A High-Performance Routing Protocol for Multimedia Applications in MANETs

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Abstract —In recent years, mobile ad hoc networks (MANETs) have attracted a lot of work. One of the hottest research topics for MANETs is the routing problem that concentrates mainly on determining a good enough route from a source to a destination. Today, this means that the derived route must satisfy certain constraints or quality of service (QoS) guarantees required by multimedia applications. Therefore, the provision of QoS assurances is needed for any MANET routing protocol. Routes in MANETs are often not reliable and stable while most of multimedia applications require time-sensitive data transmission services. Thus, we propose a high-performance routing protocol to meet the QoS requirements of multimedia applications operating over MANETs. This QoS routing protocol utilizes the remaining bandwidth and transmission delay as the routing metrics for route selection. Our proposal is more flexible than existing solutions as it relies on a two-mode algorithm to identify the best-effort route according to the changes in the requirements of multimedia applications.

Index Terms—High-performance routing protocol, Quality-of-Service (QoS), multimedia application, MANET

I. Introduction

Mobile Ad-hoc Networks (MANETs) born in the 1970s can serve as a communication tool to exchange data very conveniently. Indeed, MANETs have advanced features such as self-organization and self-configuration that support low cost network connection without using predefined infrastructure. Hence, they are suitable for use in areas such as healthcare, rescue, disaster recovery, entertainment, military and smart traffic control. MANETs can also have potential applications in future smart cities and Internet of things [1]-[8].

According to Cisco [9], global mobile data traffic will grow at a compound annual growth rate of 47 percent. Mobile devices account for most of that growth. The rapidly-growing number of mobile devices gives birth to rich multimedia applications [10]. For example, mobile video will increase 9-fold between 2016 and 2021 and account for 78 percent of total mobile data traffic by 2021. Deploying multimedia applications over MANETs has resulted in a great success in the last few years. However, the provision of QoS guarantees for multimedia applications in MANETs is a real challenge. Indeed, the main reason is the dynamic nature of MANETs as they allow node mobility, multi-hop communications, contention for channel access, and a lack of central coordination [11]. Furthermore, due to the unique features of MANETs, the practical performance of MANETs is quite low [12]. This will limit the usefulness of MANETs, especially, the ability to support for multimedia applications. Therefore, advancing the network performance is always a critical issue. Theoretically, the performance of a MANET depends on its size, communication model and radio environment. In a MANET, each mobile node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity and the routing algorithm in use. Thus, routing protocols play a particularly important role in improving the performance of MANETs.

In order to support multimedia applications, routing protocols in MANETs must be designed to be flexible, energy-efficient and highly performance achievable [1], [12]. In addition, they must have the ability to provide QoS assurances. This is because multimedia applications often have stringent time and reliability-sensitive service requirements. Traditional routing protocols for MANETs such as AODV [13] or DSR [14] with a routing mechanism based solely on the hop-count metric has several limitations as indicated in [15]. Therefore, establishing high-performance QoS routing protocols for MANETs to support multimedia applications is an urgent need. Recently, a vast of high-performance routing protocols for special types of MANETs (e.g., vehicular ad hoc networks, civil aeronautical ad hoc networks, etc.) has been proposed (see, for examples, in [16]-[20]). The interested reader can refer to [11], [21] for more existing QoS routing solutions.

We recall that a typical data transmission process consists of two steps: finding routes and transmitting data. The data can be transmitted only when the intended routes are found and available for use. The selection of routes is governed by user/application requirements. Therefore, QoS requirements must be considered during the route discovery process. In essence, QoS is an agreement to provide guaranteed services, such as *bandwidth*, *delay*, *delay jitter*, and *packet delivery rate* to users. Supporting more than one QoS constraint makes the QoS routing problem NP-complete (see [21]). Therefore, in this work we only consider the bandwidth

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in cooperated with delay as a tunable constraint. In the next sections, we will detail our proposed QoS routing protocol to deal with this constraint.

II. Related Work

The performance of MANETs is constrained by a variety of factors. Normally, we cannot fully identify all of these factors. In recent years, many routing protocols have been proposed to improve the performance or ensure QoS for MANETs in different directions. Concerning the design objective of this work, we select some typical proposals and separate them into two categories including *high-performance* routing protocols and *QoS* routing protocols. Before considering examples of each category, we enhance the basic principle behind them. It is the selection of metrics involved in routing. Note that a routing metric is a unit calculated by a routing algorithm for selecting or rejecting a routing path for transferring data. In reality, each routing protocol may use a combined routing metrics to select the intended route(s) for data transmission. This means that routing metrics will influence the design of routing protocols for MANETs.

At the beginning of MANET research, the routing algorithms using a single metric (e.g. delay, hop-count, etc.) were widely used. Then, one may question "Can a single metric support QoS?" A feasible approach is to merge QoS requirements into a single requirement, then map it to a metric, and use this metric as the basis for decision making to select the route. We can give some examples below.

Suppose that p is a route, $p = \{i_1, i_2, i_3, \dots, i_{n-1}, i_n\}$. Where i_j $(1 \le j \le n)$ are nodes in p. Let $D_{i_j,i_{j+1}}$ be the metric of the link $(i_j, i_{j+1}), 1 \le j \le n$. Then, the metric of the route p, denoted by D_P, can be defined by using an *additive* operator:

$$D_P = D_{i_1,i_2} + D_{i_2,i_3} + \dots + D_{i_{n-1},i_n} \quad (1)$$

or by using a *multiplicative* operator:

$$D_P = D_{i_1,i_2} \times D_{i_2,i_3} \times \dots \times D_{i_{n-1},i_n} \quad (2)$$

or by using a *minimum* function:

$$D_P = min\{D_{i_1,i_2}, D_{i_2,i_3}, \dots, D_{i_{n-1},i_n}\} \quad (3)$$

Now, we consider routing metrics such as delay, bandwidth and packet loss rate. Clearly, the delay metric can be computed by Equation (1), the packet loss rate metric can be determined by Equation (2) and the bandwidth metric (i.e. bottleneck bandwidth) can be specified by Equation (3). Next, the packet loss rate metric can easily be converted into a successful transmission rate metric according to Equation (4) as follows:

$$D_P = 1 - \left(\left(1 - D_{i_1,i_2}\right) \times \left(1 - D_{i_2,i_3}\right) \dots \times \left(1 - D_{i_{n-1},i_n}\right)\right) \quad (4)$$

However, current multimedia applications often require more complex QoS requirements. Thus, the recent approach to using the multi-metric has become popular. To avoid solving a NP-complete problem when using more than one metric, several metrics can be treated as a multi-metric. For example, a mixed routing metric can be combined from metrics such as *B* (bandwidth) and *D* (time delay) through a cost function as follows:

$$f(p) = \frac{\sum_{i=1}^{P} D_i}{\min_{i \in P} B_i} \quad (5)$$

Consequently, the routing algorithm will select routes with high bandwidth and low latency to ensure user QoS.

Now, we discuss here some protocols in the first category. In [16], the authors proposed a new routing protocol, named Multimedia Multimetric Map-Aware Routing Protocol (3MRP), to send video messages over vehicular ad hoc networks (VANETs) in smart cities. 3MRP uses five routing metrics (i.e. distance, trajectory, density, available bandwidth and MAC layer losses) to select the optimal route. Simulation results based on NS-2 show that 3MRP improves latency and packet delivery ratios when compared with other routing protocols for VANETs. In [17], Lin et al. proposed a routing protocol called Moving Zone Based Routing Protocol (MoZo) for the purpose of data exchange between vehicles without relying on an infrastructure system. The main idea of this proposal is that each vehicle is equipped with a GPS module to obtain location information in real time, combined with clustering techniques to improve the performance of VANETs. Obtained experimental results show that MoZo improves the routing load and packet delivery ratios. In particular, in [18], the authors propose three clustering-based routing protocols to improve the performance of VANETs. The first named Cluster-Base Life-Time Routing (CBLTR) is a protocol for electing cluster head nodes based on the lifetime of the nodes. The second called Intersection Dynamic VANET Routing (IDVR) is the optimal route selection protocol at node based on its current location, the destination location, and throughput. The last, namely the Control Overhead Reduction Algorithm (CORA), used to reduce the control packets in each cluster. As proved by simulations on MATLAB, these proposed protocols significantly improve the performance of VANETs.

For protocols in the second category, we want to highlight their features related to QoS. In [19] the authors proposed Cross Layer Decision Based Routing Protocol (CLDBRP). This aims to select a route with packet delivery ratios that satisfy QoS requirements. The proposed protocol operates over the multi-hop VANET environment using channel quality (data rate) to make decisions on route selection. Simulation results with different traffic and mobility scenarios in this work show that the proposed protocol significantly improves packet loss rates. Also, in [20], the authors proposed a protocol called Multiple QoS Parameters based Routing protocol

(MQSPR) to improve the overall performance of communications between aircraft and the ground. MQSPR uses three routing metrics: path availability period, residual path load capacity and path latency for route selection. The main purpose of this protocol is to maintain long link durations, achieve path load balancing and reduce end-to-end delay to satisfy the requirements of civil aviation communication services. Provided experimental results show that MQSPR significantly improves packet delivery ratios and performs load balancing.

From analyses above, we can conclude that it is necessary to have both high-performance and QoS guarantee routing protocols for MANETs in order to support fully multimedia applications. Furthermore, the routing metrics must be selected carefully.

III. Proposed Routing Protocol

In this section, we propose a high-performance QoS Routing Protocol for MANETs. Indeed, we modified the conventional AODV protocol to establish a better one. The reason is that we want our protocol to inherit AODV's advanced features as it always has high performance and stability in different network structures. Hence, we name our proposed routing protocol QoS-AODV (Q-AODV for short). The details of our protocol design will be provided in the following subsections.

A. Routing Metrics Selection

Various routing metrics can be used for routing problem in MANETs such as bandwidth, delay, packet loss rate, reliability, location and residual energy of node. In order to embed service quality requirements in the route selection process, we need to use suitable routing metrics. For this, we make use of a popular strategy considered feasible, that is to choose the bandwidth metric together with one of the above metrics. In our view, throughput, delay, packet loss rate, reliability, mobility, energy, etc., are very useful, but for multimedia applications, available bandwidth and end-to-end delay are most important.

B. Route Discovery

In order to support multimedia applications in MANETs, Q-AODV is designed so that it can operate in two modes as follows:

Adaptive Mode: to provide a route with the best throughput and delay.

Admission Mode: to provide the lowest bandwidth, but the best delay route that satisfies the intended requirements.

The route selection process in both modes will require knowledge of the throughput and delay of candidate routes between a pair of source-destination nodes. This can be achieved by the route discovery procedure described below.

Like AODV, Q-AODV is an on-demand routing protocol and it operates on the principle that whenever a data transfer request is made, the source node will discover route (s) from that node to the destination node. The route discovery process starts with the source node sending the RREQ (Route Request) packets, with the header changed as follows {Model-Flag, Bandwidth Request, Bandwidth, Delay Request, Delay, AODV RREQ Header}. These packets are then forwarded through intermediate nodes to reach the destination node. A different point from traditional RREQ packet forwarding is that, at each intermediate node, when receiving a RREQ packet, the intermediate node performs a procedure named Quality-Check. This procedure is described by the schema as shown in Fig. 1.

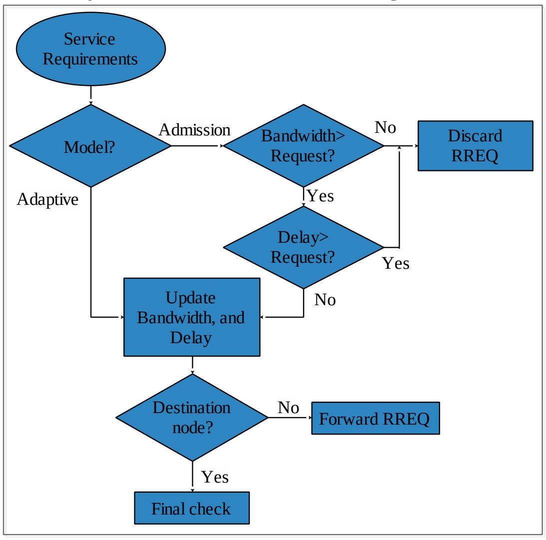

Fig. 1. RREQ packet processing procedure Quality-Check at intermediate nodes.

The Quality-Check has two main tasks as follows:

(1) To remove immediately routes that do not satisfy bandwidth or end-to-end delay conditions. This helps to decrease bandwidth, power consumption as well as routing load spent in unnecessary operations.

(2) To calculate the bandwidth and delay of the route. The bandwidth and delay of each link are determined based on information of the Hello messages (see [21] for more details).

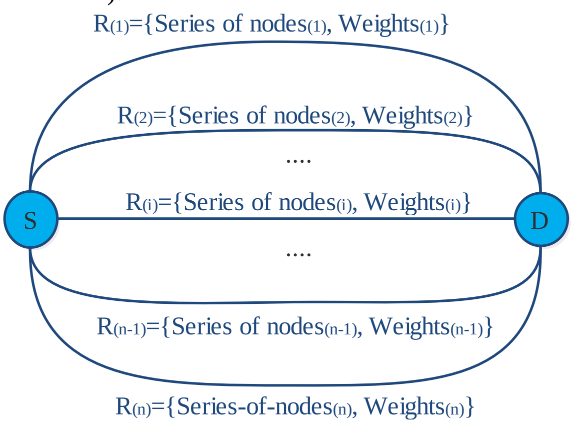

Fig. 2. The set of candidate routes between a pair of nodes.

Finally, the destination node sends the RREP (Route Reply) unicast packet with the modified header

{Bandwidth, Delay, AODV RREP Header} to the source node. In addition, similar to AODV, the protocol has route maintenance procedures using RRER (Route Error) messages. The source node receives all candidate routes (Fig. 2) if the process reaches a successful completion.

C. Route Selection Algorithm

To describe the route selection algorithm, we use a graph to represent the network model as shown in Fig. 3. We define $G = (V, E)$ is a communication graph of the MANET, where $V = \{V_1, \ldots, V_n\}$ is the set of mobile nodes, E is the set of links. Each link E_{ij} of a node pair (V_i, V_j) has a weight set $W_{ij}=(B_{ij}, D_{ij})$, where B_{ij} and D_{ij} are *bandwidth* and *delay* of link E_{ij}, respectively.

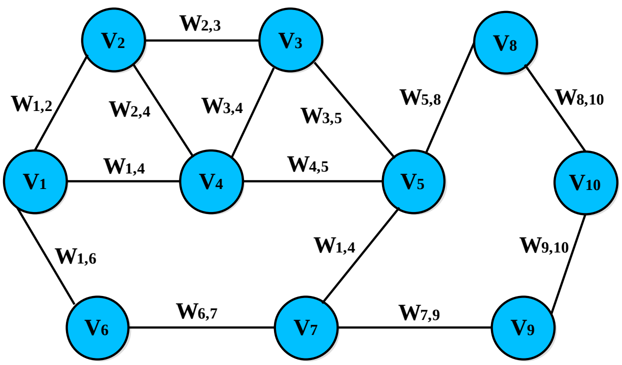

Fig. 3. The graph model of a MANET.

After receiving a set of candidate routes by the route discovery procedure, the best-effort route will be selected. We define and use a cost function as follows:

At first, let $Delay_{(i)}$ and $Bandwidth_{(i)}$ be the end-to-end delay and bandwidth of the route *i*, respectively. Note, this bandwidth value has been calculated by the source node according to the Min-Bandwidth function as depicted in Fig. 4 below.

Function ***Min-Bandwidth*** (Bandwidth, Hop-Number)
{
//Bandwidth is the value *bandwidth* field in RREQ
//Hopnumber is the hops number of the route
If $(HopNumber = 1)$ ***then***

$$\text{Bandwidth} = \text{Bandwidth}$$

If $(HopNumber = 2)$ ***then***

$$Bandwidth = \frac{Bandwidth}{2}$$

If $(HopNumber = 3)$ ***then***

$$Bandwidth = \frac{Bandwidth}{3}$$

If $(HopNumber \geq 4)$ ***then***

$$Bandwidth = \frac{Bandwidth}{4}$$

Return (Bandwidth)
}

Fig. 4. The Min-Bandwidth (bottleneck bandwidth) function.

Now, the cost function of the route *i* can be calculated as follows:

$$Cost\_Delay\_Bandwidth_{(i)} = \frac{Delay_{(i)}}{Bandwidth_{(i)}} \qquad (6)$$

Next, let Z and $Cost\_Set$ be the total number of routes and sets of routing cost of the candidate routes satisfying above conditions, respectively. We have:

$$Cost\_Set = \begin{cases} Cost\_Delay\_Bandwidth_{(1)} \\ Cost\_Delay\_Bandwidth_{(2)} \\ \cdot \\ \cdot \\ \cdot \\ Cost\_Delay\_Bandwidth_{(Z-1)} \\ Cost\_Delay\_Bandwidth_{(Z)} \end{cases} \qquad (7)$$

$$Optimalroute = Min\ (Cost\_Set) \qquad (8)$$

Accordingly, the best-effort route can be determined by Equation (8). The route selection algorithm of Q-AODV is summarized as follows.

Algorithm 1: Q-AODV Route Selection Algorithm

```
routeset=shortest-route(S,D)
// Equation (6) & (7)
Cost=∞, Selectedroute={∅}
for i=1 to sizeof(routeset) do
    if Cost>Cost_Delay_Bandwidth(i) then
        Cost=Cost_Delay_Bandwidth(i)
        Selectedroute=cons1valid(i)
    end if
end for
return (Selectedroute, Cost)
```

IV. Exprimental Results and Evaluation

A. Simulation Model and Parameters

To evaluate and compare the performance of Q-AODV with two typical routing protocols including AODV and DSR, we set up a simulation on NS2 software version 2.34. The experiments will be conducted with different scenarios in two modes: adaptive and admission. In all experiments, we use the CBR traffic type with 200 randomly assigned mobile nodes (using the Random Waypoint mobility model) in an area of 1500×1500 (m). The transmission range of the mobile node is set to 250 m. Velocities of mobile nodes are set randomly in the range $[0, V_{max}]$, where, $V_{max} = [2,4,6, \ldots, 20]$ (i.e. the real speed of vehicles in urban areas, approx. $[7.2 - 72]$ km/h).

We tested Q-AODV when nodes move with different speeds in both *adaptive* and *admission* modes. The number of end-to-end connections were 50 in all cases. For *Adaptive* mode, we will observe performance metrics such as throughput, delay, and packet delivery ratios. For *Admission* mode we will observe the metrics such as throughput, delay, and routing overhead. Simulation parameters are provided in Table I.

TABLE I. SIMULATION PARAMETERS

Parameters	Value
Simulation Time	500s
Simulation Area	1500m ×1500m
Number of Nodes	200
End-to-End Connection Number	50
MAC Layer	802.11
Traffic Type	CBR
Bandwidth	1 Mbit/s
Size of Packets	1024 byte
Transport Layer	UDP
Bandwidth Request	500 Kbps
Mobile Speed	(2-20) m/s
Communication Range	250 m
Mobility Model	Random Way Point
Protocols	Q-AODV, AODV, DSR

B. *Performance Metrics*

We use the following metrics to evaluate the experimented routing protocols' performance.

Packet Delivery Ratio (PDR) (in %): the ratio of the number of packets delivered to the destination nodes P_r over the number of packets sent by the source nodes P_s:

$$PDR = \frac{P_r}{P_s} \times 100\% \qquad (9)$$

Average End-to-End Delay (Delay): the time taken for a packet to be transmitted across a network from source to destination:

$$Delay = \frac{\sum_{i=1}^{n}(t_r - t_s)}{P_r} \qquad (10)$$

Throughput: the throughput on a link is determined by multiply the numbers of the packet are transmitted and the size of the packet per one second:

$$Throughput = \frac{P_r \times KT}{T} \qquad (11)$$

Routing Load (Routing Overhead): it is defined as the ratio of the total number of control packets per the total number of data packets received by the source node:

$$Routing\ Overhead = \frac{Control\ Packets\ Number}{P_r} \qquad (12)$$

where:
P_r is the packet number received by the destination node
P_s is the packet number sent by the source node
t_r is the time the packet is received at the destination node
t_s is the time the packet is sent at the source node
T is the time of the measurement process
KT is the size of the packet.

C. *Adaptive Mode*

In simulation, we try to compare Q-AODV with two traditional routing protocols that do not support QoS (i.e. AODV and DSR). The metrics used to measure performance of these protocols are the delay, throughput, and packet delivery ratios. The experimental results are shown in figures 5, 6, and 7. As the mobility of mobile nodes increases, the structure of the network changes more rapidly. This leads to a higher ratio of routes broken, resulting in an increased number of packets being retransmitted or route being reconfigured. All of these problems will lead to increased bandwidth consumptions and end-to-end delay, and reduced packet delivery ratios.

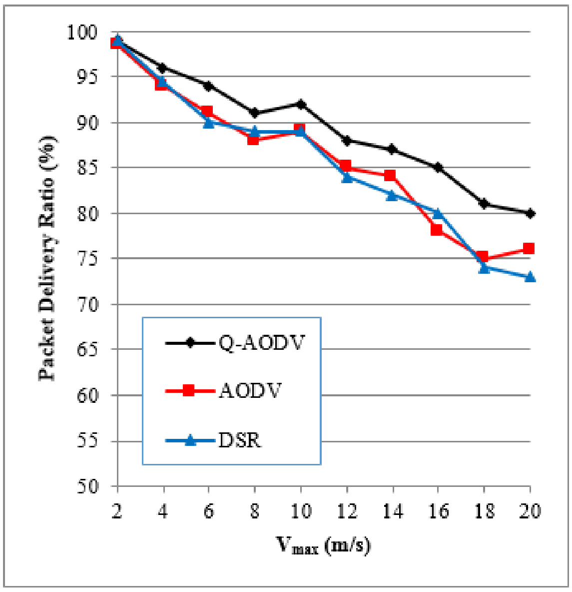

Fig. 5. The PDR of a MANET with Q-AODV in adaptive mode.

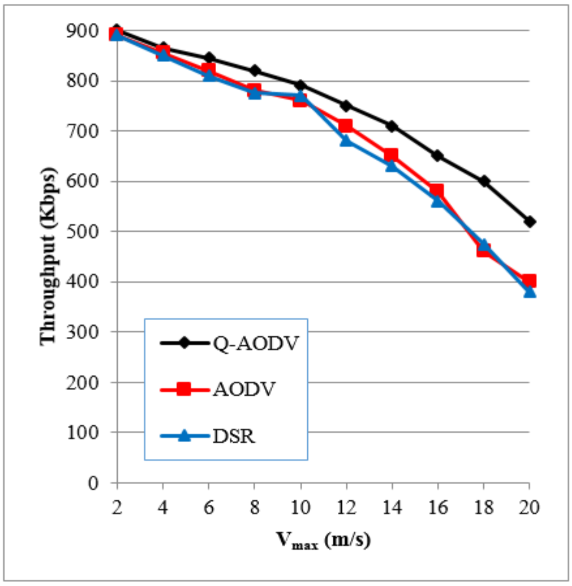

Fig. 6. The throughput of a MANET with Q-AODV in adaptive mode.

In Fig. 5, the packet delivery ratios of all three protocols decrease as the mobility of nodes increases. However, Q-AODV's packet delivery ratios are improved significantly when compared with AODV and DSR. It is about 8% higher at V_{max}=18 m/s.

In Fig. 6, at V_{max}=2 m/s, the throughputs of all three protocols are high and not much different. As V_{max} increases, the throughputs of all protocols tend to decrease. However, Q-AODV always selects a route with high throughput. Hence, the throughput it gained is better than both AODV and DSR (e.g. at V_{max} = 20 m/s, the throughput of Q-AODV protocol is up to 25% higher).

In Fig. 7, the end-to-end delays of all three protocols tend to increase rapidly as the mobility of network nodes increases. However, due to the improvements of packet delivery ratios as well as throughput, the end-to-end delay of Q-AODV is always lower than that of AODV and DSR (e.g. at V_{max} = 20 m/s, the end-to-end delay of Q-AODV is improved about 20% when compared to AODV and DSR).

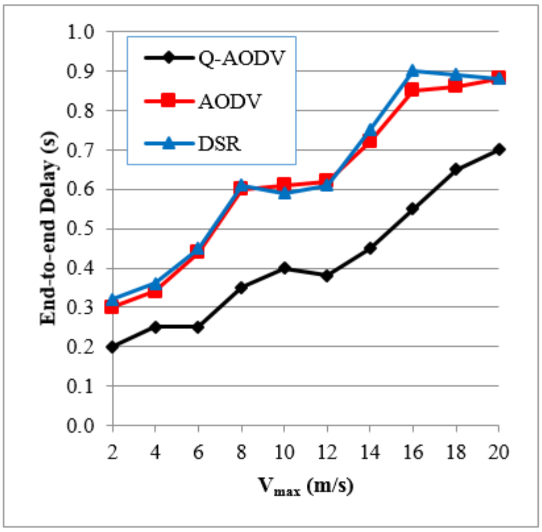

Fig. 7. The end-to-end delay of a MANET with Q-AODV in adaptive mode.

D. Admission Mode

In this mode, routes are discarded immediately if the available bandwidth is less than the required bandwidth. As a result, the number of candidate routes obtained will be less than that in the adaptive mode. Therefore, the number of routing packets as well as the ability of the collision between packets will decrease. We anticipate that the packet delivery ratios, delay, and routing overhead of Q-AODV will improve significantly when comparing to AODV and DSR. We use the same network structure and simulation parameters. The experimental results are presented in figures 8, 9 and 10.

In Fig. 8, the PDRs of all protocols are decreased as the mobility of nodes increases. However, comparing PDR between the adaptive and admission modes, we found that the PDR of Q-AODV was almost unchanged and better than that of AODV and DSR (e.g. at V_{max}=20 m/s, the PDR of Q-AODV protocol is improved about 15% higher than the PDRs of AODV and DSR)

In Fig. 9, the end-to-end delays of three protocols are increased as the mobility of network nodes increases. Comparing the obtained delays in the adaptive and admission modes, we found that, similar to the PDR metric, while the end-to-end delay of Q-AODV protocol was almost unchanged, the delays of AODV and DSR are increased rapidly. The reason is that, the absence of QoS mechanisms in both AODV and DSR (i.e. the ability to select high throughput routes of them are somehow limited).

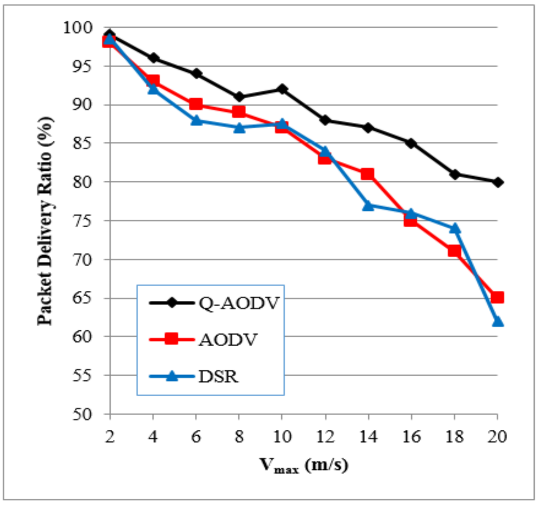

Fig. 8. The PDR of a MANET with Q-AODV in admission mode.

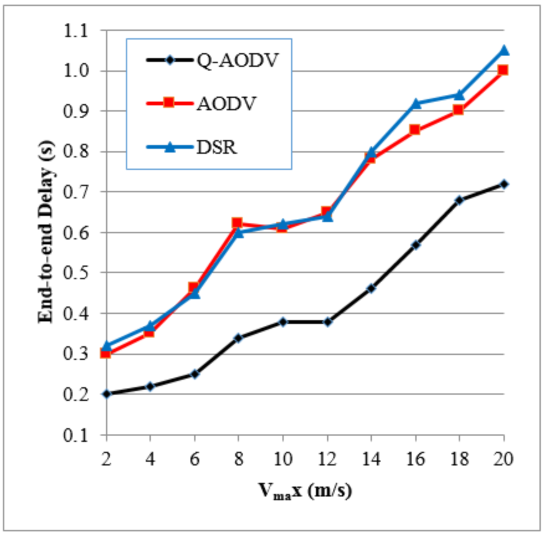

Fig. 9. The end-to-end delay of a MANET with Q-AODV in admission mode.

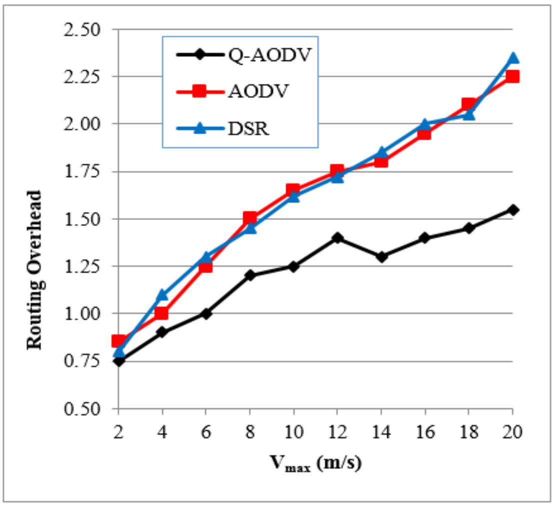

Fig. 10. The Routing overhead a MANET with Q-AODV in admission mode.

In admission mode, when the throughput of a route is considered to be lower than the required bandwidth, the RREQ packet forwarding process immediately stops and the route is removed from the route discovery process. As a result, the routing overhead of Q-AODV protocol is significantly improved compared to the two traditional protocols as shown in Fig. 10. This implies that energy and bandwidth can also be saved.

V. Conclusion

In this work, we proposed an on-demand high performance QoS routing protocol, namely Q-AODV, to support multimedia applications in MANETs. Our proposed protocol works well in both *adaptive* and *admission* modes. To evaluate the performance of the proposed protocol, we set up several experiments with different inputs. The experimental results show that the performance metrics such as throughput, average end-to-end delay, and packet delivery ratios of Q-AODV are significantly improved.

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