MAC layer based cross-layer solutions for VANET routing: A review

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Summary
Vehicular Ad hoc Networks (VANET's) are gaining popularity in research community with every passing year due to the key role they play in Intelligent Transportation System. Their primary objective is to provide safety, but their potential to offer a variety of user-oriented services makes them more attractive. The biggest challenge in providing all these services is the inherent characteristics of VANET itself such as highly dynamic topology due to which maintaining continuous communication among vehicles is extremely difficult. Here comes the importance of routing solutions which traditionally are designed using strict layered architecture but fail to address stringent QoS requirements. The paradigm of cross-layer design for routing has shown remarkable performance improvements. This paper aims to highlight routing challenges in VANET, limitations of single-layer solutions and presents a survey of cross-layer routing solutions that utilize the information from the MAC layer to improve routing performance in VANET.
Keywords:
Cross-layer, routing, MAC, VANET.

1. Introduction

Road transport is a major means of transportation even in this century and it does not seem that any other means will replace it in decades to come. Vehicles are increasing day-by-day which on one hand ease out the life of people but on the other hand introduced many kinds of problems out of which road accidents are prominent. Even after so many reforms in the road transport regarding safety of passengers, still we are far from what is to be achieved. Intelligent Transportation System (ITS) brings new hope in this situation and is becoming reality now. ITS not only aims safety and efficiency of transportation system, but also covers other aspects of passengers by offering various user-oriented applications [1]. The integral component through which all this is achieved is Vehicular Ad hoc Network (VANET).

VANET is a special type of Mobile Ad hoc Network (MANET) where vehicles act as nodes and form a communication network. Two types of communication are possible in VANET viz. vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). In V2V communication, vehicles communicate with each other in an infrastructure less manner whereas in V2I communication vehicle communicates with fixed infrastructure installed alongside roads such as base stations.

Data delivery in VANET's is a combination of V2V and V2I communication. A message from a source node to a destination node propagates through the network by following a multi-hop path where intermediate vehicles act as relay nodes. These vehicles are required to act in a self-adaptive manner taking care of topological changes and ensure successful delivery of messages. To make this happen the design of a robust and efficient routing algorithm becomes very important.

With increasing popularity of VANET's, research in designing routing solutions is going on. But most of the work address the problem considering only network layer. The paradigm of cross-layer design proves to be promising by providing performance gains in routing solutions by successfully tackling VANET constraints. In this paper a review of existing cross-layer solutions for VANET routing are covered where the other participating layer is MAC.

The rest of the paper is structured as follows. Section 2 highlights challenges posed due to VANET characteristics in designing routing solution. Section 3 raises the issues with single-layer routing. Section 4 gives an overview of cross-layer design, Section 5 explains the MAC layer based existing cross-layer routing solutions for VANET and Section 6 concludes the paper.

2. Routing challenges in VANET

The characteristics of vehicular networks makes the task of designing routing protocol more peculiar and requires to address the following challenges [2] [3]:

Neighborhood discovery is a first step towards packet forwarding and the most common way to do this is through beacons. Beacon is a one hop control message that is send periodically by a node and contains node identity as well as status. The periodicity of beacons is a critical design parameter as its frequent exchange will increase control overhead and degrades performance whereas less frequency leaves the nodes with obsolete information affecting route discovery.

Manuscript received December 5, 2021
Manuscript revised December 20, 2021
https://doi.org/10.22937/IJCSNS.2021.21.12.87

Data forwarding requires to know the next hop node to which packet needs to be handed over. One approach is to maintain routing table but in a highly dynamic scenario of VANET's it proves to be very costly and degrades performance. The other way is to decide for next hop when forwarding decision is to be taken instead of maintaining predetermined routes.

The density of vehicles is another important parameter to take care of. In a vehicular environment, highway as well as urban scenarios are possible. Highway scenario is more of sparse traffic whereas urban scenario has dense. Also, in urban scenario depending on the time-of-day traffic can be sparse or dense. Both density situations require different handling. A good routing protocol must be adaptive to take care of both situations.

As there is no limit on number of vehicles in a real time scenario, a routing protocol for vehicular networks must be able to accommodate them i.e., it should be scalable. The design approach follows plays a vital role into this. Instead of taking routing decisions based on complete network topology, local information-based decisions are better. This will reduce the control overhead to a great extent. The vehicles nowadays are equipped with tools like GPS that provides position information. The routing approach for VANET should utilize this aspect for getting neighborhood details and selecting the next hop to forward packet. This will help in improving the protocol performance.

Due to predefined and fixed road network, the movement of vehicles in VANET follows a pattern and is not arbitrary. This aspect when accompanied with available navigational information opens up new dimension in designing routing protocols as it makes future position of vehicles predictable. With this, the routing performance be enhanced further.

3. Issues with single-layer routing

Vehicular ad hoc networks are having similar characteristics as traditional wireless networks along with highly dynamic nature and very tight Quality of Service (QoS) requirements due to which a flexible approach is required in designing routing protocol to satisfy the needs of vehicular communication. Single-layer routing approaches are based on rigid layered architecture where getting flexibility is not possible as a result are unable to achieve robustness. The aim of single-layer approaches is to optimize the network layer metrics where channel or node characteristics does not matter a lot as a result of which network performance is affected.

Two of the most prominent issues where single-layer routing struggles are interference and congestion. Interference is a physical layer phenomenon and occurs due to unwanted signals from nearby transmissions affects the transmitting signal. Due to the similar structure of interference as of the transmitting signal it is hard to control and the fading effect makes the situation worse. Congestion is mainly related to the limited storage at the node or dense network conditions. Limited storage results in quick overflow as a result packet drop starts. Due to dense network, multiples nodes start transmission simultaneously which results in frequent collisions resulting in loss of packets. In single-layer approaches, different routes may contain common nodes which again end up with congestion.

There are situations where different layers play vital role in generation of such issues. In these circumstances, single-layer routing solutions may end up with degraded performance and highlights the importance of support from relevant layers paving way to the domain of cross-layer solutions.

4. Cross-layer design

It is an idea where protocols are designed by violating the principles of layered architecture such that layers communicate with each other. It is done in order to utilize the dependency between layers to improve performance. Layers share information with each other that enables them to get a deep insight of the network and helps them to take better decisions. The performance gains achieved by cross-layer designs over single-layered makes it an attractive paradigm and its significance is validated by several efforts [4].

The number of layers and which layers will involve (Fig. 1) depends on the requirements to consider. These requirements may be application related or performance related.

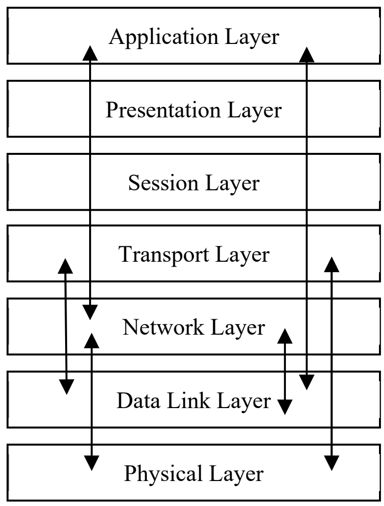

Fig. 1 Cross-layer design example.

After identification of layers where optimization is required to be done, the next important point is to find the strategy for implementation. The cross-layer communication is possible in the following ways [5]:

(i) Creation of new interfaces
(ii) Merging of adjacent layers
(iii) Design coupling without new interfaces
(iv) Vertical calibration across layers

Above four ways differs in the amount of change required in the layered architecture which in turn affect the implementation cost and extensibility aspects.

5. Cross-layer routing solutions

In this section, we are presenting cross-layer solutions designed for routing where interaction of network layer happens with MAC layer (Fig. 2).

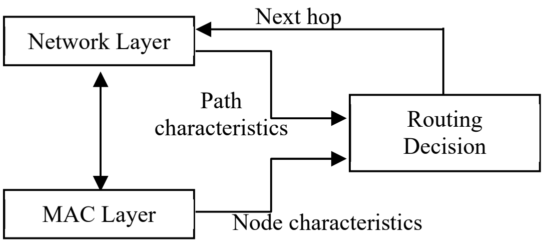

Fig. 2 Network & MAC layer based cross-layer design.

By considering parameters at MAC layer while designing routing protocol makes it more robust against issues involving point-to-point communication. Retransmission count, current contention window value, queue size, buffer space etc. provided by the MAC layer helps in mitigating packet drops and when combined with end-to-end characteristics such as round-trip time, hop count etc. in making routing decisions ensures performance improvement.

A summary of cross-layer solutions covered in this paper is given in Table 1.

Korkmaz et al. proposed Urban Multi-hop Broadcast (UMB) protocol [6] to tackle broadcast storm and hidden terminal problems and improve the reliability for multi-hop vehicle communication. It works by dividing the whole operation into two parts. First one is the directional broadcast where the transmitting node selects the farthest node in its transmission range for rebroadcasting. It is achieved on the basis of distance between transmitting node and all its neighbors where neighbors are required to contend. Second one is intersection broadcast where installation of repeaters is proposed to handle packet broadcasting around intersection. On approaching intersection, a node uses this repeater to forward packet across intersection.

They evaluated the performance by developing a Wireless Simulator based on event driven simulation library (CSIM) whereas for traffic simulation MATLAB was used. The proposed protocol was compared with 802.11-distance, 802.11-random and demonstrated better performance even for heavy load and dense traffic. The performance metrics used were successful packet delivery percentage, packet dissemination speed, load generated per broadcast packet.

The work of Menouar et. al. [7] is based on stability of route. In their protocol Movement Prediction based Routing (MOPR), the neighboring vehicle's movement information is used to predict its future location which in turn gives indication about how long the neighboring vehicle continues to be in transmission range i.e. the lifetime of the link. The neighbor's speed, position and direction is provided by the MAC layer. Each vehicle estimates the link stability of all of its neighbor's and selects the one with the most stable link as the next hop for transmission. In this manner, MOPR is capable of selecting the most stable route from all the routes available.

The performance evaluation is done on packet delivery ratio, end-to-end delay, routing overhead, routing overhead ratio using NS2 and compared with GPSR, MORA where it outperformed both of them.

In another cross-layer protocol Controlled Vehicular Internet Access (CVIA) [8], Korkmaz et. al. proposed a segment-based approach to solve hidden terminal problem while improving throughput and achieving fairness of channel access by remote vehicles, addressing best-effort traffic. In their proposal, road is partitioned into segments where if within one segment transmission is going on, in the neighboring segment it is paused i.e., neighboring segments work in opposite phase. Also, a segment alternatively switches between transmitting and non-transmitting phase. The segments are formed in such a manner that segment members are at one-hop distance from each other. Within each segment, some nodes are marked as temporary router to take care of inter-segment communication.

As a result of this segmentation approach, the packet movement in CVIA is described for different scenarios. For intra-segment communication, local packet gathering within a segment takes place where nodes contend for channel access in random manner to forward the packet to the temporary router. Also, within a segment one temporary-router delivers the received packets from other segments to another temporary-router for further passing. Inter-segment communication takes place between temporary-routers of neighboring segments where packets are forwarded in the direction of the base station. This protocol is not suitable for real-time applications due to high delay experienced by packets.

Table 1: Summary of cross-layer solutions

Protocol	***Year***	***Objective***	***Comm. Type***	***Scenario***	***Tools***	***Comparison***
UMB	2004	To address the broadcast storm, hidden node, and reliability problems of multi-hop broadcast in urban areas	V2V	Urban	WS-CSIM, MATLAB	802.11-distance 802.11-random
MOPR	2005	To select the most stable route	V2V	Urban	NS2	GPSR, MORA
CVIA	2006	To achieve fairness while improving e2e throughput for best-effort traffic	V2I	Highway	WS-CSIM, MATLAB	802.11
AMB	2007	To extend UMB to handle intersections without infrastructure support when there is line of sight among all road segments	V2V	Urban	WS-CSIM, MATLAB	802.11-distance 802.11-random
DeReHQ	2007	To discover route high in reliability	V2V	Both	NS2	A, V, AC_BK
CCBF	2007	To provide low packet delay	V2V	Urban	Nagel and Schreckenberg	802.11
DBAMAC	2007	To minimize broadcast delay	V2V	Highway	NS2	802.11
R-AOMDV	2009	To support fast propagation of broadcast messages	V2V	Urban	NS2	AOMDV
Nasri et. al.	2009	To communicate over minimum delay paths with link quality consideration	V2V	Urban	NS2	802.11
CVIA-QoS	2010	To support fast propagation of broadcast messages at intersections	V2I	Highway	WS-CSIM, MATLAB	CVIA, 802.11e
PROMPT	2010	To guarantee throughput and upper bpund on delay for voice and video based real-time traffic	V2I	Urban	NS2	DSR, GPSRJ+, VADD, CAR
SRPMT	2015	To reduce end-to-end delay by quickly adapting to the frequent topology changes	V2V	Urban	NS2	GyTAR, GPSR

The performance evaluation has been done using same tools as used with UMB/AMB and metrics used were throughput, fairness, packet failure rate and delay. It was compared with 802.11 and outperforms.

The authors of UMB later proposed an extended version AMB [9] where they further optimize broadcasting at intersection by eliminating repeaters by enabling vehicles themselves to handle it. The performance evaluation was done using same set of tools and metrics as were used with UMB and compared with same variations of 802.11 where AMB demonstrated superior performance.

Niu et. al. in their work DeReHQ [10] focus on providing QoS support in routing. Instead of just considering shortest path, quality of path is given importance by considering link reliability, e2e delay and hop count jointly as QoS parameters. To compute these parameters, vehicle density, relative speed and connection distance are used. As link reliability is given highest priority, a subset of routes amongst all are identified satisfying link reliability criteria. From this subset, routes satisfying delay bound and ho-count criteria are considered and the best route is selected. In case no route satisfies the criteria, the desired link reliability requirement is gradually reduced and shortlisting is done again. DeReHQ is designed for single-class traffic and support for priority classes is missing.

The performance evaluation was done using NS2 and end-to-end delay metric was calculated for three different mobility models Random Waypoint, Freeway and Manhattan. It is found that service differentiation was achieved in some cases only.

Wiegel et. al. in their proposal Cross-layered Cluster-based Forwarding (CCBF) [11] addresses the issues of hidden terminal and QoS. The MAC layer is designed to work on cluster architecture and shares this information along with neighbor node information with the routing algorithm. For cluster formation and its maintenance, the approaches of CBLR protocol and WCA protocol are used.

Every cluster member shares its packet queue details with the cluster head which in turn use it to form a time division-based channel allocation scheme and share it with all members. This mechanism ensures that only one cluster member use the channel at a specific time. Also, Cluster Head's (CH's) in a neighborhood agrees to release channel allocation scheme for their cluster in a particular order. This way it is ensured that hidden terminal problem is minimized. The packets are prioritized by a filtering mechanism to guarantee a low delay and thus ensuring QoS.

The performance evaluation was done using a simulation platform based on Nagel's microscopic traffic model and compared with 802.11 for packet loads of 15, 40 and 75 packets per node. Packet delivery ratio was calculated for regular data and high priority data reflecting QoS performance where CCBF performs better.

The work of Bononi et. al. Dynamic Backbone-Assisted MAC (DBAMAC) [12] focuses on ensuring fast propagation of emergency messages. To achieve this, they proposed clustering approach for backbone formation and a forwarding scheme at MAC layer to take advantage of clustering. In this approach, the vehicles are divided into two categories viz Normal Member (NM) and Backbone Member (BM). The identification of BM's and maintenance of backbone involves cluster management techniques, but in a proactive manner.

The MAC layer scheme is designed in such a way that it takes advantage of backbone structure, favors fast propagation and dynamically adjusts according to network load and cluster variations. It provides differentiated service with Backbone members having high priority over Normal members for channel access and Fast Multi-hop Forwarding (FMF) scheme is defined for this purpose. This scheme ensures that whenever a BM receives an alert message it is immediately broadcasted after a SIFS. This guarantees that medium is controlled by the multi-hop backbone without any backoff delay and collisions. When the broadcasted message is received by the next BM in the backbone, it provides an acknowledgement whereas for NM they do not. This mechanism combines both unicast as well as broadcast transmission concept.

The performance evaluation was done using NS2 with metrics considered were average number of retransmissions, average percentage of collisions, end-to-end delay. The proposed protocol was compared with 802.11, Fast Broadcast MAC and Static Backbone-Assisted MAC and performs better.

In [13], Chen et. al. proposed R-AOMDV (Ad hoc On-demand Multipath Distance Vector with Retransmission count metric) where they are of the opinion that a routing protocol must take care of variable channel character in urban VANET scenario. Frequent link breaks results in frequent route discoveries which further degrades the overall network performance. They pick up the idea of multipath routing to rectify this issue and selects AOMDV for modification. In R-AOMDV, a new routing metric is introduced which is a combination of maximum retransmission count and hop count of a path. The maximum retransmission count of a path is considered over average link quality of a path as the later ignores the worst link along the path. Hop count is considered as it is an indicator of e2e delay, lesser the no. of hops lesser is the delay. Maximum retransmission count of a path is known by comparing the MAC layer retransmission count of each individual link of the path which is a representation of link quality (reflection of local channel character) and is easy to measure. This new metric is incorporated by the introduction of two new fields in the RREP (route reply) packet, one each for both the components. When all RREP's reaches the source, source can easily compare this metric for these multiple paths and selects the optimized one.

The performance evaluation was done using NS2 with Pareto On/Off traffic model for metrics normalized routing load, packet delivery fraction, average end-to-end delay and compared with AOMDV where the proposed protocol performs better both in dense as well as sparse scenarios.

Nasri et. al. [14] addresses the problem of broadcasting at the intersections where vehicles on one road can block the broadcasting in other directions of the intersection. This happens due to overlapped communication range and road topologies. The proposed broadcast algorithm works by classifying vehicles on the basis of relative angle and location with respect to the forwarding vehicle. The vehicles are classified into two groups Back vehicles and Ahead vehicles, which are further subdivided into three classes namely Class 1, Class 2 and Class 3. Back vehicles are the vehicles whose Cos of angle between a vector from their position to the relay and vector of relay moving direction is greater than zero. Ahead vehicles are the vehicles whose Cos of angle between a vector from their position to the relay and vector of relay moving direction is less than zero.

The performance evaluation was done using NS2 for metrics transmitted bytes and delay. The proposed protocol was compared with 802.11 where is performs better.

CVIA-QoS [15] is an improved version of CVIA protocol where Korkmaz et. al. focus on real-time voice and video traffic as compared to best-effort traffic in CVIA. The aim was to guarantee throughput in a delay-bounded manner addressing the QoS needs. The idea is to first allocate bandwidth to real-time traffic and allow best-effort traffic to use the remaining. This is achieved by dividing time into slots and each slot is further divided into High Priority Period (for real-time traffic) and Low Priority Period (for best-effort traffic). The maximum length of High Priority Period is defined in the protocol to avoid starvation of packets belong to best-effort traffic. The High Priority Period consists of newly defined phases viz. registration, control, polling and propagation whereas phases in Low Priority Period are as given by CVIA protocol. The operation of the protocol centers around gateways which impose admission control and guarantee e2e throughput by making use of information about new arrivals, running sessions and buffer status at the temporary routers. Temporary routers executes the decision of gateways by implementing all the four phases.

The performance evaluation was done using a Wireless Simulator developed using CSIM library for metrics throughput, packet failure rate and delay. The proposed protocol was compared with CVIA and 802.11e where it outperforms the rest of the two.

Jarupan et. al. proposed PROMPT [16] for V2I communication which is a position-based source routing protocol where packet contains route information but this route information consists of (street, direction) pairs instead of node ID's. This solution on one hand helps in overcoming the connectivity problem due to high mobility and on the other hand is inexpensive as neighbor management is not required.

The Base Station (BS) transmit beacons on regular intervals. When a node forwards beacon, it adds its location and local traffic information to it. As a result, beacon carries complete path along with statistics of path traffic as it traverses and every node that receives beacon updates its path table. As paths does not consist of node identity, they are unaffected by node mobility. The propagation of beacons is achieved by adopting UMB protocol. When a source node wants to transmit data, it uses path table information to estimate the e2e delay and selects the route accordingly.

To further improve the performance, PROMPT uses the idea of packet train. The intermediate relay node may receive multiple packets from different sources with the same path for the same BS. Instead of contending for each packet, the relay node may club all the packets forming a packet train and contend the channel only once. As a result contention overhead reduces resulting in reduced collisions which finally reduces overall average packet delay.

The performance evaluation was done using NS2 for the metrics average delay, packet loss rate and fairness and is compared with DSR, CAR, GPSRJ+ and VADD. The proposed protocol outperforms all the other ones on all the three metrics, except in fairness where CAR is better.

Zhang et. al. in their work Street-centric Routing Protocol based on Micro Topology (SRPMT) [17] proposed a novel idea of Micro Topology (MT) which represents topology along the street (with two endpoints as two intersections) in an urban scenario i.e., vehicles and links between vehicles for that street. An MT represents static attributes such as length of street as well as dynamic attributes such as vehicle density, vehicle mobility, connectivity, signal fading, channel contention and data traffic. The complete VANET topology is considered to be composed of several MT's and a routing path from source to destination vehicle consists of consecutive MT's.

There are two aspects of SRPMT working i.e., how to decide next MT at the intersection as part of the route to destination and how to forward packet within an MT. At the intersection, the selection of next MT is based on the routing performance of each candidate MT which means shortest estimated delay towards destination. It is composed of endside-to-endside delay in the candidate MT and the remote endside delay (from the endside of candidate MT to the destination). In order to forward the packet within an MT from the usual two directions (towards each endside of the street), senders along the direction of packet transmission are only considered. From among these neighbors, the optimal next hop neighbor is selected as per the computed priorities of the relaying strategy. If geographical relaying strategy is used, it is having the priority ordering based on the geographical progress of the neighbor vehicle towards the destination.

The performance evaluation was done using NS2 for metrics packet delivery ratio, average end-to-end delay and normalized routing overhead. It was compared with GyTAR and GPSR where it performs better.

6. Conclusion

In this paper we have presented a survey of cross-layer routing solutions for VANET involving MAC layer. The challenges in designing routing solution for VANET are discussed and why single-layer approaches are not suitable is highlighted. With the discussion on various solutions, it is clear that the information from MAC layer helps in improving the performance of routing. An area that is not covered much is the use of contention window information in routing. It is evident that very few cross-layer solutions were designed till date where MAC layer is involved, especially in the last decade and hence reiterated the need of further exploration in this direction. As since many decades designing an efficient routing solution for wireless networks still remains a challenging area and particularly for VANET it is still widely open.

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