QTA-AODV: An Improved Routing Algorithm to Guarantee Quality of Transmission for Mobile Ad Hoc Networks Using Cross-Layer Model

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Abstract —In Mobile Ad Hoc Networks with the wide area and high node density, the impacts on the network performance due to physical layer impairments over wireless interconnecting transmission paths are very serious. These effects are the cause of the decrease of the network performance. In this paper, we focused on investigating the routing techniques in mobile ad hoc networks taking into account the physical layer impairments. Thence, we proposed an improved route discovery algorithm for AODV protocol based on the cross-layer model in combination with the agent technology, namely QTA-AODV (Quality of Transmission using Agent in AODV). The objective of QTA-AODV algorithm is to improve the quality of transmission of the data transmission routes, increase the network performance. The simulated results on OMNeT++ have shown that, compared with AODV algorithm, QTA-AODV can improve the signal to noise ratio of the routes, reduce from 20% to 35% of packet blocking probability. In addition, QTA-AODV algorithm also reduces the number of the control packets.

Index Terms—AODV, QTA-AODV, cross-layer routing, QoT aware routing, agent technology

I. Introduction

The multi-hop wireless network technology is one of the decisive solutions for the next generation telecommunications network, it has recently attracted significant research interests from both academia and industry communities recently. There are four main types of multi-hop wireless network, which is wireless ad hoc networks, Wireless Sensor Networks (WSN), Wireless Mesh Networks (WMN), and hybrid wireless networks [1]. Among these types, ad hoc networks are becoming more and more widely used in many fields, such as community network, enterprise network, home network, emergency response network, vehicle network, sensor network [2]. The basic characteristics of ad hoc networks are the nodes which create peer to peer communication via wireless transmission medium, no control center for the data transmission in such networks. The nodes in the ad hoc networks can operate as a client, a server as well as a router, the network topology changes frequently according to the random movement of the nodes.

Recently, several published works have been reported focusing on the control protocols for the data transmission in order to increase the performance of ad hoc networks, in which the routing protocols are the most studied. Most of published works related to routing protocols dedicate to improve the routing algorithms in order to decrease the probability of congestion, transmission delay, and increase the throughput of network [3]-[5]. The physical impairments aware routing techniques in ad hoc networks have also been developed by some research groups. The authors of [6] have modified AODV protocol in MANET based on the cross-layer model. The proposed algorithm uses three parameters of the quality link namely Signal to Noise Ratio (SNR), delay and node lifetime to improve the network performance. Their method is to modify the RREP package by adding an extra field in the packet structure to store the link cost value which is the summation of SNR, node lifetime and delay. Routing algorithm then chooses the route with the best link cost. Another published research has modified three routing protocols, AODV, Dynamic Source Routing (DSR) and Optimized Link State Routing (OLSR) to improve the performance of MANET [7], [8]. These protocols ware modified by adding two fields in the route reply packet to store the metrics of SNR and received power (RP). The route with the best value of SNR or RP will be chosen for the data transmission.

Another method was used for the study of routing algorithms in MANET which takes into account the physical impairments is to use the routing metric. Specifically, it is constructing routing metrics, which contains the parameters of the physical impairments. Then, the best path is selected based on this metrics. For this method, the authors of [9] proposed a routing metric namely Weighted Signal to noise ratio Average (WSA) for the dynamic sequence distance vector (DSDV) routing protocol. The WSA metric uses the SNR parameter provided by the physical layer through cross-layer model. Simulation results showed that, for the use

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of WSA metric, the performance of MANET is improved in terms of throughput, packet delivery ration and end-to-end delay. In addition to the methods described above, the method using fuzzy logic to study the physical impairments aware routing algorithms in MANET has also been deployed. The authors of [10] proposed a routing protocol namely Efficient Routing Protocol under Noisy Environment (ERPN) using fuzzy logic. The ERPN protocol selects the route for transmission of data packets based on the parameters of the environment noise and signal strength. Their validation shows that, the ERPN protocol increases throughput, delivery ratio, decreases link failure, lowers error rate.

In [11], we have also been developed to investigate the routing techniques which take into account the physical impairments in MANET. We proposed a routing algorithm namely QTA-DSR (Quality of Transmission using Agent in DSR) using cross-layer in combine with static agent. QTA-DSR algorithm is modified from DSR algorithm. The main objective of that is to improve the QoT of mobile ad hoc networks. By the simulation method, we have demonstrated that, the QTA-DSR algorithm can improve the SNR of the data transmission routes compared with DSR algorithm, reducing the blocking probability of data packets due to unsatisfactory constraint conditions of the quality of transmission. In this paper, we continue to develop this subject. Specifically, extending the proposed model in [11] to improve the AODV protocol. We propose a route discovery algorithm namely QTA-AODV which is proposed from AODV protocol using the cross-layer model in combination with the agent technology.

The next sections of this paper are organized as follows. Section II discusses the parameters of the physical layer impairments in MANET. Section III describes the quality of transmission of the routes in the case of AODV protocol is used. Our proposed algorithm is presented in Section IV. Section V presents the simulation results and discussions. Finally, concluding remarks and prospects of future works are given in Section VI.

II. Physical Layer Impairments in MANET

In the case of MANET with wide area and high node density, the physical layer impairments impact on the performance of networks seriously. In this section, we discuss the parameters of the physical impairments that have the most influence on QoT of MANET, including the path loss of signal power, signal-to-noise ratio (SNR), bit error rate (BER).

A. *Path loss*

In wireless propagation medium, if a signal transmitted through free space, the relation between the transmit and receive powers is given by [12]

$$P_R = P_T G_T G_R \frac{\lambda^2}{(4\pi d)^2} \qquad (1)$$

where P_T and P_R are the transmitting and receiving powers respectively, G_T and G_R are the transmitter and receiver antenna gains respectively, λ is the wavelength of the carrier using in the modulation format, and d is the distance between the transmitter and receiver. Equation (2) shows that the receiving signal power decreases according to the square of transmission distance, due to P_T, G_T, G_R and λ are constants.

B. *Signal to Noise Ratio (SNR)*

SNR is one of the important parameters to assess the quality of data channels in telecommunication networks, using both wired and wireless networks, which are defined as [10]

$$\beta_n = 10\log_{10}\left(\frac{P_s}{P_n}\right) \quad (dB) \qquad (2)$$

where P_s and P_n are the signal and noise powers respectively. For a data transmission channel, the higher SNR, the smaller BER and the better QoT. One of the methods to determine the relationship between SNR and BER is to use BERtool in MATLAB software. For this method, we have determined the theoretical curve of BER versus SNR according to different modulation techniques as shown in Fig. 1, the modulation techniques which are considered are the quadrature amplitude modulation (QAM), include 4-QAM, 16-QAM, 64-QAM, and 128-QAM. We can observe that, if the SNR increases, the BER decreases exponentially. For example, in the case of 128-QAM, if SNR is 16 dB, BER is about 10^{-2}. If SNR increases to 20 dB and 24 dB, BER decreases to about 7×10^{-5} and 3×10^{-9} respectively.

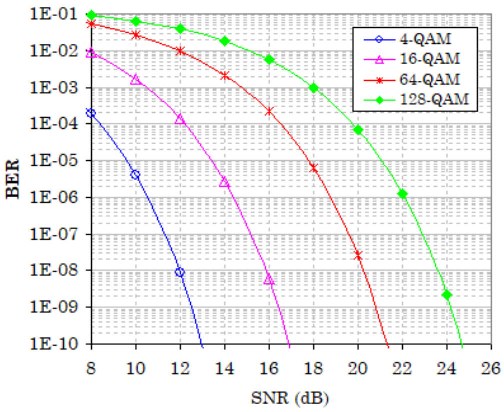

Fig. 1. BER versus SNR characteristics for QA

In mobile ad hoc networks, for the cases that the data is transmitted through the many intermediate nodes, the noise power accumulated along the route increases, thus leading to the reduction of SNR according to (2). On the other hand, when the SNR decreases, the BER increases. Therefore, SNR constraint condition must be considered in the routing algorithms to ensure QoT. In order to evaluate the reduction of SNR in the above mentioned case, we consider a data transmission route from source to destination through the n intermediate nodes (n - 1 hops) with the structure as shown in Fig. 2. In this case, the intermediate nodes operate as relays that forward the data packets to the final destination. There are two relay types can be used in multi-hop systems, such as regenerative and non-regenerative relays [13], [14]. SNR of the transmission channel depends on the relay type of the intermediate nodes, which is determined by

$$\beta_n = \begin{cases} \min(\beta_{h_1}, \beta_{h_2}, \ldots, \beta_{h_{n-1}}) & \text{if regenerati ve relay} \\ \left(\dfrac{1}{\beta_{h_1}} + \dfrac{1}{\beta_{h_2}} + \ldots + \dfrac{1}{\beta_{h_{n-1}}} \right)^{-1} & \text{otherwise} \end{cases} \tag{3}$$

where β_n and β_{hj} are the SNR at receiver of the destination node (node n in Fig. 2) and SNR of the j^{th} hop respectively.

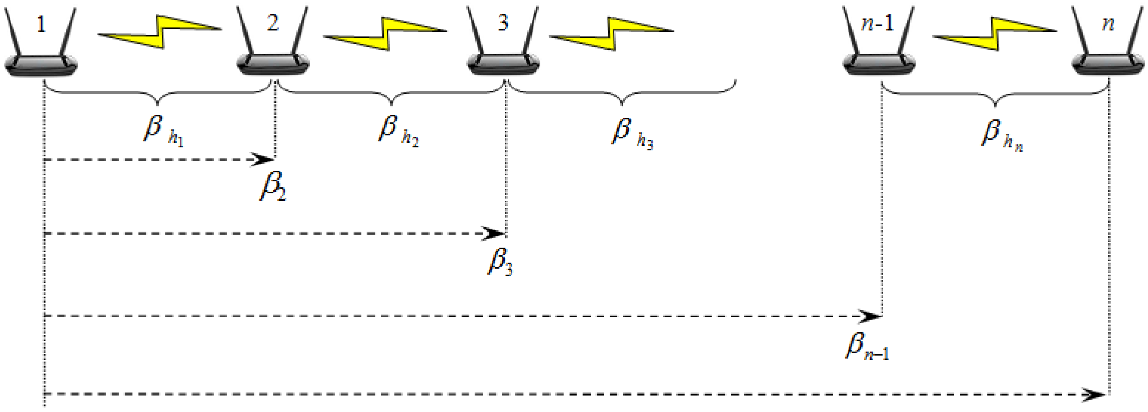

Fig. 2. The structure of the data transmission route in mobile ad hoc networks over multiple hops

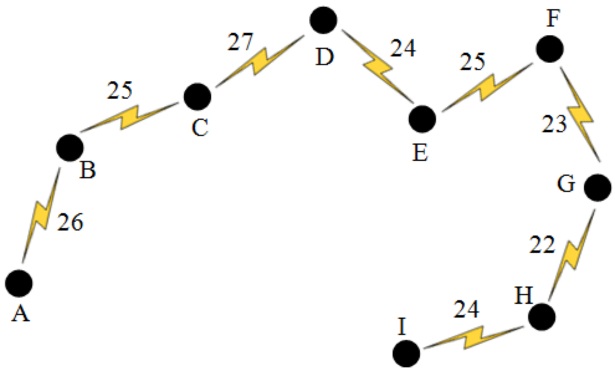

Fig. 3. An example of SNR of the data transmission route in MANET over nice nodes

To see more clearly SNR and BER versus the number of hops that data packets pass through, we consider a route of 8 hops from A to I as shown in Fig. 3. The number on each connection is its SNR value. Assuming that the data is transmitted from node A, from equation (3), we obtain the curves of SNR and BER versus the number of hops as shown in Fig. 4 and Fig. 5, respectively. From the curve in Fig. 4 we can observe that,

SNR decreases as data transmitted over multiple hops. If the data only transmits through one hop (destination node is B), SNR is 26 dB for both relay types are regenerative and non-regenerative. If the data transmits through two hops (destination node is C), SNR decreases to 25 and 22.46 dB for the cases of the relay types are regenerative and non-regenerative respectively. These value decreases to 22 and 15.21 dB in case of the data transmits through eight hops (destination node is I). Since SNR decreases, BER increases as shown Fig. 5. If the data only transmits through one hop (destination node is B), BER is about 2.18e-10. But if the data transmits through eight hops (destination node is I), BER increases to 2.6e-5 and 1.8e-1 for the cases of the relay types are regenerative and non-regenerative, respectively. Thus, in order to ensure QoT in MANET, SNR constraint condition must be considered in the routing algorithms. This issue will be analyzed in the next section below.

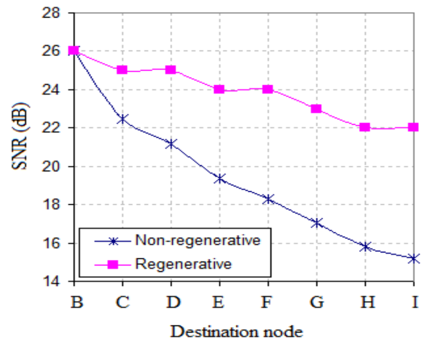

Fig. 4. Characteristics of SNR versus the number of hops

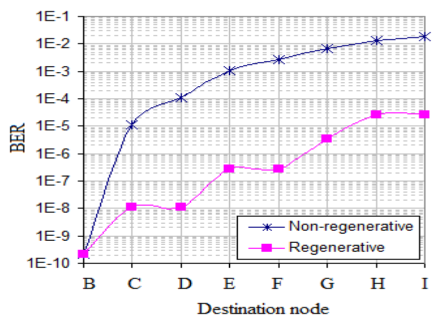

Fig. 5. Characteristics of BER versus the number of hops

III. Quality of Transmission in AODV Protocol

According to the operation principle of AODV routing protocol [15], when a source node wants to transmit a data packet to destination node, it checks its route cache first to find out whether there is a route to the destination.

If a possible route is found, uses this route to transfer data packet. In contrast, the route discovery algorithm is implemented to find a new route for data packet transfer.

In order to discover the new route, source node broadcasts the route request packet (RREQ) to all its neighbors. At each node receiving RREQ, if this RREQ has already been received, delete the RREQ. Otherwise, return the route reply packet (RREP) if its route cache has corresponding route to destination, else, forwards the RREQ packet to its neighbors, except the origin node. This process repeat until a route has been found.

According to the operation principle of the route discovery algorithm in AODV routing protocol, the weigh of the found route is the number of hops. Therefore, in some cases, the QoT of the found route is not the best, even the found route does not satisfy the constraint conditions of QoT. To see more clearly this argument, we consider an example as shown in Fig. 6. Considering the case of the node A wants to discover a new route to node H. Assuming that at the present time, the route cache of all nodes is empty. First, source node A broadcasts the RREQ packet to all its neighbors, B, E, and F. When receiving the RREQ packet, nodes B, E, and F will update the reverse path to the source node (node A) into its route cache. For example, node B will update an additional record [A, A, 1] into the route cache, that means the source node is A, the next node to go to the source node is A, the hop-count is 1. Since B, E, and F have not received this RREQ before yet, these nodes will continue to forward RREQ packets to its neighbors, except node A, the node sent the RREQ for these nodes. At node E, when receiving the RREQ packet from node B, E will delete this RREQ due to that was received from node A before. At node D, when receiving the RREQ packet from node B, D will update an additional record for the reverse path to node A, that is [A, B, 2] into the route cache of node D, that means the source node is A, the next node to go to node A is B, the hop-count is 2. Similar for the remaining nodes, until the H node receives RREQ packet from node C, since H is the destination node, RREP packet is created and sent back to the source node according to the reverse route. The result is the route A → E → C → H it is found, hop-count of that is 3.

Now, considering the case of the node F wants to discover a new route to node H. Node F broadcasts the RREQ packet to all its neighbors, A and G. At node A, when receiving the RREQ packet from node F, since A finds a route to H in its route cache, A send back RREP packet to F in order to response the route to H. Thus, the found route is F → A → E → C → H with 4 hop count.

For the result of the above route discovery, suppose that the operating principle of all nodes are the amplify and forward, according to equation **(3)** we have, SNRs of the routes of A → E → C → H and F → A → E → C → H are 23.87 dB and 21.1 dB, respectively. Considering the modulation format of 128-QAM is used, and required BER is 1e-9. According to the theoretical curve of BER versus SNR as shown in Fig. 1, required SNR for BER of 1e-9 is 24 dB. Thus both above does not satisfy the constraint conditions of QoT, due to the fact that the SNR is less than the minimum required SNR (24 dB). From the topology in Fig. 6, we can observe that, from A to H can use the route of A → E → G → I → H. Although the hop count of this route is 4, SNR of that is 24.1 dB. This value is better than SNR of the 3 hop count route of A → E → C → H that the route discovery algorithm of AODV protocol found.

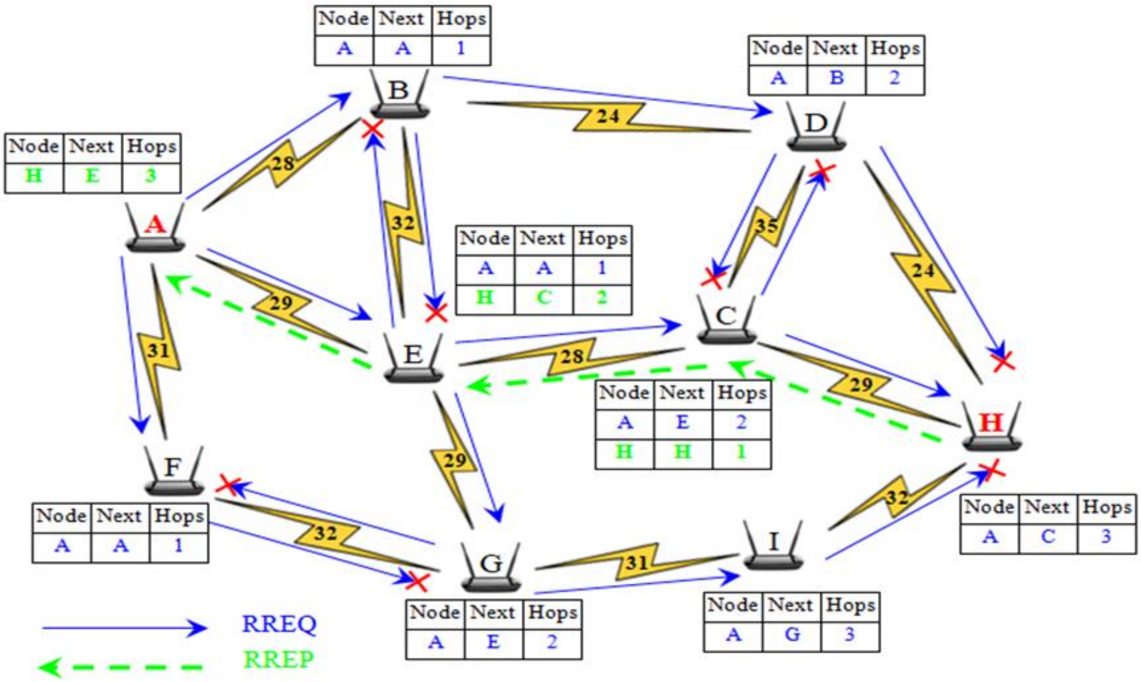

Fig. 6. An example of the route discovery in mobile ad hoc network using AODV algorithm

IV. Route Discovery Algorithm for Ensuring QoT in MANET

To ensure the QoT in MANET with the wide area and high node density, we propose a route discovery algorithm which was modified from that of the AODV protocol, namely QTA-AODV (Quality of Transmission using Agent in AODV). QTA-AODV algorithm is proposed based on the cross-layer model in combine with agent technology that we have deployed for the QTA-DSR algorithm [11]. The principle of the QTA-AODV algorithm is to use the information of QoT such as BER, SNR, end-to-end delay for the constraint conditions of the routing. This information is collected and processed by a local agent at each node based on the cross-layer model. The QoT information is also exchanged between nodes by integrating into the RREQ packet.

A. *Structure of RREQ Packet in QTA-AODV Algorithm*

To be able to exchange the information of QoT between nodes, we modified the RREQ packet format of the AODV protocol as shown in Fig. 7. The fields from (1) to (14) are the original fields of AODV. In addition, we added to fields (15) and (16) to store the QoT and end-to-end delay, respectively.

32 bits

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Type	J	R	G	D	U	Reversed	CF	Hop Count
(10)	RREQ ID							
(11)	Destination IP Address							
(12)	Destination Sequence Number							
(13)	Source IP Address							
(14)	Source Sequence Number							
N/A							(15) QoT	(16) E2E

Fig. 7. The structure of RREQ packet uses for QTA-AODV algorithm

B. *Cross-Layer Model for QTA-AODV Algorithm*

In order to use the parameters of QoT as routing metric, the network layer must be able to directly access to the information of the physical layer. This can only be performed by using cross-layer model [6], [16], [17]. In QTA-AODV algorithm, the cross-layer model is proposed as shown in Fig. 8, in which an agent is used for the exchange of the information of QoT between physical and network layers. This agent is called local agent. Whenever a RREQ packet needs to process at each node, local agent performs the following functions:

1) Collecting the information of QoT

When a RREQ packet arrives at each node, LA collects the information of the QoT from source node to current node which is stored in RREQ packet. Simultaneously, LA also reads the information of the QoT from current node to all its neighbors. These information are used for the predicting the QoT from source node to all neighbors of the current node.

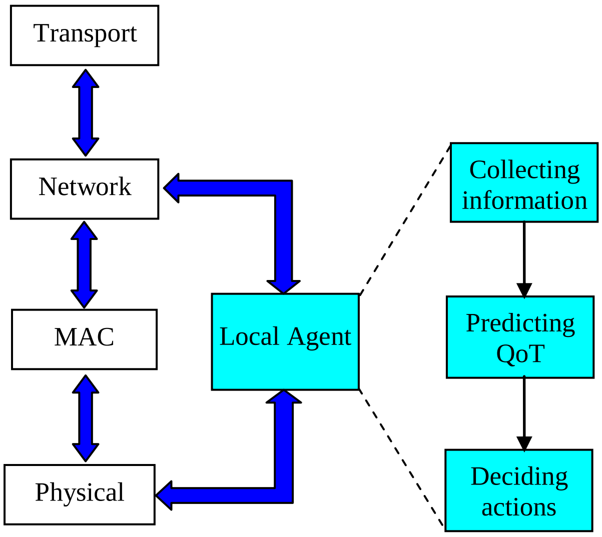

Fig. 8. Cross-layer model uses for QTA-AODV algorithm

2) Predicting the QoT

The predictable model of QoT by LA at each node as shown in Fig. 9. Assuming that the current node is I it is processing RREQ packet. In order to ensure the QoT of the found routes by QTA-AODV, LA at node I must predict QoT from source node to the all neighbors of node I before broadcasting RREQ packet. In our model, the parameters of QoT must be predicted including SNR (β_{sj}) and end-to-end delay (τ_{sj}).

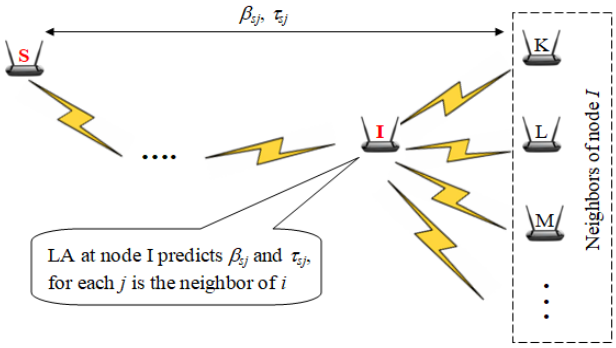

Fig. 9. QoT predictable model of QTA-AODV algorithm

(i) Predicting the SNR

When node *I* receives RREQ packet, LA will read the information of SNR from source node to node *I* (β_{si}) stored in field QoT. For node *J* is the neighbor of node *I*, LA read the information of SNR from *I* to *J* (β_{ij}). Thence, according to **(3)**, LA determines SNR from source node to the neighbors of node I as follow

$$\beta_{sj} = \begin{cases} \min(\beta_{si}, \beta_{ij}) & \text{if regenerative relay} \\ \left(\dfrac{1}{\beta_{si}} + \dfrac{1}{\beta_{ij}}\right)^{-1} & \text{otherwise} \end{cases} \tag{4}$$

(ii) Predicting the end-to-end delay

In principle, the end-to-end delay (E2E) can only determine when the packet has transmitted to the end node. In our algorithm, In order to ensure E2E is within permissible limit, we use LA at each node to predict E2E during route discovery.

E2E is the summation of time taken by a data packet to travel from source to destination. For each hop from node i to node j, E2E of that (τ_{ij}) consists of four components, namely processing delay (τ_p), queuing delay (τ_q), transmission delay (τ_t) and radio propagation delay (τ_r) [18]. Thus τ_{ij} is determined by

$$\tau_{ij} = \tau_p + \tau_q + \tau_t + \tau_r \tag{5}$$

In case of the processing delay and radio transmission delay are small enough to be able to ignore, τ_{ij} depends on two main components, τ_t and τ_q. τ_t is determined based on the bit rate of the channel and data packet size, τ_q is determined based on the queue mechanism at the network nodes. In our model, M/M/1/K queuing is used at nodes [19], thus τ_q is determined by [11], [20]

$$\tau_q = \frac{\overline{N}}{\lambda_{ij}(1-P_{ij}^{(K)})} + \frac{1}{\mu_{ij}} \tag{6}$$

where λ_{ij} and μ_{ij} are the arrival rate and service rate (packets/s) of the link from i to j, respectively. $\overline{N}$ is the average number of packets in the queue, K is the capacity of queuing (number of packets) and $P_{ij}^{(K)}$ is the probability of K packets in queuing. $\overline{N}$ and $P_{ij}^{(K)}$ are determined as follows [11], [20]

$$\overline{N} = \begin{cases} \dfrac{\rho_{ij}}{1-\rho_{ij}} - \dfrac{\rho_{ij}(K\rho_{ij}^{K}+1)}{1-\rho_{ij}^{K+1}} & \text{if } \rho \neq 1 \\ \dfrac{K(K-1)}{2(K+1)} & \text{otherwise} \end{cases} \tag{7}$$

$$P_{ij}^{(K)} = \begin{cases} \dfrac{(1-\rho_{ij})\rho_{ij}^{K}}{1-\rho_{ij}^{K+1}} & \text{if } \rho \neq 1 \\ \dfrac{1}{K+1} & \text{otherwise} \end{cases} \tag{8}$$

where $\rho_{ij} = \lambda_{ij}/\mu_{ij}$ is the traffic offered to link from i j.

To be able to predict τ_{ij}, LA at each node must know the parameters of K and ρ_{ij} (λ_{ij} and μ_{ij}). K and μ_{ij} are the input parameters of the network system. λ_{ij} is predicted by LA using the statistical method over times. According to the QoT predictable model as shown in Fig. 9, when node I receives RREQ packet, LA will read the information of E2E from source node to node I (τ_{si}) stored in field E2D. For node J is the neighbor of node I, LA will predict the information of E2E from I to J (τ_{ij}). Thence, E2E from source node to the neighbors of node I is determined by

$$\tau_{sj} = \tau_{si} + \tau_{ij} \tag{9}$$

where τ_{ij} is predicted by LA according to (5) to (8). To see more clearly the E2E predictable results by LA, we consider an ad hoc network model with three nodes as shown in Fig. 10. Nodes 0 and 2 are the source and destination nodes, respectively. The channel bandwidth is 54 Mbps, the average packet size is 1472 bytes, and the queuing length is 30 packets. According to our E2E predictable model, LA at node 1 can predict E2E from node 0 to node 2 during route discovery. In Fig. 11, we compare the E2E of simulation and that of predicting by LA. For simulation results, E2E is measured from the data packet generated at the source node (node 0) until it is delivered successfully to destination (node 2). For predicting results, LA at node 1 predicts E2E from node 0 to node 2 whenever it receives RREQ packet. From curves in Fig. 11, we can observe that, the results of the simulation and the prediction are very different at the beginning, due to the unstable network status. When simulation time is greater than 2 seconds, the predictable results by LA are close to the simulation results. This proves the accuracy of the E2E prediction method by local agent.

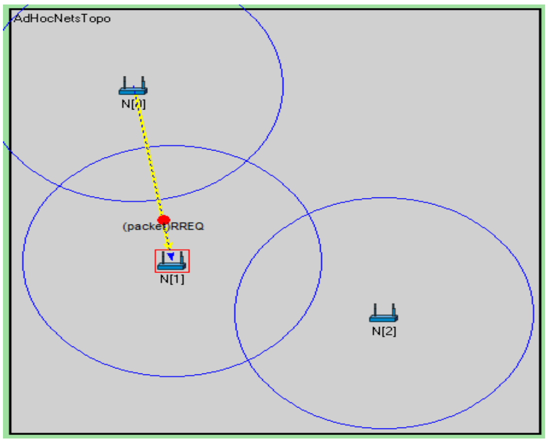

Fig. 10. An example of MANET to analyze E2E delay

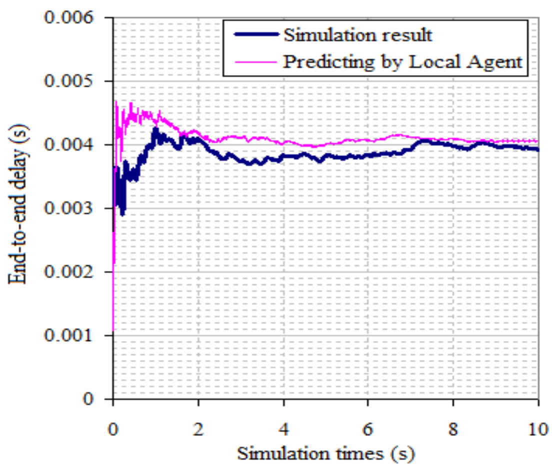

Fig. 11. Comparison E2E of simulation and that of predicting by LA

3) Deciding the actions

Based on the QoT information that LA has predicted above, QoT constraint conditions are checked as follows:

$$\begin{cases} \beta_{sj} \geq \beta_{req} \\ \tau_{sj} < \tau_{th} \end{cases} \tag{10}$$

where β_{req} and τ_{th} are the required SNR and limit of the end-to-end delay, respectively. If β_{sj} and τ_{sj} satisfy the constraint condition (10), the route discovery is continued with node j. Else, node j is not considered.

C. QTA-AODV Algorithm

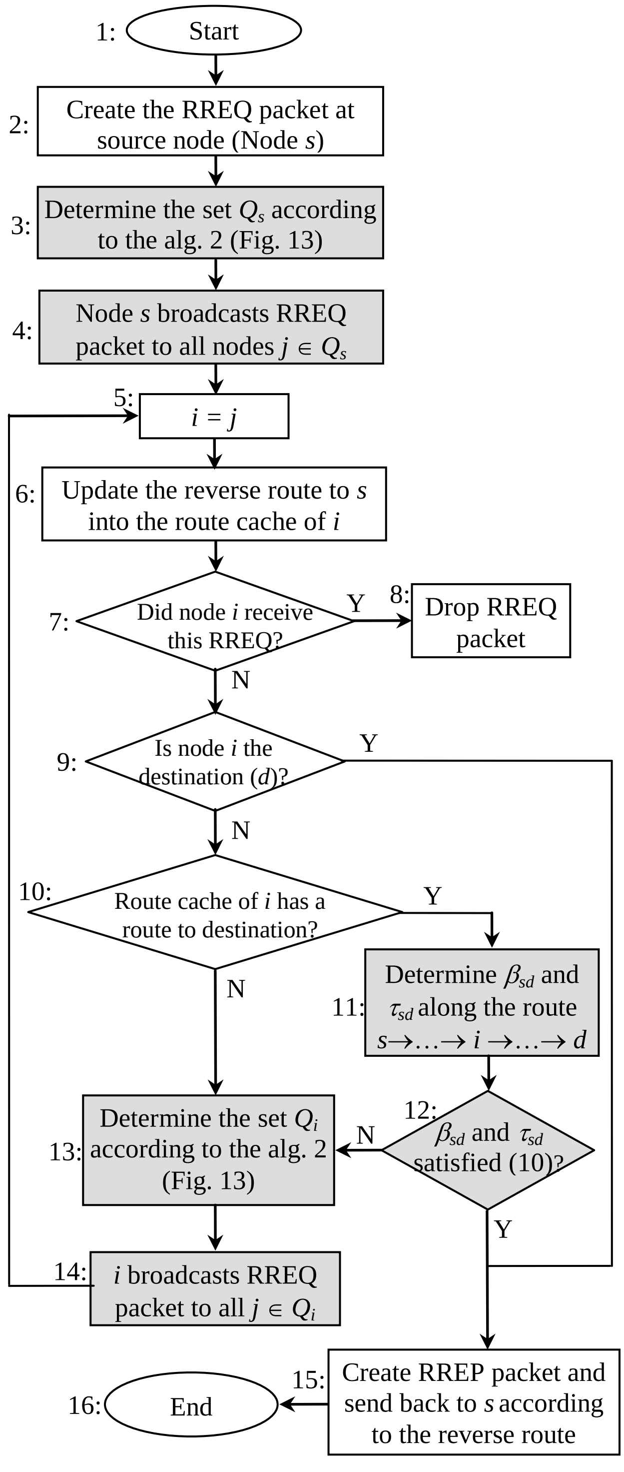

Fig. 12. Flowchart of the QTA-AODV route discovery algorithm

The route discovery algorithm for ensuring QoT in MANET (QTA-AODV) is performed according to the steps as shown in Fig. 12. There are two main differences between algorithms QTA-AODV and AODV. First, the processing to forward a RREQ packet at each node (steps 3, 4, 13 and 14). Second, the processing to send back the RREP packet to the source node at the intermediate or destination nodes (steps 11 and 12).

a) The processing to forward a RREQ packet

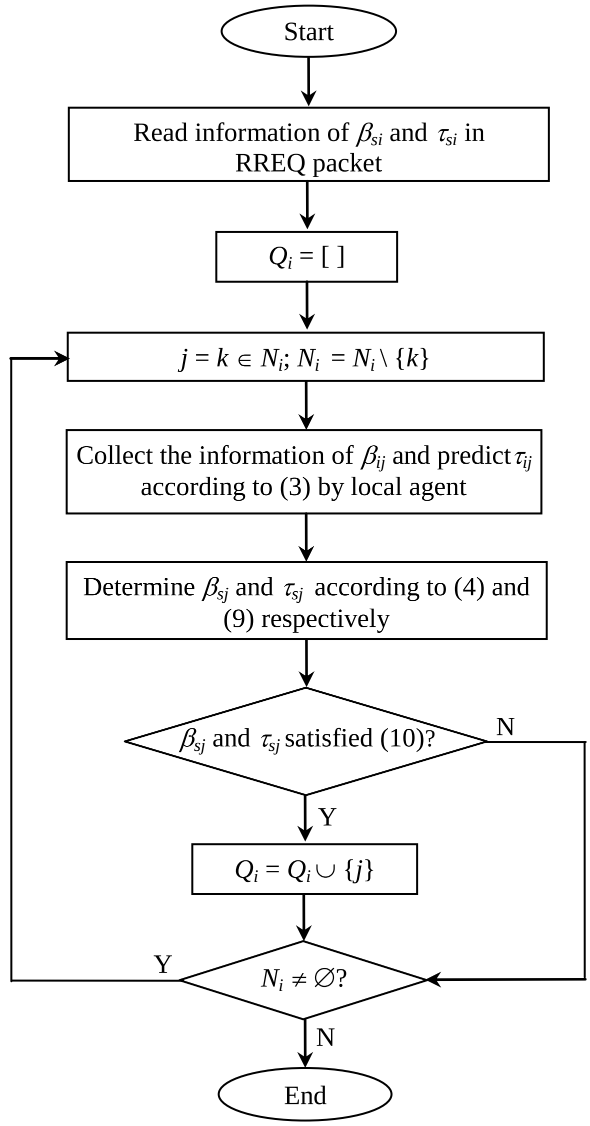

Fig. 13. Flowchart of the algorithm determine the set of the neighbors of node i satisfying the constraint conditions of QoT (Set Qi)

For the AODV algorithm, when a node needs to forward a RREQ packet, this node will broadcast the RREQ packet to all its neighbors. For the QTA-AODV algorithm, RREQ packet is only broadcast to the nodes in the set Q_i (i is current node), which is the set of the neighbors of node i satisfying the constraint conditions of QoT. The set Q_i is determined according to the flowchart in Fig. 13. When node i receives RREQ packet, LA at the node i will read firstly the information of QoT from the source node (s) to node i contained in the RREQ packet. These information include the SNR and end-to-end delay values from source node to node i (β_{si} and τ_{si}). For each node j in the set of the neighbor of node i, LA then reads the QoT sensor information of the hop from i to j nodes which include the SNR value from i to j nodes (β_{ij}), the hop delay from i to j nodes (τ_{ij}). Based on the QoT information that LA collected, LA will calculate to determine the parameters of QoT from the source node to the node j, including β_{sj} and τ_{sj} according to (4) and (9), respectively. If β_{sj} and τ_{sj} satisfy the constraint conditions (10), node j is added the set Q_i.

b) The processing to send back the RREP packet to the source node

Considering the case of an intermediate node receives the RREQ packet that its route cache has corresponding route to destination, for the AODV algorithm, RREP packet is created and sends back to the source node. For QTA-AODV algorithm, the constraint condition of QoT is checked before creates and sends back the RREP packet to the source node (as shown in the steps 11 to 14 of Fig. 12).

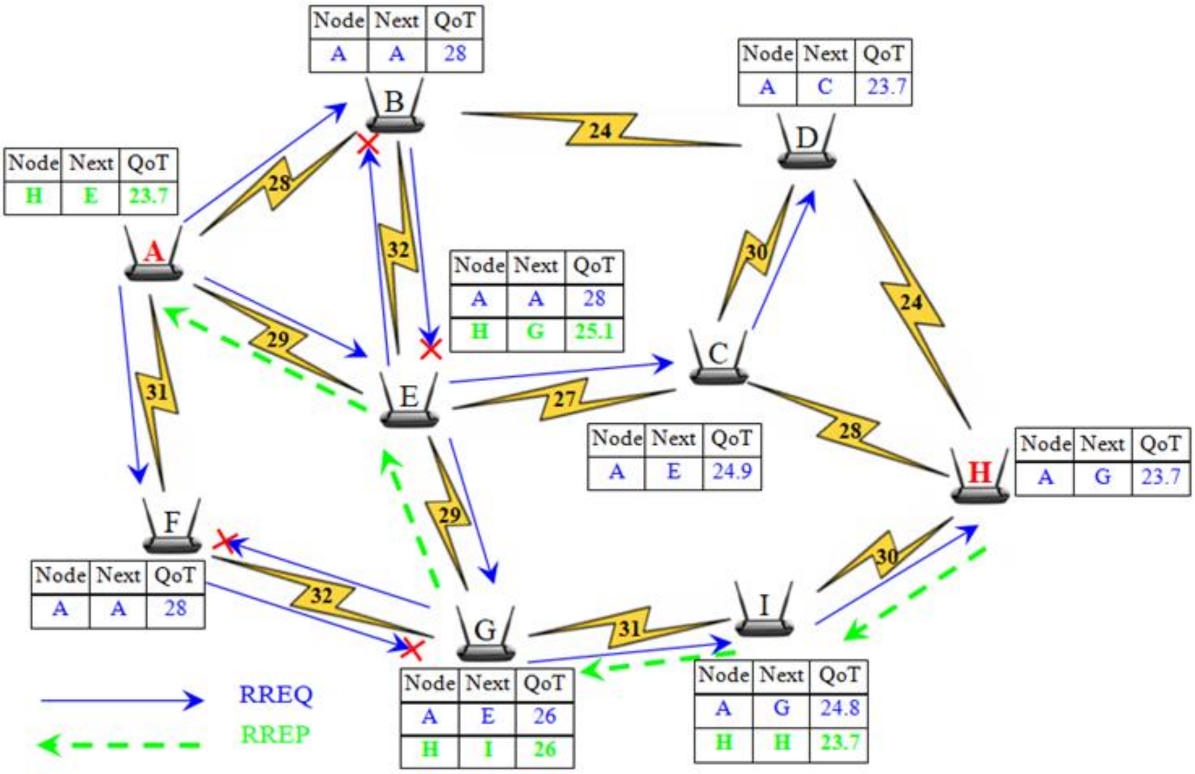

Fig. 14. An example of the route discovery in mobile ad hoc network using QTA-AODV algorithm

To see more clearly the principle of the route discovery using QTA-AODV algorithm, we consider an example as shown in Fig. 14, in which, the number on each connection is its SNR value. This topology is considered in section III (Fig. 6) for the example of the route discovery from node A to node H using AODV algorithm, the found route is A → E → C → H. Now, we also consider the example of the route discovery from node A to node H, but using QTA-AODV algorithm. Assuming that IEEE 802.11ac standard with the modulation format of 256-QAM is used, the required BER is 1e-6. According to the BER versus SNR characteristics as shown in Fig. 1, the required SNR of each route must be 23.5 dB. To discover the route to node H, node A creates the RREQ packet. Before broadcasting the RREQ packet, local agent at node A determines the set Q_A that is the set of the neighbors of node A satisfying the constraint conditions of QoT. Q_A includes the nodes B, E and F due to the fact that SNR from node A to the nodes B, E and F are 28, 29 and 31 dB respectively. These values are greater than the required SNR (23.5 dB). Node A broadcasts RREQ packet to all nodes in the set Q_A. When receiving the RREQ packet, the nodes in set Q_A (B, E, and F) will update the reverse path to the source node (node A) into its route cache. For example, node B will update an additional record [A, A, 28] into the route cache, that means the source node is A, the next node to go to the source node is A, SNR value from A to current node (node B) is 28 dB. Since B, E, and F have not received this RREQ before yet, these nodes will continue to process the RREQ packet. At node B, although B has two neighbors which are E and D (except node A), the set Q_B only includes node E, due to the fact that the SNR value from A to D along to A → B → D is 22.54 dB, this value is less than the required SNR (23.5 dB) so it does not satisfy the constraint condition of QoT. Therefore, Node B only forwards the RREQ packet to node E. Similar for the remaining nodes, until the H node receives RREQ packet from node I, since H is the destination node, RREP packet is created and sent back to the source node according to the reverse route. The result is the route A → E → G → I → H it is found, SNR of that is 23.7 dB.

As analyzed in Section III (Fig. 6), if the AODV algorithm is used in this case, the found route is A → E → C → H, its SNR is 23.15 dB. Thus, SNR of the found route by QTA-AODV algorithm is better than that of the found route by AODV algorithm.

V. Performance Evaluation

In order to evaluate the performance of QTA-AODV algorithm, we use the simulation method based on OMNeT++ Discrete Event Simulator [21]. QTA-AODV algorithm is compared with AODV algorithm in terms of the SNR, BER, blocking probability of the data packet, network throughput, and the number of the control packets. The simulation assumptions are presented in Table I. Fig. 15 shows a snapshot of the animation interface during the simulation performance. At the current time, node 8 is broadcasting the RREQ packet to all its neighbors satisfying the constraint conditions of QoT in order to discover the new route.

TABLE I: Simulation Parameters

Parameters	**Setting**
Network Size	1000m × 1000m
MAC protocol	802.11n
Modulation technique	64-QAM
Data rate	54 Mbps
Transmit Power	17 dBm
Receiver Sensitivity	-71 dBm
Transmission Range	250 m
BER threshold	10^{-9}
Minimum Required SNR	21 dB
Noise model	Thermal noise
Temperature	300^0K
Mobility model	Random – Waypoint
Speed of nodes	0 - 20 m/s
Number of nodes	From 20 to 50

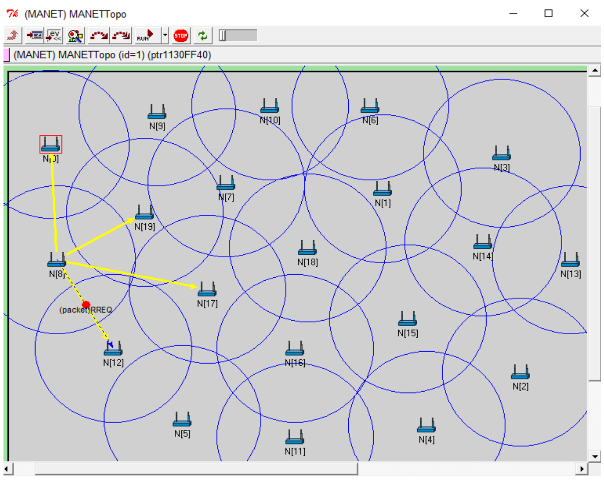

Fig. 15. A snapshot of the animation interface during the simulation of QTA-AODV algorithm

A. Study of SNR

In this section, we discuss the SNR in the cases of the AODV and QTA-AODV algorithms are used. The results obtained in Fig. 16 shows the minimum SNR versus the number of nodes among the routes under consideration. We can observe that, SNR decreases as the number of nodes increases. For AODV algorithm, SNR value is greater than required SNR (21 dB) if the network size is less than 30 nodes. However, if the network size is greater than 30 nodes, SNR value is less than the required SNR. This is the cause of the increasing of packet blocking probability due to the unsatisfactory constraint conditions of QoT.

For QTA-AODV algorithm, SNR values improved significantly compared with AODV algorithm. In particular, the minimum SNR is always greater than the required SNR (21 dB). Specifically, in case of the number of nodes are from 30 to 50, the minimum SNRs are from 29.11 down to 19.1 dB if AODV algorithm is used. These values do not satisfy the required SNR. For QTA-AODV algorithm, the minimum SNRs are from 23 down to 21.1 dB. These values are greater than the required SNR. Thus QTA-AODV algorithm always ensures the quality of transmission.

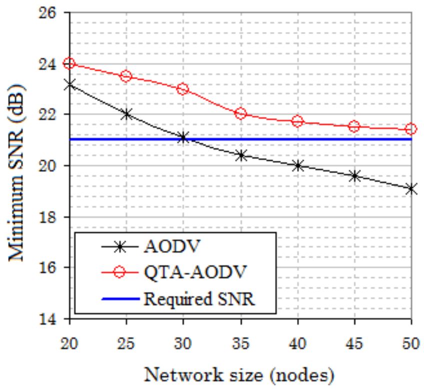

Fig. 16. SNR versus the network size for the cases that AODV and QTA-AODV

B. Study of Blocking Probability

In this section, we discuss the blocking probability of data packets (BPD) in the overall network. In our context, BPD is given by

$$BPD = \frac{N_b}{N_g} \qquad (11)$$

where N_g and N_b are the number of data packets are generated and the number of data packets are blocked in the overall network, respectively. N_b includes two components, blocking due to the congestion of the traffic load and blocking due to unsatisfactory constraint conditions of QoT.

As the SNR of QTA-AODV algorithm increases compared with AODV algorithm as analyzed in section V.A, BPD reduces in case of QTA-AODV algorithm is used. This is more clearly visible from Fig. 17, where, we plot the BPD as a function of the traffic load. In our context, the traffic load refers to the average traffic density per one wireless link that is generated by each node of MANET, expressed in Erlang. One Erlang corresponds to the amount of load traffic that occupies one channel in MANET. For example, if the capacity of each channel is 54 Mbps as in our model, one Erlang indicates that each node average generates 54 Mbps, i.e.

if the average data packet length is 1472 bytes, one Erlang equivalent to each node average generates (54e+6)/(1472*8) = 4585.58 packets/s.

The results in Fig. 17 correspond with the case of the number of nodes are 40, the average mobility spend of the nodes is 5 m/s. We can observe that, for the QTA-AODV, BPD reduced significantly compared with AODV algorithm. Considering the case of the traffic load is 0.6 Erlang, BPD of AODV and QTA-AODV algorithms are 0.0435 and 0.0319, respectively. Thus BPD of QTA-AODV algorithm reduced to 26.5% compared with BPD of AODV algorithm. For the highest traffic load, ie 1 Erlang, BBP of QTA-AODV algorithm reduced to 19.3% compared with BPD of AODV algorithm, from 0.074 down to 0.06. For the other cases, BPD decreased average 21.7% if QTA-AODV algorithm is used.

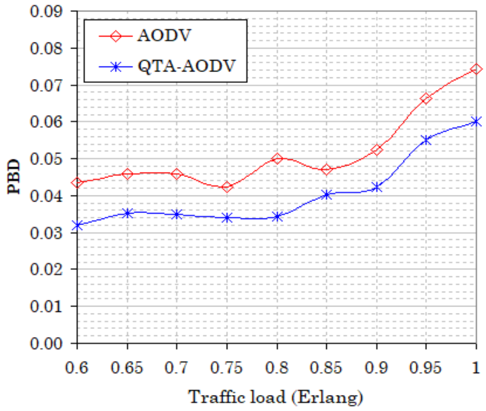

Fig. 17. The comparison the BPD versus traffic load of AODV and QTA-AODV algorithms in case of the average mobility spend of the nodes is 5 m/s, the networks size is 40 nodes

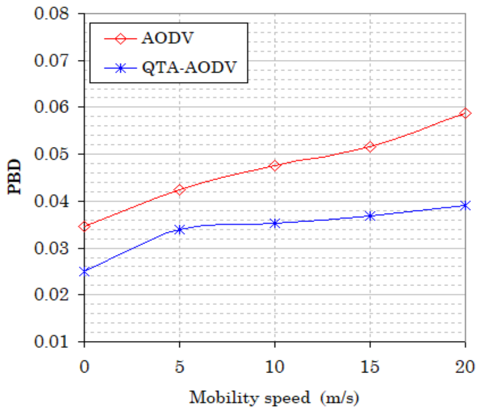

Fig. 18. The comparison the BPD versus mobility speed of AODV and QTA-AODV algorithms in case of the networks size is 40 nodes, the traffic load is 0.75 Erlang

For the cases of the variable mobility speed of nodes, PBD of both algorithms increases according to the mobility speed of the nodes as shown in Fig. 18, where, the networks size and traffic load are 40 nodes and 0.75 Erlang, respectively. We can observe that, PBD reduced significantly in the case of QTA-AODV is used. The average PBD reduction rate is 27.3%. For example, for the mobility speed of the nodes is 15 m/s, PBDs of AODV and QTA-AODV algorithms are 0.051 and 0.036, respectively. Thus BPD of QTA-AODV algorithm reduced to 28.6% compared with that of AODV algorithm.

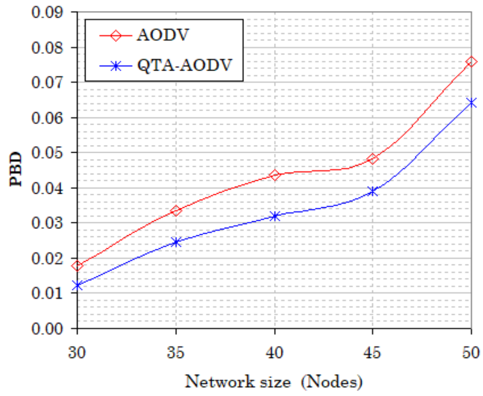

Fig. 19. The comparison the BPD versus the network size of AODV and QTA-AODV algorithms in case of the average mobility spend of the nodes is 5 m/s, the traffic load is 0.6 Erlang

Next, we analyze the case of the variable network size. The results obtained as shown in Fig. 19, where, we plot the BPD as a function of the network size. We can observe that, for both algorithms, the larger the network size, the higher the PBD, due to the fact that QoT decreases according to the network size as analyzed in section V.A. However, BPD of QTA-AODV algorithm is always less than that of AODV algorithm. The average PBD reduction rate is 23.7%.

C. Study of Network Throughput

In this section, we analyze the average receiving throughput at each node. In Fig. 20, we plot the average throughput of each node as a function of simulation times for the case that the networks size is 40 nodes, the average mobility spend of the nodes is 10 m/s, and the traffic load is 0.9 Erlang. The curves in Fig. 20 showed that, the throughput of QTA-AODV algorithm increases significantly compared with AODV algorithm. The average throughput of QTA-AODV and AODV algorithms are 19.55 and 19.90 Mbps, respectively. Thus, average throughput of QTA-AODV increases 350 Kbps compared with AODV algorithm.

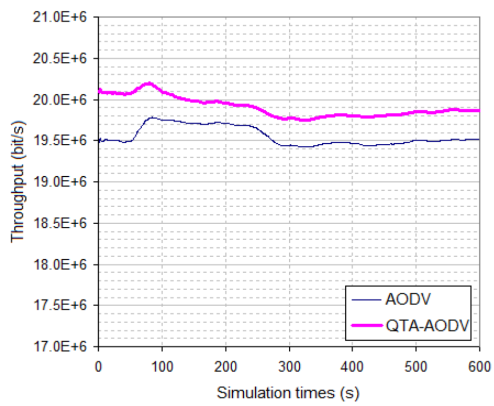

Fig. 20. The comparison the throughput of AODV, QTA-AODV algorithms for the case of the networks size is 40 nodes, the average mobility spend of the nodes is 10 m/s, and the traffic load is 0.9 Erlang.

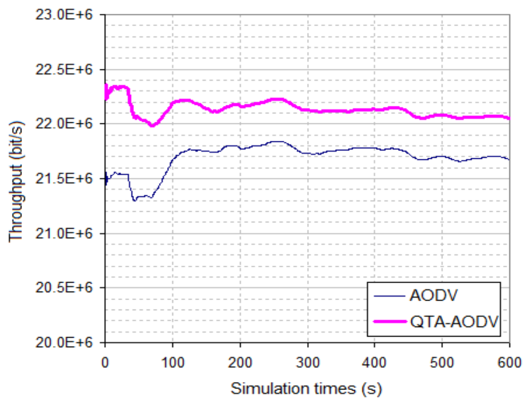

Fig. 21. The comparison the throughput of AODV, QTA-AODV algorithms for the case of the networks size is 40 nodes, the average mobility spend of the nodes is 10 m/s, and the traffic load is 1 Erlang.

The obtained results are quite similar for the case that the traffic load is 1 Erlang. This is clearly visible from Fig. 21. We can observe that, the average throughput of AODV algorithm is 21.69 Mbps. Meanwhile, this value of QTA-AODV algorithm is 22.13 Mbps, increased 440 Kbps.

In Fig. 22, we compare the throughput of AODV, QTA-AODV algorithms in the case of the variable mobility speed of nodes, the network size is 40 nodes, and the traffic load is 0.8 Erlang. We can observe that, for both algorithms, the average throughput decrease with the network size. However, the average throughput of QTA-AODV is always greater than that of AODV algorithm. The cause of the significant throughput increase is the increasing SNR (as analyzed in section V.A), which results in decreasing the number of blocked data packets due to the unsatisfactory constraint conditions of QoT.

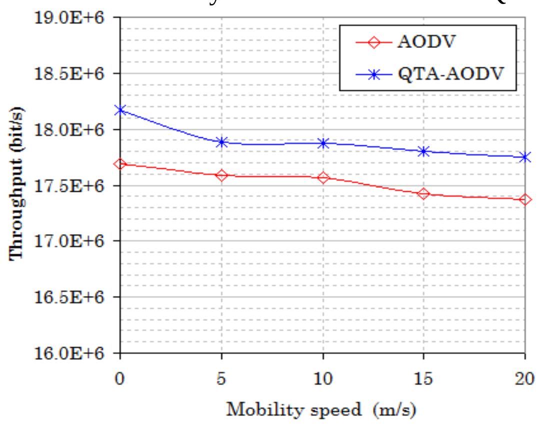

Fig. 22. The comparison the throughput of AODV, QTA-AODV algorithms versus mobility speed for the case of the networks size is 40 nodes, the traffic load is 0.8 Erlang.

D. Study of the Number of Control Packets

In this section, we discuss the number of the control packets used for the route discovery of the AODV and QTA-AODV. The results obtained as shown in Fig. 23, where, we plot the average number of RREQ packet used for each route discovery as a function of network size. We can observe that, if the network size is less than 25 nodes, the average numbers of RREQ packets of both algorithms are similar. But if the network size is greater than 25 nodes, the average numbers of RREQ packets of QTA-AODV algorithm decreased significantly compared with that of AODV algorithm. Specifically, for the network size of 40 nodes, AODV algorithm average forwards RREQ packet of 181 times for each route discovery. Meanwhile, QTA-AODV algorithm only average forward RREQ packet of 137 times. Thus, the number of RREQ reduced 24%. The curves in Fig. 23 showed that, the larger the network size, the more RREQ decreases.

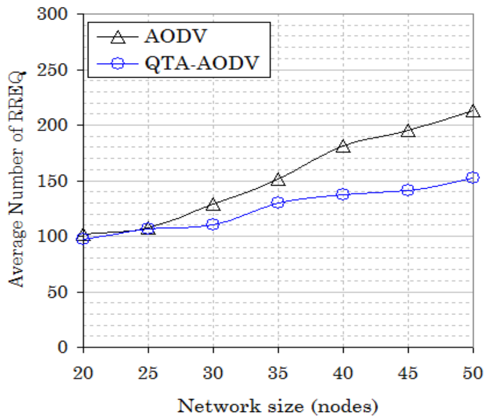

Fig. 23. Comparing the average number of RREQ packets for each route discovery of AODV and QTA-AODV

VI. Conclusions

The physical layer impairments in MANET impact on the network performance seriously, especially in case of MANET with the wide area and high node density. It is essential to study the routing algorithms taking into account the physical layer impairments. We presented in this paper the impact of the physical impairments on the performance of mobile ad hoc networks using AODV protocol. A routing algorithm was proposed then that takes into account the constraint conditions of the physical impairments using cross-layer model in combination with agent technology. The proposed algorithm called QTA-AODV, is modified from AODV algorithm. The main objective of the QTA-AODV algorithm is to improve the QoT of mobile ad hoc networks. By the simulation method, we have demonstrated that, the QTA-AODV algorithm can improve the SNR of the data transmission routes compared with AODV algorithm, reducing the blocking probability of data packets due to unsatisfactory constraint conditions of the quality of transmission, increasing the network throughput. QTA-AODV algorithm also reduced the number of the control packets compared with AODV algorithm.

In the near future, we continue to study the impact of the physical impairments on the network performance with respect to the other routing protocols in mobile ad hoc networks such as Destination-Sequenced Distance-Vector Routing (DSDV), hybrid routing protocols.

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