Jurnal
Teknologi

Full Paper

# CONNECTIVITY IN MOBILE MULTIHOP RELAY NETWORK

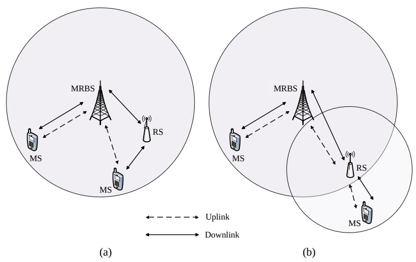
Nurul Nazirah Mohd Imam Ma'arof[a]*, Norsheila Fisal[b]

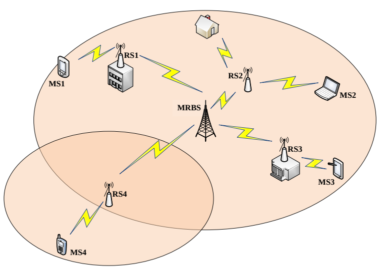
[a]Faculty of Technical and Vocational, Universiti Pendidikan Sultan Idris, 35900, Tanjung Malim, Perak, Malaysia
[b]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

**Article history**
Received
*2 December 2015*
Received in revised form
*14 February 2016*
Accepted
*14 April 2016*

*Corresponding author
nnazirah@fptv.upsi.edu.my

## Graphical abstract




## Abstract

Mobile Multihop Relay (MMR) network is an attractive and low-cost solution for expanding service coverage and enhancing throughput of the conventional single hop network. However, mobility of Mobile Station (MS) in MMR network might lead to performance degradation in terms of Quality of Service (QoS). Selecting an appropriate Relay Station (RS) that can support data transmission for high mobility MS to enhance QoS is one of the challenges in MMR network. The main goal of the work is to develop and enhance relay selection mechanisms that can assure continuous connectivity while ensuring QoS in MMR network using NCTUns simulation tools. The approach is to develop and enhance a relay selection for MS with continuous connectivity in non-transparent relay. In this approach, the standard network entry procedure is modified to allow continuous connectivity with reduced signaling messages whenever MS joins RS that is out of Multihop Relay Base Station (MRBS) coverage and the relay selection is based on Signal to Noise Ratio (SNR). The QoS performances of the proposed relay selections are in terms of throughput and average end-to-end (ETE) delay. The findings for the proposed relay selection in non-transparent relay shows that the throughput degradation between low mobility MS (30m/s) and high mobility MS (50m/s) is only about 2.0%. The proposed relay selection mechanisms can be applied in any high mobility multi-tier cellular network.

*Keywords*: Mobile multihop relay, mobility, relay selection, continuous connectivity

## Abstrak

Rangkaian Pengulang Banyak-lompatan Bergerak (MMR) adalah penyelesaian menarik dan rendah kos untuk memperluaskan liputan perkhidmatan dan meningkatkan kadar penghantaran data rangkaian tanpa wayar konvensional lompatan tunggal. Walau bagaimanapun, mobiliti Stesen Bergerak (MS) dalam rangkaian MMR mungkin menyebabkan penurunan prestasi dari segi Kualiti Perkhidmatan (QoS). Salah satu cabaran dalam rangkaian MMR adalah memilih Stesen Pengulang (RS) yang sesuai yang boleh menyokong penghantaran data untuk mobiliti MS yang tinggi bagi meningkatkan QoS. Matlamat utama kerja ini adalah untuk membangunkan mekanisme pemilihan pengulang yang boleh memberi jaminan sambungan berterusan disamping memastikan QoS dalam rangkaian MMR menggunakan alat simulasi NCTUns. Pendekatannya adalah untuk membangunkan satu mekanisme pemilihan pengulang untuk MS dengan sambungan berterusan dalam pengulang tidak telus. Dalam pendekatan ini, prosedur kemasukan rangkaian standard diubahsuai untuk membenarkan sambungan berterusan dengan mengurangkan isyarat mesej bila-bila masa MS menyertai RS yang berada di luar liputan Stesen Pangkalan Pengulang Banyak-lompatan (MRBS). Pemilihan pengulang adalah berdasarkan kepada Nisbah Isyarat kepada Gangguan (SNR). Prestasi QoS bagi pemilihan pengulang yang dicadangkan adalah kendalian dan purata kelewatan Hujung-ke-Hujung (ETE). Hasil kajian pemilihan pengulang yang dicadangkan dalam pengulang tidak telus menunujukkan bahawa kemerosotan kendalian antara mobiliti MS rendah (30m/s) dan tinggi (50m/s) hanya kira-kira 2.0%. Mekanisme pemilihan pengulang yang dicadangkan boleh digunakan dalam mana-mana rangkaian selular pelbagai peringkat yang bermobiliti tinggi.

*Kata kunci*: Rangkaian pengulang banyak-lompatan bergerak, mobiliti, pemilihan pengulang, sambungan berterusan



## 1.0 INTRODUCTION

IEEE 802.16j documentation classifies two types of RS operation modes in MMR network commonly known as transparent relay mode and non-transparent relay mode [1]. In transparent relay mode, MRBS transmits user data to MS through intermediate RSs while broadcast management messages are transmitted directly to MS. MS that is synchronized with MRBS receives the broadcast management messages from MRBS since transparent RS does not transmit preamble and broadcast management messages. Therefore, MS is not aware of the existence of RS even though MS communicates with MRBS through transparent RS. For this type of operation mode, MS should be located in the coverage area of MRBS as illustrated in Figure 1 (a). Only centralized scheduling mode is allowed to be employed in this RS mode.

In contrast to transparent RS, the RS operating in non-transparent relay mode transmits management messages as well as user data to other MS. As depicted in Figure 1 (b), RS can serve MS located outside of MRBS coverage range, thus it is possible for non-transparent relay mode to apply centralized or distributed scheduling mode. In this work, non-transparent relay modes in MMR networks are considered.

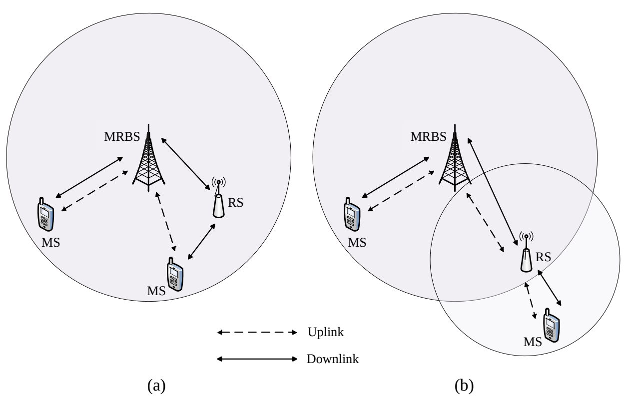



**Figure 1** RS operation mode (a) Transparent relay mode (b) Non-transparent relay mode

Typically, RS can be classified into two types, namely Amplify-and-Forward (AF) RS and Decode-and-Forward (DF) RS [1]–[3]. The classification of these types of RS is based on the scheme on how the received signal is processed. In AF scheme, the received signal is simply amplified by RS and then the signal is forwarded to the destination node. The signal quality in AF scheme is degraded since the received signal is not decoded and noise is also amplified and forwarded in the system. Even though AF scheme is easy to be implemented and less complex than DF scheme, the AF scheme is not suitable to be implemented in MMR network due to the limitation aforementioned earlier.

In DF scheme, the received signal is decoded by RS and re-encoded before it is forwarded to the destination node. The noise in the received signal is removed during the decoding process by RS. This type of RS has high complexity because of the presence of decoder and encoder in the system. The IEEE 802.16j standard has given tendency towards DF scheme over AF scheme. Thus, DF scheme is considered in the rest of this paper.

In MMR network, there are possibilities that several RSs are deployed with each of them has small coverage range. Moving MS may encounter connection loss condition, frequent handoff with RS and service interruption during data transmission. When moving MS roams and joins new RS, it needs to perform re-synchronization to integrate with the new RS before it participates in data transmission. In non-transparent relay mode, re-synchronization required complex signaling messages exchange during the network entry procedure. This circumstance leads to high average ETE delay due to complex signaling messages process.

In comparison, for transparent relay mode, MRBS acts as a coordinator to monitor and send the control signaling messages purposely to synchronize all MS and RS within its coverage area. Thus, when MS roams from current RS to another new RS, MS does not need to perform re-synchronization with MRBS. MS just need to change the data forwarding path and the service is not interrupted during the roaming process.

The proposed relay selection for MS with continuous connectivity in non-transparent relay mode MMR networks is discussed in Section 3. The first phase is to develop the node mobility function in non-transparent relay mode. The second phase is to develop relay selection mechanism that relies on link quality between MS and RS.

## 2.0 RELATED WORK

MMR network has gained a lot of attention from academia and industry as a potential primary technology for Broadband Wireless Access (BWA) [4]. The first IEEE 802.16 standard has evolved to 802.16j

[5], [4], [3]. MMR network is a standard for BWA at high speed and low cost development by IEEE 802.16's Relay Task Group [3]. MMR network has gained notable research attention because it has the potential to offer coverage extension and capacity enhancement in IEEE 802.16 networks [6], [7]. Besides, the power of MS can be preserved because MS is connected to the nearest RS instead of connected to MRBS located outside the coverage range of MS [8]. Moreover, the deployment of RS is more cost effective compared to MRBS [9].

In a nutshell, a low cost RS entity in MMR network is introduced to help extend the coverage range, improve service, boost network capacity, reduce terminal power consumption and eliminate dead spots [10]. RS is responsible for relaying data packets between MRBS and MSs located within and even outside of MRBS coverage range. Multiple RSs can be deployed within MRBS coverage area to serve MSs as shown in Figure 2.

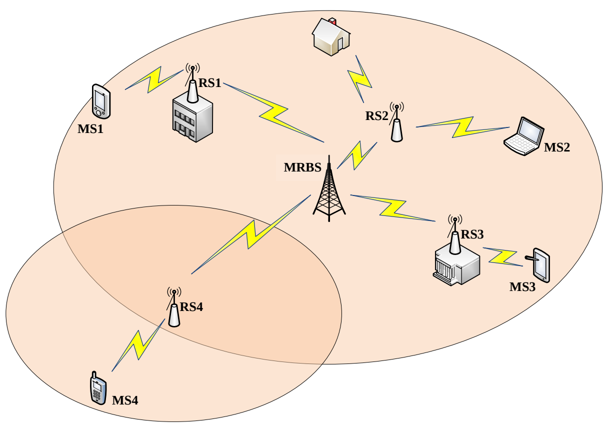



**Figure 2** A simple MMR network architecture [11]

Research has been done for relay selection mechanism based on link quality, load demand, bandwidth availability and buffer status in MMR network. But, most of the research work is meant for relay selection in transparent mode. In non-transparent relay mode, the connection is not always guaranteed. As MS moves, it may experiences connection loss or throughput degradation while transmitting data packets towards the destination node. In [12]–[14], [15] authors suggested minimizing loss by selecting potential RS that relies on channel condition. In addition, when high mobility MS moves, MS needs to establish connection frequently with the network through lengthy network entry procedures, thus, causing higher delay. In order to further lessen the possibilities of connection loss and throughput degradation in highly mobile network, a proper relay selection that can adapt to user mobility and support rapid changing connectivity with reduce signaling is proposed.

In this work, the concept of Cross Layer Design (CLD) is exploited to make decision in relay selection mechanism. The CLD concept allows different layers to interact and exchange the information with other layer to provide wider variety of design objectives and performance improvement. The CLD promises performance improvement in terms of throughput or delay. Therefore, the CLD concept has been used significantly in many research including WSN [16], vehicular network [17], [18] and multihop relay networks [19].

## 3.0 METHODOLOGY

The work is divided into two phases. The first phase is to develop the node mobility function in non-transparent relay mode. The second phase is to develop relay selection mechanism in non-transparent relay mode based on Signal to Noise Ratio (SNR). The design framework for relay selection mechanism is depicted in Figure 3. The details of the proposed relay selection and the continuous connectivity procedure in non-transparent relay mode MMR network are elaborated in Section 3.1 and Section 3.2.

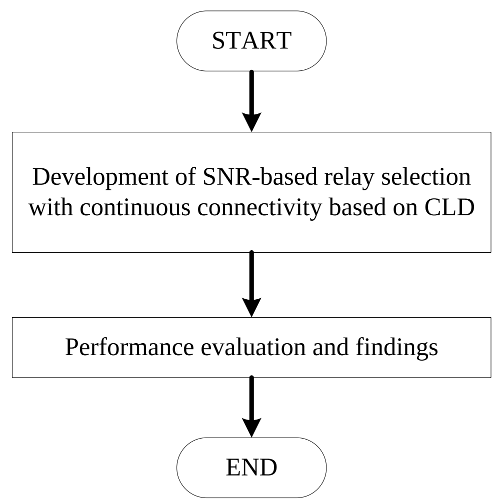



**Figure 3** Design framework for relay selection in non-transparent relay mode

### 3.1 PHASE 1: DEVELOPED NODE MOBILITY FUNCTION

The first phase is to develop the node mobility function in non-transparent relay mode. The aim is to ensure continuous connectivity whenever MS joins RS that is out of MRBS coverage range. In the standard network entry procedure in IEEE 802.16j specification, whenever MS moves out of RS coverage range, it needs to perform re-synchronization with MRBS through RS. In this work, the network entry procedure is inhibited. However, additional process is introduced to alleviate the network entry procedure to allow continuous connectivity with reduced signaling messages.

The additional process defined as connectivity procedure allows MS to join new RS when it lost the coverage range of the previous RS. If MS wants to join new RS, it only needs to reorganize with the new RS without performing the long network entry procedure with the MRBS. The connectivity procedure reduces the exchange of signaling messages to establish connection between MS and new RS. By avoiding the lengthy network entry procedure in non-transparent mode MMR network, the signaling messages can be significantly reduced and minimize delay.

In non-transparent relay mode, when MS joins RS that is out of MRBS coverage range, MS needs to be recognized by RS and MRBS. When MRBS detects a topology update due to node mobility, MRBS needs to perform re-synchronization with all RS and MS. Assume the network topology is as shown in Figure 4. In this case, MS has possibly lost connection when it moves out of RS1 coverage range. As the moving MS joins RS2, it needs to be recognized by RS2.

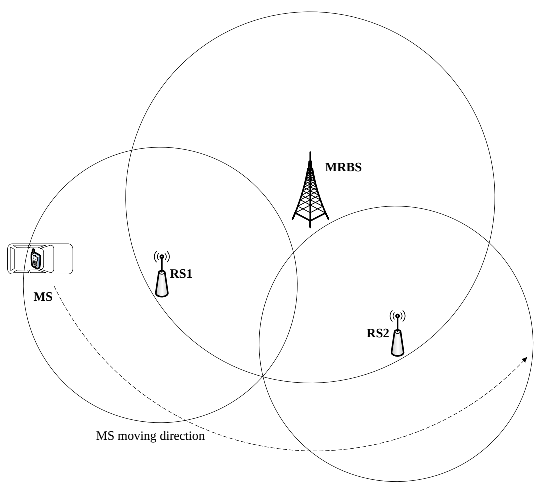



**Figure 4** Network topology for the proposed connectivity procedure

The connectivity procedure is applied whenever MS roams to another RS that is out of MRBS coverage range. Figure 5 illustrates the timing diagram of connectivity procedure in non-transparent relay mode. The same message is exchanged between MS and MRBS through RS as in [3]. Assume that the connection is already established for data forwarding. MS starts sending DT-FWD to MRBS through RS1. However, MS can possibly move outside RS1 coverage range and the connection might loss due to mobility of MS.

Additional process is introduced in the network entry procedure defined as connectivity procedure that allows MS to join RS2 when it moves out of RS1 coverage range. As the connection between MS and RS1 is loss or terminated, MS needs to wait for T48 timer expiration before retries to perform network entry procedure again. When T48 is expires, MS continue scanning for DL channel from RS2. T48 is a timeout wait for DT-FWD. Two types of signaling messages namely REQ-SYNC and REP-SYNC are introduced in the connectivity procedure. MS sends REQ-SYNC message and wait for synchronize opportunity from RS2. Referring to Figure 4, MS needs to be recognized by RS2 if MS want to join RS2. RS2 will reply with REP-SYNC message (RS2 has recognized MS) and MS is permitted to continue transmit data packets toward MRBS. Therefore, the modified network entry procedure can reduce signaling messages exchange because MS does not needs to perform the network entry procedure again when MS join RS2 that is out of MRBS coverage range.

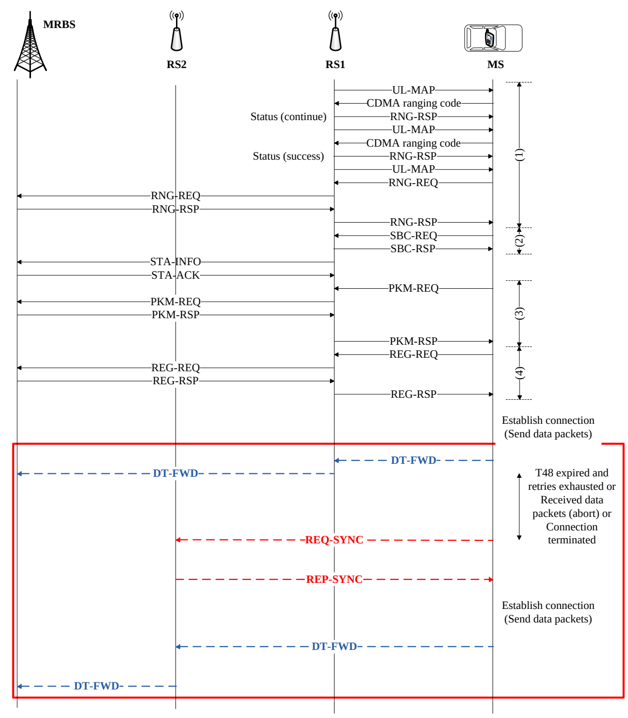



**Figure 5** Modified network entry procedure

## 3.2 PHASE 2: DEVELOPED RELAY SELECTION MECHANISM

The second phase is to develop relay selection mechanism that relies on link quality between MS and RS. The link quality parameter from Physical (PHY) layer that is Signal to Noise Ratio (SNR) information is used in Medium Access Control (MAC) layer to select a suitable RS among all available RSs for data transmission. RS with the highest SNR is selected to forward data packets towards MRBS.

The proposed relay selection mechanism that utilized CLD concept is depicted in Figure 6. Information from PHY layer is used for decision making in MAC layer to select RS with good link quality for data transmission. The implementation of such design achieves performance improvement especially in MMR network.

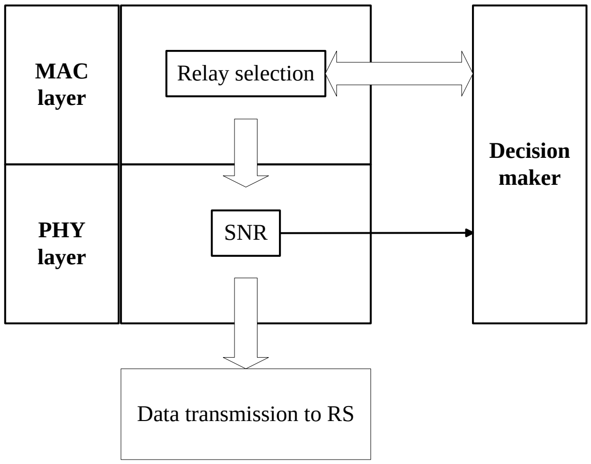



**Figure 6** CLD approach for relay selection in non-transparent relay mode

In this work, the link quality is measured based on SNR. The link quality represents channel condition for data transmission between communicating nodes. During uplink and downlink data transmission, SNR is used to determine the proper modulation type and coding rate referring to AMC table [14].

The relay selection relies on SNR as the parameter to select an appropriate RS for data transmission in MMR network. If several RS available in MS coverage range, MRBS assigned an appropriate RS with the highest SNR to attach with the MS. At the beginning the received SNR is compared with the SNR threshold i.e., 5dB. If the received SNR is fall below than 5dB, RSs are discarded from the network.

## 4.0 RESULTS AND DISCUSSION

The performances of the relay selection based on SNR are presented in comparison to benchmark scheme namely random relay selection [20]. In random relay selection method, next hop node is chosen randomly among the available RSs that offer coverage for MS. In addition, the parameter settings used in the simulation study are listed in Table 1. Two-ray ground model is used as the physical layer propagation model to study the QoS performance for both proposed and benchmark schemes in outdoor environment.

In the simulation topology, all nodes are placed in a 1000m x 1000m field. MS generates data packets at a rate of 100, 200, 300, 400, and 500 packets/sec, respectively and packets size of 128 bytes. MS moves according to the freeway mobility model where MS is assumed to move straight in a lane considering the case of rural area. Speed of each MS is assumed to be constant, without any acceleration. Throughout the simulation, the range of evaluated MS speed is set to be in between 10m/s and 50m/s in order to study the performance of low mobility and high mobility MS. The simulation lasts for 100 seconds. The performance of the relay selection is evaluated in terms of throughput and average ETE delay.

**Table 1** Parameter setting for non-transparent relay mode

| Parameter | Value | | |
|---|---|---|---|
| | BS | RS | MS |
| Power transmit (dBm) | 43 | 43 | 35 |
| Antenna gain (dB) | 15 | 9 | 5 |
| Antenna height (m) | 30 | 20 | 1.5 |
| Simulation time (sec) | 100 | | |
| MS Movement speed (m/s) | 10, 20, 30, 40, 50 | | |
| Packet size (byte) | 128 | | |
| Service rate, $\mu$ (packets/sec) | 500 | | |
| Arrival rate, $\lambda$ (packets/sec) | 100, 200, 300, 400, 500 | | |
| Frequency (MHz) | 2300 | | |
| Frame duration (ms) | 5 | | |
| FFT size | 1024 | | |
| Number of sub-carrier used | 840 | | |
| DL sub-channel | 30 | | |
| UL sub-channel | 35 | | |
| Channel Model | Cost-231 Hata [21], [22] | | |
| Path Loss Model | Two-ray Ground [23] | | |
| Traffic type | Best effort [24] | | |

Figure 7 and Figure 8 show the results for throughput and average ETE delay, respectively with the effect of mobility. MS speed is varied from 10m/s to 50m/s. The performance is compared between relay selection based on SNR and random relay selection [20]. The results show that the relay selection based on SNR achieves average performance gain of up to 9.5% in terms of throughput as compared to random relay selection. In terms of average ETE delay, the proposed scheme has successfully achieves average reduction of 2.0%. The relay selection based on SNR improves the throughput because RS with the highest SNR is chosen thus, increases the data rate of the link. Proper selection of relay with high SNR facilitates system to make use of the best modulation type and coding rate.

It is also observed that MS experienced performance degradation at higher speed for both proposed and benchmark schemes. For relay selection based on SNR, the deterioration of the throughput for high mobility MS with speed of 50m/s is about 2.0% compared to low mobility MS with speed of 30m/s. As for random relay selection, the throughput degradation is a bit higher than the proposed scheme which is 2.3%. This shows the effectiveness of the proposed scheme to provide continuous connectivity regardless of MS speed although it experiences some throughput degradation at high speed due to frequently changed RS links.

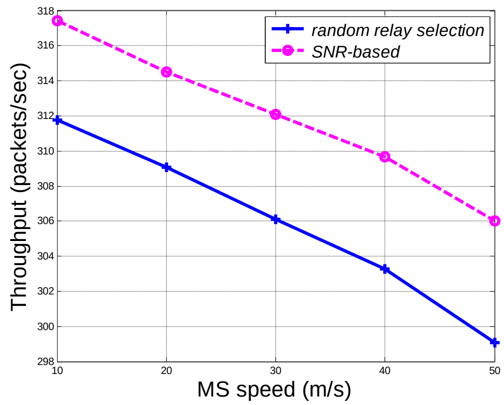



**Figure 7** Throughput for different MS speed (ρ = 0.8)

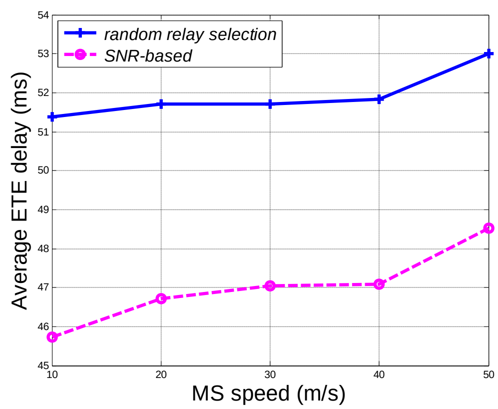



**Figure 8** Average ETE delay for different MS speed (ρ = 0.8)

## 5.0 CONCLUSION

SNR-based relay selection with continuous connectivity is successfully developed in non-transparent relay mode that enhanced the network performance in terms of throughput and delay. RS with highest SNR is chosen for the reason that better link quality and high throughput. At low mobility scenario, MS speed is about 30m/s or equal to 108km/h while at high mobility scenario, MS speed is about 50m/s or equal to 180km/h. The high mobility MS experienced slight throughput degradation about 2.0% compared to low mobility MS. The result shows that continuous connectivity is successfully provided to high mobility MS at the expense of throughput degradation due to rapid changing of RS links. Besides, MS does not have to repeat the lengthy network entry procedure, thus reduce signaling overhead.

## Acknowledgement

The authors thank the Ministry of Education Malaysia (MOE) and Universiti Pendidikan Sultan Idris (UPSI) for the Sponsorship and Telematic Research Group (TRG), Universiti Teknologi Malaysia (UTM) for the support and advice.

## References

[1] R. W. H. Steven W. Peters. 2009. The Future of WiMAX: Multihop Relaying with IEEE 802.16j. *IEEE Standards in Communications and Networking*. 104–111.

[2] Jerry Sydir. 2009. IEEE 802.16 Broadband Wireless Access Working Group - Harmonized Contribution on 802.16j (Mobile Multihop Relay) Usage Models. *IEEE 802.16 j Working Group Document*. 6(15): 1–12.

[3] I. M. T. and T. S. 2009. Air Interface for Fixed and Mobile Broadband Wireless Access Systems Multihop Relay Specification. *IEEE Computer Society*. 16: 1–296.

[4] I. M. T. and T. S. IEEE Computer Society. 2006. IEEE Standard For Local And Metropolitan Area Networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigedum 1: 1–822.

[5] I. M. T. and T. S. 2002. IEEE Standards for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems. IEEE Computer Society. 1–322.

[6] V. Genc, S. Murphy, Y. Yu, and J. Murphy. 2008. IEEE 802.16j Relay-based Wireless Access Networks: An Overview. *Recent Advances and Evolution of WLAN and WMAN Standards*. 56–63.

[7] P. Mach and R. Bestak. 2007. Performance of IEEE 802.16 with Relay Stations. *In Proceedings Conference on Telecommunications*. 381–384.

[8] S. K. Rangineni. 2008. Multihop Concept in Cellular Systems. 1–65.

[9] D. Ghosh, A. Gupta, and P. Mohapatra. 2009. Adaptive Scheduling of Prioritized Traffic in IEEE. *IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WIMOB)*. 307–313.

[10] R. Pabst, B. H. Walke, D. C. Schultz, M. Lott, W. Zirwas, S. Icm, M. Dohler, H. Aghvami, and K. College. 2004. Relay-Based Deployment Concepts for Wireless and Mobile Broadband Radio. 80–89.

[11] K. Voudouris, P. Tsiakas, and N. Athanasopoulos. 2009. A WiMAX Network Architecture Based on Multi-Hop Relays. *Qual. Serv. Resour. Alloc. WiMAX*. 978–953.

[12] N. Satiman, R. A. Rashid, N. Fisal, and N. N. M. I. Ma'arof. 2011. A SNR-based Route Selection Algorithm for WiMAX Mobile Multi-hop Relay Networks. *Wirel. World Res. Forum(WWRF 26). Doha, Qatar*

[13] L. Xiong, L. Libman, G. Mao, and I. Engineering. 2009. On Cooperative Communication in Ad-Hoc Networks: The Case for Uncoordinated Location-Aware Retransmission Strategies. *IEEE 34th Conf. Local Comput. Networks (LCN)*. 554–561.

[14] V. Genc, S. Murphy, and J. Murphy. 2008. An Interference-Aware Analytical Model for Performance Analysis of Transparent Mode 802.16j Systems. *Comput. Sci. Informatics*. 1–6.

[15] X. Ma, R. Yin, G. Yu, and Z. Zhang. 2012. A Distributed Relay Selection Method For Relay Assisted Device-to-Device Communication System. *IEEE Int. Symp. Pers. Indoor Mob. Radio Commun (PIMRC)*. 1020–1024.

[16] T. Melodia, M. C. Vuran, and D. Pompili. 2006. The State of the Art in Cross-layer Design for Wireless Sensor Networks. *Wirel. Syst. Netw. Archit. Next Gener. Internet, Springer Berlin Heidelb.* 78–92.

[17] G. Korkmaz, S. Member, E. Ekici, and F. Özgüner. 2006. A Cross-Layer Multihop Data Delivery Protocol With Fairness Guarantees for Vehicular Networks. 55(3): 865–875.

[18] B. Jarupan and E. Ekici. 2009. Location And Delay-Aware

Cross-Layer Communication In V2I Multihop Vehicular Network. *IEEE Commun. Mag.* 47(11): 112–118.

[19] R. Babaee, S. Member, and N. C. Beaulieu. 2010. Cross-Layer Design for Multihop Wireless Relaying Networks. 9(11): 3522–3531.

[20] V. Sreng, H. Yanikomeroglu, and D. D. Falconer. 2003. Relayer Selection Strategies in Cellular Networks with Peer-to-Peer Relaying. *IEEE 58th on Veh. Technol. Conf. (VTC)*. 3: 1949–1953.

[21] P. Mach and R. Bestak. 2008. WiMAX throughput evaluation of conventional relaying. *Telecommun. Syst.* 38(1–2): 11–17.

[22] WiMAX Forum. 2008. WiMAX System Evaluation Methodology 2.1: 1–209.

[23] D. M. Shrestha, S. Lee, S. Kim, and Y. Ko. 2007. New Approaches for Relay Selection in IEEE 802.16 Mobile Multi-hop Relay Networks. 950–959.

[24] P. Neves, F. Fontes, J. Monteiro, S. Sargento and T. M. Bohnert. 2008. Quality Of Service Differentiation Support In WiMAX Networks. *International Conference on Telecommunications*. 753–769.