

QoS Performance Analysis for VoIP Traffic in Heterogeneous Networks with WiMAX Access

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Abstract— Designing a heterogeneous network including systems providing different QoS, such as the emerging WiMAX, is a difficult task. The integration of a WiMAX access system with Differentiated Services (DiffServ) enhances the overall performance of the network. This paper investigates the interworking between WiMAX and DiffServ networks, by measuring one-way delay, jitter and packet drop rate of VoIP traffic from WiMAX users in a test-bed scenario with and without DiffServ. It is shown that DiffServ in the core network solves the congestion problem in efficient way by providing service priority to delay-sensitive traffic. The results show valuable gains using DiffServ network.

Keywords— QoS, DiffServ, WiMAX, VoIP, WLAN

I. INTRODUCTION

The popularity of wireless networks is widely recognized because of its strong support and ease of use in the end systems. Heterogeneous wireless networks are becoming of widespread use with Internet's real-time multimedia applications. Short range WLAN systems, as well as different cellular systems and WiMAX, provide some level of QoS and are needed to realize ubiquitous Internet services. But real-time multimedia applications, in particular interactive and live streaming applications, set strict requirements for the QoS. Some applications need relatively wide bandwidth; the bandwidth should be available in both directions constantly. Applications like voice and video need short transmission delay and jitter but they still have ability to tolerate some packet loss [1]. WiMAX is capable of reaching remote areas with high data rate transfer, mobility support and a native Quality of Service management (even if just limited to the wireless IEEE802.16 links) [2].

By looking at the literature, a remapping mechanism is proposed in [3] to dynamically adjust the mapping rules for nrtPS and rtPS (for VBR traffic sources) classes of WiMAX to DiffServ. An architecture for signalling and WiMAX resources management is proposed in [4] considering an end-to-end QoS enabled scenario. In this approach interoperability is provided between WiMAX and other networks which have different QoS schemes, like DiffServ. WiMAX and WLAN Integration design is proposed in [5] for link layer QoS. Here,

a mapping scheme of DiffServ to the link layer services for both WiMAX and WLAN is shown.

The end-to-end QoS mechanisms were developed to serve the users with the wired terminals. More research work on DiffServ approach applied to the wireless systems and mobile users in heterogeneous environment is needed in order to understand the benefits of the DiffServ networks. Current research is open regarding the mapping of QoS classes and the design of complete interworking models between WiMAX and DiffServ networks.

In our work, a WiMAX DiffServ QoS test-bed scenario is implemented to test the interoperability and the different functionalities between domains with different QoS models. The aim of our research is to map and analyse the QoS class for CBR traffic types (VoIP without silence suppression, as an example) which need constant bandwidth in both wired and wireless networks.

The paper is organized as follows. Section II explains the mechanism for IP QoS. Section III depicts the QoS mechanism in WiMAX network. Section IV illustrates our simulation scenario and results, whereas conclusion is explained in section V.

II. MECHANISMS FOR IP QoS

There are two main IP based QoS mechanisms, IntServ and DiffServ. IntServ provides end-to-end QoS in flow-based manner and uses the Resource Reservation Protocol (RSVP) for signalling, which follows the data path, performs the reservation and maintains per flow state in each router.

DiffServ has more suitable mechanisms for providing end-to-end QoS by working with aggregate traffic classes [6]. Packets of a particular service class are marked with a QoS class and receive a specific Per Hop Behaviour (PHB) for forwarding. The PHB is an externally observable forwarding behaviour which is applied to a DiffServ compliant node, or it refers to queuing scheduling, shaping or policing behaviour of a node on any packet. There are several available standard PHBs, which include default PHB, Assured Forwarding (AF) PHB and Expedited Forwarding (EF) PHB.

The packets scheduled by default PHB receive the traditional Best Effort (BE) service which has the lowest priority. The AF class is further categorized into four classes,

namely AF1, AF2, AF3 and AF4, and each class has three drop precedences: Low, Medium and High. The purpose of the AF PHB is to allow the DiffServ network to provide different levels of QoS assurances. Generally AF class is used for the traffic which can tolerate more delay and packet loss, but requires better QoS than Best effort (BE) class.

The main purpose of the EF PHB is to provide assured bandwidth equivalent to 'virtual leased line'. Asynchronous Transfer Mode (ATM) has also attempted the same assured service in its Constant Bit Rate (CBR) traffic mode. The characteristic of this type of service is to provide low delay and small packet loss ratio.

DiffServ uses IP header field (Type Of Service (TOS) in IPv4 and traffic class in IPv6) to denote the QoS class of a packet as shown in figure 1. Using DiffServ Code Point (DSCP) each router in the network can mark, shape or drop the incoming traffic. The DSCP field is made of eight bits out of which only six bits are currently in use while the last two bits are for future use. The first three bits of the class selector code points are used to specify the different classes with different priorities. The next three bits of the DSCP field are used to handle drop precedence of each of these classes.

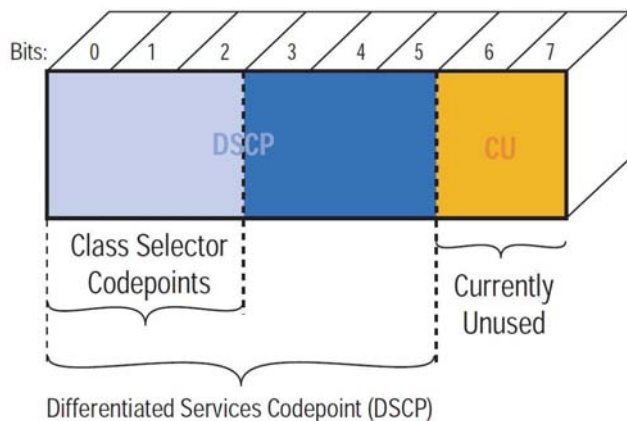


Figure 1. DiffServ Code Point field.

III. QoS MECHANISM IN WIMAX NETWORK

IEEE 802.16, referred to as WiMAX, provides specifications for air interface of Metropolitan Area Network. The standard specifies connection-oriented QoS support [7]. There are different types of services for different types of classes, which include: Unsolicited Grant Service (UGS) for real-time uplink Service Flows (SFs) of fixed packet size on periodic basis, Real-time Polling Service (rtPS) for real-time SFs having variable-size packets on periodic basis, Non real-time Polling Service (nrtPS) which supports delay tolerant data having variable-size packets for which minimum data rate is needed, and Best Effort (BE) for the data streams for which no minimum service is required. Service Flows are created and modified between MS and BS through MAC message exchange. The exchange of Dynamic Service Deletion (DSD),

Dynamic Service Change (DSC) and Dynamic Service Addition (DSA) messages are initiated by either BS or MS.

The distinguishing feature of WiMAX over its other competitors (i.e. 802.11 and 3G) is its QoS provisioning based on the association of each packet with a service flow. WiMAX is connection-oriented and each connection has a unique Connection ID (CID) and Service Flow ID (SFID) which is associated to that particular class. The data is mapped by the upper part of the MAC to QoS service classes. The external application can also request desired QoS parameters using the named service class. The traffic shaping engine is included in the MAC which is ultimately responsible for the transmission and reception of the 802.16 packets according to the applied QoS parameters. These parameters are different from one service flow to another.

WiMAX allocates traffic to a service flow and then maps it to a MAC connection using CID as shown in figure 2. In this way, IP and UDP protocols which are connectionless are transformed into connection-oriented service flows. An application or group of applications can be represented with a connection with same CID.

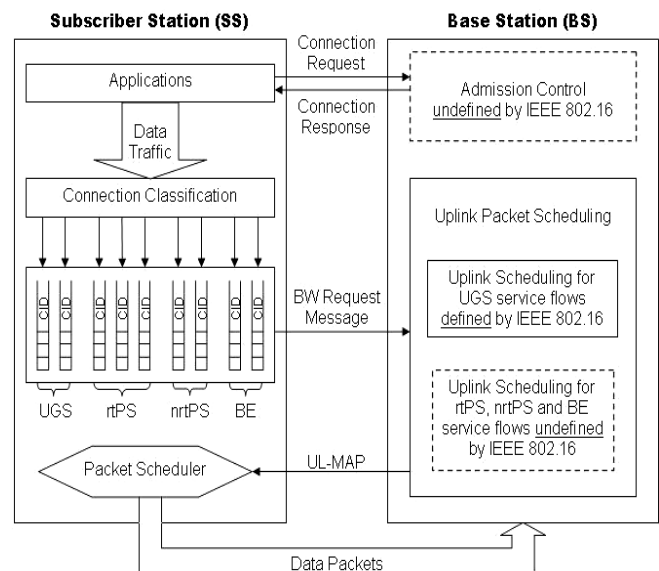


Figure 2. IEEE 802.16 QoS Architecture

The MAC layer of WiMAX is divided into two sub-layers: the common part sub-layer and the convergence sub-layer. The transport layer specific traffic is mapped by the convergence sub-layer to the core MAC common part sub-layer. The common part sub-layer is responsible for fragmentation and segmentation and is independent of the transport mechanism.

The incoming traffic type (e.g. web surfing, voice ATM CBR etc.) is classified by the convergence sub-layer and a 32-bit SFID is assigned to it. When a service flow is active or admitted, it is mapped to a 16 bit unique CID which handles its QoS requirements. Each service flow is defined by a QoS parameter set which describes its jitter, latency and throughput assurances.

After the service flow is assigned with a unique CID, it is then forwarded to the appropriate queue. Base Station (BS) performs the uplink packet scheduling by signaling to the Subscriber Station (SS) [7]. The packet scheduler in the SS will extract the packets from the queues and transmits them to the network with an appropriate time slots sent by the BS in the Uplink MAP (UL-MAP) message.

IV. INTERWORKING MODEL AND SIMULATION

We consider here the scenario of Figure 3, where the traffic from the WiMAX domain enters the DiffServ core network. In the core network the traffic will be mapped to the equivalent class of WiMAX according to Table 1 [1]. In this scenario the two nodes, Node1 and Node2, are used to

DiffServ core network which provides the service of EF class. This queue has high scheduling priority compared to the other queues and the data in this queue will be scheduled first.

A. Priority Queuing (PQ)

In our simulation scenario we have implemented Priority Queuing in the edge router of the DiffServ core network. PQ realizes a simple way of class distinction. As shown in Figure 4, if N queues are created, then the priority goes from 1 to N. The scheduler will schedule higher priority queue first and when that queue is empty it will schedule the packets from the next high priority queue. The j-th queue packets are processed only if the higher priority queues, i.e. queue 1 to j-1, are empty. If the scheduler is at queue j a packet arrives in a higher priority queue, say j-3, the scheduler will go to the queue j-3. PQ is particularly suitable for high priority traffic

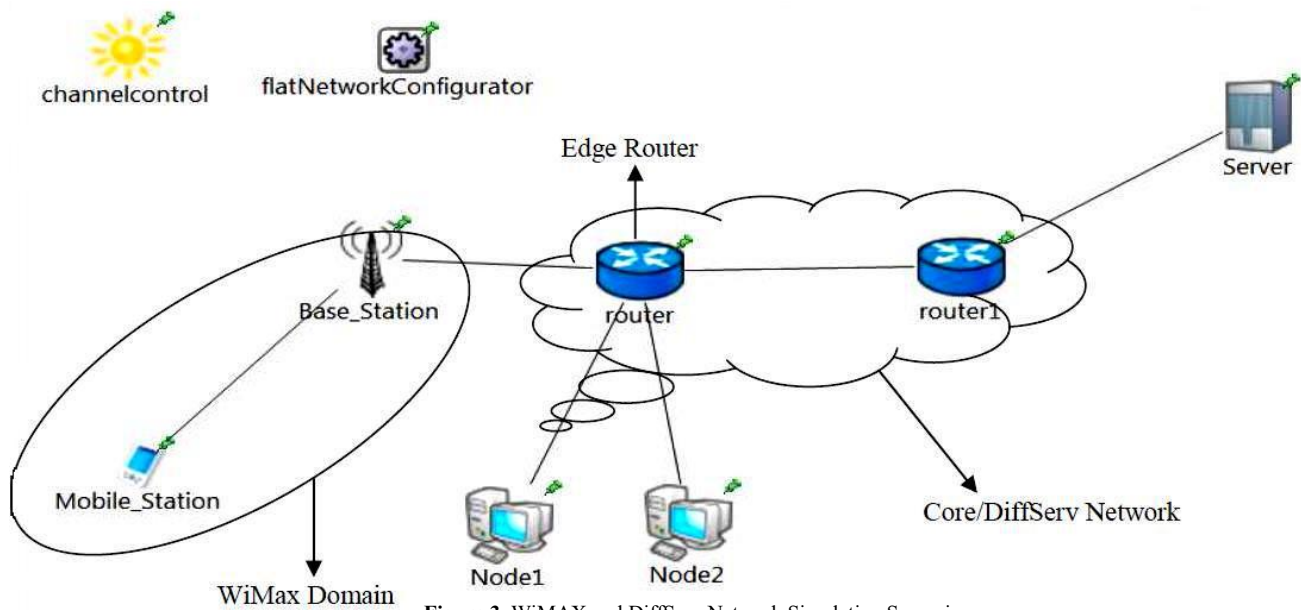


Figure 3. WiMAX and DiffServ Network Simulation Scenario

generate traffic that competes with WiMAX traffic.

and provides premium service to the traffic which is extremely

TABLE 1. WiMAX AND DIFFSERV TRAFFIC CLASS MAPPING

WiMAX Scheduling Class	DiffServ PHB	Service Example
UGS	EF	VoIP without VAD
rtPS	AF4	Audio/Video streaming
nrtPS	AF3	Transactional Services
BE	BE	E-mail download

In our test network we have considered a VoIP application with Unsolicited Grant service (UGS) and mapped it to the Expedited Forwarding (EF) class of the DiffServ network. The aim of the simulation is to examine different QoS parameters when WiMAX traffic enters the DiffServ network and when DiffServ domain is not used for CBR traffic.

In the test-bed the UGS type of traffic coming from WiMAX is mapped to a high priority queue in the edge router of the

TABLE 2. SIMULATION PARAMETERS

Parameters	Value
Channel bandwidth for UGS	1Mbps
Packet size (UGS)	80 bytes
Inter-Departure time (UGS)	0.01 sec.
First Packet time (UGS)	0.01 sec.
DiffServ core Network Bandwidth	5Mbps
Message Length (Node1 & Node 2)	1500 bytes
Message inter-arrival time (Node1 & Node 2)	Exponentially distributed with arrival rates of 199.83, 225.28, 250.73 packets per second

critical and needs to be processed as soon as possible.

We selected priority queuing because it provides dedicated queues for real time traffic, e.g. video and voice over IP.

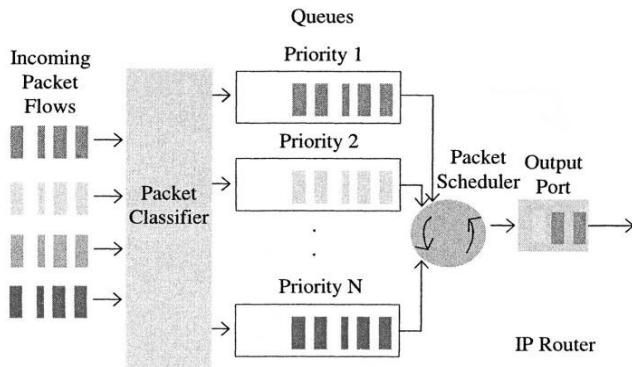


Figure 4. Priority Queuing Implemented in Edge Router

B. Simulation results

The scenario is simulated in OMNeT++ 4.0 with INET framework [8]. The simulation is performed according to the parameters shown in table 2. The simulation is run under the traffic load of 100%, 112.5% and 125% with and without DiffServ enabled core network. Node 1 and Node 2 generate exponentially distributed traffic with different arrival rates mentioned in table 2. The packets from both the nodes are not marked with DiffServ code point so they will be treated as best effort traffic upon their arrival on the edge router of the DiffServ core network.

Figure 5 shows the number of dropped packets without DiffServ core network enabled with different loads. Packets are dropped when the bandwidth required to transmit them exceeds the allocated capacity. We found no dropped packets from VoIP stream with DiffServ enabled core network because of the preferential treatment over the other traffic types. When the core network is not DiffServ enabled, it cannot provide preferential treatment to the VoIP packets coming from WiMAX domain. All the VoIP packets are

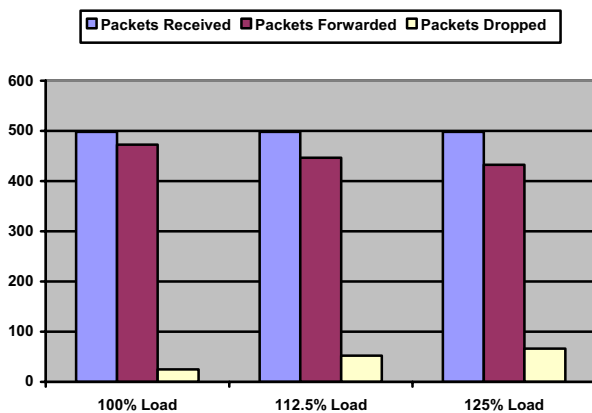


Figure 5. Packets dropped without DiffServ support

treated as best effort on the edge router along with the traffic from Node 1 and Node 2. As our interest lies in VoIP traffic from the mobile station, in figure 5 we have not considered the dropped packets coming from the other nodes.

In Figures 6, 7 and 8 some simulation traces for packet delay in the network are shown under different network loads, with and without DiffServ enabled network. H1 and H2 represent Node1 and Node 2 while MS1 represents the Mobile Station in the simulation scenario of Figure 3.

Figure 6(a) shows the packet delay along the simulation time in the scenario without DiffServ core network and with 100% of network load. As can be seen from the figure, the packets from the mobile station are mixed with those from node 1 and node 2 and routed without QoS provision. The VoIP packets are experiencing different delays over the simulation time, though these packets need a fixed and constant bandwidth and are generated with fixed size on periodic intervals. These delays affect the time sensitive data.

In Figure 6(a) the delay of the VoIP data from the mobile station varies between 37 milliseconds and 58 milliseconds in different intervals of simulation time. On the other hand, figure 6(b) refers to the VoIP stream passing through a DiffServ enabled network which shows a smooth data flow along the simulation time. It can be seen that almost all the packets experience the same fixed delay which is about 35 milliseconds and there is an average gain of 10 to 15 milliseconds achieved with DiffServ enabled network.

Figure 7(a) shows the packet delays in a scenario with 112.5% traffic load condition, without DiffServ enabled network. The VoIP stream of the mobile station experiences higher delays and most of the packets experience a delay between 46 milliseconds and 56 milliseconds. In Figure 7(b), referred to DiffServ enable network, the delay is stable at nearly 35 milliseconds.

Figures 8(a) and 8(b) show packet delays for VoIP traffic in scenarios with and without DiffServ and with 125% traffic load. Without DiffServ enabled network the majority of the packets have delays above 50 milliseconds whereas the delays in the DiffServ enabled network for VoIP is still constant around 35 milliseconds.

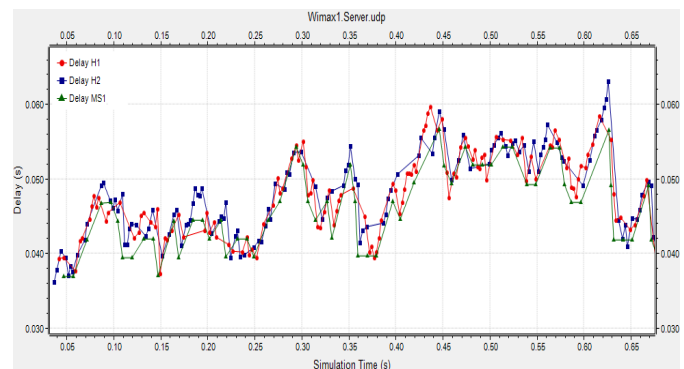


Figure 6(a). Delay without DiffServ support and with 100% load

It is important to note from all the figures that the delays of the VoIP packets are constant for all the traffic loads when

DiffServ is enabled, because, as mentioned before, PQ is used which provides premium service to the higher priority queue and all the packets will be scheduled first before providing the service to lower priority queue.

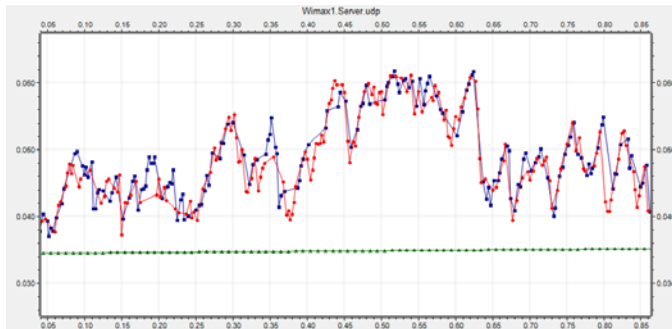


Figure 6(b). Delay with DiffServ support and 100% load

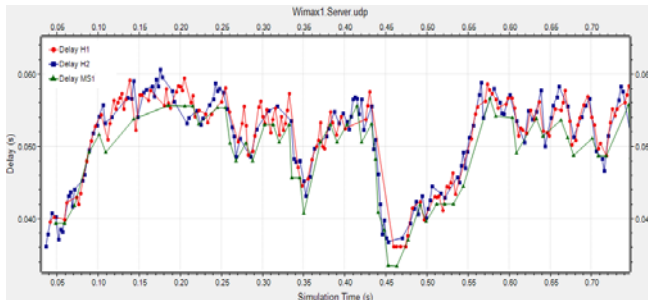


Figure 7(a). Delay without DiffServ support and 112.5% load

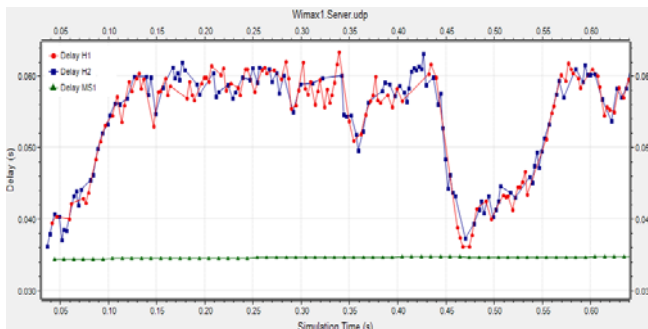


Figure 7(b). Delay with DiffServ support and 112.5% load

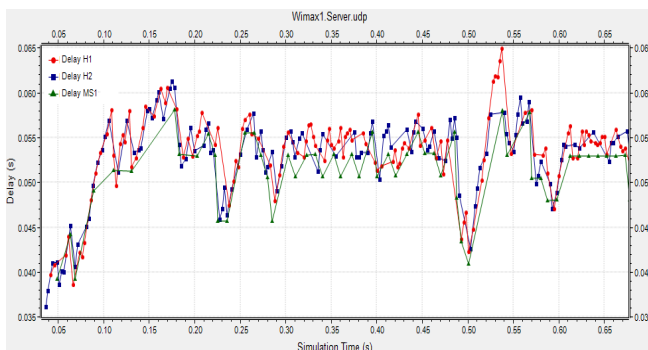


Figure 8(a). Delay without DiffServ support and 125% load

On the other hand, in the scenario with with DiffServ enabled network the traffic from node 1 and node 2 experiences delay larger than the one in non DiffServ network. Though in both

the cases we have not marked the packets of nodes 1 and 2, so their traffic is treated as Best Effort. The increase of the delay is the cost of the preferential treatment provided to the VoIP packets.

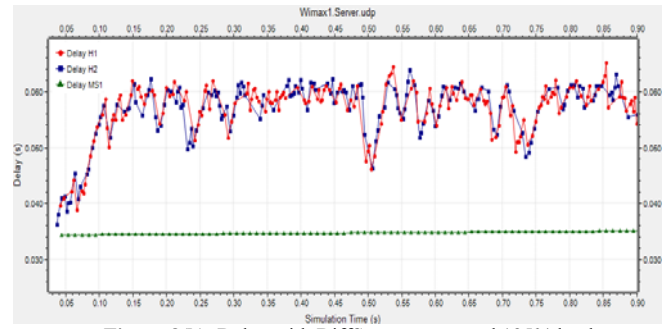


Figure 8(b). Delay with DiffServ support and 125% load

Jitter and delays affect the QoS of the VoIP stream. From the point of view of perceived QoS, jitters and delays of few milliseconds are acceptable. According to ITU-T specification [9] one way delay should not be more than 150 ms while there is no precise limit for jitters. Figure 9 shows the values of jitters for different loads with and without DiffServ enabled network. It can be seen that as the network load increases, the jitter of the packets decreases: this is because when the network approaches saturation point the fluctuations of packet delays decrease.

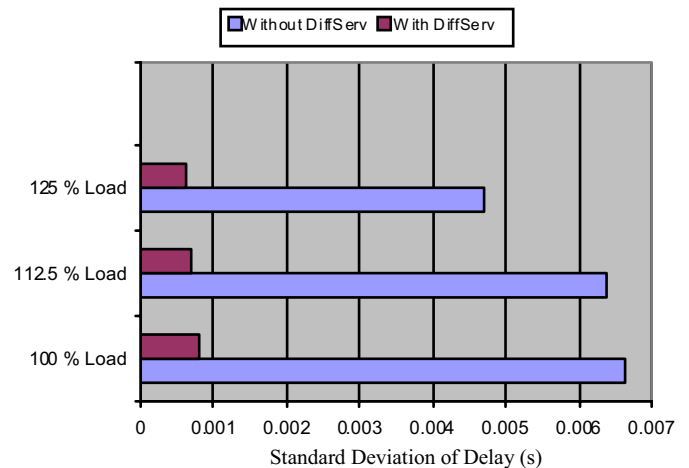


Figure 9. VoIP service jitters in networks with and without DiffServ.

V. CONCLUSION

The measurements in the test-bed network show that DiffServ network clearly provides better QoS for multimedia services. Though the effect of DiffServ in normal traffic conditions is not significant, it clearly performs better in congested network. Internet by default is a Best Effort network and DiffServ improves the performance of the core network by providing the minimum required QoS level. Time sensitivity may not have a big impact on applications like FTP but it is a great limitation for real-time traffic. PQ should be used only when

the amount of delay-sensitive traffic is small compared to overall traffic and needs to be processed as soon as possible, as in our test-bed where we were sending 64 Kbps of voice traffic while the total bandwidth of the core was around 5 Mbps.

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