Performance Evaluation of Cross-layer Qos Framework for WiMAX Mesh Networks

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Abstract

Due to current advances in technology, broadband wireless networks are increasing in popularity. For large area network deployment, IEEE 802.16 mesh networks can provide a wide area, high speed and high quality multimedia service. IEEE 802.16 mesh configuration eliminates the need to have a direct link between subscriber stations (SSs) and the base station (BS) and a node can choose the links and path of the highest quality to transmit data and avoid the congested area. To provide a better QoS service over the 802.16 network, layer 3 (L3) and layer 2 (L2) QoS services must be integrated. Therefore, cross-layer mechanisms were designed in our previously proposed IEEE 802.16 QoS frameworks. To compare and identify our proposed cross-layer scheme to traditional two scheduling schemes is a very important part for performance evaluation, so this paper tries to address more simulation to identify the difference. The result of the performance evaluation also demonstrates that our proposed framework scheme has higher throughput, lower delay and signal cost than comparable systems.

Keywords: *IEEE 802.16, WiMAX, Mesh, QoS*

1. Introduction

The IEEE 802.16 working group has launched a standardization process called the *Wireless Metropolitan Area Network (Wireless MAN^{TM})*. To provide long distance wireless network access, the IEEE 802.16 tries to achieve for different physical frequencies. Its purpose is to facilitate the optimal use of bandwidth 2-66 GHz as well as the interoperability among devices from different vendors. According to the standard, 2 to 11 GHz and 10 to 66 GHz band, there are two defined versions of 802.16a and 802.16c respectively. The 10-66 GHz bands, can provide a high data rate up to 134 Mbps between two devices within radio *LOS (Line-of-sight)*, while the 2-11 GHz bands, (both licensed and license-exempt, are addressed in IEEE Project 802.16a initially) now released specification of 802.16 (IEEE Std 802.16-2004/d [10]) focuses on fixed location wireless access and supports up to 75 Mbps bit rate within radio *NLOS (Non-line-of-sight)*. Moreover, there is the proposed new 802.16 standardization interface named 802.16e [11], which supports wireless access with high mobility and has also been completed lately. It provides one of the potential solutions to B3G/4G architecture. The *WiMax Forum (Worldwide Interoperability for Microwave Access)*, a wireless industry consortium with about 100 members including major vendors such as *AT&T, Fujitsu, Intel,* and *Siemens Mobile*, is supporting 802.16 technology and promoting its commercial use, which means 802.16 is becoming the most important technology in the *broadband wireless access (BWA)*.

The basic *PMP (Point to Multipoint)* configuration of an 802.16 network consists of a *base station (BSs)* and a couple of *subscriber stations (SS)* that connect to the BS via a high-speed wireless link, as illustrated in Figure 1 (a). The BS acts as a gateway to the Internet. Legacy LANs or even more complex subnet systems can connect to the 802.16 network via SS. An 802.16 network (including the Legacy LANs that connect to the SS) can cover a large geographical area since the distance between the BS and the SS can be up to 30 miles (in the case of 802.16-2004). In this paper [13], the research has adopting simulation tool to present the performance of IEEE 802.16 PMP network. On the other hand, as an extension of the 802.16 PMP configuration, the 802.16 mesh mode provides options for SSs to choose the link to the BS or other SSs, and the structure is shown in Figure 1 (b).

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There are two basic mechanisms to schedule data transmission in the IEEE 802.16 mesh network [10] - centralized and distributed scheduling. In centralized scheduling, the BS works like the cluster head and determines the time slot allocation of each SS. In order to transmit data packets, the SS is required to submit the request packet (Layer 2 frame namely *BW-REQ*) to the BS via the control channel. The BS grants the access request by sending the slot allocation schedule called the *UL_MAP* (uplink map for slot access) to all SS nodes. Since all the control and data packets need to go through the BS, the scheduling procedure is effortless, but a longer path in the Mesh network is inevitable. In centralized scheduling-based research works [3][14], different scheduling and routing mechanisms were proposed to improve the performance by lowering the interference of routes and reducing the congestion near the hotspot of the BS. However, longer path creates more link consumption, which further causes a significant decrease in network utilization. For designing QoS mechanisms, most of the centralized-based research works [9][16] are focused on the construction of the routing tree based on different QoS types. For real time traffic, they proposed the idea of different proportion to divide the control sub-frame and the data sub-frame in the article [7]. It is well accepted that the centralized control manner is helpful to simplify bandwidth allocation. But the reduction of performance impact of centralizing scheduling in QoS supporting is rarely addressed in the literature.

On the other hand, in distributed scheduling, every node competes for channel access using the *pseudo-random election* algorithm based on the scheduling information of the two-hop neighbors. Distributed scheduling is more flexible in terms of route selection (e.g. the shortest path route can be used) at the cost of higher signaling overhead for the exchange of scheduling information. Some research works [2][12] focused on the improvement of the throughput by modifying the original distributed access scheme, and some articles [8][15] tried to identify and model the effect of parameters in distributed scheduling for assigning different traffic types to achieve QoS support. Considering QoS support for whole flow in 802.16 mesh network, these articles [1][4][5][17] wanted to reserve the whole flow path bandwidth in mesh network with distributed scheduling beforehand to avoid the SSs 2 hop competition exceed in each data packet transmission. Despite the performance benefit of distributed scheduling over centralized scheduling, the complicated behavior of distributed scheduling makes it difficult to provide precise bandwidth allocation, which also makes it inappropriate in QoS support.

To support the QoS of the 802.16 mesh network, the following four necessary criteria must be satisfied:

(1) There must be QoS integrated signaling protocols between the IP layer and 802.16 layer.

(2) Because the IP layer and 802.16 MAC layer take different approaches for processing user traffic, there must be traffic mapping mechanisms between the two layers to provide traffic flow with the appropriate QoS service.

(3) To support the higher priority traffic flow, a different scheme should be used to achieve the traffic requirement such as a lower delay.

In this paper, we focus on the advanced QoS framework for IEEE 802.16 mesh network. We not only design a cross-layer framework, but also show the pros and cons at those QoS scheduling schemes. The simulation investigates the system effect of our proposed scheme, and leads to further discussion.

The rest of the paper is organized as follows. Firstly, we present the overall architecture as well as the novel features of the previous proposed QoS framework at the BS and SS in section 2. Secondly, key mechanisms in the proposed framework for QoS support in IEEE 802.16 mesh network are presented in section 3. Thirdly, simulation studies for performance evaluation and comparisons are presented in section 4. Finally, section 5 will conclude this paper.

2. Cross-layer QoS framework

As mentioned in section 1, there are both pros and cons in the basic centralized and distributed scheduling schemes for the IEEE 802.16 mesh network. The centralized scheduling scheme has the advantage of centralized control with better and more effective QoS support but suffers from a longer transmission path, which increases the consumption of link capacity. On the other hand, the distributed scheduling has the advantage of using shortest-path route but suffers from a larger signaling cost due to 2-hop neighbors competition for channel access. Therefore, we try to design a QoS framework that uses the advantages of the centralized and distributed scheduling schemes while avoiding their disadvantages as much as possible. In previous works [6], our briefly proposed QoS framework considered both L3 and L2 layers to design a cross-layer QoS support. Figure 2 displays the construction of the proposed QoS framework at the BS and SS nodes. The main idea behind the framework was that we take advantage of the centralized control on scheduling and route selection. However, our scheme avoided the longer transmission path by adopting the flow setup phase and maintaining routing information at each SS for QoS flows to provide more efficient route control.

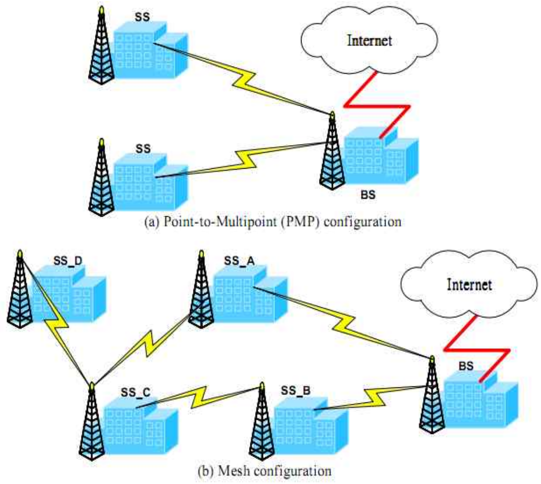

Figure 1. Two configurations in IEEE 802.16

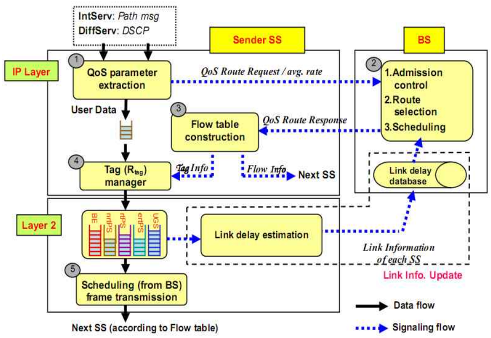

Figure 2. Cross-layer QoS framework

3. QoS mechanisms

The IEEE 802.16 standard provides the quality of service (QoS) required for successfully operating multimedia services in BWA systems. Five types of services are offered in IEEE 802.16 [11], namely, *Unsolicited Grant Service (UGS), extend real-time Polling Service (ertPS), real-time Polling Service (rtPS), non-real-time Polling Service (nrtPS),* and *Best Effort (BE)*. Among these, *UGS* is suitable for supporting real-time multimedia traffic, which requires sufficient bandwidth and minimal delay.

IEEE 802.16 does not include a specific scheduling algorithm for point-to-multipoint (PMP) or mesh modes [10]-[11] because neither mode is included in the mandatory modules required for standardized operation. To satisfy criteria 1, 2 and 3, a cross-layer framework should be constructed. In our previous work [6], some mechanisms with a cross-layer QoS framework were proposed, such as the QoS mapping rule, admission control policy, and routing tag construction. All the mechanisms can achieve QoS supporting and improve the performance in IEEE 802.16 mesh network.

4. Performance evaluation

4.1. Simulation environment and parameter

A simulation study has been conducted to evaluate the proposed routing and scheduling scheme. Two major contrasts are compared with our proposed schemes: centralized scheduling with routing via BS and distributed scheduling with minimal-hop-count routing. The IEEE 802.16 mesh network in the simulation is a 5x5 mesh and the BS is located at the center. Link capacity of the network is 20 Mbps by using Microsoft Visual C++ 6.0 on Windows XP. A time frame structure with 10 ms period is defined for slot allocation. Other parameters used in the simulation are displayed in Table 1.

There are total 25 flows (5 flows for each of the five service types) in each round of the simulation. Flows with ID 1~5 are UGS flows, ID 6~10 ertPS flows, etc., and a larger flow ID in each service type is assigned to the flow with a longer Euclidean distance between the source SS and the destination SS. The source SS and destination SS of each flow are randomly selected from the 802.16 mesh network. Three performance criteria are defined for comparison: (1) *Average delay (ms)* of data frames per hop

(SS), (2) *Average throughput (Mbps)*, and (3) *Average signaling cost (average number of signaling packets per time frame)*.

4.2. Performance comparison

As shown in Figure 3-Figure 5, for different service types under total data flow rates of 0.5, 2.5, and 5 Mbps, respectively, the *average delay* and the *delay variation* per hop in the proposed schemes are smaller than those in the centralized schemes and considerably smaller than those in the distributed scheme. For lower-priority nrtPS and BE, the centralized schemes show an exponential increase in delay when the data flow rate increases. To study the delay behavior in greater detail, we compared the end-to-end average delays of the different service types for total input flow rates ranging from 0.5 Mbps to 5 Mbps (Figure 6-Figure 10). Some of our observations and interpretations are as follows:

(1) The delay performance of the proposed schemes is better than that of the centralized schemes and considerably better than that of the distributed scheme.

(2) The poor delay performance of the centralized schemes can be attributed to the following two reasons: First, the longer path (all flow paths must go through the BS) used in these schemes increases the consumption of link capacity, which has an effect similar to that of an increase in input load. Second, the absence of *spatial reuse (SR)* in standard centralized schemes makes the effective network capacity smaller than that of our proposed scheme. Even if *SR* is incorporated to modify the centralized schemes, the longer path still degrades the delay performance, and the combination of a longer path and the absence of *SR* considerably degrade the delay performance of standard centralized schemes (w/o *SR*). The proposed scheme outperforms the distributed scheme to such an extent that even the distributed scheme has incorporated the minimal-hop-count route. The major reason is based on the data subframe allocation after the three-way handshake procedure; as per the *pseudo-random election* algorithm, only one SS can win the contention scheme between two hop neighbors. The distributed scheme needs more time to allocate a data slot to the winning SS, which results in a greater system delay due to a large number of losing SSs having data in the queue. It is worth noting that all the schemes proposed in this study exhibit almost the same delay performance even if different route selection rules are applied; this is because the rules are applied to a shorter path.

(3) The *average delay* for all the five schemes exponentially increases with the data flow rate in rtPS, nrtPS and BE, because the higher-priority traffic in UGS and ertPS is not saturated. However, the significant increase in the delay of the centralized schemes indicates that these schemes reach saturation at the SSs much earlier than the other three schemes. As mentioned above, the major reason is based on the routing mechanism used in the centralized schemes.

(4) Our proposed schemes and the distributed scheme are applied at a higher capacity based on *SR* in SSs with higher concurrent transmission. Moreover, our proposed schemes demonstrate a more effective load distribution when the data flow rate increases. Therefore, under heavy loads, the proposed schemes show an even better delay performance than the other schemes.

(5) Since the scheduling algorithms in the proposed schemes and the centralized schemes adopt priorities for different service types, the average delay of UGS traffic is always smaller than that of ertPS traffic, the ertPS delay is smaller than the rtPS delay, and so on. However, we observe a different characteristic in the distributed scheme, where the average delay is almost similar for each service type. This result can be attributed to the contention algorithm used in the distributed scheme and is applicable only to individual SSs, i.e., QoS traffic is not considered for the mesh network in distributed schemes.

Figure 11-Figure 15 display the *average throughput* of the schemes. As expected, the *average throughput* gradually increases with the data rate. Although the distributed scheme has lower system utilization than the centralized schemes in higher service types, we can observe intersecting curves in lower service types. This is due to the longer path in the centralized schemes. However, the limitation of the centralized scheme is that its throughput performance is worse than that of our proposed scheme, which is due to the same reasons as those provided above for the poor delay performance with longer paths. With regard to rtPS, nrtPS, and BE, when the data rate increases, the centralized scheme reaches the saturated point (the decreasing of throughput in heavy load) more easily than the other schemes. This is because using *SR* enhances the link capacity and increases the time required to reach saturation. As shown in Figure 16 with total input flow rates ranging from 0.5 Mbps to 10 Mbps, our proposed

scheme beats the other schemes in terms of average throughput because of the effect of load distribution due to the delay-based route selection and scheduling; in addition, the proposed scheme has a higher SRF value. For very heavy loads, our proposed scheme shows higher throughput when the minimal-delay-first [6] methodology is used than when the minimal-hop-count methodology is used; however, the maximal gain is only 5%. This indicates that the minimal-hop-count route selection is appropriate for IEEE 802.16 mesh networks.

The *average signaling cost* of the schemes is shown in Figure 17; the distributed scheme incurs the highest signaling cost because it incorporates two-hop information exchange as opposed to channel access. Our proposed scheme has a slightly higher signaling cost than the centralized schemes because it carries out periodic reporting. However, the signaling cost does not increase with the load because all the mesh SSs send requests almost simultaneously over a unit timeframe when the total data rate is 2.5 Mbps. Furthermore, little difference is noted between the proposed schemes with different routing rules; the reason is the higher activity of the SSs due to the large distribution area in the minimal-delay-first route. According to the simulation result, reduction ratio of the signaling cost of the proposed scheme over the distributed scheme can be up to 45%, but it is only higher 8% than the centralized schemes.

4.3. Scalability of capacity issue

Considering the effect of the size of the mesh network, we design three different mesh sizes to evaluate the throughput performance of our proposed scheme, the parameters in Table 2. This simulation only applies rtPS traffic generated without admission control. The throughput performance of the IEEE 802.16 mesh networks degrades seriously as the mesh size increases (Figure 18). This simulation result agrees with our assumption that the total throughput significantly decreases with an increase in the mesh network size. For example, when the input rate is 10 Mbps, the proposed scheme shows a maximum throughput of only 2.9 Mbps for a 15 × 15 mesh size. The lower throughput is due to the longer route path in a larger mesh network. We can consider that our proposed scheme outperforms the centralized and distributed schemes even if large mesh sizes are used. Consequently, the IEEE 802.16 mesh network offers a large area and can be deployed in a convenient manner, but scalability in terms of the size of the mesh network could be a major factor that affects the network performance.

Table 1. Simulations parameters

Description	*Value*
Network size	5×5 mesh
Link capacity	20 Mbps
Time frame duration	10 ms
# of slots per time frame	200
# of flows per service type	5
Average date rate per service type flows	0.1~1 Mbps
Variation of data rate per non-UGS flow	±25%
State report interval	50ms
Weight for WRR scheduling scheme	UGS:10, ertPS:6, rtPS:3, nrtPS:2, BE:1

Table 2. Simulations parameters

Description	*Value*
Network size	5×5, 10×10, 15×15 mesh
Link capacity	20 Mbps
Time frame duration	10 ms
# of slots per time frame	200
# of rtPS flows	50
Average date rate total flow	0.5~10 Mbps
Variation of data rate rtPS flow	±25%

5. Conclusion

In the IEEE 802.16 mesh mode structure, there is no need to have a direct link between SSs and the BS, providing a more flexible approach for network deployment. Data frames in the 802.16 mesh mode can be transmitted directly between two neighboring SS nodes and sent to the destination node in the hop-by-hop manner. Therefore, routing and scheduling for QoS support are important issues in the IEEE 802.16 mesh network. Two basic scheduling schemes, the centralized scheme and the distributed scheme, associated with their corresponding routing mechanisms were defined in the 802.16 standard. In this paper, we investigated the performance problems of each scheduling schemes. Moreover, a cross-layer QoS framework incorporating the proposed routing and scheduling mechanisms was also presented in the paper. Simulation results demonstrated that the proposed framework and the associated mechanisms can achieve a better performance in terms of delay, throughput, and signaling cost over the basic centralized and distributed scheduling schemes.

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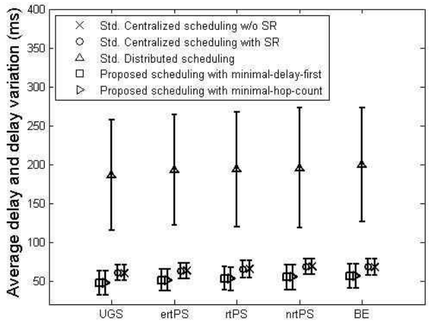

Figure 3. Delay and delay variation with total flow data rate 0.5 Mbps

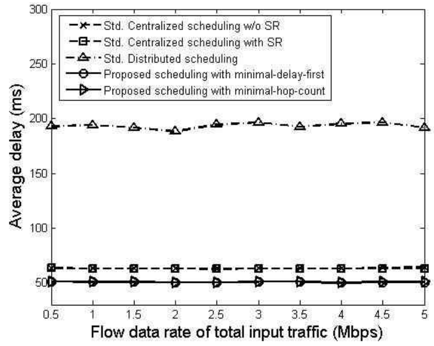

Figure 7. Average delay of ertPS flows

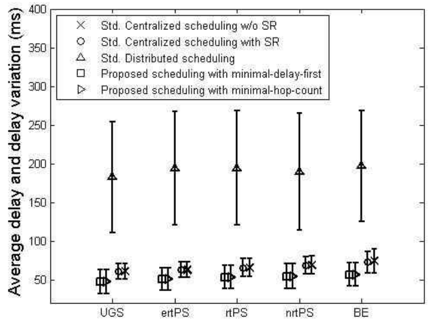

Figure 4. Delay and delay variation with total flow data rate 2.5 Mbps

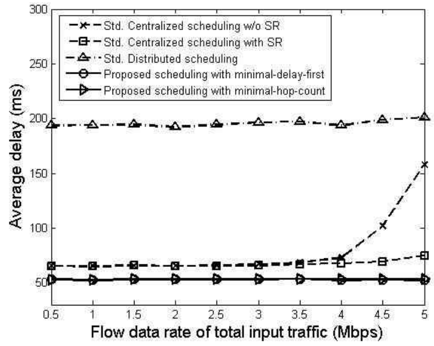

Figure 8. Average delay of rtPS flows

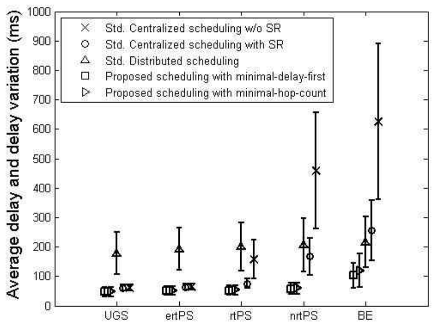

Figure 5. Delay and delay variation with total flow data rate 5 Mbps

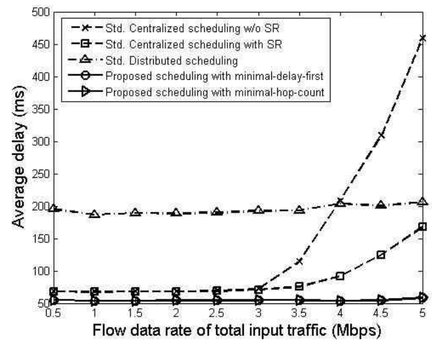

Figure 9. Average delay of nrtPS flows

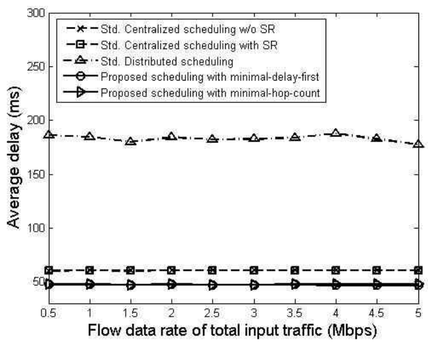

Figure 6. Average delay of UGS flows

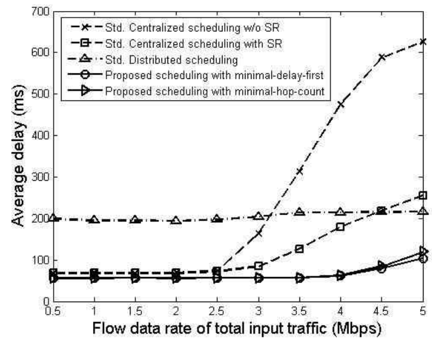

Figure 10. Average delay of BE flows

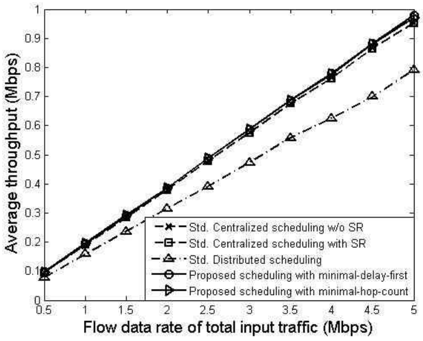

Figure 11. Average throughput of UGS flows

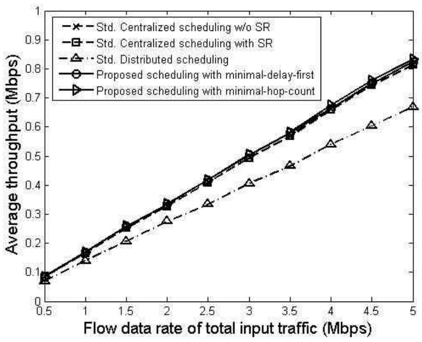

Figure 12. Average throughput of ertPS flows

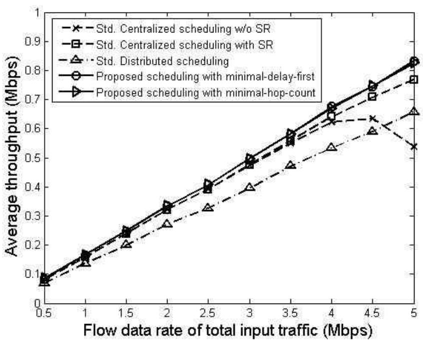

Figure 13. Average throughput of rtPS flows

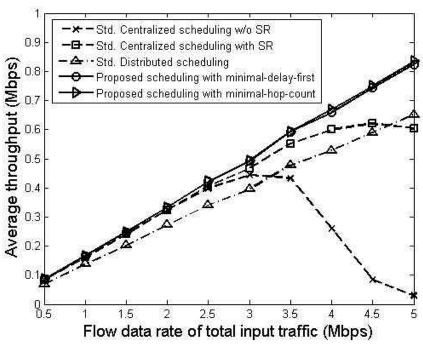

Figure 14. Average throughput of nrtPS flows

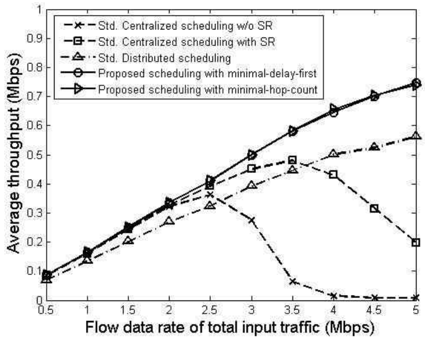

Figure 15. Average throughput of BE flows

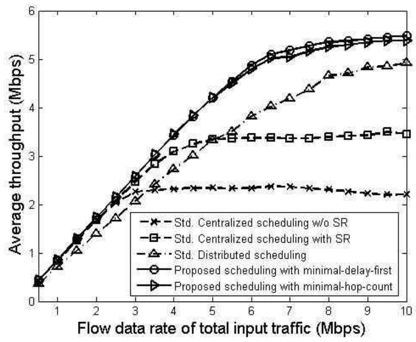

Figure 16. Average throughput of all flows

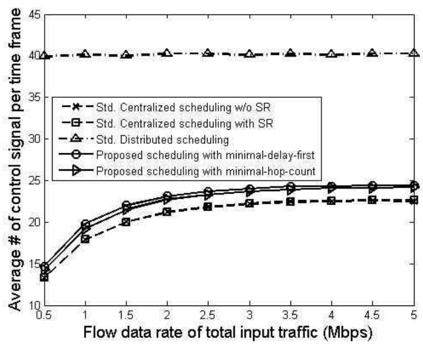

Figure 17. Average signaling cost

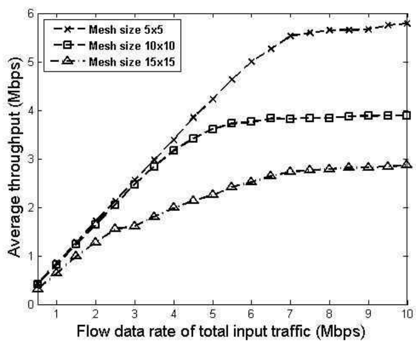

Figure 18. Average throughput of rtPS flows with different mesh size