Approaching P2P Communication in a Vehicular Ad Hoc Network

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Abstract— **This paper introduces P2P communication across a VANET and seeks to establish under what conditions (mobility, network size, wireless channel) data streaming is feasible. Routing of streamed services over multiple hops and multiple paths may result in significant packet losses, resulting in unacceptable quality of service. This paper examines the impact of differing traffic densities and different road layouts upon a P2P overlay network. The work modeled the emerging IEEE 802.11p for vehicular networks. It is shown that the mobility pattern of the vehicles involved needs to be closely modeled to determine signal reception patterns, as does the wireless channel environment, to avoid over optimistic assessment of communication within a VANET.**

Index Terms— **ad-hoc network, channel model, mobility model, P2P, vehicle-to-vehicle communication**

I. INTRODUCTION

VEHICULAR wireless networks (VANETSs) are spontaneous, infrastructure-less networks whose elements are mobile vehicles, cars or emergency response vehicles, traveling in city, urban and suburban road layouts. In a VANET, different vehicles federate themselves to provide end-to-end, 'on-the-fly' connectivity. Direct inter-vehicle communication can be an aid both to road safety and to passenger comfort (through roadside information and entertainment services) [1]. Compared to a cellular network, a VANET may be toll free, avoids the delay in setting up a long communication circuit, and on a highway will operate where there are coverage gaps in a cellular network. There are strong pressures pushing car manufacturers towards equipping cars with WLAN capability, if they have not already done so at the high end of the car market.

On the other hand, P2P networks are application-oriented overlays, which have already enabled a range of applications in the wired Internet such as file sharing and more recently P2P streaming. Several decentralized P2P streaming systems such as mesh-P2P streaming [2] have been deployed to provide live and on-demand streaming services on the Internet and the same ideas may be useful in providing real-time multimedia streaming in a VANET. Despite their differences, VANETs and P2P both enable multi-source distribution and multi-path delivery, as is also the case for mobile ad hoc networks [3]. This paper's contribution is to investigate P2P streaming across a VANET and seek to establish under what circumstances (mobility, network size, wireless channel) communication is challenged by the level of packet losses. Compared to streaming over general ad hoc networks [4], VANETs have several advantages. Battery power is no longer a problem, implying that larger buffers (with passive and active energy consumption) can serve to absorb streaming latency arising from multi-hop routing. In addition, satellite navigation systems in cars already use GPS devices, which can also support location-aware routing.

The first contribution of this paper is to show that greater realism is needed in modeling road layouts and driver behavior. Some mobility models such as BonnMotion only incorporate an ideal model of road layouts and as a result do not account for bottlenecks such as traffic signals at intersections and the presence of queuing. While this may be perfectly adequate for generic comparison, clustering of vehicles within wireless range will affect the ability to pass packets over a network link. The proximity of vehicles will be maintained for longer within queues or during traffic congestion, which will facilitate packet exchange. However, for contention-based medium access control there will be an increased risk of not being able to access the wireless medium, temporarily interrupting communication.

Interestingly, it has been shown [5] that behavior at bottlenecks in the presence of obstacles of whatever form is similar in a wide range of highways across the globe. Vehicular mobility can be split into macro-mobility effects such as road layout, number of lanes, and speed limits, and micro-mobility effects, especially driver behavior, which should account for the presence of other vehicles, both nearby and due to traffic congestion. This implies that the fixed speed simulations that are common in ad hoc network modeling are no longer applicable to VANETs, whereas vehicle density has a more important role to play.

An additional contribution of this paper is closer modeling of wireless channel conditions. General purpose VANET simulations have tended to restrict modeling of the wireless channel to either simple free space propagation, or two-ray path loss, but not account for wireless multi-path interference, as can occur especially in a built environment. In [6], it was shown that modeling of ad hoc routing protocols at higher layers of the protocol stack but neglecting physical layer modeling could give misleading rankings of the protocols. In [7], shortcomings of the ns2 simulator for ad hoc wireless modeling are also highlighted and various error models, appropriate for indoor environments, are considered.

To improve wireless channel modeling, we consider the effect of channels with Ricean and Rayleigh probability density functions characterization of multi-path interference or fading, in addition to the attenuation resulting from path loss. In a Ricean model, parameterized (K) by the number of potential reflected paths, there is one line-of-sight (LOS) signal and other interfering paths. In Rayleigh fading, there is no LOS component and, consequently, Rayleigh fading is usually taken to be a worst case scenario (if there is no frequency selective fading). However, it could be that in communication between vehicles on an urban road there will often be a LOS component, as the vehicles will be aligned along road segments. Simulations may also mislead if they take no account of packet length by simply thresholding the SNR level rather than determining the Bit Error Rate (BER). We consider the general effect of fading and path loss on the VANET but specialize to a Ricean channel (K = 3) with two-ray path loss, together with BER modeling.

The remainder of this paper is organized as follows. Section II details the way a P2P application is mapped onto an ad-hoc network and shows our test overlay network. Section III describes our simulation methodology and also considers mobility models for VANETs. The paper then presents in Section IV results of applying different mobility models and channel conditions. Finally, Section V draws some conclusions.

II. P2P OVER VANET

Both VANETs and P2P networks are decentralized, autonomous and highly dynamic in a similar way. In both cases, network nodes contribute to the overall system performance in an intermittent and unpredictably manner but nonetheless exhibit a high-level of resilience and availability. Fig. 1 illustrates a P2P application overlay over a VANET, in which an overlay network is placed over the network layer. The overlay node placement is logically different to that of the physical placement of the nodes.

In this paper, we have simulated a mesh-P2P-type architecture, as shown in Fig. 2. We have used seven nodes to form a mesh out of which two nodes are source nodes. Three nodes (peer C, peer D and peer E) join with these source nodes to retrieve the data streams. These three nodes then connect to two further nodes (peer F and peer G) to serve the data streams that they are to receive from peers A and B. Here, nodes C, D and E download and upload at the same time. The packetized data streams in Fig. 2 could represent multi-description coded video streams sent over different paths for protection against channel error [8]. However, the P2P packet scheduling algorithm and peer selection/querying mechanism is beyond this paper's scope and we assume that it has been achieved.

III. MODELING A VANET

A. Simulation settings

The Global Mobile System Simulator (GloMoSim) [9] simulation library was employed to generate our results.

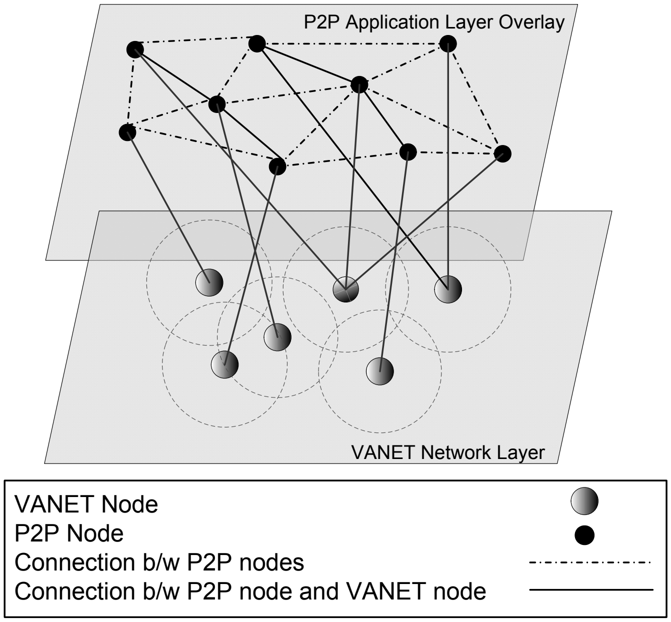


Figure 1. An example of a P2P application overlay over VANET, after [4].

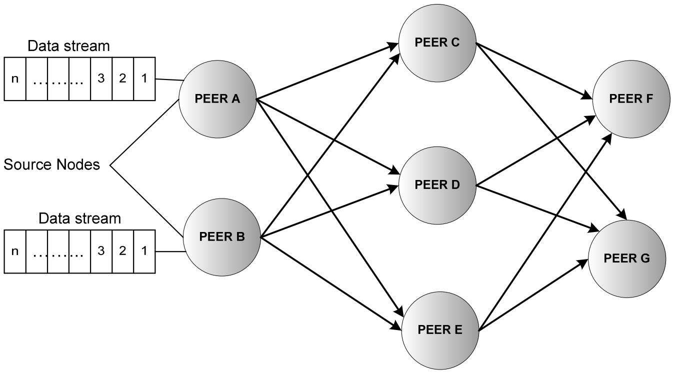


Figure 2. Mesh-based P2P topology sending data streams from sources to receivers

GloMoSim was developed based on a layered approach similar to the OSI seven-layer network architecture. IP framing was employed with UDP transport, as TCP transport can introduce unbounded delay, which is not suitable for delay-intolerant video streaming. Total simulation time was 900 s, after a period of 3600 s to settle down the simulator. There was one video source, while eight nodes acted as video receivers from a default number of 100 nodes in the simulation. GloMoSim has been altered so that nodes start at random locations rather than at the origin.

B. Default radio environment

As a default, a two-ray propagation model with an omni-directional antenna height of 1.5 m at receiver and transmitter was selected for which the reflection coefficient was -0.7, which is the same as that of an asphalt road surface. The plane earth path loss exponent was set to 4.0 (for an urban environment rather than 2.4 for a highway [10]), with the direct path exponent set for free space propagation (2.0). As in IEEE 802.11p transmission is at 5.9 GHz with a bandwidth of

10 MHz, the two-ray crossover distance is about 556.5 m. By default in IEEE 802.11p, the transmission power is 33 dBm (2W), which is assumed to be sufficient for safety messages though higher power is permitted to approaching emergency vehicles. The receiver default power threshold was set to -58.4 dBm, a normal value. The MAC was CSMA/CA with Request-to-Send/Clear-to-Send (RTS/CTS) turned on to reduce hidden and exposed nodes. As there was only one class of traffic, IEEE 802.11p's Enhanced Distributed Channel Access (EDCA) with priority queueing does not have an impact on the simulations. Lastly, IEEE 802.11p's most robust Binary Phase Shift Keying (BPSK) modulation mode was simulated, introducing a packet length dependency through BER modeling. Accordingly, the data-rate was set to 3 Mbps.

C. *Mobility modeling*

The performance of routing algorithms is long known to be dependent on mobility patterns. For example, for the well-known Random Waypoint model, the authors of [11] already observe that results were very sensitive to motion changes created by different pause times. In turn, the model of mobility will affect the delivery of video data. In [11], two idealized models relevant to vehicular mobility were described, namely Freeway Mobility and Manhattan Mobility. The Freeway model limits vehicles to 1-D motion in either direction. Nodes are tied to one of several lanes; the speed is dependent on a node's previous speed; and in the 'car-following' restriction, a following node cannot exceed the speed of a preceding node to avoid approaching within a safety distance. The Manhattan grid model, an extension of the Freeway model, restricts the number of lanes in either direction to just one, but introduces a turning probability to give greater mobility. Both Freeway and Manhattan are related in that they should result in high spatial and temporal dependency. However, though the grid layout is characteristic of many North American city centers in the authors' experience it differs from older cities with more irregular street layouts and from newer American cities without. Driver behavior in these models is also not closely modeled.

In VanetMobiSim [12], a variety of urban road layouts can be generated of increasing density by means of the random backbone mode using Voronoi tessellations. Maps extracted from the US Census Bureau's TIGER database may also be input, but this level of detail was inappropriate for the generic investigations conducted in this paper. User defined and geographic data files can also be input to the mobility modeler. In the simulations, a 1000×1000 m^2 area was defined and nodes (vehicles) were initially randomly placed within the area. Other settings to do with road cluster density, intersection density, lanes (2) and speeds are given in Table I. Though downtown, suburban and other defaults can be declared, in fact the main difference in the road layout types is the road density settings. The number of traffic lights (at intersections) and time interval between changes is also defined and will have an important effect on the simulation results. A weakness of VanetMobiSim is treatment of nodes when they reach the boundary of the simulated area, as currently they are simply reflected to maintain the node density within the area.

The real advantage of VanetMobiSim is the variety of driver behavior models. A summary of the mobility settings applied in the simulations is also given in Table 1. In all of the mobility models tested, random trips were generated, though VanetMobiSim has a trip generator facility. Again for the generic simulations in this paper, that facility is not required.

TABLE 1. VANET MOBISIM SETTINGS FOR ROAD LAYOUTS AND MOBILITY MODELS.

Global Parameters	
Simulation Time	900 s
Terrain Dimension	1000 x100 m^2
Graph type	Space graph (Downtown model)
Road Clusters	4
Intersection Density	2e^{-5}
Max. traffic lights	6
Time interval between traffic lights change	10000 ms
Number of Lanes	2
Min. Stay	10 s
Max. Stay	100 s
Nodes (vehicles)	50, 100
Min. Speed	3.2 m/s (7 mph)
Max. Speed	13.5 m/s (30 mph)
CSM model	
Min. and max. pause time	0 s
FTM Model	
Density of traffic jam	0.2 cars/m
Recalculation of traffic parameters time	0.1 s
IDM Model, IDM-IM Model, IDM-LC Model	
Length of vehicle	5 m
Max. acceleration	0.6 m/s^2
Normal deceleration	0.5 m/s^2
Traffic jam distance	2 m
Node's safe time headway	1.5 s
Recalculation of movement parameters time	0.1 s
Other Parameters of IDM-LC Model	
Safe deceleration	4 m/s^2
Politeness factor of drivers when changing lane	0.5
Threshold acceleration for lane change	0.2 m/s^2

The Constant Speed Motion (CSM), the simplest of these, does not produce realistic motions and is included for comparison with earlier results in other papers. In the Fluid Traffic Model (FTM), the nodes behavior is influenced by the traffic density. The Intelligent Driver Model (IDM) accords with car-following model developed elsewhere [5], based on live observations. VanetMobiSim adds to this with modeling of intersection management (IDM-IM). The IDM-IM is extended to include lane change behavior in the IDM-LC model. Therefore, the micro-mobility models presented by VanetMobiSim are of increased sophistication in driver behavior, which together with wireless channel increase the realism and reduce optimistic assessments of what can be achieved in a VANET. Unfortunately, when driver behavior is introduced into simulations it is no longer possible to easily examine node speed dependencies, as the vehicles will have a range of speeds depending on local conditions, though the minimum and maximum speeds are not exceeded.

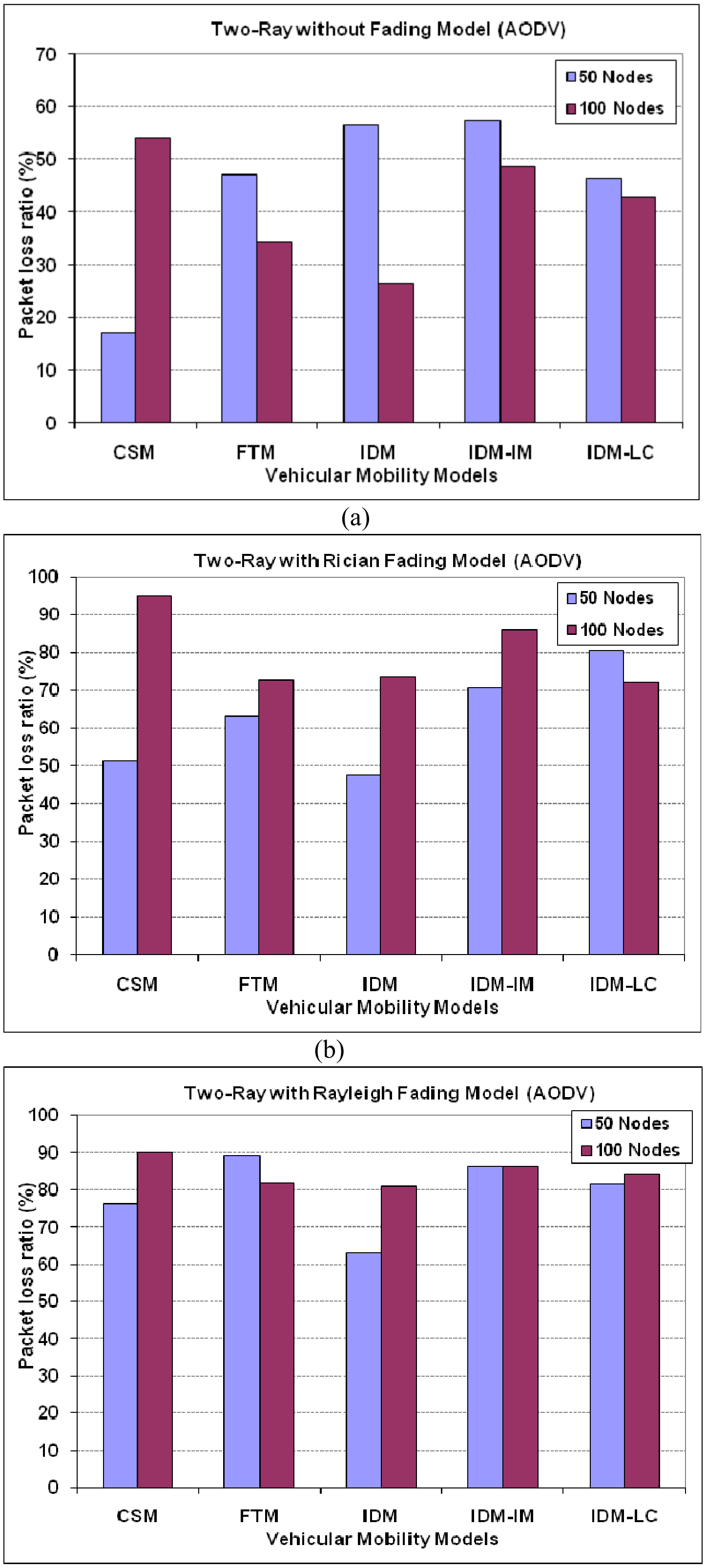
D. Routing protocols

The well-known Ad-hoc On-demand Distance Vector (AODV) was firstly selected as it does not transmit periodic routing messages, which can result for proactive, table-driven protocols in greater control overhead unless network traffic is high. In reactive protocols such as AODV, routes are discovered only when they are actually needed. AODV discovers routes in a hop-by-hop fashion rather than through source routing. Sequence numbers avoid routing loops. A disadvantage of a reactive protocol is the latency introduced by the route discovery process but in the context of a VANET this is less of a problem for one-way streaming than it would be in an unconstrained ad hoc network. The reason for this observation is that in a VANET buffering at the receiving vehicle can absorb delay whereas the energy consumption of large buffers on battery-powered devices is a problem. Variation of delay (jitter) is also catered for by a jitter buffering, with the main penalty of buffering in *one-way* streaming arising from start-up delay.

However, AODV's route discovery mechanism is unconstrained by geographic locality, whereas the Location Aware Routing (LAR) protocol [13] is able to restrict the area for route propagation by virtue of GPS information gathered from the nodes in the VANET. The advent of satellite navigation systems has indicated the benefits of GPS provision within vehicles and if WLAN is available, GPS will also most likely be present. The result is that LAR will incur less control packet overhead. The main weakness of LAR appears to be [14] increased latency in comparison with other reactive protocols but as this is less of an issue in a VANET we accordingly selected it for simulation.

IV. SIMULATIONS

In this Section, we average the results from destination nodes in the P2P overlay network, as described in Section II.. Of course, for packets to reach a destination node from the two sources nodes, those packets must be routed across multiple hops to pass through the intermediate nodes in the overlay to the destination. The other destination(s) will also receive packets at the same time. In Fig. 3, routing is under the



(a)

(b)

(c)

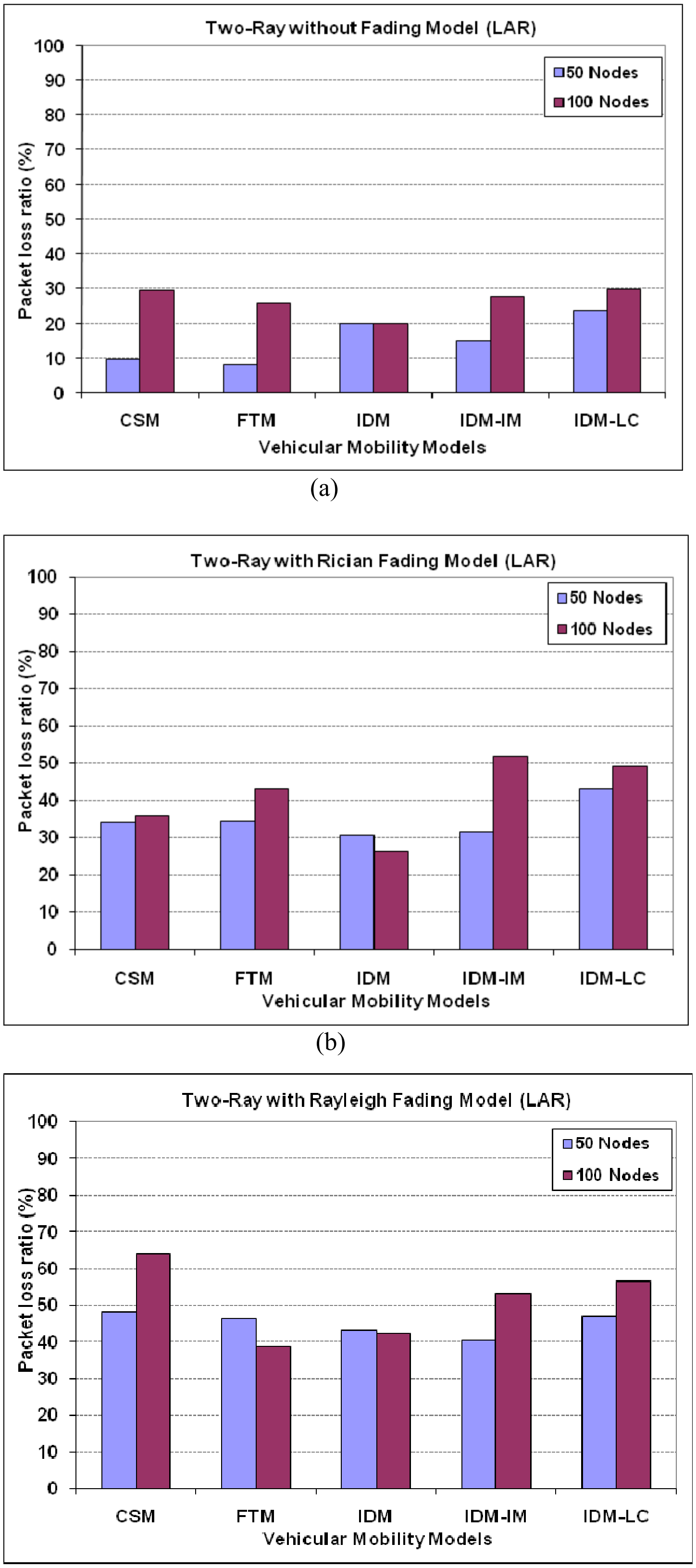
Figure 3. 625 m range: Packet loss ratio compared by mobility model for different network sizes for (a) no fading, (b) Ricean fading, (c) Rayleigh fading, with routing by the AODV protocol

AODV protocol with the range of mobility models outlined in Section III.B. However, the effective range is reduced to 625 m range, as the transmission power was set to 19.3 dBm rather than the default 33 dBm with a potential range of 1300 m. In most urban settings, the presence of buildings will impede transmission [15] through reflections, diffraction and absorption of signals and the reduced power level is a concession to that fact. In fact, IEEE 802.11p's range is significantly higher than prior varieties of 802.11 with ranges of up to 340 m reported [16] for an outdoor environment with a two-ray model of path loss.

However, from Fig. 3 it is apparent that packet loss ratios greatly exceed what is acceptable for communication and approach saturation under the worst case scenario of a Rayleigh fading model in Fig. 3c. (The packet loss ratio is the ratio of packets sent to packets declared lost on the transmission path.) Inspecting Fig. 3a, the packet loss ratios when driver behavior is modeled in all cases for network sizes of 50 nodes is higher than for simple CSM modeling. Whereas network size increases the packet loss ratio in the simple model, for FTM and IDM-type models, a larger network size results in more lost packets. However, when fading is introduced into the models, the situation is reversed: as a general trend there may be more packet losses when there are more nodes.

This is unexpected behavior in an ad hoc network, as often the presence of more nodes gives greater opportunities to exchange packets. However, the restrictions of the road layout apply to all mobility models in the sense that the presence of more nodes means that on average more hops need to be traversed if there are more nodes in the vicinity of a packet source. The number of hops has a strong influence on packet loss [17] as it increases the risk an intermediate node will move out of the range of the next hop destination. Including fading increases the risk that the signal level will be below that of the receiver's threshold. Therefore, whereas previously it was possible according to the mobility model for a packet to be received with fading, depending on the severity of the effect (Ricean or Rayleigh) the impact is accentuated. A number of factors are at play and simulations are best placed to show the way the factors interact as sometimes the effect is intuitively unexpected. A mathematical model would be difficult to construct for all but the simplest situations.

Fortunately, if the LAR protocol is substituted for AODV, Fig. 4, the results are significantly different, despite the restriction to 625 m maximum range. As indicated in Section III.C, location aware routing can have a dramatic effect because the route discovery process is restricted. In Fig. 4a, the loss levels would make even streaming of video acceptable as they are below 10% in some scenarios. In scenarios with 100 nodes, inclusion of error resilience or application-layer forward error correction could reduce the effective packet loss rate to the desired range below 10%. Fig. 4a shows the possibilities of P2P applications under good channel conditions. However, it is clear from Fig. 4b and 4c that even



(a)

(b)

(c)

Figure 4. 625 m range: Packet loss ratio compared by mobility model for different network sizes for (a) no fading, (b) Ricean fading, and (c) Rayleigh fading, with routing by the LAR protocol

with a superior routing protocol, if fading is present then packet loss rates are not acceptable for most applications.

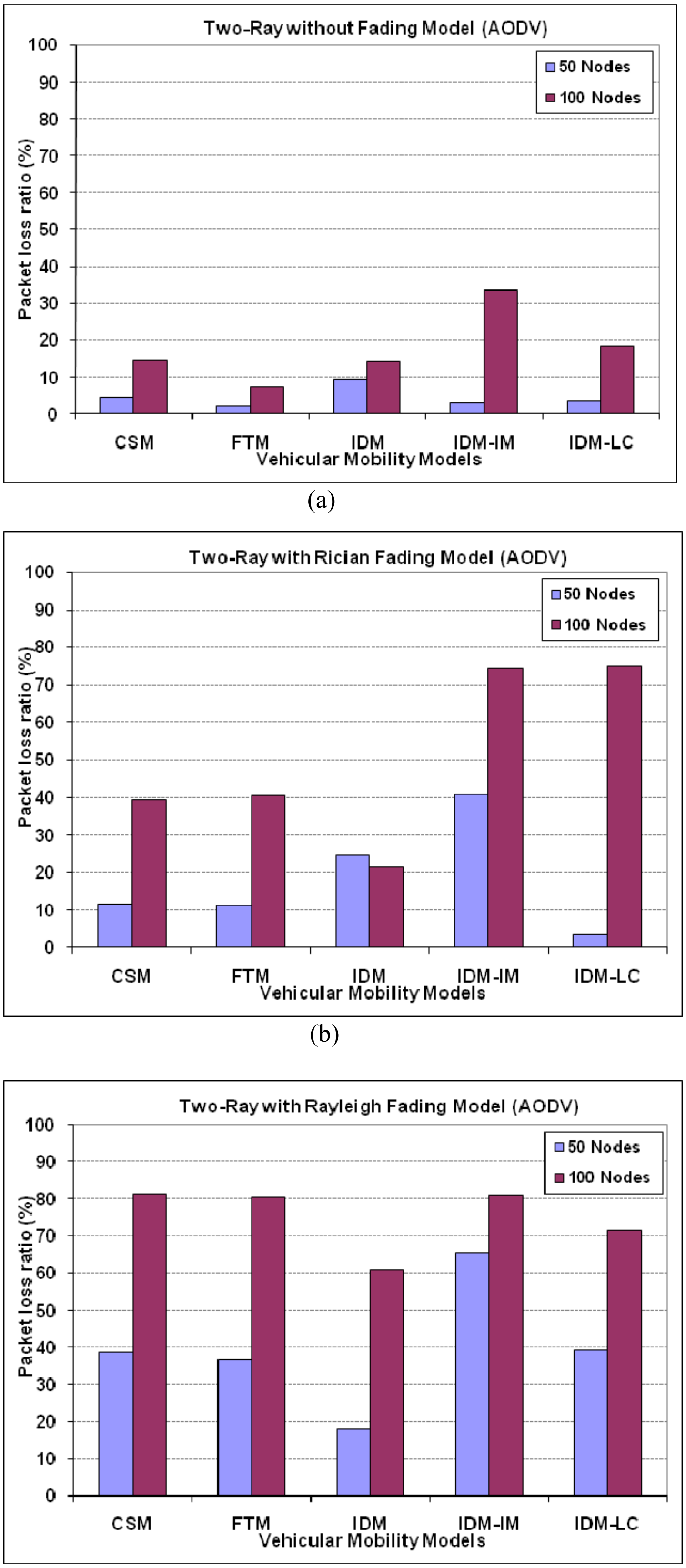
Rather than change of protocol, we also investigated the effect of increasing the range to 800 m, by increasing the transmitter power to 23.6 dBm. In Fig. 5, it will be apparent that this has a very significant effect on packet losses. In good channel conditions, Fig. 5a, AODV is able to perform similarly to LAR because nodes remain in range of each other despite intervening motion. In fact, packet loss levels would easily support video streaming except for larger networks. Therefore, again node density is an important factor in these types of networks. This is more apparent when the impact of fading in bad channel conditions is taken into account, Fig. 5b and Fig. 5c, where the packet loss ratios for the larger 100 node network are very much higher. Again, though closer nodes are potentially able to forward packets they are more prone to packet loss due to the impact of fading and packets tend to make more hops across the network increasing the risk of packet loss [17]. The effect of hop counts is now examined for AODV. As LAR does not consider hop counts during routing, the hop counts are not returned by the simulator. However, the trends are equally represented by AODV.

In Fig. 6, the impact of hop count is examined for the Ricean model. Hop counts are large than those reported in the literature for general ad hoc networks. For example, the research in [17] reports no more than three hops for all protocols surveyed and for all node speeds. Though by comparison between Fig. 4b and Fig. 6a, it is apparent that hop count is only one factor affecting packet loss rates, it is clear that increased hop counts are an important factor in explaining increased packet loss rates for denser networks. When more realistic drive behavior modeling is introduced, the trend is to increase the number of hops over the less realistic models, except for CSM. Increasing the transmission range, Fig. 6b, decreases the number of hops but once again increased node density results in an increased number of hops.

End-to-end delay was not the main focus of the investigations, because it is expected that buffering will be possible in a VANET and this can absorb delay and jitter at a cost in start-up delay for streaming applications. In general, for AODV results it was found that the level of end-to-end delay did not exceed 1 s and was usually above 0.5 s. This characterization is simply a guide to buffers sizes, as it is the maximum expected delay that is significant. It was also found as reported by earlier [14], that use of LAR can result in longer delays than AODV and could exceed 5 s. Number of overhead packet trends generally follow hop counts, with less control packets required when routing under LAR.

V. CONCLUSION

In this paper, we have sought to elicit how more realistic mobility models and the inclusion of fading channel models impact the feasibility of peer-to-peer applications over a VANET. As packet loss is most likely to affect performance in this type of network, this was the focus of the analysis. IEEE 802.11p's range is significantly higher than for other



(a)

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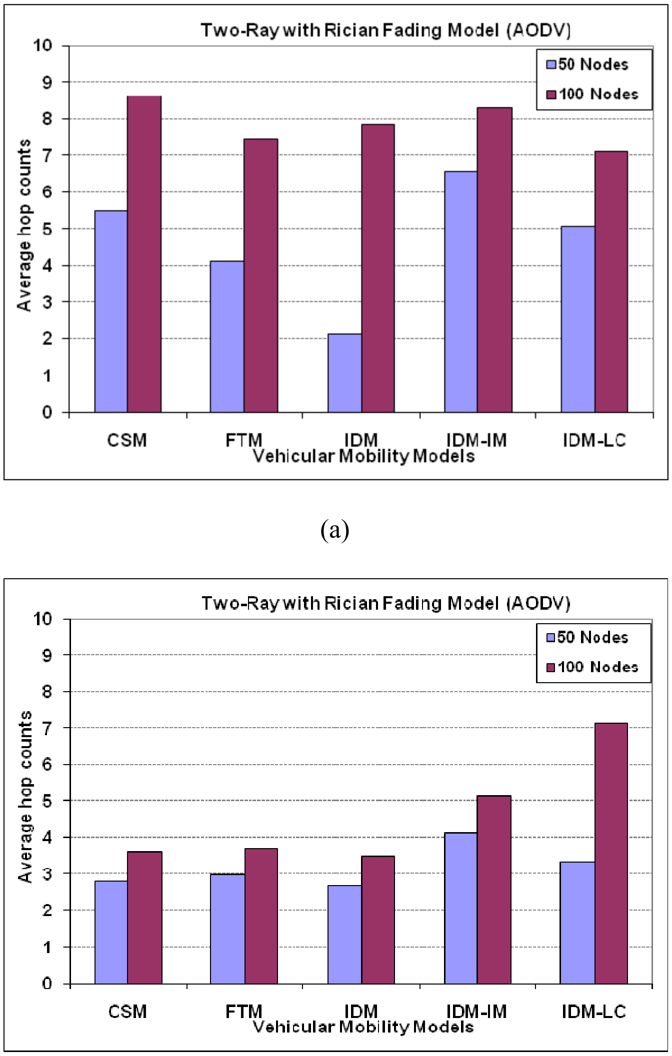
Figure 5. 800 m range: Packet loss ratio compared by mobility model for different network sizes for (a) no fading, (b) Ricean fading, (c) Rayleigh fading, with routing by the AODV protocol



(a)

(b)

Figure 6. Average hop counts for various mobility models with a Ricean fading model for ranges of a) 625 m, b) 800 m.

varieties of IEEE 802.11 and it may only be sustained in highway settings, without the effect of a built environment. Transmission range is important for the AODV routing protocol and if a location aware protocol is not applied then it is likely that packet loss ratios will be unacceptable at relatively low ranges.

It was found that including micro-mobility features could increase packet loss for the lower density network tested. However, no strong trends were apparent and the most detailed model tested could result in a reduction of packet losses in some circumstances. Network density turned out to be a strong factor in the performance of these networks, often leading to increased packet loss. This was traced to the increased number of packet hops, though increased medium access contention at road intersections and traffic light queues has a part to play, as easily predictable effects were not apparent in our simulations. The number of packet hops is much increased in these types of network. Turning to fading, this can easily increase packet loss ratios beyond what is acceptable. Therefore, it cannot be assumed that a two-ray path loss model is enough to model these networks as it will result in over optimistic expectations. P2P communication maps well onto VANET and the onus is now to develop applications that can take advantage of this communication paradigm. More closely modeling the effect of the built environment upon signal transmission is a topic for future investigation.

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