Indian Journal of Science and Technology, *Vol 9(19), DOI: 10.17485/ijst/2016/v9i19/92304, May 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Improving Multipath Routing Protocols Performance in Mobile Ad Hoc Networks based on QoS Cross-Layer Routing

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Abstract

Background/Objectives: Improving performances of routing protocols which use the multipath scheme and the hop count routing metric in ad hoc networks in order to satisfy quality of service requirements of different application traffics. **Methods/Statistical Analysis:** This paper proposes a technique to estimate the values of delay and packet loss ratio of MAC layer's links by using the ETX technique and the service time calculation of DCF in CSMA/CA principle, respectively. After that, these values are combined with the weights which are obtained from application traffic classification using cross-layer approach to establish new routing metrics. These metrics are suitable for Quality of Service (QoS) requirements of applications. **Findings:** Traditional multipath routing protocols operate only in Network layer and utilize a static routing metric which leads them to be unable to give route priority to different traffic classes from Application layer. After applying the suitable dynamic routing metrics of delay and packet loss ratio for application traffic classes when implementing new multipath routing protocol named QCLR in NS2 simulator, the results of performance evaluations show that the performance of proposed protocol higher than AOMDV protocol regarding to higher throughput, lower overhead traffic, higher packet delivery ratio and smaller end-to-end delay for both of Class 1 and Class 2 traffics. **Applications/Improvements:** Improving quality of routing service for applications which have different traffic classes, especially for multimedia applications.

Keywords: Ad hoc, Cross-layer, Packet Loss Ratio, QoS, Routing Metric, Service Time

1. Introduction

There are many differences between a Mobile Ad hoc Network (MANET)[1] and a conventional wireless network in term of mobility, performance, power and link bandwidth. Therefore, routing protocols in MANET would be eligible to the nature of nodes mobility, power and bandwidth limitation, network topology's chance, and the change in the quality of the links.

Routing protocols in MANET can be divided into two categories of unipath and multipath routing protocols. In unipath routing protocols, nodes establish only one route to each predefined destination and insert it into their routing tables. Consequently, whenever a route is false, it has to reestablish the routing procedure. As a result, it leads to routing delay and bandwidth consuming of control packets in routing protocols. In order to solve this problem, multipath routing protocols has been introduced. There is more than one route to each destination in routing tables of multipath routing protocols. Whenever the main route is false, one of redundant paths will be utilized. Therefore, packet forwarding delay and routing overhead would be reduced.

Researchers in[2–5] pointed out that the shortest path using hop count criteria is not the best route in MANET. The shortest path tends to use links which are near the center of the network. Consequently, middle most nodes-would have higher data forwarding load in comparison

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with nodes far away from the center. Therefore, it would lead to congestion. For example, AOMDV protocol[6] uses hop count as a routing metric and does not apply load balancing technique in traffic distribution. As a result, in proposed multipath routing protocols[7], congestion caused by forwarding traffic through the network center is still unresolved.

Moreover, routing metrics in multipath routing protocols are static. They are not flexible and dynamic when estimating routes according to QoS of traffic classes which are required from Application layer.

This study proposes enhancements of multipath routing protocols which use hop count as routing metric in order to perform routing priority based onQoS requirements from traffic classes of Application layer. The proposed method utilizes cross-layer approach to extract packet loss ratio and delay of service time of MAC layer's links. Moreover, the study classifies traffic classes received from Application layer to establish suitable routing metric for each traffic class by selecting suitable weights of routing metric parameters. AOMDV protocol[6] is chosen to be enhanced, which had been implemented in NS2 simulation software. The proposed routing algorithm, which is enhanced from AOMDV, named QCLR (QoS Cross-Layer Routing). The rest of this paper is structured as follows. Section II describes related works. Details of QCLR protocol are presented in section III. In section IV, AOMDV and QCLR protocols are compared and evaluated in term of performance using NS2. Finally, section V consists of the conclusions and future research orientations.

2. Related Works

In[8], a new routing metric named C2WB which can be aware of load and interference of wireless network was proposed. The metric is estimated by the values of average contention window and channel utilization of CSMA/CA network access method. OLSR protocol is chosen to integrate the new metric. Results of performance comparison and evaluation between modified and original OLSR protocols in NS2 simulator show that the modified protocol can aware and avoid congested areas to improve the network capacity and balance the network traffic.

Authors in[9] present a new multipath routing scheme named Q-SMS which can be aware of QoS. In the new routing scheme, the method to estimate the remainder capacity of the link and control the progress of Route Request, Route Reply and Route Maintenance having QoS was put forward. Simulation results show that the performance of the Q-SMS is better than the previous SMS's one regarding lower routing overhead, smaller average end-to-end delay and higher goodput.

The route confidence, unidirectional link rejection and node energy based on Received Signal Strength were presented in[10]. These are parameters of cross-layer communications between physical, MAC and network layers in proposed cross-layer design to improve the performance of mobile ad hoc networks.

In[11], a routing protocol with congestion aware ability was proposed. The protocol named CARM uses a new routing metric which is composed of the delay of channel, the data rate, the number of retransmission and the delay of buffer. Additionally, the protocol uses the new routing metric together with the avoidance of the mechanism of mismatched link data rate routes to adapt to congestion areas and improve link capacity of network.

A new method of cross-layer design using Fuzzy Logic System (FLS) was presented in[12]. Three layers in the cross-layer design are application, data-link and physical. FLS uses the ratio of packets transmission success, ground speed and link delay as input parameters to calculate adjusting factors. These factors were used to decide the transmission power, control of rate, times of retransmission and ACM (adaptive modulation and coding).

In[13], mechanisms of feedback and admission control scheme were used in a proposed routing protocol having QoS aware charateristics to satisfy the demands of QoS from real-time applications. The routing protocol uses the approximate bandwidth to estimate the network traffic. There are two bandwidth estimation methods used by these mechanisms to calculate the residual bandwidth on nodes.

The scheme of clustering which separates the network into clusters and the mechanism to restrict traffics to these clusters by determinating which traffic is trasmitted only in the cluster was proposed in[14]. These mechanism were used to implement the proposed routing protocol which achieves better performance regarding to the smaller end-to-end delay, the lower node energy comsumption and the higher packet delivery ratio.

Ad hoc networks using TDMA are objectives in the study of QoS routing which was proposed in[15]. Based on calculation of end-to-end path's bandwidth, the QoS routes are established in route discovery process and used to forward traffics on demand of itsQoS requirements. The results of the performance evaluation for the QoS protocol and AODV protocol show that the proposed protocol achieves smaller delay and higher throughput than AODV.

The protocol named AMAODV (Adaptive Mobility aware AODV) using a new routing metric was presented in[16]. The protocol is developed from AODV protocol which uses the hop count as routing metric. The new routing metric is calculated based on information of queue size, hop count, distance and relative velocity from a node to its' neighbor.

In[17], the proposed routing protocol can find routes having higher throughput and lower delay in Mobile Ad hoc Network. The protocol uses estimation techniques of node energy level, channel busy level to establish routes, and the mechanism to remove malicious nodes.

3. QoS Cross-Layer Routing

Delay and packet loss ratio are main QoS parameters of traffic classes from Application layer which we focus on this study. Hence, in order to create a valuate function for routing metrics and propose a routing protocol, which meets QoS requirements of traffic from Application layer, we need to estimate packet loss ratio and delay values of each link in MAC layer and classify traffic classes according to QoS from Application layer.

3.1 Estimating Packet loss ratio of a link

There are a number of approaches introduced to estimate packet loss ratio of a link in MAC layer. In our study, the packet loss ratio is estimated by calculating number of loss packets on both directions of a link between two nodes in a specific time period is proposed.

Suppose that l is the link between node A and node B, d_f and d_r are successful packet transfer ratio in the direction from A to B and vice versa, respectively. Packet loss ratio of this link is calculated by the formula described as follows;

$$FER_l = 1 - d_f d_r \tag{1}$$

To estimate the values of d_f and d_r in (1), ACK transmission mechanism would be utilized after sending periodically signal packets. However, this method would consume bandwidth and processing resources. Accordingly, we utilize a simple and effective method named Expected Transmission Count (ETX) defined in[18]. Each node in a network link periodically (T seconds) broadcast a sized fixed probe package. The opposite node counts the number of probe packets in W second period ($W>T$). Successful packet transfer rate in one direction is expressed as the number of received probe packets divided by the number of expected probe packets (W/T).

When implementing QCLR protocol in NS2, HELLO packet of AOMDV protocol is used as probe packet to estimate values of d_f and d_r. Periods for broadcasting HELLO packets and counting received HELLO packets are 1 second and 10 seconds, respectively.

3.2 Link Delay Estimation

Delay of a link is determined based on "*service time*" concept which was introduced in[8]. According to IEEE 802.11 standard, time needed to successfully transmit a frame of MAC layer through a wireless link is considered as service time of this link. In IEEE 802.11 standard, delay in transmitting a frame in MAC layer is determined based on the operation of Distributed Coordination Function (DCF) following Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) principle.

The time to successfully transmit a packet through a shared wireless channel between two nodes operating on DCF in MAC layer following CSMA/CA principle is calculated as the total value of back-off time, transmission time and deferring time. Back-off time is the time needed to reduce back-off counter value to zero when the channel state is idle. Transmission time is the time from the sending node starting transmit a frame until it receives an ACK of receiving node. Deferring time is the time when a node wants to transmit a frame in busy state of the channel. The value of the back-off counter doesn't vary in the deferring time's duration.

Suppose $T_{s,l}$, $T_{b,l}$, $T_{t,l}$, and $T_{d,l}$ are service time, back-off time, transmission time and deferring time of transmitting a frame through link l, respectively. Service time is calculated as follows;

$$T_{s,l} = T_{b,l} + T_{t,l} + T_{d,l} \tag{2}$$

$T_{s,l}$ is estimated in[8] as follows;

$$T_{s,l} = \frac{1}{1-CU_l}\left(\left(ACW - \frac{CW_{\min}}{2}\right)T_{slot} + \frac{1}{1-FER_l}\frac{PL}{B_e}\right) \tag{3}$$

where ACW is Average Contention Window, $CW_{\min}$ is the Start Contention Window, T_{slot} is the Slot Time, FER_l is the frame error ratio of link l, PL is the frame payload size, B_e is efficient bandwidth, and CU_l is the channel utilization at sending node of the link.

Values of T_{slot} and CW_{min} are directly obtained from IEEE 802.11 implementation at MAC layer. Value of FER_l is calculated by (1). Supose that n is the maximum back-off stage of CSMA/CA implementation, ACW is estimated as follows;

$$ACW = \frac{(1-FER_l)(1-(2FER_l)^n)}{(1-2FER_l)(1-FER_l^n)} CW_{min}, \tag{4}$$

The last parameter for estimation is CU_l. Channel utilization at node n is the ratio of a node to sense the busy state of transmission channel over the total sensing time on the channel of the node. This value is estimated from implementation of CSMA/CA principle at MAC layer by using the sensing busy channel counter and the total sensing channel counter. In our implementation, the value for frame payload size (PL) in (**3**) is 1500 bytes and data rate of 802.11b link is 11 Mbps. Consequently, we establish the channel sensing period is 1ms (approximately equal to the time to transmit a 1500 bytes - frame over a link at speed of 11 Mbps) and the period for updating value of CU_l is 2s (relatively higher than channel sensing period to estimate value of CU_l accurately)

However, according to[19], the estimation of CU_l in mentioned method is affected by data load in the same traffic flow. In the other words, when the other nodes and the current node are in the same path of traffic forwarding to destination, if the current node stays in radio range of other nodes, the usage of wireless channel still causes the busy state for the current node while other nodes use the channel to forward that traffic to the destination. As a result, the heavier the traffic load, the more powerful the affection on CU_l at nodes in the path. To solve the problem, in our implementation for CU_l, we only update the value for sensing busy channel counter with traffic that are not passing through node n.

3.3 Classifying Traffic of Applications

In this paper, we use the ITU-G1010[20] to classify the traffics as the requirements of application QoS. According to[20], we classify the application traffics into three classes. The thresholds of application QoS parameters can be seen in Table 1.

In the three classes of these application traffics, we focus on two parameters, namely packet loss ratio and delay. The traffic of the Class 1 applications requires the average service quality of packet loss ratio and delay. For the Class 2 applications, maximum delay threshold is accepted, but a higher QoS for packet loss ratio is required. As for the traffic of Class 3 applications, it requires the highest QoS for the accuracy of the transmission (not acceptable packet loss) and the delay requirements are minimal in the three classes. Based on the analysis above, we apply the method in[21] to determine the weights of packet loss ratio and delay parameters taken from the MAC layer when choosing the paths for the traffic of the application classes in the routing process. The results of determination packet loss ratio and delay weights are presented in Table 2.

Table 1. Thresholds of application QoS parameters.

Threshold of	Class 1	Class 2	Class 3
Delay	0.15 s	0.4 s	0.004 s
Jitter	0.001 s	0.001 ms	Not applicable
Packet loss ratio	0.03	0.01	0
Data rate	4 kbps	16 kbps	20 kpbs

Classification of application traffics according to QoS requirements defined by[20] is implemented based on the idea of getting information about the socket of the packet passed down from the Transport layer. The communication point of the connection between end-to-end services can be expressed by the socket. The socket address on the source or destination nodes consists of the node's IP address and the application service's port number. At routing layer, each protocol of application programs can be performed by using a socket. Each socket includes three main properties: domain, type, and address. In fact, there are two domains most widely used namely, Unix and Internet. This paper aims to show the range of Internet domain service classes as VoIP, FTP, video or interactive games. In the technique proposed here, the information exploited is destination port number of the socket.

3.4 Routing Metric Determination

As indicated above, the objective of enhancing AOMDV protocol in our study is to build a routing measurement which is consistent with the QoS requirements of the traffic from the Application layer based on estimating values of packet loss ratio and delay of links.

Determining the formula and estimating the values of packet loss ratio and delay of each link were described in subsection 3.1 and 3.2. Packet loss ratio and delay of the end-to-end route are multiplication and sum of packet loss ratio and delay of every link belongs to that route, respectively. These calculations are described as follows;

Table 2. Weigh of application QoS parameters

Weight of	Class 1	Class 2	Class 3
Delay	0.5323	0.0790	0.1031
Jitter	0.3155	0.1993	0.0476
Packet loss ratio	0.1025	0.6064	0.6240
Data rate	0.0497	0.1154	0.2253

$$P_r = 1 - \prod_{l \in r}(1 - FER_l) \tag{5}$$

$$D_r = \sum_{l \in r} T_{s,l}, \tag{6}$$

where P_r and D_r are packet loss ratioand delay of route r, respectively; FER_l and $T_{S,l}$ are packet loss ratio and delay of each link in route r, respectively. Values of FER_l and $T_{S,l}$ are determined using (1) and (3).

Based on the idea of establishing a routing metric of a route which is suitable with QoS requirements of traffic transmitted from Application layer using QoS classes, we propose RMV (Routing Metric Value) of a transmission route of the ith traffic class as follows;

$$RMV_{r,i} = w_{d,i}\frac{D_{ts,i}}{D_r} + w_{p,i}\frac{P_{ts,i}}{\text{Pr}}, \tag{7}$$

where P_r and D_r are packet loss ratio and delay of router, which are calculated by (5) and (6); $P_{ts,i}$ and $D_{ts,i}$ are thresholds of packet loss ratio and delay of the ith traffic class, whose values are determined using Table 1, respectively; $W_{d,i}$ and $W_{p,i}$ are weights of delay and packet loss ratio of the ith traffic class, whose values are determined in Table 2, respectively.

3.5 QoS Routing Mechanism

The QCLR protocol, is proposed based on multipath routing protocol AOMDV. QCLR protocol inherits basic mechanisms from AOMDV protocol such as route finding mechanism, route remaining and route error notification. This inheritance guarantees the operation of a multipath routing protocol. However, in order to achieve the efficient routing performance according to QoS requirements of delay and packet loss ratio of traffics from Application layer, we proposed an enhanced AOMDV protocol, namely QCLR, which is described as follows:

1. Adding two fields *PKT_DELAY* and *PKT_PLR* into RREQ và RREP packets. These two fields contain corresponding values of delay and packet loss ratio, which are calculated from either source node (*RREQ*) or destination node (*RREP*) to the current node, of reverse path (*RREQ*) and forward path (*RREP*).
2. Adding three fields *PATH_DELAY*, *PATH_PLR*, and *PATH_STABILITY* into each path in the path list of each entry in the routing table. These fields consist of corresponding values of delay, packet loss ratio and the stability of the path.
3. Adding two fields *LINK_DELAY* and *LINK_PLR* into each entry in neighbor table of each node. Values of these fields are delay and packet loss ratio of the link between the current node with its neighbor.
4. Replacing hop count routing metric in route finding process which is applied for different traffic classes by routing metric which is determined by *RMV* function in (7).

Operation of QCLR protocol in Routing Layer is described as follows;

1. When a node receives a *RREQ* or *RREP* packet, after creating a new path or updating a path list of the entry having destination as the source node (reverse path) or destination node (forward path), the node finds LINK_DELAY and *LINK_PLR* value of the neighbor node from its neighbor tableand recalculates the values of *PATH_DELAY* and *PATH_PLR* of the path as followed:

$$PATH_{DELAY} = LINK_{DELAY} + PKT_{DELAY} \tag{8}$$

$$PATH_{PLR} = 1 - (1 - LINK_{PLR}) \times (1 - PKT_{PLR}) \tag{9}$$

2. If the node forwards the *RREQ* or *RREP* packet, it will update the value of the corresponding *PKT_DELAY* and *PKT_PLR* using the value of the *PATH_DELAY* and *PATH_PLR* which are newly recalculated by (8) and (9).
3. When the node updates its routing table, if the path exists, the *PATH_STABILITY* value of the path will be increased by one. The initial value of *PATH_STABILITY* is one when the node adding newly path into its routing table.
4. When receiving the multiple *RREP* packets sent from the same destination node via different paths, the receiving node sorts these paths by the ascending order of the values routing metric which are calculated by *RMV* function in (7).
5. After finding the path and performing the procedures above, only a maximum of three paths to the same

destination will be installed in the routing table. The path having greatest *RMV* value will be selected as the main path and the two paths will remain redundant ones. The backup path is used only when the main path is deleted or corrupted.

6. If two paths have the same value of RMV, the path having greater value of *PATH_STABILITY* will be selected to forward the traffic.
7. If two paths have the same values of *RMV* and *PATH_STABILITY*, the path having an appropriate metric for input traffic will be selected to forward the traffic. Class 1 and Class 2 traffics will select the path which have smaller *PATH_DELAY*. For Class 3 traffic, the chosen path is one having smaller *PATH_PLR*.

4. Performance Evaluations

4.1 Simulation Parameters

To evaluate the performance of the proposed QCLR protocol, we use NS2 to simulate AOMDV and QCLR protocols. Simulation parameters are chosen to highlight their QoS routing mechanisms for different application traffic classes. Our simulation is performed in square area having 2000m side length. The network size varies from 16 nodes to 25, 36 and 49 nodes and the traffic loads are 20%, 40%, 60% and 80% per each network size. The selected technology of Physical and MAC layers is IEEE 802.11b with 250m node's outdoor transmission range. The model of propagation is Shadowing. We setup node's initial positions in matrix form to guarantee the route availability between any pair of nodes. In the matrix, all nodes will move randomly with mobility speed at 10 m/s. Duration of simulation is 200 seconds and each source node start its traffic in 5^{th} second. The selected traffic model is Constant Bit Rate (CBR) and User Datagram Protocol (UDP) is selected on Transport layer. The performance of the proposed protocol and AOMDV protocol is evaluated on Class 1 and Class 2 traffics which is simulated by CBR traffics operating at 64 kbps and 200 kbps data rate, respectively.

4.2 Perfomance Evaluation Metrics

The performance of QCLR and AOMDV protocols is evaluated by following metrics:

- End-to-end delay: The average delay of the packet transmission from the source to the destination. The unit is milliseconds (ms).
- Throughput: An average transmission rate of data packets. The unit is kilo bits per second (kpbs).
- Traffic Overhead: The number of protocol control packets per number of data packets received and protocol control packets.
- Packet Delivery Ratio: The number of packets which are received by destination node per number of sent packets which are sent by source node

4.3 Simulation Results

4.3.1 *Average End-to-end Delay*

The average end-to-end delay of Class 1 and Class 2 traffics after simulating 36 nodes traffic loading at 20%, 40%, 60% and 80% is presented in Figure 1. As can be seen from the figure, although QCLR needs extra time to process its control packets when computing its routing metric, the average end-to-end delay of the two classes traffic forwarded by QCLR protocol is smaller than that of AOMDV protocol. This result shows that the selected paths for traffic classes of QCLR protocol are more stable and preferable than those of AOMDV protocol.

4.3.2 *Average Throughput*

To evaluate the average throughput of Class 2 traffic, we change the network size (16, 25, 36 and 49 nodes) and traffic load (20% and 80%). Figure 2 illustrates that QCLR protocol achieves higher throughput than that of AOMDV protocol. When simulator run on16 nodes and 25 nodes network size, QCLR protocol achieves the average throughput of 20% traffic load approximate Class 2 traffic's data rate. When the traffic load and the network size increase, the achieved average throughput of both

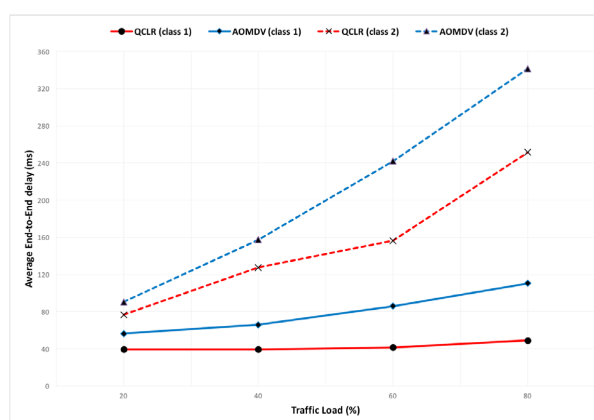

Figure 1. Average packet delay versus traffic load.

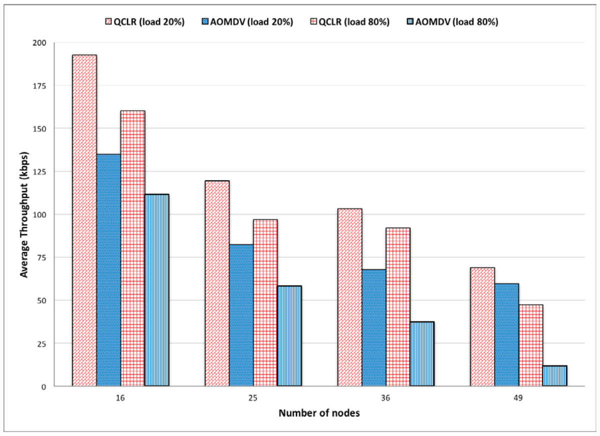

Figure 2. Average throughput versus network size.

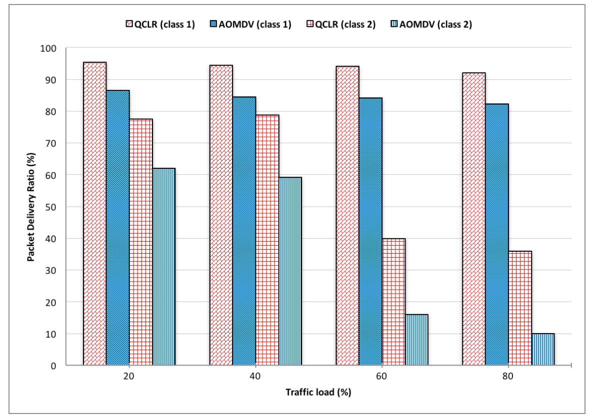

Figure 3. Packet delivery ratio versus traffic load.

protocols decreases, but the QCLR protocol still has a higher throughput than AOMDV protocol. This result is explained by the way these protocols choose different routing metrics.

4.3.3 Packet Delivery Ratio

The packet delivery ratio of QCLR and AOMDV protocols when traffic load varies from 20% to 80% of 36 nodes network for Class 1 and Class 2 traffics are shown in Figure 3. QCLR achieves higher packet delivery ratio than AOMDV for both the traffic classes. The packet delivery ratios of Class 1 traffic of the two protocols are almost unchanged when varying the traffic load. For Class 2 traffic, this ratio decreases when traffic load increases, the packet delivery ratio of QCLR changes less than that of AOMDV. Based on these results, it's can be said that QCLR protocol have better response ability against traffic load variation than that of AOMDV protocol.

4.3.4 Overhead Traffic

In the last assessment, we vary the network size (16, 25, 36 and 49 nodes) with 80%of traffic load. We use traffics of Class 1 to measure overhead traffic of QCLR and AOMDV protocols. Figure 4 shows better results for the proposed QCLR protocol comparing with the AOMDV protocol. The number of control packets generated by QCLR protocol is smaller than AOMDV's. These results demonstrate QCLR protocol found out and utilized the path having better stability than AOMDV protocol. Therefore, when the network topology changes, the number of finding routes of QCLR protocol are less than AOMDV protocol.

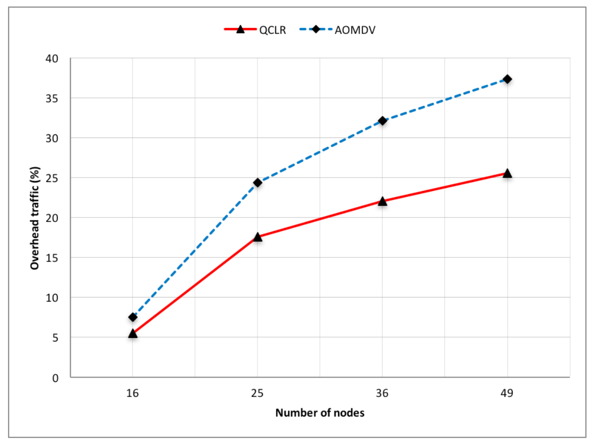

Figure 4. Overhead traffic versus network size.

5. Conclusion

This paper focuses on improving performance of multipath routing protocols which use the routing metric established by hop count. This enhancement based on classifying traffic from Application layer into traffic classes of QoS requirements and building the routing metric which is suitable for defined traffic classes. To establish this routing metric, cross-layer approach was used to collect Packet loss ratio and delay values of links in MAC layer from Routing layer and destination port of socket of packets from Application layer. Additionally, in the estimation process of QoS routing metric, each traffic class is assigned pairs of weights which are appropriate to their QoS requirements. An enhancement of AOMDV multipath routing protocol, namely QCLR, would be able to find multipath, distinguish QoS of forwarded traffic and operate in multiple layers. The performance evaluation of AOMDV and QCLR protocols, which simulated in NS2, indicate that proposed QCLR protocol has better performance in terms of average delay, successful packet transfer rate, throughput and overhead traffic.

Although, there are four QoS parameters, this paper only carried out two parameters, namely packet loss ratio and delay. Therefore, routing metric established and applied in QCLR protocol would not change dynamically according to jitter and data rate parameters of traffic from Application layer. In addition, energy consumption level should be taken into consideration when comparing performance of these two routing protocols because the proposed routing algorithm has more complex computation in mobile nodes in comparison with AOMDV protocol.

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