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VARIABLE QUANTUM DEFICIT ROUND ROBIN SCHEDULING FOR IMPROVED FAIRNESS IN MULTIHOP NETWORKS

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ABSTRACT

To increase the coverage area, Multichip WiMAX networks are particularly useful without the need to deploy expensive base stations. One of the most common variants in Multihop WiMAX is the Wireless Mesh Networks.Scheduling algorithms for WiMAX has been a topic of interest for a long time since the very inception of WiMAX networks. Though a lot of literature is available for scheduling in point–to-multipoint (PMP) networks, relatively less emphasis has been on scheduling in Multihop networks. One problem inherent with Multihop networks is unfairness between users with different service class types. This problem is even worse with real time bursty traffic. This necessitates the need for a scheduling algorithm that allows a fair share of resources among the users. In this work, we propose a vqDRR based scheduling mechanism that provides Quality of Service while at the same time maintaining fairness among users in a Multi-hop networks. We compare the performance of the proposed algorithm with the fair distributed credit based scheduler in terms of latency, throughput utilization and fairness.

KEYWORDS

Quality of Service, Scheduling, fairness, WiMAX & Multihop

1. INTRODUCTION

IEEE 802.16, popularly known as WiMAX, is at the forefront of the technology drive because of the growing demand for high-speed wireless broadband networks. Adding multihop technology increases the coverage area of WiMAX networks without the need to deploy expensive base stations. A multihop WiMAX network may also lead to increased user throughput as more efficient modulation techniques can be used over shorter links [1].

In WiMAX, the MAC layer at the Base Station (BS) is fully responsible for allocating bandwidth to all users, in both the uplink and the downlink. The traffic from the Base Station (BS) to the Subscriber Station (SS) is classified as downlink traffic while that from the SS to the BS is classified as uplink traffic. The MAC is connection-oriented, which means that all services are mapped to a connection identified by a 16-bit connection identifier (CID). The downlink subframe sent by the BS contains the DL-MAP and UL-MAP. The DL-MAP specifies the downlink channel access and the associated burst profile. The UL-MAP defines the uplink channel access, that is, the time slot in which the SS can transmit in the uplink subframe and the uplink data burst profiles.

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Scheduling is a critical component impacting significantly on its performance. Scheduling schemes helps in providing service guarantees to heterogeneous classes of traffic with different QoS requirements. A task of a scheduling algorithm in a multi-class network is to categorize the users into one of the pre-defined classes. Each user is assigned a priority taking into account its QoS requirements. Subsequently, bandwidth is allocated according to the priority of the users as well as ensuring that fairness between the users is maintained. Fairness refers to the equal allocation of network resources among the various users operating in both good and bad channel states. In general, a scheduler for WiMAX needs to be simple, efficient, fair, scalable, and have low computational complexity.

It is observed that the existing schedulers do not perform effectively with respect to real time traffic for multihop networks. In addition, each of the traffic classes has a different scheduling requirement and, consequently, it has become necessary to design appropriate scheduling frameworks. In this work, we propose a scheduler based on the arrival rates and the current queue information that can handle real time bursty traffic efficiently and at the same time ensures fairness between users.

In the rest of the article, Section II gives a brief overview of IEEE 802.16 Point-to-Multipoint (PMP) mode. Section III describes WiMAX mesh and Section IV describes the aggregation tree construction, Sections V describes the previous work, Section VI discusses the proposed mechanism that addresses scheduling for improved fairness in multihop WiMAX Networks. We also describe simulation results in Section VII and Section VIII concludes.

2. OVERVIEW OF IEEE 802.16

The basic architecture of IEEE 802.16 is similar to that of cellular networks. In a particular region, there is a Base Station (BS) and multiple Subscriber Stations (SSs). IEEE 802.16 Point-to-Multipoint (PMP) mode is a star-shaped network where every SS communicates directly with the BS. IEEE 802.16 standard defines the physical layer (PHY) and the data link layer which are the bottommost layers of the protocol stack ([2], [3]).

IEEE 802.16 in PMP mode defines five types of scheduling services [4] to support quality of service. They can be classified as Unsolicited Grant Services (UGS), Real-time Polling services (rtPS), extended Real-time Polling services (ertPS), non Real-time polling services (nrtPS) and Best Effort (BE).

Application of Unsolicited grant services (UGS) is Voice over IP (VoIP) without silence suppression. The mandatory service flow parameters that define this service are maximum sustained traffic rate, maximum latency, tolerated jitter, and request/transmission policy.

Applications of Real-time Polling service (rtPS) are Streaming audio and video, MPEG (Motion Picture Experts Group) encoded. The mandatory service flow parameters that define this service are minimum reserved traffic rate, maximum sustained traffic rate, maximum latency, and request/transmission policy.

Application of Extended real-time (ertPS) is VoIP with silence suppression. The mandatory service flow parameters are guaranteed data rate and delay.

Application of Non-real-time Polling service (nrtPS) is File Transfer Protocol. The mandatory service flow parameters to define this service are minimum reserved traffic rate, maximum sustained traffic rate, traffic priority, and request/transmission policy.

Applications of Best-effort service (BE) are Web browsing, data transfer. The mandatory service flow parameters to define this service are maximum sustained traffic rate, traffic priority, and request/transmission policy.

Different connection management strategies have been proposed, but the most common one is of management connections first, real-time connections followed by non-real time connections and finally Best Effort connections.

3. WIMAX MESH

A mesh network consists of a mesh BS and multiple SSs. In contrast to the PMP mode, a SS can be multiple hops away from the BS in the mesh mode and may communicate with the BS with the help of intermediate nodes. Figure 1 shows a mesh network.

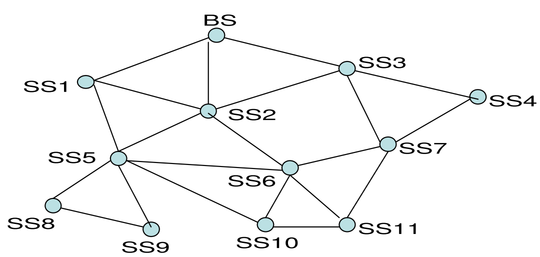


Fig.1 Wimax Mesh topology

IEEE 802.16 defines a new mesh frame format. A Mesh frame is addressable by a 12-bit frame number and is divided into a number of minislots. Each frame consists of a control subframe and data subframe. The control subframe may be a network control subframe or a scheduling control subframe. The network control subframe is used to send network control messages like MSH-NENT and MSH-NCFG that enable new nodes to join a mesh. The scheduling control subframe is used for sending centralized scheduling messages like MSH-CSCF and MSH-CSCH. Scheduling control subframe may also be divided into transmission opportunities where distributed scheduling messages (MSH-DSCH) are sent. The network control subframe is repeated periodically after a few scheduling control subframes. The data subframe is used for transmitting data packets and some distributed scheduling messages.

There are two mechanisms by which data transmissions can be scheduled in the mesh mode - centralized and distributed. Scheduling is done so that there are no collisions during the transfer of data in the data subframe. In centralized scheduling, the BS determines how the SSs should share the channel in different time slots. The scheduling procedure is simple; however the connection setup delay is significant. Hence centralized scheduling is not suitable for occasional traffic needs. In distributed scheduling, the nodes themselves determine the schedule of data transmissions without the help of the BS. Therefore, distributed scheduling is more flexible and efficient for connection setup and data transmission. Distributed scheduling may be coordinated or uncoordinated. In coordinated distributed scheduling, every node competes for channel access using a pseudo-random election algorithm based on scheduling information of two-hop neighbors. MSHDSCH messages are sent during the scheduling control subframe to set up the schedule. Uncoordinated distributed scheduling uses "idle" slots in the data subframe to determine the schedule of data transmissions. In both cases, data subframe is allocated based on request-grant-confirm three-way handshaking among the nodes.

4. AGGREGATION TREE CONSTRUCTION:

In order to analyze the impact of the structure of the aggregation tree on the available bandwidth for each flow, we look at multi-stream aggregation for a simple grid network shown in Figure 2.

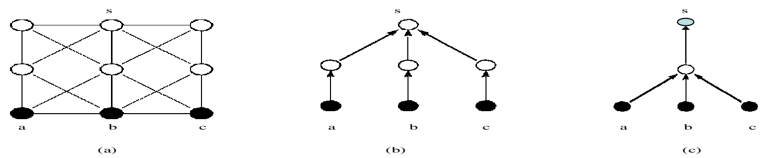


Fig. 2. Example to depict that the aggregate throughput of all contending flows is same no matter where they merge (a) Connectivity Graph.Two instances of aggregation tree: (b) &(c).

Nodes a, b and c are the source nodes and s is the tree root [5]. Consider two trees shown in Figure 2(a) and Figure 2 (b) depicting two different sets of routes for the each flow from source to root node. For the first case (Figure 2 (b)), there are 6 competing transmitters and each get equal share of the channel capacity (i.e. C/6). So the maximum achievable aggregate throughput at the root is 3 * C/6 = C/2.

For the second case(Figure 2 (c)) where the three flows merge before reaching the root, there are only 4 transmitter and thus every node now gets 1/4th share of the channel bandwidth. Thus the aggregate throughput at the root is C/4. But if the sources are restricted to send at a rate C/6, then the intermediate relay node gets to use the remaining channel time i.e. C/2 and the aggregate throughput is same as in case 1. Thus with flow control, merging two or more contending flows does not impact the aggregate throughput.

5. PREVIOUS WORK

A significant amount of work has already gone into scheduling disciplines that provide delay guarantees and fairness. Time stamp scheduler essentially uses the idea of assigning time stamps to packets and then transmitting the packets in some order that achieves fairness. WFQ [6] and WF2Q [7] algorithms fall into this category. However, both of the schemes require a reference with the GPS server to be maintained. Variants of WFQ include Self-Clocked Fair Scheduling [8] and Virtual Clock [9], which do not need to maintain a reference GPS server and hence can compute the time stamp in a more efficient way. Though time stamp schedulers have good delay properties, their processing time is quite high.

Round-robin schedulers [10] [11] are the other broad class of work-conserving schedulers. These schedulers typically assign time slots to flows in some sort of round-robin fashion. Though they have better complexity compared to packet schedulers, however they have poor delay characteristics, particularly for packets of varying sizes. There is another class of algorithms that try to combine the tight delay bound of time stamp based schedulers and the low time complexity of round robin based schedulers. They usually adopt a basic round robin like scheduling policy plus time stamp based scheduling on a reduced number of units [12]. Bin Sort Fair Queuing [13] is based on arranging packets into different bins based on their time stamps and scheduling in a FIFO manner.

Stratified Round Robin [14] uses the round robin approach for inter-class scheduling and the time stamp approach for intra-class scheduling after grouping flows into respective classes. Recently proposed algorithms like ADRR [15] enhance the deficit round robin scheduling discipline by taking into account the channel quality experienced by the transmitting node. The ADRR scheduler is designed to achieve performance isolation among links characterized by heterogeneous channel conditions. In the DRR scheme, Stochaic fair queuing is used to assign flows to queues. For servicing the queues, Round-robin servicing is used, with a quantum of service attached to each queue. It differs from the traditional Round-robin in that if a queue is unable to send a packet in the previous round because a packet was too large, the remainder from the previous quantum is added to the quantum for the next round. Queues that are not completely serviced in a round are compensated in the next round. However, once a flow is serviced, irrespective of its weight, it must wait for $N-1$ other flows to be serviced until it is serviced again. Also, during each round, a flow transmits its entire quantum at once. As a result, DRR has poor delay and burstiness properties.

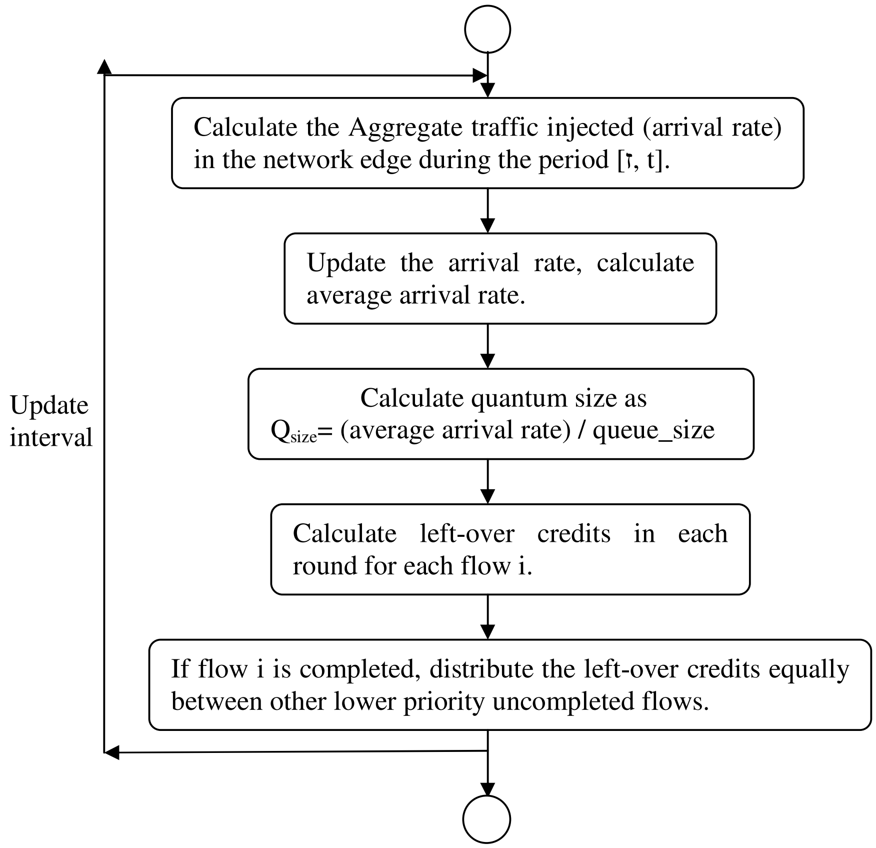
Two credit based scheduling schemes with enhancement to the basic DRR, are Fair distributed credit based scheduling scheme (FDCBSS) and Selfless distributed credit based scheduling scheme (SDCBSS) [16]. The first one is based on distribution of excess credits equally between all higher priority flows while the other proposed scheme is based on distribution of excess credits to the highest priority flow which is yet to be completed. These schemes are used to schedule flows between two classes of flows, real-time and non real-time flows.

6. PROPOSED MECHANISM (vqDRR)

One of problems that still remain open in the DRR scheduling is determining the value of quantum size to be chosen for effective occupancy of the queue. The choice of a fixed quantum size is agreeable if the arrival rates remain more or less constant over the scheduling period. However, problems arise if the traffic is bursty and the arrival rates vary rapidly. Too large value for quantum size will result in wastage of the service if the arrival rate drops down. On the other hand too small values for the Quantum size may not be adequate to serve the packets in a queue adequately.

Further, the scheduling mechanisms considered in previous works fail to address scheduling with Multihop networks effectively. This is due to the fact that in Multi-hop networks, the problem is that the Base Station has smaller arrival rates from mobile nodes far away while the rates are more for nodes nearby. In such a case, with a scheduling scheme such as the Round Robin Scheduling, choice of a fixed quantum size is undesirable. The condition is even severe if the traffic is real time and bursty or unsteady in nature. Under such circumstances, it is inevitable that the quantum size be adjusted in accordance with the traffic conditions.

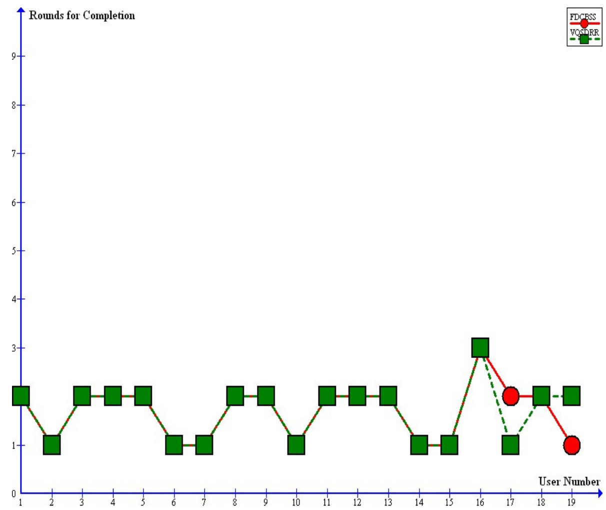
In this work, we propose a scheduler at the Subscriber Station that can handle real time bursty traffic efficiently and at the same time ensures fairness between users. The average arrival rate is calculated periodically based on the number of hops of the user from the base station, burstiness of the traffic, and the current and the previous arrival rates and the quantum size adjusted accordingly. Once the quantum size has been determined, the scheduler operates as in FDCBSS, wherein the completed flows distribute any left-over credits equally among subsequent flows which are yet to be completed. The aggregate traffic [17] injected at a network edge during the interval $[\tau, t]$ is given as $A_s(\tau, t) \leq \alpha\, r_s\ (t - (\tau + \beta\, r_s$ Where $\alpha \leq 1 / (H^{*}-1)$ where H is the number of hops in the longest path for the network. r_s is the reserved traffic rate β is the burstiness of the traffic. Here $A_s(\tau, t) = \alpha * A_s(\tau, t) + (1 - \alpha)\ A_{s}\_Current(\tau, t)$ where $A_s(\tau, t)$ is the average arrival rate and $A_{s}\_Current$ is the current arrival rate of the traffic over the period $[\tau, t]$.The value of α is set to 0.3 after extensive simulations. This provides better estimates for the actual arrival rates service time. The algorithm is as follows:



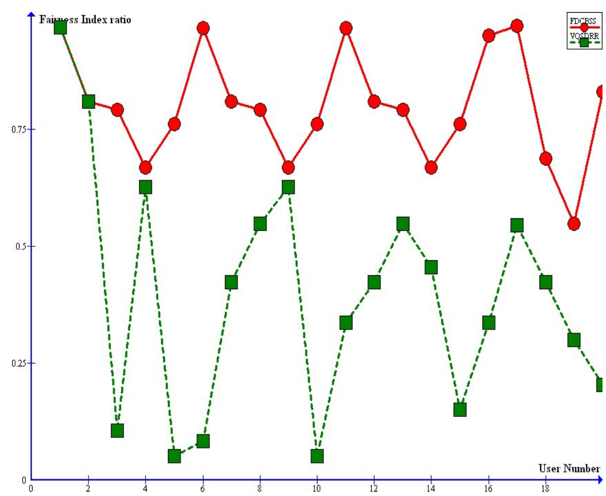
7. SIMULATION RESULTS

A custom simulator written in java is used in this work. The simulation runs in two threads – variable quantum based scheduler and fixed quantum scheduler. Both these modules can be run either concurrently or independently. Simulation has been carried out on 20 queues, each containing maximum packets of variable size, for different quantum sizes for 20 seconds and the results have been evaluated. The packets are generated according to Poisson arrival process. The number of flows is limited in this work so that the sum total of their minimum bandwidth requirements matches the maximum capacity of the network.

As simulation parameters, Maximum quantum size was chosen to be 250, the number of hops 'H' to be 5, burstiness of the traffic 'β' was chosen as 4. Frame duration was 20 ms with FFT size 1024 and QPSK ½ modulation was employed. The fairness index ratio is defined as FI = $(Th_{max} - Th_{min}) / Th_{max}$. A higher value of throughput index and a smaller difference in maximum and minimum throughputs implies a small value for FI, which is desirable.



Graph 1: Rounds of two schedulers



Graph 2: Fairness Index of two Schedulers

The algorithm proposed has shown reasonable improvement in terms of fairness of the flows at the expense of few increased rounds (the delay or latency) which makes it suitable for bursty traffic such as real time traffic in multihop networks.

8. CONCLUSION

It is observed from the results, this technique perform better compared to the Fair distributed credit based scheduling scheme in [16]. As in [16], in our method, any excessive idle bandwidth is reallocated to avoid wasting of available transmission capacity. However, the quantum size is adjusted based on the arrival rate, number of hops etc with the aim to improve the fairness at a slight expense of delay, since with multiuser real time flows, fairness is one of the prime considerations, while reducing the delay was the main objective in [16]. Performance metric such as fairness of the proposed scheduling algorithm, showing the effectiveness of our approach compared to other scheduling algorithms.

Scheduling in Mobile Multihop Relay (MMR) networks, while maintaining the backward compatibility with the legacy 802.16e mobile stations is an area that demands further research.

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