Analyzing bit error rate of relay sensors selection in wireless cooperative communication systems

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ABSTRACT

Cooperative communication systems, which make use of the intermediate relays between the transmitter and the receiver, have been employed as an effective technique to combat the channel fading and to enhance system performance. Cooperative systems have some drawbacks such as high latency and may diversity order not guaranteed. To alleviate the negative effects of these factors, the relay selection protocol is employed in cooperative communication systems to increase overall cooperative system performance. Relay selection in the cooperative systems enables the source to cooperate with the single relay node rather than multiple relay nodes which guaranteed the diversity order.

Keywords:
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1. INTRODUCTION

Cooperative networks (CNs) have been grown and gain much attention recently as a new model of the communication system that makes intermediate nodes help the source to retransmitted its data if the source to destination link (SDL) failed due to error propagation or the relay nodes retransmit the source data in addition transmitted source data and the destination combine them to achieve diversity gain. To achieve the diversity gain through cooperation, the source broadcast the data to the relay node and the destination (exploiting the broadcast nature of the wireless medium in CNs), and either the relay nodes process the data that received from the source before retransmitting to the destination, or the relay nodes doesn’t process the data but directly retransmit to the destination. The relay nodes can process the data such that estimation, demodulation and forward, decoding and re-encoding, etc.

Recently, inclusive work on CNs have been inspected as the relay nodes repeat the data to the destination and it receives the data from the relay nodes only has been considered in [1-3], or the destination receive the data from the source and relay nodes has been considered in [4-7]. Generally, if the relay nodes process the data before retransmitting that mean the relay nodes within the range of the source and the destination and such retransmitting, it can cause a reduction in the spectral efficiency (degree of the freedom of the channels). Loosely speaking, the cooperation is to achieve diversity gain but multiplexing gain may not
if the cooperation system not designs properly. Hence it is important to evaluate their performance in the term of diversity-multiplexing trade-off [8].

Since, retransmission the data by the relay nodes to the destination, it is inherently reducing the spectral efficiency. There are several techniques have been explored in the literature to overcome the above problems through distributed space-time coding [9, 10], relay nodes work on full-duplex, it is mean the relay node can receive and transmit at same time [11], dynamic allocation of the time slots [12], best relay selection [13, 14]. In the practical, the implementation of distributed space code require to setup multiple antennas at the mobile set and this not practical for small devices, full-duplex cooperation required the relay to cancel its self-interference from the received signal, but this not robust in the low-cost radio devices, dynamic allocation required overhead and global information, relay selection is a simplistic way and can achieve spectral efficiency as well as diversity gain.

The best relay selection (BRS) can generally be categorized into two classes: the reactive BRS [15-17], and proactive BRS [18-20]. The reactive BRS protocol prompts the relay selection process after the source broadcasting the data to the destination and relay nodes. However, the proactive BRS protocol in selecting the relay node before the source broadcasting (transmitting). The disadvantage of the proactive BRS is that relay node retransmits what was transmitted by the source to the destination even when the direct transmission is sufficient such a disadvantage reduce the spectral efficiency. Hence designing an efficient and robust BRS can achieve better spectral efficiency.

Internet of Things (IoT) has been an ever-growing ecosystem that integrates hardware, computing devices, physical objects, software, and animals or people over a network enabling them to interact, communicate, collect and exchange data. There are different major types of IoT services, from the industrial applications to eHealth care applications. In this work, the smart wearable/implants sensors, machine devices attached on or inside a human body for monitoring in a hospital digital healthcare system are concerned, to collect data about the health status of a person for a heartbeat, blood pressure, glucose level, etc., through the sensors on the wearable technologies [21-23]. Wireless body area networks which it is abbreviated as WBAN can be practically utilized for delivering information related to the human body for a master node or central computer [24, 25], in which it has the ability for being observed, saved as well as examined theoretically. Reliability is a major issue of the WBAN, for this reason, cooperative communication is considered to provide reliable and efficient delivery of the information [26, 27].

The contributions of this paper are summarized as follow:

a. We propose a relay selection protocol that selects the best relay node base on link quality from the source to relay and from the relay to the destination that can gain the cooperation system better performance.

b. We assume the relay process the data before retransmitting to the destination, where the process type is decoding and re-encoding again that offer extra coding gain to the cooperation system and the spectral efficiency.

c. We reveal the proposed protocol can reduce the bit error rate compared to classical cooperation mode (cooperation without selection protocol) and previous work.

A new architecture of an IoT health-based paradigm is shown in the Figure 1 which can be divided into four layers. The WBSN (wireless body sensors network) layer (layer#1), in this layer, sensors might be attached directly to the human body or sewed into the fabric (wearable sensors), or implanted inside the human body. Such sensors can be EEG, ECG, or EMG, etc. The data recorded via sensors are transmitted to the master node (MN) via wireless 802.15.6 standard, then MN transfer what were transmitted by the sensors to the next tier over one of the wireless technology or cables.

Figure 1. An example of the WBSN in IoT-based health networks

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Smart interface (layer#2), in this layer, smart devices are utilized, (i.e., smartphone, laptop or tablet). In this layer, data are inspected and analysed, then the data transferred to layer 3 over one of the selected wireless communication technologies (i.e., Bluetooth, Wi-Fi or cellular Base-station). Layer 2 represents the bridge tier that connects the WBSN to the infrastructure internet, and some time located within WBSN area. Infrastructure internet layer (layer#3), this level bridge the gap between the layer#2 and layer#4 via exiting communication technology. Care-Services layer (layer#4), in this layer, the received data patient server, the Patient server: in this layer, the data are stored, analyzed and forwarded to the suitable service, such as emergency, physician, or family. The rest of the paper is organized as follow: We provide a channel formulation of decode and re-encode of CNs in section 2. In section 3, we present the details and the main idea of a proposed relay selection protocol, in the sequel, we evaluate the spectral efficiency, bit error rate, diversity order and outage probabilities of the proposed relay selection protocol in the subsections’, 3.1, 3.2 and 3.3. Analysis and performance results are addressed in section 4. And finally, section 6 draws the conclusion and future work.

2. RELAY SELECTION FOR PROPOSED ARCHITECTURE

2.1. Inter-node SNR modelling

In this section, the channel formulation of the decode and forward cooperation is described. In this work, the cooperation takes place over the two-time slot, first-time slot sensor broadcast the data over a wireless channel using 802.15.6 for second-tier and third-tier, then at second time slot, the D2D users re-forward the received data to the third tier over 802.11b. In the first time slot, the received signals at the destination ( yn1-t3) and relay ( yn2-t3) are given as:

\[ y_{t1-t3} = \sqrt{P_b}h_{t1-t3}x + \eta_{t1-t3}, \]  
\[ y_{t1-t2} = \sqrt{P_b}h_{t1-t2}x + \eta_{t1-t2}. \]

The \( h_{t1-t2}, h_{t1-t3} \) are the fading coefficients for corresponding tier#1 to tier#2 and tier#1 to tier#3 links, respectively; \( x \) is the modulated signal transmitted from the source, and \( \eta_{t1-t2}, \eta_{t1-t3} \) are the complex white Gaussian noise with zero mean and unit variance for corresponding tier#1 to tier#2 and tier#1 to tier#3 links, respectively. In the second time slot, the signal received at the destination (yn2-t3) from the relay is given as:

\[ y_{t2-t3} = \sqrt{P_b}h_{t2-t3}x + \eta_{t2-t3}. \]

The \( h_{t2-t3} \) is the fading coefficient for corresponding tier#2 to tier#3 links, \( x \) is the modulated signal transmitted from the relay to the destination, and \( \eta_{t2-t3} \) is the complex white Gaussian noise with zero mean and the unit variance for corresponding tier#2 to tier#3 links. In what follows, the instantaneous received signal-to-noise ratio of the three links, tier#1 to tier#3 and tier#1 to tier#2 and tier#1 to tier#2 links, are given as:

\[ y_{t1-t3} = \frac{P_b}{N_0}|h_{t1-t3}|^2. \]  
\[ y_{t1-t2} = \frac{P_b}{N_0}|h_{t1-t2}|^2. \]  
\[ y_{DF} = \frac{P_b}{N_0}|h_{t2-t3}|^2 + \frac{P_b}{N_0}|h_{t2-t3}|^2. \]

2.2. Relay selection

In this section, the proposed best D2D users selection (BD2DS) algorithm is described. The proposed BD2DS algorithm operation is modified version of the traditional automatic repeat request (ARQ) algorithm, if the tier#3 device transmits a negative ACK to the sensors (tier#1 device) indicating the failure of the reception, the tier#2 device retransmits the lost signal tier#3 device, then tier#3 device sum-u the signals via maximal ratio combing (MRC). Accordingly, The BD2DS algorithm in this paper can be summarized as follow; 1) the tier#3 device admit a direct transmission signal’ (tier#1 to tier#3) if the link quality of tier#1 to tier#3 greater than the links quality of tier#1 to tier#2 and tier#2 to tier#3, 2) the best D2D users’ do retransmission if the link quality of tier#1 to tier#3 less than the quality of the links of the tier#1 to tier#2 and tier#2 to tier#3. Thus, the BD2DS selection methodology can be mathematically modelled as:
\[ \mu = \beta_{t1-t3} > \beta_{\text{max}} \]  (7)

Let \( \beta_{t1-t3} \) be a common channel coefficient representing the channel between any given two nodes. \( \beta_{t1-t3} \) is modeled as zero-mean complex Gaussian random variables with variance \( \sigma_{\beta_{t1-t3}} \). The \( \beta_{\text{min-max}} = \min\{\max(\beta_1, \beta_2, \ldots, \beta_k)\} \). \( \beta_k = \max\left(\frac{\sigma^2_{(t1-t3)k}}{d^{(t1-t3)k}_a}, \frac{\sigma^2_{(t2-t3)k}}{d^{(t2-t3)k}_a}\right) \). In which \( k=1,2,\ldots, L \) is the number of D2D users in the tier#2. Based on the event given in (7), the proposed BD2DS algorithm can be described as follows; after the sensors broadcasting the data to the destination and D2D users. In the second time slot, the tier#3 device checks the criteria given in (7), and if the criteria \( \beta_{t1-t3} > \beta_{\text{min-max}} \) is satisfied the tier#3 device resolves the transmitted data and transmits positive ACK, otherwise the tier#3 device transmits negative ACK. In the latter case, the best D2D users node re-transmits its decoded re-encoded data. The tier#3 device is assumed knows the quality of the links of the tier#1 to tier#2 and tier#2 to tier#3 of all D2D users.

2.3. Bit error rate formation of the proposed method

In this section, it is shown the BD2DS algorithm has diversity order is 2, in which single relay has been chosen within the relay region. The general definition of the error probability between two nodes (i; j) given as [28]:

\[ P_e = Q\left(\sqrt{A |h_{i,j}|^2} \right) \leq \frac{1}{\pi} \int_0^{(M-1)\pi} \exp\left(-A \theta \frac{|h_{i,j}|^2}{d^{(i,j)}}\right) d\theta \]  (8)

In which the \( A = k_{\text{psk}} P_b \), \( k_{\text{psk}} \) is \( \sin(\pi M) / \pi M \) the modulation order, and \( A \theta = (1/ \sin^2(\theta)) \). The expression of error probability of a decode and forward algorithm consists of two parts; 1) the source broadcasts the data to the destination and relays, but the relay does not forward to the destination the data that received from the source since the destination send a positive ACK to relay, 2) the destination receives the data from source and relays since it sends a negative ACK to relay. Therefore, considering these cases, the error probability of the DF algorithm is given as [23]:

\[ P_{e}^{DF} = Q\left(\sqrt{A |h_{sd}|^2} \right) \times \left[ \int_{0}^{\frac{(M-1)\pi}{M}} \exp\left(-A A_\theta |h_{sd}|^2\right) d\theta \right] + \left[ 1 - Q\left(\sqrt{A |h_{sr}|^2} \right) \right] \]  (9)

In which \( 1 - Q\left(\sqrt{A |h_{sr}|^2} \right) \) is error-free of tier#1 to tier#2 links. The probability of error of the DF algorithm can be upper bounded by removing the negative term and setting \( L = 1 \) we rewrite (9) as:

\[ P_{e}^{DF} = \frac{1}{\pi} \int_{0}^{\frac{(M-1)\pi}{M}} \exp\left(-A A_\theta |h_{sd}|^2\right) d\theta + \frac{1}{\pi} \int_{0}^{\frac{(M-1)\pi}{M}} \exp\left(-A A_\theta |h_{sr}|^2 + A A_\theta |h_{rd}|^2\right) d\theta \]  (10)

The error probability of BD2DS algorithm can be express as:

\[ P_e^{DF} = P_e^{bp} P(\mu) + P_e^{tp} P(\mu) \]  (11)

The first term of (11) is comprised of two multiplied terms, the probability of error of the broadcasting phase ‘\( P_e^{bp} \)’ and the probability of the correct reception from the broadcasting phase ‘\( P(\psi) \)’. The first term can be express as:

\[ P_e^{bp} P(\mu) = \int_{0}^{\mu} P(e | \mu) \ Pr\left(\mu \frac{\sigma_{\text{sd}}}{\lambda}\right) p_{\text{sd}} (L_{\text{sd}}) dL_{\text{sd}} dL_{sr} \]  (12)

The \( Pr(e | \psi) \) is given in (10) as broadcasting phase term, \( Pr(\psi | L_{sd} / \lambda) = (1 - exp(-\frac{L_{sd}}{\mu} / \lambda) ) \) and \( p_{\text{sd}} (L_{\text{sd}}) = (1/\sigma_{\text{sd}})exp(-L_{sd} / \sigma_{\text{sd}}) \), we rewrite (12) as:

\[ Pr(e | \psi) \text{term(1)} \ Pr(\psi) = \frac{1}{\sigma_{\text{sd}}} \int_{0}^{\infty} \exp(-A L_{sr}) \left( 1 - \exp\left(\frac{-L_{sd}}{\mu} (y_1 + y_2)\right) \right) d\theta d\theta dL_{sd} dL_{sr} \]  (13)

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Then (13) can be upper bounded by setting \( \sin(\theta) = 1 \) and \( \int_{0}^{(M-1)\pi} \int_{0}^{(M-1)\pi} d\theta d\theta = \left(\frac{(M-1)}{M}\right)^{2} \) [29, 30], then we rewrite (13) as:

\[
P_{e}^{bp}(\mu) \leq \frac{m}{\kappa_{psk} A_{p} P_{c} + \frac{1}{\sigma_{sd}^{2}}} (A \sigma_{sd}^{2})^{-1} - \bar{m} \left( 1 + A \left( \frac{1}{\sigma_{sd}^{2}} + \frac{1}{\sigma_{dr}^{2}} \right) \right)
\]

(14)

Solving the integration of (14) concerning \( Isd \), and substitute \( \gamma_{1} \) and \( \gamma_{2} \); further, SDL is assumed to be fixed during the cooperation, \( \sigma_{sd}^{2} = 1 \). We rewrite (14) as:

\[
P_{e}^{bp}(\mu) \leq \frac{m}{\kappa_{psk} A_{p} P_{c} + \frac{1}{\sigma_{sd}^{2}}} (A \sigma_{sd}^{2})^{-1} - \bar{m} \left( 1 + A \left( \frac{1}{\sigma_{sd}^{2}} + \frac{1}{\sigma_{dr}^{2}} \right) \right)
\]

(15)

In which \( \bar{m} = \left( \frac{M}{M-1} \right)^{2} \).

The second term of (11) is comprised of two multiplied terms, the probability of error of the MRC \( P_{e}^{TP} \), and the probability of the correct reception from both relay and direct transmission \( P(\bar{\mu}) \). can be express as:

\[
P_{e}^{TP}(\bar{\mu}) = \int_{0}^{\infty} \int_{0}^{\infty} P(e|\mu) P(\mu | I) p_{f}(I) dI
\]

(16)

In which \( I = [Isd, Isr, Ir_{rd}] \), \( P(\mu | I) \) is the probability of the BD2DS algorithm protocol and it is given as:

\[
P_{r}(\mu | Isd, Isr, Ir_{rd}) = P_{r}(Isd < \lambda I_{max}, I) = 1 - \exp \left( -\left( A A_{\mu} + \frac{1}{\sigma_{sd}^{2}} \right) I_{max} \right)
\]

(17)

\( P(e|\mu) \) is the second term of the (10), and \( p_{f}(I) = p(I_{sd}) \ p(I_{sr}) \ p(I_{rd}) \); we rewrite (16) as:

\[
P_{e}^{TP}(\bar{\mu}) = \frac{1}{\pi} \int_{0}^{(M-1)\pi} \int_{0}^{(M-1)\pi} \exp(-A A_{\mu}(I_{sd} + I_{sr} + I_{rd})) \left( 1 - \exp \left( -\left( A A_{\mu} + \frac{1}{\sigma_{sd}^{2}} \right) I_{max} \right) \right)
\]

(18)

Evaluate the integration concerning \( Isd \) and we take into account the upper bound assumption that is made on (14), we rewrite (18) as:

\[
P_{e}^{TP}(\bar{\mu}) \leq \bar{m} \int_{0}^{(M-1)\pi} \exp(-A(1 - \exp(-(A + 1) \lambda I_{max})) p_{f}(I_{sr}) p_{f}(I_{rd}) dI_{sr} dI_{rd}
\]

(19)

in which \( \bar{m} \) is \( M/(M-1) \); taking into account worst case state by substituting \( Isr=k \) \( I_{max} \) and \( Ir_{rd}=k \) \( I_{max} \), where \( r \), i.e., \( Pr(e) = 0.1 > Pr(e) = 0.2 > ... > Pr(e) = 0.9 > Pr(e) = 1 \), then we rewrite (19) as:

\[
Pr(e|\psi_{DCC})_{Term(2)} \leq \bar{m} (A + 1)^{-1} \int_{0}^{I_{max}} \exp(-A \lambda I_{max}) p(I_{max}) dI_{max} = \bar{m} (A + 1)^{-1} \int_{0}^{I_{max}} \exp(-A \kappa I_{max} + \lambda A + \lambda) dI_{max}
\]

(20)

Given a moment generating function of \( I_{max} \), \( M_{I_{max}}(\cdot) \) [31], we can rewrite (20) as:

\[
Pr(e|\psi_{DF})Pr(\psi_{DF})_{Term(2)} \leq \bar{m} (A + 1)^{-1} \left[ M_{I_{max}}(A \kappa) - M_{I_{max}}((A + \lambda A + \lambda)) \right]
\]

(21)

The \( I_{max} \) is constituted two random variables are \( Isr \) and \( Ir_{rd} \), and the moment generating function of two independent random variables is given as \( Mx,y(s,t) = Mx(s) My(t) \), then we rewrite (21) as:

\[
Pr(e|\psi_{DP})Pr(\psi_{DP})_{Term(2)} \leq \bar{m} \left( \frac{d_{psk} A_{p} F(P_{C})}{\sigma_{sd}^{2} + F(P_{C})} \right)^{-1} - \left( \frac{d_{psk}^{2} + F(P_{C})}{\sigma_{dr}^{2} + F(P_{C})} \right)^{-1} \left( \frac{d_{psk}^{2} + F(P_{C})}{\sigma_{rd}^{2} + F(P_{C})} \right)^{-1}
\]

(22)

in which \( \omega_{a} = \left( \left( d_{psk}^{2} \sigma_{sd}^{2} + d_{psk}^{2} \sigma_{dr}^{2} / \sigma_{rd}^{2} \times \sigma_{sd}^{2} \right) \right) \), \( F(P_{m}) = k_{psk} P_{m} k + \lambda \) and \( F(P_{m}) = k_{psk} P_{m} k + \lambda \). Finally, the total error probability of BD2DS algorithm is obtained by adding the (15) and (23), it is given as:
3. SIMULATION AND RESULTS

It is clear that, as the selection criteria consider both distances and links quality, the cooperation probability is higher compare to the case that considering one of the channel characteristics, i.e., either distance or channel gain. Figure 2 shows the bit error rate compares to the signal-to-noise ratio (SNR), the important results appear in the Figure 2 can be summarized as follow. The bit error rate reduces once the classical cooperation employed compare to direct transmission. The bit error rate reduces more compare to classical cooperation mode in the previous case, further enhancement as selection consider the best relay node in mid-distance among the source and the destination. Selecting a node far away from the source or the destination (not in the middle location between source and destination), the performance reduces from the case as we select the node at the mid-distance among the source and the destination.

Figure 2. The bit error rate for direct transmission, with relay selection and without relay selection of cooperative mode channels gain and distances from the source to relay and from the relay to destination

4. CONCLUSION

In this paper, we have proposed a relay selection protocol for cooperative networks, the advantage of the cooperation and relay selection can be exploited. The relay selection criteria based on a maximum link from the source to relay and from the relay to the destination, we demonstrated that the proposed relay selection can substantially improve the spectral efficiency, bit error rate, diversity order and outage probability comparing with non-selective cooperative networks.

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