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# CROSS-LAYER RELAY SELECTION FOR COOPERATIVE RELAY SYSTEM IN IEEE 802.16j NETWORK

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**Abstract.** The IEEE 802.16j amendment has been developed to improve the performance of the IEEE 802.16e standard in terms of its network capacity and coverage area via employment of relay stations. An optional feature of cooperative relay has been initiated to fully utilize multihop network environment. This work focuses on the selection of cooperative relay path/paths through cross-layer approach to forward data from source to destination. The selection scheme jointly considers the signal-to-noise ratio (SNR) from physical (PHY) layer and buffer status from medium access control (MAC) layer. The SNR of the communication link between the base-station and the mobile station has to be compared to a certain threshold before making decision on the optimal cooperative relaying mode. Numerical and simulation results show that cooperative relaying improves the throughput and delay of the IEEE 802.16j system. In addition, the average transmission time of cooperative relay system decreases when the parameter from the MAC layer is considered in the relay selection scheme.

*Keywords*: Cooperative relay, IEEE 802.16j, relay selection, cross-layer design

## 1.0 INTRODUCTION

As responding to the high demand on wireless communication technology, the IEEE developed the standard IEEE 802.16e [1], also known as WiMAX which gives excellent capabilities in terms of data rate and coverage area. These advantages are further extended with the introduction of the amendment IEEE 802.16j [2] via usage of relay station (RS). RS comes with the advantages of improving throughput at cell edges, extending coverage area of the BS, and increasing system capacity.

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RS is known to improve network capacity and provide coverage extension with much lower cost than employing a new base-station (BS). Thus, the research on relaying technology is becoming more popular since a few years back. A feature in IEEE 802.16j include cooperative relay, where RS or several RSs cooperatively transmit data to the destination.

Cooperative relaying is a method designed to improve data rate between source and destination. It is an extension to relay network where it exploits the spatial diversity and MIMO technology [3]. The diversity concept achieved by cooperating is based on two features; the broadcasting nature of wireless medium and viewing the individual nodes of relaying systems as distributed antennas as a generalization of multiple antenna systems [4]. In order to achieve a good system performance, choosing the right RS to cooperatively relay data is essential.

It is crucial to look into the path selection of cooperative relay as it determines the performance of the communication system. IEEE 802.16j applies static tree topology which faces possible link degradation that would require retransmission at the source. Network congestion at RS is also an issue regarding selecting relays, in such a RS may have a good channel condition, but it is heavily loaded with traffics from other users. Thus, cooperative relay with reliable path selection scheme is believed to improve the performance of IEEE 802.16j network in terms of delay and throughput.

There are a few relay selection schemes at date, namely, fixed relay selection scheme, threshold-based adaptive relay selection scheme and best relay selection scheme. Fixed relay selection scheme chooses a fixed number of relays ($M$) out of available RSs ($K$) to transmit data [5], while in threshold-based adaptive relaying scheme, a destination computes an optimum threshold and broadcasts it to relays in the reverse link [6]. As for best relay selection scheme, only RS with the best channel condition is chosen [7]. This research will focus on fixed relay selection scheme to ease the space-time code used during data transmission.

Antenna diversity has been proven as one of the best ways to reduce the effect of multipath fading in scattering environment [8]. Alamouti [9] has proposed space-time code (STC) for 2x1 transmit diversity system. With the application of maximum ratio combining (MRC) scheme and maximum likelihood detection (MLD), full transmit diversity can be achieved in Alamouti scheme. The use of STC in cooperative relay system was initially proposed by Erkip et. al [10] and Ohtsuki et. al [11]. Coded cooperative communication works by sending different portions of user data through independent fading channels. An enhanced STC was then proposed by the authors in [12] known as distributed STC to reduce the complexity at the RS.

The operation at the RS could be improved using cross-layer design. This technique can be utilized in many ways to ensure QoS is attained in a system. The interdependence of the parameters from candidate layers must be carefully revised in order to design the strategies of a cross-layer functional system. The authors in [13] used cross-layer design in selecting relays and resource allocation for cooperative relay networks. Stackelberg game is also included to further optimized the system developed.

This work is intended to propose an enhanced cross-layer relay selection scheme for cooperative relay system in IEEE 802.16j based on the channel condition and buffer status at the candidate RS. A cross-layer selection at the MAC and PHY layers is done in the relay selection scheme whereby $M$ out of $K$ relay stations are selected to cooperatively relay data from source to destination.

This paper is organized as follow. This section gives an introductory to the whole work in this paper with its related references. Section 2 briefly explains the IEEE 802.16j PHY layer and MAC layer specifications along with RS mode and RS's forwarding data scheme. In the same section, the cooperative relay strategies used in this work is also discussed. In section 3, the proposed relay selection scheme and its numerical analysis are described thoroughly. Results and discussions are provided in Section 4. Finally, Section 5 concludes this paper.

## 2.0 THE IEEE 802.16j WIMAX RELAY

One of the most interesting physical modes supported by WiMAX standard is orthogonal frequency division multiple access (OFDMA) technology. In physical (PHY) layer, OFDMA divides a channel into a number of subcarriers. These subcarriers are grouped together into sub-channels. A particular subscriber is assigned one or more sub-channels in multiple access process. These sub-channels are then grouped into bursts which can be allocated to multiple users for simultaneous transmissions. Each burst allocation can be changed from frame to frame as well as it is within the modulation order. Adaptive modulation and coding (AMC) is suggested in WiMAX standards for different SNR condition. In OFDMA technology, data is transmitted via multiple parallel channels over wireless networks. Thus, by applying OFDMA in WiMAX PHY layer, the interference is reduced resulting in improved system capacity and better QoS guarantee. In medium access control (MAC) layer, IEEE 802.16 standard specifies QoS parameters for different service classes like data rate, packet error rate, latency, and jitter. There are five distinct classes of service including Unsolicited Grand Service (UGS), real-time Polling Service (rtPS), extended real-time Polling Service (ertPS), non-real-time Polling Service (nrtPS), and Best Effort (BE) service to support a wide variety of multimedia applications.

As defined in the IEEE 802.16j draft amendment, relaying can be done in two modes which is transparent mode and non-transparent mode. In transparent mode, RSs become invisible to each MS. When connecting to a RS, the MS considers it as being connected to a BS. The allowable number of hops is two as the RS only forwards the signal received without any preamble, frame control header (FCH), DL/UL-MAP, and DCD/UCD message. In addition, this mode can only operate in centralized scheduling and RS employment is purposely for capacity enhancement. While non-transparent mode can support more than two hops communication as the RS transmit its own preamble, FCH, DL/UL-MAP, and DCD/UCD message. Thus, this mode not only enhanced user capacity but also increase coverage area of the BS. Contrary to transparent mode, the MS recognizes the non-transparent RS as a BS. Both centralized and distributed scheduling can be used in this mode.

There are two ways of forwarding data using RS which are amplify-and-forward (AF) and decode-and-forward (DF). AF relay is also known as wireless repeater [16]. In AF scheme, RS receives a signal, amplifies, and re-shapes it. Then, re-transmit the signal to the destination. The main advantages of AF are simplicity, low cost, and low delay. The disadvantage is that AF scheme amplified and re-transmitted noise and interference together with the desired signals. As for DF scheme, the RS decodes the signal received from source before forwarding it to the destination [17]. If there are no decoding errors, DF scheme always performs better at the cost of higher complexity. The major advantage of DF relaying is that noise and interference are not propagated to the destination. The drawback is that the decoding and re-encoding process incurs a significant delay as compared to the AF scheme.

## 2.1 Cooperative Relay Strategies

In IEEE 802.16j amendment, RS aims at enhancing the network capacity via transparent relaying using two hops communication. On the other hand, it looks forward on improving the network coverage via non-transparent relaying using two or more hops. Both scenarios are illustrated in Figure 1. Current implementation of WiMAX relay is that the base station (BS) chooses RS with higher signal-to-noise ratio (SNR) to send the data packets to the MS or the BS just use direct transmission to MS. The BS needs to decide on which path to take to fully utilize the channel. By using cooperative relay, BS chooses alternative relay routes when the SNR is low. This method aiming at increasing downlink bandwidth rather than following the pre-determined routed, so that the capacity and network throughput is increased, and the end-to-end delay decreased hence, enhancing quality-of-service (QoS).

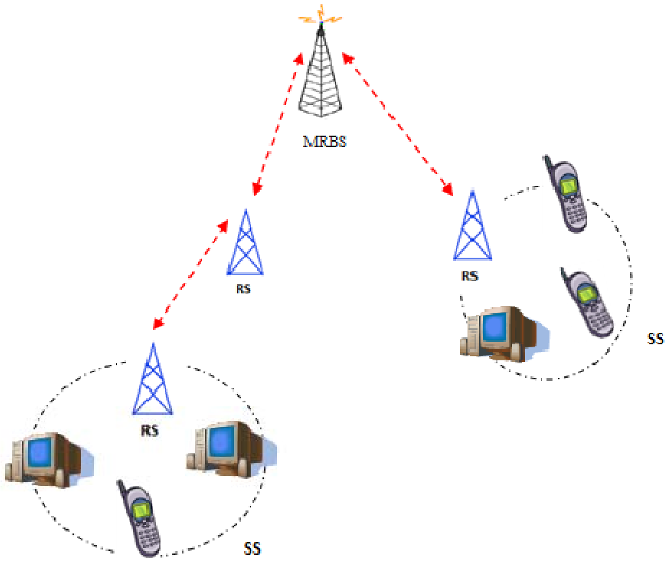


**Figure 1** Multihop relay network model

The work is focused on cooperative relay and connection-based approach. The cooperative relay adopts some of cognitive radio (CR) features, which is able to sense and analyze the surrounding radio condition. When a link is detected, the BS will compute the SNR in each path of BS-MS, BS-RS, and RS-MS and decide the modulation scheme to use based on the SNR values. Then, it will adapt the weight (symbols per bit) of each link based on its modulation and coding schemes (MCS). The computation of weight is shown in Table 1. The radio cognition implemented in this work is cooperative relay based on connection-based networking such that MS is allowed to choose its route when certain condition does not match the criteria. Connection-based implementation will be applied on the MAC layer of BS, RS, and MS. The BS uses this information to decide on whether it needs to implement cooperative communication or not.

In connection-based method, BS will decide a connection based on SNR condition, initially. Then, BS will receive transmission from a MS in uplink connection. BS will decide to use alternative path when SNR condition is weak so that packets will be sent via more than one relay at a time. If the weightage of the selected link is more than 0.33 (1/3), it means that the SNR from BS to MS value is lower than 16-QAM (½) or SNR received is lower than 11 dB. The threshold 11 dB is chosen from an experimental work done in [15] showing that 11dB is the minimum value which the cooperation strategy is better than single RS selection strategy. When SNR is above 11 dB, the capacity gain achieved by two RS selection strategy is better than single RS and direct connection from MS to BS. This is because MS in WiMAX network can gain higher channel capacity when two RS are selected rather than only have single RS. In this work, the corresponding SNR threshold used is 11 dB, therefore any signal power lower than this is considered as having low SNR condition.

**Table 1** MCS table defines the relationship between weight and modulation coding scheme

| Modulation | Coding rate | Received SNR (dB) | Bits per symbols | Weight (Symbols per bit) |
|---|---|---|---|---|
| **QPSK** | ½ | 5 | 1 | 1 |
| **QPSK** | ¾ | 8 | 3/2 | 2/3 |
| **16-QAM** | ½ | 10.5 | 2 | ½ |
| **16-QAM** | ¾ | 14 | 3 | 1/3 |
| **64-QAM** | ½ | 16 | 3 | 1/3 |
| **64-QAM** | 2/3 | 18 | 4 | ¼ |
| **64-QAM** | ¾ | 20 | 9/2 | 2/9 |

## 3.0 PROPOSED RELAY SELECTION ALGORITHM

Figure 2 illustrates the network model considered in this work. The figure shows a 3-hop cooperative relay network consists of a two-antenna BS, single-antenna RSs and one single-antenna MS. The RS is in non-transparent mode, using decode-and-forward (DF) technique and it is half-duplex mode; which indicates that transmit and receive cannot be carried out at the same time. The proposed algorithm will only focus on downlink communication.

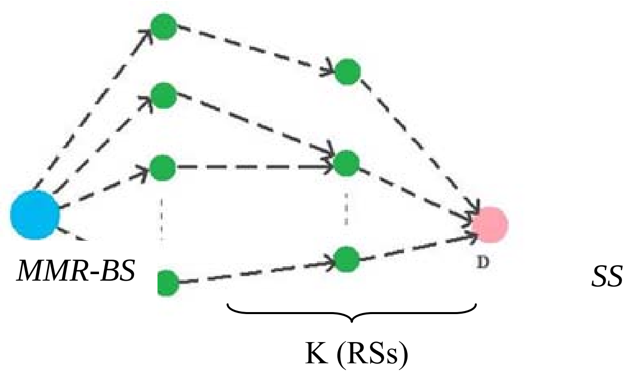


**Figure 2** 3-hop cooperative relay topology

Say, for a hop link, the transmitting node is denoted by *A* and the receiving node by *B*. The received signal at node *B* can be defined as:

$$y_B = h_{A,B} x_A + n_B \quad (1)$$

where $x_A$ is the signal transmitted at the node *A*, $h_{A,B}$ is the channel gain of a link from *A* to *B*, and $n_B$ represents the additive white Gaussian noise (AWGN) at the node *B* with zero mean and equal variance $N_0$. The signal to noise ratio (SNR) can be defined as

$$SNR = P_r / N_0 \quad (2)$$

where $P_r$ is the received power. From Shannon's capacity formula, where $BW$ represents the bandwidth used in this network, the maximum achievable data transmission rate can be obtained as

$$R_{max} = BW\ log_2(1 + P_r/N_0) \quad (3)$$

It is also assumed that the channels between all hops are uncorrelated, and the channels are independent and identically distributed, and the nodes have full knowledge of channel parameters for the next hop in order to obtain a theoretical bound of performance.

As mentioned previously, the relay selection scheme will be decided using cross-layer design between PHY and MAC layers. The parameters involved would be the channel SNR value, total buffer size and buffer status at candidate RSs. A mathematical analysis on selection criteria will be explained briefly for one hop, as the next hop only repeats the same procedure.

Initially, the BS will sense its environment to get the instantaneous SNR. The RSs will periodically report its buffer status to the BS and superordinate RS. The optimal problem formulation of relay selection can be denoted as

$$\gamma \begin{cases} \text{maximize throughput, } \varepsilon \\ \text{minimize latency, } \tau \end{cases} \quad (4)$$

where and $\gamma$ represents the set of selected relays. Throughput of the cooperative system depends on the capacity or maximum data transmission rate, $R_{max}$ while latency, τ can be represented as

$$\tau = \frac{\beta - \beta_{rn}}{R_{max}} \quad (5)$$

where $\beta$ is the total buffer size at the candidate RS and $\beta_{rn}$ is the buffer status (empty buffer) at the candidate RS. As a start, relay selection will consider the parameters from the corresponding hop and estimation of the parameters from the next hop. For instance, if the selection is performed at the BS, it will decide on choosing RSs using the parameters from the first hop and second hop. From equation (3), the value of $BW$ is normalized to 1. Selection would be made to maximize the following equation

$$R_{max} = log_2\left[1+\frac{P_{1,r}}{N_0}\right] + E\left\{log_2\left[1+\frac{P_{2,r}}{N_0}\right]\right\} \tag{6}$$

$P_1$ represent the power at the intended RS and $P_2$ is the power at the next hop which will only be determined by the distribution of Rayleigh fading. Total transmission time can be computed as

$$\tau_{total} = \tau_1 + E\{\tau_2\} \tag{7}$$

$$= \frac{\beta_1-\beta_{r1}}{R_{max}^1} + E\left\{\frac{\beta_2-\beta_{r2}}{R_{max}^2}\right\} \tag{8}$$

in which the notation $\tau_1$ and $\tau_2$ are the transmission time at the corresponding hop and the next hop. The total buffer size $(\beta_1, \beta_2)$ and buffer status $(\beta_{r1}, \beta_{r2})$ at the RSs are attained from the MAC layer and the calculation of the maximum achievable rate is obtained from the instantaneous SNR at PHY layer. Since the selection of relays should minimize transmission time, the set of selected relays must obey,

$$\gamma = \arg\min_{all\ n\in N}(\tau_1 + E\{\tau_2\}) \tag{9}$$

## 3.1 Analysis of Relay Selection Scheme

Mathematical analysis provided in this section shows the average transmission time for the next hop, given only the distribution of Poisson data arrival and Rayleigh fading. As mentioned, both distributions will be considered jointly. Given the following joint probability property

$$E\{XY\} = E\{X\}E\{Y\} \tag{10}$$

The estimated transmission time from $M$ RS/s to destination $(E\{\tau_{rd}\})$ can be represented as

$$E\{\tau_{rd}\} = [\sum_{i=0}^{\infty} \beta_{rn} x_i F_i] \left[\int_0^{\infty} \frac{1}{log_2\left(1+\frac{P}{\sigma^2}y\right)} g(y)dy\right] \quad (11)$$

where $F_i$ and $g(y)$ is the probability density function (pdf) for Poisson and Rayleigh distribution respectively. According to the authors in [14], for the Rayleigh distribution, it follows the pdf of the $(N\text{-}M\text{+}1)$th order statistic of $N$ independent random variables.

There are two different functions need to be multiplied in the right hand portion of equation (11). The second part has been derived and proved in [14]. The first part shows a sum function that represents the expected value for a discrete Poisson distribution. Given the pdf of Poisson distribution as

$$p(X = x) = \frac{\lambda^x . e^{-\lambda}}{x!} \quad (12)$$

where $\boldsymbol{\lambda}$ is the mean number of success of arrival data (that occur) in a specified region. Thus,

$$E\{\tau_{rd}\} = \left[\sum_{x=0}^{\infty} \beta_{rn} x \frac{\lambda^x . e^{-\lambda}}{x!}\right] \left[\int_0^{\infty} \frac{1}{log_2\left(1+\frac{P}{\sigma^2}y\right)} g(y)dy\right] \quad (13)$$

After simplifications and factorization, the closed-form, lower bound analytical approximation of $E\{\tau_{rd}\}$ is obtained as

$$E\{\tau_{rd}\} = \beta_{rn} . \boldsymbol{\lambda} . \frac{1}{log_2\left(1-\frac{P}{\sigma^2} log_2\left(\frac{M-1}{N}\right)\right)}, 1 < M < N \quad (14)$$

Whereas for upper bound,

$$E\{\tau_{rd}\} = \beta_{rn} . \boldsymbol{\lambda} . \frac{1}{log_2\left(1-\frac{P}{\sigma^2} log_2\left(\frac{M}{N}\right)\right)}, 1 < M < N \quad (15)$$

In which $N$ represents the total available RSs and $M$ is the number of cooperating relays.

## 4.0 RESULTS AND DISCUSSIONS

This section provides both numerical and simulation results based on the explained cooperative relay system. Numerical result includes the performance of the cross-layer relay selection in terms of its average transmission time in comparison to the single relay selection scheme. Moreover, the simulation results give an insight of the advantages obtained using cooperative relay system when looking into the throughput and delay performance.

### 4.1 Numerical Result

In Figure 3, the numerical result for the upper bound and lower bound of the average transmission time in the next hop when cross-layer relay selection considered is provided. The result shows improvement in the average transmission time of the cooperative relay system in comparison to the single layer relay selection done in [14].

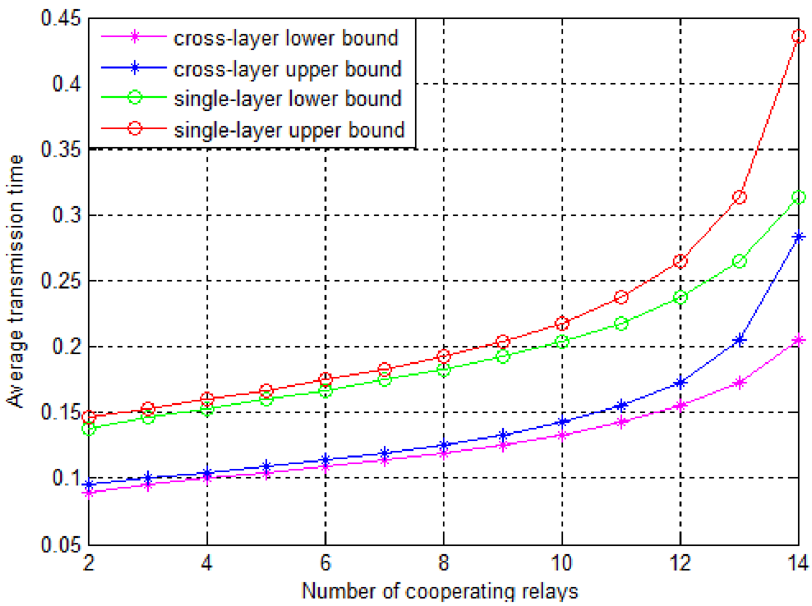


**Figure 3** Comparison of average transmission time for cross-layer relay selection and single-layer relay selection

From the numerical result obtained, both relay selection schemes show similar pattern of average transmission time when the number of cooperating relays varies. For upper bound with six cooperating relays, the average transmission time for cross-layer relay selection improves 31% compared to the single-layer relay selection scheme. Consequently, at six cooperating relays, the lower bound for cross layer relay selection gives 35% improvement in comparison to the lower bound of single layer cooperative relay system. The analysis of average transmission time does not exceed 14 cooperating relays as the upper bound of the cross layer relay selection scheme tends to go to infinity. The result proves that considering the parameter from MAC layer could improve system performance as it lessens the probability of congestion at the RS.

## 4.2 Simulation results

We consider IEEE 802.16j based two-hop wireless relay network to investigate the network performance in terms of throughput and delay. The modulation chosen for the simulation is 16-QAM with 3/4 coding rate and 3 bits per symbol. The corresponding SNR to this modulation is 11 dB, therefore any signal power lower than this is considered as having low SNR condition. For this study, 10 MSs are added to an 802.16j network where the distance from each MS is approximately 5 km to BS as depicted in Figure 4. The number of RS is varied from 1 to 3.

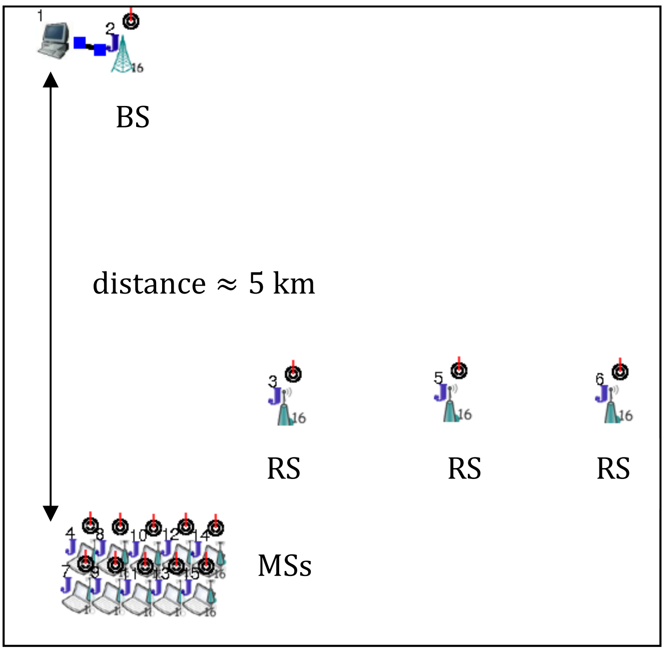


**Figure 4** Network model to study the effect of number of relays in 2-hops communication

The deployment of cooperative relay in WiMAX has a few major effects on the QoS of the system. In this work, the effect of the number of RSs is observed accordingly with consideration on the throughput and delay. In WiMAX relay network, data throughput is a major issue when more than one relay is deployed in a cell due to bandwidth partitioning. Therefore, cooperative relay is used to tackle this issue.

The deployment of RS will affect the throughput between BS and MS. Throughput for cooperative relay and without cooperative relay implemented in the network are shown in Figure 5.

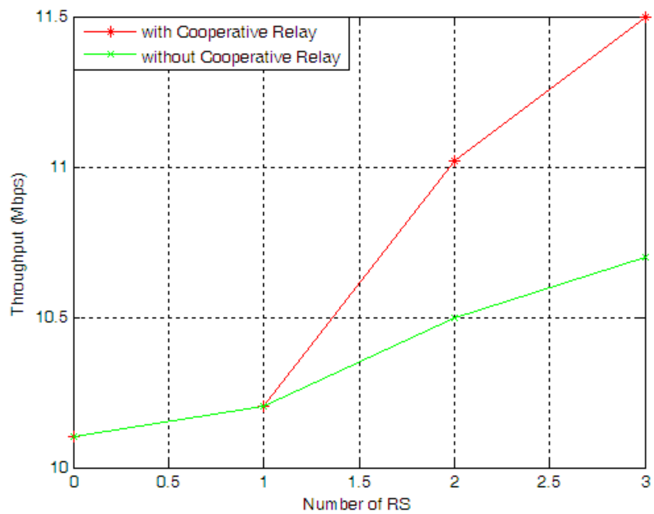


**Figure 5** Average throughput for 10 users in a network

From Figure 5, it can be observed that when there is no RS deployed in a network, the average throughput is 10.103 Mbps. As a RS is placed in a network, there is an enhancement in throughput. The throughput is increased to 10.202 Mbps. There is no difference made to throughput when cooperative relay is applied for one RS. When two RS is used, the average throughput is 10.5 Mbps and enhanced by 4.95% to 11.02 Mbps using cooperative relay. When three RS is placed in a network, throughput is raised of 7.5% from 10.7 Mbps to 11.5 Mbps.

The deployment of RS in two-hop communication will also affect the delay between BS and MS. The delay performance for a cooperative relay system and non-cooperative relay system is shown in Figure 6.

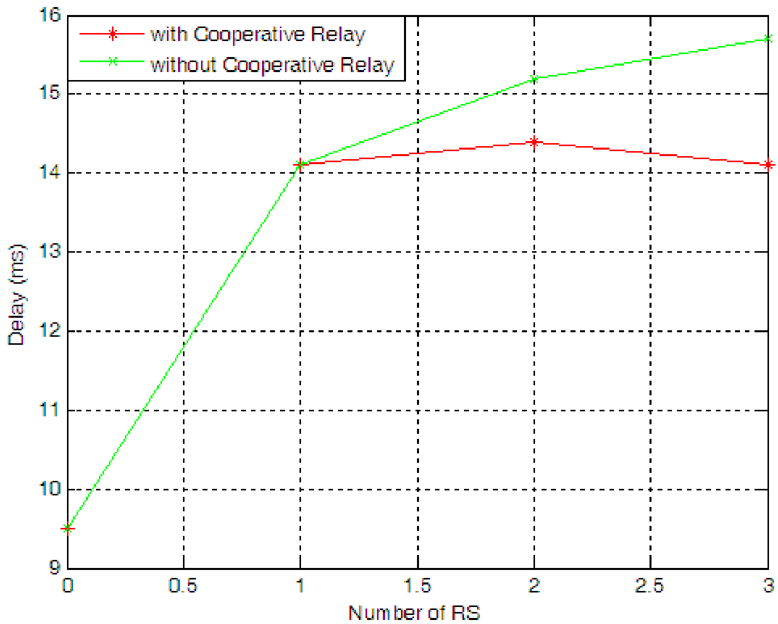


**Figure 6** Average delay for 10 users in a network

Figure 6 showed that the delay is the same for both cooperative and without cooperative relay cases, when there is direct communication between BS-MS and one RS is added to the network. This is due to the fact that cooperative relay only takes effect when two or more RSs is used. When there is no RS, the delay is 9.5 ms. The delay is increased to 14.1 ms when one RS is added to the network. This is due to an additional time in scheduling process at the BS. When two RS are deployed in the network, average delay is increased to 15.2 ms. By using cooperative relay, the delay reduced by 5.26% to 14.4 ms. This result is acquired by considering of alternative path selection method used in cooperative relay. This is also because of a reduction in delivery time when data is send via two or more paths in cooperative relay. When three RS is placed in the network, delay is increased to 15.7 ms for non-cooperative relay case. However, when cooperative relay is implemented, the delay is more minimal which is 14.1 ms. The delay difference between cooperative and without cooperative relay when three RS are added in a network is 1.6 ms which is declined of 10%.

These results obviously showed that delay increases when one or more RSs are added in a network. Even though there has been significant growth in throughput, delay increase as a trade off. To deal with these problems, cooperative relay shows its ability to reduce delay.

## 5.0 CONCLUSIONS

Cooperative communication is a good method to consider in improving the system of the IEEE 802.16j mobile multihop relay network. By using cooperative communication, the throughput of the system improves by 4.95% using two RSs. Furthermore, delay is reduced by 5.26% when employing cooperative relay compared to conventional relaying. This work focuses on improving relay selection method with cross layer relay selection scheme to create reliable paths for data transmission. Hence, the relation of the parameters in PHY and MAC layer need to be considered jointly in a carefully designed cross layer algorithm. Numerical result shows 31% improvement in average transmission time when relay selection considers cross-layer parameters.

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## REFERENCES


[1] IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems. *IEEE 802.16e 2006*. Feb. 2006.

[2] Draft Amendment to IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems–Multihop Relay Specification. *IEEE Draft Standard P802.16j/D9.* Feb. 2009.

[3] P. Liu, Z. Tao, Z. Lin, E. Erkip and S. Panwar, 2006. Cooperative Wireless Communications: A Cross-Layer Approach. *IEEE Wireless Communications*. 13: 84-92.

[4] S. S. Ikki and M. H. Ahmed, 2008. Performance of Multiple-Relay Cooperative Diversity Systems with Best Relay Selection over Rayleigh Fading Channels. *EURASIP Journal on Advances in Signal Processing*.

[5] L. Xie, X. Zhang, P. Qiu, 2006. Relay Selection Strategies for Distributed Space-Time Cooperative Systems over Wireless Ad-Hoc Networks. *Computer Communications and Networks, 2006. ICCCN 2006. Proceedings.15th International Conference.* 213-218.

[6] T. W. Ban, B. C. Jung, D. K. Sun, W. Choi "Performance Analysis of Two Relay Selection Schemes for Cooperative Diversity," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07),* 2007.

[7] A. Bletsas, A. Lippman and D. P. Reed, 2005. A Simple Distributed Method for Relay Selection Cooperative Diversity Wireless Networks, based on Reciprocity and Channel Measurements. *IEEE Vehicular Technology Conference*. 3: 1484- 1488.

[8] W. C. Jakes, Ed., 1974. *Microwave Mobile Communications*. New York: Wiley.

[9] Siavash M. Alamouti, 1998. A Simple Transmit Diversity Technique for Wireless Communications. *IEEE Journal on Select Areas in Communications*. 16: 1451-1458.

[10] A. Stefanov, E. Erkip, 2003. On the Performance Analysis of Cooperative Space-Time Coded Systems. *IEEE Wireless Communications and Networking*. 2: 729-734.

[11] T. Ohtsuki, 2005. Performance Analysis of Statistical STBC Cooperative Diversity using Binary Sensors with Observation Noisem. *IEEE Vehicular Technology Conference*. 3: 2030-2033.

[12] P.A. Anghel, G. Leus, and M. Kaveh, 2006. Distributed Space-Time Cooperative Systems with Regenerative Relays. *IEEE Transactions on Wireless Communications*. 5(11): 3130-3141.

[13] Beibei Wang, Zhu Han, K.J. Ray Liu, 2009. Distributed Relay Selection and Power Control for Multiuser Cooperative Communication Networks Using Stackelberg Game. *IEEE Transactions on Mobile Computing*. 8(7).

[14] Seunghoon Nam, Mai Vu, Tarokh, V. 2008. Relay Selection Methods for Wireless Cooperative Communications. *Conference on Information Sciences and Systems*. 859- 864.

[15] Liu Zhanjun, Chen Chunlin, Li Yun, Liu Qilie, Zhuang Hongcheng, 2010. Cooperative Relay Selection Strategies in Two-hop IEEE 802.16 Relay Networks. *International Conference on Future Computer and Communication (ICFCC)*. 2: 504-508.

[16] S. Berger, M. Kuhn, A. Wittneben, T. Unger, and A. Klein, 2009. Recent Advances in Amplify-and-forward Two-hop Relaying. *IEEE Communications Magazine*. 47(7): 50-56.

[17] Hsiao-Chen Lu, Wanjiun Liao, and Frank Yeong-Sung Lin. 2011. Relay Station Placement Strategy in IEEE 802.16j WiMAX Networks. *IEEE Transaction on Communications*. 59(1): 151-158.