Joint Routing, Scheduling and Admission Control Protocol for WiMAX Networks

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Abstract: *In WiMax networks the routing and the scheduling are tightly coupled. The routing and scheduling problem for WiMAX networks is different from 802.11 based mesh networks and can be designed and operated separately. Standard problems in wireless systems include Bandwidth allocation and Connection Admission Control (CAC). In this paper we design a joint routing, scheduling and admission control protocol for WiMax networks. In the adaptive scheduling, packets are transmitted as per allotted slots from different priority of traffic classes adaptively, depending on the channel condition. A bandwidth estimation technique is combined with route discovery and route setup in order to find a best route. The admission control technique is based on the estimation of bandwidth utilization of each traffic class, with the constraint that the delay requirement of real-time flows should be satisfied. The current available bandwidth is estimated for all the nodes and for the new incoming flows, it estimates the requested bandwidth and decides to admit this new flow or not. By simulation results, we show that our proposed protocol achieves better throughput and channel utilization while reducing the blocking probability and delay.*

Keywords: *Routing, scheduling, admission, channel, WiMax networks, bandwidth.*

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1. Introduction

1.1. WiMAX Networks

In Metropolitan Area Networks (MANs), Worldwide Interoperability for Microwave Access (WiMAX) or IEEE 802.16 is typically considered as the most reliable wireless access technology [7]. Getting High bit rate and reaching large area in a single base station is possible in this technology. Hence connectivity to end users becomes cost-effective [1]. Installation of wired infrastructure can become cost-effective or technically achievable when the qualities like low cost, high speed, rapid and easy deployment in Wireless Metropolitan Area Network (WMAN) is combined with the last-mile access [17]. WiMax is also encaged in mobile service, mobile commerce, mobile entertainment, mobile learning and mobile healthcare [18]. BSs have a contact with fixed Subscriber Stations (SSs) and Mobile Subscriber Stations (MSSs) by means of air interface [7]. The development of the WiMax networks is restricted to certain situations and research works on WiMAX access networks is still taking place to permit and optimize the utilization of this technology in the future [1]. The applications of WiMax needs varying and diverse QoS guarantee since WiMAX is heterogeneous with unsystematic mix of real and non-real time traffic [16, 2]. The 802.16 standard provides two modes for sharing the wireless medium:

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

Nodes are arranged in a cellular structure in the PMP mode in which the base station assists a set of SSs within the same antenna sector in a broadcast mode. Here all SSs attain the same transmission from the BS. SSs transmissions are targeted to the BSs and get synchronized. Nodes are organized Ad-hoc in the mesh mode and scheduling is distributed among them. The uplink from SS to BS and downlink from BS to SS data transmissions in the IEEE 802.16 standard are frame-based [19]. The main problem in the design of a communications system over a wireless link is to deal with multi-path fading, which causes a significant degradation in terms of both the reliability of the link and the data rate [5].

1.2. Routing and Scheduling Issues

In WiMAX networks, the routing and the scheduling are tightly coupled. The routing and scheduling problem for WiMAX networks is different from 802.11 based mesh networks and can be designed and operated separately. The problems of scheduling algorithm for both PMP and mesh mode are still unclear in spite the IEEE 802.16 standards specify several QoS schemes and related message formats. Since the network bottleneck is in the wireless links, there is no sign of performance improvement in the joint centralized routing and the scheduling. Traffic gets delivered to the internet successfully only when SSs is close to BSs [3]. The existing works on scheduling and routing algorithms for WiMAX mesh networks improve performance by proposing scheduling and routing which reports the interference and increase spatial reuse only [8]. The routing protocols are not considered in the IEEE 802.16 standards because it considers only MAC and PHY layer protocols. Routing and scheduling bandwidth allocation problems can be solved by the following ways:

- *Centralized Routing and Centralized Scheduling (CRCS):* BSs receives the traffic and position information of the stations. The BSs sends the corrected routes and schedules and back to the SSs.
- *Distributed Routing and Centralized Scheduling (DRCS):* The routes of the SSs are distributed to the BSs. When the routes are found, the BSs get information from the SSs. A collision free transmission schedule is determined by the BSs.
- *Distributed Routing and Distributed Scheduling (DRDS):* The stations distribute their routes to the BSs and after this SSs works with the next hop station towards the BSs. Collision free transmission schedules are determined by the BSs in a distributed way.
- *Hybrid Routing and Scheduling (HRS):* Both routing and scheduling algorithms can be implemented in either a distributed or a centralized way [3].

1.3. Bandwidth Allocation and Admission Control

Standard problems in wireless systems include bandwidth allocation and connection admission control. For assigning limited wireless resource to continuous and incoming connections so that QoS requirements are satisfied, bandwidth allocation is needed. Limited radio resource accepts too many connections and causes overwhelming. This can be prevented by admission control. In all the existing works, radio link level queuing performance is not considered [11].

By using Connection Admission Control (CAC), packet scheduling, dynamic sub-carrier assignment etc., QoS guarantee between Base Station (BS) and SSc can be achieved in IEEE 802.16 in order to keep up multimedia services. CAC guarantees the QoS, and also controls the selection of scheduling and resource allocation algorithms [19]. Only the resource management in homogeneous wireless networks is handled in the present admission control strategies but not the problem of heterogeneous wireless environment. The mobility of the terminals in mobile communication environment makes the resource allocation, a difficult task when resources are always insufficient. Efficient call admission control policies can optimize the resource utilization and solves the problem [13].

The introduction of a new call in the connection-oriented systems and decision of accepting a new connection is performed by the CAC mechanism. QoS of present connections should not be affected by the new call and also before taking a decision, system offers QoS requirements of the new call. These are established by the CAC. Because of user mobility, the continuous calls of present cell must be handed over to another cell. Network overload or aggressive channel conditions leads to limited resources in the receiving cell. Thus when the arrival rate of new or handoff calls exceeds the capability of a cell, the receiving cell starts dropping calls or refuse handoff attempts [6].

There is no clear structure for CAC and even though implicit conventional bandwidth based CAC is suggested, it cannot guarantee QoS to application services. This can make the execution difficult as well as unsuitable for application using diverse services of 802.16 [12].

1.4. Proposed Solution

In this paper we design a joint routing, scheduling and admission control protocol for WiMAX networks. In the adaptive scheduling, packets are transmitted as per allotted slots from different priority of traffic classes adaptively, depending on the channel condition. In this protocol, a bandwidth estimation technique is combined with route discovery and route setup in order to find the best route. The bandwidth estimation technique is applied on the standard on-demand routing protocol by modifying the route request and route reply packets. The admission control technique is based on the estimation of bandwidth utilization of each traffic class, with the constraint that the delay requirement of real-time flows should be satisfied.

2. Related Works

Goyal and Sahoo [2] have proposed an efficient algorithm for computing extra bandwidth request for RTPS service class which performs much better in terms of average packet delay and packet drop percentage compared to some simple algorithms.

Nahle and Malouch [8] have proposed a joint routing and scheduling algorithm for improving the performance of WiMAX mesh networks in terms of throughput. Their routing algorithm selects highest end-to-end data rate paths for maximizing the network capacity. Also their scheduling algorithm ensures best scheduling on the selected links for maximizing network utilization, and guarantees fairness as well. In their work, although they do not account for interference, they enhance the capacity of the network. Nevertheless, they believed that their proposed joint algorithm helps reducing interference, since shorter links are chosen which means that lower power is needed.

Prasad and Kumar [12] have proposed to design an adaptive power efficient packet scheduling algorithm that provides a minimum fair allocation of the channel bandwidth for each packet flow and additionally minimizes the power consumption. In the adaptive scheduling algorithm, packets are transmitted as per allotted slots from different priority of traffic classes adaptively, depending on the channel condition. Suppose if the buffer size of the high priority traffic queues with bad channel condition exceeds a threshold, then the priority of those flows will be increased by adjusting the sleep duty cycle of existing low priority traffic, to prevent the starvation.

Hong *et al*. [4] have considered the QoS problem for routing and scheduling in TDMA-based Wireless Mesh Backhaul Networks (WMBN). They proposed an integrated routing and scheduling mechanism to provide QoS guarantees to real-time services with unrestricted topologies for TDMA based WMBN. They also devised a linear programming optimization to solve the amount of non-collision bandwidth for a path according to the available resource and the interference.

Nie *et al.* [10] have proposed a Two Level Scheduling (TLS) scheme with support for quality of service and fairness guarantees for downlink traffic in a WiMAX network. A central controller Base Station has a number of users, and each mobile subscriber station has different channel conditions. The same mobile subscriber station may have different service requirements at different times in the WiMAX network.

Ravichandran *et al*. [14] have provided a better solution for CAC using Fuzzy logic concept which improves the Admission Control (AC) of calls by classifying the input under various classes. Also they considered the performance metrics such as call dropping probability and call blocking probability. They classified all data traffic into handoff real time (Class 1), new real time (Class 2), handoff non real time (Class 3), new non real time (Class 4) according to the different multimedia services and defined two parameters delay and probability of error as input fuzzy sets for each traffic class.

3. Proposed Joint Routing, Scheduling and Admission Control Protocol

3.1. Scheduling Technique

3.1.1. System Design

WiMAX system has five types of the traffic service, namely:

- Unsolicited Grant Service (UGS).
- Real Time Polling Service (RTPS).
- Extended Real Time Polling Service (ERTPS).
- Non- Real Time Polling Service (NRTPS).
- Best Effort (BE).

The traffic flow is categorized into the following 3 classes:

1. Class1 (UGS, rtPS and ertPS).
2. Class2 (nrtPS).
3. Class2 (BE).

Each node n_i maintains 3 queues q_{i1}, q_{i2} and q_{i3} for the traffic classes Class1, Class2 and Class3 respectively. Each node shares the queuing information with other nodes within the communication range in control frame of the 802.16e. A Channel Condition Estimator (CCE) monitors the channel periodically and estimates the channel state error SINR. If there is no channel error, then resources are scheduled as per their priority of traffic classes. If there is a channel error, then:

- Precede the transmission if the node has Class1 packets.
- Otherwise, the transmission is stopped and the allotted slots are assigned to other neighboring nodes.

To minimize power consumption of a Mobile Station (MS) with multiple real-time connections, we have to determine the length of a sleep period and a listen period under the radio resource and QoS constraints. Considering a mobile station j with N real-time connections, the QoS parameters of connection i can be denoted as:

$$Qji\{Ps_i, AT_i, D_i\}$$

Where:

- D_i is the delay constraint of any two consecutive packets for connection i.
- PS_i is the average packet size in bytes for connection i.
- ATi is the average inter packet arrival time in milliseconds for connection i.

These connections could be either downlink from a base station to a mobile station or uplink from a mobile station to a base station.

3.1.2. Channel Error Estimation

Here, we denote a communication link as l_i=(s_j, r_i), where s_j is the sender and r_i is the receiver node. According to our model, the Packet Reception Rate (PRR) experienced on link l_i, in the absence of interference, is given by $f(SNR_i)$, where SNR_i is the signal-to-noise ratio at node r_i. Formally, $SNR_i = \frac{P_i}{N}$ where P_i is the received power at node r_i of the signal transmitted by node s_i, and N is the background noise power.

In presence of multiple concurrent transmissions on links $l_1...l_k$, the PRR on link l_i=(s_j, r_i) is given by $f(SINR_i)$, where $SINR_i$ is the signal-to-noise-and interference ratio measured at r_i when all the $Sj'S$ are transmitting. Formally:

$$SNIR_i = \frac{P_i}{N + \sum_{j \neq i} P_j} \tag{1}$$

where P_j denotes the received power at node r_i of the signal transmitted by node s_j for each $j\neq i$.

3.1.3. Scheduling

In a Mobile WiMAX system, a mobile station can switch to sleep mode if there is no packet to send or receive in order to save power. The IEEE 802.16e defines three power-saving classes to accommodate network connections with different characteristics. According to the specification, each connection on a mobile station can be associated with a power-saving class, and connections with a common demand property can be grouped into one power-saving class. The parameters of a power-saving class, i.e., the time to sleep and listen, the length of a sleep period and a listen period can be negotiated by a base station and a mobile station [15].

When a mobile station establishes multiple connections with different insist properties, the sleep-mode behaviors associated with all connections are determined by the period that a mobile station can sleep. In multiple real-time connections, power consumption of a mobile station might not be reduced even in the sleep mode if there is no proper scheduling of the sleep mode operations. The station might have to stay awake in the listen period even if there is no packet available because the periodic power save scheme requires a fixed sleep and listen periods. For determining the sleep and wakeup cycles in a frame basis, a Non-Periodic (NP) scheme which has a variable length of sleep and listen periods should be applied. Whenever a connection is established or released on a MS, the BS activates this scheme to re-schedule the resources in the following frames for the mobile station.

All connections on a mobile station are checked to determine their traffic class and sorted according to their priority level. Within each class, the connections are sorted based on their request dead-lines. After the scheduler decides the scheduling priorities of connections, the packets from the first priority connection i from the node j are scheduled. Let $RBW_{ij}(K)$ be the requested bandwidth of the connection i of the node j in the k^{th} *OFDM* frame. Let TBW_j be the total available bandwidth in an *OFDM* frame of duration T_f to the node j. To schedule $RBW_{ij}(K)$ both the bandwidth and delay constraints are to be satified (i.e.,):

$$\text{If } RBW_{ij}(k)<TBW_j\text{-}ABW_j(m), m\geq k \quad (2)$$

$$\text{If } (m\text{-}k\text{+}1)\times Tf\leq DC_i \quad (3)$$

where $ABW_j(m)$ is the already allocated bandwidth for the node j for other connections in the m^{th} frame and DC_i is the delay constraint in milliseconds of any two consecutive packets for connection i.e., let $F\{RBW_{ij}\}$ be the set of feasible scheduling frames for RBW_{ij}. To assign the priority and select a frame $F_i\in F\{RBW_{ij}\}$ the following steps are followed:

1. If F_i is an in-used frame and if the resources of the in-used frames are still available to accommodate, RBW_{ij} high priority is assigned for F_i.
2. If there are two in-used frames F_i and F_j then the priority is assigned for min (F_i, F_j).
3. If F_i, i=1, 2…n are un-used frames, then priority is assigned for the last un-used frame F_n. This is because, if a latter frame can be selected, it gains more opportunities to serve other packets in the following *OFDM* frames.

After the above steps, RBW_{ij} is scheduled to the selected frame.

3.2. Bandwidth Estimation

Direct range is the area within transmission range and the indirect range is the area between transmission range and interference range. Number of competitive nodes is the total numbers of these two areas. The tables of Direct Range Members (DRM) and Indirect Range Members (IRM) are maintained by each node. First hop node gives the DRM and IRM can be determined from two or more hops or hidden nodes. Bandwidth of neighboring nodes can be obtained proactively or reactively. We use proactive approach here. In order to decrease collision and to deliver bandwidth information, every node issues a signal at its own defined interval which can be synchronized with the neighboring nodes. In order to collect neighboring nodes information, all neighboring nodes may send their own bandwidth data by one-hop with double power.

The proposed scheme should assure that without any congestion the interference range must have enough bandwidth to transmit data, and so local and neighboring nodes in the interference range should be identified precisely. Both local bandwidth and the bandwidth of all interference range nodes should be considered by a node while transmitting data. In our proposed system, a special signal is sent at a predefined interval with double power and signals from the neighboring nodes are collected, in order to update DRM and IRM tables.

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:

$$L_{BW}=C_{BW}\ X\frac{idle_t}{\text{int}_t} \quad (4)$$

where C_{BW} denotes the channel capacity, idle_t denotes the idle time in a predefined interval int. 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:

$$R_{BW}=NM_{BW}-L_{BW} \tag{5}$$

3.3. Requested Bandwidth Estimation

Let N and F_L be the session duration and frame length respectively. Let the traffic arrival rate be TRj (bps) and packet size is b_i bits. When a traffic flow wants to establish a connection with *BS*, it sends parameters TR_i, and b_i to the *BS* and waits for the responses from *BS*. An extra parameter, delay requirement $Dreq_i$, will be sent by *rtPS* flows. In order to meet delay requirement of *rtPS* packets, packets generated at time t must start to send after K_i=1 frames after t, where:

$$k_i = \frac{Dreq_i}{F_L} \tag{6}$$

If data rate is bigger than TR_i, these b_i bits can be shared by k_i-1 frames before deadline. Therefore, our estimation of the data volume in a time frame is:

$$(TR_i * F_L) + \frac{Dreq_i}{k_i - 1} \tag{7}$$

And, the expected bandwidth of the flow is estimated as:

$$TR_i + \frac{Dreq_i}{(k_i - 1) * F_L} \tag{8}$$

Let N_{rtPS} be the number of *rtPS* connections, BW_{req} be the bandwidth required by all *rtPS* connections, we can know that BW_{req} can be calculated as:

$$BW_{req} = \sum_{i}^{N_{rtPS}} (TR_i + \frac{Dreq_i}{(k_i - 1) * F_L}) \tag{9}$$

3.4. Connection Admission Control

In order to avoid starvation of some traffic classes, we set a threshold of bandwidth used for each class. They are:

$$T_{UGS}, T_{rtPS}, T_{nrtPs}, \text{ and } T_{BE},$$
$$T_{UGS}+T_{rtPS}+T_{nrtPs}+T_{BE+}BW_{Tot}, \tag{10}$$

where BW_{Tot} is the total bandwidth. When the bandwidth occupied by a class is more than its threshold, this class will have lower priority to the bandwidth resource. For the three flows, TR_i, the token rate, will be used to estimate bandwidth. Our *CAC* algorithm is as follows:

Algorithm:

1. *Calculate the residual bandwidth BW_{res} and requested bandwidth BWreq using 5 and 9, respectively.*
2. *If $BW_{req} < BW_{res}$ then*
   Accept the new flow
   Else
3. *If $BW(nrtPS) > Th_{nrtPS}$ and $BW(BE) > Th_{BE}$*
   Allocate less time slots
   Go to step 2.
4. *Else if then $BW(rtPS)>Th_{rtPS}$ and $BW(UGS)>Th_{UGS}$*
   Degrade Tr_i of UGS and rtPS
   Go to step 2
   Else
5. *Reject new flow.*
   End if.
   End if.
   End if.

In the above algorithm, step-5 refers to the "Stealing bandwidth from upper class". Stealing bandwidth from upper class may be an issue. Stealing bandwidth from BE and nrtPS flows is relatively simple. We can easily decrease the bandwidth used by them because of they are not real-time flows. To steal bandwidth from the other two real-time classes, we will choose some connections of these two classes and degrade their TR_i, e.g., make TR_i to be C•TR_i, where 0<C<1.

3.5. Route Discovery Process

The proposed bandwidth allocation scheme can be applied to any on-demand routing protocols such as Ad-hoc on Demand Distance Vector (AODV) and Dynamic Source Routing (DSR). We apply our scheme to the AODV routing protocol by modifying the Route Request (RREQ) and Route Reply (RREP) packets.

3.5.1. 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 ID_S 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_j 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

3.5.2. 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.
- MLA_{BW}: Is the minimum available bandwidth.
- *V:* Is a vector comprising combined ID_S 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:* Inter-mediate node.
- *d:* Destination node.

Steps:

1. *Destination node sends the modified RREP packet.*
2. *Intermediate node n_j 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.
5. *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 correctness of bandwidth estimation has a remarkable effect on system performance. If the estimated bandwidth is less than that of network capacity, the AP will reject the flows which are below the capacity of network. On the other hand, if the estimated bandwidth is greater than that of network capacity, the AP admits a flow whose bandwidth consumption is beyond the capacity of network which will degrade the whole system performance. To obtain the best result, we should minimize the difference of estimated bandwidth and capacity of the network.

4. Simulation Results

4.1. Simulation Model and Parameters

To simulate the proposed scheme, Network Simulator (NS2) [9] is used. The proposed scheme has been implemented over IEEE 802.16 MAC protocol. In the simulation, clients (SS) and the BS are deployed in a 1000meter×1000meter region for 50seconds simulation time. All nodes have the same transmission range of 250meters. In the simulation, the video traffic (VBR) and CBR traffic are used. The simulation settings and parameters are summarized in Table 1.

Table 1. Simulation settings.

Area Size	1000×1000
Mac	802.16
Clients	2,4,6,8 and 10
Radio Range	250m
Simulation Time	50 sec
Traffic Source	CBR, VBR
Video Trace	JurassikH263-256k
Physical Layer	OFDM
Packet Size	1500bytes
Frame Duration	0.005
Rate	2,4,6,8 and 10Mb
Error Rate	0.01,0.02,….0.05

4.2. Performance Metrics

We compare our proposed our Joint Routing, Scheduling and Admission control Protocol (JRSAP) scheme with the Interference-aware Multi-path Routing and Bandwidth Allocation (IMRBA) scheme [2]. 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 number of packets received successfully
- *Average End-to-End Delay:* The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.
- *Blocking Probability:* It is the ratio of number of requests rejected to the total number of requests.
- *Bandwidth Received:* It is the average received bandwidth in Mb/sec.

The performance results are presented in the next section.

4.3. Results

4.3.1. Effect of Varying MSS

In our first experiment, the number of MSS is varied as 2, 4, 6, 8 and 10 and we measure the channel utilization, throughput, energy, end-to-end delay and blocking probability.

Figure1 shows the channel utilization obtained, when the number of MSS is varied. It shows that JRSAP has better utilization than the IMRBA scheme.

Figure 2 shows the throughput obtained with our JRSAP scheme compared with IMRBA scheme. It shows that the throughput of JRSAP is more than the IMRBA, as MSS increases.

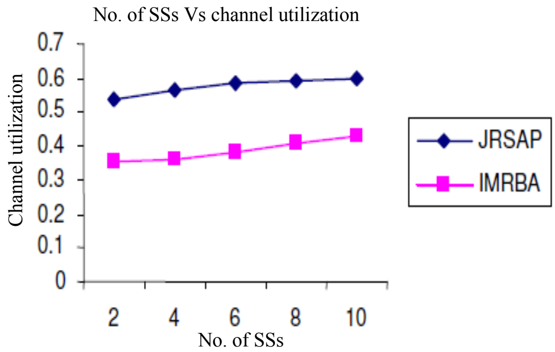

Figure 1. MSS Vs utilization.

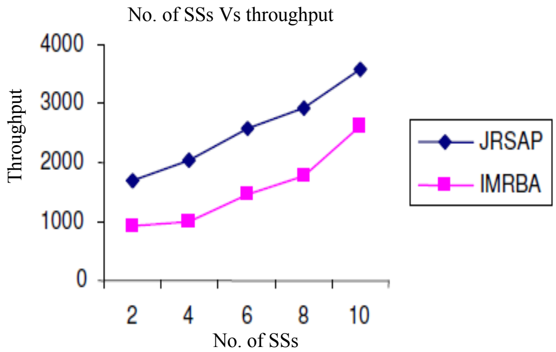

Figure 2. MSS Vs throughput.

Figures 3 and 4 shows the delay of CBR and VBR traffic occurred, when MSS is varied. It shows that the delay of JRSAP is significantly less than the IMRBA scheme for the both the traffics.

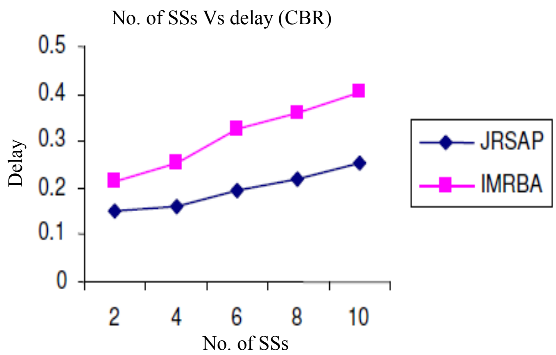

Figure 3. MSS Vs delay (CBR).

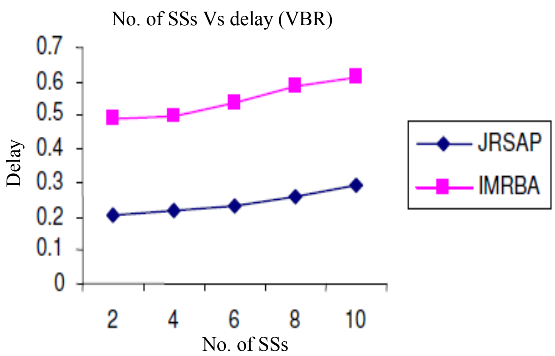

Figure 4. MSS Vs delay (VBR).

Figure 5 show that the blocking probability is more for IMRBA when compared with our proposed JRSAP scheme.

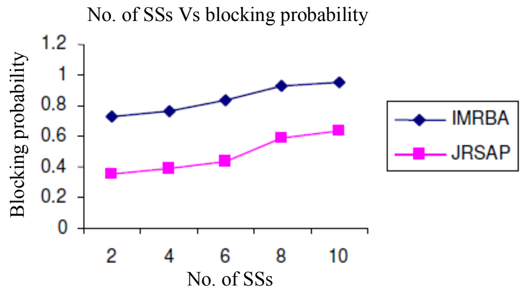

Figure 5. MSS Vs blocking probability.

4.3.2. Effect of Varying ErrorRate

Normally, when the channel error rate is increased, the channel utilization of all the flows will tend to decrease. As it can be seen from the Figures 6 and 7, the utilization of all the flows slightly decreases, when the error rate is increased.

Figures 6 and 7 shows the channel utilization for CBR and VBR traffics obtained for various error rates. It shows that JRSAP has better channel utilization than the IMRBA scheme.

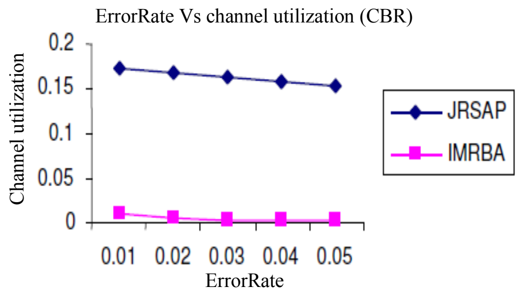

Figure 6. ErrorRate Vs utilization (CBR).

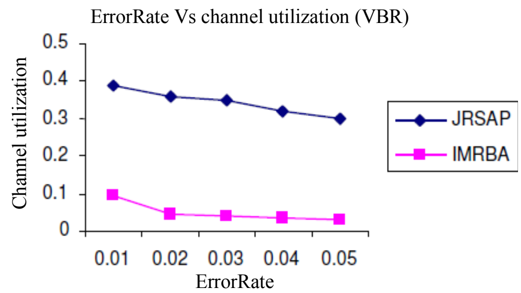

Figure 7. ErrorRate Vs utilization (VBR).

Figures 8 and 9 shows the delay for the CBR and VBR traffics occurred for various error rates. It shows that the delay of JRSAP is significantly less than the IMRBA scheme.

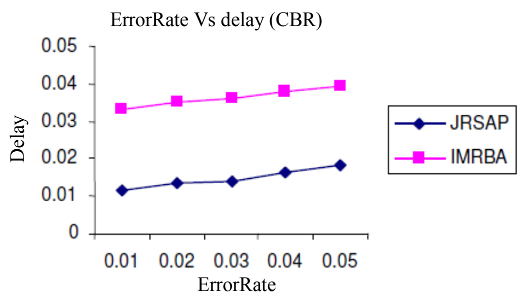

Figure 8. ErrorRate Vs delay (CBR).

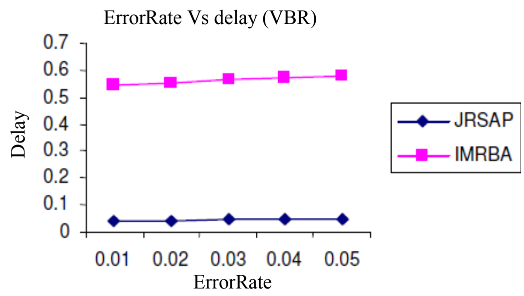

Figure 9. ErrorRate Vs delay (VBR).

4.3.3. Effect of Varying Rate

Figure 10 show that the bandwidth utilization is more for our proposed JRSAP when compared with the IMRBA scheme.

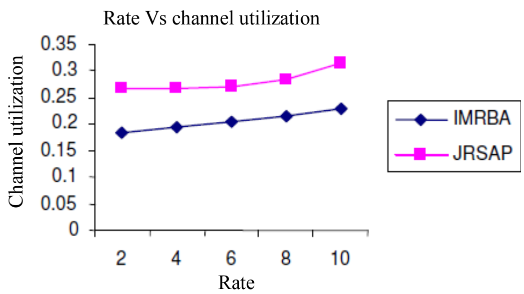

Figure 10. Rate Vs utilization.

Figure 11 shows that the bandwidth received is more for our proposed JRSAP when compared with the IMRBA scheme. From Figure 12 it is clear that the delay for our proposed JRSAP scheme is less when compared with the IMRBA scheme.

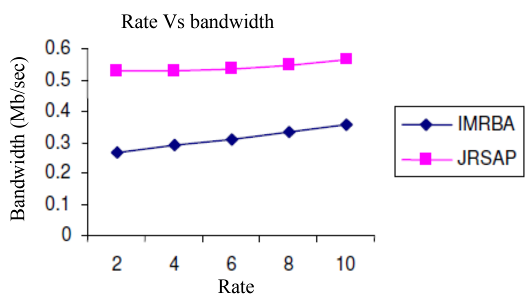

Figure 11. Rate Vs bandwidth received.

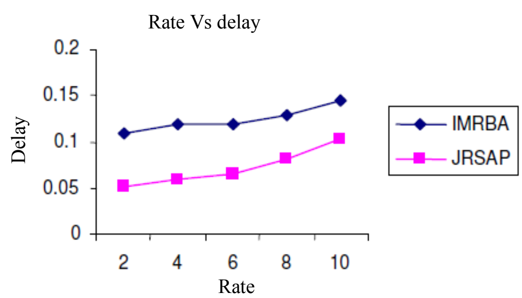

Figure 12. Rate Vs delay.

4.3.4. Effect of Varying Class

In our experiment we vary the classes: UGS, rtPS, nrtPS and BE, as 1, 2, 3 and 4. From Figure 13 it is clear that the delay for our proposed JRSAP scheme is less when compared with the IMRBA scheme. Figure 14 show that the blocking probability is more for IMRBA when compared with our proposed JRSAP scheme.

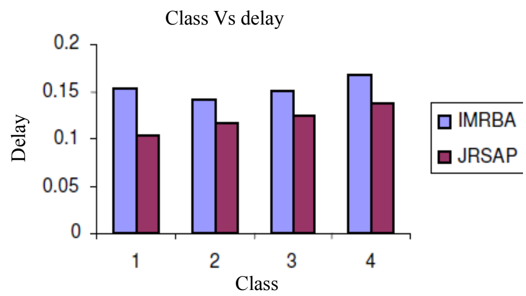

Figure 13. Class Vs delay.

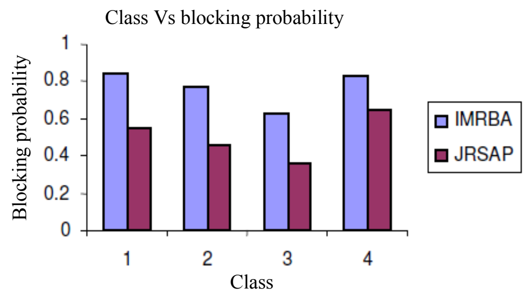

Figure 14. Class Vs blocking probability.

5. Conclusions

In this paper we have designed a joint routing, scheduling and admission control protocol for WiMax networks. In the adaptive scheduling, packets are transmitted as per allotted slots from different priority of traffic classes adaptively, depending on the channel condition. A bandwidth estimation technique is combined with route discovery and route 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. The admission control technique is based on the estimation of bandwidth utilization of each traffic class, with the constraint that the delay requirement of real-time flows should be satisfied. The current available bandwidth is estimated for all the nodes and for the new incoming flows, it estimates the requested bandwidth and decides to admit this new flow or not. By simulation results, we have shown that our proposed protocol achieves better throughput and channel utilization while reducing the blocking probability and delay.

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