Performance analysis of routing protocols of mobile ad hoc networks for VoIP applications

Mohammed Shaffatul Islam, Adnan Riaz and Mohammed Tarique, *Members, IEEE*

***Abstract*— Mobile Ad hoc Networks (MANETs) have been an active field of research for the last few years. Many ground breaking applications have been suggested for MANETs including the Voice over Internet Protocol (VoIP). In order to support VoIP application over MANETs a suitable routing protocol is essential. Several routing protocols have been proposed for MANETs. In this paper, the performances of different routing protocols have been investigated and compared for VoIP application. Some popular routing protocols namely Dynamic Source Routing (DSR), Ad hoc On-demand Distance Vector (AODV), Temporally-Ordered Routing Algorithm (TORA), Optimized Link State Routing Protocol (OLSR), and Geographic Routing Protocol (GRP) have been considered in this investigation. The OPNET simulation results show that the TORA protocol is a good candidate for VoIP application.**

***Index Terms*—Ad hoc networks, routing, DSR, AODV, TORA,OSLR, GRP, VoIP**

I. INTRODUCTION

MODERN wireless communication systems are rapidly evolving day by day. The main objective of this evolution is to provide a user with communication services at anytime and from anywhere of the World. Technological advancements and the popularity of the portable computing devices have made this objective an attainable one. Now-a-days, a user can move around while maintaining connectivity with the rest of the World. This type of communication system, categorically known as mobile computing, has grown extensively in the last two decades [1-2]. Existing mobile computing networks can be classified into two broad categories namely (a) infrastructure based networks, and (b) Mobile Ad hoc Networks (MANETs). Infrastructure based networks are administered and maintained centrally. On the other hand MANETs are decentralized and autonomous networks consisting of liberated mobile nodes [2][3][4]. These mobile nodes can be mobile phones, laptops, personal digital assistants (PDAs), MP3 players, and personal computers. These nodes can randomly communicate with each other and hence they can form arbitrary topologies. They not only act as a source or a destination but also forward packets for neighboring mobile nodes. The self-organizing capability of the MANET makes it suitable for certain circumstances when we need to set-up a network on an emergency basis [4]. Some of the applications of MANETs include setting up a network in natural disaster areas, in pre-planned surveillance systems, and in the battle fields [1-5]. One of the limitations of MANETs is its inherent dynamic topology because the hosts (i.e., the source and the destination) and the routers can move around. Another limitation of MANETs is the scarce bandwidth. MANETs need to support a number of simultaneous connections by using a very limited bandwidth. Several other limitations of MANETs can be found in [21]. In order to cope with these limitations an efficient routing protocol is essential for MANETs. Many routing protocols have been proposed for MANETs. In this work we have investigated, analyzed and compared the performances of these routing protocols for VoIP application via OPNET simulator. The main motivation of this paper is to suggest a suitable routing protocol for MANETs so that the performances of the same can be optimized for VoIP applications. Since there have been numerous routing protocols for MANETs we keep this work within a reasonable size by limiting ourselves only to some popular and widely investigated routing protocols namely (1) Dynamic Source Routing (DSR) [12], (2) Ad-hoc On-demand Distance Vector (AODV) [13], (3) Temporally-Ordered Routing Algorithm (TORA) [14], (4) Optimized Link State Routing Protocol (OLSR) [15], and (5) Geographic Routing Protocol (GRP)[15]. It has been shown in the literatures that the performance of a routing protocol varies with the network size. So, we have considered two cases namely (a) a small scale network, and (b) a large scale network. Some of the important performance metrics of VoIP application such as throughput, delay, Jitter, and Mean Opinion Score (MOS) have been investigated and compared. The rest of the paper is organized as follows: section II presents some of the related works found in the literatures. Section III contains brief descriptions of the investigated routing protocols. The Quality of Service (QoS) issues of VoIP application have been discussed in section IV. Section V explains the effects of codecs on voice transmission. Simulation models and results are presented in Section VI. The paper is concluded with section VII.

Mohammad Shaffatul Islam is with Electrical and Electronic Engineering (EEE) department, Khulna University of Science and Technology (KUET). Khulna, Bangladesh (e-mail: mashru.islam@ gmail.com).

Adnan Riaz is with the Technical University of Munich, Munich, Germany (e-mail: adan.riaz@tum.de).

Mohammed Tarique (correspondence author) is with the College of Engineering, Ajman University of Science and Technology, United Arab Emirates (e-mail: m.tarique@ajman.ac.ae).

II. RELATED WORKS

The performances of different 'codecs' have been investigated and compared in [11]. It is shown in [11] that G.711 and GSM-EFR codecs are considered more effective (compared to other codecs) for both small scale and large scale networks respectively. We also considered these two voice codecs in this paper. The voice codec G.711 is a popular waveform codec based on pulse code modulation. This is an uncompressed high quality codec that requires a bandwidth of 64Kbit/s. On the other hand voice codec GSM-EFR is an Enhanced Full Rate (EFR) codec that is an improved version of GSM-FR. This code is based on Algebraic Code Excited Linear Prediction **(**ACELP**)** algorithm. It has a bit rate of 12.2Kbps [11]. At best of our knowledge no previous work has investigated the performance of VoIP application in MANET scenario by using different codecs. But the work presented in [8] is somehow related to our work. In [8] a single hop IEEE 802.11 based ad hoc networks have been investigated. Network load in terms of simultaneous voice streams was varied in [8]. Two performance metrics namely delay and Jitter have been investigated. Packet polarization has been evaluated in a small scale network consisting of 40 nodes. Node mobility has been evaluated in the scenario of 40 nodes allowing direct communication between two nodes. On the other hand, node mobility case has been investigated with a node degree of approximately 11 neighbors per node and an average route length of 2.2 hops. Neither the scalability nor the Quality of Service (QoS) of voice codec performance analysis has been investigated in this work. In another study [10] the performances of MANETs for VoIP application over OSLR, have been evaluated. This work justified the suitability of OLSR as a routing protocol for MANETs running VoIP application. The major limitation of this study is that other established routing protocols have not been considered. Moreover, the performance has been analyzed based on the packet loss only. Other important performance parameters such as delay and scalability are not accounted in this work. In [6] different routing protocols have been analyzed for transmitting voice over hybrid MANET. The hybrid MANET is a special type of network that interconnects a MANET with a fixed infrastructure based IP network. Other research works have been conducted to investigate the performances of the voice transmission using VoIP applications in the MANET scenario. But none of works has made any concrete conclusion about choosing an optimum routing protocol for voice transmission. In this paper, we have investigated some of the routing protocols namely AODV, DSR, OLSR, TORA and GRP. The performances of these routing protocols have been investigated for VoIP applications in term QoS parameters namely throughput, delay, Jitter, and Mean Opinion Score (MOS). These performance parameters have also been compared with the values recommended by International Telecommunication Union (ITU).

III. ROUTING PROTOCOLS FOR MANETS

Designing an efficient routing protocol for MANETs is an exigent problem. Two main functions of a routing protocol are (i) to discover a path between a source and a destination, and (ii) to maintain these discovered paths. These two functions should be implemented by using minimum overhead or control messages. Dynamic topology is a major obstacle that a routing protocol has to deal with. An efficient routing protocol should also have some other desired characteristics namely distributed operation, loop-free path discovery, and demand based operation. It should also support unidirectional link, maintain a set of routes and have a "Sleep" period operation [2][7][8]. Researchers have proposed several routing protocols for MANETs. These MANET routing protocols can be classified as proactive (table-driven) and reactive (on-demand) [3]. Proactive routing protocols refer to the routing protocols in which the routing information is periodically exchanged among mobile nodes. Each node is allowed to build a global knowledge of the network independently. The most typical representative of a proactive routing protocol is Dynamic Destination Sequenced Distance Vector (DSDV) [20]. On the other hand the reactive routing protocols work on-demand. It works on-demand in a sense that a mobile node discovers a route when it has some packets to send to another mobile node. The most typical representative of the reactive routing protocol is Dynamic Source Routing (DSR) protocol [12] and Ad hoc On Demand Distance Vector (AODV) routing protocol [3]. These protocols use blind 'flooding' mechanisms during the route discovery process. According to this mechanism each mobile node is obliged to re-broadcast a route request that it receives from its neighboring mobile nodes. Hence, blind 'flooding' wastes valuable resources like network bandwidth. To overcome this shortcoming other types of protocol have been proposed in the literatures namely (a) mixed routing protocol: it is a combination of proactive routing protocol and reactive routing protocol, and (b) position-based routing protocol: it is based on the location information of the mobile nodes. Other numerous routing protocols have also been proposed in the literatures [1-2][19]. Since we limit this effort only to Dynamic Source Routing (DSR), Ad-hoc On-demand Distance Vector (AODV), Temporally Ordered Routing Algorithm (TORA) [14], Optimized Link State Routing (OLSR)[16] and Geographic Routing Protocol (GRP) [17], brief descriptions of these investigated routing protocols have been provided in the following subsections.

A. Dynamic Source Routing (DSR) Protocol

The Dynamic Source Routing (DSR) [3] protocol is a reactive routing protocol proposed for MANETs. When a node generates a packet to send to a certain destination and it does not have a known route to that destination, this node initiates a route discovery process. There are two main mechanisms in DSR protocol namely route discovery and route maintenance. During the route discovery procedure mobile nodes maintain ID lists of the recently seen requests to avoid processing the same route request again and again. The route maintenance procedure is used when routes become invalid due to unpredictable movement of the routers. Each router monitors the links that it uses to forward packets. Once a link is down, a route error packet is immediately sent to the initiator of the associated route. Therefore, the invalid route is quickly discarded. The main advantage of the DSR protocol is that no periodic routing packets are required. It has some disadvantages too. Since DSR is a reactive protocol, it cannot detect whether a destination is unreachable or the route request is lost. Therefore, it incurs more overhead if the underlying MAC layer does not support a guaranteed delivery [11]. Moreover, the DSR protocol performs poorly in the networks with high mobility and heavy traffic loads because of large overhead packets. Scalability is said to be another disadvantage of the DSR protocol because it relies on blind broadcasts (i.e., blind flooding) to discover the routes [11].

B. Ad Hoc on Demand Distance Vector Routing (AODV)

The Ad hoc On-demand Distance Vector (AODV) [13] routing protocol is also a reactive routing protocol proposed for MANETs. The mechanisms of the AODV protocol are similar to those of DSR protocol. The main differences between these two protocols are in maintaining and using the routing information. In AODV, the number of hops is recorded in the route record instead of a list of intermediate router addresses. Each intermediate router sets up a temporary reverse link in the process of a route discovery. This link points to the router that forwarded the request to this intermediate router. Hence, the reply message can find its way back to the initiator during the route discovery process. When the intermediate routers receive the reply, they can also set up the corresponding forward routing entries. To prevent old routing information being used as a reply to the latest request a destination sequence number (DSN) is used in the route discovery packet and the route reply packet. A higher sequence number implies a more recent route request. The AODV protocol uses the control messages namely Route Request (RREQ), Route Replies (RREP) and Route Error (RERR). The route maintenance of the AODV protocol is similar to that of the DSR protocol. One advantage of AODV is that it is a loop-free routing protocol due to the destination sequence numbers associated with the routes. Similar to DSR, poor scalability is the main disadvantage of the AODV protocol [3] [13].

C. Temporally-Ordered Routing Algorithm (TORA)

The Temporally-Ordered Routing Algorithm (TORA)[14] is considered as an adaptive routing protocol for multi-hop networks. The TORA protocol is a distributed algorithm so that routers only need to maintain knowledge about their neighbors [3][14]. This protocol takes the advantages of a reactive routing protocol and a proactive routing protocol. Sources initiate route requests in a reactive mode. At the same time selected destinations may start proactive operations to build traditional routing tables. TORA supports multiple path routing. It has been investigated and proved that TORA minimizes the communication overhead associated with network topology changes [3]. The reason is that TORA maintains multiple paths and it does not need to discover a new route when the network topology changes or all routes in the local route cache fail. TORA assigns directions to all links according to the heights of their neighboring routers in terms of *upstream* or *downstream*. A link is considered as an upstream link for the "lower" neighboring router. At the same time, it is also a downstream link for the "higher" neighboring router. An upstream link of a router implies that data flows to a corresponding destination must go through this router via that link. A downstream link of a router means that the data flows can only leave this router to the neighboring router via this link. TORA is a complex routing algorithm compared to DSR protocol. It has four main operations namely (i) creating routes, (ii) maintaining routes, (iii) erasing routes, and (iv) optimizing the routes [14]. Four types of packets are used to perform these operations namely query (QRY), update (UPD), clear (CLR), and optimization (OPT) [14].

D. Optimized Link State Routing Protocol (OLSR)

The Optimized Link State Routing (OLSR) protocol is a proactive link state routing protocol proposed for MANETs. One key idea is to reduce the control overhead by reducing the number of broadcasts as compared with pure blind 'flooding' mechanisms. The basic concept of OLSR is the use of multipoint relays (MPRS) [15]. MPRS refer to the selected routers that can forward broadcast messages during the flooding process. To reduce the size of broadcast messages every router declares only a small subset of all of its neighbors. OLSR has three functions: packet forwarding, neighbor sensing, and topology discovery [15]. Packet forwarding and neighbor sensing mechanisms provide routers with information about the neighbors and offer an optimized way to flood messages in the OLSR network using MPRS. The neighbor sensing operation allows routers to diffuse local information in the whole network. Topology discovery is used to determine the topology of the entire network and to construct the routing tables. OLSR uses four message types: 'Hello' message, Topology Control (TC) message, Multiple Interface Declaration (MID) message, and Host and Network Association (HNA) message [15] [16]. OLSR protocol is particularly suitable for large and dense networks. The larger and the more dense a network, the more optimization can be achieved as compared to the classic link state algorithm [15-16].

D. Geographic Routing Protocol (GRP)

Geographic Routing Protocol (GRP) is a position-based protocol classified as Proactive Routing Protocol [18]. Each location of the node will be marked by Global Positioning System (GPS) and the flooding will be optimized by quadrants [17]. Flooding location is updated on the distance when a node moves and crosses a neighborhood. A 'Hello' message will be exchanged among nodes to identify their neighbors and their positions. By using route locking a node can return its packet to the last node when it cannot keep on sending the packet to the next node. GRP divides an ad hoc network into many quadrants to reduce route the flooding [17]. The entire World is divided into quadrants from Lat, Long (-90, -180) to Lat, Long (+90, +180). Every node knows the nitial position of every other accessible node once initial 'flooding' is completed in the network. When the node moves a distance that is longer than the user has specified or when the node crosses a quadrant the routing flooding will take place [17].

IV. Quality of Service (QoS) for VOIP

Traditionally circuit switching has been used for carrying voice traffic. But it requires a huge infrastructure. Hence, it is considered an expensive solution for VoIP application. Now-a-days, a subscriber wants to communicate in myriad other ways such as e-mail, instant messaging and video in addition to voice traffic. Circuit switching is not considered a suitable technology for this type of multimedia communications [2]. VoIP technology is more suitable for multimedia communication. Some of the reasons are as follows (a) low equipment cost, (b) low operating expense, (c) integration of voice and data application, (d) potentially low bandwidth requirement, and (e) widespread availability of the Internet Protocol (IP). When addressing the Quality of Service (QoS) needs for VoIP the following performance parameters need to be considered (a) packet loss rate (for high quality VoIP services) should be less than 0.25 percent, (b) one-way latency should be no more than 150 ms as per the International Telecommunication Union (ITU) G.114 specifications, (c) Jitter should be less than 10 ms, and (d) 21-106 kilobits per second (kbps) of guaranteed priority bandwidth is required per call.

The voice quality can be interpreted as a way of evaluating speech clarity and the characteristic of the analog voice itself. However, it also depends on the underlying transport mechanism. Voice quality should be assessed from an end-to-end perspective regardless of the systems, devices, and transmission methods used. In addition, voice-quality metric should also be expressed in the context of the users' experience. In this work we measure the voice quality in terms of the metrics mentioned in ITU-T P.862 (Perceptual Evaluation of Subjective Quality Speech Quality Assessment) [6]. According to ITU-T P.862 Objective Mean Opinion Score (OMOS) should be used to measure the quality of speech. Because the subjective quality of speech evaluated by humans with Mean Opinion Score (MOS) or Degradation Mean Opinion Score (DMOS) scale. OMOS provides more detailed analysis compared to ordinary subjective MOS. The complete scales for speech quality assessment are listed in Table I.

V. Effects of codecs

Non-linear perceptual 'codecs' compress voice in such a way so that the perceptually important information is preserved. In other words, these 'codecs' preserve how the voice sounds without preserving all of the frequency spectrum information. This non-linear compression might then imply that the technique of measuring the parameters stated above may not indicate a true reflection of the actual quality of an audio output. For instance, the effect of the packet loss is smaller compared to the Jitter for the 'codecs' that uses packet loss concealment strategies. This is obvious because the 'codecs' can conceal a few consecutive packet losses by estimating a replacement for them. But the influence of Jitter cannot be concealed unless it exceeds the packet loss indication delay. The delay does not affect speech quality directly but instead affects the quality of a conversation. For example, most users will not notice a delay of 100 ms, but they will notice a slight hesitation in their partner's response for longer delay. Hence, a short delay results in better conversation quality and in a better perceived overall voice quality. When the delay is excessive, users might also notice an 'echo' which exists in most conversations. But this 'echo' is undetectable due to short end-to-end delay in the network. Each end station in VoIP or video over IP conversation has a Jitter buffer. Jitter buffers are used to compensate the changes in the arrival times of data packets containing voice. A Jitter buffer can be dynamic and adaptive. If there are instantaneous changes in arrival times of packets that are beyond the capability of a Jitter buffer's ability to compensate, there will be jitter buffer over-runs and under-runs. Both of them result in the degradation of voice quality. For our investigation we used Voice codes G.711 for transmission in smaller network and GSM-EFR in the large network. These two voice codes are used for VoIP applications as they are superior candidate for voice applications in their respective network scenario [11].

TABLE I
Speech Quality Rating, MOS and DMOS

Rating	Speech Quality (MOS)	Level of Distortion (DMOS)
5	Excellent	Imperceptible
4	Good	Just perceptible but not annoying
3	Fair	Perceptible and slightly annoying
2	Poor	Annoying but not objectionable
1	Unsatisfactory	Very annoying and objectionable

VI. Simulations and Results

The performances of different routing protocols for VoIP applications have been investigated via OPNET simulator. The default parameters used in the simulations are listed in the Table II. Simulations were conducted for a moderately loaded network. We choose two different areas of operation namely 800m x 800m and 1600mx 1600m. These two different network sizes were selected so that we can measure the performances of the networks for small and large scale inter-node distances. The protocols used and the application settings for the simulation are listed in the Table III. The performances of the simulated networks have been analyzed based on different performance matrices namely (1) voice quality, (2) Jitter, (3) throughput, (4) packet end-to-end delay, (5) Wireless LAN delay, and (6) packet delay variation. The voice quality has been monitored in terms of MOS scale. We only considered the packet end-to-end delay of the application. The overall end-to-end delay is calculated as the average of the delay of all packets. In the simulations we considered two cases namely (a) a small scale scenario, and (b) a large scale scenario.

TABLE II
SIMULATION PARAMETERS

Parameters	Values
Number of nodes	25 and 85
Network size	800m × 800m and 1600m × 1600m.
Node location	Placed in row and column based manner.
Mobility	Random waypoint model with continuous movement. The maximum and the minimum speed of the mobiles were 5m/s and 10 m/s respectively.
Communication model	Selection by strict channel match
Distance Threshold	300m
Simulation time	600 simulation seconds

TABLE III
SIMULATED APPLICATION AND PROTOCOLS

Parameters	Values
Physical layer	Segmented calculation of the signal power and SNR
MAC layer	IEEE802.11 DCF with transmission rate of 12 Mbps for voice application
Routing	AODV,DSR,TORA, OLSR and GRP
Applications	Voice
Codec	G.711 and GSM-EFR
Frame size	20 ms
Compression and Decompression delay	0.02 sec.
Type of service(TOS)	Interactive voice

A. The small scale scenario

In small scale scenario G.711 voice codec is used to transmit data in a MANET consisting of 25 nodes. Different routing protocols have been chosen according to Table III. The voice quality in terms of MOS values of different routing protocols is shown in Fig.1. It has been observed that the voice quality of TORA protocol outperforms other routing protocols over the transmission period. It is also observed from Fig.1 that the voice MOS value of TORA protocol is stable and it increases slightly with respect to time compared to the voice MOS values of other protocols. The performance of DSR protocols degraded tremendously from the starting of transmission. The voice MOS values of other protocols such as AODV, GRP and OLSR also have decreased with the transmission time. For example, at 300 seconds the voice MOS value of TORA protocol is 3.54 in the scale of 5. For other protocols like OLSR, AODV and GRP have MOS values of 2.54, 1.93 and 1.62 respectively in the same scale at the same time (i.e. 300 second). The voice quality of the DSR protocol is the worst among all the investigated routing protocols which is 1.16 seconds.

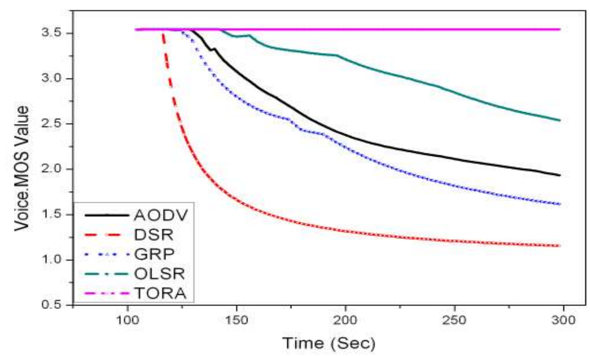


Fig 1: Voice quality of different MANET Protocols for G.711 codec

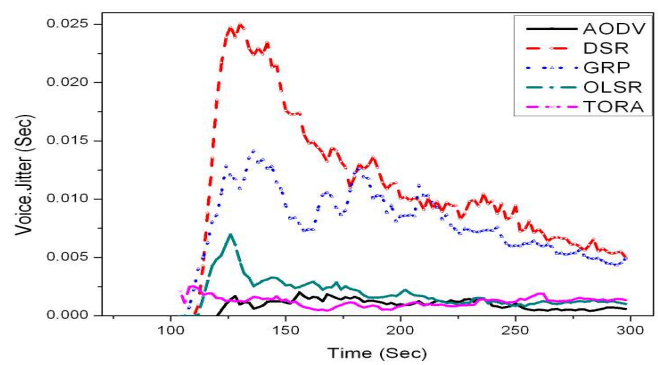


Fig 2: Voice jitter For G.711 codec

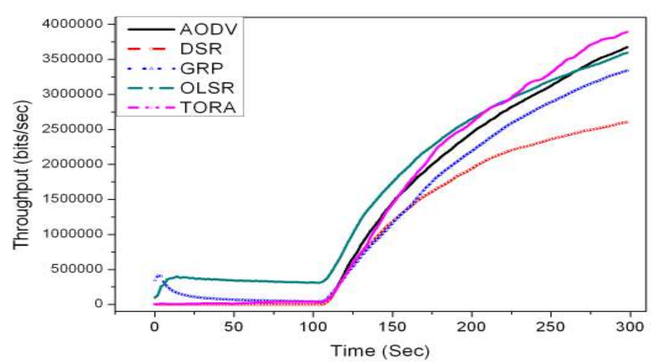


Fig 3: Throughput analysis of MANET routing protocols for G.711 codec

By analyzing the voice Jitter performance as shown in Fig.2 we can conclude that TORA has the minimum and acceptable voice Jitter of 0.00082 sec at 200 seconds. On the other hand

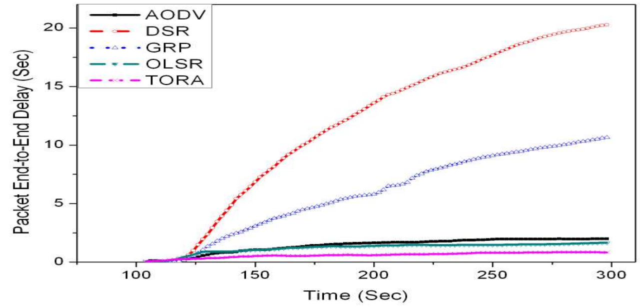
AODV and OLSR have voice Jitters of 0.00097 sec and 0.00193 sec respectively. The voice Jitters are severe for DSR and GRP protocol with respect to other three routing protocols. These Jitter values are 0.008567451 sec and 0.010044743 sec respectively that occurred at 200 seconds.

Fig. 3 shows the throughput performances of different routing protocols with respect to transmission time. It is depicted in this figure that the throughput increases as the voice transmission time increases for all the routing protocols. It is evident that the throughput of TORA protocol increased significantly with voice transmission and the highest throughput occurred at 300 sec. The figure shows that this throughput was 3893566.4 bits/sec. At the same time AODV, OLSR and GRP have attained throughputs of 3673585.92 bits/sec, 3594760 bits/sec and 3339413.467 bits/sec respectively. The delay performances of different routing protocols are illustrated in Fig. 4. Analyzing the delay performances of different routing protocols based on Fig. 4 we can conclude that the packet end-to-end delay, wireless LAN delay and packet delay variation are the minimum for TORA protocol. The delays for other protocols are not as much significant as that of TORA and the delay performance is the worst for DSR protocol. Analyzing all the performance matrices it is evident that TORA protocol is the best candidate for VoIP application especially with voice codec G.711 over MANET in small scale network. Analyzing the delay performances of different routing protocols presented in Fig. 4 we can conclude that the packet end-to-end delay, wireless LAN delay and packet delay variation are the minimum for TORA protocol.

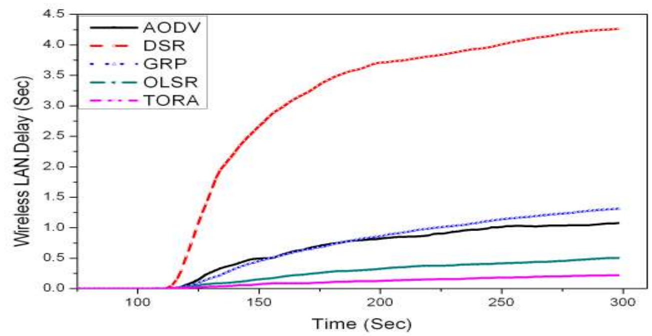
The delays for other protocols are not as much significant as that of TORA and the delay performance is the worst for DSR protocol. So from the study and analyzing all the performance matrices it is evident that TORA protocol is the best candidate for VoIP application especially with voice codec G.711 over MANET in small scale network.

B. Large scale scenario

For investigating the performance of VoIP application in a large scale scenario GSM-EFR voice codec was used. In this large scale scenario the simulated MANET contains 85 nodes. The same routing protocols (as listed in Table III) have been used in this investigation. The voice quality in terms of MOS values is depicted in Fig. 5. This figure shows that the performances of GRP, OLSR and TORA protocols are more or less same at the starting of the network operation. It is also shown in the same figure that the voice MOS value of GRP protocol is stable whereas the MOS values of OLSR and TORA decrease after 180 seconds of voice data transmission. The MOS values of the AODV and DSR protocols degraded with respect to time. The DSR protocol has the lowest MOS value compared to other protocols. This lowest MOS value is 1.34 occurred at 250 seconds in the scale of 5. Fig. 6 shows the voice Jitters of different routing protocols. It is depicted that the performance of TORA protocol is the best compared to other protocols. The TORA protocol has the least amount of Jitter during the whole transmission compared to other four investigated routing protocols. The DSR protocol has the highest Jitter among the studied routing protocols for the large scale scenario.



(a)



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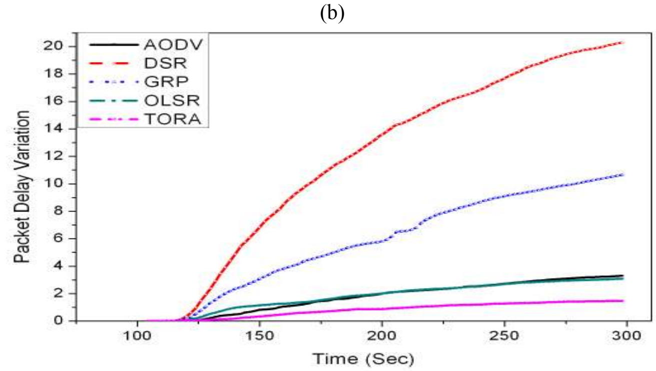


(c)

Fig 4: Delay analysis for small scale scenario for G.711 voice codec (a) Packet end to end delay (b) Wireless LAN delay and (c) Packet delay variation.

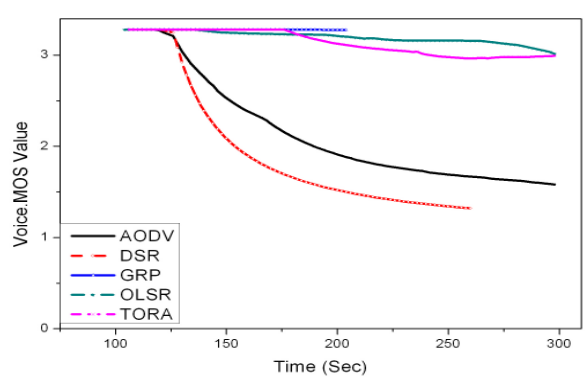


Fig 5: The MOS values of different routing protocols

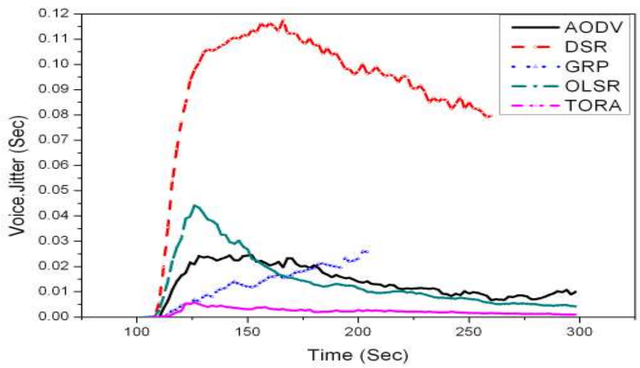


Fig 6: Voice jitter for GSM-EFR codec

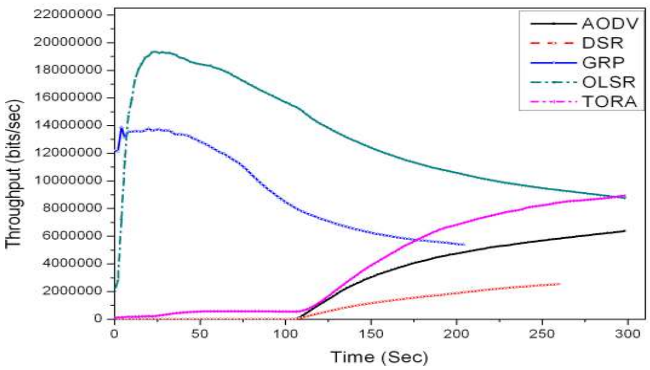


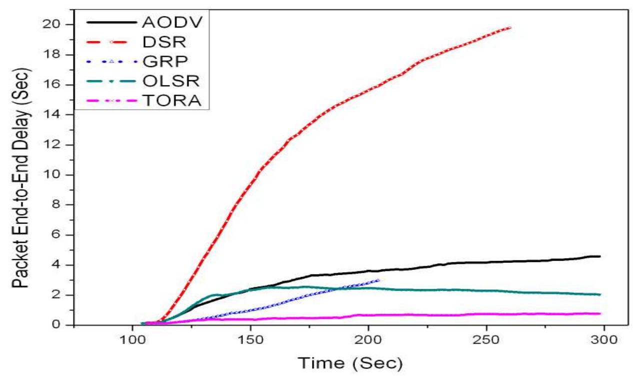
Fig 7: Throughput of GSM-EFR codec

The throughput comparisons of the investigated protocols have been presented in Fig. 7. It is depicted in this that the throughputs of OLSR and GRP protocols are dominant at the starting of the data transmission. But the throughput started decreasing with the transmission time. On the other hand the throughputs of DSR, AODV and TORA protocol started increasing after 110 seconds of voice data transmission. It can also be concluded from Fig. 7 that the throughput performance of TORA protocol is the best compared to other routing protocols. On the other hand, the throughput performance is the worst for DSR protocol.

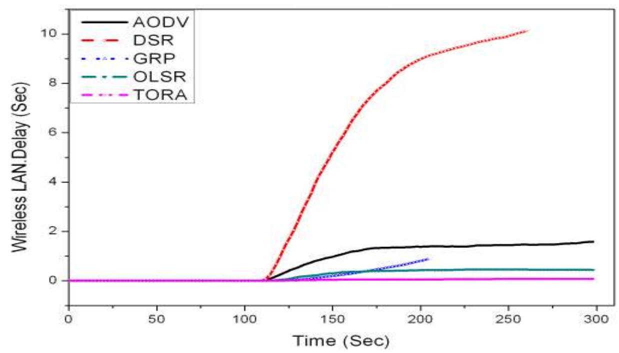
The results of the delay analysis are shown in Fig. 8. These figures show that the packet end-to-end delay, wireless LAN delay and packet delay variations are the least for TORA protocol. Other protocols poorly perform compared to TORA protocol. Comparing the delay performances of different routing protocols we can conclude that the DSR protocol is not suitable for VoIP application. Because the packet delay variation of DSR protocol is as large as 100 sec and the end-to-end delay is nearly 19 sec.

The delay performances of other four routing protocols are also acceptable for VoIP application. But TORA protocol stands out as the best candidate compared to other protocols. For example, the packet end-to-end delay is nearly 1 sec, wireless LAN delay is zero and the packet delay variation is nearly 1 sec. These delay figures are considered excellent for VoIP application according to ITU recommendations.

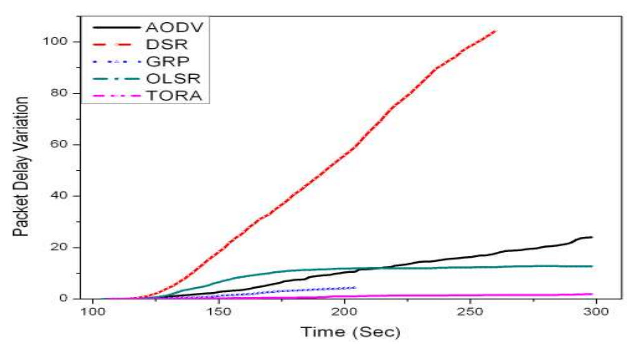
Studying the performances of different routing protocols for the large scale scenario we can conclude that the performances of TORA, OLSR and GRP protocol are acceptable for voice transmission although the throughput and voice MOS values are not superior.



(a)



(b)



8(c)

Figure 8: Delay comparisons of different routing protocols for 85 nodes (a) Packet end to end delay, (b) Wireless LAN delay and (c) Packet delay variation.

The TORA protocol outperforms other protocols due to its adaptability and proactive nature. In large scale scenario the performance of DSR is the poorest and hence it is should not considered a suitable routing protocol for voice transmission.

VII. CONCLUSIONS

In this paper, the performances of different popular routing protocols have been investigated for VoIP application in MANET scenario. After studying all the performance matrices we can conclude that TORA protocol is a good candidate compared to other protocols that we have investigated in this work. The TORA protocol uses the optimized routing algorithm to adjust the heights of routers to improve routing algorithm. This kind of adaptive routing algorithm makes TORA more suitable for VoIP application over MANETs compared to other routing protocols. The TORA protocol also minimizes the overhead control messages that results in low delay. On the other hand the performance of DSR protocol is the poorest compared to other routing protocols. Hence, the DSR protocol (in its current form) is not suitable for VoIP application over MANET in both small scale and large scale scenarios. The reactive nature and failure to control overhead messages make the DSR protocol poorly performs in terms of QoS parameters. In addition, the traffic loads and node mobility degraded the performances of the DSR protocol. In large scale condition GRP and OLSR performs better than small scale condition for their proactive nature and position based routing respectively. But, the performances of these two protocols are not comparable with those of TORA protocol. Although this investigation goes in favor of TORA protocol, for using voice codes G.711 and GSM-EFR in small and large network respectively we need do to a more comprehensive study to confirm this claim. We need to investigate the other routing protocols proposed in the literatures. In addition to this other proposed 'codecs' also need to be investigated. These are all left as the future works.

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