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Outage Analysis of Relay Selection Methods for IEEE802.16j

Najmeh Forouzandeh mehr *, Hossein Khoshbin **
* Ferdowsi University of Mashhad, Iran, na_fo44@stu.um.ac.ir
*Communication and Computer Research Center
**Ferdowsi University of Mashhad, Iran, khoshbin@um.ac.ir

Abstract: *The IEEE 802.16e standard serves as the backhaul of broadband wireless access in the emerging fourth-generation mobile networks. Deploying relay stations as defined in IEEE 802.16j enhances the coverage area and throughput of the IEEE 802.16e. In this paper, we study the problem of relay selection for a wireless cooperative network in context of IEEE 802.16j emerging standard. We propose Best relay selection method, which selects outage optimal relay station for each subchannel. We provide analytical approximations of proposed schemes performance in terms of outage probability .Both theoretical and simulation results show that the Best relay selection method can achieve significant gain compared to other relay selection methods.*

Keywords: Relay selection, cooperative communications, IEEE 802.16j, outage probability

1. Introduction

The WiMAX is a broadband wireless technology which supports fixed, nomadic, portable and mobile access. IEEE 802.16e amendment has been defined in order to support portability and mobility. IEEE 802.16e has adopted SOFDMA (Scalable OFDMA) which allows for a variable number of carriers, in addition to the previously-defined OFDM and OFDMA modes [1]. The emerging IEEE 802.16j Mobile Multi-hop Relay (MMR) is currently developed for increasing the coverage area and throughput of the IEEE 802.16e standard via the deployment of fixed or nomadic relay terminals. It also takes advantages of the less complexity and lower cost of relay stations (RSs) [2]. Cooperative transmission can be seen as a “virtual” MIMO systems, where multiple transmit antennas are in fact implemented both at the source and the relay terminal in a distributed manner. Cooperation among users in a wireless network can substantially improves system's robustness to fading. Because it increases the diversity gain which itself leads to increase in the achieved transmission range, the achievable data rate, and reliability [3]. Therefore, the cooperative transmission techniques are very promising for IEEE 802.16j network [4]. Since the mobile multi-hop concept is newly established in the IEEE 802.16 networks, we review the closely related RS selection algorithms in two-hop cellular networks. The performance of various cooperative diversity schemes to choose the best relay among a collection of available relays in a two-hop cellular network has been analyzed for instance, relay selection protocol based on geographic positions of terminals, the distance, and path-loss [5] and on the instantaneous values of the source-destination and source-relay channels gain [6]. [7] Presents relay selection methods to optimize the total transmission time for a given fixed amount of data.

Several path management schemes are being discussed and presented as the part of contributions in the IEEE 802.16j TG meetings. Related contributions [8-9] propose centralized and distributed signalling mechanisms for the routing path creation in the medium access control sub-layer (MAC) of the MR-BS. However, these schemes do not consider strategies for selecting appropriate RSs along the path while more than one path exists.

In this paper, we propose a relay selection method in the context of IEEE 802.16j standard using opportunistic relaying in per sub channel basis. In particular, each sub channel chooses the best relay independently. Performance of the proposed relaying scheme will be evaluated in term of outage behaviour and compared to some other schemes like nearest relay selection. It is shown that the proposed relay selection has much better performance that other considered schemes.

This paper is organized as follows. In Section II, we present the system model and the cooperative relaying Protocol. In Section III, we describe the details of our proposed relay selection and other relay selection schemes. In Section IV, we analyze these methods and provide a lower bound to outage probability of these schemes. . In Section V, we provide simulation results and compare them with the analytical approximation. Section VI provides our conclusion and final remarks.

2. System Model

We consider an IEEE 802.16j based relay network with two hops; network in each hop is similar to IEEE802.16e based cellular network. A single cell with multiple users is adopted so that the BS is at the center of cell and users are uniformly located within the cell. We assumed users are low mobility, each mobile station is equipped with single antenna and its transmission is constrained to half- duplex mode. It is also assumed that the best placement for relay stations is pre-determined and the relaying scenario is done in downlink where base station (BS) transmits information to mobile stations (MSs).

For direct transmission, the received signal at subcarrier n of destination d from source user s can be modelled as:

$$y_{s,d}(n) = \sqrt{PD_{s,d}^{-v}}H_{s,d}(n)x_s(n) + z_{s,d}(n), \qquad (1)$$

where P is the transmitted power in each subcarrier. $x_s(n)$ is the source transmitted signal , $y_{s,d}(n)$ is the received signal at destination and $z_{s,d}(n)$ is an additive white Gaussian noise with zero mean and variance N_0 . We can express the channel coefficient $H_{s,d}(n)$, the frequency response of the channel evaluated at the n^{th} subcarrier as $H_{s,d}(n) = \sum_{l=0}^{L-1} \alpha_{s,d}(l) \exp\left(-\frac{j2\pi n\tau_{s,d}(l)}{N}\right)$, L is the number of independent delay paths, $\tau_{s,d}(l)$ is the delay of l^{th} path and N is number Of subcarriers. For the $S \to R$, $R \to D$ and $S \to D$ links , the wireless Stanford University Interim (SUI) - NLOS channel model presented in [10],[11] is used with a path-loss exponent of 3. $\alpha_{s,d}(l)$, L and $\tau_{s,d}(l)$ are defined from this channel model. The observed SNR at destination node d obtained by transmission from source node s can be written as:

$$SNR_{s,d}^{(n)} = SNRD_{s,d}^{-v}\left|H_{s,d}(n)\right|^2 \qquad (2)$$

For Rayleigh fading, $\left|H_{s,d}(n)\right|^2$ has an exponential distribution with parameter $\sigma_{s,d}^{-2}$, where $\sigma_{s,d}^2$ is the variance of channel gains. Throughout this paper, we characterize the performance of system in terms of outage probability.
Outage probability is the probability that the instantaneous achievable rate of the channel is less than the target rate R in other words, $P_{out} = P(I < R)$, where I is the mutual information and for an OFDM symbol and it is equal to $I = \frac{1}{N}\sum_{n=0}^{N-1} I^{(n)}$. $I^{(n)}$ is the random element indicating the mutual information for the n^{th} OFDM subcarrier .For direct transmission and with independent and identically distributed Zero-mean circularly symmetric complex Gaussian inputs, it can be shown as $I^{(n)} = \log\left(1 + SNR_{s,d}^{(n)}\right)$. A two-phase transmission as shown in Fig.1, is adopted as one of cooperative relaying formats in 802.16j standard [4] and we also used this scheme here. In the first phase, base station transmits data packet for a pre-selected relay, in the second phase both BS and RS transmit simultaneously to the MS. In this method, each signal source playing the role of different transmit antenna in the conventional STBC. The STBC encoding is performed at the RSs, so the channel utilization is more efficient because the MMR-BS needs to transmit the packet only once. BS and RS use space-time coding in the form of Alamouti scheme [12]. After the two phases end, the MS space-time decodes.

3. Relay Selection Methods

In this section we describe the details of our proposed relay selection methods. Particularly, Best relay selection and Nearest relay selection method. In both of these schemes, one or two relays can be selected in the second phase. If one relay is selected, as shown in fig.1 (a) half of space-time coding process is done at the BS and the other half is done (as it is shown in fig.1 (b)) at the selected RS. In the case of two relay selection, space-time coding is not performed at the BS , instead one half of coding process is done at one of selected RSs and the other half is performed at the other RS.

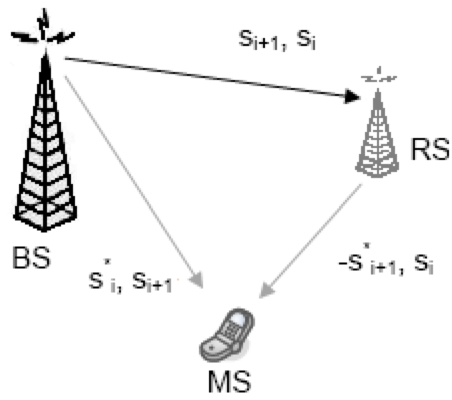

Fig.1 (a) partial encoding in BS and RS when just one RS is selected

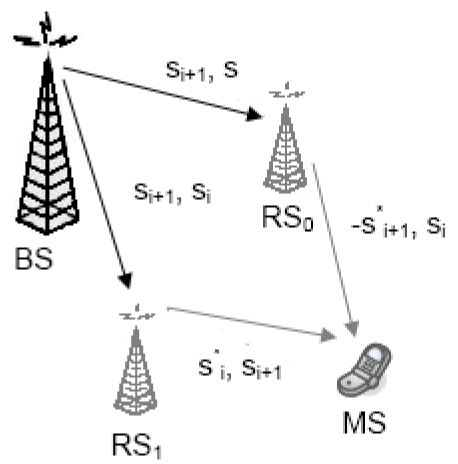

Fig.1 (b) partial encoding in BS and RSs when two relays are selected

3.1 Best Relay Selection Method

This proposed relay selection scenario is performed in a per-subchannel manner. In practice the allocation in the frequency domain is not addressed at the level of subcarriers .Typically, subchannels which are the smallest granular units in the allocation are created by grouping subcarriers in an OFDM symbol in various ways. The formation of these subchannels from subcarriers is important concept in OFDMA systems .The formation can be classified in two types: one is mapping Contiguous group of subcarriers into a subchannel called as adjacent subcarrier mode (ASM) and the other is the permutation based grouping called as diversity subcarrier mode (DSM) [13]. Each sub-channel can be modeled as a flat fading channel with approximately equal SNR level. In 802.16e both ASM and DSM based subchannelization have been defined.

Here we focus on RS-assisted network controlled method [14], a method for path selection in which RS make measurements of the MR-BS and/or other RSs and then report them to MR-BS, and then MR-BS makes decision. So we can assume channel state information (CSI) of BS-RS and RS-MS links is available at BS.

In order to minimize system outage behaviors and improve the average throughput, before the transmission of each subchannel the Best relay is selected to maximize the minimum of the received SNR at RS and MS for all available RSs to assist the transmission.

3.2 Nearest Relay Selection Method

In the first phase of this relaying scheme, each RS is assigned to the mobile station (MS) with the shortest distance to it then the selected RS listens to BS's transmission. This scheme requires infrastructures for knowledge or estimation of distances. We assume that the network topology is known to the MR-BS prior to running the relay selection.

3.3 Best-Two Relay Selection Method

This relaying method is similar to Best relay selection method explained above, but two best relays are chosen in the first phase. That is to say, after minimums of received SNR (at RS and MS) for all RSs, min ($SNR^{(n)}_{s,r_k}$, $SNR^{(n)}_{r_k,d}$) , k=1,···,K , were sorted in decreasing order , simply relay stations which are assigned to first and second values are chosen. Then, BS forwards its data to them. Then in the second phase, these two RSs transmit for the MS. Like the previous cases relaying in done in per subchannel manner.

4. Outage Analysis

In this section, we first analyze the outage probability of the proposed cooperative protocol. For Best relay selection scenario, the mutual information between BS and MS can be shown to be:

$$I^{(n)} = \frac{1}{2}\log\left(1 + SNR^{(n)}_{s,d} + SNR^{(n)}_{best}\right) \qquad (3)$$

$$SNR^{n,k}_{best} = \arg\max_k \min\left(SNR^{(n)}_{s,r_k}, SNR^{(n)}_{r_k,d}\right)$$

$$SNR^{*} = \min\left(SNR^{(n)}_{s,r_k}, SNR^{(n)}_{r_k,d}\right)$$

Where r_k is k^{th} relay station, $k = 1,\cdots,K$ .The outage probability is bounded as follows:

$$P(I^{(n)} < R) = P(SNR^{(n)}_{s,d} + SNR^{n,k}_{best} < 2^{2R} - 1)$$

$$= P(SNR^{(n)}_{s,d} + \max(SNR^{*}) < 2^{2R} - 1)$$

$$> P(\max(SNR^{(n)}_{s,d} + SNR^{*}) < 2^{2R} - 1)$$

$$= \prod_k P(SNR^{(n)}_{s,d} + SNR^{*} < 2^{2R} - 1) \qquad (4)$$

Since SNR^{*} is the minimum of two independent exponential random variables, it is exponential random variable with parameter $\sigma_*^{-2} = \left(\sigma^{-2}_{s,r_k} + \sigma^{-2}_{r_k,d}\right)$. So $(SNR^{(n)}_{s,d} + SNR^{*})$ is the sum of two independent exponential random variables with distinct parameters and its c.d.f can be obtained from theorem 1 in [6]. Considering above notifications, the lower bound for outage probability yields:

$$P\left(I^{(n)} < R\right) > \prod_k \left(1 - \left\{\begin{array}{l} \left(1 - \frac{\sigma_*^{-2}}{\sigma_{s,d}^{-2}}\right)^{-1} e^{-(2^{2R}-1)/\sigma_{s,d}^{-2}} + \\ \left(1 - \frac{\sigma_{s,d}^{-2}}{\sigma_*^{-2}}\right)^{-1} e^{-(2^{2R}-1)/\sigma_*^{-2}} \end{array}\right\}\right) \qquad (5)$$

The mutual information between BS and MS for nearest relay selection can be written as:

$$I^{(n)} = \frac{1}{2}\log\left(1 + SNR^{(n)}_{s,d} + SNR^{(n)}_{r_{nearest},d}\right) \qquad (6)$$

And the outage probability is given by:

$$P(I^{(n)} < R) = P(SNR^{(n)}_{s,d} + SNR^{(n)}_{best} < 2^{2R} - 1)$$

$$= 1 - \left\{\begin{array}{l} \left(1 - \frac{\sigma^{-2}_{r_{nearest},d}}{\sigma_{s,d}^{-2}}\right)^{-1} e^{-(2^{2R}-1)/\sigma_{s,d}^{-2}} + \\ \left(1 - \frac{\sigma_{s,d}^{-2}}{\sigma^{-2}_{r_{nearest},d}}\right)^{-1} e^{-(2^{2R}-1)/\sigma^{-2}_{r_{nearest},d}} \end{array}\right\}$$

5. Simulation Results

Each OFDMA symbol has 1024 subcarriers which are partitioned into subchannels containing 24 data subcarriers. System bandwidth and carrier frequency are 10MHz and 2.5 GHz, respectively. The cell is equally divided into 3 sectors. In each sector, 4 RSs are randomly distributed within a sector, as illustrated in Figure 2. The cell radius is fixed at 2km. The heights of the MSs, BS and RS are 1.5 m,50 m and 30 m .The channel has an exponential power delay profile, as specified by the (SUI) hilly terrain model , path–loss at each link is calculated accordingly [8].

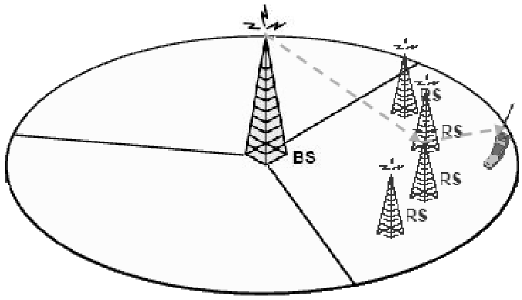

Fig.2 An example of RS assignment in one sector of the cell

Fig.3 shows the outage probability versus the average channel SNR and compares the performance of the proposed relay selection schemes (Best relay selection, Best-two relay selection, nearest relay selection, two nearest relay selection and the lower bound). We consider rate R=1 b/s/Hz. It can be seen that the best relay selection scheme outperforms the nearest selection scheme significantly. Besides , in both schemes a diversity gain is observed in the selection of two relays compare to the selection of just one relay whether the best one or the nearest one .

In fig.4. Best relay selection method is compared with other selection methods include nearest relay selection, randomized relay selection and shortest hop. It can be observed that Best relay selection method significantly reduces the outage probability of system compared with other methods numerated above.

Fig.5. compares the nearest and Best relay selection methods when the location of user (MS) changes in every sunbchannel randomly within the sector.As it can be seen in higher SNRs selecting the RS with higher channel strenth leads to lower probablity of outage compared to the situation BS allocate the nearest RS to user for cooperation .This can be expliand in this way that in nearest relay selection just experiancing the lowest path loth considerd as a rule of selection. But by choosing RS as described in Best relay selection method path loss and also other random attenuating effects of channel like fading due to multipath propagation are going to be minimized.

6. Conclusion

In this paper, we examined the problem of relay selection for cooperative communications in context of IEEE 802.16j standard . We proposed *Best relay selection* which is done in a per subchannel mode. We analyzed the outage performance of proposed Relaying schemes and showed that Best relay selection method outperforms other examined relay selection methods include nearest relay selection, randomized relay selection and shortest hop .In both *Best relay selection* and nearest relay selection , when two relay selected instead of just one relay the performance is significantly improved. Future work may include the analysis of cooperative relaying with imperfect time and frequency synchronization and synchronization issues.

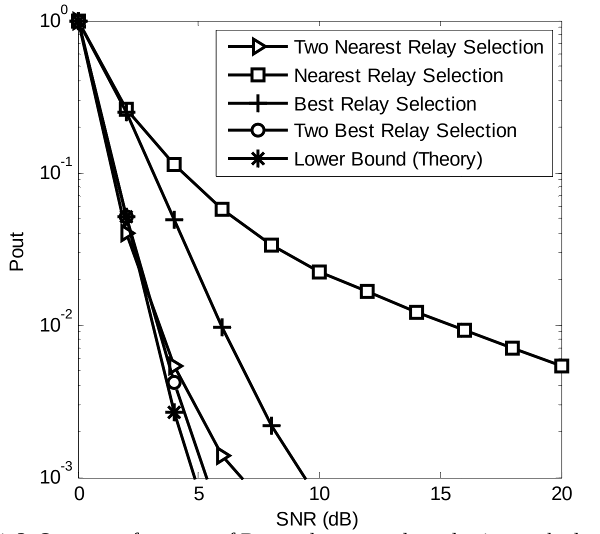

Fig3. Outage performance of Best and nearest relay selection methods each for two cases: one and two relay selection along with lower bound (theory) for Best relay selection

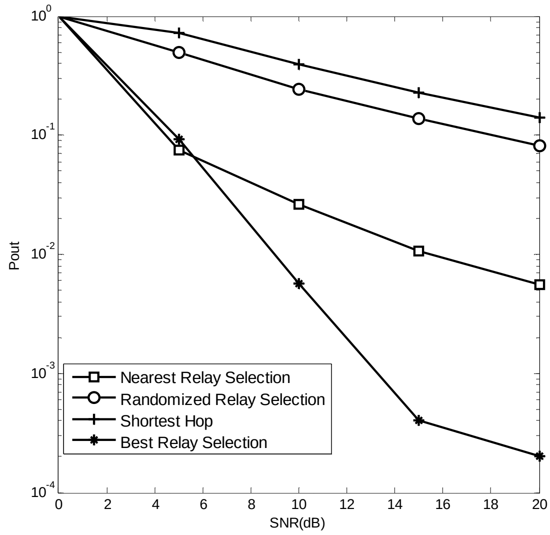

Fig4.Comparation of different relay selection methods

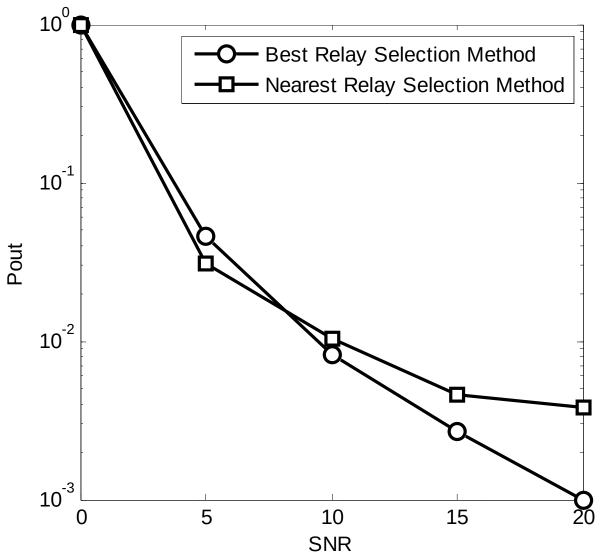

Fig.5. Outage performance of Best and nearest relay selection methods when user moves within the cell

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