2009 International Conference on Computer Engineering and Applications
IPCSIT vol.2 (2011) © (2011) IACSIT Press, Singapore

QoS and System Capacity Optimization in WiMAX Multi-hop Relay Using Flexible Tiered Control Technique

Anas F. Bayan [1], Tat-Chee Wan [2] and R. Sureswaran [3]

[1, 2, 3] National Advanced IPv6 Centre of Excellence (NAv6)
School of Computer Sciences
Universiti Sains Malaysia (USM), Penang, Malaysia

Abstract. WiMAX which is based on IEEE 802.16 standards attempts to provide high Quality of Service (QoS) performance, data rate and coverage within wireless networks to work as last mile solution for end user access. One of the main important issue for deploying real time and non-real time broadband wireless access networks is to guaranty Quality of Service (QoS) provisioning and bandwidth allocation among different classes of services (UGS, rtps, n-rtps, BE) in WiMAX multi-hop relay networks. In order to achieve high utilization of bandwidth allocation while providing QoS to various real time and non-real time application, QoS architecture, scheduling and admission control mechanisms need to be embedded into the MAC layer protocol in order to support scalability and bandwidth extension. In this paper a new network architecture is proposed to improve the QoS for individual user flows in the system and increase the overall system capacity for QoS flows. We propose suitable criteria for supporting tiers of QoS for various user applications according to their distance from WiMAX base station in the proposed network architecture. Finally a new technique named Flexible Tiered Control (FTC) technique is proposed as a solution to control the number of users that connect to the network and calculate the system capacity in terms of a three level relay topology.

Keywords: WiMAX, Multi-hop relay, Scheduling, Bandwidth allocation, QoS, Tiers

1. Introduction

Nowadays wireless technology has grown rapidly, and providing seamless access to information across wireless link to the end user over a wide area has become a crucial goal in wireless communications technology. For example, in areas where wireless signals are very week and/or with limited or no internet backbone such as in rural areas, dense urban environment and inside building coverage, a multi-hop wireless relay based system plays an important role in improving coverage and capacity in order to fill-in the wireless gaps and provide wireless access to the end users.

The standard IEEE 802.16-2004 [1], defines two main topologies which are point-to-multipoint (PMP) and mesh. Both topologies can be used to deploy wireless data services to end users.

PMP topology is the traditional transmission mode in WiMAX, where all the subscriber stations (SSs) connects directly to the central WiMAX Base Station (BS) through the wireless link. Thus, connections are established between SSs and BS for data transmissions, and direct communications between SSs are not allowed. Any communications or data transmission between two SSs are routed through the WiMAX BS.

In mesh topology, the existing SSs are not directly connected to the BS. SSs are acting as relay stations (RSs) and permit communications between SSs in order to achieve coverage extension of a BS without installation of another BS which may be costly. Therefore, SSs relay transmissions of other SSs that cannot directly communicate with the BS [2].

Fig. 1 shows an example of WiMAX PMP topology including mesh relay network expansion topology.

+ Corresponding author. Tel.: + 60174026254; fax: +6046533001.
E-mail address: anas@nav6.org.

In PMP operation mode, WiMAX clients either fixed or mobile within the BS coverage range will establish connections directly with the BS for the purpose of data transmission. If direct communications between SSs cannot be done, it has to go through the WiMAX BS. Whereas in mesh relay expansion operation mode traffic can occur directly between SSs and be routed through other SSs. Thus, each SS which are not in the transmission range of their destination can send their packets through other SSs in order to reach the desired destination via multi-hop communications.

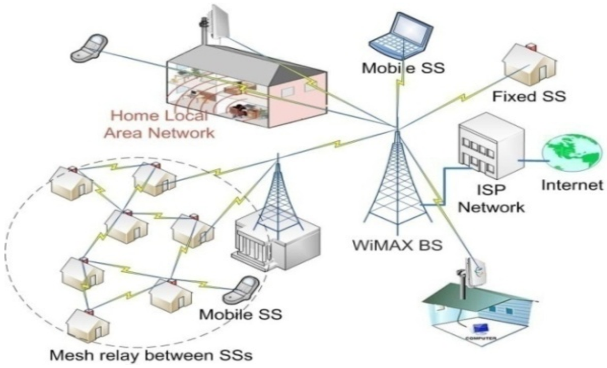

Fig. 1: Example of WiMAX PMP topology including mesh relay network expansion topology

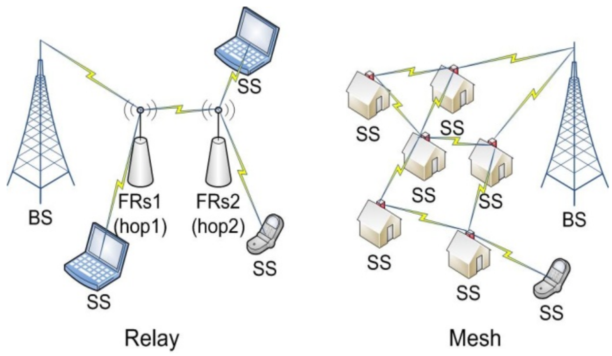

Fig. 2: Key difference between mesh and relay mode.

Adding relay capabilities to IEEE 802.16 system provide solution to overcome the potential problems in deploying wireless access to the users where there is limited or no internet backbone. The relays can be used for increase the capacity of a wireless system and extend the coverage of MMR-BS. However, in multi-hop wireless relay based systems many different designs are possible to be applied and further work need to be done by the researchers to explore the most suitable network designs for different deployment scenarios with guaranteeing the QoS [9].

In this paper, we propose a new network model for WiMAX multi-hop relay network to improve the QoS for individual user flows in the system and increase the overall system capacity for QoS flows with control the number of users connected to each tier. In order to support tiers of QoS for various user applications according to their distance from WiMAX base station in MMR network we propose the criteria that should be taken into account while designing the scheduling algorithm for the whole system.

The major contribution in this paper is the proposed FTC technique to control the number of users that connect to the network and calculate the system capacity in terms of a three level relay topology.

The rest of the paper is organized as follows. Section II briefly describes the key difference between mesh and mobile multi-hop relay. Section III, explore and briefly explains about IEEE 802.16j mobile multi-hop relay (MMR) background. Section IV, present the recommended number of hops to be used in MMR network. Section V, we define the propose network model. Finally in section VI, we conclude the paper with a summary.

2. Mesh VS Multi-hop Relay

Multi-hop communications in WiMAX could occurred in WiMAX mesh operation mode and in WiMAX mobile multi-hop relay (MMR) networks by installing Relay Station that allow for multi-hop communications. Service deployment and client's communications in WiMAX can be achieved via single-hop or multi-hop mode. In the single-hop mode, the SSs communicate directly with a BS like in PMP operation mode. While in the multi-hop mode, the SSs can communicate between each other and the communication between the SS and the BS may go among multiple hops like in mesh operation mode. Also in mobile multi-hop relay network that enable multi-hop communications, SSs may forward traffic to other SS, RS or BS through multiple hops. Fig. 2 shows the key difference between mesh mode and multi-hop relay mode.

3. Concept of Multi-hop Relay in WiMAX Network

Mobile multi-hop relay (MMR) which is also known as IEEE 802.16j, was introduced by the IEEE 802.16's Relay Task Group [3] to enhance coverage, throughput and system capacity of WiMAX networks by manipulating and specifying the multi-hop relay capabilities and functionalities of interoperable relay stations and base stations. This standard is compatible with the previous IEEE 802.16-2004 and IEEE 802.16e. Therefore, traditional WiMAX clients will work normally in a MMR enhanced infrastructure.

3.1. RS Usage models

In IEEE 802.16j network, the Internet Service Provider (ISP) may deploy RSs for different reasons [4]. Listed below are the possible reasons that ISP might deploy RSs:

1) Enhanced Data Rate Coverage: This can be achieved by providing higher uniform Signal to Interference and Noise Ratio (SINR) to the users within the MMR cell coverage. In other words, this can also be done by providing higher throughput to individual Mobile Stations (MSs) within the MMR cell coverage.

2) Range Extension: In order to provide coverage to group of users located outside of the BS coverage where the SINR is low and limited for instance, rural area or outskirts area, RSs are deployed to extend the coverage area beyond the perimeter of the BS coverage.

3) Capacity Enhancement: Increased the system capacity can be achieved by allowing aggressive frequency reuse within the BS cell and by enhancing the SINR where the SINR is limited. Thus RSs are deployed to increase the system capacity to high load regions within the BS cell. Where RS might be deployed individually or in clusters around the perimeter of the BS cell according to the needed capacity.

3.2. Types of RS

RS can be defined as Fixed, Nomadic or Mobile RS to suit different deployment scenarios or usage models. These RS is use for the system performance enhancement by allowing coverage extension and increasing the throughput. In certain scenario, the ISP may choose different types of RS to be deployed according to the topology, traffic and mobility within the surrounding area of each RS location. Hence, in such MMR network each usage scenario might include multiple RS types and multiple usage models [4] [5].

4. Optimal Number of Hops in MMR Networks

In a multi-hop relaying network with fixed relay station, the relay station consider as part of the network infrastructure. As we mentioned earlier, the relay station functionalities are to extend the coverage range, increase the capacity, reduced the dead spots and improve the overall services in the network. One of the most important aspects in deploying wireless multi-hop relay with the use of fixed relay stations is to define the optimal number of hops along the path between the source and the destination. Therefore, the number of hops (RSs) in the network must be carefully considered.

Research work done by Wei [7] has indicated that by increasing the number of hops (RSs) in WiMAX multi-hop relay system, the achievable client access capacity decreases dramatically. Wei's has also proposed that the achievable access capacity can be enhanced by using higher level modulation schemes or higher turbo coding rate respectively. Fig. 3 shows normalized achievable capacity for each number of hops using different type of modulation and coding schemes.

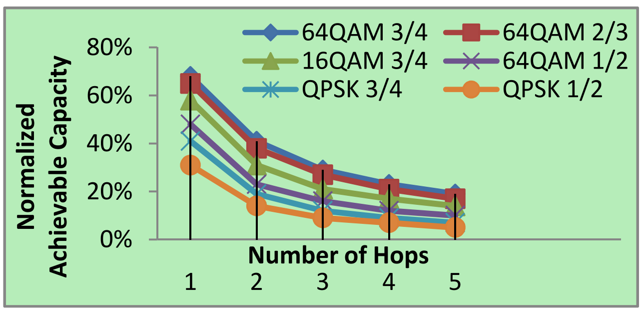

Fig. 3: Shows normalized achievable capacity versus number of hops for different modulation and coding schemes [7].

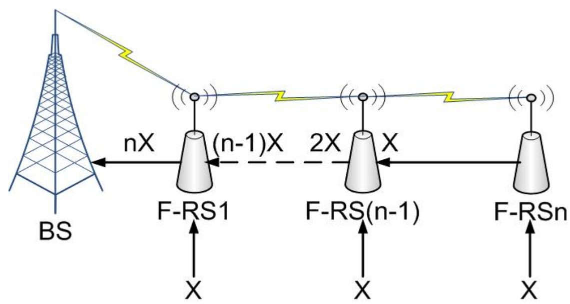

Fig. 4: Example of amount of traffic at wireless relay link

As shown in Fig. 3, when the number of hop is one and 64QAM-3/4 is used, 68% of the whole capacity can be allocated for user access while when the number of hop is two, 41% of the whole capacity can be allocated for user access. For three hops, only 29% of the whole capacity can be allocated for user access. From the figure, we can interpret that the achievable user access capacity can be significantly improved by using higher level modulation scheme or higher turbo-coding rate. For example, when the number of hops is two and 64QAM-3/4 is used, the achievable access capacity can reach 41% compared to 14% when using QPSK-1/2.

Fig. 4 shows an example of total amount of traffic transported at each hop or at wireless relay link. We assume the traffic load is identical at each hop. Let, n=3 where n is the number of hops, X is the traffic load at each hop

At hop F-RS3, local traffic is X so the amount of traffic transported at the wireless relay link between F-RS2 and F-RS3 will be X. The total amount of traffic transported at previous two hops which is between F-RS1 and F-RS2 will be 2X. For wireless relay link between the BS and F-RS1, the amount of traffic transported will be 3X. From Fig. 4, we conclude that by increasing the number of hop, the total amount of traffic to relay increased respectively. Thus, bottleneck might be occurred at F-RS1.

Wei [7] in his research work has stated that the maximum number of hops recommended to be used in MMR network is not more than three hops to guarantee that there's sufficient capacity for the local client to access the network. Therefore, we assume that the maximum number of hops recommended is based on Wei's work. Increasing the number of hops per connection might result to higher delay and affects the bandwidth efficiency. It's not recommended to use centralized scheduling mode if the number of hops > 2 [8].

5. Proposed Network Model and Discussion

A proposed network model is shown in Fig. 5. It will consists of one base station, three hops and subscriber's stations, where these subscribers stations might be mobile or fixed and it may connect directly to the base station if it's in the coverage area of the BS else, it will connect to the network and get the services through the relay stations which is installed as fixed relay stations in order to enhance the coverage and capacity of the base station.

In our proposed network model, the clients who are in the range of the BS will connect directly to the BS without the need to go through RS. While, the clients that are out of the BS range and coverage and it's in the range of RS will connect to the network through RSs. This may lead to multi-hop communications between users and BS.

In order to achieve high utilization of bandwidth allocation and to support tiers of QoS for various user applications according to their distance from WiMAX base station, the following should be taken into account while designing the scheduling algorithm for the whole system:

- Achieve high utilization of bandwidth allocation
- Maintain fairness's between different user's applications
- Provide bandwidth guarantees and high priority for real time application
- Maintain the QoS for the lower tier users
- Load balancing for each wireless zone and define the appropriate QoS.

To guarantee the QoS in the proposed network model and to provide optimal services for users in multi-hop network environment according to their distance from MMR-BS, we propose to define three tiers of QoS (QoS A, QoS B and QoS C) where each tier of QoS is specified for one hop or one wireless zone as shown in Fig. 5.

The IEEE 802.16j specifies five classes of services UGS, rtPS, ErtPS, nrtPS and BE. In view of the fact that rtPS and ErtPS have similar QoS parameter, our focus will be on three classes of services. Within each tier of QoS in the proposed network model, rtPS, nrtPS and BE classes are supported with their specific QoS parameters such as minimum rate, maximum rate, maximum delay and tolerated jitter. Each wireless zone which is consists of MMR-BS or RS and users connect to the BS or RS has limited capacity of users.

In order to maintain the QoS, it is essential to control and determine the number of users connect to each zone in regards to different levels of QoS. Controlling and determining the number of user is very crucial in order to maximize the throughput for each individual user requirement of QoS, maintain fairness between users in the networks and guarantee QoS for real time application users. The more users connect to the network, the more traffic congestion toward the MMR-BS. Therefore, we propose the Flexible Tiered Control (FTC) technique as a solution to control the number of users that connect to the network and calculate the system capacity in terms of a three level relay topology. Hence, for better QoS and resource utilization, Total Traffic (TF) at MMR-BS must be less than or equal to the MMR-BS capacity. TF at each hop can be defined as in the following equations (1- 4).

$$TF_0 \ \ at\ Hop_0 = \sum_{i=0}^{n_0} U_0 i + \sum_{r=0}^{m_0} TF_{1_r} \tag{1}$$

$$TF_{1_r}\ at\ Hop_1 = \sum_{i=0}^{n_1} U_1 i + \sum_{r=0}^{m_1} TF_{2_r} \tag{2}$$

$$TF_{2_r}\ at\ Hop_2 = \sum_{i=0}^{n_2} U_2 i + \sum_{r=0}^{m_2} TF_{3_r} \tag{3}$$

$$TF_{3_r}\ at\ Hop_3 = \sum_{i=0}^{n_3} U_3 i \tag{4}$$

$$TF_j \ \ at\ Hop_j = \sum_{i=0}^{n_j} U_j i + \sum_{r=0}^{m_j} TF_{j+1_r} \tag{5}$$

$$TF_0 = \sum_{i=0}^{n_0} U_{0i} + \sum_{r=0}^{m_0}\sum_{i=0}^{n_1} U_{1ri} + \sum_{r=0}^{m_1}\sum_{i=0}^{n_2} U_{2ri} + \sum_{r=0}^{m_2}\sum_{i=0}^{n_3} U_{3ri} \tag{6}$$

Let $\quad U_{0i} = U_{1ri} = U_{2ri} = U_{3ri} = \boldsymbol{U} \qquad (7)$

$$n_0 = n_1 = n_2 = n_3 = \boldsymbol{n} \tag{8}$$

$$m_0 = m_1 = m_2 = m_3 = \boldsymbol{m} \tag{9}$$

$$TF_0 = \propto_0 \sum_{i=0}^{n} U + \propto_1 \sum_{r=0}^{m}\sum_{i=0}^{n} U + \propto_2 \sum_{r=0}^{m}\sum_{i=0}^{n} U + \propto_3 \sum_{r=0}^{m}\sum_{i=0}^{n} U \tag{10}$$

$$TF_0 = \ \propto_0 \sum_{i=0}^{n} U + \sum_{j=1}^{3} \propto_{\mathrm{j}} \sum_{r=0}^{m}\sum_{i=0}^{n} U \tag{11}$$

$$TF_0 = \propto_0 n\, u + \sum_{j=1}^{3} \propto_{\mathrm{h}} m\, n\, u \tag{12}$$

$$TF_0 = \left\{ \left(\propto_0 + \sum_{j=1}^{3} \propto_{\mathrm{j}} m \right) n\, u \right\} \leq BS\ capacity \tag{13}$$

From equations (1 – 4) we derived equation (5) to calculate total traffic at each level (wireless zone). Where$j \in [0, L]$, L is Layer, *(n_j)* is number of users at level *j* and *(m_j)* is number of relays at level *j.* In equation (6) we show how to calculate total traffic load in the network at the BS for a three level relay topology, whereas total traffic at any level in the network should be less than or equal to the BS capacity. Where (*U*) in equation (7) represent the traffic load per user, (*n*) in equation (8) represent number of users, (*m*) in equation (9) represent number of relays and ($\propto_0, \propto_1, \propto_2 \propto_3$) are control parameter for each level on a three level relay topology.

At the end in equation (13) we define the system capacity in terms of a three level relay topology where the QoS for individual users are constrained by the variables $\propto_0, \propto_1, \propto_2 \propto_3$ at the respective levels, where $\propto$ is a fraction less than one of the total BS capacity.

$\propto$, it could be used as a fixed control parameter for controlling the number of users connected to the network. Where it is used to accept or reject users at each relay in accordance with the predefined number of users (n) allocated for each relay on the network while maintaining the QoS for each tier. Hence, users request can be accepted or rejected based on its required QoS parameters, total network capacity (available bandwidth) and already accepted flows.

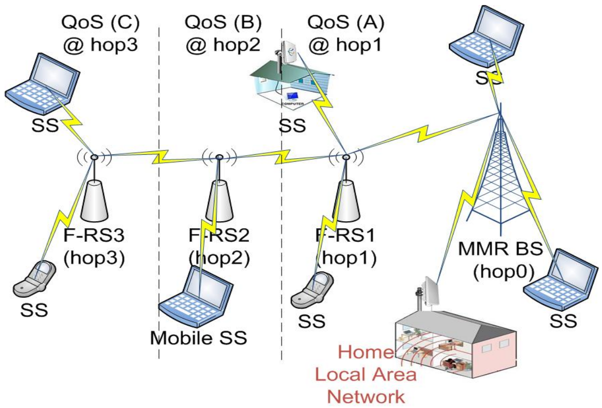

Fig. 5: Network model

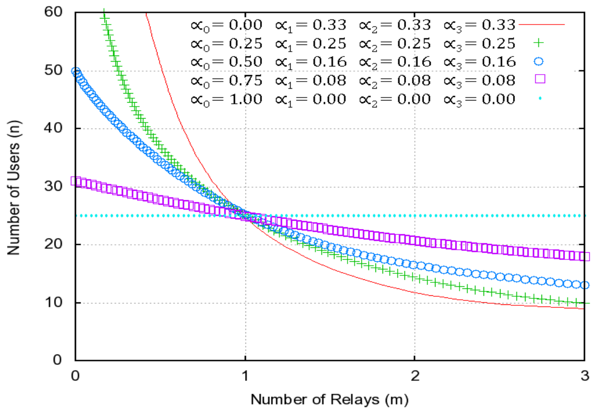

Fig. 6: Maximum number of users (n) per relay to satisfy Equ. 13 for various values of $\propto$

Fig. 6 shows the impact of the FTC technique on controlling the number of users connected to the network and enhance the system capacity for each number of relays by using different control parameters of $\propto$ as fixed control parameter. As a result, the optimal number of users per relay is 25 users. Whereas at the BS, the impact on the number of users was high, different control parameters shows different results on user's number.

6. Conclusion

In this paper, we have proposed a new network model for WiMAX multi-hop relay based system to improve the QoS for individual user flows in the system and increase the overall system capacity for QoS flows with control the number of users connected to each tier. In the proposed model we have defined three tiers of QoS where each tier is specified for one wireless zone. In order to achieve maximum utilization of bandwidth allocation and support tiers of QoS, we proposed the criteria that should be taken into account while designing the scheduling algorithm for the whole system such as the need to maintain fairness's between different user's applications, provide bandwidth guarantees and high priority for real time application, maintain the QoS for the lower tier users, assure load balancing for each wireless zone and define the appropriate QoS. The achievable number of user's access per relay and the overall system capacity can be enhanced by using the FTC technique. To ensure QoS in the proposed network topology, we conclude that the total traffic load at any level must be less than or equal to the BS capacity

7. References

[1] IEEE 802.16-2004, "IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," Oct. 2004.

[2] Kuran, M.S., Yilmaz, B., Alagoz, F., Tugcu, T. "Quality of Service in Mesh Mode IEEE 802.16 Networks," *Proc. IEEE International Conference on Software in Telecommunications and Computer Networks 2006*, SoftCOM 2006, Sept. 29 2006, pp. 107 – 111.

[3] IEEE 802.16's Relay Task Group, [Online]. Available: http://wirelessman.org/relay/

[4] IEEE C802.16j-06/026, "802.16j (Mobile Multihop Relay) Usage Models."

[5] IEEE 802.16j-06/015, "Harmonized Contribution on 802.16j (Mobile Multihop Relay) Usage Models."

[6] Soldani, D., Dixit, S. "Wireless Relays for Broadband Access," *IEEE Communications Magazine*, March 2008, pp.58-66.

[7] Wei, Z., "Capacity Analysis for Multi-hop WiMAX Relay,"

[8] Y. Zhou, "Maximum number of hops for centralized scheduling mode," Slides S802.16j-08/050, Jan. 2008.

[9] Genc, V., Murphy, S., YU, Y., Murphy, J. "IEEE 802.16J Relay-Based Wireless Access Networks: An Overview." *IEEE Wireless Communications Magazine* 15, no. 5 (October 2008): 56-63.