Jurnal
Teknologi

Full Paper

RELAY SELECTION IN MOBILE MULTIHOP RELAY NETWORK

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

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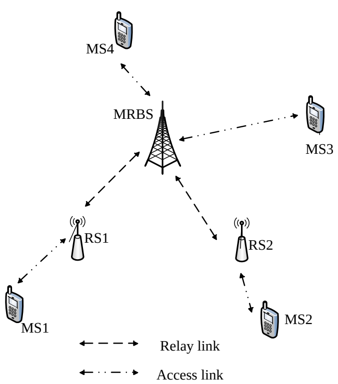
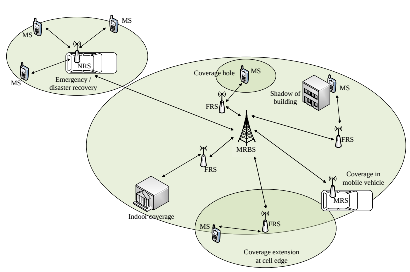
Graphical abstract





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 relay selection that allows cooperative data transmission in transparent relay that guarantees continuous connectivity. The proposed relay selection defined as Co-ReSL depends on weightage of SNR, α and weightage of Link Expiration Time (LET), β. The QoS performances of the proposed relay selections are in terms of throughput and average end-to-end (ETE) delay. The findings for Co-ReSL shows that at heavy traffic load, throughput increases up to 5.7% and average ETE delay reduces by 7.5% compared to Movement Aware Greedy Forwarding (MAGF) due to cooperative data transmission in selective links. 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 pemilihan pengulang yang membolehkan penghantaran data secara koperasi dalam pengulang telus yang menjamin sambungan berterusan. Pemilihan pengulang yang dicadangkan didefinisikan sebagai Co-ReSL bergantung kepada pemberatan SNR, α dan pemberatan LET, β. Prestasi QoS bagi pemilihan pengulang yang dicadangkan adalah kendalian dan purata kelewatan Hujung-ke-Hujung (ETE). Hasil kajian Co-ReSL menunjukkan bahawa pada beban trafik berat, kendalian meningkat sehingga 5.7% dan purata kelewatan ETE berkurang sebanyak 7.5% berbanding dengan Pemaju Tamak Peka Pergerakan (MAGF) disebabkan oleh penghantaran data secara koperasi dalam pautan terpilih. 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

MMR network consists of multiple RSs assist MRBS to forward data to or from MSs. Coexistence of MRBS, RSs and MSs in the same cell forms a multi-level tree where the MRBS acts as the root. There are two types of communication links defined in MMR network as depicted in Figure 1. The communication link between MRBS and RS is called as relay link whereas the communication link between RS and MS or between MRBS and MS is called as access link.

In MMR network, the node which is responsible for receiving the uplink traffic from the other node is referred as the superordinate station of the other node. For instance, RS1 is the superordinate station for MS1. Following the same manner, MS1 is called as the subordinate station of RS1. MRBS or RS can be a superordinate station while a subordinate station can be either RS or MS. In short, if the node is a superordinate station of an MS, the station is called either access BS or access RS.

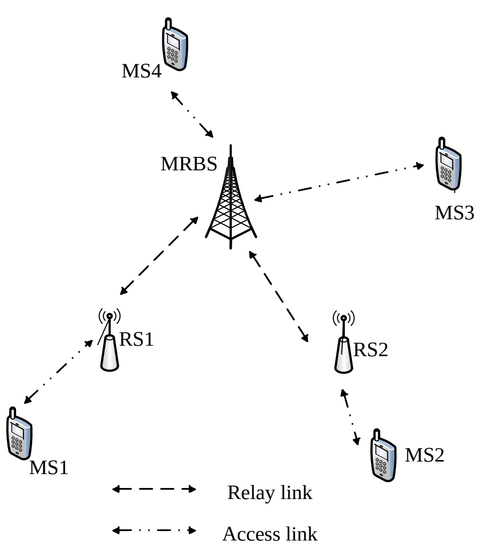


Figure 1 Types of communication links in MMR network

Motivation related to relay-based development concept in MMR network is presented in [1]. Typically, RS entities introduced in MMR network offer main benefits of coverage extension and improve the system capacity. Besides, the cost of setting up new BS is reduced by deploying a low cost RS to support the rapid growth of number of MS in MMR network. This low cost RS is responsible for relaying data packets from MRBS to MS or vice versa. The benefits of multihop RS are discussed in detailed in the following aspects:

- **Coverage extension**

Multihop RS extends the MRBS coverage range especially for the MSs located at cell edges. Thus, introduction of RS can extend the coverage range of the cell [2], where RS has the capability to serve MS that is located outside of MRBS coverage range. Besides, deployment of RS provides solution to coverage holes problem due to shadowing of buildings or valley between buildings.

- **Improve the system capacity**

MS at cell edges suffer poor received signal from the MRBS. Thus, RS is introduced to improve the capacity of the cell. When MS is closer to RS, it receives strong signal from RS. The signal quality is thus improved at the cell edge and throughput is increased because high data rate is used for data transmission in MMR network.

- **Low cost RS deployment**

RS deployment does not require any dedicated backhaul equipment. Thus, RS deployment is less complex compared to the deployment of MRBS. In this case, RS is considered as a cost effective and easy solution to be installed in the network to aid the service provision for indoor and outdoor environment.

2.0 RELATED WORK

The importance of multihop relaying in mobile network has increased over the last several years. Mobile networks are highly potential in providing support for Intelligent Transport System (ITS), multimedia and expediting the Internet access in highways [3]. Today, the technologies developed for establishment of mobile network include the IEEE 802.11 [4], IEEE 802.11p [5] and IEEE 802.16 standards. Taking advantage of wider communication range and higher data rate, IEEE 802.16j standard is proposed by standardization bodies to support mobile and multi-hop relay in mobile network [6]. There are three types of RSs consisting of fixed, nomadic, and mobile RS according to [7] as shown in Figure 2. The fixed RS (FRS) is permanently set up at a specific location. Even though the nomadic RS (NRS) is also stationary when operating, its position can be migrated as needed. Another type of RS is the mobile RS (MRS) which is moving in a similar way as Mobile Station (MS).

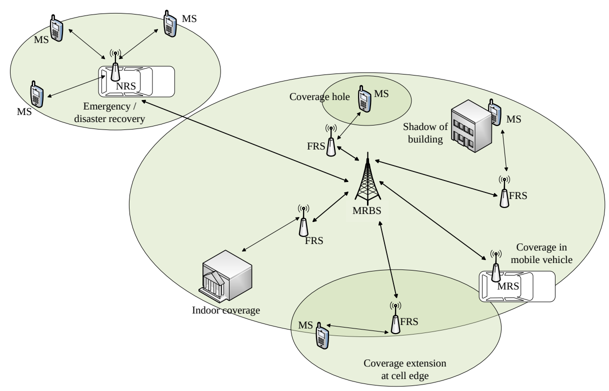


Figure 2 Scenario for fixed, nomadic and mobile RS [8]

A typical multihop relaying in mobile network is shown in Figure 3. The networks consist of one MRBS, several RSs and MSs along the highway. RS operating in non-transparent relay mode is capable to extend coverage area and enhance capacity [9], [10], [11]. However, as the MS moves from one point to another, the performance is degraded due to random variation of channel and network condition [12]. The communication link between paired MRBS and MS are weaken eventually, and data packets can be lost or never received at the destination. Therefore, relay selection scheme is proposed to overcome the performance degradation problem during data transmission for MS in mobile network. Even though, in practical environment MS can either send data packets directly to MRBS or through RS by multihop, the focus of this work is only on multihop relaying.

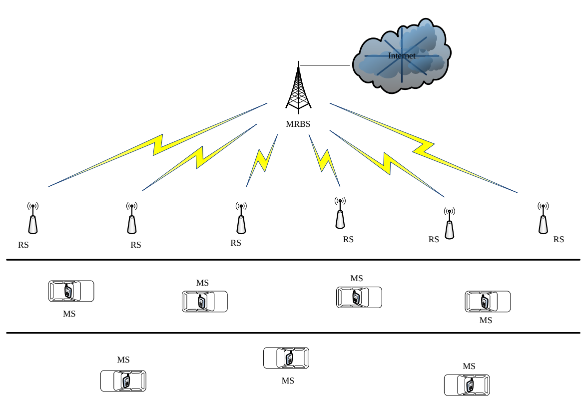


Figure 3 Multihop relaying in mobile network [13]

Mobile network brings a lot of conveniences to our daily life. Users can still enjoy surfing the Internet even while travelling in moving transport, such as bus, train, lorry, and car. Nonetheless, due to node mobility, data forwarding path may be very unstable most of the time and communication links between the nodes can be disconnected recurrently. Relaying MS data becomes more challenging because node moves with high speed [14]. The main challenge and issue in mobile network is to design relaying strategy that is able to adapt to the rapidly changing topology of fast moving nodes. Details about challenge that need to be addressed in MMR network are discussed as the following:

- **Relaying strategy**

Relaying strategy is currently being considered as an approach for coverage extension and capacity enhancement in WiFi [15], WiMAX [16], [17], [18] and 4G LTE-Advanced network [19], [20], [21], [22]. Relaying strategy uses particular nodes that act as intermediate nodes for a pair of communication link instead of just relying on direct communication between MS and BS. The intermediate node can be several RSs which allow multihop data transmission in mobile network. This kind of relaying strategy has also been used already in Wireless Sensor Network (WSN) [23], [24], [25] and ad-hoc network.

In mobile networks, the relay chosen to assist data transmission to an MS at a particular location may no longer be beneficial if the MS moves to another location due to variation of link condition. A proper relaying strategy needs to be proposed to adapt with the probability of the link disruption. As the MS moves from one location to another, it could lack of continuous network connectivity. Thus, this violates the guarantee for a connected end-to-end communication.

One of the most important factors in relay strategy is the link transmission rate. As state in the IEEE 802.16j standard, IEEE 802.16j uses an Adaptive Modulation and Coding (AMC) scheme for allocating different modulation and coding rates to different channel condition. When SNR increases at the receiver, the sender will adopt a higher order modulation mode which allows it to transmit at higher link rate. Similarly, as SNR gets worse, the sender switches its modulation mode to a lower order to adapt to the degraded channel condition. In AMC, the time varying distance between two communicating nodes play a major role in choosing the link transmission rate.

- **Node mobility**

The movement of MS is predicted by using mobility prediction as proposed in [26]. Mobility prediction is widely used in other networks such as in underwater sensor networks [27], wireless LAN [28], mobile ad-hoc networks [29] and vehicular ad-hoc networks [30]. BS is responsible to select an access station for MS to help in forwarding data towards BS. In mobile communication, connectivity is not always available and messages might be lost or never received at the destination. During the transmission process there are two types of operations, which are either the messages is directly transmitted to the destination or is forwarded through RS by multi-hoping relay strategy. Thus, a proper relay selection is necessary to improve the network performance in terms of throughput and average end-to-end (ETE) delay. In the event where the destination node is mobile, the distances change with time which affected the received Signal to Noise Ratio (SNR) due to path loss of the channel. If the distance between moving node and relay node increases, the link rate between communicating nodes decreases and thus, reduces the system throughput [31].

3.0 METHODOLOGY

This section describes the proposed relay selection that utilizes cooperative data transmission for MS in transparent relay mode MMR network. The relay selection named as Co-ReSL relies on the weightage of SNR and LET. The purpose is to select RSs that provide good link quality and high link stability to reduce the performance degradation at high mobility MS. The network consists of one MRBS several RSs and MSs within MRBS coverage range. In this work, two hops communication is assumed for data transmission. The design framework for Co-ReSL in transparent relay mode is illustrated in Figure 4.

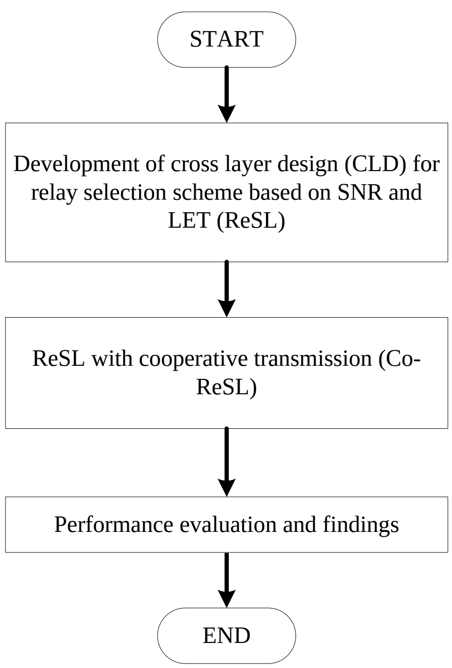


Figure 4 Design framework for Co-ReSL in transparent relay mode

The development of the proposed relay selection that allows cooperative relay transmission consists of two phases includes assigning the weight factor for both SNR and LET, and the decision to choose potential RSs in order to achieve performance improvement for data transmission in MMR network. The following section discusses the two phases in details.

3.1 PHASE 1: WEIGHT SCORE

The first phase is to assign the weight factor for both SNR and LET. The selection of RS that allows cooperative relay transmission is developed defined as Co-ReSL. There are two main parameter uses in order to select potential RSs for data transmission that is SNR and LET. The link quality is obtained from the received SNR and the LET concept is used in the proposed relay selection to improve the link stability between MS and RS. The idea is to define a function to select the potential RSs for data transmission that meet the requirement at high mobility MS. The function is known as weighted score, which depends on weight of SNR and LET factors. The weighted score W_i is computed by MRBS to decide on MS access station as in Equation (1).

$$W_i = \alpha SNR + \beta LET \qquad (1)$$

Both α and β are considered as the weight of SNR and LET factors with $\alpha + \beta = 1$.

- **Signal to Noise Ratio**

As stated in [32], to allow nodes pairing the minimum received SNR is at least 5dB and above. As the SNR received from two communicating nodes below the SNR threshold i.e., 5dB, the nodes is assumed to be disconnected from the network as express in Equation (2). Thus, data transmission process between the nodes is not allowed.

$$\sigma_{RS_i} \geq \sigma_n \quad (where\ \sigma_n > 5dB) \qquad (2)$$

where σ_{RS_i} and σ_n represent SNR from relay node i and SNR threshold, respectively.

- **Link Expiration Time**

The concept of Link Expiration Time (LET) is used to improve network performance in MMR network. LET is defined as the duration of time for nodes to remain connected within the coverage range of each other. By using the movement parameters such as position and speed of two neighbor nodes, the validity of the communication link is checked.

Link Expiration Time (LET) is introduced as a statistical derivation to forecast the average distance of relay nodes are within the coverage of MS. This mobility prediction method utilizes the location and mobility information provided by GPS. It is also assumed that all nodes in the network have their clock synchronized. Therefore, if the motion parameters of two nodes are known, like speed, direction and radio propagation range, we can determined the duration of time these two nodes will remain connected.

Let consider two nodes, i and j are within the transmission range r of each other. Let v_i and v_j be the speed, (x_i, y_i) is the coordinates of node i, and (x_j, y_j) be the coordinates of node j. Let θ_i and θ_j be the movement direction angles for node i and node j, respectively. Then, the amount of time two nodes will stay connected is predicted by the formula given by Equation (3) [33].

$$LET = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \quad (3)$$

The parameters a, b, c and d are determined using the formula illustrated by Equation (4), (5), (6) and (7). Parameter a is the relative velocity of the receiver node with respect to the sender node along Y-axis. It is determined using Equation (4).

$$a = v_i cos\theta_i - v_j cos\theta_j \quad (4)$$

Parameter b is used to determine the distance of the receiver node from the sender node along X-axis and is determined using Equation (5).

$$b = x_i - x_j \quad (5)$$

The third parameter used to determine LET is c. Parameter c is the relative velocity of receiver node with respect to the sender node along Y-axis. Equation (6) gives the formula to determine c.

$$c = v_i sin\theta_i - v_j sin\theta_j \quad (6)$$

d is the distance of the receiver node from the sender node along Y-axis. This parameter is determined using the formula given in Equation (7).

$$d = y_i - y_j \quad (7)$$

3.2 PHASE 2: RELAY SELECTION SCHEME

The second phase is to choose potential RSs in order to achieve performance improvement for data transmission in MMR network. Parameters at PHY and MAC layers are used to select potential RSs for data transmission as shown in Figure 5. The parameters include SNR from PHY layer and LET from MAC layer. Based on the weightage of SNR and LET, the potential RSs are re-arranged in descending order based on high to low weighted score, W_i. Then, the data packets are sent multicast through multiple links from MS to the selected potential RSs.

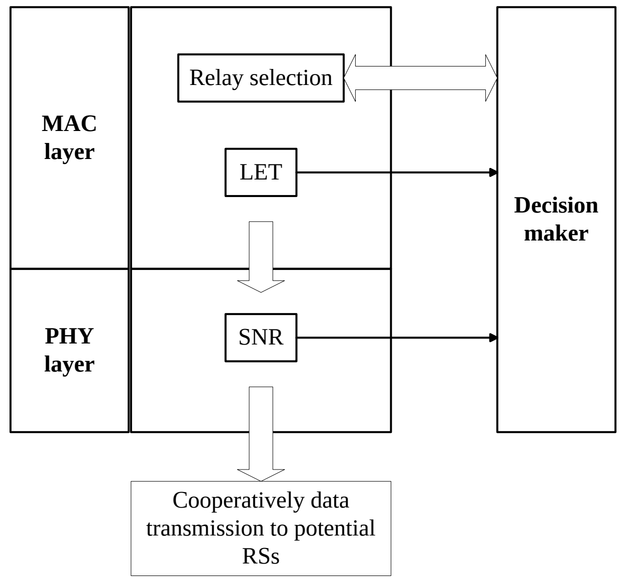


Figure 5 CLD approach for Co-ReSL in transparent relay mode

At high mobility MS, the duration of nodes remain connected depends on the MS speed. If the MS speed is high, the potential for communication link to be disconnected is also high. Therefore, Co-ReSL is proposed to reduce the occurrence of communication link disconnection. Nodes with low LET is discarded from inclusion. To achieve this functionality, Co-ReSL offers an idea to select multiple RSs with good link quality and high link stability to maintain connectivity between two nodes. There are several assumptions made for supporting the proposed Co-ReSL in transparent relay mode MMR network as follows:

i) All nodes on the road participate in sending and relaying data packets whereas the penetration of MSs is 100 percent.
ii) No sudden changes of direction while nodes are travelling. Overtaking maneuver is out of concern in this scope of work.
iii) MS moves according to the freeway mobility model where MS is assumed to move straight in a lane due to system complexity considering the case of rural area.
iv) Constant velocity for all MSs, i.e. the speed is between 36kmph to 180kmph. Speed of each MS is assumed to be constant, without any acceleration and deceleration.
v) MS has capability to store the packet in its buffer, carry the packet, and when appropriate, MS is able to forward the packet to the next hop neighbor node.
vi) The decision of selecting next RS is made at the time when MS is assumed still in the current position.
vii) Assume that all nodes, i.e. RS and MS are equipped with GPS for location tracking. The

location given by GPS in (longitude, latitude) is already converted to Cartesian coordinate (x, y).

MMR network provides coverage extension and throughput enhancement. Cooperative communication is anticipated as an efficient solution in multihop data transmission because it provides robust forwarding by selecting multiple links to simultaneously send data packets from MS to MRBS through RS or vice versa. Compared to direct communication, cooperative communication allows MS to transmit data packets with high speed and high reliability [34]. Therefore, cooperative communication is exploited for data transmission to enhance the QoS performance in MMR networks.

In this work, the cooperative relay transmission is exploited where multiple RS forward data packets toward MRBS. Assume that MS able to generate duplicate data packets to send to several potential RSs. Several potential RSs is obtained by using Co-ReSL. The SNR and LET information are collected and measured. Then, this information is computed using weighted score, W_i. RS with the highest value of W_i is listed at the highest order in the routing table. The value of W_i is re-arranged from high to low corresponds to the RS ID.

In this work, the number of cooperative transmission is limited to three to reduce the system complexity. Moreover, the results for four cooperative transmissions are about the same as three cooperative transmissions. At MRBS side, if MRBS already receives packet ID number 1 and after a certain time it receives the same packet ID from different RS, the later packet ID is dropped.

4.0 RESULTS AND DISCUSSION

The performance of Co-ReSL is evaluated in comparison to Movement Aware Greedy Forwarding (MAGF) as proposed in [33]. Co-ReSL uses cooperative links while MAGF used single link for data transmission. The parameter settings are listed in Table 1. Two-ray ground model is considered as the physical layer propagation model in studying the QoS performance of both schemes.

In the simulation setting, all nodes are placed in a 1000mx1000m field. The source node generates data packets at the rate of 200, 400, 600, 800, and 1000 packets/sec, respectively and packets size of 128 bytes. MS moves according to the freeway mobility model where a MS is restricted to move in a straight lane as in the case of rural area. The speed of MS evaluated in the simulation is varied from 10m/s to 50m/s. The simulation lasts for 60 seconds. The performance of relay selection is evaluated in terms of throughput and average ETE delay.

Table 1 Parameter setting for 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)	60		
MS Movement speed (m/s)	10, 20, 30, 40, 50		
Packet size (byte)	128		
Service rate, μ (packets/sec)	1000		
Arrival rate, λ (packets/sec)	200, 400, 600, 800, 1000		
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 [35], [36]		
Path Loss Model	Two-ray Ground [37]		
Traffic type	Best effort [38]		

4.1 Selection for weight of SNR factor, α and weight of LET factor, β

Two different traffic load condition is assumed to determine the optimal values for weight of SNR factor, α and weight of LET factor, β. The results for various α values are evaluated in terms of throughput and average ETE delay and presented in Figure 6 and Figure 7, respectively.

For light traffic load ρ = 0.2, by setting α = 0.8, the throughput increases up to 12.1% and average ETE delay decreases by 13.4% compared to the lowest throughput and highest average ETE delay at α=0.2. For heavy traffic load ρ = 0.8, the throughput improves up to 8.7% and average ETE delay decreases by 7.7% by using α = 0.8 compared to the lowest throughput and worst average ETE delay obtained at α = 0.2. Based on the simulation study, setting α = 0.8 for SNR and β = 0.2 for LET outperforms all other weight combinations. Therefore, α = 0.8 and β = 0.2 is chosen to be used in all simulation study throughout the thesis.

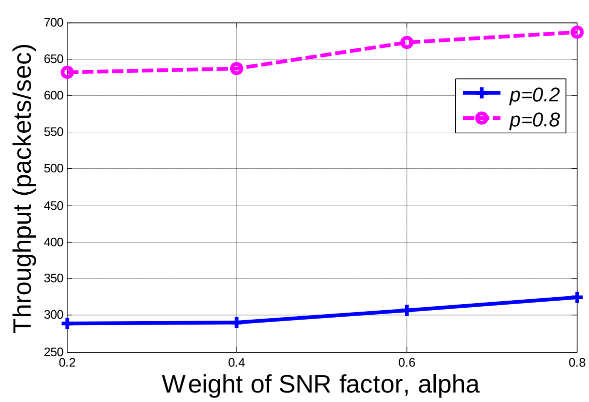


Figure 6 Throughput in different weight of SNR factor, α

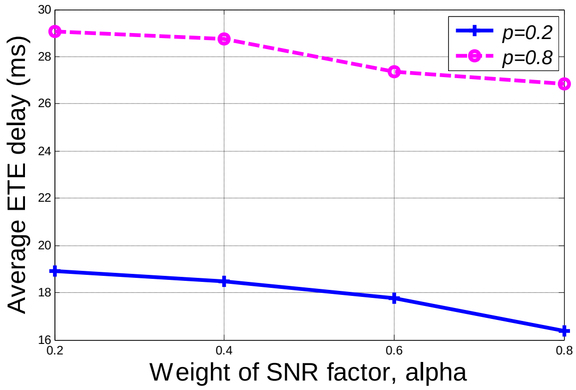


Figure 7 Average ETE delay in different weight of SNR factor, α

4.2 Effect of Traffic Load

Herein, the performance of Co-ReSL is analyzed for various traffic loads. Packets are transmitted from MS to MRBS using the proposed relay selection mechanism. The result obtained from Co-ReSL is compared with MAGF [33]. In MAGF, the selection relies on LET to find the most stable path for data transmission. The traffic load is varied from ρ = 0.2 to ρ = 0.95. MS speed is set to be 30 m/s. Figure 8 and Figure 9 show the system performance in terms of throughput and average ETE delay with variation of traffic load, respectively.

For light traffic load case of ρ = 0.2, the throughput performances for Co-ReSL and MAGF are almost similar to each other. This is because the network has enough available resources to support light traffic load demands. For heavy traffic load case of ρ = 0.8, Co-ReSL shows significant performance improvement compared to MAGF. Throughput is increased up to 5.7% by implementation of Co-ReSL as compared to MAGF.

In terms of average ETE delay, both Co-ReSL and MAGF yield quite similar performance. In light traffic, the packets do not have to queue and wait to be served in the system. As a result, delay for both Co-ReSL and MAGF is small. For heavy traffic load case, average ETE delay decreases by 7.5% for Co-ReSL compared to MAGF. In contrary to light traffic case, the number of packets is high. Thus, the user packets need to be served consecutively according to their arrival time, which involves certain waiting time.

From the simulation study, it is proven that Co-ReSL outperforms MAGF. This is due to the spatial diversity gain obtained by utilizing cooperative links for data transmission in Co-ReSL whereas MAGF uses only a single link. Besides, the weight of both SNR and LET assist Co-ReSL to choose potential RSs with good link quality and high link stability.

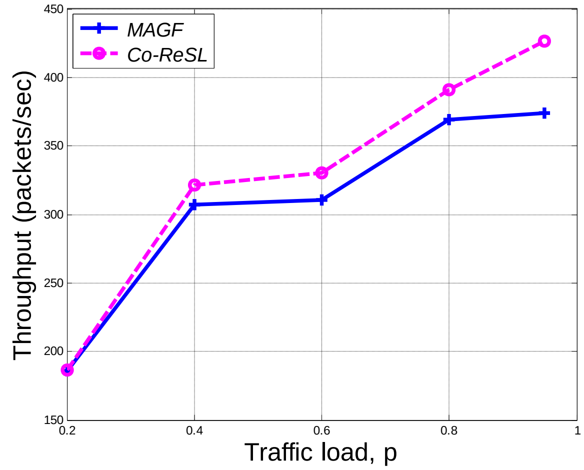


Figure 8 Throughput among MAGF and Co-ReSL (MS speed = 30m/s)

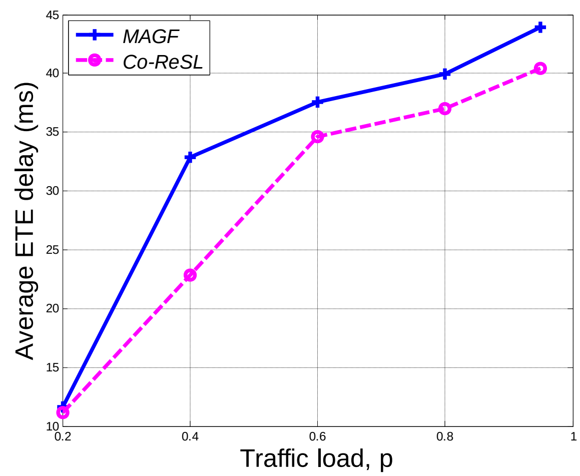


Figure 9 Average ETE delay among MAGF and Co-ReSL (MS speed = 30m/s)

5.0 CONCLUSION

Co-ReSL relay selection that ensure continuous connectivity is successfully develop in transparent relay mode to further enhance the network performance in terms of throughput and delay. Relay selection is decide based on link quality and link stability, thus enhanced throughput and minimize delay. Besides, cooperative data transmission on selective relay links enhanced QoS performance for high mobility MS in MMR network.

At high traffic load, ρ = 0.8, Co-ReSL outperformed MAGF in terms throughput by about 5.7% and reduces average ETE delay 7.5%. This is because Co-ReSL used cooperative links while MAGF used single link for data transmission. In addition, the weightage of SNR and LET facilitate Co-ReSL to select reliable RS with good link quality and high link stability. Choosing communication links with good channel condition and stable communication links with longer lifetime enhances QoS in the network. The decision leads to cooperative communication on reliable channel with longer lifetime. The usage of cooperative communication leads to higher throughput in MMR network.

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.

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