^{E}tx\_ack + 2\,E_{rx\_ack})[1 + pe_{sd}(1 - pe_{sr})] \qquad (12)$$

Therefore energy efficiency for single-stage cooperative communication scheme can be written as,

$$\eta\,cc = \frac{x(\frac{NpLfb}{R})ps1}{Etotal1cc + Ecc-ack1} \qquad (13)$$

Where *ps*1 is the packet success probability for single-stage cooperative communication [11].

IV. RESULTS AND DISCUSSION

The various analytical and simulation results are obtained from the mathematical models presented in the previous section, using MATLAB.We performed Monte Carlo simulations to validate the analytical results. Tables 1,2 and 3 show the different system related parameters required for getting the results. The different system parameters related to in-body communication channel, on-body LOS and on body NLOS communication channels are got from [6-10]. The WBAN nodes are kept at a distance separation of a maximum of 5 meters and payload size is set to a maximum of 2000 bits as per the IEEE802.15.6 standard. The path loss which is distance dependent, log normal shadowing, Rayleigh fading and additive white Gaussian noise into the simulations are also considered. The receiver is non coherent energy detection based, targeting on low complexity WBAN applications. On-off keying modulation With BCH coding is used for simulation, based upon the standard specification.If there exists at least one bit constituting the packet is falsified it results in a packet error. By knowing in detail , the energy employed for transmit and bit processing, energy efficiency parameter is assessed as a ratio of the energy expenditure needed in a successful packet transmission to the energy consumed in total while during the transmission stage.

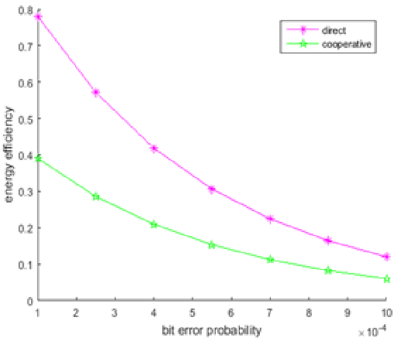

Fig. 2: Energy efficiency v/s bit error probability for on-body LOS direct and 1-relay cooperative communication.(s-d hop distance =27 cm)

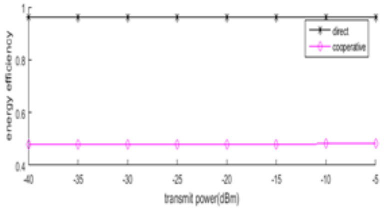

Fig. 3: Energy efficiency vs transmit power for on-body LOS communication at a source to destination hop distance of 7cm (packet size 500bits)

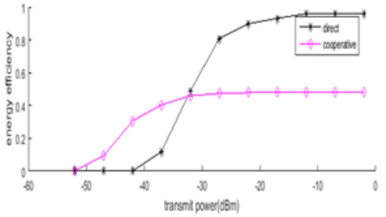

Fig. 4: Energy efficiency vs transmit power for on-body LOS communication at a source to destination hop distance of 117cm (packet size 500bits)

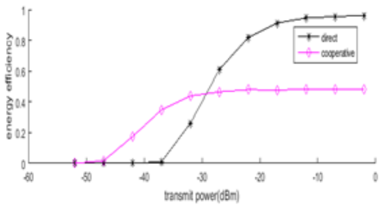

Fig. 5: Energy efficiency vs transmit power for on-body LOS communication at a source to destination hop distance of 147cm (packet size 500bits)

Figure 3-12 shows the comparison of the energy efficiency of a single stage cooperative communication and direct communication for the line of sight(LOS) and non line of sight(NLOS) respectively in an on-body communication channel versus transmit power for different s-d hop distances.We consider that the source and the relay transmit with same powers, as it is simple to implement because optimization space is one-dimensional. For very small distances the energy efficiency is constant, because the transmit power constitutes a smaller part of the total utilized power in the whole process for small distances.

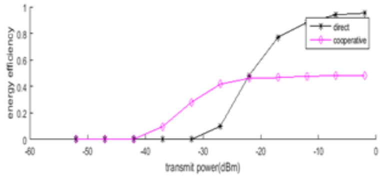

Fig. 6: Energy efficiency vs transmit power for on-body LOS communication at a source to destination hop distance of 247cm (packet size 500bits).

For larger distances, transmit power actually comprises a larger part in the total utilized power, and hence energy efficiency varies significantly with transmit power. The results clearly indicate that in source-destination distances below threshold, direct transmission is very much energy efficient than cooperation, that is the power consumption due to cooperation (receiving and processing process) is more than its gains (i.e, saving the transmit power). For distances greater than threshold, the cooperation gain increases as the transmit power starts occupying a major part of the total power consumed. The result highlights that as the distance increases energy efficiency falls down due to high packet error rate.It is also noticed that energy efficiency of direct communication falls quickly than cooperative communication due to its high packet error compared to cooperative communication. Further, for large distances the energy efficiency of direct communication is very low for all the values of transmit powr in NLOS communication; i.e; for large distances whatever be the transmit power the energy efficiency of direct communication is very low, see Figs 11 and 12. It can be seen that when comparing LOS and NLOS communication, LOS communication support larger hop length and also gives better energy efficiency for a particular source-destination distance. The result have established that for higher value of source-destination distance transmit power have to increase to get a better energy efficiency in the case of direct communication but it will reduce the battery life time and hence from the results we can conclude that, for larger distances it is better to go for cooperative communication instead of direct link where energy wastage is more. Cooperation can provide certain gains with regards to the transmit power required, due to spatial diversity which it adds to system. The additional processing and receiving power consumption at the relay and destination nodes needed for cooperation is clearly a trade-off when applying cooperation.

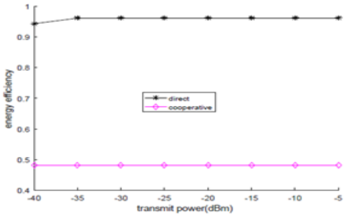

Fig. 7: Energy efficiency vs transmit power for on-body NLOS communication at a source to destination hop distance of 7cm (packet size 500bits).

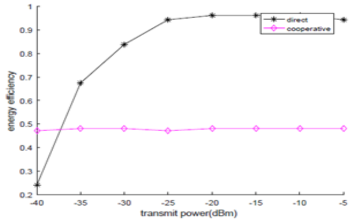

Fig. 8: Energy efficiency vs transmit power for on-body NLOS communication at a source to destination hop distance of 17cm (packet size 500bits).

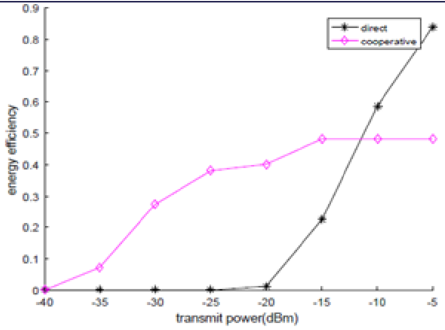

Fig. 9: Energy efficiency vs transmit power for on-body NLOS communication at a source to destination hop distance of 47cm (packet size 500bits).

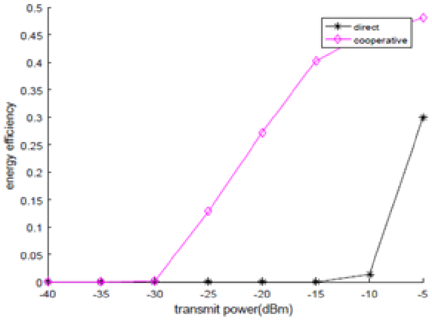

Fig. 10: Energy efficiency vs transmit power for on-body NLOS communication at a source to destination hop distance of 67cm (packet size 500bits).

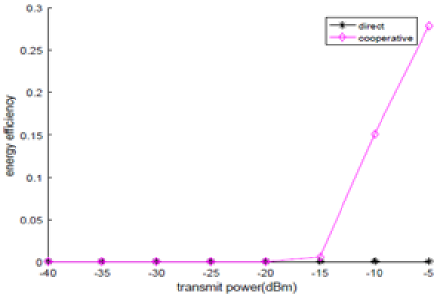

Fig. 11: Energy efficiency vs transmit power for on-body NLOS communication at a source to destination hop distance of 117cm (packet size 500bits).

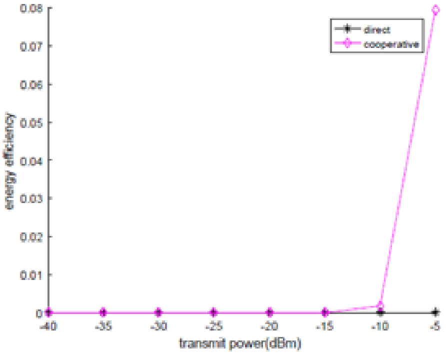

Fig. 12: Energy efficiency vs transmit power for on-body NLOS communication at a source to destination hop distance of 147cm (packet size 500bits).

V. CONCLUSION

The energy efficiency analysis and the reliability aspects of IEEE 802.15.6 based WBANs for direct communication as well as single-relay cooperative communication scenarios by taking into account the UWB based PHY layer has been analyzed. The main aspects of the energy efficiency of direct and cooperative communication scenarios deployed in the WBAN are assessed by taking into account the impact of the Forward Error Correction on the successful packet detection into the analysis. The results demonstrate that there is a threshold distance which exists and separates the regions of the direct transmission from the regions where cooperation is advantageous with respect to the energy efficiency. In the case of on-body NLOS communications, if the threshold distance is below about 47 cm, cooperation overhead is greater than gains acquired and it is well noted that direct communication proves to be highly energy efficient. For an on-body LOS communication, the threshold distance equals about 130 cm for a particular set of channel parameters. If the distance is greater than the threshold value, the gains in co-operative methods are attained. The results obtained, gives some guidelines in finding out the optimal number of relays for a given communication scenario. We also noticed that an increase of a number of relays is not always advantageous. One must be a little cautious before applying the technique of the cooperative communication in sensor networks. For encapsulating the three steps have to be taken into account:1)The cooperation technique whether to be applied or not. 2) Choosing a partner or relay for cooperation, how to be done efficiently? . 3) The number of the relays to be determined inorder to be assigned to help the source which actually is an important factor in cooperative communication scenario.

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