# A CROSS-LAYER DESIGN FOR AOMDV ROUTING PROTOCOL TO SATISFY QoS IN MOBILE AD HOC NETWORKS

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ABSTRACT
This paper proposes a cross-layer multi-path routing protocol, named Cross-layer Multi-path Routing Protocol (CMRP) for ad hoc networks. The protocol is developed based on AOMDV protocol and integration of two cross-layer designs. The Application-Routing cross-layer design aims to classify traffics of different application classes by Quality of Service (QoS) of the applications. The Routing-MAC cross-layer design aims to determine the appropriate routing metrics including link delay and packet loss ratio for each traffic class. The results of performance comparison between AOMDV protocol and CMRP protocol on the Network Simulator (NS2) with different traffic classes show that CMRP achieves better performance rather than AOMDV including end-to-end delay, throughput, overhead traffic and packet delivery ratio.
**Keywords:** *ad hoc; multi-path; routing; QoS; cross-layer*

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# THIẾT KẾ LIÊN TẦNG CHO GIAO THỨC ĐỊNH TUYẾN AOMDV NHẰM ĐẢM BẢO CHẤT LƯỢNG DỊCH VỤ TRONG MẠNG AD HOC DI ĐỘNG

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TÓM TẮT
Bài báo này đề xuất một giao thức định tuyến đa đường liên tầng cho mạng ad hoc với tên gọi là *"*Cross-layer Multi-path Routing Protocol*"* (CMRP). Giao thức này được phát triển trên cơ sở cải tiến giao thức AOMDV với sự tích hợp của hai thiết kế liên tầng. Thiết kế liên tầng Application-Routing dùng để phân loại lưu lượng dữ liệu của các lớp ứng dụng khác nhau theo yêu cầu chất lượng dịch vụ (QoS) của các ứng dụng. Thiết kế liên tầng Routing-MAC thực hiện việc xác định các độ đo định tuyến phù hợp từ trễ liên kết và tỉ lệ mất gói tin cho mỗi lớp lưu lượng dữ liệu. Kết quả đánh giá hiệu năng giữa giao thức AOMDV và giao thức CMRP trên phần mềm mô phỏng NS2 với các lớp lưu lượng dữ liệu khác nhau cho thấy giao thức CMRP được đề xuất có hiệu năng tốt hơn giao thức AOMDV theo các độ đo trễ đầu cuối, thông lượng, chi phí định tuyến và tỷ lệ truyền thành công.
**Từ khóa:** *ad hoc; đa đường; định tuyến; QoS; liên tầng*

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## 1. Introduction

The problem of routing in ad hoc networks is always paid much by researchers because these networks do not rely on a pre-existing infrastructure and the random mobility of the mobile nodes. There are many routing protocols proposed and developed for ad hoc network. However, in many traditional ad hoc routing protocols, e.g. in the single-path routing AODV [1], the multi-path routing AOMDV [2], the "hop count" is used for routing metric. Therefore, the path selected to forward application traffics is still the shortest path by hop count rather than the appropriate path for the traffic of different application classes.

To achieve the ability of priority routing for traffic of application classes which having different QoS requirements, the routing mechanism must classify the traffics by application QoS and the selected path to forward the traffics in each network node must have the metrics matching the QoS requirements of each application class. To achieve this requirement, the routing layer should obtain the information about the link quality at the MAC layer.

There have been many suggestions to gather the information about the quality of links and find the best path for packets [3]-[6]. The designs approaching towards cross-layer design to explore the potential of information received from the lower layers [7]-[11] have been proposed. However, the use of information on link quality investigation to form the routing metrics for satisfaction application QoS has not been mentioned. This paper proposes a cross-layer multi-path routing protocol including the investigating and predicting information techniques on the link quality at the MAC layer, the technical classification of application traffic under QoS requirements and technical QoS routing. The multi-path AOMDV routing protocol is chosen to improve to the cross-layer multi-path routing protocol named CMRP. Based on simulation of the two protocols on NS2, we compare and evaluate their performance.

The rest of this paper is organized as follows: Section II will describe the cross-layer designs and the primary tasks to develop CMRP protocol which meets QoS requirements based on improvements of AOMDV protocol. The simulation results of the two protocols on the NS2 and the comparisons, reviews and analysis of performance are presented in Section III. Finally, Section IV will make conclusions.

## 2. Cross-Layer Designs of CMRP

### *2.1. Proposed cross-layer designs*

Based on the idea of choosing the most appropriate path for the traffics of the Application layer as the requirements of QoS, we propose two cross-layer designs. One is Application-Routing cross-layer to perform data classification according to the QoS requirements of the applications. The other is the Routing-MAC cross-layer to collect the information about the link quality in the MAC layer. The designs are represented in the Figure 1.

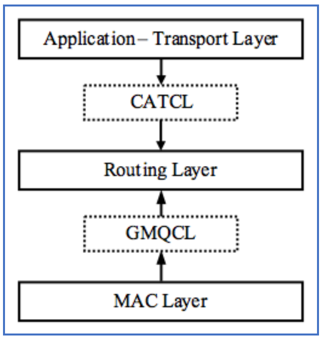


**Figure 1.** *Cross-layer designs of CMRP*

The first cross-layer design is implemented by the entity named Classification Application Traffic Cross- Layer (CATCL) responsible for the classification of traffics starting from the Application layer via Transport layer. CATCL gets information in the socket of received packets to determine which traffic class that the packets belong to according the thresholds of application QoS parameters are defined in [12]. The second cross-layer design is implemented by the entity named Getting MAC Quality Cross-Layer (GMQCL) responsible for retrieving the information about the quality of the links at the MAC layer to serve the construction of routing metrics. The process of routing of CMRP protocol will incorporate the information from the CATCL and GMQCL entity to select the appropriate path for the traffic of each application QoS class. The detailed CATCL, GMQCL entity deployment, and the routing process will be respectively presented in the following subsections in section II.

### *2.2. Classifying application traffic according to the QoS requirements*

In this paper, the ITU-G1010 [12] is used to classify the traffics as the requirements of application QoS. According to [12], the application traffics are classified into three classes. The thresholds of application QoS parameters are presented in Table 1.

**Table 1.** *Threshold of application QoS parameters*

| QoS | Class 1 | Class 2 | Class 3 |
|---|---|---|---|
| Delay | 150 ms | 400 ms | 4 ms |
| Jitter | 1 ms | 1 ms | Not use |
| Packet loss rate | 3% | 1 % | 0 % |
| Data rate | 4 kbps | 16 kbps | 20 kbps |

In the three classes of these application traffics, the delay and the packet loss rate parameters are focused. The traffic of the Class 1 applications requires the average service quality of delay and packet loss rate. For the Class 2 applications, maximum delay threshold is accepted, but a higher is required QoS for packet loss ratio. 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 above analysis, the method in [10] is used to determine the weights of "*service time*" and "*packet loss ratio*" parameters which are taken from the MAC layer through the GMQCL entity when choosing the paths for the traffic of the application classes in the routing process.

The idea used to classify application traffics according to QoS requirements defined by [12] is to get information about the socket of the packet passed down from the Transport layer. The socket is an inter-process communication point used to connect the service end points [13]. The address of a socket is formed from the IP address and port number of the application service on the source or destination nodes. At routing layer, each protocol of application programs can be performed 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.

### *2.3. Gathering information from the MAC layer*

To cater for the QoS routing process, information at MAC layer, which are the delay and packet loss rate should be obtained. The delay and packet loss rate of an end-to-end path can be calculated by the delay and packet loss rate of each constituent link of the path at the MAC layer.

The percentage of packet loss when transmitting frames on link *l* is defined under [14] as (1).

$$FER_l = 1 - d_f \times d_r \quad (1)$$

where $d_f$ and $d_r$ are forward and backward delivery ratios of links, respectively. They are measured by the periodic HELLO message of AOMDV.

Delay when transmitting frames via a link is determined based on MAC-layer delay model for shared wireless channel access in the Distributed Coordination Function (DCF) mode of IEEE 802.11. The DCF access method is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) principle. The delay is formed from back-off time, transmission time and deferring time.

- Back-off time is the time required to back-off counter decrease to zero when the channel is idle.
- Transmission time is the time from starting frame transmission until receiving ACK.
- Deferring time is the time a node stops decreasing its back-off counter due to busy state of channel when this node is trying to transmit a frame.

In this paper, the delay of the link is calculated by "*service time*" [11]. Let $T_{b,l}$, $T_{t,l}$, $T_{d,l}$, and $T_{s,l}$ are back-off time, transmission time, deferring time, and service time of a link *l*, respectively. These values have been calculated as (2).

$$T_{s,l} = T_{b,l} + T_{d,l} + T_{t,l} = \frac{\left(\overline{CW_l} - \frac{CW_0}{2}\right)T_{slot} + \frac{1}{1-FER_l} \times \frac{PL}{B_e}}{1-c_n} \quad (2)$$

where $\overline{CW_l}$ is Average Contention Window, $CW_0$ is the Start Contention Window, $T_{slot}$ is the slot time, $FER_l$ is the frame error rate on link *l*, *PL* is the frame payload size, $B_e$ is Efficient Bandwidth, and $c_n$ is the Channel Utilisation.

$\overline{CW_l}$ is calculated by (3)

$$\overline{CW_l} = \frac{(1-FER_l)\left(1-(2FER_l)^{r+1}\right)}{(1-2FER_l)\left(1-FER_l^{\,r+1}\right)} \times CW_0 \quad (3)$$

where r is the maximum back-off stage.

In CMRP's implementation, PL is set to 1500 bytes.

The values of $B_e$ are shown in Table 2 [15].

**Table 2.** *Efficient Bandwidth*

| **Operating rate** (Mbps) | **RTS/CTS off** | **RTS/CTS on** |
|---|---|---|
| 11.0 | 7.15 | 5.17 |
| 5.5 | 4.34 | 3.52 |
| 2.0 | 1.80 | 1.64 |
| 1.0 | 0.94 | 0.89 |

Let $PLR_p$ and $T_{s,p}$ denote the packet loss rate and the delay of path *p* respectively. The value of $PLR_p$ and $T_{s,p}$ is calculated by (4) and (5) respectively.

$$PLR_p = \prod_{l \in p} FER_l \quad (4)$$

$$T_{s,p} = \sum_{l \in p} T_{s,l} \quad (5)$$

When implementing on NS2, to ensure GMQCL entity can obtain information about the quality of the links in a way, two new fields *TSER_NB* and *FER_NB* are added on the neighbor table of each node. The value of each respective field shows frame error rate and delay of the link between the current node and neighbor node. During the operation of the protocol CMRP, the GMQCL entity will recalculate the value of the two fields *FER_NB* and *TSER_NB* in all entries of neighbor table of each node after a period *CMRP_HELLO_WINDOW_SIZE* which is set to 10 seconds in implementation.

### *2.4. QoS routing mechanism*

To improve the routing performance for the different application QoS classes in ad hoc networks, we propose a new QoS routing mechanism in CMRP protocol. Based on the original routing protocol AOMDV operation, the protocol CMLP proposed here shows the balance multipath routing techniques according to the input information of link quality and traffics of application QoS class.

In the AODMV protocol, a source node can find multiple loop-free routes to a destination node in a process of route exploration. The source node then chooses the shortest route (minimum hop count) to forward data packets. To implement QoS routing mechanism for different application traffic classes in CMRP, some modifications are made to the following:

- Adding two new fields $TSER\_PKT$ and $FER\_PKT$ in both $RREQ$ and $RREP$ packets. The value of each respective field shows the packet loss rate and delay of the path from the source node (*RREQ*) or destination node (*RREP*) to node currently receiving the package.
- Adding three new fields $PLR\_RT$, $TSER\_RT$ and $RS$ on each path in the path list of each entry in the routing table. The value of each respective field shows the packet loss rate, delay and robustness of the path.

$RS$ value is calculated based on the time the path appearing in the routing table. Whenever the process of routing table updates occurs, if the path also exists in the routing table, its *RS* value will be increased by one. The path having higher $RS$ value is considered as more sustainable than the path having lower $RS$ value.

When a node receives a *RREQ* or *RREP* packet, after creating new path or updating path list of the entry having destination as the source node (reverse path) or destination node (forward path), the node will recalculate the values of $TSER\_RT$ and $PLR\_RT$ of the path by (6) and (7).

$$PLR\_RT = FER\_NB \times FER\_PKT \quad (6)$$

$$TSER\_RT = TSER\_NB + TSER\_PKT \quad (7)$$

where $FER\_NB$ and $TSER\_RT$ be the packet lost rate and the delay of the link between the sent (*RREQ* or *RREP* packets) and received nodes respectively.

Then if this node forwards the *RREQ* or *RREP* packet, it will update the value of the corresponding *FER_PKT* and *TSER_PKT* equal to the value of the $PLR\_RT$ and $TSER\_RT$ newly recalculated.

When receiving the multiple *RREP* packets sent from the same destination node via different paths, the received node sorts these paths by the ascending order of the values of function called Path Quality Value (PQV), which is defined as (8).

$$RQV_p = w_d \frac{D_{ts}}{TSER\_RT_p} + w_e \frac{P_{ts}}{PLR\_RT_p} \quad (8)$$

where $TSER\_RT_p$ and $PLR\_RT_p$ be the delay and the packet loss rate of the path p respectively. $D_{ts}$ and $P_{ts}$ be the threshold of delay and packet loss rate respectively in Table 1. $w_d$ and $w_e$ are the respective weights of the delay and the packet loss rate. The weights change according to each application traffic class [12].

Based on the application QoS information that CATCL entity collected, the QoS routing mechanism of CMRP will performs the calculation of the value RQV according to the appropriate weights. The same path can have many different sets of weight for each traffic class.

When the found paths to the same destination are sorted by their *RQV* value, the CMRP protocol performs the classification of paths according to their *RS* value.

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 largest *RS* value will be selected as the main path and the two paths remain redundant ones. The backup path is used only when the main path is deleted or corrupted.

If the two paths have the same value of *RQV* and *RS*, a path having appropriate metric for input traffic will be selected to forward the traffic. If the traffic belongs to Class 1 or Class 2, the path having lower delay will be selected. If the traffic belongs to Class 3, the chosen path is one having smaller packet loss rate.

## 3. Performance Evaluations

### *3.1. Simulation parameters*

To evaluate the performance of the proposed CMRP protocol, NS2 simulator is used to simulate AOMDV and CMRP protocols. Simulation parameters are chosen according to RFC-2501 recommendation [16] and the purpose to highlight their QoS routing mechanisms for different application traffic classes. Common and specific simulation parameters are respectively summarized in Table 3 and Table 4.

**Table 3.** *Common simulation parameters*

| Parameter | Values |
|---|---|
| Network size | (10, 20, 30, 40) |
| Simulation area | 2000m x 2000m |
| Transmission range | 250m |
| Active node ratio | (20%, 40%, 60%, 80%) |
| PHY/MAC technology | 802.11b |
| Propagation model | Shadowing |
| Mobility model | Random way point |
| Node average mobility speed | 5 m/s |
| Simulation time | 200s |
| Time to start traffic | 10s |

**Table 4.** *Specific simulation parameters*

| Parameter | Class 1 | Class 2 |
|---|---|---|
| Traffic model | CBR | CBR |
| Transport protocol | UDP | UDP |
| Data rate | 64 Kbps | 160 Kbps |
| Weights (wd, wp) | (0.6, 0.4) | (0.5, 0.5) |

### *3.2. Performance metrics*

There are four metrics are used to evaluate the performance of CMRP and AOMDV protocols:

- Average end-to-end delay: The average delay when a packet is transmitted from source to destination. The unit is milliseconds (ms).
- Throughput: An average transmission rate of data packets. The unit is Kb/s
- Route instability: Represents the effects of route fluctuation on the network performance.
- Packet Delivery Ratio: The number of received per number of sent data packets.

### *3.3. Simulation results*

*3.3.1. Average end-to-end delay*

The result of average end-to-end delay of Class 1 and Class 2 traffics after simulating 30 nodes networks loading at 20%, 40%, 60% and 80% is presented in Figure 2. As can be seen from the figure, although CMRP 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 CMRP protocol is lower than AOMDV protocol. This result shows that the selected paths for traffic classes of CMRP having more stability and preferability than AOMDV's.

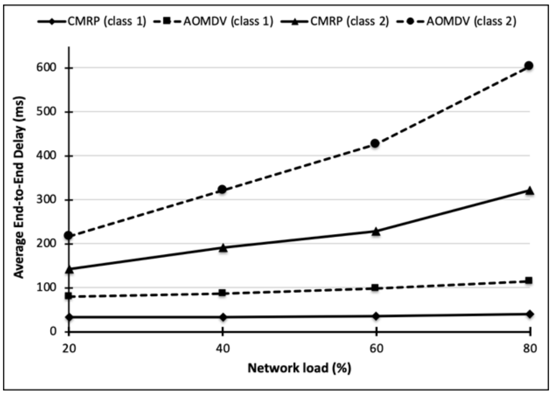


**Figure 2.** *Average Delay vs. Network Load*

*3.3.2. Average throughput*

In the assessment of average throughput for Class 2 traffic, we vary the network size (10, 20, 30 and 40 nodes) and network load (20% and 60%).

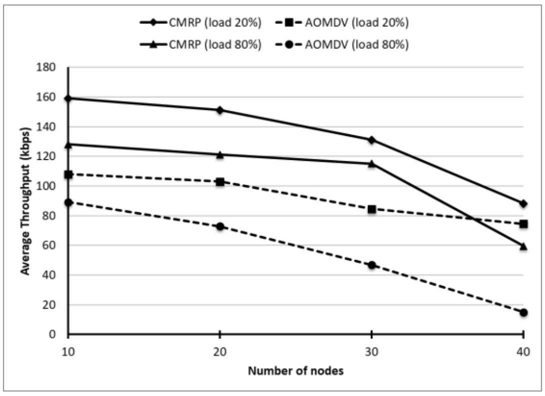


**Figure 3.** *Average Throughput vs Network Size*

Figure 3 shows that CMRP protocol achieves better throughput rather than AOMDV protocol. When the network size varies between 10 and 20 nodes, CMRP protocol achieves the average throughput of 20% traffic load approximately input data rate (160 Kbps). When the network load and the network size increase, the achieved average throughput of both protocols decreases, but the CMRP protocol still has a higher throughput rather than AOMDV protocol. This result is explained by the way these protocols choosing different routing metrics.

*3.3.3. Packet Delivery Ratio*

Figure 4 shows the packet delivery ratio of CMRP and AOMDV protocols when network load varies from 20% to 80% of 30 nodes network for Class 1 and Class 2 traffics. CMRP achieves packet delivery ratio better than AOMDV for both the traffic classes. The packet delivery ratio for Class 1 traffic of the two protocols is almost unchanged when varying network load. For Class 2 traffic, this ratio decreases when network load increase, packet delivery ratio of CMRP changes less than AOMDV's. Based on these results, we conclude that CMRP protocol is more scalable than AOMDV protocol.

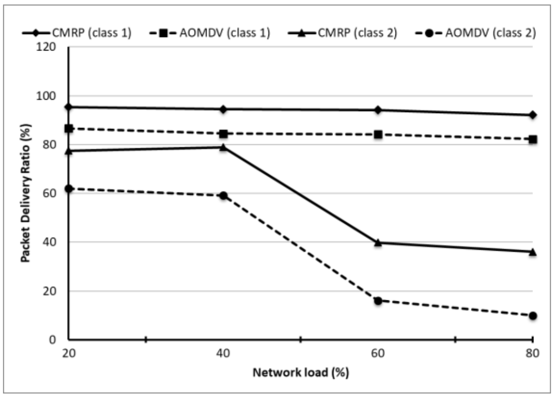


**Figure 4.** *Packet Delivery Ratio vs. Network Load*

*3.3.4. Overhead traffic*

In the last assessment, the network size is varied from 10 to 20, 30 and 40 nodes for a network load equal to 80% and measure overhead traffic ratio for Class 1 traffic. Figure 5 shows better results for the proposed CMRP protocol comparing with the AOMDV protocol. The number of control packets generated by CMRP is smaller than AOMDV's. This is due to the fact that CMRP reduces the number of route recovery calls. In reality, CMRP selects the most stable path providing the best quality to reduce the path recovery probability.

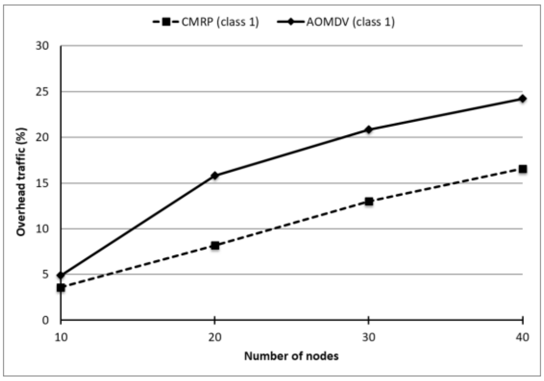


**Figure 5.** *Overhead Traffic vs. Network Size*

## 4. Conclusion

This paper focuses on the application QoS satisfaction issues in the process of routing with additional requirements on the quality of the end-to-end transmission path. Routing layer is conducted interaction with the lower layers to get accurate information about link quality from a source node to a destination node. Additionally, routing layer also interacts with the upper layer to sort and choose the path according to the traffic of application classes. The requirements for service quality of applications are grouped into classes based on predefined service parameter thresholds. The simulation done in this paper offers the results demonstrating the performance of the CMRP protocol is better than the AOMDV protocol's. The performance metrics are improved on the CMRP rather than on the AOMDV including the less average delay, greater throughput, higher packet delivery ratio and lower overhead traffic. However, when looking at the overall perspective, there should be further performance evaluations of the CMRP protocol in power consumption.

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