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Frame structure for Mobile multi-hop relay (MMR) WiMAX networks

F. E. Ismael[1]*, S. K. Syed-Yusof[1], M. Abbas[2], N. Fisal[1] and N. Muazzah[1]

[1]CoE Telecommunication Technology, University of Technology, Malaysia (UTM), Johor, 81310 UTM Skudai, Malaysia.
[2]Head of Wireless Communication Cluster, MIMOS Berhadi, Malaysia.

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Mobile Multi-hop Relay (MMR) WiMAX network uses Relay stations (RSs) to extend the cell coverage, and enhances the link quality and the throughput. In MMR WiMAX networks, the number of hops between the Subscriber stations (SSs) and the Base station (BS) is allowed to be more than two hops when Non transparent RS (NT-RS) is used. However, this requires modification to the frame structure of NT-RS to reduce the delay of relaying the data packets across multiple hops. Therefore, this paper presents a new NT-RS frame structure aimed to decrease the multi-hop relaying delay in order to improve the performance of the data transmission over MMR WiMAX network. The proposed frame structure serves the sub-ordinate SSs as well as NT-RSs in the access zones, while using the relay zones to communicate with its super-ordinate stations. The performance of the proposed frame structure is tested through a simulation work. The results showed that, the forwarding delay is reduced, and hence the link layer and the Transmission control protocol (TCP) throughput are improved significantly.

Key words: IEEE 802.16j, transmission control protocol (TCP) performance, non transparent relay stations (NT-RS), frame structure.

INTRODUCTION

The service quality near the cell boundary of single hop deployment of WiMAX network degrades due to bad channel. Therefore, a multi-hop system using RS to relay the data packets between BS and the end SSs is introduced in (Yang et al., 2009; IEEE802.16j, 2009). The RS can improve the performance at the cell boundaries as well as extending its coverage to areas where weak signals are received or no signal at all. The network utilizing this multi-hop structure is called Mobile multi-hop relay (MMR) WiMAX network. The functionality of the BS should be extended in order to support incorporation of RSs into the network. The BS that incorporates these new functions is called a Mobile multi-hop relay base station (MMR-BS) (Canton and Chahed, 2001).

The IEEE 802.16j allows the number of hops to be more than two when non-transparent RSs are used. In the case of more than two hops between the MMR-BSand the SS, there is a need to coordinate the transmission of intermediate RSs in order to efficiently utilizing the available resources. There are two ways to approach this; Single frame (SF) structure and Multi frame (MF) structure. SF structure suffers from poor capacity of the relay zones as the number of hops increases. On the other hand, the forwarding delay of the data packets across multiple hops is relatively long, especially for large number of hops when MF structure is considered. As a result, the SSs at different hops experience different performances of data transmission. This can be seen clearly for services such as TCP traffic where the rate of injecting segments into the network depends on the rate of acknowledgement (ACK) reception. TCP is the most common transport protocol used in the internet, which provides end-to-end connection oriented and reliable data transmission service

*Corresponding author. E-mail: fathi_sml@yahoo.com.

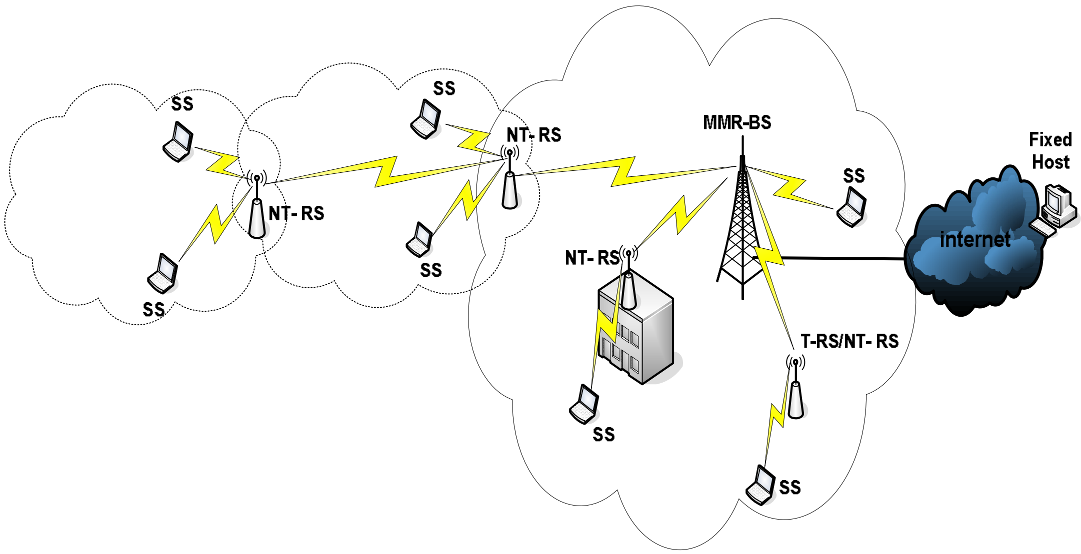

Figure 1. MMR WiMAX network architecture.

(Aweya, 2003). Due to the limitations of MF and SF structures, there is a need for a new construction of the Orthogonal frequency division multiple access (OFDMA) frame to overcome these limitations. Therefore, in this paper a new multi frame (NMF) structure for NT-RS is proposed, that is able to reduce the forwarding delay, and maintains the capacity of the MMR WiMAX network.

MOBILE MULTI-HOP RELAY WIMAX NETWORK

MMR WiMAX network architecture

The IEEE 802.16j uses various RSs to relay the data packets between the MMR-BS and end SSs. Figure 1 shows an example of MMR WiMAX network architecture consisting of one Mobile multi-hop relay base station (MMR-BS) connected to the internet through backbone network and a number of RSs to relay the data between the MMR-BS and the end SSs. The RSs used in IEEE 802.16j are backward compatible with IEEE 802.16e SSs; hence modifications are not required at the end SSs. In addition, RSs have less complexity and lower cost, as compared with the BS. Therefore, by using such RSs, an operator could deploy a network at a lower cost than using only expensive BSs to provide wide coverage (Genc et al., 2008b; Peters and Heath, 2009; Yang et al., 2009; Upase and Hunukumbure, 2008).

As shown in MMR WiMAX network model in Figure 1, the RSs can be used for coverage extension and throughput enhancement. Figure 2 shows the means of achieving these goals using different types of RSs. The coverage extension is achieved through two different scenarios; extending the coverage range of the BS and addressing coverage holes caused by shadowing as shown in Figure 1. On the other hand, enhancing system capacity will be gained by the use of multiple links with better quality (Genc et al., 2008b; Lei et al., 2008). Better link quality in terms of Signal to Noise ratio (SNR) allows the use of higher modulation level, and hence the overall throughput increases. In addition, multi-hop communication supports spatial reuse of frequency channels among RSs, which increases the overall system capacity. There are two different relaying modes of operation; transparent mode RS (T-RS) and non-transparent mode RS (NT-RS) (Genc et al., 2008b; Soldani and Dixit, 2008; Yang et al., 2009; Upase and Hunukumbure, 2008). The key difference between these two relaying modes of operation is the ability to generate and send control information to its sub-ordinate stations through the frame header. The RS operating in transparent mode cannot generate and transmit control information, but in non-transparent mode, the RSs do generate and transmit its own control information to its sub-ordinate stations.

The T-RSs (Genc et al., 2009; Upase and Hunukumbure, July 2008) only forward controls information generated by the MMR-BS, and hence they do not extend the coverage area of the BS. However, T-RS is used to enhance the system capacity in terms of throughput within the BS coverage area. T-RS has less complexity and is cheaper, as compared with the NT-RS. So, the T-RS can only operate in a centralized scheduling mode and for topology, up to two hops only. The NT- RSs (Yang et al., 2009; Sayenko et al., 2010; Upase and Hunukumbure, 2008) operate in either centralized or distributed scheduling. In the case of centralized scheduling, NT-RSs only forward the control information provided by the MMR-BS to their sub-ordinate SSs. However, when NT-RSs operate in distributed

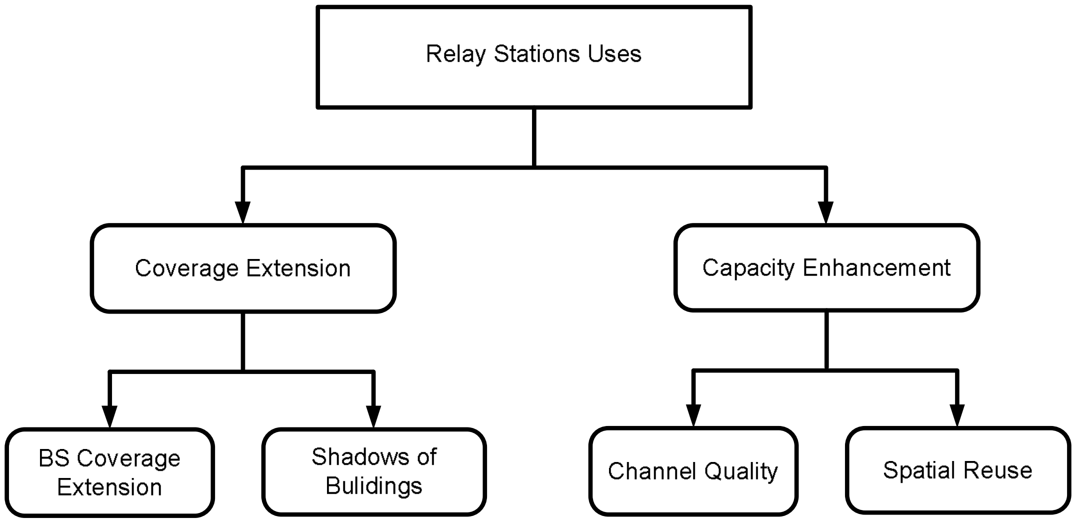

Figure 2. Relay stations functionalities.

scheduling, they generate their own control information. NT-RSs are used to provide cell coverage extension as well as capacity enhancement. They can operate in topologies larger than two hops in either a centralized or distributed scheduling mode. Despite the benefits of using of RS in the MMR WiMAX network, the resource management schemes should be modified to incorporate the RS operation. This issue is arising because in multi-hop system, there is more than one intermediate node and therefore, their transmission should be coordinated. The coordination of the intermediate nodes transmission aim to avoid interference between their transmissions and maximizes the resource utilization (Hui and Chenxi, 2009). In the following section, the frame structures and relaying modes to coordinate these transmissions will be discussed.

OFDMA frame structure and relaying modes

In IEEE 802.16e, an OFDMA frame compose of two sub-frames; a downlink (DL) sub-frame and an uplink (UL) sub-frame (IEEE802.16e-2005, 2006). The DL sub-frame is to transmit from MMR-BS to the end SS and the UL sub-frame for the reverse direction. Multi-hop functionality is defined, and hence PHY layer specifications are changed according to the multi-hop operations. The RS should receive and transmit in both UL and DL. Therefore, to accommodate the RS in IEEE 802.16j, each sub-frame of the OFDMA frame is spitted into an Access zone (AZ) and a Relay zone (RZ). The Downlink access zone (DL-AZ) is used to transmit to the end SS that is served by MMR-BS, while Uplink access zone (UL-AZ) is utilized to receive from it. Similarly, the Downlink relay zone (DL-RZ) and the Uplink relay zone (UL-RZ) are used to relay the data to and from the super-ordinate RSs, respectively (Hoymann et al., 2006; Mach and Bestak, 2009; Sayenko et al., 2010). There are two types of relaying; transparent and non transparent, which will be discussed in the following section.

Transparent relaying

In transparent relaying, the SSs served by RSs are able to receive and decode the control information from the MMR-BS. So, the intermediate and the access RSs are not required to transmit control information by themselves. Although the SSs are inside the coverage range of the MMR-BS but by using multiple hops with the aid of RSs higher throughput is achieved (Genc et al., 2009). Thus, the goal of this type of relaying is to enhance network capacity in terms of throughput. This scheme of relaying is called transparent relaying; because the SS is unaware of the RS existence. In the transparent relaying all control information originates from the MMR-BS. The transparent relaying frame is shown in Figure 3. The control information is sent at the beginning of the DL sub-frame to all sub-ordinate stations. The control information includes; Preamble in the 1st symbol and its main usage is to enable SS to synchronize with the BS. DL-MAP determines the specified burst in the DL sub-frame allocated to each SS. UL-MAP defines the burst location and size in the coming UL sub-frame for each SS, and lastly, Frame control header (FCH) which is a special management burst that is used for the BS to advertise the system configuration. Therefore, all SSs and RSs are able to receive and decode the control information, and determine their own time to transmit or receive. The MMR-BS then proceeds in the DL sub-frame, which is utilized to send data to the sub-ordinate stations. The DL sub-frame is divided into two zones;

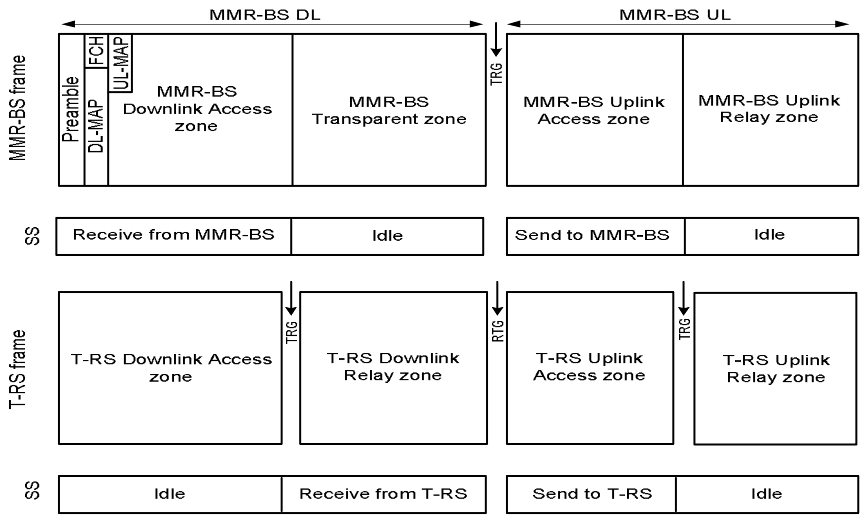

Figure 3. Transparent relaying frame structure.

DL-AZ and transparent zone. In the DL-AZ, the MMR-BS transmits to the SSs at the first hop and as well as the RSs at the first tier. While, in the transparent zone the RSs transmit to their sub-ordinate SSs. In addition, during the transparent zone MMR-BS can transmit to its subordinate SSs, or remain silent, or transmit cooperatively with the RSs. The DL sub-frame and the UL sub-frame are separated with a small transition time to switch from transmit to receive or vice versa. Similarly, the UL sub-frame is partitioned into two zones; UL-AZ and UL-RZs. In the UL-AZ, the end SSs transmit to their serving RS or MMR-BS, while in the UL-RZ, the RSs transmit to the MMR-BS (Genc et al., 2008a).

Non-transparent relaying

In non-transparent relaying, the SSs are served by RSs and cannot receive or decode the control information from the MMR-BS (Sayenko et al., 2010). So, the RSs serving these SSs must be able to generate and transmit its own control information at the beginning of each frame. The end SS considers the serving RS as its BS and is not able to deal with control information sent by MMR-BS. These RSs are called non-transparent because the SS synchronizes and receives control information from it. The SSs that are out of range of the MMR-BS are unable even to receive the control information sent by it, so the non-transparent RS sends to them its own frame and hence extend the MMR-BS coverage. The frame structure of non-transparent RS is shown in Figure 4 which consists of DL access; DL relay; UL access and UL relay zones, in which, both the MMR-BS and the RS transmits control information at the beginning of the frame. So, the SSs synchronize with the RS, which is synchronized with the MMR-BS. The DL sub-frame starts with the AZ, which is utilized by the MMR-BS to transmit to its sub-ordinate SSs. After the DL-AZ, is the DL-RZ that begins with relay-amble (R-amble) which is control information specifically for sub-ordinate RSs. The UL sub-frame is partitioned into two parts, UL-AZ to receive from sub-ordinate SSs and UL-RZ to receive from sub-ordinate RSs. The main issue facing non-transparent relaying is how the RS and MMR-BS can transmit simultaneously in time and possibly in frequency without causing severe interference. Furthermore, non-transparent RSs are more sophisticated and thus much expensive than transparent RSs.

Three hops frame structure

In the scenario of Figure 1, the access RS transmits to the SS in the DL-AZ and expects data from its super-ordinate station in the DL-RZ. The problem is that its super-ordinate station is a RS that may also be required to receive in the DL-RZ. To address the issue of multiple hops, the frame structure of MMR-BS and the non-transparent RS are required to be adapted. There are some efforts done in the literature to address this issue. These schemes will be discussed in the following sections. There are two ways to approach this; Single frame (SF) structure with multi RZs and Multi frame (MF) structure (Koon et al., 2007; Seung-Yeon et al., 2008; Mach and Bestak, 2009; Peters and Heath, 2009; Taha et al., 2011). In SF structure with multi RZs, the number of DL-AZs and UL-RZs are determined depending on the number of intermediate NT-RS between MMR-BS and the SSs. Figure 5 shows an example of SF structure for three hop MMR WiMAX system. In the DL-RZ, the first RZ is used by MMR-BS to relay the data of the first tier

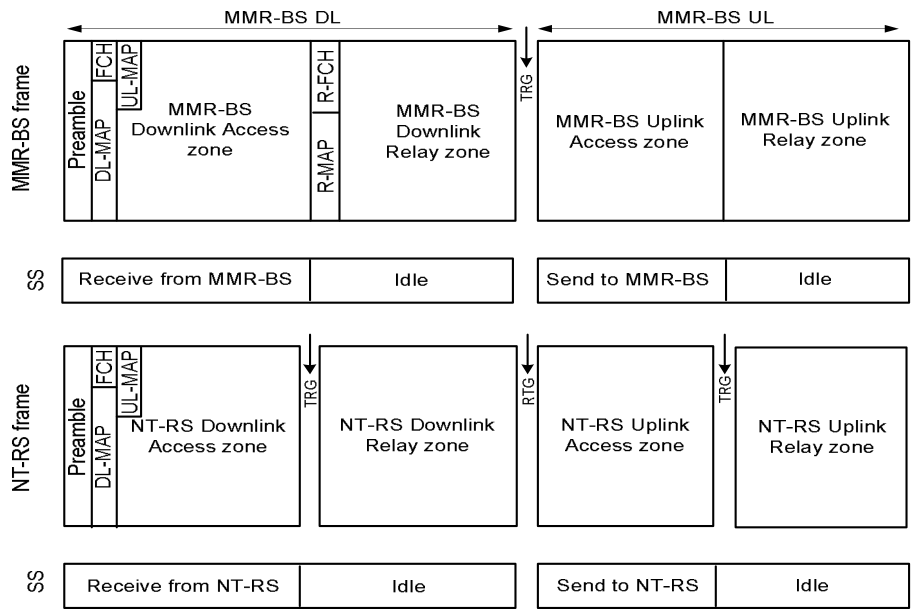

Figure 4. Non transparent relaying frame structure.

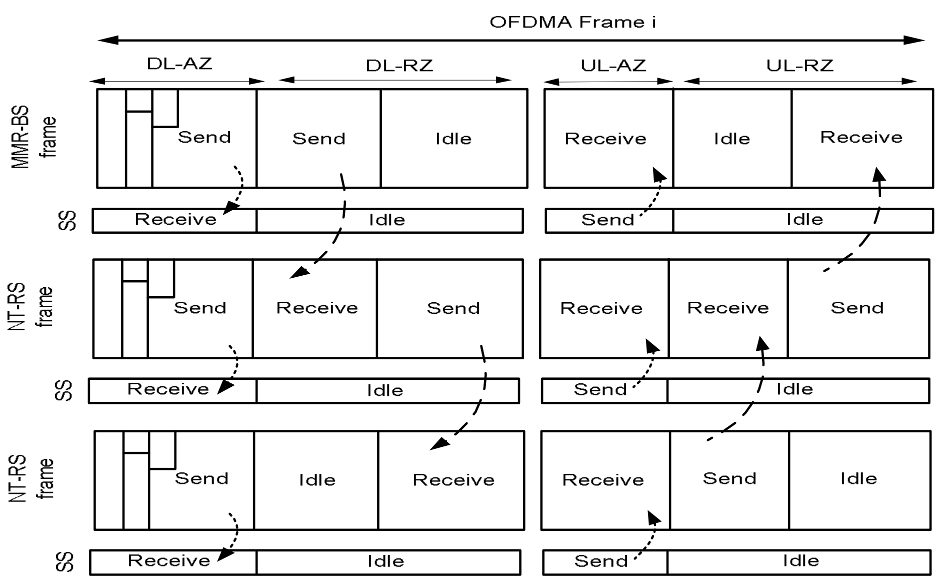

Figure 5. Single frame structure for three hops.

NT-RS. The second RZ is utilized to relay the second tier NT-RS. By the same way, they use specific RZs in the UL to send their data to their super-ordinate stations (MMR-BS or NT-RS) (Koon et al., 2007; Hui and Chenxi, 2008; Seung-Yeon et al., 2008; Taha et al., 2011). In this frame structure, the data is relayed across multiple hops in one frame duration time. However, it requires centralized resource allocation in the MMR-BS for both DL and UL, which will be very complex when large number of hops is considered. In addition, as the number of hops increases, the system capacity in terms of number of SSs and the sending data rate degrades severely. These limitations make it not suitable for multi-hop systems with large number of hops.

The other approach is to group frames together into what is called a multi-frame (Hui and Chenxi, 2008; Taha et al., 2011). In this frame structure, simultaneous transmission in the DL-AZ and UL-AZ of both NT-RSs

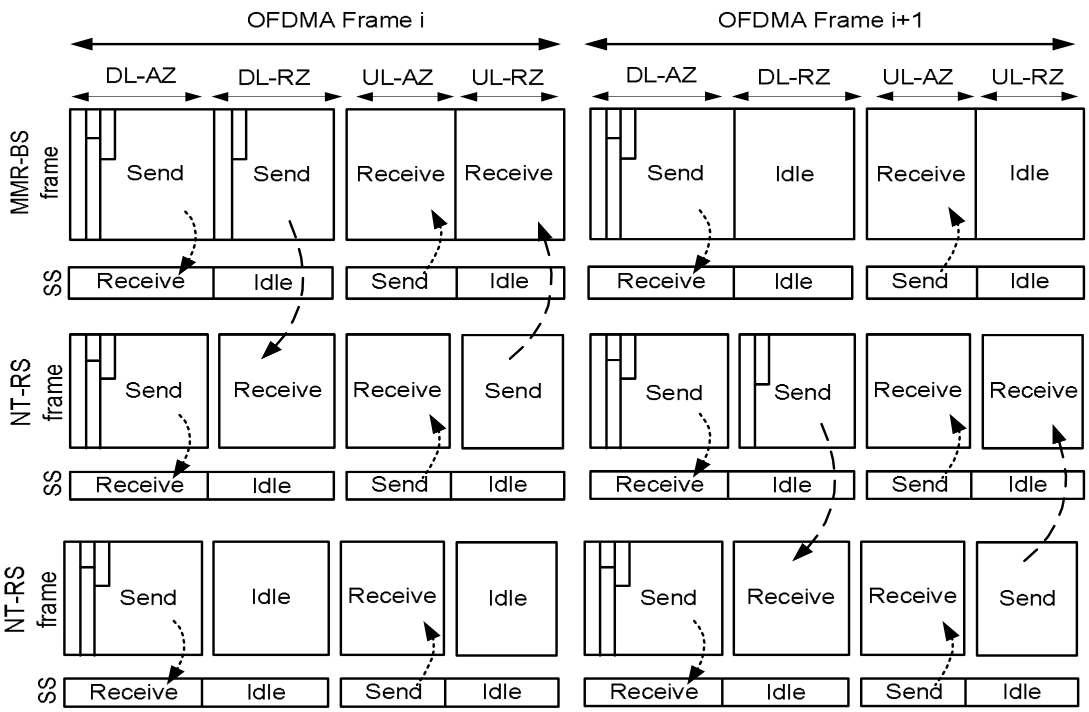

Figure 6. Multi frame structure for three hops.

and MMR-BS is allowed while in the RZs, only one station (either MMR-BS or NT-RS) is eligible to transmit and the others should be in receiving mode. The same concepts are applied for the first tier and second tier NT-RS. Therefore, RSs at odd tiers transmit in the RZs of odd-numbered frames, and RSs at even tiers transmit in the RZs of even-numbered frames. Figure 6 gives an example of MF structure for three hops MMR WiMAX system during two successive frames. The DL-RZ of the first frame (OFDMA frame i) is utilized to relay the data from MMR-BS to its sub-ordinate NT-RSs, while UL-RZ is used to relay the data from the NT-RSs in the first tier to the MMR-BS. However, the second frame (OFDMA frame i + 1) is used to relay the data between the first tier and second tier NT-RSs for the DL and the UL. This frame structure is applicable for centralized and distributed scheduling architectures.

The relay zone is used by the intermediate RSs alternatively to communicate with their super-ordinate RS and sub-ordinate RS. As result, the delay of relaying the data packets across multiple hops is increased exponentially with the hop level. Therefore, in order to enhance the performance of MMR WiMAX network, this paper proposes amendments to the multi-frame structure of NT-RS that aims to decrease the delay and maintain the capacity of MMR WiMAX network. The new multi-frame structure uses the access zones to communicate with its sub-ordinate stations and the relay zones to communicate with its super-ordinate stations. The details of the proposed frame structure will be discussed in the following section.

The proposed new multi frame structure

NMF structure design concepts

In this section, a new multi-frame (NMF) structure for the NT-RS is proposed based on the MF structure for the time division duplex (TDD) systems. Figure 7 shows the frame structure of the MMR-BS and the frame structure of the NT-RSs at the first and second tiers. It gives the specific time for the NT-RSs to communicate with their sub-ordinates stations (SSs and NT-RSs) and super-ordinates stations (MMR-BS and NT-RSs). The proposed NMF uses the same frame structure specified by the standard (IEEE802.16j-2009, 2009) for the MMR-BS; however, the frame structure of NT-RS is customized to decrease the forwarding delay and at the same time maintain the capacity of the system in terms of number of SSs and transmission rates.

In NMF structure, the whole frame is divided into two main sub-frames, DL and UL sub-frames separated by small transmit receive guard (TRG) time to allow the MMR-BS to change the mode from transmission to receiving. Further, the downlink sub-frame is divided into three parts where the first part is for control message transmission (preamble, DL-MAP, UL-MAP and the FCH), the second one is for data transmission to the SSs that are served directly by the MMR-BS named downlink

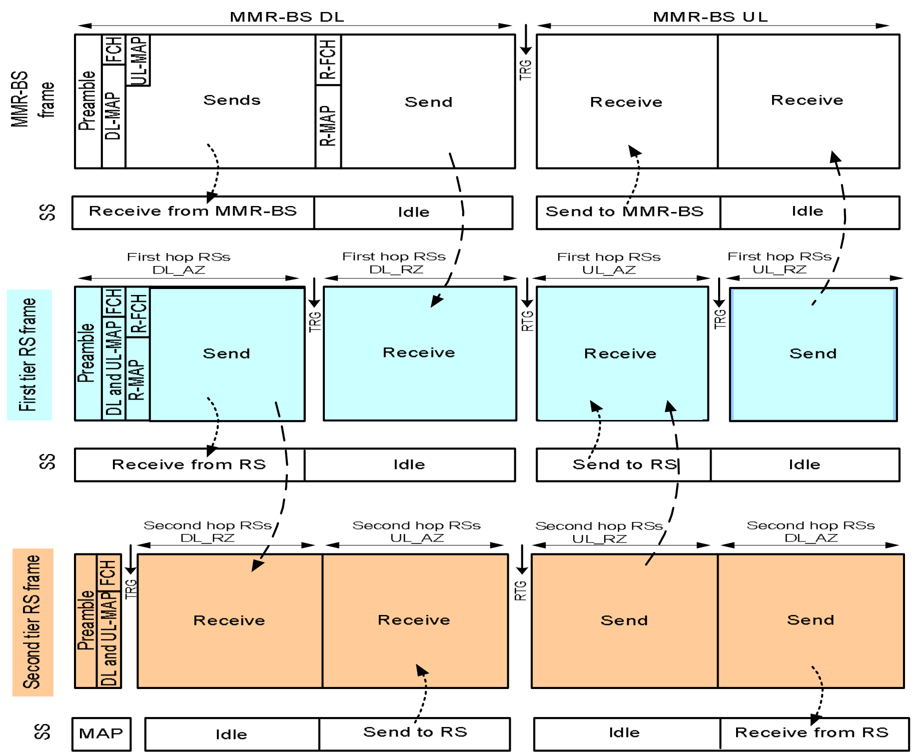

Figure 7. NMF frame structures of MMR-BS and NT-RSs.

access zone (DL-AZ) and the last part is utilized for data transmission to the first tier NT-RSs which is called downlink relay zone (DL-RZ). Also, the uplink sub-frame is partitioned into two parts, one is to receive from first hop SSs called uplink access zone (UL-AZ) and the other is to receive from the first tier NT-RSs named uplink relay zone (UL-RZ). In the proposed NMF structure, the intermediate NT-RSs utilize the access zones to communicate with their sub-ordinate stations (SSs and NT-RSs) and the relay zones to communicate with their super-ordinates station (MMR-BS or NT-RS) as shown in Figure 7. The intermediate NT-RSs receive data from their super-ordinate station in the DL-RZ and from their sub-ordinate stations in the UL-AZ. On the other hand, it transmits data to their super-ordinate station in the UL-RZ and to their sub-ordinate stations in the DL-AZ. The allocated resources to the sub-ordinate stations (SSs or NT-RSs) are determined by scheduling algorithms. There are no zone capacity limits for the SSs or the NT-RSs served by the same super-ordinates NT-RS. Therefore, it is very flexible in allocating the available resources to both SSs and NT-RSs and this allows them to utilize the available resources efficiently.

The first tier NT-RS frame structure consists of four parts separated by small guard time (TRG/RTG) to allow the NT-RS to change its mode from sending to receiving or vice versa. At the beginning of this frame structure, the control information is sent to inform the sub-ordinate stations with their slots for transmission and reception. Next, it is followed by the downlink zone which comprises of two parts namely DL-AZ and DL-RZ. The DL-AZ is utilized for downlink data transmission to the sub-ordinate stations. The allocated slots to each SS or NT-RS are determined by the scheduling algorithm. In the DL-RZ, the first tier NT-RS receives data from its super-ordinate station, which is the MMR-BS. Consequently, the UL-AZ is used to receive data from sub-ordinate stations (SSs and NT-RSs) and the UL-RZ is utilized to transmit data to the MMR-BS. The second tier NT-RSs frame structure is constructed by the same way as that of the first tier with a few differences. The frame structure of the second tier NT-RS has only two guard times to change the mode of the NT-RS from sending to receiving or vice versa. In addition, it doesn’t send control message for the sub-ordinate NT-RSs because in this paper, only three hops are considered. If it is required to extend the hops to more than three, the control messages should be added at the beginning of the last sub-frame which is used to transmit to the sub-ordinate stations. As seen from the previous discussion, the proposed NMF structure is different from MF structure in that it eliminates the superposition manner of using of the relay zones, and hence it reduces the delay of relaying the data packets across multiple hops. In the following section, the capacity of the proposed NMF frame structure will be analyzed numerically.

NMF NT-RS frame capacity

The aim of this numerical analysis is to determine the number of slots and the capacity of all access and relay zones of the proposed NMF structure. Firstly, the number of OFDMA symbols in the whole frame, downlink and uplink zones of the MMR-BS are determined by Equations (1) to (9). Equation 1 gives the sub-carrier spacing (Δf) which is determined by the sampling factor (F_s) and the Fast fourier transform (FFT) size (N_{FFT}). While, Equation (2) gives the sampling factor, where BW is the bandwidth and *n* is a factor depends on the value of the bandwidth, where its value is normally (8/7) or (28/25) if the bandwidth is multiple of 1.25, 1.5, 2, 2.75 MHz (Andrews et al., 2007; Ergen, 2009).

$$\Delta f = \frac{F_s}{N_{FFT}} \quad (1)$$

$$F_s = floor\left(\frac{n * BW}{8000}\right) \quad (2)$$

The useful OFDMA symbol time (T_b) is given by the Equation (3) and the cyclic guard time (T_g) in Equation (4), where *G* is the ratio of the cyclic guard time to the useful OFDMA symbol time, and which it takes one of the values (1/32, 1/16, 1/8 and 1/4) (Andrews et al., 2007; Ergen, 2009).

$$T_b = \frac{1}{\Delta f} = \frac{N_{FFT}}{F_s} = \frac{N_{FFT}}{\left\lfloor \frac{n * BW}{8000} \right\rfloor * 8000} \quad (3)$$

$$T_g = G * T_b = \frac{G * N_{FFT}}{\left\lfloor \frac{n * BW}{8000} \right\rfloor * 8000} \quad (4)$$

The OFDMA symbol time is the summation of the useful OFDMA symbol time and cyclic guard time as shown in the Equations (5) and (6) (Andrews et al., 2007; Ergen, 2009).

$$T_{symb} = T_b + T_g = \frac{N_{FFT}}{\left\lfloor \frac{n*BW}{8000} \right\rfloor * 8000} + \frac{G*N_{FFT}}{\left\lfloor \frac{n*BW}{8000} \right\rfloor * 8000} \quad (5)$$

$$T_{symb} = (1 + G)\frac{N_{FFT}}{\left\lfloor \frac{n * BW}{8000} \right\rfloor * 8000} \quad (6)$$

The number of OFDMA symbols in an OFDMA frame or part of the frame is calculated by dividing the duration of the frame or the sub-frame by the OFDMA symbol time. So, the number of OFDMA symbols in an OFDMA frame, downlink and uplink sub-frames for the MMR-BS are determined by the Equations (7), (8) and (9), respectively. The number of symbols in the downlink and the uplink sub-frames are determined by the downlink $(DL_{Ratio})_{MMR\text{-}BS}$ to the uplink $(UL_{Ratio})_{MMR\text{-}BS}$ ratios as shown in Equations (8) and (9).

$$N_{symb}^{frame} = \frac{(T^{frame} - TRG)}{T_{symb}} = \frac{(T^{frame} - TRG) * \left\lfloor \frac{n*BW}{8000} \right\rfloor * 8000}{(1+G) * N_{FFT}} \quad (7)$$

$$N_{symb}^{(DL)_{MMR\text{-}BS}} = \left(N_{symb}^{frame}\right) * \frac{(DL_{Ratio})_{MMR\text{-}BS}}{(DL_{Ratio})_{MMR\text{-}BS} + (UL_{Ratio})_{MMR\text{-}BS}} \quad (8)$$

$$N_{symb}^{(UL)_{MMR-BS}} = \left(N_{symb}^{frame}\right) - N_{symb}^{(DL)_{MMR-BS}} \quad (9)$$

Next, the number of sub-carriers, channels and slots in the frame structure of the MMR-BS can be determined through Equations (10) to (15). The number of subcarriers is determined by the total bandwidth (BW) divided by the sub-carrier spacing (Δf) as in Equation (10) (Andrews et al., 2007; Ergen, 2009).

$$N_{subcarr}^{frame} = \frac{BW}{\Delta f} \quad (10)$$

The available sub-carriers are divided into two parts; some of them are used for data sending while the remaining reserved as control sub-carriers as in Equation (11) (Andrews et al., 2007; Ergen, 2009).

$$N_{subcarr}^{frame} = N_{Data,subcarr}^{frame} + N_{Cont,subcarr}^{frame} \quad (11)$$

To determine the number of channels and slots for the downlink and uplink sub-frames, Partial usage sub-carriers (PUSC) permutation is used (Andrews et al., 2007; Ergen 2009). In the downlink sub-frame, the number of channels is calculated by dividing the number of data sub-carriers by the cluster size which contains 32 sub-carriers; 24 of them for data and 8 for pilot signals as in Equation (12).

$$N_{channel}^{(DL)_{MMR-BS}} = \frac{N_{Data,subcarr}^{frame}}{Cluster_{size}} \quad (12)$$

To calculate the number of slots in the downlink of the MMR-BS, the calculated number of channels is multiplied by the number of OFDMA symbols in the downlink sub-frame and the total is divided by the number of symbols per slot which is 2 for the downlink PUSC permutation as shown in Equation (13) (IEEE802.16e-2005, 2006; Andrews et al., 2007).

$$N_{slots}^{(DL)_{MMR-BS}} = \frac{N_{symb}^{(DL)_{MMR-BS}} * N_{channel}^{(DL)_{MMR-BS}}}{N_{symb}^{slot}} \quad (13)$$

For the uplink sub-frame, the number of channels is calculated by dividing the number of data sub-carriers by the size of the tile, which is a group of 4 tiles each one contains 6 sub-carriers (4*6); 18 of them for data and 6 for pilot signals as in Equation (14) (Andrews et al., 2007; Ergen, 2009).

$$N_{channel}^{(UL)_{MMR-BS}} = \frac{N_{Data,subcarr}^{frame}}{Tile_{size}} \quad (14)$$

To determine the number of slots in the uplink sub-frame of the MMR-BS, the calculated number of channels is multiplied by the number of OFDMA symbols in the downlink sub-frame and the total is divided by the number of symbols per slot which is 3 for the uplink PUSC permutation as shown in Equation (15) (Andrews et al., 2007; Ergen, 2009).

$$N_{slots}^{(UL)_{MMR-BS}} = \frac{N_{symb}^{(UL)_{MMR-BS}} * N_{channel}^{(UL)_{MMR-BS}}}{N_{symb}^{slot}} \quad (15)$$

The Equations (16) to (19) gives the number of slots in the downlink access zone, downlink relay zone, uplink access zone and the uplink relay zone for the MMR-BS, respectively. The number of slots in the downlink access zone of the MMR-BS is calculated by multiplying the number of slots in the downlink sub-frame of the MMR-BS by the ratio of the downlink access zone to the summation of the downlink and uplink ratios as in Equation (16). The numbers of slots in the downlink relay zone of the MMR-BS is calculated by excluding the number of slots in the access zone of the MMR-BS from the total number of slots in the downlink sub-frame of the MMR-BS, as in Equation (17).

$$N_{slots}^{(DL\_AZ)_{MMR-BS}} = \frac{N_{slots}^{(DL)_{MMR-BS}} * (DL\_AZ)_{Ratio}}{(DL\_AZ)_{Ratio} + (DL\_RZ)_{Ratio}} \quad (16)$$

$$N_{slots}^{(DL\_RZ)_{MMR-BS}} = N_{slots}^{(DL)_{MMR-BS}} - N_{slots}^{(DL\_AZ)_{MMR-BS}} \quad (17)$$

The same procedure is performed to calculate the number of slots in the uplink access zone and uplink relay zone of the MMR-BS as in Equations (18) and (19).

$$N_{slots}^{(UL\_AZ)_{MMR-BS}} = \frac{N_{slots}^{(UL)_{MMR-BS}} * (UL\_AZ)_{Ratio}}{(UL\_AZ)_{Ratio} + (UL\_RZ)_{Ratio}} \quad (18)$$

$$N_{slots}^{(UL\_RZ)_{MMR-BS}} = N_{slots}^{(UL)_{MMR-BS}} - N_{slots}^{(UL\_AZ)_{MMR-BS}} \quad (19)$$

As mentioned before, the first tier NT-RSs are directly connected to the MMR-BS, they use their access zones to communicate with their sub-ordinate stations (SSs and NT-RS) and also their relay zones to communicate with the MMR-BS as in the proposed frame structure shown in Figure 7. When the MMR-BS decided to allocate resources to the SSs served by the first tier, NT-RS should consider these capacities to avoid packets dropping in the queues of the intermediate NT-RSs due to limited storage. Equations (20) and (21) determine the maximum number of slots of the DL-AZ and UL-AZ of the first tier NT-RSs as a function of the MMR-BS zones.

$$N_{slots,Max}^{(DL\_AZ)_{NT-RS_1^n}} = N_{slots}^{(DL\_AZ)_{MMR-BS}} \quad (20)$$

$$N_{slots,Max}^{(UL\_AZ)_{NT-RS_1^n}} = N_{slots}^{(UL\_AZ)_{MMR-BS}} \quad (21)$$

Equations (22) and (23) determine the maximum number of slots of the DL-RZ and UL-RZ of the first tier NT-RSs as function of MMR-BS zones, which are used to relay the data to sub-ordinate and super-ordinate stations, respectively.

$$N_{slots,Max}^{(DL\_RZ)_{NT-RS_1^n}} = N_{slots}^{(DL\_RZ)_{MMR-BS}} \quad (22)$$

$$N_{slots,Max}^{(UL\_RZ)_{NT-RS_1^n}} = N_{slots}^{(UL\_RZ)_{MMR-BS}} \quad (23)$$

The second tier NT-RSs are those served by the first tier NT-RSs, and they use the access zones to communicate with their sub-ordinate stations (SSs) and the relay zones to communicate with their super-ordinate NT-RSs as in the proposed frame structure shown in Figure 7. Equations (24) and (25) determine the maximum number of slots of the DL-AZ and UL-AZ of the second tier NT-RSs as a function of the first tier NT-RS slots, which are utilized to communicate with the sub-ordinate stations.

$$N_{slots,Max}^{(DL\_AZ)_{NT-RS_2^n}} = N_{slots,Max}^{(UL\_RZ)_{NT-RS_1^n}} \quad (24)$$

$$N_{slots,Max}^{(UL\_AZ)_{NT-RS_2^n}} = N_{slots,Max}^{(DL\_RZ)_{NT-RS_1^n}} \quad (25)$$

Table 1. Simulation parameters.

Parameter	Value
Physical Layer	OFDMA
Operating frequency	3.5 GHz
Bandwidth	20 MHz
FFT size	2048
OFDMA frame duration	20 ms
Duplex mode	TDD
TRG/RTG gap	50 µs
Cyclic prefix length	1/8
OFDMA symbols	198
DL:UL ratio	6:4
DL-AZ:DL-RZ ratio	1:1
UL-AZ:UL-RZ ratio	1:1
Fragmentation/packing	on
CRC/ARQ	on
Propagation model	Two ray ground

Meanwhile, Equations (26) and (27) determine the maximum number of slots of the DL-RZ and UL-RZ of the second tier NT-RSs as a function of the first tier NT-RS slots, which are utilized to relay data to the sub-ordinate and super-ordinate stations, respectively.

$$N_{slots,Max}^{(DL\_RZ)_{NT-RS_2^n}} = N_{slots,Max}^{(DL\_AZ)_{NT-RS_1^n}} \quad (26)$$

$$N_{slots,Max}^{(UL\_RZ)_{NT-RS_2^n}} = N_{slots,Max}^{(UL\_AZ)_{NT-RS_1^n}} \quad (27)$$

The slot capacity from the information theory side of view is calculated by utilizing Shannon's theorem. Equation (28) gives the maximum capacity of one sub-carrier over one OFDMA symbol, while Equation (29) gives the capacity of one slot composed of number of sub-carriers over number of OFDMA symbols.

$$C_{subcarr\_Max,symb} = \frac{BW_T}{N_{subcarr}^{frame} * N_{symb}^{frame}} \log_2(1+\frac{E_s}{N_0}) \quad (28)$$

$$C_{slot\_Max} = \frac{BW_T}{N_{subcarr}^{frame} * N_{symb}^{frame}} * N_{subcarr}^{slot} * N_{symb}^{slot} * \log_2(1+\frac{E_s}{N_0}) \quad (29)$$

Equations (30) and (31) give the maximum theoretical channel capacity as defined by Shannon's theorem for the whole OFDMA frame and sub zones of the MMR-BS, where * in Equation (31) represents DL-AZ, UL-AZ, DL-RZ or UL-RZ. It is calculated by summing the individual capacities of all the slots in the OFDMA frame or the specific access or relay zone.

$$C_{frame}^{Max} = \sum_{i=1}^{N_{slots}^{frame}} C_{slot_i} \quad (30)$$

$$C_{(*)_{MMR-BS}}^{Max} = \sum_{i=1}^{N_{slots}^{(*)_{MMR-BS}}} C_{slot_i} \quad (31)$$

The more practical capacity is determined by the modulation scheme and the coding rate. Equation (32) gives the amount of data bits that can be sent in one slot, where MOD_{slot} is a factor that represents the number of bits can be sent in one symbol which determined by the modulation scheme and CR_{slot} is the channel coding rate.

$$R_{slot} = \frac{BW_T}{N_{subcarr}^{frame} * N_{symb}^{frame}} * N_{subcarr}^{slot} * N_{symb}^{slot} * MOD_{slot} * CR_{slot} \quad (32)$$

Equation (33) gives the practical capacity of the downlink and uplink access and relay zones of the MMR-BS, where * represents DL-AZ, UL-AZ, DL-RZ or UL-RZ. It is calculated by summing the individual capacities of all the slots in the OFDMA frame or the specific access or relay zone.

$$R_{(*)_{MMR-BS}} = \sum_{i=1}^{N_{slots}^{(*)_{MMR\_BS}}} R_{slot_i} \quad (33)$$

RESULTS AND DISCUSSION

In this section, the performance evaluation of the proposed NMF structure is conducted, which is composed of two parts. The first part discusses the capacity of NMF structure in terms of the number of SSs that can be admitted and the maximum transmission rates at each zone, as compared to MF and SF structures. In the second part, the effect of the proposed NMF on the relaying delay is analyzed, and hence the improvements in link layer and TCP traffic are discussed.
The system model considered in this paper is three hops MMR WiMAX networks as shown in Figure 1. Simulations in ns-2 network simulator considering the system parameters of MMR WiMAX network are used in order to perform the experiments. The main features of the MAC layer and physical layer of the MMR WiMAX network are implemented in the simulation software. The simulation is performed with the simulation parameters shown in Table 1. The simulation scenarios evaluate the effect of the proposed NMF structure on TCP performance. It is assumed that the TCP segment size is 1024 bytes for all

the simulations. In addition, it is assumed that all the sending hosts are always having data to be sent to the SSs in the different hops and there are sufficient resources to forward them. The NT-RS uses the next frame to relay the data received in the current frame and the link layer frame error percentage is 10%.

Capacity evaluation of NMF

The purpose of this performance evaluation part is to show how the proposed NMF structure can utilize the available relay link slots flexibly and efficiently. The network model shown in Figure 1 is considered. The simulations are conducted using the simulation parameters as stated in Table 1. The ratios of downlink and uplink access and relay zones as shown in Table 1; are 6:4 for downlink and uplink, and 1:1 for the access and relay zones. In addition, the downlink and uplink relay zones of the SF structure are divided equally between the second and third hops. The SSs are accepted with their maximum sustained rate until the capacity of the access zone is reached. Then, the excess slots above the minimum reserved rate are determined and hence more SSs are admitted with lower rates. The process of admitting new SSs is stopped when the transmission rate of each SS becomes equal to the minimum reserved rate or the available slots are insufficient to provide the new SSs with the required data rates. Different simulation scenarios and various SSs distribution are conducted. In each scenario, the maximum number of SSs supported in the access and relay zones, as well as the maximum data rates is presented.

In the first scenario, a three hop network model with only one branch comprising of two NT-RSs is considered. Figure 8 shows a distribution of the SSs of 50% in the first hop and 25% of the SSs at the second and third hops. While, Figure 9 gives the system capacity when there are no SSs in the second tier NT-RS and all the available slots are utilized by the SSs served by the first tier NT-RS. The result indicates that the maximum number of SSs supported in the access zone is the same for all frame structures. However, in the relay zone, the SF structure can accommodate only 50% percent of that can be served by MF and NMF structures. In the second scenario, three hops network architecture with one MMR-BS and two branches with two NT-RSs in each one are considered. The SSs are distributed; 50% in the first hop, they are served directly by MMR-BS access zone, and the SSs in the relay zone are divided equally between the NT-RSs as in Figure 10. Figures 8 to 10 shows that, the link data rate is raised up as the number of admitted SSs increased. However, when it reaches its maximum capacity, the link data rate remains constant even if the number of SSs is increased. In addition, MF structure and NMF structure can accommodate the same number of SSs in the first, second and third hops and provide typical link data rate. On the other hand, SF structure can accommodate the same number of SSs as that for MF and NMF structures at the first hop, and hence a typical link data rate is achieved for them. However, in the second and third hops, the number of SSs served by SF structure is only half of those supported by MF and NMF structures. Therefore, the link data rate is reduced by 50% as compared with the data rate of MF and NMF structures. In the last scenario, the capacity of MF, NMF and SF structures are evaluated for single branch with four hops. The same simulation parameters as in Table 1 are used. The relay zone of the SF structure is divided into three equal partitions to be used by the NT-RSs at the first, second and third tiers.

Figure 11 depicts the maximum number of SSs that can be accommodated in each hop as well as the link data rate. The SSs are distributed; 50% served by the access zone of the MMR-BS and the remaining SSs are distributed equally between the NT-RS. As shown in the Figure 11, the capacity of relay zone of the SF structure is reduced to about 33% as compared to MF and NMF structure. In all the frame structures discussed above, the link data rate in each hop is increased with the increment of the number of admitted SSs until it reaches the maximum capacity. After that, if the number of SSs is increased, the link data rate remains constant. In addition, when the numbers of the NT-RSs increases, the slots available to each NT-RS are limited, and hence the number of SSs that can be served will be relatively small. This gives a limit to the number of hops that can be used, as well as the number of NT-RSs in each tier. As shown from the results, MF structure and NMF give typical capacity for all the scenarios discussed before. However, the capacity of SF structure is reduced to $1/(n - 1)$ of the capacity of MF and NMF structures, where n is the number of hops. The poor capacity of SF structure as the number of hops increases makes it inconvenient for more than two hops.

Link layer and TCP traffic performance

The delay of relaying the data packets across multiple hops using MF structure is increased proportionally withthe number of hops, which results in very poor throughput of both link layer and TCP traffics. Therefore, the forwarding delay can be reduced by using different multi-frame configuration as that proposed in NMF structure. The effect of the forwarding delay on the link layer and the TCP performances will be discussed in the next section. To evaluate the effect of the proposed NMF structure, simulation with the same parameters as shown in Table 1 is conducted. The TCP traffic is transmitted to the MMR WiMAX network from the fixed hosts in the internet. The performance of one SS at each hop is considered to observe the performance enhancement in

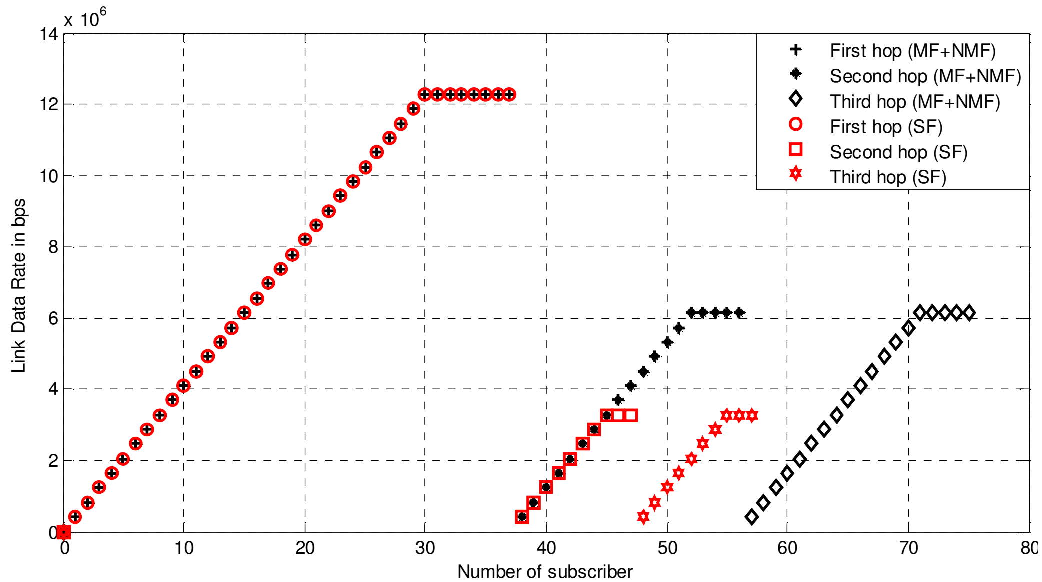

Figure 8. Access and relay zones capacity of equally distributed SSs at the relay zone.

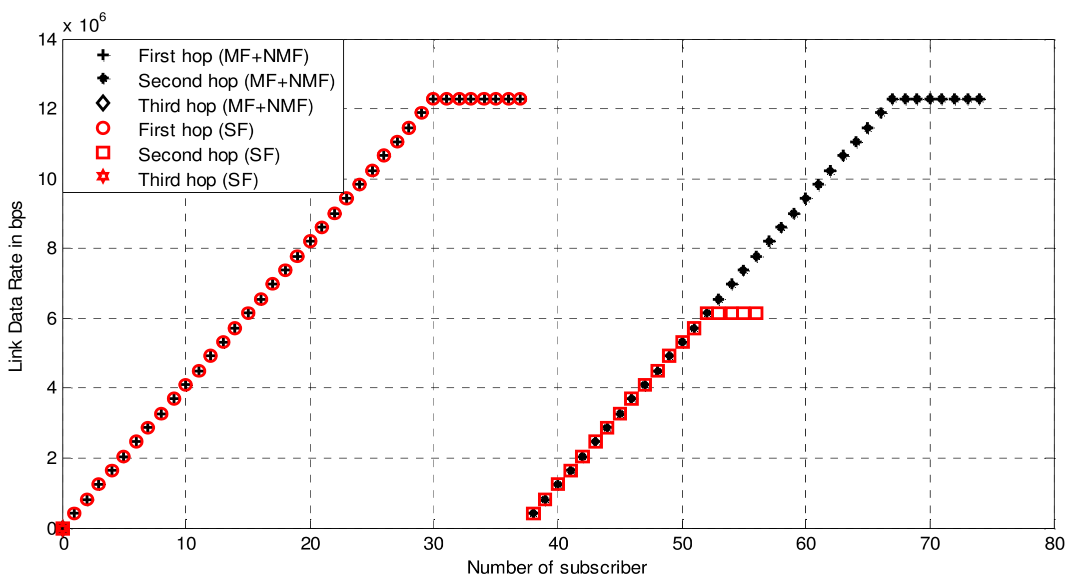

Figure 9. Access and relay zones capacity of even SSs distribution.

various hop levels. The performances of the proposed NMF structure are compared with the MF structure (Zhifeng et al., 2007). It is assumed that the NT-RS uses the next frame to relay the data received in the current frame and the link layer frame error percentage is 10%. The delays that are induced due to relaying data packets a cross *n* hops using MF and NMF structures are compared in Figure 12. The results in Figure 12 indicates that for MF structure, as the number of hops is increased, the link layer forwarding delay is rapidly increased with the rate of (2**n* - 1), while in the proposed NMF structure, the delay is slightly increased with the rate of *n,* where n is the number of hops between MMR-BS and the end SSs. Figure 12 shows that the proposed NMF structure gives 33 and 40% reduction in the delay for the second and third hops, respectively. Due to shorter forwarding delay induced in the link layer from the NMF structure, as compared with the MF structure, better link layer throughput is obtained for NMF structure as shown in Figure 13. The SSs at the first hop gained almost the

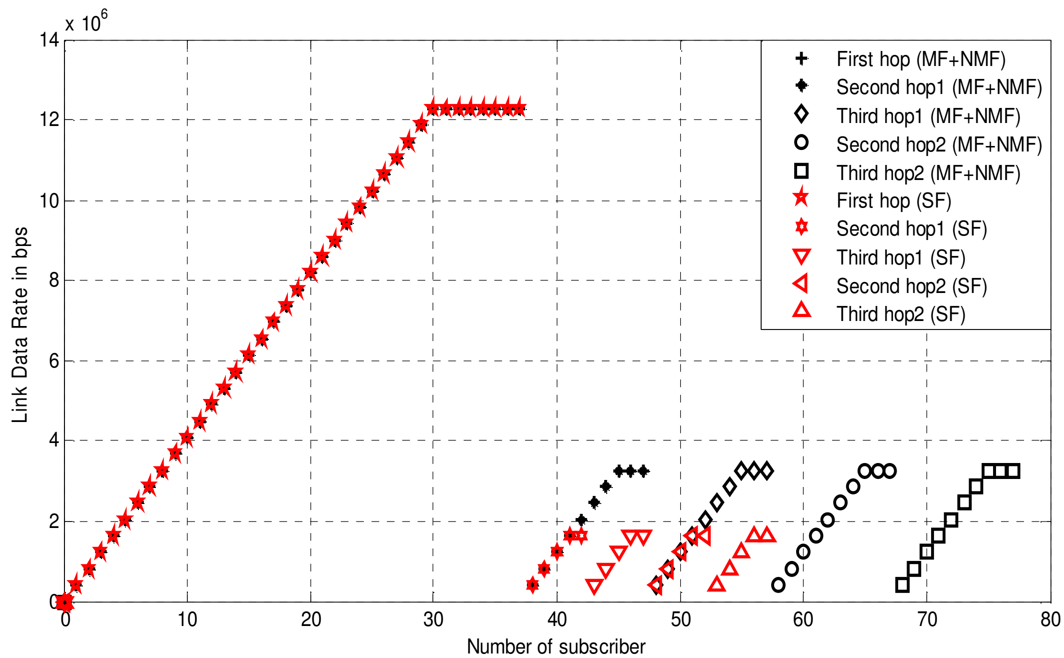

Figure 10. Access and Relay zones Capacity of three hops with two branches.

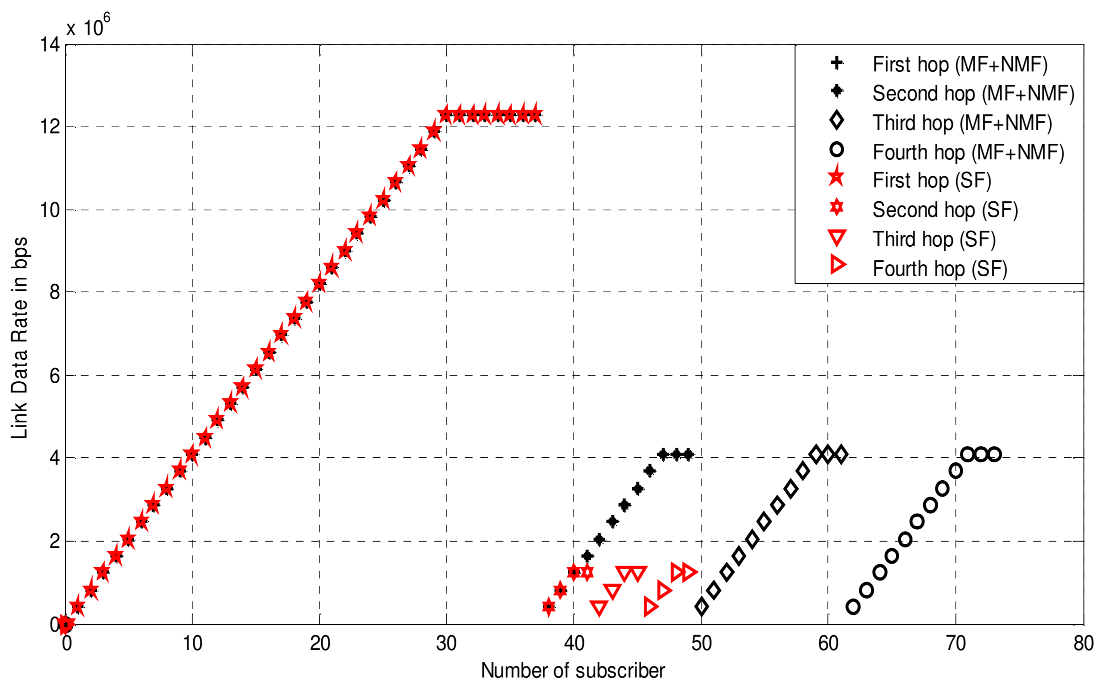

Figure 11. Access and relay zones Capacity of four hops network model.

same throughput because both frame structures experienced typical forwarding delay, while the throughput of the proposed NMF structure outperforms the MF structure by 35 and 53% at the second hop and compared with MF structure especially for the SSs at second hop and third hop. In addition, RTT is increased proportionally with the hop level for both MF and NMF structures. Due to a shorter RTT at the second and third

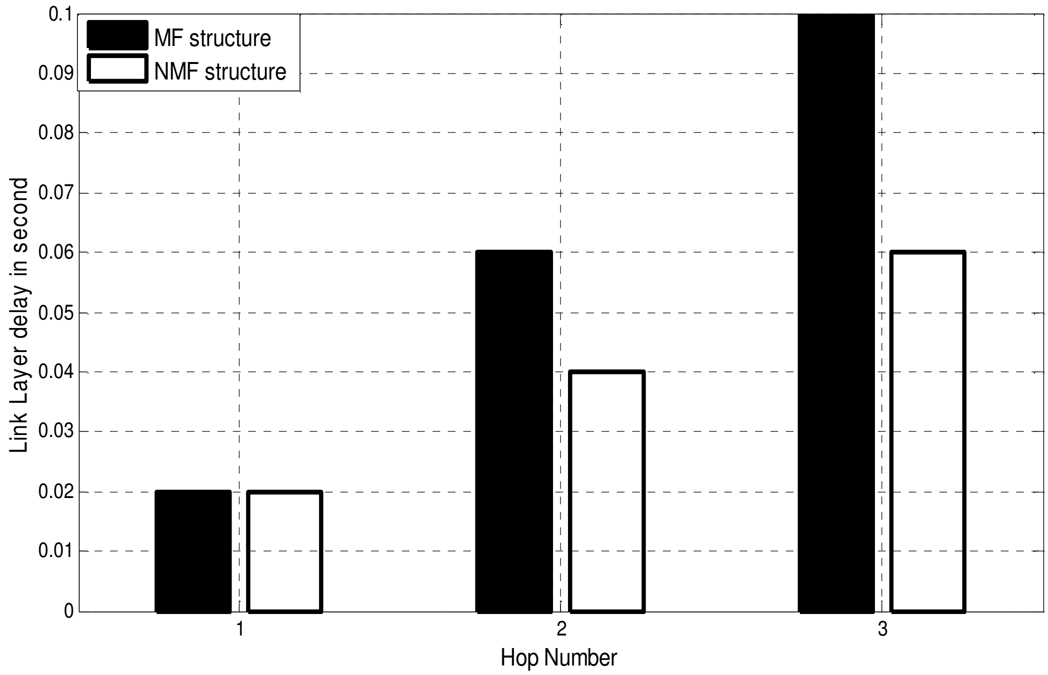

Figure 12. Link layer delays of different hops.

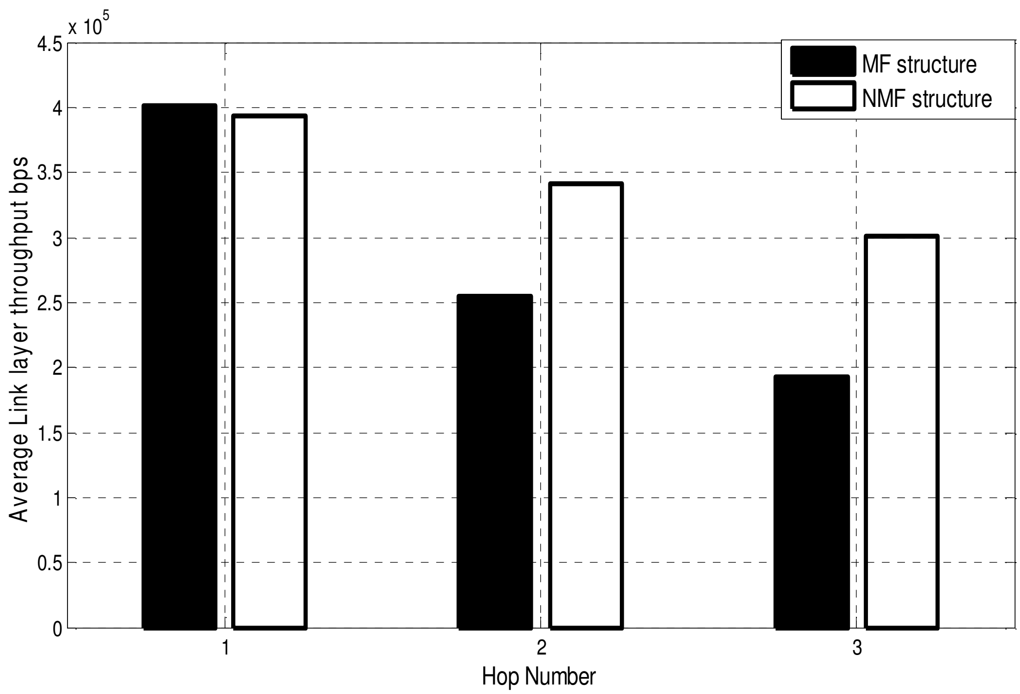

Figure 13. Link layer throughput comparisons of different hops.

hop levels, the congestion windows (CWNDs) of the SSs using the proposed NMF structure are higher than those applying MF structure (Figure 14a to c). The development of the TCP CWND of the SSs at first, second and third hops are shown in the Figure 15a to c, respectively. In Figure 15a, the SSs at the first hop that is applying the MF and NMF structure have almost the same CWND due to typical RTT. In Figure 15b, the CWND of the NMF

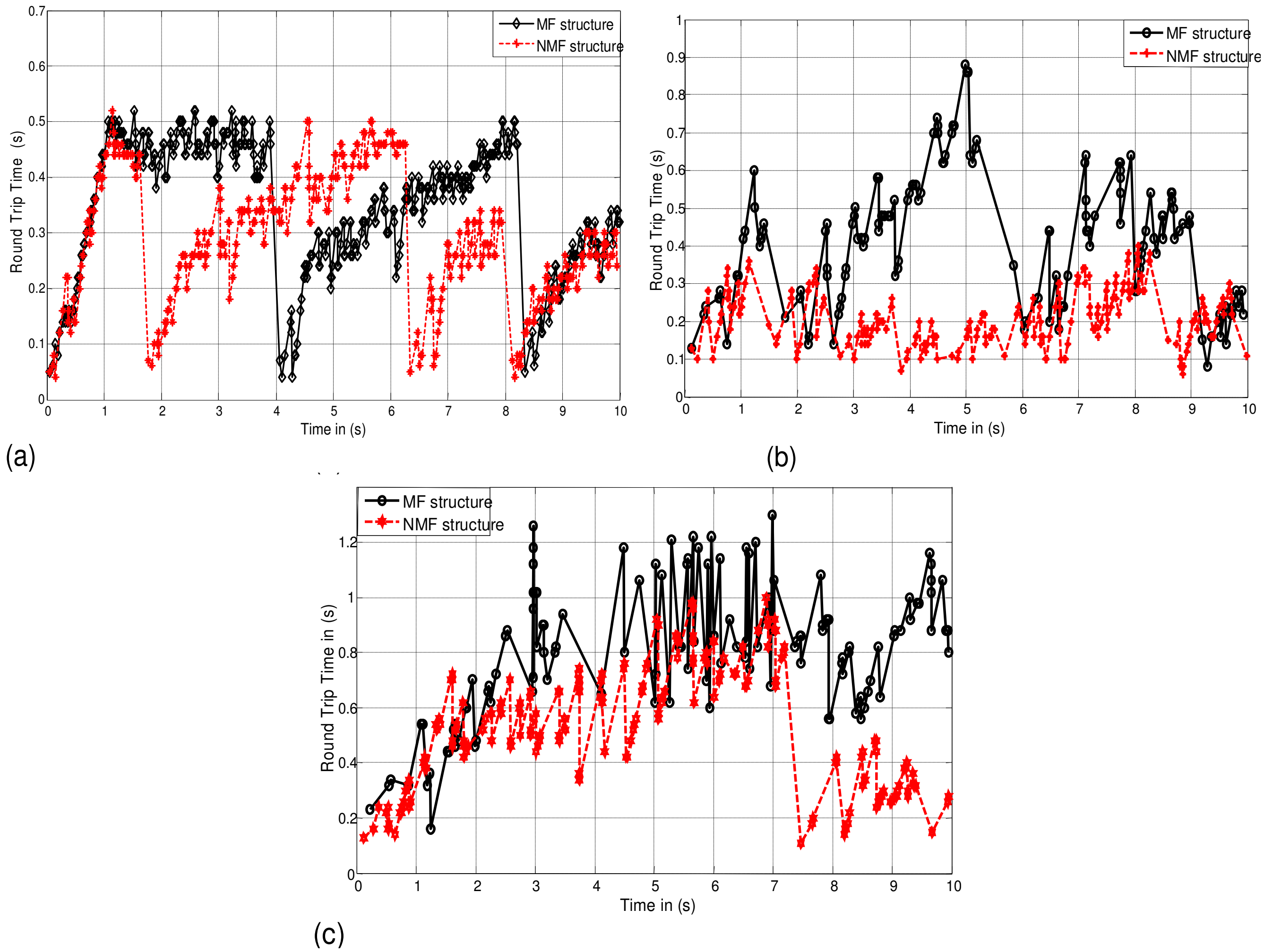

Figure 14. (a) RTT comparisons of the first hop; (b) RTT comparisons of the second hop; (c) RTT comparisons of the third hop.

structure at second hop is increased up to 20 packets before the timeout occurs, while that for the MF structure remains below 12 packets for most of the simulation time. In Figure 15c, the CWND of the NMF structure at third hopgrows from 8 up to 20 packets. However, the CWND of the MF structure lies between 6 to 10 packets. In general, as shown in Figure 15a to c, the rate of the CWND development is affected by the value of the RTT.

Therefore, the CWND of the NMF structure grow rapidly to higher values as compared with those using MF structure. In addition, the CWND of the SS at the first hop is developed faster, and it becomes slower as the number of hops increases. The reason for this is the slower TCP ACK reception rate due to longer RTT as the number of hops increases.

Higher congestion window allows the TCP host to send more TCP packets without waiting for the TCP ACKs, which results in higher TCP throughput and as shown in Figure 16. Figure 16 gives the TCP throughput comparison of the SSs at different hops. The throughputs of the SSs at the second and third hops are increased by 30 to 40% when the proposed NMF structure is applied. However, the first hop SS gained almost the same performance for the MF and NMF structures.

Conclusion

This paper presented a new multi-frame (NMF) structure to enhance the performance of MMR WiMAX networks. The results showed that the proposed NMF structure is able to support flexible SSs distribution at different hops which are the same as that of MF structure. However, the relay zone capacity of NMF is 100% greater than SF structure when three hops architecture is considered. On the other hand, the forwarding delay is reduced with 33 and 40% for the second hop and third hop correspondingly as compared to MF structure. This allows the link layer throughput to be improved by 35% for the second hop and 53% for the third hop.

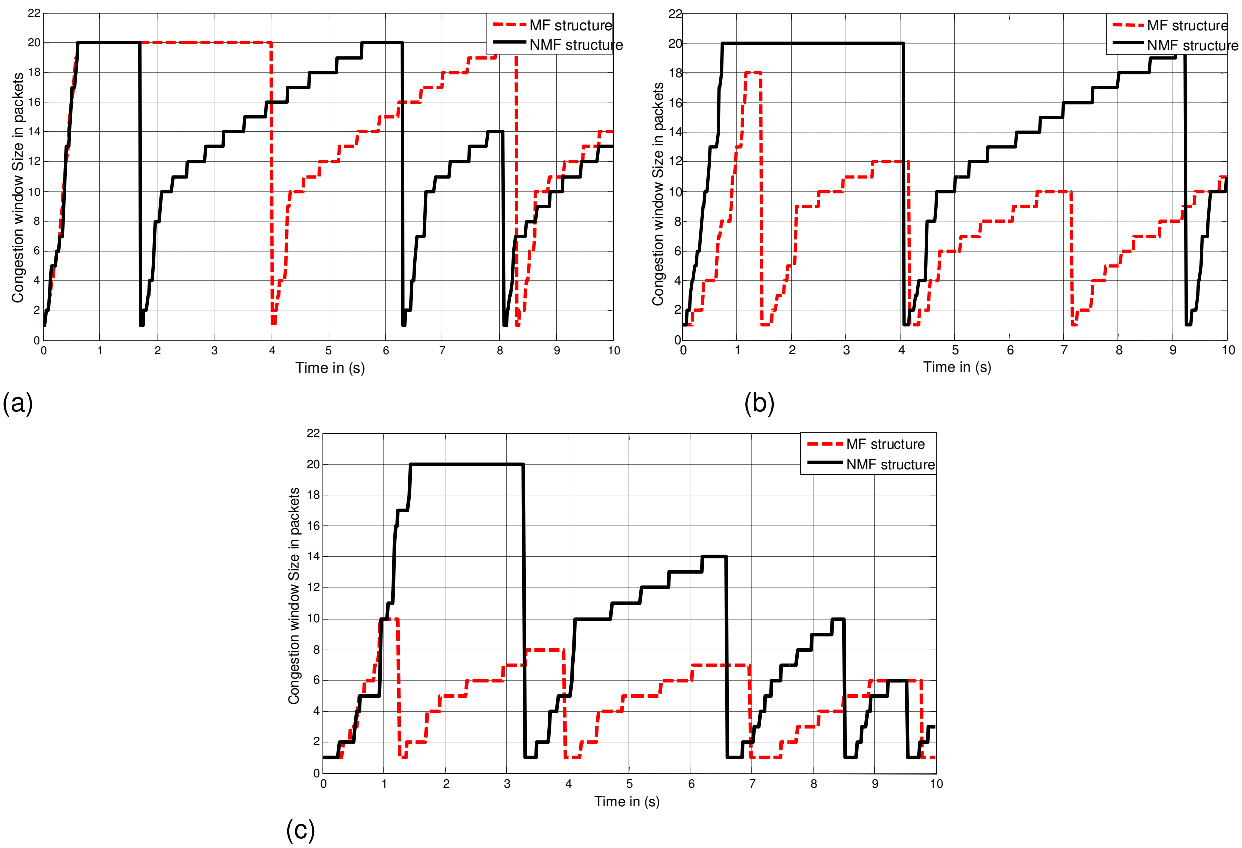

Figure 15. (a) TCP congestion window development of the first hop; (b) TCP congestion window development of second hop; (c) TCP congestion window development of third hop.

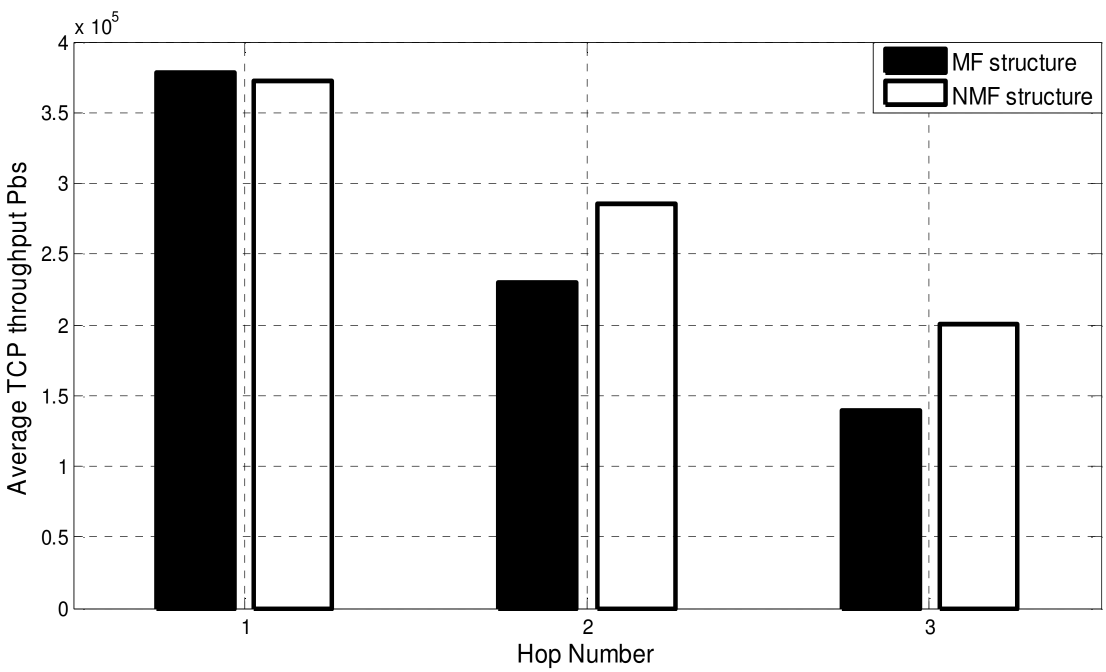

Figure 16. A comparison of average TCP throughput for different hops.

Consequently, the TCP throughput is also increased with 30 and 40% for the SSs at second hop and third hop.

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REFERENCES

Andrews JG, Arunabha G, Rias M (2007). Fundamentals of WiMAX: Understanding Broadband Wireless Networking Upper Saddle River, NJ: Prentice Hall. http://tocs.ulb.tu-darmstadt.de/187530629.pdf.

Aweya J (2003). Transmission Control Protocol. Wiley Encyclopedia of Telecommunications, John Wiley & Sons, Inc. DOI: 10.1002/0471219282.eot202.

Canton AF, Chahed T (2001). End-to-end reliability in UMTS: TCP over ARQ. IEEE Global Telecommunications Conference, 2001, GLOBECOM '01.

Ergen M (2009). WiMAX Physical Layer for Mobile Broadband, Springer US. pp. 271-307.

Genc V, Murphy S, Murphy J (2008a). Performance analysis of transparent relays in 802.16j MMR networks. 6th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks and Workshops, WiOPT, 2008.

Genc V, Murphy S, Murphy J (2008b). IEEE 802.16J relay-based wireless access networks: an overview. Wireless Commun. IEEE 15(5):56-63.

Genc V, Murphy S, Murphy J (2009). Analysis of Transparent Mode IEEE 802.16j System Performance with Varying Numbers of Relays and Associated Transmit Power. IEEE Wireless Communications and Networking Conference, WCNC 2009.

Hoymann C, Klagges K, Schinnenburg M (2006). Multihop Communication in Relay Enhanced IEEE 802.16 Networks. IEEE 17th International Symposium on Personal, Indoor and Mobile Radio Communications.

Hui Z, Chenxi Z (2008). System-Level Modeling and Performance Evaluation of Multi-Hop 802.16j Systems. International Wireless Communications and Mobile Computing Conference, IWCMC '08.

Hui Z, Chenxi Z (2009). Resource Allocation in 802.16j Multi-Hop Relay Systems with the User Resource Fairness Constraint. IEEE Wireless Communications and Networking Conference, WCNC, 2009.

IEEE802.16e-2005 (2006). Local and Metropolitan 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 Corrigendum 1.

IEEE802.16j-2009 (2009). IEEE standard for Local and Metropolitan Area Networks – Part 16: Air Interface for Fixed Broadband Wireless Access Systems– Multihop Relay Specification.

Koon HT, Zhifeng T, Jinyuan Z, Anfei L (2007). Adaptive Frame structure for Mobile Multihop Relay (MMR) Networks. 6th International Conference on Information, Communications and Signal Processing.

Lei X, Fuja TE, Costello DJ (2008). An analysis of mobile relaying for coverage extension. IEEE International Symposium on Information Theory, ISIT 2008.

Mach P, Bestak R (2009). Optimization of Frame Structure for WiMAX Multi-hop Networks Wireless and Mobile Networking, Springer Boston 308:106-116.

Peters SW, Heath RW (2009). The future of WiMAX: Multihop relaying with IEEE 802.16j. Commun. Mag. IEEE 47(1):104-111.

Sayenko A, Alanen O, Martikainen H (2010). Analysis of the Non-Transparent In-Band Relays in the IEEE 802.16 Multi-Hop System. IEEE Wireless Communications and Networking Conference (WCNC).

Seung-Yeon K, Se-Jin K, Seung-wan R, Hyoung-Woo L, Choong-ho C (2008). Performance analysis of single-frame mode and multi-frame mode in IEEE 802.16j MMR system. IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2008.

Soldani D, Dixit S (2008). Wireless relays for broadband access [radio communications series]. Commun. Mag. IEEE 46(3):58-66.

Taha A-EM, Pandeli K, Hossam H, Najah AA (2011). Evaluating frame structure design in WiMAX relay networks. Concurrency Comput. Pract. Exper. 25:608-625.

Upase B, Hunukumbure M (2008). Dimensioning and cost analysis of Multihop relay enabled WiMAX networks. FUJITSU Sci. Tech. J. 44(3):303-317.

Yang Y, Hu H, Xu J, Mao G (2009). Relay technologies for WiMax and LTE-advanced mobile systems. Commun. Mag. IEEE 47(10):100-105.

Zhifeng T, Anfei L, Koon HT, Jinyun Z (2007). Frame Structure Design for IEEE 802.16j Mobile Multihop Relay (MMR) Networks. IEEE Global Telecommunications Conference, GLOBECOM '07.