Scientific Research and Essays Vol. 6(14), pp. 3015-3026, 18 July, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.387
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

SQR-AODV: A stable QoS-aware reliable on-demand distance vector routing protocol for mobile ad hoc networks

Shahram Jamali[1]*, Bita Safarzadeh[2] and Hamed Alimohammadi[3]

[1]Department of Computer Engineering, University of Mohaghegh Ardabili, Ardabil, Iran.
[2,3]Department of Computer Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran.

Accepted July 7, 2011

In a mobile ad hoc network (MANET), the topology of the network may change rapidly and unexpectedly due to mobility of nodes. Thus, setting up routes that meet high reliability is a very challenging issue. Another important problem in the MANETs is the energy consumption of nodes. When the energy of a node is depleted, it stops working thus links break. Hence it is very important to find a route that has sufficient energy level and high stability, and so can obtain reliable routing and data transmission. To address the aforementioned problems, we propose a reliable QoS routing protocol which bases on the route life time that is obtained using mobility information, the residue energy and hop count. Therefore in this scheme, data is sent through a route with high stability, high residue energy level and low latency. Simulation results show that the SQR-AODV protocol achieves high reliability and stability and also long life time of the network, with high packet delivery ratio, high throughput, low energy consumption and considerable load balancing as compared to best-known on-demand protocol, AODV.

Key words: Mobile ad hoc network, routing, ad hoc on-demand distance vector, quality of service.

INTRODUCTION

A mobile ad hoc network sometimes called a mobile mesh network is a self configuring network of mobile devices connected by wireless links. Random mobility of the devices in the MANETs causes that the links between the nodes change frequently. Many routing protocols have been proposed for MANETs (Hanzo and Tafazolli, 2007; Perkins and Bhagwat, 1994; Perkins and Royer, 1999). These routing protocols can be classified to two classes: table-driven (also called proactive) and on-demand (also called reactive). The proactive routing protocols maintain fresh lists of destinations and the routs by periodically distributing routing tables throughout the network. Well known protocol of this type is the DSDV (Perkins and Bhagwat, 1994). Main disadvantages of such algorithms are: respective amount of data for maintenance, slow reaction on restructuring and failures.

On the other hand, two famous reactive protocols are the ad hoc on-demand distance vector routing (AODV) (Perkins and Royer, 1999) and the dynamic source routing (DSR) (Johnson and Maltz, 1996). The main disadvantages of such algorithms are: high latency time in route finding, excessive flooding that can lead to network clogging. While DSDV itself does not appear to be used today, other protocols have used similar technique. The best-known sequence distance vector protocol is AODV, which, by virtue of being a reactive protocol, can use simpler sequencing heuristics. DSR is similar to AODV in that it forms a route on-demand when a transmitting node request one. However, it uses source instead of relying on the routing table at each intermediate node. The mobile ad hoc wireless networks are rapidly becoming the preferred solution for flexible and low cost networking.

There are many MANET routing protocols that focus on finding a short path from a source node to a destination node without any consideration for utilization of network

*Corresponding author. E-mail: jamali@iust.ac.ir.

resources or for supporting specific application requirements, such as quality of service (QoS) considerations (Boshoff and Helberg, 2008; Du, 2004; Hanzo and Tafazolli, 2007; Vergados et al., 2008). On the other hand, many applications of MANETs need to get QoS-enabled packet delivery services such as military and first responder applications. Packet delivery ratio (PDR) is one important QoS parameters in MANETs. For maximizing this parameter, routing of network must find routes with high stability and sufficient energy level. In this paper, we propose a stable QoS-aware 'on-demand distance vector routing protocol' (SQR-AODV) for MANETs by constructing most reliable route path from a source node to a destination node. Our protocol is an enhancement over AODV. It selects a routing path based on the two following parameters:

1) Stability of paths from the source node to the destination node. For calculating stability of a path, SQR-AODV uses the link life time (LLT) between two connected mobile nodes using mobility information of nodes obtained by global positioning system (GPS).
2) Residue energy of paths found from the source node to the destination node. For determining residue energy of a path, we find node with minimum residue energy along that path.

Then we use three parameters: the route life time, the residue energy and the number of hops to select a routing path with high stability, sufficient energy level and low latency, and consequently high quality. This paper is organized as follows: subsequently, a review is done on the researches that have been done in the field of the QoS-aware routing, after which the proposed protocol in the study is explained. The study further presents the simulation results and discussion, before finally presenting the conclusion.

RELATED WORK

In the MANETs, finding the routes that satisfy QoS requirements in order to communicate and transit data through the network is a complex issue. It is the critical applications because the nodes have high mobility and consequently the network topology is highly dynamic. Therefore, there is a need for a protocol that setup a route with mentioned properties, considering QoS constraint such as delay, power and throughout. Some researchers have proposed proactive routing protocol for QoS support (Chen and Nahrstedt, 1999; Sivakumar et al., 1999). However, the proactive protocols are more reliable to suffer performance degradation than on-demand protocols due to state route information. Many on-demand QoS routing protocols have been proposed for MANETs. In Barolli et al. (2003), finding routing paths was made faster using the genetic algorithm. Sun and Hughes (2003) proposed the adaptive QoS protocol based on the prediction of link performance. This algorithm uses link status probabilities and performance to determine the motion of the node. Xue and Ganz (2003) proposed a QoS routing in IEEE.802.11b to obtain bandwidth and end-to-end delay for routing. Boshoff and Helberg (2008) modified the AODV routing protocol to a multi-path protocol for MANETs. In this protocol, end-to-end delay was used for route selection instead of hop count. In Reddy et al. (2006) a multi-path routing protocol was proposed that focused on reliability and security as two important issues for QoS routing. Ziane and Mellouk (2007) proposed an algorithm using reinforcement learning method that was optimized based on the swarm intelligence paradigm. This algorithm provided adaptively for QoS support. In recent years, many routing algorithms were proposed for MANETs that need the coordinates of nodes for routing process.

In order to obtain this information, global positioning system (GPS) can be employed (Boukerche and Rogers, 2001; William and Mario, 1999). We can calculate the stability of routing path using current and future position of nodes. Therefore, the best path is mathematically determined which can be shortest path or not. Clearly, if the routing process is accomplished without any consideration to the movement of nodes and the stability of routing path, the links may be easily broken. There are many routing protocols that deal with network's stability for maximizing it (Chiu et al., 2002; Griffin et al., 2002; Kim et al., 2001). We know that a route breakage causes the route discovery and maintenance procedures to be executed which need many resources. Therefore, it is important to find and setup a route with longer life time as possible (Lim et al., 2002; Tseng et al., 2003). If a routing protocol can enhance stability, it leads to lower overhead and higher efficiency. As another research, Wang and Lee (2009) proposed a reliable multi-path QoS routing protocol with a slot assignment scheme. In the protocol, two parameters: the route life time between two connected mobile node and the number of hops was used to select a routing path with low latency and high stability. One of the essential concepts in the MANETs is the energy constraints that have more importance if we are designing a QoS protocol because when the energy of a node is depleted, it failed. This node failure causes that the links between the node and others is broken. In the following, we review some of the research that considered the energy concept for routing in the MANETs. In Liang and Ren (2005) a multi-path routing protocol was proposed considering mobility and energy of the nodes. Based on these parameters, a fuzzy logic system was presented for the next hop selection. Akkaya and Younis (2003) designed a QoS routing protocol with energy consideration that is performed effectively and with best effort traffic. This protocol discovers a path with minimum cost. In fact, route selection parameters or link cost for real-time data is based on parameters of transmission energy, energy level of node, fault rate and other communication factors.

An energy saving scheduling method was proposed in Liao and Yen (2009) in order to improve energy efficiency and guarantee WiMAX QoS. This algorithm schedules the packets in order to decrease status transmission and satisfy delay and jitter requirements. Many algorithms have been proposed, but AODV protocol is the most employed routing protocol in the MANETs. In order to make AODV a reliable and stable, we should take into account more parameters in route selection, in addition to hop count, because the shortest route is not always the best route. For this goal, the residue energy and stability are two most important concepts.

SQR-AODV: Proposed routing protocol

In a MANET, nodes are able to move randomly at any time and change network topology. Thus, setting up routes with high stability is not an easy problem. In addition, since MANETs are power-constrained, then energy consumption of nodes is another important problem. When the energy of a node is depleted, it stops working thus links connected to it break some part or even whole of the network will be failed. Therefore it is very important to find a route that has sufficient energy level and high stability, and so can obtain reliable routing and data transmission. Here, we propose a high reliable stable routing protocol with mobility prediction for MANETs. The proposed protocol includes route discovery, route selection and route maintenance phases.

Link life time

The link life time prediction is a method; in order to be employed each mobile device should be equipped with a GPS receiver for obtaining its longitude and latitude. Using this geographical information and considering the network area map we can determine the position of each node. For calculating the nodes direction and speed, the position information of them should be updated continuously. Assuming two mobile nodes A and B are within the radio transmission range of each other, we let:

(X_A, Y_A): coordinate of mobile node A;
(X_B, Y_B): coordinate of mobile node B;
V_A: mobility speed of mobile node A;
V_B: mobility speed of mobile node B;
θ_A: direction of motion of mobile node A ($0<\theta_A<2\pi$);
θ_B: direction of motion of mobile node B ($0<\theta_B<2\pi$).

Using the aforementioned parameters, we can define the link life time equation as follows (Rappaport, 1995):

$$LLT = \frac{-(ab+cd) + \sqrt{(a^2 + c^2)r^2 - (ad-cb)^2}}{(a^2 + c^2)} \quad (1)$$

Where,

$$a = v_A\cos\theta_A - v_B\cos\theta_B,\ b = x_A - x_B,\ c = v_A\sin\theta_A - v_B\sin\theta_B,\ d = y_A - y_B$$

The link life time is calculated at each hop during the route request packet is traversing the path. Each node calculates the life time of the link between itself and previous hop. If node A is the previous hop of the packet for node B, it appends its position and movement information to the route request packet. When node B receives this packet, it calculates the life time of the link A→B.

Route discovery

When a source node wants to transmit some data to a destination node, it needs an active route from itself to the destination. If the source node has no active routing information regarding the destination, it initiates the route discovery process. Like AODV, our protocol neither maintains any routing table nor exchange routing table information periodically. When a source node requires a communication, it broadcast a route request (RREQ) packet to its neighboring nodes until they reach to the destination node. In our protocol, each RREQ packet records information of all links-status and nodes along traversed path. Link-status information is delivered from the source node to the destination node. The destination node may receive link-status information from different RREQ packets; it means that there are different feasible paths. Finally, required computation for route selection is accomplished at the destination node and result is backward to the source node in order to decide route. We define RREQ packet format as follows:

Type: the type of packet;
S: the source node address;
D: the destination node address;
SEQ: the packet sequence number;
PMI: the position and movement information of mobile nodes that consists of location, velocity and direction;
RLT: minimum of life time of links that RREQ packet traversed them;
RME: minimum of residue energy level of nodes that RREQ packet traversed them;
HC: hop count;
TTL: the maximum hop length of the path that is constructing.

Now, we explain route discovery process. To start we should describe four parameters:

LLT: denotes the link life time between two nodes which is calculated by using Equation 1. Each mobile node indentifies its position and movement information using GPS. First, when a source node broadcasts a RREQ

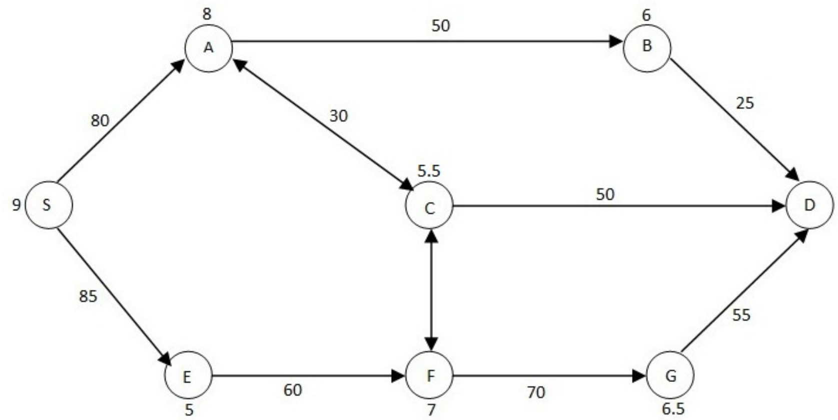

Figure 1. The RREQ packet delivery.

packet, it appends its position and movement information (such as location, velocity and direction) to the PMI field of RREQ packet. Upon a node receives the RREQ packet, it calculates the link life time by using PMI field of the RREQ packet and its own position and movement information.

RLT: is the minimum link life time along a routing path. Therefore, the RLT is equal to the minimum of LLTs for a route.

RME: is the minimum of the residue energy level of nodes along a routing path.

Hop count (HC): is number of links of a path. Now, we describe stages of the RREQ packet delivery process.

Stage 1

Source node S sets up TTL to number of all the nodes in the network. Then it broadcasts a route request packet to its neighboring nodes.

Stage 2

When the intermediate node N_t receives the RREQ, if itself is not the destination, it updates some fields of the RREQ packet such as PMI, RLT and RME as earlier explaned. Then it decrements the TTL value and increments hop count. If the node N_t is not the destination and also the TTL value is not zero, then it forwards the RREQ packet to all its neighboring nodes. If TTL value is zero, it drops the RREQ packet and does not re-forward that to any node.

Stage 3

If node N receives a RREQ packet and it is the destination node, it first appends the RREQ packet information to its own routing table and after that, uses Equation 2 to calculate route quality factor that is R. Then, it appends this value to the route reply (RREP) packet and backwards the RREP packet to the source node through same path. The destination node does this operation for all received RREQ packets. The R value is the main parameter for route selection in the SQR-AODV protocol. The R is defined as follows:

$$R = \frac{RLT \times RME}{HC} \tag{2}$$

Clearly, in order to maximize the R value, RLT and RME should be maximized and HC should be minimized as possible. RREP packet includes the following fields:

Type: the type of packet;
S: the source node address;
D: the destination node address;
SEQ: the packet sequence number;
R: the ratio of path;
TTL: the limitation of hop-length.

Stage 4

After sending the RREQ packet, the source node waits for a period of time. Consequently, it may receive different RREP packets from different routes. At the end of the period of time, it finds the maximum of the R values of all received RREP packets and selects the path with maximum R value for sending data and saves this value in its routing table. Therefore, data is sent through a route with low latency, high stability and sufficient residue energy level. In fact, there is a trade-off between these three concepts in proposed protocol. In the following, we give an example of the routing process for proposed protocol. In Figure 1 a part of a network is shown as example. If the source node S wants to send some data to the destination node D, it broadcasts a RREQ packet with the destination address equal to the node D address. Firstly, neighboring nodes of S receive the RREQ packet (A and B) and append required information to it, then forward to their neighboring nodes. This process will be continued until the RREQ packet arrive the destination node. As we describe, the RREQ packet collects required information at each node in its way. Node D receives six RREQ packets from six paths. According to Figure 1, these six paths are: path 1 (S→A→B→D), path 2 (S→A→C→D), path 3 (S→E→F→G→D), path 4 (S→E→F→C→D), path 5 (S→E→F→C→A→B→D) and path 6 (S→A→C→F→G→D). In Figure 1, the residue energy of each node is represented above the node and the LLT of each link is represented above the link. Based on this information, the node D calculates the R values.

The R values of mentioned paths are: R_1 = 49.8, R_2 = 55, R_3 = 63.75, R_4 = 43.75, R_5 = 20.85 and R_6= 33. Then the destination node D appends these values to the RREP packets and replies with the RREP packets along according paths. The detailed route discovery and route reply processes are described as Algorithms 1 and 2. Then, the source node S receives six RREPs after a determined period of time for waiting for the RREP packets. Then, it selects path 3 for sending data because of its higher R value compared with other five paths. Thus, the most stable path in our protocol SQR-AODV is S→E→F→G→D.

Route maintenance

In the MANETs, links have a high failure probability because the mobile nodes are moving during whole of the network life time. Other reason of link failures in the MANETs is the energy depletion of the nodes. Therefore, a mechanism is needed that reroutes between the nodes over a new path. This mechanism is often called route maintenance. SQR-AODV protocol uses route maintenance algorithm of AODV to come with this problem.

SIMULATION EXPERIMENTS

The base protocol used to compare the performance of SQR-AODV is the AODV (Perkins and Royer, 1999). The metrics used to assess the performance of SQR-AODV against AODV are the packet delivery ratio, energy of nodes and throughput. Here, we explain the simulation environment and the simulation results are discussed subsequently.

Simulation environment

Extensive simulation experiments were conducted using the network simulator version 2 (NS-2). NS2 is a scalable event-oriented simulation environment for wireless and wired communication systems. SQR-AODV runs at the network layer using the MAC protocol 802.11. We assume that the mobility of the mobile nodes is random. In our simulation, each mobile node selects a position at random and moves to an arbitrary location at a randomly chosen speed. Node mobility is changed by varying the node pause time. Pause time is inversely proportional to the mobility of the nodes, that is, the lower pause time is the higher mobility of the node. The parameters used in our simulations are:

a) Terrain dimensions: 1000×1000.
b) Simulation time: 1000 s.
c) Mobility model: random way point.
d) Pause time: 0 to 20 s.
e) Speed of the mobile node: 0 to 5 m/s.
f) Underlying MAC protocol: IEEE 802.11.

We use CBR for the traffic model. Traffic model parameters used in our simulations are:

a) Packet size: 50 kb.
b) Data sending rate: automatically valued by setting up the time interval.
c) Time interval: different for various scenarios.

As mentioned earlier, the performance of SQR-AODV is compared with AODV. We vary the number of nodes and the traffic load (data sending rate) to change the degree of overhead of the routing and data transmission in the network. As mentioned earlier, we have different traffic loads in our experiments as follows:

a) Low → time interval: 3 s.
b) Middle → time interval: 2 s.
c) High → time interval: 1 s.

Study on packet delivery ratio and throughput

In first step we compare SQR-AODV and AODV in middle traffic load. Figure 2 shows the packet delivery ratio of these protocols as the number of nodes changes. We observe that the packet delivery ratio of SQR-AODV is considerably better than AODV. In Figure 3 we see that the throughput of SQR-AODV algorithm is higher than AODV as the SQR-AODV protocol selects most reliable path at any situation of the network due to considering the path stability and energy in addition to hop count. Figures 4 and 5 show the packet delivery ratio and the throughput of the protocols as the traffic load changes respectively. These results obtained for constant number of 200 nodes. We observe that in the different traffic loads, the SQR-AODV protocol behaves better than AODV, considerably. Figures 6 and 7 present the packet delivery ratio and the throughput of SQR-AODV as the number of nodes changes in the three different traffic

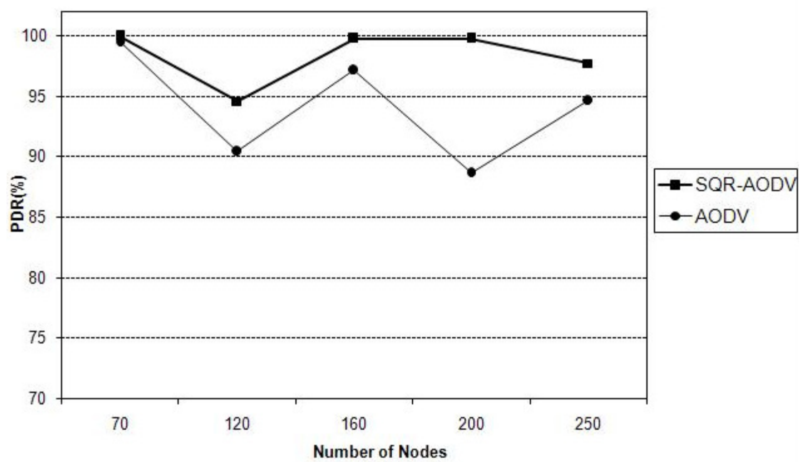

Figure 2. Packet delivery ratio vs. number of nodes.

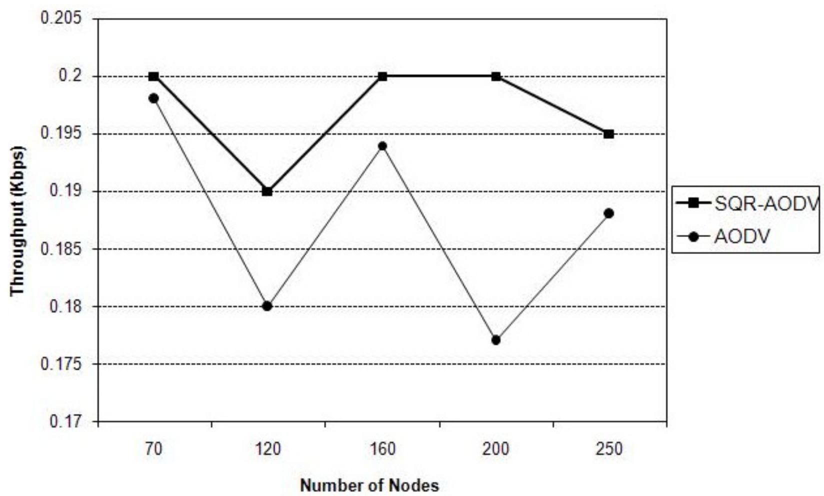

Figure 3. Throughput versus number of nodes.

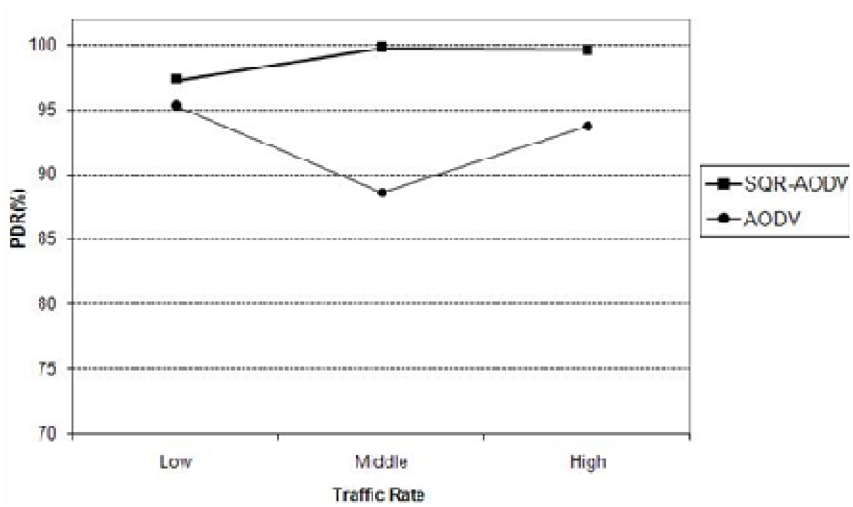

Figure 4. Packet delivery ratio versus traffic rate with 50 mobile nodes.

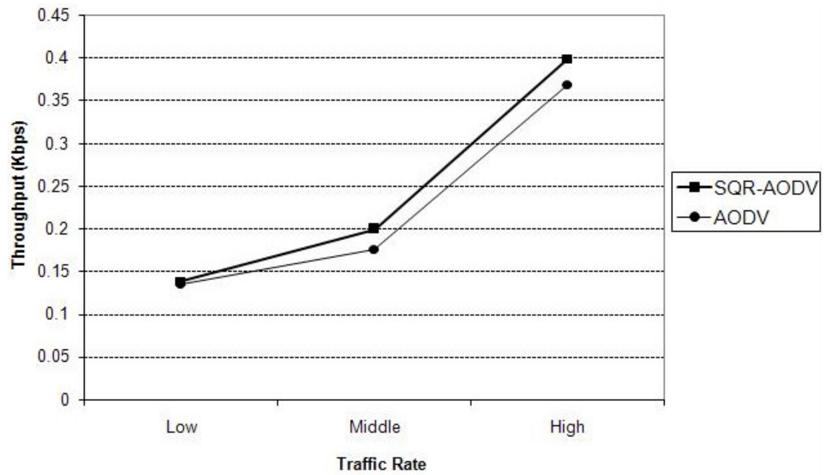

Figure 5. Throughput versus traffic rate with 50 mobile nodes.

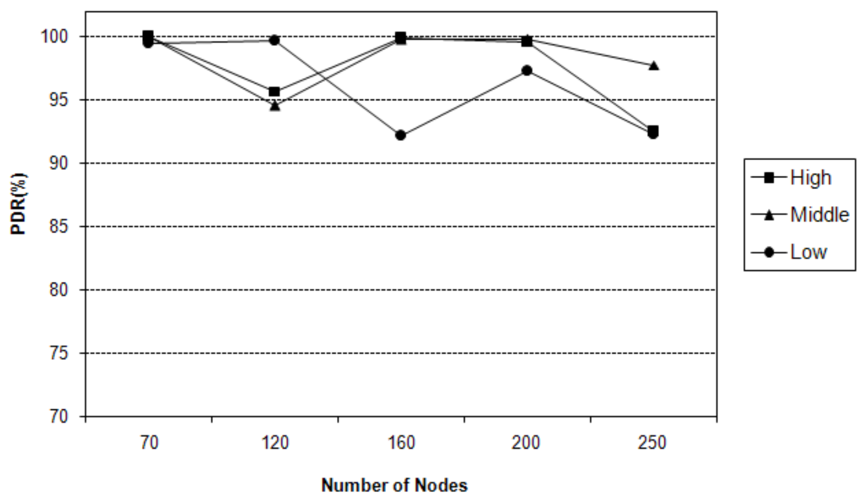

Figure 6. Packet delivery ratio versus number of nodes with different traffic rate.

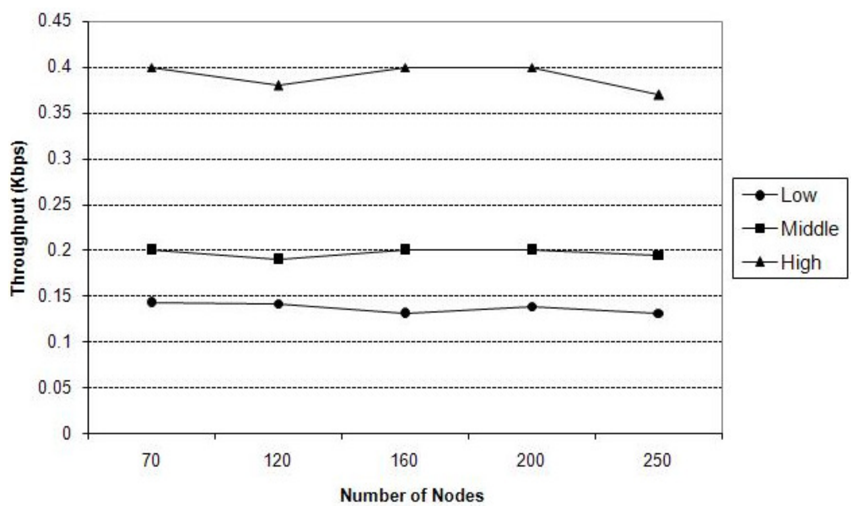

Figure 7. Throughput versus number of nodes with different traffic rate

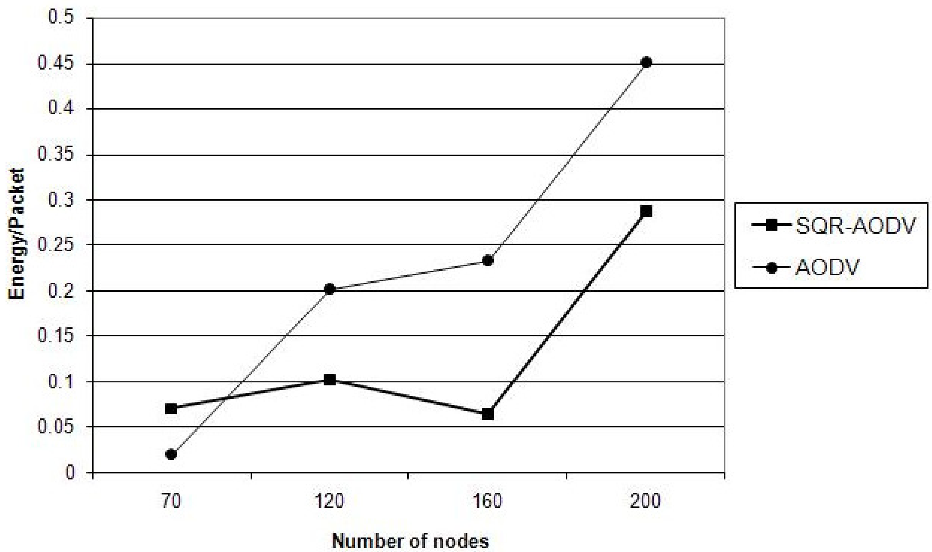

Figure 8. Energy/packet versus number of nodes with low traffic rate.

loads. Results presented in Figure 6 shows that the packet delivery ratio does not change meaningfully. Therefore, we can say that when the number of nodes and the traffic load increase at the same time, the packet delivery ratio increases also. Considering Figure 7 we see that variation of the traffic load affects the throughput so that higher traffic load leads to higher throughput. In addition, we can see that the SQR-AODV protocol has considerable scalability. Finally, from view point of the throughput, higher number of nodes does not decrease the performance. Some swingy behaviors are seen in the figures mentioned earlier. We can discuss these swings as follows: increasing the number of nodes cause to increase two important parameters of routing overhead and connectivity of the network.

In some cases of the number of nodes and traffic load, the routing overhead has more considerable effect on the network performance compared to the network connectivity and in some other cases the network connectivity is a more effective parameter. In the first case we observe lower network performance and second case leads to higher network performance. In addition we cannot say that the randomness of some factors in the simulations have no effect on the network status and performance. Considering this fact we had to use average of each parameter values obtained through several times repeated simulations for monitoring and analyzing it.

Study on energy consumption

Figure 8 shows the energy consumption of whole of the network in case of the low traffic load per received packet in the destination. Considering this figures we can say that the AODV protocol consumes lesser energy compared to the proposed protocol. In addition, notice that most of MANETs do not have a low traffic. Figure 9 shows the energy consumption of whole of the network in case of the middle traffic load per received packet to the destination. We can see that the SQR-AODV protocol in all cases of the number of nodes excepted case of 70 nodes. It means that the proposed protocol consumes lesser energy than the AODV protocol while number of nodes and consequently routing overhead increases. Figure 10 illustrates the energy consumption of whole of the network in case of the high traffic load per received packet to the destination. We observe our protocol has lower energy consumption in case of high traffic load considerably. Three recent figures show that when the traffic load of the network increases the SQR-AODV protocol gives much better results compared to AODV. This matter normally leads to optimized consumption of available power of the mobile nodes and finally longer the network life time. In following simulation results we focus on the load balancing. In Figures 11, 12 and 13; we see the residual energy level of the mobile nodes in the network with 30 nodes. Simulation time of these examinations is 5000 s. Notice that node 0 is the destination node and node 29 is the source node. Figure 11 shows results of the low traffic load examination. We see that in most of the nodes the AODV protocol has lesser energy consumption than our protocol excepted node 17. Also both protocols have same energy consumption at the source and the destination nodes.

Figures 12 and 13 show the residual energy level of nodes in the middle and high traffic load, respectively. These figures show lower energy consumption and higher load balancing of the proposed protocol in comparison with AODV protocol. Therefore we can say

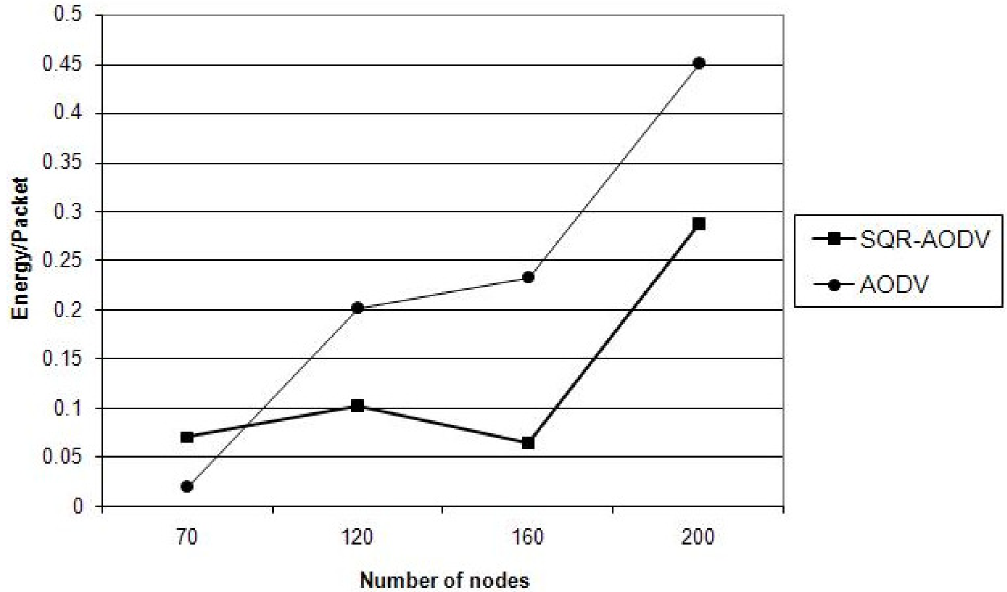

Figure 9. Energy/packet versus number of nodes with middle traffic rate.

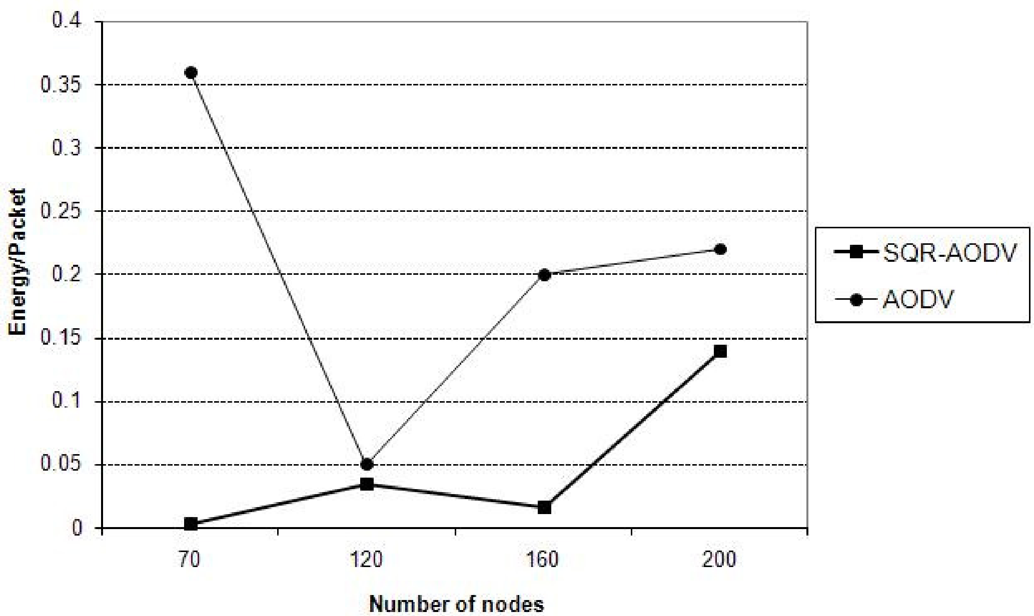

Figure 10. Energy/packet versus number of nodes with high traffic rate.

when the traffic load increases, the SQR-AODV protocol operates much better than AODV in term of load balancing. Considering these figures, we see that the residual energy level of one of the nodes is much lower than other intermediate nodes and close to the residual energy level of the source and the destination nodes. This matter may cause network partitioning; it means that AODV does not use power of nodes efficiently. While the SQR-AODV protocol leads to same energy consumption of all the intermediate nodes, that is our protocol results in a sufficient load balancing in whole of the network. All of discussed results show that the SQR-AODV protocol is high reliable and scalable in different network situations, at least importing to considered metrics. Analyzing the performance of SQR-AODV thought simulation we see that, it is an efficient algorithm whose packet delivery ratio and throughput are better than that of the AODV algorithm due to select best path at each time. Also our

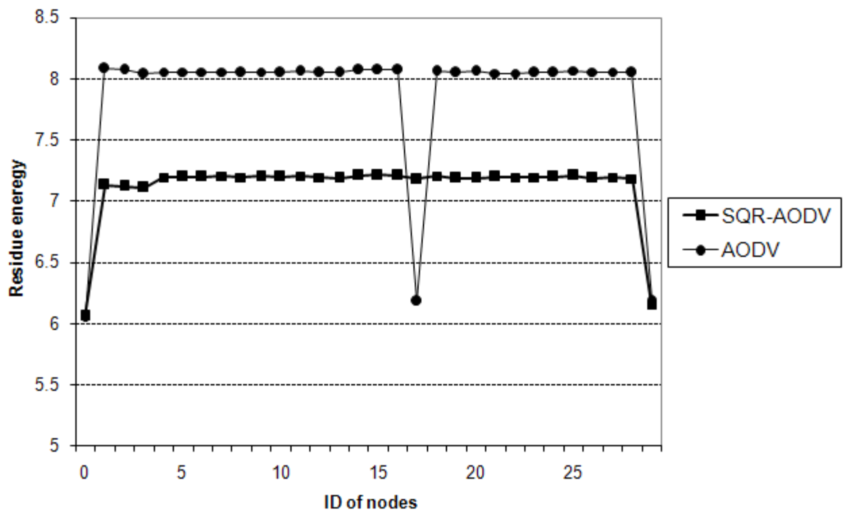

Figure 11. Residue energy versus node ID with low traffic rate.

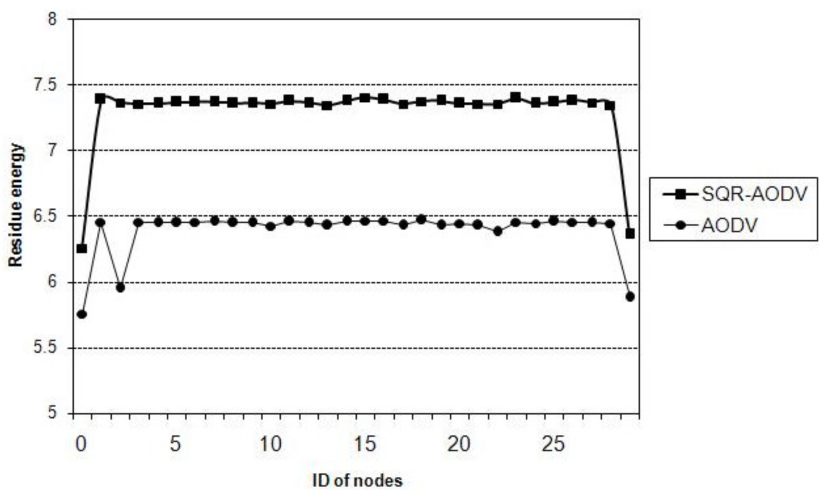

Figure 12. Residue energy versus node ID with middle traffic rate.

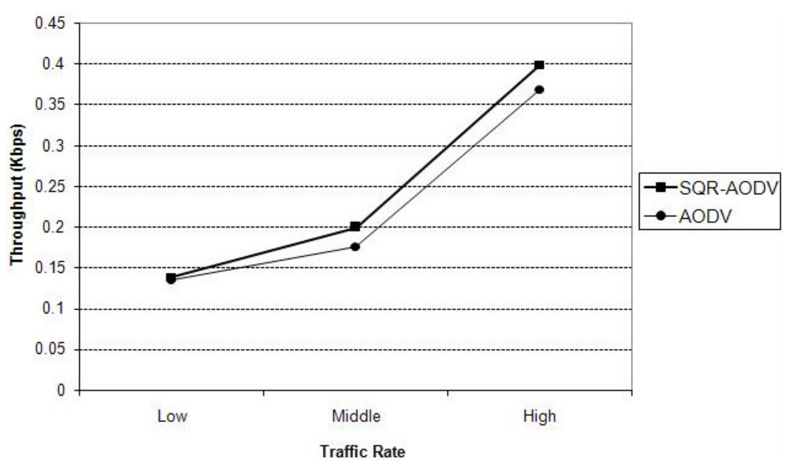

Figure 13. Residue energy versus node ID with high traffic rate.

protocol achieves high energy efficiency and load balancing, thus it prolongs the network life time and provides high reliability communications.

CONCLUSION

In this paper we proposed a stable QoS-aware reliable on-demand distance vector routing protocol for MANETs. Using this approach we examined the QoS routing problem with searching for a high reliability route from a source node to a destination node. In order to select a reliable route, proposed protocol uses three parameters, the route life time that is calculated using position and mobility information, the route minimum energy and the number of hops. Therefore, there is a trade-off between all of the important parameters in route selection. Through extensive simulation experiments, we observe that the SQR-AODV algorithm achieves high reliability and scalability with high packet delivery ratio and throughput compared to AODV routing protocol. It also provides high energy efficiency and load balancing thus prolongs the network life time and makes up high reliability communications.

REFERENCES

Akkaya K, Younis M (2003). An energy-aware routing protocol for wireless sensor networks. In: Proceedings of the 23 rd International Conference on Distributed Computing System Workshops. pp. 1-6.
Barolli L, Koyama A, Shiratori N (2003). A QoS routing method for ad-hoc networks based on genetic algorithm. In: Proceedings of the 14th international workshop on database and expert systems applications. pp. 175-179.
Boukerche A, Rogers S (2001). GPS query optimization in mobile. In: Proceedings of the sixth IEEE conference on symposium. pp. 198-203.
Boshoff JN, Helberg ASJ (2008). Improving QoS for real-time multimedia traffic in ad-hoc networks with delay aware multi-path routing. In: Proceedings of the IEEE 2008 conference on wireless telecommunications symposium. pp. 1-8.
Chen S, Nahrstedt K (1999). Distributed quality-of-service routing in ad hoc networks. IEEE J. Selected Area Commun., pp. 1488-1505.
Chiu CY, Wu HK, Chen GH (2002). Stability aware cluster routing protocol for mobile ad hoc network. In: Proceedings of the ninth international conference on parallel and distributed systems. Chungli, Taiwan. pp. 471-479.
Du X (2004). QoS routing based on multi-class nodes for mobile ad hoc networks. Ad Hoc Networks. pp. 241-254.
Griffin TG, Bruce FB, Wilfong G (2002). The stable paths problem and interdomain routing. IEEE/ACM Transactions on Networking. pp. 232-243.
Hanzo L, Tafazolli R (2007). A survey of QoS routing solutions for mobile ad hoc networks. J. IEEE Commun. Surv., pp. 50-70.
Johnson DB, Maltz DA (1996). Dynamic source routing in ad hoc wireless networks. Dordrecht: Kluwer Academic Publishers, pp. 153-181.
Kim WI, Kwon DH, Suh YJ (2001). A reliable route selection algorithm using global positioning systems in mobile ad-hoc networks. In: Proceedings of the 2001 IEEE int. conf. commun., pp. 3191-3195.
Liang Q, Ren Q (2005). Energy and mobility aware geographical multipath routing for wireless sensor networks. In: Proceedings of the IEEE wireless commun. Network. Conf., 3: 1867-1871.
Liao WH, Yen WM (2009). Power-saving scheduling with a QoS guarantee in a mobile wimax system. J. Network Comput. Appl., 32: 1142-1152.
Lim G, Shin K, Lee S, Yoon H, Ma J-S (2002). Link stability and route lifetime in ad-hoc wireless networks. In: Proceedings of the international IEEE Conference on Parallel Processing Workshops. pp. 116-123.
Perkins C, Bhagwat P (1994). Highly dynamic destination-sequenced distance-vector (dsdv) routing for mobile computers. In: Proceedings of the 1994 ACM SIGCOMM Symposium on Communications, Architectures communications, Architectures and Protocols, 233-244.
Perkins CE, Royer EM (1999). Ad hoc on-demand distance vector (aodv) routing. In: Proceedings of the 1999 IEEE workshop on mobile computing systems and applications. pp. 90-100.
Rappaport TS (1995). Wireless communications: principles and practice. Upper Saddle River, NJ: Prentice-Hall.
Reddy TB, Sriram S, Manoj BS, Murthy CSR (2006). MuSeQoR: Multipath failure-tolerant security-aware qos routing in ad hoc wireless networks. Computer Networks. pp. 1349-1383.
Sivakumar R, Sinha P, Bharghavan V (1999). CEDAR: A core-extraction distributed ad-hoc routing algorithm. IEEE J. Selected Areas Commun., pp. 1454-1465.
Sun H, Hughes HD (2003). Adaptive QoS routing based on prediction of local performance in ad hoc networks", In: Proceedings of the 2003 IEEE Conference on Wireless Communications and Networking, pp. 1191-1195.
Tseng YC, Li YF, Chang YC (2003). On route lifetime in multi hop mobile ad hoc networks. IEEE Transactions on Mobile Computing. 366-376.
Vergados DD, Vergados DJ, Douligeris C, Tombros SL (2008). QoS-aware tdma for end-to-end traffic scheduling in ad hoc networks. IEEE Wireless Communications. pp. 68-74.
Wang NC, Lee CY (2009). A reliable QoS aware routing protocol with slot assignment for mobile ad-hoc networks. J. Network Comput. Appl., pp. 1153-1166.
William S, Mario G (1999). IPv6 flow handoff in ad hoc wireless networks using mobility prediction. In: Proceedings of the 1999 GLOBECOM Conference. pp. 271-275.
Xue Q, Ganz A (2003). Ad hoc QoS on-demand routing (aqor) in mobile ad hoc networks. J. Parallel Distrib. Comput., pp. 154-165.
Ziane S, Mellouk A (2007). A QoS adaptive multi-path reinforcement learning routing algorithm for MANET. In: Proceedings of the IEEE/ACS Int. Conf. Comput. Syst. Appl., pp. 659-664.

Algorithm 1. Route discovery process.

Suppose n is the number of mobile nodes and N is the set of mobile nodes, $N = \{N_1, N_2, \ldots, N_t\}$. Assume that node N_i seeks to find a path to node N_j, and N_t receives the request packet, where $N_i, N_j, N_t \in N$ and $1<i, j, t<n$ and $i \neq j$.
if (node Nt is the destination node Nj)
{
Node N_t counts down the time waiting to receive a request packet.
Node N_t checks the route life time (RLT) of the request packet.
Node N_t checks the route minimum energy (RME) of the request packet.
Node N_t calculates the value of R the request packet.
Node N_t relays reply packets to the source node through paths that received the request packet from them.
}
else
{
Node N_t calculates RLT and RME then puts them in RLT and the RME of the request packet.
Node Nt forwards the request packet to the neighboring nodes.
}

Algorithm 2. Route reply process.

Suppose n is the number of mobile nodes and N is the set of mobile nodes, $N = \{N_1, N_2, \ldots, N_n\}$. Assume that the destination node N_i wants to reply with the route reply packet to the source node N_j, node N_i transmits the route reply packets, and node N_k receives the route reply packet, let $N_i, N_j, N_k \in N$ and $1<i, j, k<n$ and $i \neq j$.
if (node N_k is the source node N_j)
{
Node N_k counts the waiting time required to receive a RREP packet from different routes.
Node N_k selects the path of the maximum value of R as the main path.
Node N_i starts to send data along the selected path.
}
else
{
Node N_k records the value of R in accordance with the information in the RREP packet.
Node N_i forwards the RREP packet to the upstream nodes.
}