Performance Comparison of VoIP over Wireless Ad Hoc Networks Using Different Routing Protocols and Queuing Techniques

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***Abstract*—This paper describes performance evaluation of VoIP over wireless ad hoc networks using OPNET tool. The simulation study is completed by running VoIP application in different network scenarios with different routing protocols; namely: AODV, TORA and DSR and with different queuing techniques: FIFO, PQ and WFQ. The following performance parameters: the delay jitter, packet end-to-end delay, wireless LAN delay, and number of packets sent/received are used to compare the efficiency of different scenarios.**

***Keywords*— VoIP; Performance evaluation; Routing Protocols; Ad-hoc Networks.**

I. Introduction

At the present time, massive multimedia streams are communicated between multimillions of people around all corners of the world's continents over the Internet. That is done by means of social networks Web sites and multimedia broadcasting. From technical point of view such transferred multimedia streams are requiring transfer with minimum delay overhead, efficient routing, via suitable level of satisfactory quality of service (QoS) and quality of experience. However, driven by huge multimedia communications, use of mobile devices by millions of people, and mix of arrangements of networks by wire and wireless networks, routing has turn out to be the most crucial issue in international networking world's infrastructure [2]. Nowadays, wireless ad hoc networks have become very widespread in the computing industry. Wireless ad hoc networks have no pre-defined infrastructure, the nodes are dynamic, nodes are capable of doing routing functions, and nodes are connected in a random way with each other due to their nodes' mobility. The wireless ad hoc networks are widely used in conferences, military, emergency and education. However, the IEEE 802.11 family of standards is one of enabling technologies of wireless ad hoc networks which use the Ethernet protocol and CSMA/CA (carrier sense multiple access with collision avoidance instead of CSMA/CD) for path sharing. Voice over Internet Protocol (VoIP) enables voice/video communication between two or more members over Internet. VoIP is a technology that supported by a number of protocols working together to build up an operational architecture for VoIP-based communication. In networks that are supporting VoIP, the voice signal is digitized, compressed, translated to IP packets and transmitted through IP network. However, VoIP signaling protocols are employed to setup, negotiate capabilities, maintain and terminate communication sessions over the IP networks during the conversion. IP networks inherently experience network deficiencies such as packet end-to-end delay, delay jitter and packet loss. However, when packets start queuing up at the router interfaces they produce a delay on the stream and taking more time to exit the router. Then when the queue buffers are consumed the routers will start discarding packets.

This paper is organized as follows: related work is briefly discussed in section 2. Section 3 introduces the reader to wireless ad hoc networks. Routing in wireless ad hoc networking is described in section 4. QoS discussed in section 5. Section 6 outlines some points about queuing. Finally, practical simulation results are given in section 7.

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II. Related Work

There are a number of studies have been carried out by many researchers in this field. This section provides an overview of some significant research papers. In [9], authors analyzed VoIP application with OPNET using different routing protocols, but they had not considered the effect of queuing techniques in the analysis process. In [10], authors compared wireless ad hoc routing protocols using NS2 simulator, but the comparison had not measured the VoIP application. In [11] authors evaluated the VoIP application on the wireless LAN (802.11) using OPNET, however, they used only four levels of priority to classify the traffic as QoS measure for a 2 minute time interval.

III. Wireless Ad Hoc Networks

An ad hoc network is a set of wireless autonomous nodes dynamically establishing a temporary network via wireless links with infrastructure-less organization and decentralized administration. The nodes in ad hoc networks operate together with the purpose of dynamically constructing wireless irregular communication links between each other using minimum organization and management efforts. Nodes in ad hoc networks may be highly mobile, less mobile, or stationary with limited energy and different memory and computational resources. Moreover, the nodes have different capabilities depending on their usage and functions. However, the nodes work as routers to relay other nodes data and produce their own data. Therefore, in ad hoc networks a packet may need to be forwarded over multiple hops in order for it to reach its destination.

IV. Routing in Wireless Ad Hoc Networks

The routing protocol states how routers communicate together in order to select proper routes for data transfer between senders and receiver ends. Routing protocols is always needed to forward packets in computer networks. The routing protocols have to do route selection for different senders/ receivers pairs over multihop network, and packet delivery to the final receiving end. The sender and receiver in wireless ad hoc networks are communicating together either over the single hop or through multiple hops with the support of intermediate nodes along the path between them. However, the nodes in wireless ad hoc networks are working as a host and as a router. Ad hoc routing protocols can be categorized into three classes: proactive (table-driven) protocols, reactive (on-demand) protocols and hybrid protocols.

A. Proactive (table-driven)

In this type of routing protocols, every node keeps a topology table that contains the active nodes connectivity. This table is always kept up to date, which give the proactive protocols the name of *table-driven*. However, all active nodes exchange routing information contained in such tables with neighbors to maintain a correct picture of the current ad hoc network topology. Hence, in proactive routing; packets are immediately forwarded to the next hop since routes are already known in the given topology, continuously evaluated and kept up-to-date. In addition, less sending delay is incurred before sending the packet. Conventional distance-vector routing protocols is a typical example of this kind.

B. Reactive (on-demand)

In this class of routing protocols, routes to the destination are searched only at the moment of communication. Therefore, that is why they are called *on-demand* and reacts only when needed. However, when a node wants to send a data to another node it consults the routing table if it has a route it will use it to send that data; otherwise the sender starts discovery procedure to find a route to the intended destination. This in turn, reduces routing overhead, since no routing needed unless there is packet to send. Flooding algorithms are typical example of this kind. Moreover, it needs more sending delay than the proactive protocols; which affected also (increases) by the dynamic changes of the ad hoc network topology.

C. Hybrid

In hybrid protocols the features of proactive and reactive routing protocols are being combined to achieve more flexible protocols. Hybrid protocols inherit the advantage of high-speed routing from proactive routing and less overhead control messages from reactive protocols. Hybrid routing protocols may show proactive or reactive performance depending on the situation, therefore provide flexibility based on the wireless network.

D. Reactive routing protocols discussed in this paper

1- Dynamic Source Routing (DSR)

DSR is a reactive, source-routed routing protocol designed for extremely dynamic networks. In DSR, each node preserves route collection information that keeps all routing paths from the node itself to all other nodes in the network. Basically, in DSR routing the source node introduces the “Route Discovery” method in order to discover a routing path to a required node when there is no entry about that node in the route collection. Moreover, DSR uses “Route Maintenance” technique to retain the routes when there are connection failures in the routes or when any topology changes happened. Thus, renews broken routes rapidly to make the node reachable by other nodes. However, when a route is found, the sending node sends packets with headers holding full path information toward the receiving end. Moreover, each node along that path forwards packets to the next node in the network according to control information contained in the packet’s header. DSR maintains only routes for nominated nodes, and does not make any periodic advertisements with other unwanted nodes. DSR as source routing protocol can make the usage of discovery messages information dissemination unpractical due to node routing cache overhead in large networks. Therefore; DSR is not scalable for large networks [2].

2- Ad hoc On-demand Distance Vector (AODV)

AODV is a reactive, distance-vector routing protocol suitable for highly dynamic networks. By deploying the AODV, every node in AODV holds a routing table that contains only active routing entries. Furthermore, the AODV builds and preserves routes in the similar way of DSR protocol. However, the AODV keeps only its local connections with close neighbors and it is not using periodic advertisement and it keeps only routing information about needed routing entries in which it takes the advantage of DSR protocol [2]. In another words, AODV searches route entries for nodes only when needed and are kept in route cache only as long as they are necessary for current communication. Therefore, AODV does not play any role when the endpoints of the current communication have effective routes to each other. AODV protocol has loop freedom feature and when link failures occurs immediate notifications is issued to the set of affected nodes only. This in turn, reduces the number of routing messages in the network significantly [3].

3- Temporally Ordered Routing Algorithm (TORA)

TORA is a reactive, greatly adaptive distributed routing protocol designed to operate in a dynamic multihop networks. TORA is based on link reversal algorithm and it uses a directed acyclic graph (DAG) to generate multiple routing paths upon requests from sender to receiver. TORA is designed to reduce reaction to topologies changes. One important thing with TORA is that control messages are normally localized to a minimal set of nodes. This will assures that all routes are loop-free and offers multiple routes for any two communicating nodes. TORA provides only routing task and rest on Internet MANET Encapsulation Protocol (IMEP) for other underlying functions; which further increases the overhead to the protocol [3].

V. QUALITY OF SERVICE

QoS is the ability to manage network resources to satisfy application requirements and user contribution. A network that provides QoS is a network that offers certain assurance level for delivering the transferred packets in continuous and integral way. Multimedia streaming applications over the Internet have strict QoS constraints that must be fulfilled. From an operational point of view QoS is defined as the capability of the network to fully satisfy the application requirements, without influencing on the application's execution and satisfying user experience. Internet services such as VoIP, multimedia streaming and web-casting, require QoS guarantees for their operation. As the Internet usage grown with different applications such as multimedia applications; different requirements have been imposed to be discussed during the design of advanced network infrastructures such as security and QoS service levels or real-time flow classification. However, these introduced functions have overheads translated into extra processing inside the router during forwarding of the packet en route for its final destination. QoS performance relies on selecting the most appropriate routing paths that have enough resources for all connections to be established with efficient resource utilization. Queuing mechanism has an important task in improving the performance of packet scheduling.

A. QoS quantitatively measures

To quantitatively measure quality of service, several related aspects of the network service are often considered, such as end-to-end transmission delay, delay variation (jitter), packet loss, bandwidth, throughput, network up-time, etc.

1- The delay jitter

The delay jitter can be defined as the variability of successive packets delays within the same packet flow at appearance to the receiving end; i.e. the delay is oscillating from packet to packet in the same packet stream (e.g. in a single VoIP call) when received at the destination. The jitter can be caused by propagation delay, node delay, link delay and variable queuing delays. The delay jitter can be usually removed by putting on sequence numbers, timestamps on packets at the sender and introduce a playout delay via buffering at receivers [5][6].

2- End-to-end delay

End-to-end delay can be defined as the one way delay taken by the packet during transmission along the end-to-end path from source to destination. However, the packet goes through various different forms of delays at each node along the path, such as node processing delay (including packetization), transport delay, propagation delay, and queuing delay. The lengthy delays in VoIP conversation will produce short pauses (silences) which can make it unacceptable in QoS sense if it goes beyond the 400ms [5] [6].

3- Packet loss

Packet loss is defined as the percentage of packets gets lost along the communication path after the packet is transmitted by the sender into the network. The packet loss may occur when a router's queues are filling-up and turn into congestion state. However, various applications will have varied tolerance levels of packet loss. Hence, the probability of packet loss measures the node's performance along the path between the sender and receiver [5] [6].

4- Throughput

Throughput in the network is the total rate at which packets are transferred from the source to the destination at a prescribed time period (e.g. packet/seconds). However, in some sense as a performance measure, the throughput can be measured on a single node, link, subnet or a path; for a node the throughput is representing the total number of packets that are forwarded via that node in specified time period [5] [6].

5- *Bandwidth*

Bandwidth can be measured as a link bandwidth and it is defined as the transmission rate in bits/second of that link. However, the bandwidth is affected by the increase on end-to-end delay and packet loss. For example, the VoIP application to be practically operational it is an essential requirement that be able to complete the conversation between the calling parties using a definite bandwidth rate. Therefore, bandwidth is the maximum number of bits/second that might be sent over the ad hoc network [5][6].

B. Crucial QoS advanced functions

The most important advanced functions that are constructing the main basis for QoS in networks for transmitting multimedia information include [5] [6].

1- Packet classification:

It is the function of distinguishing packets into several classes in order to operate necessary procedures or certain rules to each class of data streams such as VoIP or real-time video streaming. However, to do packet classification the router may need to check other packet fields such as destination address or payload type. After classification, other traffic handling policies like policing and marking can be involved.

2- Traffic prioritization:

The router may need to apply definite traffic prioritization mechanism in order to preserve certain QoS level to meet the agreed link's bandwidth such as those required to transmit real-time streaming such as VoIP and video conferencing.

3- Policing and marking:

Policing is a technique which is applied to make sure that a traffic flow does not rise above a defined maximum rate value, i.e. the process of handling out of profile traffic. However, a simply policy could be as follows transmit the packet if it conforms to the specified bit rate and to drop the packet if it exceeds that rate limit. Marking is commonly used in combination with policing to impose a defined agreed rate in service level agreement (SLA) to a specific streams of traffic by allowing the marking of the traffic exceeding the specified transmission rate in order to handle it differently when the capacity accepts that or discard it and acknowledge it for retransmission.

4- *Queuing and scheduling*:

Due to high traffic through the Internet buffers are used to store packets in queues temporarily inside the router before getting transmitted. The order of the transmission is determined by several factors such as the packet's service class or the service guarantees level associated with the packet's class. Different queues have different priority levels and every queue consumes different amount of bandwidth on the same output link according to their priority value. However, scheduling algorithm is used to select the next packet to be transferred from such queues subject to the bandwidth prescribed for each queue.

VI. QUEUING TYPES

Queuing is implemented as buffers that are used to store packets which are waiting to be passed through the router temporarily. The order in which forwarding of the packets in different queues are made is based on the packet queuing method and classification. However, scheduling and queuing are made together; scheduling prioritizes the traffic according to the bandwidth and delay requirements. In this section, queuing mechanisms that are used in the paper context is briefly described [6].

A. First in first out queuing (FIFO):

FIFO is simple and easy to implement technique; using FIFO mechanism the first packet reaches the router input is the first one transferred to the router's output. However, FIFO queuing is unable to distinguish packets according to the service class [4].

B. Priority queueing (PQ):

In PQ the packets of various streams of traffic at the router's input ports are classified into several priority classes. Each class has unique buffering queuing to be used by stream of packets that have designated parameters; such as source IP address, destination port and with a suitable level of priority for the packets composing of the stream such as VoIP stream. In PQ queuing when selecting a packet to transmit, the router will serve the nonempty queues according to the priority; transmitting from the highest priority queue first then services the less priority queues sequentially. The essential advantage of PQ is the separation of streams of the traffic into dissimilar classes; each class with different priority and favored handling. For example, real-time multimedia streaming such as VoIP can be assigned higher priority handling queue while ftp or http traffic is assigned lower priority queuing. In another hand, PQ queuing services the higher priority queues traffic first making the packets of the other low priority queues waiting for longer period or discarded if they gone to bandwidth starvation state [6].

C. Weighted fair queuing (WFQ):

Fair queuing (FQ) is basically a round-robin mechanism with bit-by-bit approximation view to the round-robin scheme. FQ –is difficult to implement and it faces the problem of insertion on the sorted queue which increases the processing time of the packet inside the router when there are many traffic flows running together in the same path [6]. WFQ is a variation of FQ and it is a bit-by-bit weighted round-robin queuing mechanism in which a weight is assigned to each class of a traffic stream according to the class priority or traffic type [6].

VII. RESULTS

In this paper the OPNET simulation tool is used to analyses the VoIP over ad hoc network design model. OPNET is a discrete event system simulator that simulates the system behavior by modeling each event happening in the system and processes it by user-defined processes. OPNET allows designers to design and study the performance of the communication protocols, devices, and applications with considerable flexibility. It provides a graphical editor interface to build models for various network entities from physical layer modulator to application processes [8].

The model network consists of 15 wireless nodes distributed in 1000m x 1000m area as shown in figure (1). In the simulation run which lasted for 60 minutes (3600 seconds) period, the VoIP traffic has been configured between all nodes by using "create traffic flow" option in OPNET tool, with the following input parameters: call rate is 500 calls per hour, average call duration is 300s (5 min), voice flow duration is 3600s (simulation time period), the encoder scheme is G.711, traffic type is interactive voice with delay, throughput and reliability including overhead (bytes) of RTP/UDP/IP. Therefore, the voice traffic after has been generated by the OPNET tool produced a huge data measured in hundreds of gigabytes flown in the network.

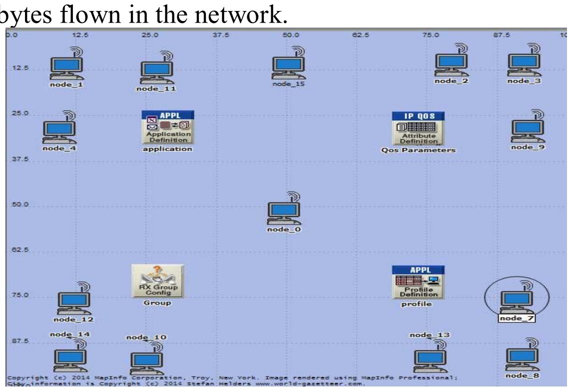

Figure (1): Wireless ad hoc model

The experimental study included the VoIP application in 12 different scenarios with combination of the following features:

- Three different wireless ad hoc routing protocols (AODV,TORA, DSR);
- Each protocol is analyzed with three different queuing techniques (FIFO, PQ,WFQ);
- Each protocol is analyzed also without application of queuing;
- Each queuing techniques is tested with three routing protocols.

A- *Results of measuring wireless LAN (802.11b) delay*

The three routing protocols (AODV, TORA, DSR) results are shown in figures 2, 3, 4 respectively, each showing the measurements of the protocol for different queuing mechanism. From figure (2), for AODV protocol the AODV(FIFO) case has the lowest wireless LAN delay (the best) which is around 0.8 value, while AODV(WFQ) case has the highest (the worst) value near of 2.95 and AODV(PQ) has around 1.2 value. Figure (3) for TORA showed that the wireless LAN delay is around 0.9 (the lowest) for the TORA(FIFO) case, while it is around 1.9 for both TORA(PQ) and TORA(WFQ). Figure (4) showing the results of wireless LAN delay for DSR. However, the delay for DSR(FIFO) is around 3.9 values, while for DSR(PQ) it is around 3.6 values and it is nearly 0 for DSR(WFQ) case. Therefore, AODV (FIFO) has the lowest wireless LAN delay among all tested scenarios.

B- *Results of measuring packet end-to-end delay*

The results of comparing packet end-to-end delay by using different queuing techniques (FIFO, PQ, WFQ) for each routing protocol (AODV, TORA, DSR) are shown in figures 5, 6, 7. From figure (5), results show that AODV(FIFO) has packet end-to-end near 1.5 and for AODV(WFQ) has nearly 3.43. While it is nearly 1.9 for AODV(PQ). Figure (6) illustrates the results of TORA protocol. However, the packet end-to-end delay of TORA(FIFO) is nearly 2.5, while TORA(WFQ) and TORA(PQ) has 3.8 value. Figure (7) clarifies results of DSR protocol. The packet end-to-end delay for DSR(FIFO) is 4, while it is for DSR(PQ) about 5.5 and for DSR (WFQ) near the zero value. Therefore, the comparison shows that AODV(FIFO) has 1.9 which is the lowest value of packet end-to-end delay. Moreover AODV(PQ) recorded 1.9 which is a good value compared to PQ queuing of TORA and DSR.

C- *Results of comparing the routing and queuing together*

The results of comparing voice jitter using different queuing techniques (FIFO, PQ, WFQ) for all routing protocol (AODV, TORA, DSR) are shown in figures 8, 9, 10. From figure (8), results show that DSR(FIFO) has the least value of voice jitter, which is nearly zero value. While AODV(FIFO) has less than 0.015. Figure (9) illustrates the results of the voice jitter for PQ queuing case; however, TORA(PQ) has got almost zero value, while AODV(PQ) has got under 0.02 value. Figure (10) shows the results of applying WFQ queuing, the DSR(WFQ) and AODV(WFQ) have got nearly zero value of voice jitter.

VIII. CONCLUSION

In this paper a performance analysis study for VoIP over wireless ad hoc networks have been carried out using OPNET tool. The applicability of using AODV, TORA and DSR protocols with different queuing mechanisms (FIFO, PQ, and WFQ) for VoIP application has been measured in terms of packet delay jitter, packet end-to-end delay and wireless delay.

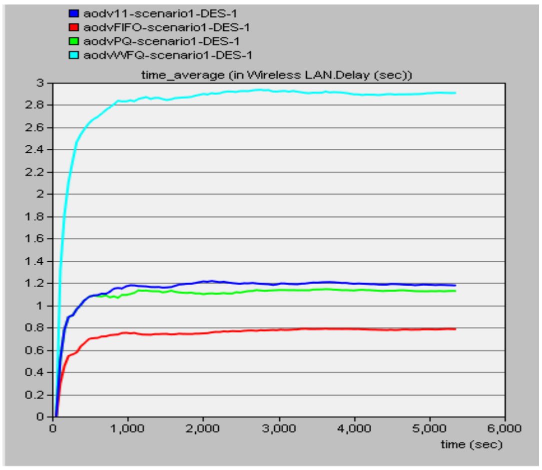

Figure (2): comparison of wireless delay (sec) of AODV protocol for: no queuing (Blue), FIFO (Red), PQ (Green), WFQ (light blue)

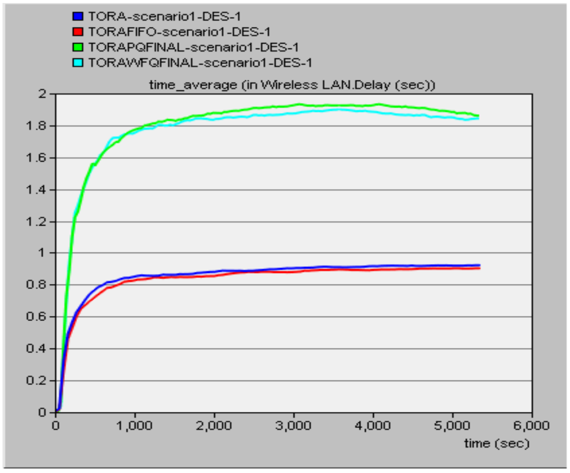

Figure (3): comparison of wireless delay (sec) of TORA protocol for: no queuing (Blue), FIFO (Red), PQ (Green), WFQ (light blue)

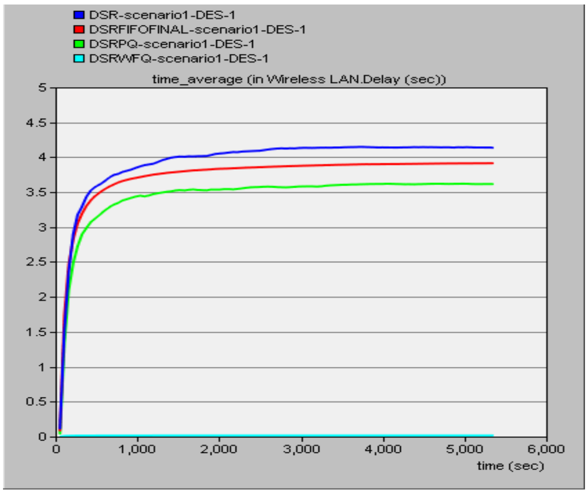

Figure (4): comparison of wireless delay (sec) of DSR protocol for: no queuing (Blue), FIFO (Red), PQ (Green), WFQ (light blue)

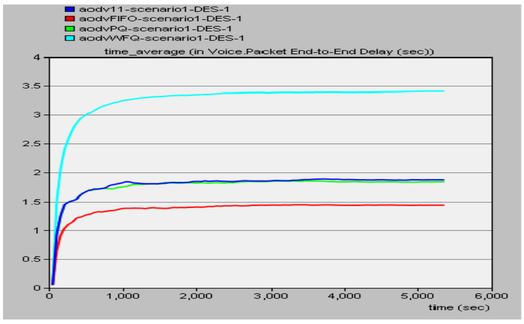

Figure (5): comparison of packet end-to-end delay (sec) of AODV protocol for: no queuing (Blue), FIFO (Red), PQ (Green), WFQ (Light blue)

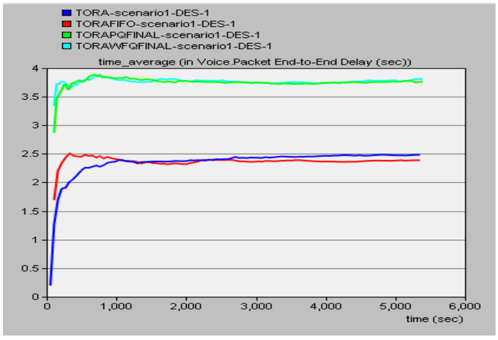

Figure (6): comparison of packet end-to-end delay (sec) of TORA protocol for: no queuing (Blue), FIFO (Red), PQ (Green), WFQ (Light blue)

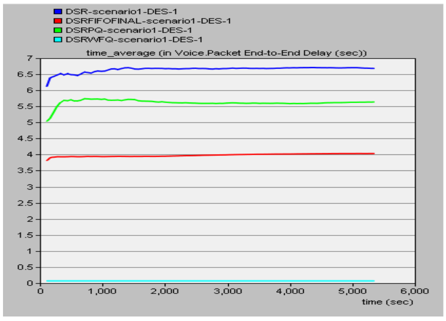

Figure (7): comparison of packet end-to-end delay (sec) of DSR protocol for: no queuing (Blue), FIFO (Red), PQ (Green), WFQ (Light blue)

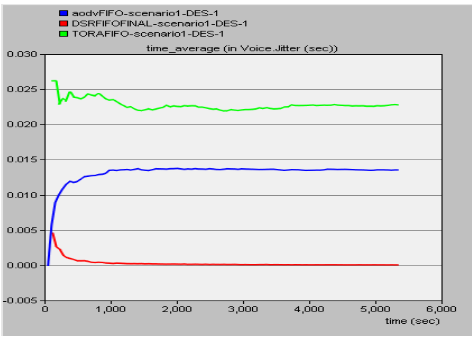

Figure (8): comparison of voice jitter (sec) with FIFO queuing: AODV (Blue), DSR (Red), TORA (Green)

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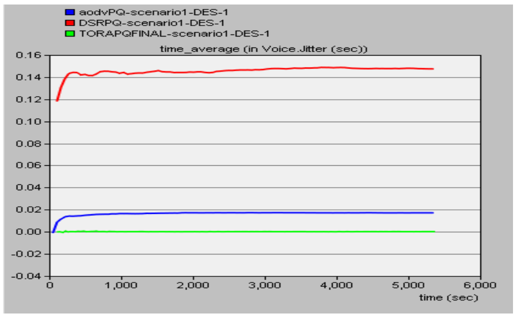

Figure (9): comparison of voice jitter (sec) with PQ queuing: AODV (Blue), DSR (Red), TORA (Green)

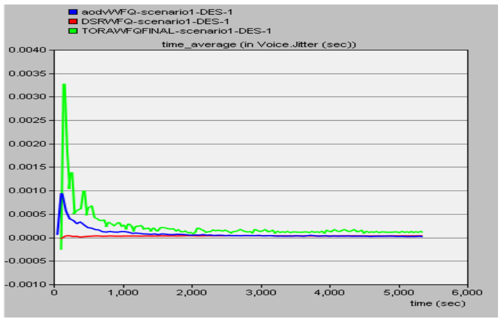

Figure (10): comparison of voice jitter (sec) with PQ queuing: AODV (Blue), DSR (Red), TORA (Green)

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