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Adaptive V2V routing with RSUs and Gateway support to Enhance Network Performance in VANET

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Abstract— In a VANET communication, link stability can neither be guaranteed nor make the established route link permanent due to the dynamic nature of the network. In V2V communication without the involvement of any infrastructural units like RSU access points or gateway, the probability of successful link establishment decreases when vehicle's speed varies, red traffic light increases, cross-road increases and finally when the density of the running vehicles is sparse. To ensure route establishment and control route request broadcast in a sparse VANET with cross-road layout, RSUs are used in this paper for route discovery within one gateway zone when a next hop vehicle to relay the route request packet is unavailable. RSUs are static but the vehicles are dynamic in nature, so relying completely on RSU for forwarding data is not recommended because chances of link failure, link re-establishment, and handoff overhead will be high. So, in this paper, RSUs and Gateways are evoked for route discovery and data forwarding only when necessary. Moreover, a local route repair is attempted in this paper when the path length is high to reduce or avoid loss of buffered packets along the route and to maintain a more stable link with the help of RSUs.

Keywords—VANET, RSU, Gateway, Ad Hoc Networks, Local Link Repair.

1. Introduction

In building and integrating a smart traffic management system and incorporate each vehicle to become a part of the Internet of Things (IoT) entity, Vehicle Ad Hoc Network (VANET) is a vital component. In a dynamic multi-hop wireless network environment where vehicles can stop, speed up, slow down, take different turns and may collide, the density of the vehicles along any road or highways can vary depending on the time, situation, surrounding events and environmental factors like rain, snow, cyclone, accident etc. In such environment, setting up a stable end-to-end link is a challenge because the state of the network may change dynamically over time. So, a topology based reactive routing protocol like AODV [1] suits well in such dynamic network settings [2]. However, route undiscoverable situation in V2V is not uncommon especially when vehicle density is too low, and the destination is too far away because the probability of missing next hop link increases because of the dynamic nature of the vehicles in

VANET and the physical structure of roads and highways (straight, cross-road, curve etc.). Since the hop count of a path is inversely proportional to the end-to-end throughput [3] in a Multi-hop Ad-Hoc network, the route with the least possible hop should be considered. In a V2V communication, to collect local information of the passing vehicles and to distribute information, Road Side Units (RSU) is installed and their mobility is restricted in general.

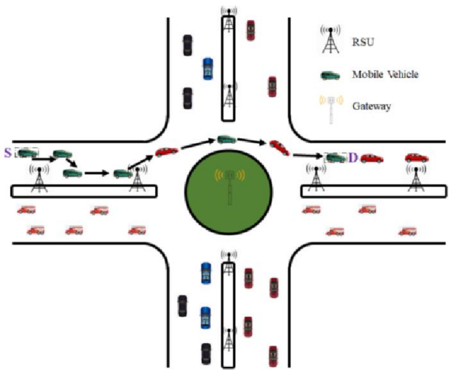

Figure 1: V2V communication in a high dense VANET.

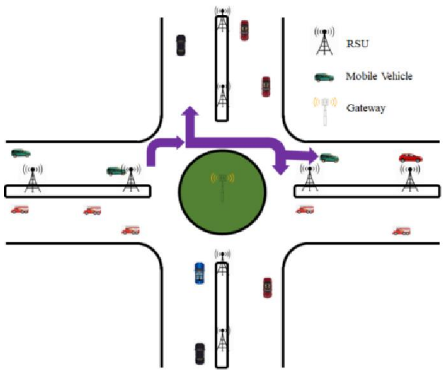

Figure 2: V2V communication in a low dense VANET.

Some may argue that without RSU, information collection and distribution from and to the vehicles can be executed directly using internet; however, in a bandwidth hungry world with limited wireless network resources, RSUs and Gateways play a crucial role in collecting and disseminating information from and to the vehicles by targeting only the region of interest. RSUs can help in ensuring safety and security by monitoring speed limits and vehicles activity, provide traffic condition information, report accident or road blockade etc. all in real time with least possible delays and without interrupting internet bandwidth. In fact, RSUs offload the internet bandwidth and make the V2V communication viable by optimizing the utilization of limited wireless bandwidth. Activities of road or highway can be relayed to the gateway through RSUs to propagate and distribute information via Wide Area Network (WAN) or internet to enhance connectivity with the rest of the region or globally if necessary.

In a multi-hop VANET communication as shown in Figure 1, if the vehicle density is high and the distribution is uniform then a communication link is stable. However, if vehicle distribution density is low and if one of the potential relay vehicles accelerate or slows down or take a turn in the ring road as shown in Figure 2, the link stability between the source and destination decreases. In order to ensure a more stable link, this paper proposed a routing mechanism which uses the support of RSUs in absence of next hop relay vehicle and conducts a local link repair if the link is broken closer to the destination to reduce route discovery overhead and overall data loss. However, the limitation of the model is the use of RSUs for routing in absence of vehicle to relay.

The remainder of the paper is organized as follows. Related work is presented in section 2 and assumptions are listed in section 3. In section 4, an adaptive routing is proposed. It is followed by simulation results and discussion in section 5; and finally, conclusion and future directions are highlighted in Section 6.

2. Relevant Background Study

The RSUs are static and available always, so various authors take an advantage of the presence of RSUs and use in discovering path between a source and a destination. However, it should be clear when to use and when to avoid RSUs for packet forwarding otherwise RSUs purpose will be redefined and the V2I or I2V or I2I bandwidth usage will be overloaded. The authors of [4] use RSU backbone to route packets to in VANETs by using geographic forwarding. However, the authors depend on the RSU backbone network to relay packets to distant locations. It was investigated in [5] that even with a small number of RSUs, the probability of network connectivity, delay and the message penetration time are significantly improved in VANET. In general, RSU are place for information dissemination, so it is vital to understand the number of RSU requirement and placement for better connectivity as analyzed in [6]. Moreover, the connectivity of VANET is not determined only by RSU, but rather there are other factors like vehicle density, distribution, traffic lights, vehicles speed and communication range in governing the connectivity in VANET [7]. The authors of [8] investigate the Network dwell time (Time Before Handover and Exit Time) by considering the overlapping RSUs transmission ranges, to help in predicting the handover time and make a successful proactive handover to maintain a better connectivity. In order to increase network performance, a hybrid (vehicle-to-vehicle and vehicle-to-RSU) communications scheme is designed in [9] where two nodes can communicate only when they have consensus about a common idle channel and next hop node has the minimum message delivery time. However, in an ever-changing dynamic network due to high mobility maintaining accuracy about minimum message delivery time to relay within its neighborhood will be a challenge. The path from source to destination is made by using road id's and Gateway nodes assist in locating the destination and forward packets from one segment of a road to other [10]. In order to ensure limited delay, bound packet forwarding, RSUs are used by placing minimal number of RSUs in the system at the right spots [11]. Many authors used RSUs to forward packets, however in this paper RSUs will be invoked if and only if the next hop vehicle is not within its transmission range and conduct local route repair if necessary to reduce packet loss when link is broken.

3. Assumptions

In implementing and testing to validate the proposed routing mechanism, using network simulator NS2, there are some assumptions considered about the test environment. As described by the authors of [12], this work also follows a simple wireless communication model with a perfect radio propagation channel as used in academic practice with the following assumptions:

i. The surface of communication is flat.
ii. A radio’s transmission area is circular.
iii. If node A can hear node B, then node B can also hear node A (symmetry) when nodes don't move and use same transmission power.

iv. If node A can hear node B at all, node A can hear node B perfectly.
v. Signal strength is a function of distance.

Other assumptions include, vehicles travel with the same average speed at all time and the RSUs are functional at all time and a local gateway is installed in every ring-road as sown in Figure 3.

4. Proposed Adaptive Routing

The proposed routing protocol is called an adaptive V2V routing with RSUs and Gateway support (AV2VR) where the RSUs are invoked for routing only when one or more vehicles connecting the source and destination are missing or if the link is broken due to acceleration or slow down or due to changing direction in cross road. It is a reactive routing protocol like AODV. The proposed mechanism is to ensure connectivity in a sparse V2V network either in highways or in city traffic as shown in Figure 5. In order to maintain efficient network traffic management, information distribution, and storage, a local gateway can be assigned for each zone or for multiple zones depending on the area size and traffic condition of a highway or city traffic as shown in Figure 3. In this paper, the study covers the aspect when a next hop vehicle in V2V communication between source and destination is mission; it also covers the aspect when a link is broken around the destination so that a local link repair could be conducted. However, the study does not cover the aspect when the destination is not within the same zone as the source. Nodes are considered to be within the same zone when they all lie within a same local gateway as shown in Figure 5.

In a V2V communication, RSUs are generally used to disseminate or collect information from or to the vehicles; however, in this proposed routing mechanism RSUs are used to define additional responsibilities as highlighted below:

- Firstly, it records the identity of all the vehicles passing within its vicinity along with its speed, so that RSU can keep track of the destination and either stop rebroadcasting of route request ($\boldsymbol{R_{req}}$) or forward as deemed necessary to reduce route discovery overheard. If the destination is not recorded in RSU then the $\boldsymbol{R_{req}}$ is forwarded only to the RSUs or local Gateway by using a unique ID tag of RSUs or Gateway to increase the chances of discovering the destination as shown in the flowchart of Figure 4. A route reply ($\boldsymbol{R_{reply}}$) is initiated only when a destination is discoverable within a zone via V2V or via RSUs or mixture of V2V and RSUs. Moreover, in this study, if the Gateway could not locate the destination within the surrounding RSUs of a ring-road, the $\boldsymbol{R_{req}}$ is not forwarded to other gateways of other zones.

- Secondly, RSUs are invoked and involved in route discovery when next hop vehicle to forward the route request are unavailable or link is broken due to missing of possible relay vehicle because of acceleration or slow down or changing movement direction or halt due to accident.

Another contribution of this paper is that when link failure occurs due to broken link or vehicle acceleration or slow down or changing direction, link repair is initiated from a point where link failure occurs and local link repair is performed *if and only if* Ɽ ≥ 5 and ꜰ ≥ 3 in this study, where Ɽ is the path length of the route and ꜰ is the number of hops up to the point of failure from the source and Ɽ= ꜰ + Δ, where Δ is the number of hops from the point of failure to the destination. It means that link repair is conducted only for high path length and when a link failure point is closer to the destination compared to the source's hop count. The reason is that if the link failure occurs closer to source, it's better to re-initiate the route discovery since number of buffered packets along the route will be less compared to a high hop path length where buffered packets along the route is high and if new route is established from the source then all the old buffered packets along the earlier route will be lost and local repair can also avoid a fresh generation of heavy flooding route request initiating from the source.

In a real V2V network scenario, unavailability of next hop vehicle is highly likely because it is not realistic to always assume that there will be a continuous presence of vehicles along a highway or any city road. Thus, during a route discovery RSU are involved in forwarding the route request packets *if and only if* a next hop possible relay vehicle is missing. Thus, the approach is a hybrid of V2V, V2I, I2V, and I2I for effective route establishment in a very dynamic and a sparse VANET. In the process, the IDs of the vehicles, RSUs, and local Gateways are given different tags to associate, represent and uniquely identify their own category during route discovery and route reply process. The local Gateway keep track of all the RSUs associated within a zone.

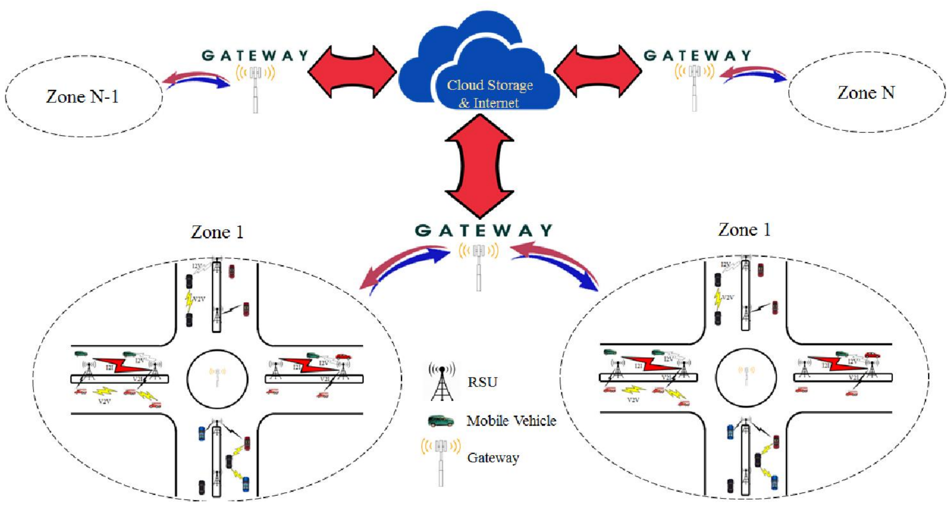

Figure 3: An Architecture of VANET with Infrastructural RSU and Communication Backbone setup.

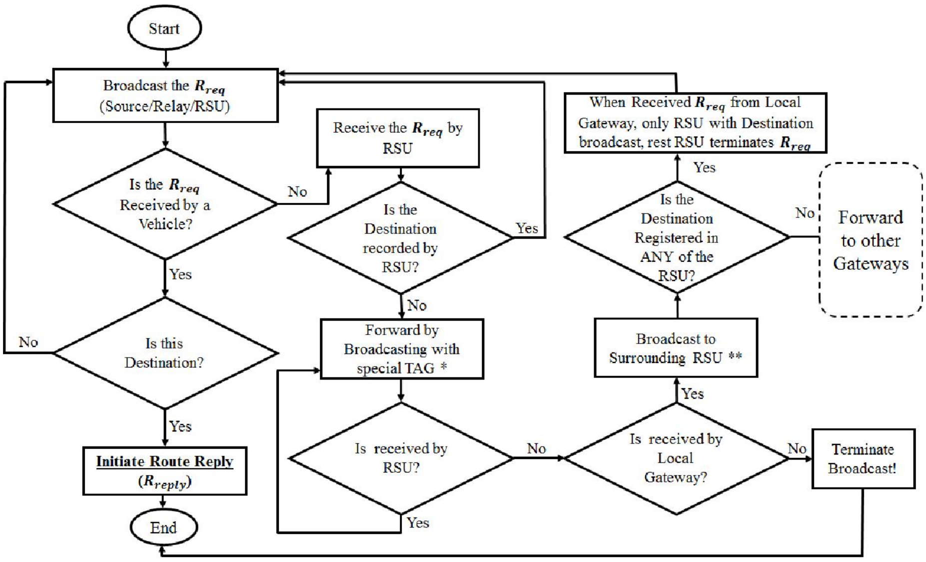

Figure 4: Flow Chart of Route Request in presence of V2V, V2I, I2I, and I2V.

In an event of missing next hop vehicle in V2V communication, during the route request initiation, the route request packets are not forwarded throughout the network in this study, rather the relay or forwarding of the route request packets are restricted by the record in RSUs or local Gateway. If the RSU does not hold the record of a destination, then the route request is forwarded via the neighboring RSUs or the local Gateway. When the RSUs could not locate the destination and the local Gateway of a zone could not get respond from surrounding RSUs of the ring-road then the forwarding of route request is terminated to reduce unnecessary flooding of route request broadcast activity. When one of the RSUs respond to the local Gateway about the destinations, the rest of the other RSUs in the ring-road terminates the route request broadcast. If the search of destination is to be expanded beyond the zone, then the route request is forwarded to gateways of other zones (this aspect is however not covered in this study as mentioned earlier). The route reply steps are like that of a reactive AODV routing protocol, however, the destination initiate route reply through V2V link if the route exists, otherwise, a route with a combination of V2V and RSUs (V2I, I2V, and I2I) are considered as shown in Figure 5.

Thus, RSUs, local Gateway and the next hop vehicles are used in discovering route and if a route is discovered through V2V then the route discovered via RSUs are ignored, because when a route is established via moving vehicles, the chances of link stability is higher compared to route discovered via RSUs which are static in nature. However, when vehicles don’t move in same direction or have a broken link due to acceleration or slow down then RSU can help in providing a better connectivity especially when vehicle density is sparse, and which is the motivation of this paper. So, the RSUs are considered only when a next hop vehicle is missing or not available to forward or relay packets. Relying completely on RSU for packet forwarding is not practical because vehicles are always in motion while the RSUs are static in general. So, the paper uses RSU only when a route via V2V is not discoverable. The detail algorithm in the form of a flowchart for route request model is depicted in Figure 4. Thus, if a V2V communication cannot discover a route due to unavailability of a next hop vehicle to relay then the proposed routing mechanism AV2VR is triggered to increase the probability of route discovery using RSUs and local Gateway of a zone.

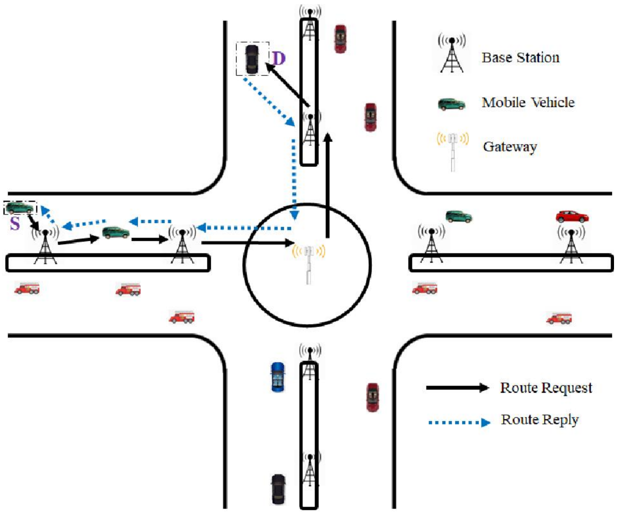

Figure 5: Link support via RSU in a sparse VANET communication.

In order to avoid frequent re-routing or re-discover of route due to vehicle's speed, direction, density and limited transmission range of the vehicles, the transmission range of the RSUs can be made much higher to maintain longer link stability and provide better scope of handoff since RSUs are stationary in nature. However, in this paper, the transmission power of all the vehicles and RSUs are made equal to 250m.

5. Network Settings, Results, and Discussion

To analyze the performance of the proposed routing protocol a network topology of Figure 5 is considered, where vehicles are sparsely spaced and tested with an average speed of 20m/s and 40m/s. The simulation is conducted using NS2 with CBR traffic and each round of simulation is conducted for 100 seconds each. The distance between the moving vehicles and the consecutive RSUs are 200m apart. The distance between the local Gateway and RSUs of a ring-road of a given zone is also considered as 200m. The path length between the source and the destination is separated by at least six hops and the data packet size is a constant 1000 bytes. Moreover, after the selected destination is traveled for 1km, it turns left in a roundabout and proceeds with the same initial speed while the source and rest of the vehicles continue traveling on the same straight road. For a RSU with a transmission range of 250m, a vehicle with a speed of 20m/s will take 25 second to cover from one end to the other i.e. 500m [$Time = Distance/Speed$]. Since the transmission range is fixed, the duration of link stability will also depend on the speed of vehicle, quickness of seamless handoff and duration of local link repair. The proposed AV2VR is compared with a local link repair AODV based routing protocol [13]. The network parameters used in the simulation is listed in detail in Table 1.

Parameter	Value/protocol used
Grid Size	10,000 m^2
Routing Protocol	LL repair AODV/AV2VR
MAC	IEEE 802.11b
Queue Type	DropTail
Queue Size	100
Bandwidth	11Mb/s
SIFS	10μs
DIFS	50μs
Length of Slot	20μs
Default Power (*Pt*)	24.49 dBm
Default *RXThresh*	-64.37dBm
Default *CSThresh*	-78.07dBm
CPThresh	10.0
Max_{Retry}	7
Simulation Time	100s
Traffic Type	CBR
Frame size	1000 bytes
Speed	20m/s and 40m/s

Table 1: Network Simulation Setup Parameters.

As shown in Figure 6, the end-to-end network performance increases as the offered load increases, however, the network gets saturated above 750kb/s offered load. The saturation point will be different depending on the path length of the route since the throughput is inversely proportional to the hop. The local link repair AODV yield comparatively low throughput because once the link is broken and if the link repair cannot be completed the source may continue to send packet up to the point where the link is broken with a hope of repairing the broken link. However, in a sparse network environment where there is no next hop vehicle to forward or relay then the packets will never get delivered to the destination. Unlike LL Repair AODV, the proposed AV2VR uses the nearest RSUs in absence of the next hop vehicle to forward and relay packets when link is broken by establishing a route via the available RSUs to deliver the packets to the destination vehicle. When the offered load is 1000kb/s, the end-to-end throughput is approximately 1.6 times the performance of LL Repair AODV. Even if the vehicles are moving and destination is moving on different direction as shown in network topology of Figure 5, the overall network performance is increased despite the increased in the path length because of forwarding the packets via RSUs in absence of next hop relay vehicle in V2V communication.

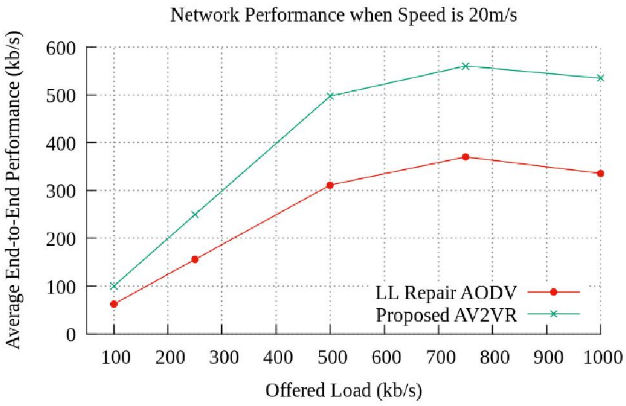

Figure 6: Network Performance when the average speed of the vehicles is normal i.e. 20m/s.

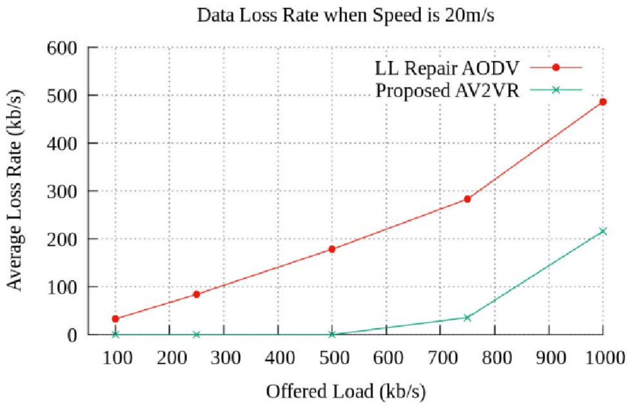

Figure 7: Average loss rate along the route when the average speed of the vehicles is normal i.e. 20m/s.

In a distributed data communication of wireless networks, loss of data is mainly due to buffer overflow, data collision, exceeding the data retransmission limit and total link failure leading to loss of buffered packets. The loss rate is depicted in Figure 7 when the average speed of the vehicles is 20m/s. Here in this study, the loss is focused on the buffer overflow and loss due to link failure. In LL repair AODV based routing the loss is evident from low offered load of 100kb/s to a high network offered load of 1000kb/s as shown in Figure 7. When the offered load is high i.e. 1000kb/s, the loss is as high as nearly 50% of the offered load. In this network setup, with a speed of 20m/s, the destination vehicle turns to left direction of a ring road at the 50th second i.e. after traveling 1km from its initial position. It means that shortly after the half of the simulation time, the destination vehicle breaks the link. Once the link is broken by the destination vehicle because of moving in different direction and due to sparse vehicle density, it becomes impossible to re-establish a route in LL repair AODV. So, packets keep forwarded from the source vehicle hoping to eventually repair the broken link, but it never happened, rather the buffer gets overflowed and packets get dropped eventually, leading high loss rate as the offered load increases. Unlike LL repair AODV protocol, in the proposed mechanism AV2VR, when a link is broken, it conducts a local link repair by using the nearest RSU to relay the packets and eventually forward to the destination. When the offered load is up to 500kb/s there is hardly any loss of packets because the rate of forwarding was faster than the packet buffering rate. When the offered load is high i.e. 1000 kb/s, the loss due to buffer overflow is only approximately 20% in the proposed AV2VR routing mechanism, but the loss in LL repair AODV is as high as approximately 50% because LL repair AODV could not conduct local link repair because of lack of next hop relay vehicle in a sparse vehicle density. Thus, the approach of using nearby RSU to route packets in absence of next hop relay vehicle is proven to be effective.

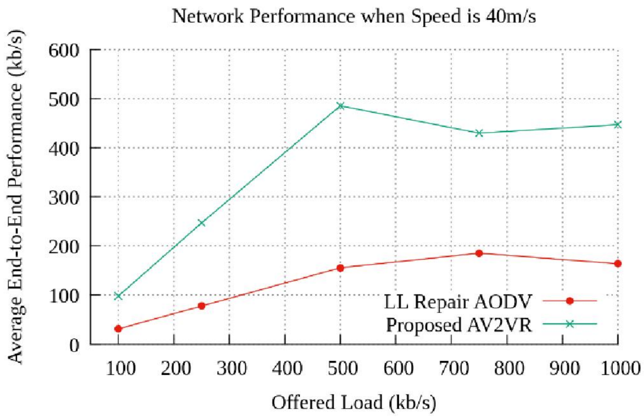

Figure 8: Network Performance when the average speed of the vehicles is high i.e. 40m/s.

As shown in Figure 8, when the speed of the vehicles is increased to high speed i.e. 40m/s which is 144km/hr., the end-to-end throughput drops heavily in LL repair AODV and performs under 200kb/s irrespectively of the offered load. This is mainly because the link breakage point reaches faster as the speed increases. In this network setting, the destination vehicle reaches the crossroad at the 25^{th} second before taking a turn and move in different direction and breaks the link and due to the absence of potential relay neighborhood vehicle, the local link repair could not be conducted in LL repair AODV. Due to early link breakage and inability to recover the link state, the end-to-end performance sinks as the speed of the vehicle increases. However, in the proposed AV2VR routing mechanism, in absence of next hop relay vehicle in a sparse vehicle density, a neighbor RSU is discovered to relay packets to the destination. Thus, a high end-to-end throughput is achieved without much loss. As the offered load increases beyond 500kb/s the throughput saturates between 400kb/s to 500kb/s for AV2VR. The performance of AV2VR routing provides much higher throughput compared to LL repair AODV and achieve a throughput of 3 times more with any given load.

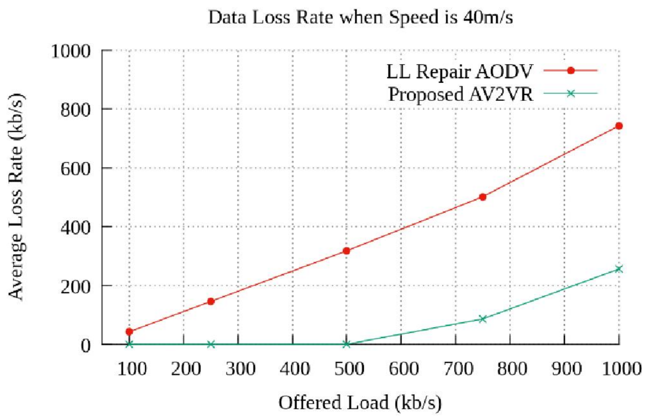

Figure 9: Average loss rate along the route when the average speed of the vehicles is high i.e. 40m/s.

When the link breakage occurs faster and local link repair could not be conducted due to lack of relay vehicle then it is expected to have a lesser end-to-end throughput and a higher loss rate as shown in Figure 9. The loss of packets along the route in LL repair AODV is much higher compared to that of the proposed AV2VR routing mechanism, because in AV2VR protocol, as soon as a link breakage occurs, a link repair steps is carried out by considering the RSU as a next hop relay entity in absence of a next hop forward vehicle. In this network setting, the path length is initially at least 6 hops and it increases as the destination moves away in different direction, and the vehicles are moving at a higher speed of 40m/s, so the loss rate is above 742kb/s when the offered load is 1000kb/s in case of LL repair AODV, while with the proposed AV2VR, loss rate is only 256kb/s. In case of AV2VR routing, there is no buffer overflow loss until the offered load crosses 500kb/s and when the offered load is 750kb/s, the loss rate stands only at 87kb/s while LL repair AODV loss rate stands above 500kb/s. It is also observed that the loss rate of the proposed AV2VR routing mechanism is low irrespective of the speed of the vehicles because of successful link repair which is conducted with the help of the RSUs in absence of the next hop relay vehicle unlike LL repair AODV which could not conduct local link repair in absence of the relay vehicle. When a local link repair could not be conducted and a new route is established then all the earlier buffered packets along the older routes are dropped, so local link repair is a must when path length has high hop, which is the reason why a local link repair is conducted in AV2VR if the route path length Ɽ ≥ 5.

6. Conclusion and Future Direction

The proposed AV2VR routing mechanism which uses the support of RSUs in absence of next hop relay vehicles in a sparse VANET ensures a much higher end-to-end throughput with less packet loss rate irrespective of the offered load or the speed of the vehicles. It is also observed that if a local link repair could not be performed as seen in

LL repair AODV, sources should be informed about the indiscoverable or unrecoverable link state otherwise the loss rate increases, and end-to-end throughput decreases because source forward packets with a hope that link can be recovered locally, but it never happens in absence of relay neighborhood.

This work is an initial study to reduce the broadcast route request and increase the link stability in absence of next hop relay vehicle with the help of RSUs and conduct local link recovery if link failure occurs. Future work will cover discovery of an unrecorded destination within a zone and conduct a well-informed smart routing with least possible route discovery overhead. The future work will also cover the optimization of path length, RSU installation and explore its corresponding theoretical analysis aspect. The extended work will cover an estimation of energy consumption and cover the detail analysis with different data traffic model, different data rates, different network density and build an average requirement of RSUs based on transmission ranges and established a relationship between RSUs requirement and vehicle density. In future, when a local route repair fails then the buffered packets will be redirected to reduce or avoid any possible loss and inform the source to reduce the overall loss of packets and reduce unnecessary network contention leading to unprofitable network congestion.

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