IACSIT International Journal of Engineering and Technology, Vol.2, No.5, October 2010
ISSN: 1793-8236

A Joint Routing and Bandwidth Allocation Protocol for IEEE 802.16 WiMax Mesh Networks

R Murali Prasad and P.Satish Kumar

***Abstract*—Bandwidth allocation and routing are two important mechanisms in the provision of guaranteed QoS in wireless networks. The QoS provisioning algorithms developed in mobile ad hoc networks might not be applied directly in wireless mesh networks, since, WiMax based backhaul mesh networks have different characteristics. In this paper, to solve the routing and resource allocation issues, we propose to design a joint routing and bandwidth allocation protocol for WiMAX networks. In this protocol, a bandwidth estimation technique is combined with route discovery and setup in order to find a best route. While estimating the bandwidth, both local bandwidth and the bandwidth of all nodes within the interference range, are considered. The bandwidth estimation technique is applied on the standard on-demand routing protocol by modifying the route request and route reply packets. By simulation results, we show that the proposed protocol achieves more throughput and bandwidth utilization when compared with the existing protocol.**

***Index Terms*— IEEE 802.16, WiMax Mesh Networks, QoS, metropolitan area networks (MANs), Route Discovery.**

I. Introduction

A. WiMAX Networks

IEEE 802.16 also known as the WiMAX, is considered as a standard for metropolitan area networks (MANs) [1]. It is one of the most reliable access technologies which provide the option of supplying connectivity to end users in an economical way since this technology enables obtaining high bit rate and reaching large areas with a single Base Station [2]. In the areas where the installation of wired infrastructure is cost-effective or technically achievable, a large number of applications can be achieved due to the fact that the WMAN has certain advantages of low cost, high speed, rapid and easy deployment. As a result, WiMAX can be used widely in several related fields, comprising of mobile service, mobile commerce, mobile entertainment, mobile learning and mobile healthcare [4]. Fixed subscriber stations (SSs) maintain contact with the mobile subscriber stations (MSSs) by means of air interface [1]. In spite of the deployment and the utilization of WiMAX standard, several topics have yet to be described to permit and optimize the utilization of this technology in future [2]. Traffic on WiMAX is varied with random mix of real and non-real time traffic with applications needing widely varying and miscellaneous QoS guarantee [5, 6].

Two modes are provided by the 802.16 for sharing the wireless networks.

- Point-to-Multipoint (PMP) and
- Mesh (optional).

A cellular-like structure is formed in the PMP mode. Within the same antenna sector, the base station (BS) supports a set of subscriber stations (SSs) in a broadcast mode. Transmissions from SSs are passed to the BS and synchronized there. In mesh mode, scheduling is distributed in the nodes which are organized ad hoc. The uplink (from SS to BS) and downlink (from BS to SS) data transmissions in IEEE 802.16 are frame based [7].

B. Routing in WiMAX

Most of the nodes are either stationary or mobile in wireless networks. Instead of dealing with mobility or minimizing power usage, the routing algorithms improve the network capacity or the performance of individual transfers. Some fundamental challenges in routing over wireless mesh networks (WMNs) are:

- Both short and long time scale issues should be addressed in routing design. Ensuring both long-term route stability and achieving short-term opportunistic performance can be done by a good wireless mesh routing algorithm.
- Soft and hard failures, like transient channel outages, links with intermediate loss rates, from several channel disconnections, nodes under denial-of-service (DOS) attacks, and failing nodes are the issues to be handled by the wireless routing. Wireless routing should be designed such that it is not affected by these failures.

Both the issues are to be addressed by the routing and also should be scalable for the large node population. Random routing is done in IEEE 802.16 standard where the parent is selected randomly by the SSs while building a tree. Routing has considerable impact on performance of the system and will decide the end to end QoS to different users [8].

C. Bandwidth Allocation in WiMAX

For utilizing the bandwidth efficiently and to improve the lengthy contention delay, WiMAX has separate downlink (DL) and uplink (UL) channels. Instead of implementing arbitrary contentions in Wi-Fi for managing the DL/UL transmissions and allocating bandwidth for mobile stations (MSs), WiMAX which has a control center named base station (BS) has been accomplished. By sending Bandwidth requests packets or by crediting with the data packet,

R Murali Prasad, Department of Electronics and Communications, MLR Institute of technology, Hyderabad(e-mail: muraliprasadphd@gmail.com).
P. Satish Kumar, Professor, Department of Electronics and Communications, MLR Institute of technology, Hyderabad

bandwidth can be requested. Requests can be aggregated or incremental. Grant per Connection (GPC) and Grant per Subscriber Station (GPSS) are the two ways for allocating bandwidth grants [10].

The bandwidth-request delay acquired in transmitting uplink TCP acknowledgement (ACK) degrades the performance of downlink TCP flow. On receiving the TCP data packets, the subscriber station (SS) transmits the corresponding TCP ACK packets to the base station (BS). In the centralized scheduling framework of the IEEE 802.16 Broadband Wireless Access (BWA) networks, the transmissions require bandwidth request/ allocation procedure since the ACK packets have a separate uplink connection. This causes increase in round trip time (RTT) of downlink TCP flow and in turn decreases its throughput [13].

D. Joint Routing and Bandwidth Allocation

Resources in an IEEE 802.16 network are generally symbolized by time slots within a frame. The uplink/downlink bandwidth demands of each SS and their link qualities are given for solving the resource allocation problem. Four issues are considered:

- Tree reconstruction: Depending upon the SSs' current bandwidth demands and link qualities, routing tree is determined
- Bandwidth allocation: The number of time slots of each SS is determined according to the uplink and downlink bandwidth demands.
- Time-slot assignment: Time slots are assigned to each SS in a frame.
- Bandwidth guarantee: to assure the fixed amount of bandwidth transmission on time, slots for each SS is scheduled [14].

A join routing and bandwidth allocation algorithm is designed for WiMAX networks to solve the above issues [14].

II. Related Work

Yi-Neng Lin et al [9] have proposed the Highest Urgency First (HUF) algorithm to conquer the challenges with the physical-layer by taking into consideration the adaptive modulation, coding scheme (MCS) and the urgency of requests. In their algorithm, downlink and uplink sub-frames are determined by reserving the bandwidth for the most urgent requests and proportionating the remaining bandwidth for others. Then, independently in the downlink and uplink, their HUF allocates bandwidth to every mobile station according to a pre-calculated U-factor which considers urgency, priority and fairness.

Claudio Cicconetti et al [12] have proposed a Fair End-to-end Bandwidth Allocation (FEBA) algorithm. Their FEBA is implemented at the Medium Access Control (MAC) layer of single-radio, multiple channels IEEE 802.16 mesh nodes, operated in a distributed coordinated scheduling mode. Also their FEBA negotiates bandwidth among neighbors to assign a fair share to each end-to-end traffic flow.

Eun-Chan Park et al [13] have proposed a framework of a virtual bidirectional connection with a simultaneous bandwidth allocation for both downlink TCP data and uplink acknowledgment (ACK) to improve TCP performance in IEEE 802.16 broadband wireless access networks. They also proposed a hybrid approach combining proactive bandwidth allocation with piggyback bandwidth request. Their proposed framework removes the unnecessary bandwidth-request delay, and also decreases signaling overhead involved in the bandwidth-request.

Arijit Ukil and Jaydip Sen [15] have presented a QoS aware cross-layer optimized resource allocation scheme for WiMAX networks to optimize the system performance as well as maintaining the end-to-end QoS of individual users. They also proposed an algorithm to cater the need of better resource management particularly for heterogeneous traffic consisting of soft and hard QoS constraints applications in 4G networks by exploiting time-diversity gain.

Alessandra Scicchitano et al [16] have compared the various allocation schemes for MPEG video traffic, ranging from a fixed bandwidth allocation based only on average source rate and worst channel conditions, to fully dynamic schemes taking into account the current channel conditions and buffer occupation at the SSs. They also described an analytical framework based on a discrete-time Markov chain, which models the wireless channel behavior and integrates the non-controlled MPEG video source.

III. Proposed Joint Routing and Bandwidth Allocation Protocol

A. System Model

We consider a wireless metropolitan area mesh network in which the infrastructure/backbone is built using IEEE 802.16 technology. The mesh network consists of fixed wireless mesh routers and end mobile clients. The wireless mesh routers form a multihop wireless backbone to relay traffic to and from mobile clients. An IEEE 802.16 cell consists of a base station and one or more mobile stations based on point-to-multipoint (PMP) network topology. Wireless mesh routers also serve as base stations to mobile stations within their coverage area.

We describe an IEEE 802.16-based wireless mesh network as a set of nodes $N = \{1, \cdots, N\}$ that includes all the mobile clients and mesh routers and a set of wireless links $L = \{1, \cdots, L\}$ that includes all the backhaul links as well as the links between mobile stations and base stations. Assume the bandwidth requirement for the new arrival is REQ_{bw}. Each node and each link along the chosen route must have at least MIA_{bw} units of bandwidth available for the new connection.

The routing problem is to decide a QoS route with bandwidth constraint for each source node and an assignment of its flow to all links in the network. For this, the paper proposes a joint routing and bandwidth allocation protocol in which a bandwidth estimation technique is combined with route discovery and setup in order to find a best route.

B. Bandwidth Estimation

Direct range is the area within transmission range and indirect range is the area between transmission range and interference range. The number of competitive nodes is the total numbers of these two areas. So, two tables are maintained by the nodes, the Direct Range Members (DRM) which are found from the first hop nodes and Indirect Range Members (IRM) table which are found from two or more hops nodes or hidden nodes. Neighboring nodes' bandwidth can be obtained proactively or reactively. Proactive approach is chosen by our proposed scheme to obtain bandwidth information at neighboring nodes. To decrease collision and to deliver bandwidth information, every node issues a signal at its own defined intervals which are coordinated with the neighboring nodes. All neighboring nodes send their own bandwidth data by one-hop with double power to collect neighboring nodes information.

In the proposed scheme, each node within the interference range ensures that it has enough bandwidth to transmit data without causing congestion. And so, identification of local and the neighboring nodes within the interference range is done accurately. Local bandwidth and the bandwidth of all interference range nodes should be considered by a node to transmit data. In our proposed system, special signals are sent out by the nodes with double power in predefined interval and signals are collected from neighboring nodes and finally the DRM and IRM tables are updated.

The local bandwidth and neighboring nodes' bandwidth are determined as below.

Since bandwidth is shared among neighboring nodes, a node listens to the channel and estimates bandwidth based on the ratio of idle and busy times for a predefined interval.

The local bandwidth L_{BW} is estimated as follows:

$$L_{BW} = C_{BW} \; X \; \frac{idle_t}{\text{int}_t} \quad (1)$$

Where C_{BW} denotes the channel capacity, $idle_t$ denotes the idle time in a predefined interval int_t .

The neighboring nodes bandwidth is given by NM_{BW} which is collected from the neighboring nodes.

So the residual bandwidth R_{BW} is calculated as

$$R_{BW} = NM_{BW} - L_{BW} \quad (2)$$

C. Route Discovery Process

The proposed bandwidth allocation scheme can be applied to any on-demand routing protocols such as AODV and DSR. We apply our scheme to the AODV routing protocol by modifying the route request (RREQ) and route reply (RREP) packets.

a) Route Request

In addition to the standard RREQ header, the route request packet contains the following

RREQ header,
REQ_{BW}
$V(Id_k, c_k, i, d)$

Where,

REQ_{BW} is the Requested bandwidth

V is a vector comprising combined IDs of the nodes in the interference range from source node s up to node i for the destination node d and their corresponding counts.

Id_k - id of the nodes in the interference range

c_k - counter for the node n_k

i - intermediate node

d - destination node.

Steps:

1. If node n_i has no one hop neighbor, then
   Drop RREQ
   Else
   Send RREQ
2. If node n_v receives RREQ,
   If $REQ_{BW} > R_{BW}$, then
   Drop RREQ
   Else
   Calculate $< (n_k, c_k), i, d >$
   Forward RREQ
   End if.
   End if.

b) Route reply

A route reply packet contains the following

RREP header,
REQ_{BW}
Mi_{BW}
$V(Id_k, c_k, i, d)$

Where,

REQ_{BW} is the requested bandwidth,

MIA_{BW} is the minimum available bandwidth,

V is a vector comprising combined IDs of the nodes in the interference range from source node s up to node i for the destination node d and their corresponding counts.

Id_k - id of the nodes in the interference range

c_k - counter for the node n_k

i - intermediate node

d - destination node.

Steps:

1. Destination node send the modified RREP packet.
2. Intermediate node n_i receives RREP.
3. n_j calculates $MAX_{BC} = \max(c_k)$
4. If $R_B < (MAX_{BC} * REQ_{BW})$ then
   $MIA_{BW} = (MAX_{BC} * REQ_{BW}) - R_{BW}$
   Forward RREP to n_{j-1}
   Else
   Send failure message to source
   End if.
3. Source chooses the RREP with maximum MIA_{BW} as the best path.

Here MAX_{BC} is the maximum value of bandwidth counter for a node which is around node n_j within its interference range.

The system performance mainly depends on the correctness of bandwidth estimation. Flows below the capacity of network are rejected by the AP if the estimated bandwidth is less than that of network capacity. AP admits a flow whose bandwidth consumption is beyond the capacity of network when the estimated bandwidth is greater than that of network capacity. This will degrade the whole system performance. Difference of estimated bandwidth and capacity of the network should be minimized for better results.

IV. Simulation Results

A. Simulation Model and Parameters

To simulate the proposed scheme, network simulator (NS2) [17] is used. The proposed scheme has been implemented over IEEE 802.16 MAC protocol. In the simulation, clients (SS) and the base station (BS) are deployed in a 1000 meter x 1000 meter region for 50 seconds simulation time. All nodes have the same transmission range of 250 meters. In the simulation, the video traffic (VBR) and CBR traffic are used.

The simulation settings and parameters are summarized in table I.

TABLE I: SIMULATION SETTINGS

Area Size	1000 X 1000
Mac	802.16
Nodes	50
Radio Range	250m
Simulation Time	50 sec
Traffic Source	VBR
Physical Layer	OFDM
Packet Size	1500 bytes
Frame Duration	0.005
Rate	1Mb
OFDM Bandwidth	10 MHz

B. Performance Metrics

We compare our proposed joint routing and bandwidth allocation (JRBA) algorithm with the interference-aware multi-path routing and bandwidth allocation (IMRBA) algorithm [6]. We mainly evaluate the performance according to the following metrics:

Channel Utilization: It is the ratio of bandwidth received into total available bandwidth for a traffic flow.

Throughput: It is the bandwidth received measured in Mb/s.

Average End-to-End Delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

The performance results are presented in the next section.

C. Results

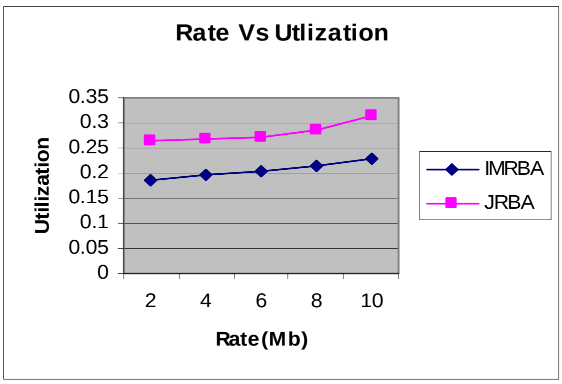

Fig. 1 Rate Vs Utilization

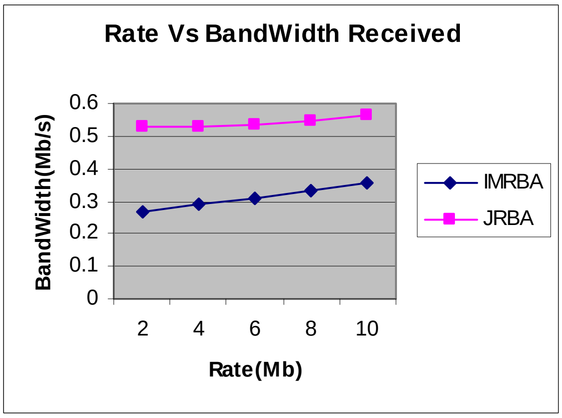

Fig. 2 Rate Vs Throughput

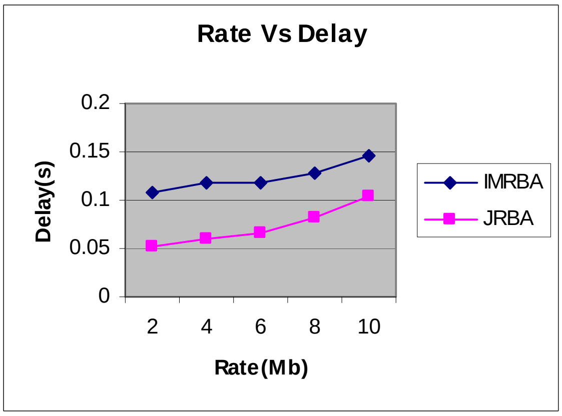

Fig. 3 Rate Vs Delay

Fig. 1 shows that the bandwidth utilization is more for our proposed JRBA when compared with the IMRBA scheme. Fig. 2 shows that the throughput is more for our proposed JRBA when compared with the IMRBA scheme. From Fig. 3 it is clear that the delay for our proposed JRBA scheme is less when compared with the IMRBA scheme.

V. Conclusion

Routing will have significant impact on the performance of the system and will largely decide the end to end QoS to different users. In this paper, to solve the routing and resource allocation issues, we have designed a joint routing and bandwidth allocation protocol for WiMAX networks. In this protocol, a bandwidth estimation technique is combined with route discovery and setup in order to find a best route. While estimating the bandwidth, both local bandwidth and the bandwidth of all nodes within the interference range, are considered. The bandwidth estimation technique is applied on the standard AODV routing protocol by modifying the route request and route reply packets. By simulation results, we have shown that the proposed protocol achieves more throughput and bandwidth utilization when compared with the existing protocol.

References

[1] Chung-Wei Lin, Yu-Cheng Chen and Ai-Chun Pang, “A New Resource Allocation Scheme for IEEE 802.16-based Networks”. 3rd IEEE VTS Asia Pacific Wireless Communications Symposium (AWPCS 2006), Aug. 2006.

[2] M. Castrucci, I. Marchetti, C. Nardini, N. Ciulli and G. Landi, “A Framework for Resource Control in WiMAX Networks”, In Proc. of

the 2007 International Conference on Next Generation Mobile Applications, Services and Technologies, pp. 316-321, 2007.
[3] Hanwu Wang and Weijia Jia, “Scalable and Adaptive Resource Scheduling in IEEE 802.16 WiMAX Networks”, IEEE, GLOBECOM, 2008.
[4] S.C. Wang, K.Q. Yan and C.H. Wang, “A Channel Allocation based WiMax Topology”, International MultiConference of Engineers and Computer Scientists, March 18 - 20, 2009.
[5] Arijit Ukil and Jaydip Sen, “QoS Aware Cross-Layer Optimized Resource Allocation in WiMAX Systems”, Wireless VITAE, 1st International Conference on 17-20 May 2009.
[6] Xu-Zhen, Huang-ChuanHe and Hu-XianZhi, “Interference-aware Multi-path Routing and Bandwidth Allocation for Mobile Wireless Networks”, ICCS, IEEE, 2008.
[7] Claudio Cicconetti, Alessandro Erta, Luciano Lenzini, and Enzo Mingozzi, “Performance Evaluation of the IEEE 802.16 MAC for QoS Support”, IEEE Transactions On Mobile Computing, Vol. 6, No. 1, January 2007.
[8] Yaaqob A.A. Qassem et al, “Review of Network Routing in IEEE 802.16 WiMAX Mesh Networks”, Australian Journal of Basic and Applied Sciences, 2009.
[9] Yi-Neng Lin et al, “A Latency and Modulation Aware Bandwidth Allocation Algorithm for WiMAX Base Stations”, in the Proceedings of The IEEE Wireless Communications & Networking Conference (WCNC '08), March 2008.
[10] R. Mahmood et al, “A Novel Parameterized QoS based Uplink and Downlink Scheduler for Bandwidth/Data Management over IEEE 802.16d Network”, International Journal of Recent Trends in Engineering, Vol 2, No. 1, November 2009.
[11] Hung-Chin JANG and Wei-Ching Lin, “Effective Bandwidth Allocation for WiMAX Mesh Network”, Journal of Systematic, Cybernetics and Informatics, volume 8 - number 2 - year 2010.
[12] Claudio Cicconetti et al, “Bandwidth Balancing in Multi-Channel IEEE 802.16 Wireless Mesh networks”, INFOCOM 2007, 26th IEEE International Conference on Computer Communications, 6-12 May 2007.
[13] Eun-Chan Park et al, “Bidirectional Bandwidth Allocation for TCP Performance Enhancement in IEEE 802.16 Broadband Wireless Access Networks”, Personal, Indoor and Mobile Radio Communications, PIMRC 2008, IEEE 19th International Symposium on 15-18 Sept. 2008.
[14] Lien-Wu Chen et al, “Exploiting Spectral Reuse in Routing, Resource Allocation, and Scheduling for IEEE 802.16 Mesh Networks”, IEEE transactions on vehicular technology, vol. 58, no. 1, January, 2009.
[15] Arijit Ukil and Jaydip Sen, “QoS Aware Cross-Layer Optimized Resource Allocation in WiMAX Systems”, Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology, 2009. Wireless VITAE 2009, 1st International Conference on 17-20 May, 2009.
[16] Alessandra Scicchitano et al, “Bandwidth Allocation for Video Streaming in WiMax Networks”, Vehicular Technology Conference, 2009, VTC Spring 2009, IEEE 69th on 26-29 April 2009.
[17] Network Simulator, http://www.isi.edu/nsnam/ns

R Murali Prasad received Engineering degree from the Institution of Engineers (i) in 1989 and M.Tech degree from the department of Electronics and Communications, Pondicherry Engineering College in 1993.He worked in various engineering colleges as faculty member. Presently he is working as faculty member in the Department of Electronics and Communications, MLR Institute of technology, Hyderabad. He is pursuing Ph.D at JNT University Anantapur under the guidance of Dr.P, Satish Kumar. His areas of interest are digital communications, control systems and wireless communications.

Dr. P. Satish Kumar received B.Tech degree in the Department of Electronics and Communication from Nagarjuna University in 1989 and M.Tech degree from Pondicherry University in 1992. He completed Ph.D degree from JNT University, Hyderabad in the year 2004. He is having 18 years of teaching experience. He has published 15 research papers at national and international level. Presently he is working as professor in the Department of Electronics and Communications, MLR Institute of technology, Hyderabad. His research areas are multirate signal processing, image processing and wireless communications.