Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2017) 25: 1762 – 1772

doi:10.3906/elk-1507-147

ERP: An efficient reactive routing protocol for dense vehicular ad hoc networks

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Received: 15.07.2015 • **Accepted/Published Online:** 22.06.2016 • **Final Version:** 29.05.2017

Abstract: A vehicular ad hoc network (VANET) is a type of mobile ad hoc network (MANET) that provides an exchange of messages between vehicles. VANETs encourage researchers to create safety and comfort applications that will lead to intelligent transport systems. Conventional ad hoc routing methods may cause flooding of packets to find routes in a VANET. Hence, finding a route from the source to the destination vehicle by local broadcast techniques in densely populated urban areas may create a broadcast storm and network bandwidth is unnecessarily wasted to discover routes between source and destination vehicles. In this paper, an efficient routing protocol (ERP) is proposed to utilize the network bandwidth efficiently by avoiding unnecessary rebroadcast. This new protocol finds a minimum connected dominating set of vehicles (MCDSV) and treats them as a virtual backbone for communication in VANETs. Vehicles in the virtual backbone act as forwarders and are responsible for local broadcasting in the network. Vehicles that are not in the MCDSV are not allowed to broadcast packets as forwarders and hence the bandwidth utilization is minimized. The proposed protocol has been implemented in NS2 and its performance is compared with other routing protocols for packet delivery ratio, control overhead ratio, and average end-to-end delay.

Key words: Minimum connected dominating set of vehicles, vehicular ad hoc networks, unicast routing

1. Introduction

A vehicular ad hoc network (VANET) contains vehicles that may communicate vehicle-to-vehicle through wireless communications. Vehicles in a VANET communicate by one-hop communication (source vehicles directly communicate with the destination vehicle) or by multihop communication (source vehicles cannot directly communicate with the destination vehicle) [1]. VANETs play an important role in the intelligent transportation system's (ITS) ability to manage traffic efficiently. VANET applications are considered effective safety applications by researchers and automobile manufacturing companies. VANETs have distinct features like high mobility, dynamic network topology, road restrictions, and scalability that differentiate them from MANETs [2]. VANETs applications are utilized to warn drivers of traffic jams and conditions of the road to avoid accidents. They are also utilized to broadcast caution messages to the drivers of rear vehicles to avoid rear-end collisions on highways. Figure 1 presents a sample scenario for a junction of a dense VANET.

Connectivity, routing, and security are the main issues in VANET systems [3]. The dynamic network topology of VANETs makes routing packets a challenging job for researchers [4]. In VANETs, all vehicles other

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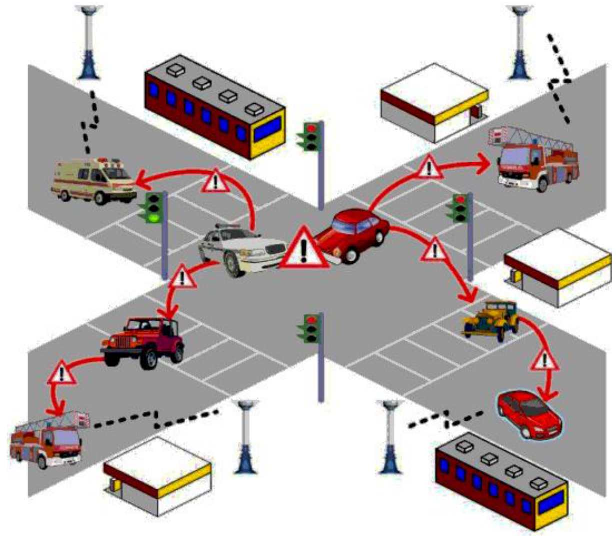

Figure 1. A sample VANET scenario.

than the source and destination vehicles are considered as routers or forwarders. The aim of an efficient routing protocol is to provide an optimal path between the source and destination with the fewest overhead packets [5]. Different routing protocols have been developed for VANETs and they are classified based on techniques used, quality of services, routing information, characteristics, network structures, routing algorithms, etc. Speed and dynamically changing topologies of VANETs lead to frequent disconnections in routing paths between source and destination vehicles [4]. That results in finding a new route by sending a route request and route reply packets, which increases the bandwidth of the network [6].

The protocol proposed here is designed to reduce bandwidth utilization by avoiding unnecessary local broadcasting of packets for finding a route between source and destination vehicles. This protocol finds the minimum connected dominating set of vehicles (MCDSV), makes the vehicles in the set a virtual backbone of the network communication, and treats them as routers or forwarders. In this proposed protocol, forwarder vehicles (i.e. the set of vehicles in the MCDSV) are only responsible for forwarding the packets, while the remaining vehicles do not forward the forwarding packets. This routing method differs from the conventional routing protocols where all the vehicles broadcast the route request packets, which potentially increases the network bandwidth.

The rest of the paper is organized as follows: Section 2 describes the related works on routing of VANETs. Section 3 explains the network model and the notation for VANETs. Section 4 proposes a new algorithm for routing the packets. Section 5 provides a simulation and simulation results of the proposed routing protocol and compares the results with the other three protocols. Section 6 concludes the paper.

2. Related work

This section describes various unicast routing protocols proposed in the literature. The routing protocols in VANETs are broadly classified into topology-based routing protocols and position-based routing protocols. These protocols are described as follows.

2.1. Topology-based routing protocols

The destination sequenced distance vector (DSDV) protocol is a proactive routing protocol for MANET [7] that routes the packets from source to destination. It executes the policy of the distance vector and maintains one route between source and destination vehicles using the shortest path technique. Each vehicle broadcasts hello messages to its neighbor vehicles periodically to maintain the latest routes in the routing table. This protocol utilizes the bandwidth of the network unnecessarily by finding routes that are not required.

The optimized link state routing (OLSR) protocol maintains a routing table by applying a link state procedure [8]. All the feasible routes to network vehicles are stored in the routing table. Every vehicle must send its updated routing table data to its neighbor vehicles when the network topology of the vehicle is changed. The OLSR protocol frequently sends control overhead messages to neighbor vehicles, which leads to network congestion.

The fisheye state routing (FSR) protocol updates its routing table periodically by collecting information from neighbor vehicles [9]. The route discovery process and delay in finding the route is not available in this protocol, which is the advantage of this proactive protocol. The main issue with the FSR protocol is that the size of the routing table is increasing due to an increase in network size. These proactive protocols are not suitable for VANETs due to their high-speed mobility and a dynamically changing topology network.

The ad hoc on-demand distance vector (AODV) routing protocol is a reactive routing protocol [10,11] intended for MANETs AODV offers low network overhead compared to proactive routing protocols by reducing overhead packet flooding in the network. In AODV the recent active path entries are kept in the routing table, which reduces the memory size, and the information of the next hop is compared with the whole path. It uses the idea of destination sequence numbers to remove loops in the routes and enhances the network utilization.

The dynamic source routing (DSR) protocol is a reactive protocol [6,11] and has a quick reaction to frequently changing network topology. In the route discovery method, when a source vehicle needs to find a route, it sends a route request message to all its neighbors. All vehicles in between that receive the request message broadcast it again, except the destination vehicle. Then the source vehicle receives the route reply message back from the destination vehicle and that route is stored in the routing table of the source vehicle. The advantages of this routing protocol are best visible in networks. The drawback of DSR is that routing overhead increases while the network size increases, and it degrades the network performance.

The ad hoc on-demand multipath distance vector (AOMDV) is an extension of AODV protocols [12] that finds many routes during the route discovery phase from source to destination vehicles. In the route discovery process, it accumulates multiple routing paths between source vehicles to destination vehicles. If any path is failing, there is no need to find a new route for the destination. The improved performance of this protocol makes it more efficient and provides uninterrupted communication between the communicating vehicles for data dissemination. It reduces overhead by minimizing frequent route establishment.

The speed direction-ad hoc on-demand distance vector (SD-AODV) protocol is an improvement on the AOMDV protocol [13]. Here the new parameters, i.e. the direction and speed, are added to the hop count field in order to choose the next hop during the route establishment process. Both parameters are merged with the hop count field to select a route.

The retransmission-ad hoc on-demand multipath distance vector (R-AOMDV) protocol [13] uses a technique that combines hop count and transmission count at the MAC layer. The R-AOMDV protocol process in the route discovery phase is similar to the AOMDV protocol. In the R-AOMDV protocol, two parameters are added in the message field of the route reply: the total hop count (THC), which is calculated by the network layer, and the maximum transmission count (MRC), which is calculated by the MAC layer that is used to measure the quality and reliability of the whole route. The performance of R-AOMDV is better than that of the AOMDV protocols. Its disadvantages are packet loss and increase in end-to-end delay.

The temporally ordered routing algorithm (TORA) protocol is a reactive routing protocol [13]. This protocol creates a directed graph, which has the source vehicle as a root of a tree. This protocol consists of a tree assembly in which packets move from higher vehicles to lower vehicles. This protocol is a loop-free routing and multipath routing as information moves down to the destination vehicle and does not move back upwards to the forwarding vehicle. The main advantages of TORA are that it provides a route towards each vehicle of the network topology and it reduces control message broadcast.

The zone routing protocol (ZRP) is a hybrid routing protocol [13] and has both proactive and reactive characteristics. It is designed to increase the scalability of proactive protocols and to minimize control messages. It divides the network into different zones, where each zone may have a different size. Routing within zones, or intrazone routing, is performed by a proactive protocol. On the other hand, to increase system scalability, routing between zones or interzone routing is done by a reactive protocol. However, the disadvantage is that it introduces too much latency when finding new routes.

2.2. Position-based routing protocols

The geographic source routing protocol (GSR) is suitable in urban scenarios [14]. It merges topological information with position-based routing to find the optimal route. Reactive location service (RLS) is used to gain the location details of the destination vehicle. This service is used to discover the position details of the destination vehicle during the route discovery phase. The drawbacks of this protocol are that it does not work well in sparse networks and the overhead packets are larger because of hello messages that are regularly used as control messages.

Greedy perimeter stateless routing (GPSR) is a position-based routing protocol proposed by Karp and Kung [15]. By using the vehicle position they find the optimal route between the source and destination vehicle. They compared other protocols in the urban areas of big cities and proved that GPSR outperformed other distance vector protocols. This protocol faces some difficulties due to obstacles like big buildings in urban areas.

The greedy perimeter coordinator routing (GPCR) protocol uses the greedy forwarding technique, which is proposed for high mobility scenarios (urban areas) [16]. All the vehicles here are aware of their location from the navigation system. It sends hello messages periodically to know the neighbor information and through location service the position details of the destination are obtained. Here, the packets are forwarded to a neighbor who is closer to the destination location. The GPCR protocol maintains the routes using two components: sending the packet to the next intersection, and decision-making. Decision-making is used to decide the next hop vehicle (coordinator vehicle). The coordinator vehicle decides the path to which the packets will be delivered. If the density is low then the vehicles are not able to connect with the destination vehicle and transmission delay increases.

The spatially aware packet routing (SAR) protocol is used to rectify the limitations of the recovery approaches used by the greedy perimeter stateless routing (GPSR) protocol [17]. SAR algorithms consist of GSR and GSR-based packet forwarding. The underlying spatial model permits the vehicle to send the data packet along the streets. The main disadvantage of SAR is the lack of a guarantee that a forwarding vehicle can always find a suitable neighbor on the GSR.

The connectivity-aware routing (CAR) protocol [18] is another type of position-based routing protocol that is used to find the optimal path between source and destination. It is used to maintain the active route information of various routes from source to destination in the cache. This protocol is also used to predict the location of the destination vehicles and maintain the path as the position of the vehicle changes.

The spatial and traffic aware routing (STAR) algorithm was designed to overcome the drawbacks of the SAR algorithm [19]. As compared to the SAR protocol, the STAR algorithm calculates its path slowly by providing a partial path in the header of the packet. It totally depends upon the next hop vehicle to offer the additional section of the route. Each and every vehicle sends hello messages periodically that consist of its ID, details from its traffic-table, and its position. STAR calculates the route on demand and collects the details about the vehicle ID from the vehicle traffic table and the location of the vehicles. Using these details, it selects the next hop vehicle.

Geographical Opportunistic (GeOpps) is a protocol [20] that uses the navigation system to collect details using GPS. These details are used to choose the next forwarding vehicle that is closer to the destination vehicle. A store and forward strategy was used to provide efficient routing and the navigation system was used to provide efficient packet delivery. The merit of GeOpps is that all the vehicles are not required to calculate the transmission rate and optimal route. This depends only on network topology and vehicle mobility.

From the literature, it is observed that researchers have not put much focus on the broadcast storm while finding routes using route requests from source to destination vehicles in VANETs. Hence, this paper addresses this issue of broadcast storm for routing the packets and gives a solution using MCDSV, treating them as a virtual backbone for communications in an effective manner with a smaller number of overhead packets in dense VANETs.

3. Network model and notation

All the vehicles in VANETs use wireless channels to communicate with each other. It is assumed that vehicles that are able to communicate with one hop from the source to the destination are called neighbors. In VANETs, packets are able to be sent in both directions and the underlying MAC protocol manages the scheduling of the packets in different vehicles for collision-free communications. A vehicle floods the packets in all directions and broadcasts the packets locally.

$G = \{V, E\}$ is considered an undirected graph with a set of vehicles and a set of communication links between vehicles that represents this ad hoc network. In this graph (G), V_i represents a vehicle in the set V and $< V_i, V_j >$ represents an edge (i.e. a communication link) between neighbor vehicles V_i and V_j in the set E [21].

A dominating set of vehicles (DSV) is a subset of G, the dominating vehicles in the graph G. Each and every vehicle in the network is available either in the DSV or the neighbor of the DSV. A connected dominating set of vehicles (CDSV) is a subgraph of G. The vehicles in the CDSV are able to communicate with each other without using the vehicles in the nondominating set of vehicles. The set CDSV is called a minimum connected dominating set of vehicles (MCDSV) if and only if the set has a minimal number of vehicles in the CDSV. The set of vehicles in the MCDSV acts as a virtual backbone of the VANET. Each vehicle V_i that is not in the MCDSV has a dominator vehicle in the MCDSV as a neighbor of vehicle V_i and is represented by dominant (V_i) [21].

Figure 2 describes dominators of the network. Here, red cars act as dominating vehicles and the rest of the vehicles are acting as nondominating vehicles. In this scenario, only dominating vehicles are forwarding the packets and the rest of the nondominating vehicles are not allowed to forward the packets.

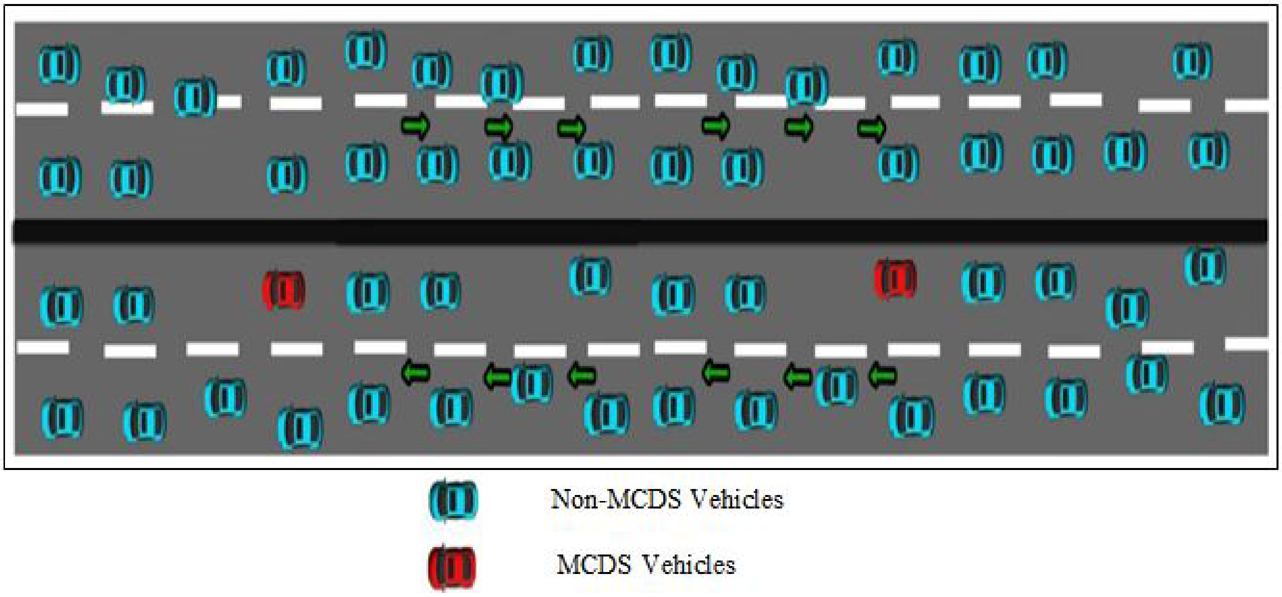

Figure 2. A road segment in an urban area.

Algorithm 1 is used to find the MCDSV.

Algorithm 1 MCDSV.

```
1: INPUT: Set of vehicles V
2: OUTPUT: MCDSV
3: # To find the dominating set of vehicles
4: N = V
5: DSV = { }            # empty set
6: while !Empty( N )
7:     Pick n that has maximum neighbor vehicles
8:     DSV = DSV U {n} # U – union
9:     N = N – ({n} U Neighbor ( n ))
10: end while
11: # To find the minimum connected dominating set of vehicles
12: MCDSV = DSV
13: for all {m,n} in DSV do
14:     if Hop_Distance(m, n) <= α then # Hop_Distance function returns number
                                        # of hops between two vehicles
15:         G = shortest path vehicles from m to n
16:         MCSDSV = MCDSV U G
17:     end if
18: end for
19: return MCDSV.
```

Lines 4–10 find the dominating set of vehicles as follows: choose a vehicle from the set of vehicles V that has maximum neighbor vehicles and is not available in the dominating set of vehicles (DSV). Include that vehicle in the DSV and remove that vehicle and its neighbor from the set of vehicles N. Repeat this step until the set N is empty. Lines 12–20 find the minimum connected dominating vehicles set by searching the gateway vehicle between the dominating vehicles set when they are not neighbors; the value of α takes 3 hops distance between the DSV for a dense network (rush hour traffic), and it takes 5 for a sparse network (midnight traffic). Using this proposed algorithm, the MCDSV has been found by sending hello packets periodically and the cost of the packets is considered as control overhead packets. The time complexity of this algorithm is $O(N^3)$, where N is the number of vehicles in the networks.

4. Proposed routing protocol

In dense VANETs, there are more overhead packets due to the large number of vehicles. Thus, it requires a robust routing protocol that reduces the overhead packets in the network. An efficient reactive routing protocol for a dense vehicular ad hoc network has been proposed in this paper to reduce the overhead packets. The route establishment phase and the route maintenance phase are the two phases of this proposed protocol. In this proposed protocol, we consider the route establishment phase. In the route establishment phase, hello, route request, and route reply packets are used to form a route between the source and destination vehicles. In conventional routing protocols, route request packets sent by the sender initiate the process of route creation. All neighbor vehicles of the sender rebroadcast the route request to their neighbors until the packets reach the destination vehicle. Then the route reply packet sent by the destination vehicle to the source vehicle confirms the route establishment phase.

In our proposed routing protocol, hello packets have been used to create the MCDSV using Algorithm 1. The vehicles in the MCDSV have been used to create a virtual backbone in the VANETs. Here, only the vehicles in the MCDSV rebroadcast the packets until they reach the destination vehicle, but in conventional routing protocols all vehicles rebroadcast the route request packets and utilize most of the network bandwidth. The ERP protocol reduces bandwidth utilization by avoiding an unnecessary broadcast storm for the routing discovery phase.

4.1. Route request

The process of route request is explained as follows: let N_S and N_T be source and destination vehicles, respectively. Let θ be the threshold value for time for route reply.

Algorithm 2 Route discovery algorithm.

```
INPUT: Source vehicle N_S, Destination vehicle N_T
OUTPUT: A shortest path from the source to destination vehicle
Let O be route reply threshold time.
Send RREQ (N_S, N_T) packets.
If no path is found within threshold time then
        STORE_AND_FORWARD (N_S, N_T)
End if
    Reply to route request
```

Vehicle N_i, which is in the MCDSV or not in the MCSDSV, or N_T receives a RREQ(N_S, N_T) and handles route request packets using the algorithm below.

In this proposed protocol, the source vehicle floods route request packets to the neighboring vehicles of

Algorithm 3 RREQ algorithm.

INPUT: Source vehicle $\mathbf{N_S}$, destination vehicle $\mathbf{N_T}$
OUTPUT: A shortest path from the source to destination vehicle
If $N_i = N_T$ Then
    RReply(N_T, N_S)
Else
    If CheckVehicle(N_i, Route_Table) or !MemberMCDSV(N_i) Then
        DiscardPacket(RouteReq(N_S, N_T))
    else
        AddVehicle(N_i, Route_Table)
        RReq(N_S, N_T)
    end if
end if

the source vehicle. If vehicle N_i is the destination vehicle, then it sends the route reply to the sender, or else it checks whether N_i exists in the routing table or is not a member of the MCDSV and then it discards the packet. Otherwise, it updates the routing table of vehicle N_i and sends a route request packet from vehicle N_i. This technique avoids unnecessary overhead packets in the network. Hence, it eliminates the broadcast storm in the dense network.

5. Simulations and results

NS2 is used as a tool for network simulation [22]. Simulation of Urban Mobility (SUMO) [23] and Mobility Model Generator for Vehicular Networks (MOVE) [24] are used as simulation tools for mobility simulation of the vehicles in an urban environment. Traces of vehicle movements are simulated in SUMO and are exported as NS2 TCL commands using a TraceExporter tool, which is available in SUMO as a JAR file.

5.1. Simulation scenario

A scenario of grid topology of 1000 $\times$ 800 m^2 with a block size of 200 $\times$ 200 m and mobility patterns has been generated using MOVE and SUMO tools. This scenario contains five horizontal roads, four vertical roads, and twenty intersections. Vehicles move inside the grid of horizontal and vertical streets on the map. Each line represents a double lane road. A file transfer protocol (FTP) has been attached to each source. Each simulation takes 200 s and different scenarios are generated by varying the source and destination vehicles. An average of these values is used to plot the graph. Network density is varied by increasing the number on vehicles placed in a fixed terrain size of 1000 $\times$ 800 m^2 from 50 to 250 vehicles to assess the performance of these routing protocols. Two different average speeds have been used for the vehicles. The range of transmission for all vehicles is assumed to be fixed at 250 m.

5.2. Results

The proposed routing protocol has been simulated using NS2 and its performance has been compared with other protocols like AODV, DSDV, DSR, and AOMDV. Every vehicle in the VANET is configured with a wireless interface operating at a speed of 2 Mbps. The proposed routing protocol ERP is evaluated and compared with existing protocols using packet delivery ratio (PDR), average end-to-end delay, and control overhead ratio (COR) metrics. The effectiveness of the proposed protocol is demonstrated by running the simulation 10 times. The mean values of PDR, COR, and average end-to-end delay are considered for its performance evaluation.

Figures 3 and 4 show the PDR evaluated for different protocols by increasing the number of vehicles (vehicular density) with two different average speeds of vehicles. The performance of the PDR of ERP is higher than that of the other routing protocols. From Figures 3 and 4 it is observed that the PDR is more or less the same with the increase in the average speed of vehicles and is not dropping much in the proposed ERP routing protocol. The other protocols show drops in PDR when the average speed of the vehicles increases from 30 km/h to 50 km/h, and this shows that the proposed ERP routing protocol is not affected by the speed factor.

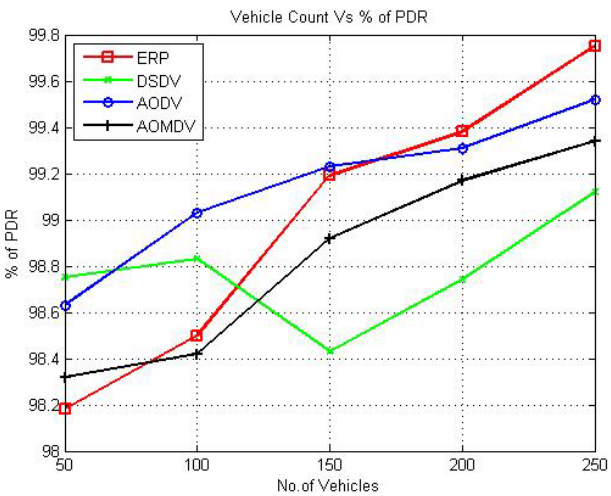

Figure 3. Effect of vehicle count on PDR with 30 km/h average speed.

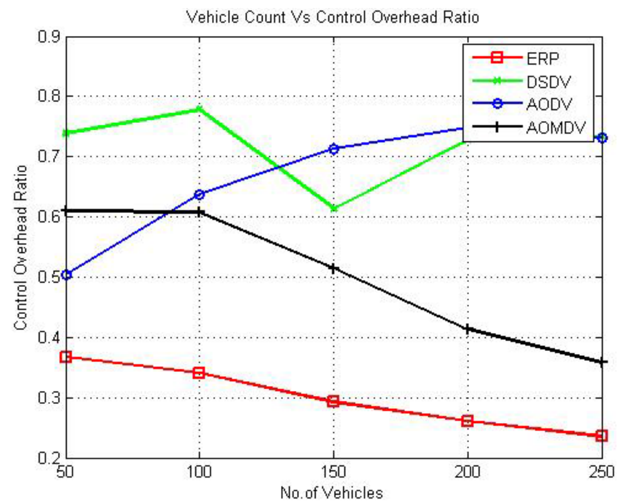

Figure 4. Effect of vehicle count on PDR with 50 km/h average speed.

Figures 5 and 6 show the effect of the number of vehicles on the COR at two different average speeds. Routing protocols like AODV, DSDV, and DSR are using route request and route reply again when there is a break in the routing path. The proposed ERP protocol has a smaller COR compared to other routing protocols as flooding of packets for route discovery is controlled by using the MCDSV as a virtual backbone. In the ERP routing protocol, there is a 20% to 30% decrease in COR in dense vehicular networks.

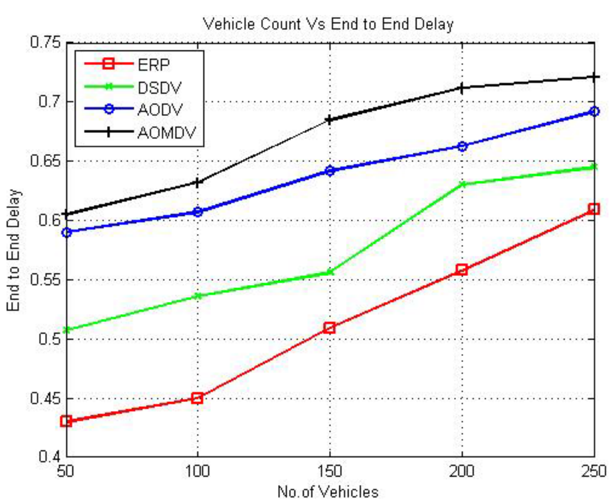

Figure 5. Effect of vehicle count on COR with 30 km/h average speed.

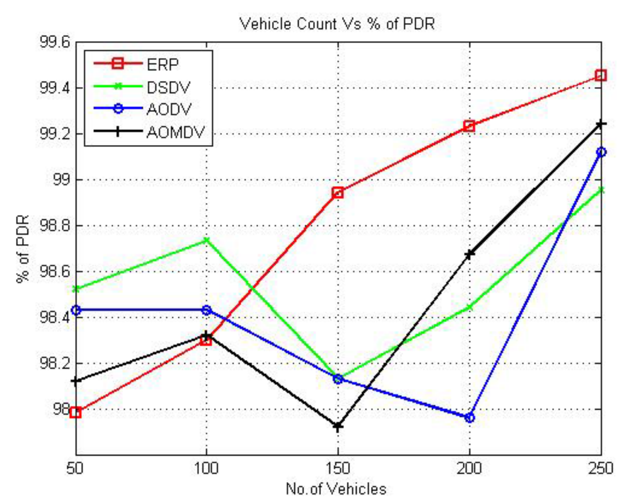

Figure 6. Effect of vehicle count on COR with 50 km/h average speed.

Figures 7 and 8 show the effect of the number of vehicles on end-to-end delay at two different average speeds. Among the four protocols, ERP achieves the best average end-to-end delay performance compared to other routing protocols due to a better utilization of network bandwidth by avoiding unnecessary control overhead packets. Among the protocols mentioned above, AOMDV gives the best performance when the number of vehicles is between 100 and 150 due to maintaining multiple paths from source destinations. Even so, the proposed ERP routing protocol outperforms AOMDV when vehicle count further increases to 200 and above. Hence, the results of the proposed ERP routing protocol increase the PDR and decrease the COR and average end-to-end delay, showing that ERP is an efficient reactive routing protocol for unicast routing in urban scenarios.

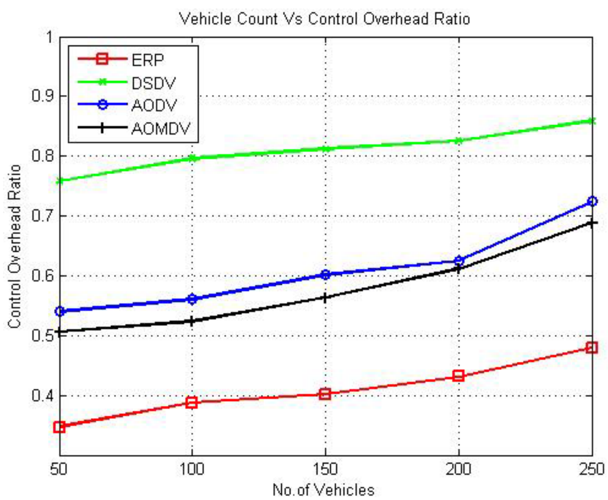

Figure 7. Effect of vehicle count on end-to-end delay with 30 km/h average speed.

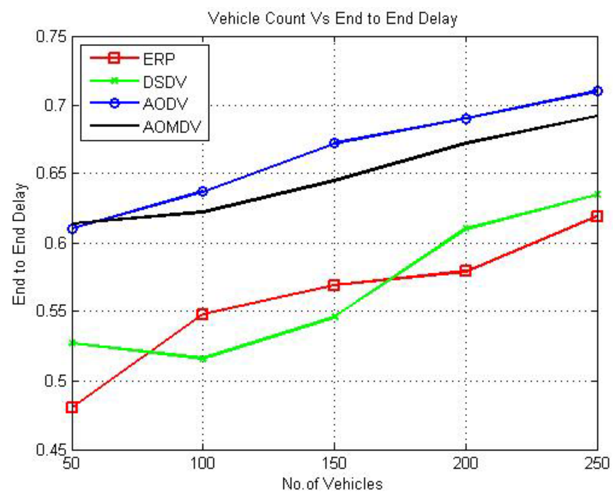

Figure 8. Effect of vehicle count on end-to-end delay with 50 km.

6. Conclusion

A new unicast routing protocol ERP for VANETs is presented in this paper. This protocol is based on finding a route from source to destination using the MCDSV as a virtual backbone. This type of communication within the network eliminates the broadcast storm by avoiding unnecessary local broadcast of packets by nonmembers of the MCDSV in the network. The performance of this routing algorithm has been compared to other unicast routing protocols like AODV, DSR, DSDV, and AOMDV in a highly dynamic environment through simulations. Simulation results show that ERP provides about 10% improvement in PDR and 20% to 30% decrease in average end-to-end delay and COR compared to other routing protocols. The results indicate that ERP is an efficient unicast routing protocol for VANETs. A future direction of this paper is to test this protocol in rural areas and assess its performance with other routing protocols.

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