Improving QoS for Real-time Multimedia Traffic in Ad-hoc Networks with Delay Aware Multi-path Routing

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Abstract

A Mobile Ad-hoc Network (MANET) is a wireless network in which nodes, in the absence of fixed access points, communicate via single or multi-hop paths. Each node in a MANET should thus be able to perform necessary routing functions, and a MANET routing protocol should be able to adapt fast and effectively to sudden changes in network layout. Providing trustworthy Quality of Service guarantees in a MANET is very challenging due to the dynamic and uncertain nature of these networks.

We extend the AODV routing protocol for MANETs to a multi-path protocol which uses end-to-end delay, instead of hop count, as metric for route selection. Multiple paths, together with the end-to-end delay provided by each path, are stored in routing tables. Upon route failure, the route table is first searched for an alternative route to the destination before a new route discovery process is initiated. This reduces both routing overhead and end-to-end packet delay.

The proposed protocol is implemented and tested in OPNET Modeler and shows significant improvements in delay, delay variation, packet delivery fraction and routing overhead compared to AODV, DSR, OLSR and DYMO.

1. Introduction

MOBILE Ad-hoc Networks (MANET) are mobile wireless networks with no fixed or guaranteed layout. In these networks, nodes communicate by transmitting data directly to each other, or via multi-hop routes using intermediate nodes. All nodes in a MANET should thus be able to perform the necessary routing functions to discover routes and forward data packets in such a network [1], [2].

Characteristics such as node mobility, limited transmission bandwidth and limited energy resources of mobile nodes contribute to the uncertain nature of these networks [3]. Mobile Ad-hoc Networks can be used very effectively in environments where no network infrastructure is available, but real-time and reliable communication is needed. Examples are military deployments, disaster rescue operations and electronic classrooms [1], [4].

Routing is a determining factor for the effective operation of a MANET and routing protocols used in these dynamic networks should be able to adapt fast and efficiently to unexpected changes in network layout. The limited bandwidth and energy resources of mobile devices and the dynamic and uncertain nature of MANETs and the lack of centralized control make the routing problem even more involved compared to wired networks [4], [5].

Providing real-time services with certain Quality of Service (QoS) guarantees in wireless networks is a challenging task. This is due to different applications issuing various QoS requests, the dynamic and distributed nature of mobile networks, as well as frequent link breakages and node failures in wireless networks. Furthermore, some applications may demand high bandwidth, flow synchronization and may be delay sensitive [6], [7]. To ensure that the QoS demands of different network applications are met, a MANET should be able to service various types of QoS requests.

Some popular and well studied routing protocols for MANETs include Ad hoc On-demand Distance Vector (AODV) routing [8], Dynamic Source Routing (DSR) [9], Optimized Link State Routing (OLSR) [10] and one of the most recently proposed protocols; Dynamic MANET On-demand (DYMO) routing [11]. None of these however focus specifically on providing acceptable QoS for real-time traffic.

A large amount of work has been done to develop new QoS routing protocols for MANETs [7], [17],

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[18], as well as extending existing protocols with QoS features [12], [19], [20], [21]. To the best of our knowledge, these protocols are all experimental and none of them are considered for standardization.

We propose to extend the AODV protocol to discover and store multiple routes of which the end-to-end delay is also recorded and stored. Each application packet is classified according to the value contained in the Type-of-Service (ToS) field in the Internet Protocol (IP) header, and an end-to-end delay request is assigned accordingly. Application packets requesting a route are transmitted only if a discovered route's recorded delay is less than the requested delay. If an active route fails, a source node first searches for an alternative route in its route table before initiating a new route discovery process. Since this is an initial study, only voice and video traffic are considered with equal delay requests from both traffic types.

The rest of the paper is organized as follows: Section 2 gives an overview on related work, which is also used as the foundation of this study. Section 3 summarizes the proposed extension of the AODV protocol. In section 4, the simulation setup is discussed and the results are provided and discussed in section 5. Section 6 contains a brief discussion of the study.

2. Related Work

A. The AODV routing protocol [8]

AODV is a reactive routing protocol for MANETs that uses hop count as metric for route selection. Each node stores only information of the next hop in a route to a destination. It uses three main message types for route discovery and maintenance: Route Request (RREQ), Route Reply (RREP) and Route Errors (RERR) messages.

Whenever a node requests a route to another node, it broadcasts a RREQ message which is propagated through the networks until it reaches the intended destination node, or an intermediate note with a valid route to the destination. One of these will then reply by sending a RREP message via the discovered route. Whenever a link breakage occurs, any node detecting this immediately notifies all nodes that used the link that the link no longer exists. This is done by sending a RERR message to all these nodes.

Whenever a node receives new route information to a specific destination node, the new information is evaluated through the following route updated rule:

if $(seq\_nr^d_i < seq\_nr^d_j)$ **or** $((seq\_nr^d_i = seq\_nr^d_j)$
  and $(hop\_count^d_i > hop\_count^d_j))$
then
  $seq\_nr^d_i := seq\_nr^d_j;$
  $hop\_count^d_i := hop\_count^d_j + 1;$
  $next\_hop^d_i := j;$
endif

The notation applies for a node i which receives routing information to destination d from neighbor j. The destination sequence number, hop count and next hop for a destination d at node i is represented by $seq\_nr^d_i$, $hop\_count^d_i$, and $next\_hop^d_i$ respectively.

Any node that is part of one or more active routes, broadcasts a *Hello* message locally every HELLO_ INTERVAL [8] milliseconds in order to offer connectivity information.

B. QoS for AODV [12]

QoS for AODV [12] is an extension to AODV originally proposed in 2000 by the authors of AODV. An operational overview on this initial version is provided. Refined versions can be found in [13] and [14].

Nodes are allowed to request the delay and bandwidth required from a route. A *Delay* and *Bandwidth* field is appended to the RREQ and RREP messages. For a RREQ message, these fields contain the maximum allowed transmission time and minimum required bandwidth between the forwarding node and the destination. For a RREP message, it contains the current estimate for the cumulative delay and the available bandwidth between the forwarding node and the destination.

If a node somewhere along a QoS route detects that the guaranteed QoS can no longer be provided, all sources that used the route should be notified by sending an ICMP QOS_LOST message to the sources.

The route table entries are appended with four new fields: *Maximum delay*, *Minimum available bandwidth*, *List of sources requesting delay guarantees*, and *List of sources requesting bandwidth guarantees*.

Two prominent weaknesses of this version are: The NODE_TRAVERSAL_TIME value that is used to calculate route delay, is only a conservative estimation of the average one hop traversal time [8] and may not always be trustworthy since queuing delay, amongst others, may vary dramatically depending on network congestion. Secondly, the *ICMP QOS_LOST* message only notifies nodes that delay has increased or bandwidth has decreased [12], but no specific information is provided.

C. AODV-Multipath [4]

In [4], modifications to AODV are proposed enabling the discovery of multiple node-disjoint paths. Intermediate nodes should no longer discard multiple RREQ messages, but store the information of these packets in the RREQ table (Fig. 1(a)), and forward them. Furthermore, only a destination node is allowed to reply to a RREQ message.

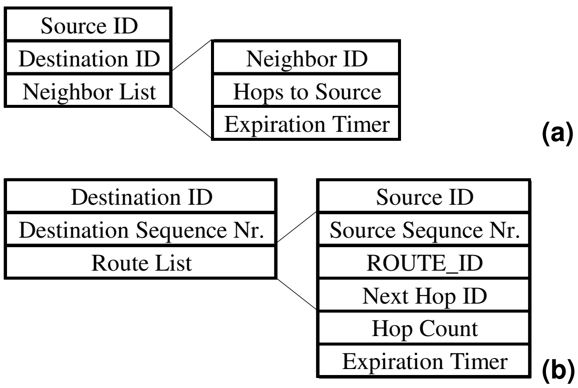

Figure 1. (a) Route request table entry (b) Route table entry

For each RREQ message of a single route discovery instance received by a destination node, a RREP message is created containing a unique route ID number in an appended *ROUTE_ID* field. The RREP packet is then sent back to the source via the node from which the destination received the RREQ packet.

Whenever an intermediate node receives a RREP message, it updates its route table (Fig. 1(b)), searches for the shortest route to the originator, and deletes the corresponding entry from its RREQ table. It then forwards the RREP message. If the RREQ table is empty, it generates a Route Discovery Error (RDER) message and sends it to the previous hop. The previous hop then attempts to use an alternative route to forward the RREP message.

3. Delay Aware AODV-Multi-path (DAAM)

We combine selective and modified components of [4] and [12] in a new protocol we call Delay Aware AODV-Multi-path (DAAM). Multiple node disjoint paths are set up during a single route discovery, and the delay of each route is recorded during the route discovery. Whenever a data packet arrives at the routing layer from the application layer, the type of data contained in the packet is classified according to the ToS field in the IP header and a delay request is assigned accordingly. This is then used to determine if a new discovered route is suitable for a certain traffic type. No IP/UDP/RTP header compression is done since this could complicate the use of the ToS field in the IP header to assist QoS decisions.

A. Changing the metric

RREQ and RREP messages are modified to contain a *Delay* field in which the cumulative delay up to the node processing the packet is recorded. This route delay value is then stored with the specific route entry in the route table. Whenever a new route is discovered and one or more packets are queued for the specific destination, the delay requested by each packet is compared with the delay offered by the route, and the route is only used if the route delay is equal to or less than the requested delay.

If a new route to a destination is discovered, a modified version of the AODV update rule [8] determines whether or not the new route is preferred above the existing route. This rule states the following: If a new route's sequence number is the same as the existing one's, but the new route provides lower delay, or the new route has a higher sequence number and thus is fresher, and its delay is anything lower than the requested delay, the new route is selected over the existing. The DAAM update rule is as follows:

if $(((seq\_nr^d_j == seq\_nr^d_i)$ **and**
$(route\_delay^d_j < route\_delay^d_i))$
or $((seq\_nr^d_j > seq\_nr^d_i)$ **and**
$(route\_delay^d_j < delay\_request)))$
then
$seq\_nr^d_i := seq\_nr^d_j;$
$hop\_count^d_i := hop\_count^d_j + 1;$
$next\_hop^d_i := j;$
$route\_delay^d_i = route\_delay^d_i;$
endif

The notation applies as for the AODV route update rule, with the addition of $route\_delay^d_i$, representing the route delay to destination d at node i, and *delay_request*, representing the delay request of an application packet.

As in AODV, each node that is part of at least one active route, broadcasts a *Hello* message locally every HELLO_INTERVAL milliseconds to offer connectivity information [8]. Nodes compare the link delay determined from a received *Hello* message with a delay threshold which is permitted per link, and if it is more than the threshold value, the link is no longer used. It is assumed that such a link can no longer provide the requested QoS.

Finally, all packets that are queued for route discovery are discarded if they are queued for longer than a maximum accepted delay period, typically 400 milliseconds for real-time traffic [15].

B. Multi-path routing

A multi-path routing scheme as proposed in [4], using the change in metric proposed in section *A*, can be implemented as follows: Instead of discarding multiple RREQ messages, intermediate nodes forward them, except for the case where a RREQ message with the same request ID has already been received from the same previous hop. The RREQ table is managed as in AODVM. Upon receiving a RREP message, an intermediate node searches for the reverse route with the smallest hop count in the RREQ table. Once a next hop node is selected, the entire entry of the specific source-destination pair is deleted from the RREQ table. This prevents the node from forwarding multiple RREP messages, in order to assure that multiple paths are node-disjoint. If no reverse route is available, the RREP message is discarded.

If a RREP message reaches the node which originated the RREQ, the new discovered route is stored in the route table, together with the route ID and route delay. If a route that uses the same next hop address already exists, the DAAM route update rule is evaluated in order to decide whether or not the new route should be used instead of the existing one.

Now, whenever the route discovery process would have been initiated as in AODV, DAAM first searches the route table for alternative routes which also complies with the delay request of the application packet. If an alternative route is available, it is selected as the new active route and the route discovery process is aborted.

4. Simulation Setup

OPNET Modeler was used to perform network simulations. The network setup is as follows: An ad-hoc network containing 81 nodes is set up over a physical area of 100x100 m^2. A total of six nodes are set up to perform GSM quality Voice-over-IP (VoIP) communication and six other nodes to perform low quality (128x120 pixels, 10 fps) video conferencing. Delay requests of both traffic types are set to 150 ms, as recommended by the ITU-T [15]. Communicating nodes are distributed evenly on the edge of the network area. The *Transmission Power* of all nodes is set to 2×10^{-5} W and the *Packet Reception-Power Threshold* is set to -95 dBm, forcing nodes on the opposite edges of the network to communicate via multi-hop paths. Two main scenarios are configured; one is configured to be a static network and the other to be mobile. The IEEE 802.11b MAC protocol is used. It allows data rates of up to 11 Mbps, however, 5.5 Mbps is selected in order to evaluate the protocols' performance in less ideal conditions.

Table 1. General network parameters [2]

Parameter	Value	Units
Network Area	100x100	squared meter (m^2)
Wireless Nodes	81	none
Transmission Power	5×10^{-5} or 2×10^{-5}	watt (W)
MAC Layer Protocol	*IEEE* 802.11b	
Data Rate	5.5	Megabits/second (Mbps)
Node Speed (mobile scenarios)	[0, 5]	meter/second (m/s)
Link Delay Threshold	0.1	seconds
Active Route Timeout	1	seconds

Table 2. Voice-over-IP parameters [2]

Parameter	Value	Units
Voice Nodes	6	nodes
Encoder Scheme	GSM	
Voice Frames per Packet	5	frames
Max. Delay Request	0.15	seconds

Table 3. Video conferencing parameters [2]

Parameter	Value	Units
Video Nodes	6	nodes
Frame Inter-arrival Time	10	frames/second (fps)
Frame Size	128x120	pixels
Max. Delay Request	0.15	seconds

This setup simulates a large office network configuration where on average six persons are busy with VoIP and six other with video conferencing. In such an office scenario, employees would mainly sit at their desks (static scenario), but can also move around with mobile devices such as laptops, mobile phones or PDA's (mobile scenario).

For each scenario, five test runs of 20 minutes each are performed, each with a different seed value, used for random number generation. Random numbers are used for certain stochastic events during the simulation such as node movement and data destination selection.

Tables 1, 2 and 3 summarize the most important simulation parameters. Other protocol specific parameters are kept default as recommended in [8].

5. Simulation Results

Graphs of the mobile scenario are presented in

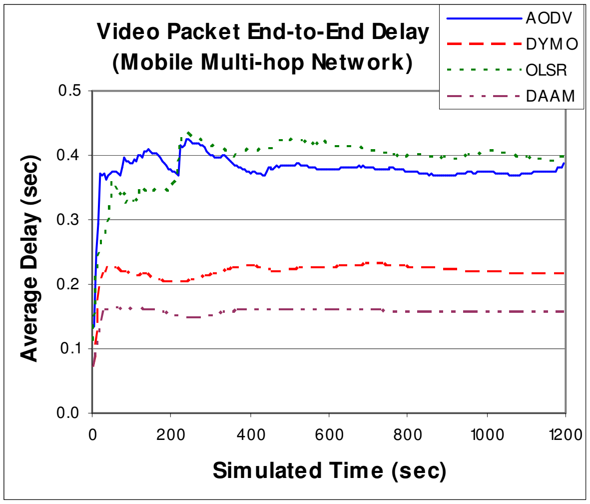

Figure 2. Mobile multi-hop network – Video packet end-to-end delay

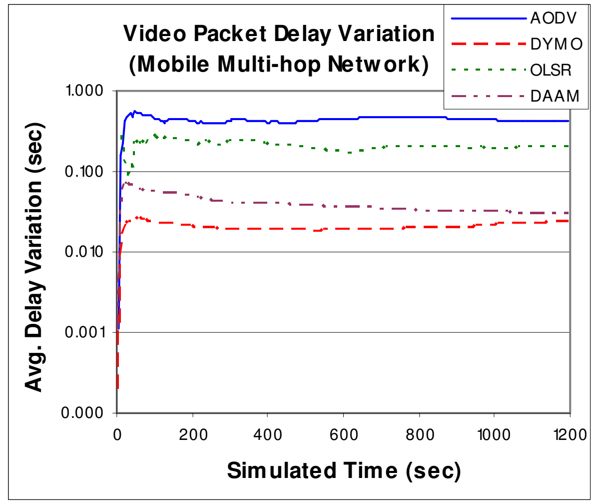

Figure 4. Mobile multi-hop network – Video packet delay variation

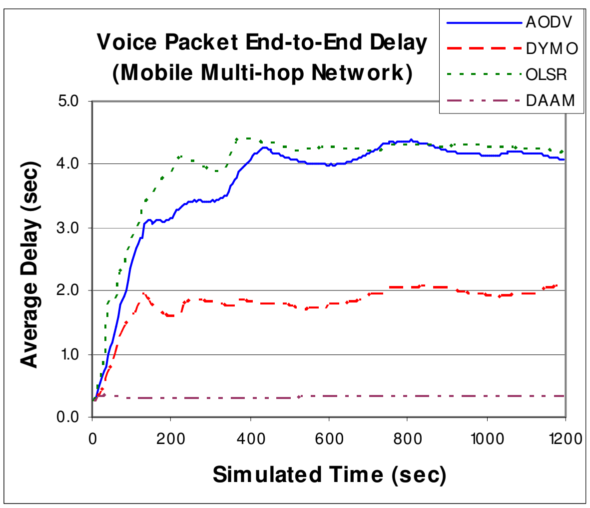

Figure 3. Mobile multi-hop network – Voice packet end-to-end delay

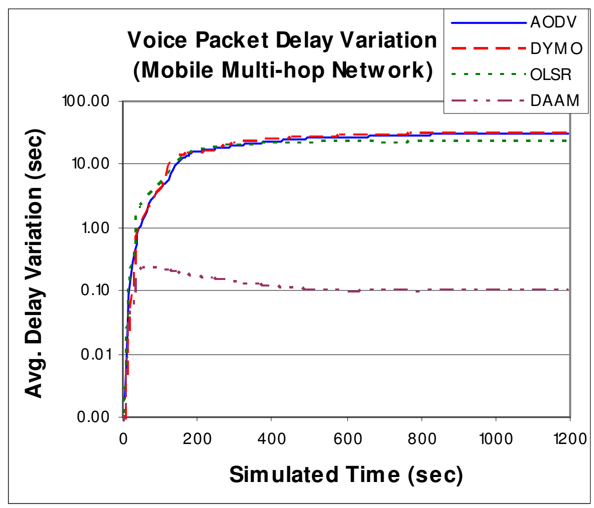

Figure 5. Mobile multi-hop network – Voice packet delay variation

this section. The performance of DAAM is compared with that of AODV, DSR, DYMO and OLSR. Tables 4 and 5 contain summaries of all protocols' performance in mobile and static scenarios. The results of DSR are not plotted on the graphs due to its bad performance. It is however included in the tables.

A. End-to-end delay

The average end-to-end delay of video and voice traffic is presented in this section. First, the average values of all five test runs are calculated, and each value presented at time *t* on the graphs is the average of these values taken over (0; t].

For video traffic, AODV and OLSR fluctuate around the maximum acceptable delay value of 400ms. DYMO and DAAM are at much more acceptable levels of 0.217s and 0.157s (Fig. 2). For voice traffic, DAAM is the only protocol managing acceptable delay at 0.315s. DYMO is next in line at 2.081s and AODV and OLSR manages only 4.080s and 4.190s (Fig. 3).

B. Delay variation

The average delay variation is presented and calculated in the same manner as the average end-to-end delay. Graphs are plotted on a logarithmic scale due to the large variation between the results of different protocols.

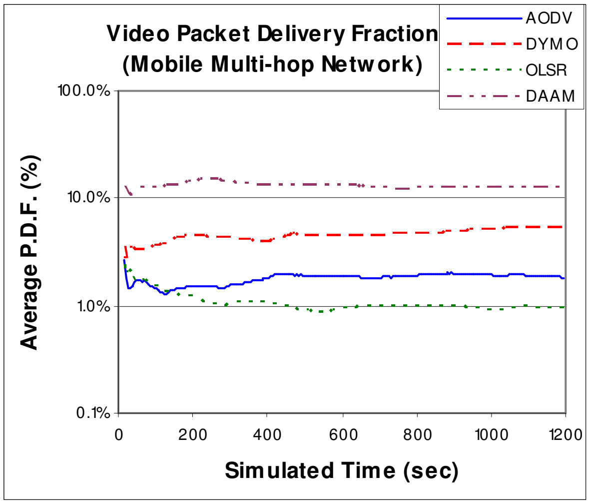

Figure 6. Mobile multi-hop network – Video packet delivery fraction

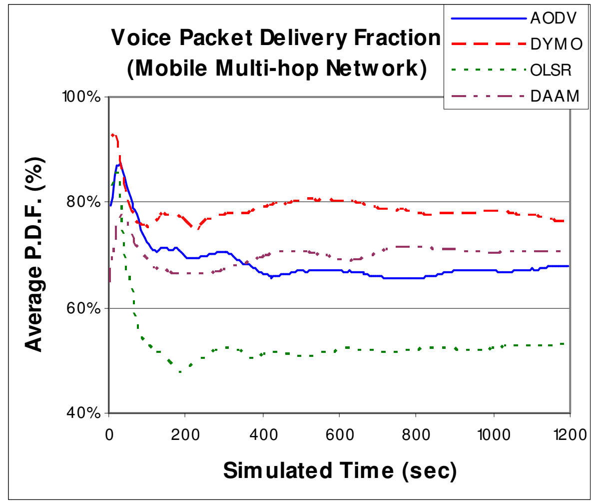

Figure 7. Mobile multi-hop network – Voice packet delivery fraction

For video traffic, the average delay variation for the four tested protocols is as follows: 0.418s for AODV, 0.202s for OLSR, 0.029s for DAAM and 0.024s for DYMO (Fig. 4). For voice traffic, all protocols except for DAAM only managed an average delay variation of more than 20s. DAAM managed 0.101s, improving that of AODV by 99.68% (Fig. 5).

Much higher consistency can be observed in the average end-to-end delay graphs of DAAM that any of the other protocols (Fig. 2 and Fig. 3). Contributing to this significant improvement in delay variation is the fact that packets are rather being discarded if queued for longer than the maximum allowed period since they will eventually become unusable when received at the destination.

C. Packet Delivery Fraction

The *Packet Delivery Fraction* (P.D.F.) is defined as the percentage transmitted data packets that are received at the intended destination. The average P.D.F. is presented: First, the average of the P.D.F.s of all five test runs at each sample point is calculated, then these values, in (0; *t*], are used to calculate the average P.D.F. value at time *t*. The P.D.F.s for video traffic are presented on a logarithmic scale, and on a linear scale for voice traffic.

DAAM realizes the highest P.D.F. for video traffic with an average of 12.58 %, followed by DYMO with 5.326% (Fig. 6). For voice traffic, DYMO manages the highest P.D.F. at 76.06%, followed by DAAM at 70.36% (Fig. 7).

D. Routing Overhead

The overhead caused by a routing protocol is important to be kept as small as possible, especially in wireless networks where bandwidth is limited. Overhead is mainly caused by messages used to discover and maintain routes. Routing overhead

Table 4. Protocol comparison for mobile multi-hop networks

Protocol Video Traffic	Average Delay (s)	Improve-ment to AODV	Average Delay Variation (s)	Improve-ment to AODV	Packet Delivery Fraction (%)	Improve-ment to AODV	Routing Traffic Sent (bps)	Improve-ment to AODV
AODV	0.386		0.418		1.836%		99059	
DSR	202.5	-52364%	3343	-800493%	0.008%	-99.54%	466908	-371.3%
DYMO	0.217	43.81%	0.024	94.35%	5.326%	190.1%		
OLSR	0.399	-3.36%	0.202	51.64%	0.955%	-47.95%	132026	-33.28%
DAAM	0.157	59.39%	0.029	92.94%	12.58%	585.3%	30715	68.99%
Voice Traffic								
AODV	4.080		31.55		67.96%		99059	
DSR	107.6	-2536%	3182	-9984%	12.84%	-81.10%	466908	-371.3%
DYMO	2.081	49.00%	31.24	1.006%	76.06%	11.91%		
OLSR	4.190	-2.674%	22.56	28.51%	52.79%	-22.32%	132026	-33.28%
DAAM	0.315	92.27%	0.101	99.68%	70.36%	3.525%	30715	68.99%

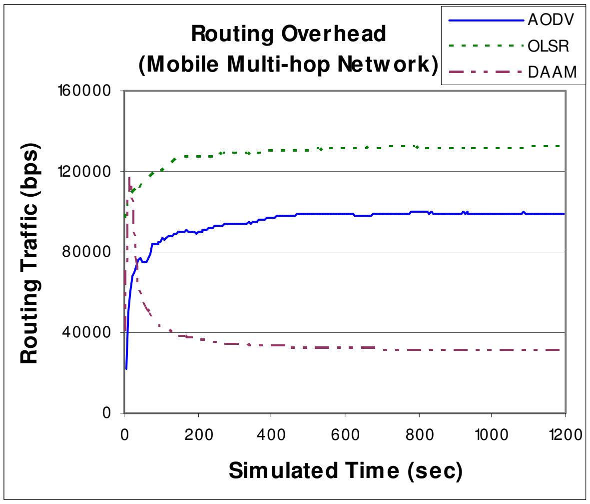

Figure 8. Static multi-hop network – Routing overhead

figures for DYMO is not provided since the recording of this specific statistic is not yet implemented in the OPNET implementation that is used [16].

OLSR shows a significant increase in routing overhead by 33.28% compared to AODV due to its proactive nature. DAAM on the other hand, due to its efficient route discovery, reduces routing overhead by 68.99% when compared to AODV. The initial route discovery overhead of DAAM is the highest, as expected in order to discover multiple paths, but then decreases to only a third of the overhead caused by AODV.

6. Conclusion

Our proposed protocol, DAAM, shows remarkable improvements of end-to-end packet delay and delay variation of voice and video traffic, routing overhead, and packet delivery fraction of video traffic compared to AODV, DSR, OLSR and DYMO. This is for mobile (Table 4), as well as static (Table 5) multi-hop MANETs. End-to-end delay was the main design criteria and DAAM not only shows the lowest end-to-end delay in all scenarios for both traffic types, but also all end-to-end delay is lower than the ITU-T's maximum recommendation of 400 ms.

Although the P.D.F.s for voice traffic are in some cases lower for DAAM than that of OLSR and DYMO, the delay is improved to an acceptable level and delivered packets are thus expected to be usable.

Routing overhead of DAAM is the lowest (excluding that of DYMO) due to efficient route discovery and management. Once routes are established, route rediscovery is only necessary if all known routes to a destination fail.

A potential drawback of the current design is that route delay information might not always be up to date. Link delay however, is continually monitored and evaluated, as mentioned in section 3. This functionality is not optimal, but quite efficient for its simplicity. A more optimal solution would be to notify all sources that use a link in an active route of the exact change in delay, if the link's delay has changed. Each source can then update the delays of all routes that use the link.

It would be more realistic to compare DAAM with one or more other QoS protocols, but as mentioned, the QoS protocols mentioned in the introduction are only experimental. To the best of our knowledge, OPNET implementations of these, or any other QoS protocols, are not officially available. This is thus left for further studies.

A performance comparison to other proposed QoS protocols is strongly recommended for future work for further verification of the protocol's performance.

Thorough validation of the protocol is not yet done. The protocol's robustness in the event of node failures, the performance in heavy congested networks, as well as the physical implementation feasibility, are all yet to be determined.

Table 5. Protocol comparison for static multi-hop networks

Protocol Video Traffic	Average Delay (s)	Improve-ment to AODV	Average Delay Variation (s)	Improve-ment to AODV	Packet Delivery Fraction (%)	Improve-ment to AODV	Routing Traffic Sent (bps)	Improve-ment to AODV
AODV	0.409		0.175		1.759%		117991	
DSR	250.7	-61159%	3663	-2092248%	0.015%	-99.13%	470921	-299.1%
DYMO	0.173	57.80%	0.025	85.78%	14.94%	749.0%		
OLSR	0.405	0.930%	0.134	23.26%	0.860%	-51.12%	131624	-11.55%
DAAM	0.103	74.78%	0.010	94.40%	25.40%	1343%	29905	74.65%
Voice Traffic								
AODV	7.855		60.97		51.34%		117991	
DSR	152.9	-1847%	4036	-6520%	10.81%	-78.95%	470921	-299.1%
DYMO	1.407	82.08%	0.712	98.83%	86.32%	68.14%		
OLSR	3.239	58.77%	7.686	87.39%	62.03%	20.84%	131624	-11.55%
DAAM	0.271	96.55%	0.004	99.99%	57.61%	12.23%	29905	74.65%

7. Acknowledgments

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