A Seamless Quality-Driven Multi-Hop Data Delivery Scheme for Video Streaming in Urban VANET Scenarios

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***Abstract*—In this paper, we propose an integrated network-layer scheme for seamless delivery of video packets in VANET. First, we introduce a new quality-driven routing scheme for delivering video streams from a fixed network to a destination vehicle via multi-hop communications. The routing scheme aims to optimize the visual quality of the transmitted video frames by minimizing the distortion, the start-up delay, and the frequency of the streaming freezes. We then propose an efficient network mobility management scheme, which introduces a novel adaptation of Proxy Mobile IPv6 (PMIPv6) for multi-hop VANET scenarios, and incorporates a handover prediction mechanism. Numerical results are given to demonstrate that our integrated scheme can achieve good performance for the video quality metrics, the handover delay, and the signalling cost.**

I. Introduction

Vehicular networks have been envisioned to play an important role in the future wireless communication service market. Yet, the streaming of high quality video to fast-moving vehicles is still fraught with fundamental challenges, attributed to the high mobility and dynamic nature of the network. First, the multi-hop path selection for delivering video packets to the destination vehicle is key to provide smoothness and quality to the video playout. Second, the handover events caused by the mobility of the destination vehicle may affect the continuity of video sessions for IP-based video streaming applications.

To address the aforementioned issues, we introduce an integrated network-layer scheme for seamless delivery of video packets in urban VANET scenarios. In order to have a smooth video playout, it is necessary to have enough packets in the playback buffer at the destination [1]. In addition, the perceptual quality of the reconstructed video frames should also be taken into consideration. Therefore, we propose a new quality-driven routing scheme for delivering video streams from a Road Side Unit (RSU) to a destination vehicle.

Since the destination vehicle may be moving through service areas controlled by different Access Routers (AR), in order to address the problem of handovers experienced by the vehicle, we also propose a network mobility management scheme for multi-hop VANET with prediction of handovers, which works in conjunction with the quality-driven geo-routing protocol. The proposed scheme is based on Proxy Mobile IPv6 (PMIPv6) [2], and is combined with the geo-networking features present in VANET.

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The remainder of this paper is organized as follows: In section II, we describe our system model. Section III describes the proposed quality-driven geo-routing scheme. In section IV we introduce the multi-hop PMIPv6 management scheme. Numerical results and discussions are provided in section V.

II. System model

We consider a VANET based on Dedicated Short Range Communications. Vehicles are equipped with On Board Units (OBU) and broadcast the location, direction, speed, acceleration, and traffic events to their neighbors [3]. The VANET topology is shown in Fig.1. The RSUs are spaced by 1.2Km from each other and the effective radio coverage is 350m. Thus, there are 500m between two consecutive RSUs that rely on multi-hop links for Vehicle to Infrastructure (V2I) communications. The OBU's radio coverage is approximately 200m.

The video is streamed from an AR to the proper RSU, and from there to the destination vehicle. While the destination vehicle is in the transmission range of the RSU, they connect directly in a one-hop fashion. Once the vehicle exits the coverage range of the RSU, video packets are transmitted to the vehicle using multi-hop paths (i.e., intermediate vehicles serve as relays). According to the RSU's coverage, vehicle transmission range, and distance between RSUs, there would be at most a 3-hop connection between the RSU and the destination vehicle for video streaming. When the destination vehicle gets closer to the next RSU compared with its distance to the previous RSU, the AR switches the video streaming to the next RSU. Hence, we assume that the data transmission would follow a repetitive sequence of {1-hop, 2-hop, 3-hop, 2-hop}.

The service area of each AR is well-defined by the network operator and may contain several RSUs. This means that, for IP addressing configuration purposes, the AR sends Router Advertisement (RA) messages inside a delimited geographic area [4]. The AR announces itself by means of geocast messages with the flag `AccessRouter` activated. In this way, vehicles in the infrastructure-connected VANET learn the exact position of an AR and directly request the assignment of an IP prefix by following the procedure explained in section IV. All the ARs and the RSUs are assumed to belong to a single PMIPv6 domain. Details of the basic operation of PMIPv6 at the infrastructure side can be found in [2]. Details

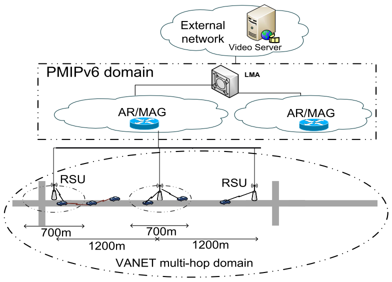


Fig. 1. VANET Topology

of our adaptation of PMIPv6 in the VANET multi-hop domain are presented in section IV.

III. Quality-Driven Routing Protocol

The proposed routing protocol is designed based on the optimization of video quality in terms of improving the visual quality of the transmitted video frames, as well as the smoothness of the streaming. In the following subsections, we first describe the video quality metrics, and then introduce the proposed quality-driven routing protocol.

A. Startup Delay and Frequency of Streaming Freezes

Let each vehicle have an infinite buffer, which is a reasonable assumption given the high storage capability that can be deployed in vehicles. The video playback process is divided into two phases: 1) charging phase; and 2) playback phase. The charging phase starts once the buffer becomes empty. Thus, the playback is kept frozen until the buffer is filled with b packets (i.e., b is a threshold of the playback). The charging phase of the destination vehicle's buffer or start-up delay, D_s , is given by $D_s = min\{t|X(0) = 0,\ X(t) = b,\ t > 0\}$ where $X(t)$ is the number of packets in the buffer at time t . Due to dynamic packet arrivals and departures during the playback phase, the playback phase may stall when the buffer becomes empty. Denote the playback phase by a random variable T . Charging and playback phases iterate until the whole video is played. We analyze the start-up delay in the proposed video streaming framework over an urban VANET. A larger playback threshold will result in larger start-up (charging) delay. We keep the playback threshold fixed and, instead, analyze the start-up delay according to the dynamics of the vehicular density.

To derive an analytical formulation for start-up delay in video streaming at the destination vehicle, the playout buffer can be modeled as a $G/G/1/\infty$ queue that follows the diffusion approximation method presented in [1]. By applying the diffusion approximation, the transient solution of the queue length can be exploited by obtaining its p.d.f. at any time instant t . The average start-up delay is given by $E(D_s) = \frac{b}{\lambda}$, where b is the playback threshold and λ is the arrival rate of the packets at the destination vehicle. The playback terminates when the buffer becomes empty again. According to [1], the average number of streaming freezes after t seconds can be approximated using diffusion approximation as follows:

$$E(F) \approx -\frac{\lambda(\lambda-\mu)}{\mu b}t \tag{1}$$

Both $E(D_s)$ and (1) indicate that as the arrival rate of video packets at the destination vehicle increases, the performance of streaming improves in terms of start-up delay and frequency of streaming freezes. Hence, the goal of routing at the link layer is to minimize the transmission delay in order to improve the streaming performance in terms of the above mentioned metrics. However, these metrics do not include the visual quality of the video frames. Hence, we also consider video frame qualities in terms of peak signal to noise ratio (PSNR), while designing the inter-vehicle routing protocol.

B. PSNR of Delivered Video Frames

A multi-hop network can be modeled as a graph with N vertices (nodes) and L edges (links). The intermediate hops are in fact mobile relays which use decode and forward scheme in order to prevent amplification of the noise along hop to hop transmission. Let S denote a set of video packets to be transmitted. Each video packet $\sigma \in S$ has video source z_σ and destination d_σ . The rate of the video stream for packet σ is bounded by $\underline{R}_\sigma \leq R_\sigma \leq \overline{R}_\sigma$, $\sigma \in S$, while the upper and lower bounds are determined by the encoder used at the source node. The end-to-end video frame distortion is given by:

$$D_\sigma^e = \underbrace{D_0 + \frac{\theta}{R_\sigma - R_0}}_{\text{encoding distortion}} + D_{loss} \tag{2}$$

where θ , D_0 and R_0 are parameters for the specific video encoder and video sequence. D_{loss} is the mean square error due to channel noise or packet drops due to exceeding the transmission delay deadline. Details of the derivation of end-to-end video frame distortion over a VANET scenario can be found in [5]. The total distortion is the summation of all the packet distortions of a video stream.

C. Inter-Vehicle Routing Protocol

We consider the streets in an urban vehicular scenario as a directed graph, where the intersections are the nodes and the roads are the edges of the graph [3]. Only edges with vehicles on them can be selected for packet forwarding. The proposed data delivery model has two modes of operation: 1) straight way; and 2) intersection. For the straight way, the vehicle carrying the packet to be forwarded selects N_D neighboring vehicles that are in its transmission range, and are geographically closer to the destination vehicle. Then, it selects the next candidate hop that minimizes the frame distortion in (2) with minimum channel loss probability. At the intersection, the vehicle must select the next straight path in order to forward the packet. The delivery delay can be estimated using the stochastic model proposed in [3] by solving the following set of equations:

$$D_{mn} = d_{mn} + \sum_{j \in N(n)} (P_{nj} \times D_{nj}) \tag{3}$$

where D_{ij} is the expected packet delivery delay from intersection I_i to the destination, if the packet is forwarded through road r_{ij}. P_{ij} is the probability that a packet is forwarded through road r_{ij} at I_i. $N(j)$ is the set of neighboring intersections of I_j . If any routing loop happens at the intersection, the packet is dropped, since video streaming is a delay sensitive application and can not tolerate large delivery delays. In fact, our scheme maximizes the arrival rate of packets at the destination according to $\lambda^* = \lambda(1 - PL)$ because the end-to-end packet loss probability will be minimized. p_{ij} is the packet loss probability of link between node i and j . Hence, the start-up delay and average number of streaming freezes is reduced. The carrying vehicle applies greedy geographic forwarding for transmission of signalling messages. The details of the data routing for delivery of video packets are given as follows. On straight way, if any vehicle is in the transmission range and closer to the destination, apply greedy geographic routing and select candidate nodes $\{c_i | i = 1..N_D\}$, such that $|D(c_i) - D(c_{i+j})| \leq \delta$ for $j = 1$ to $N_D - 1$. Then, select a node among candidates giving minimum packet distortion. At the intersection, if any vehicle is not in the transmission range, then drop the packet. Otherwise, proceed as follows. 1) Solve the set of equations in (3). 2) Select road r_{ij} which results in minimum delay. 3) Apply greedy geographic routing and select candidate nodes, $\{c_i | i = 1..N_D\}$, such that $|D(c_i) - D(c_{i+j})| \leq \delta$ for $j = 1$ to $N_D - 1$. 4) Select a node that gives minimum packet distortion among the candidates. 5) If routing loop happens at intersection, then drop the packet.

TABLE I
IP REQUEST FOR MULTI-HOP PMIPV6

At destination vehicle
1. Complete layer 2 connection to an intermediate vehicle.
2. IP layer processing:
- Generate Router Solicitation (RS) message (all-routers multicast address as the IP destination).
- Pass RS packet to the geo-routing layer.
3. Geo-routing layer processing:
- Create geo-header (translate multicast address to geo-cast address).
- Set the flag `RouterRequired` in the geo-header.
- Forward packet using the geo-routing protocol.
At intermediate vehicle or RSU
1. Geo-routing layer processing:
- **if** `RouterRequired` is set **and** AR exists in location table, **then** change geo-header destination to geo-unicast AR's address.
- Forward packet using the geo-routing protocol.
At the AR/MAG
1. Geo-routing processing:
- Store location of destination vehicle.
- Pass RS packet to the IP layer.
2. IP layer processing:
- Start PMIPv6 signalling to the LMA.
At the LMA
1. If MN already exists in the domain, **then**
- Update MN location.
- Keep the same network prefix assignment.
else Create binding cache for the MN.
2. Create list with candidate ARs, locations and service areas.
3. Send PBA to MAG with home network prefix and candidate ARs.

IV. IP Mobility for Quality-Driven Data Delivery

In section III, we select the multi-hop path that offers the minimum end-to-end distortion for the delivery of video packets. However, the assumption that the destination vehicle remains connected to the same RSU is unrealistic. If a change of RSU occurs in the topology shown in Fig.1, it may also mean that the vehicle enters to a service area under the control of a different AR. Therefore, we now propose an IP mobility management scheme for seamless video streaming service when an active connection is affected by a change of IP addresses at the destination vehicle.

The proposed scheme is an adaptation of PMIPv6 for multi-hop VANET with handover prediction. The standard PMIPv6 [2] requires a direct connection between mobile node and AR (also known as Mobile Access Gateway [MAG]). Therefore, it is necessary to devise a method for multi-hop transmission in PMIPv6, so that new connections are effectively detected and signalling messages are delivered through the multi-hop path. Our scheme works in conjunction with the geo-routing algorithm described in section III-C, and relies on the IPv6 support for VANET using geo-networking features [6]. The geo-routing layer forwards the IP packets in the multi-hop path that creates a virtual point-to-point link between the destination vehicle and the AR, with no need of processing IP headers at intermediate vehicles, nor at the RSU.

A. IP configuration in the PMIPv6 domain

The first time a vehicle enters the vehicular network, it acquires a valid IP address from the domain, so that packets from the video server can be successfully delivered to the vehicle. PMIPv6 is defined for the case when a mobile node connects directly to an AR. Thus, we only address the case when a multi-hop path to the AR is used. Table I describes the steps to request a valid IP prefix. The IP configuration process uses geo-routing at each vehicle for the virtual point-to-point link. It also relies on standard control messages defined in Neighbor Discovery (ND) for IPv6 for finding routers in the domain and for keeping track of reachability between IP neighbors. However, we modify the way those messages are processed in order to take advantage of the geo-networking features of VANET. Note that during the IP request process described in Table I, it is possible for the destination vehicle to receive one of the beacon messages sent by the AR announcing its services in the connected VANET, right before the RS message is initially forwarded. Therefore, the vehicle may send an RS message to the AR's location directly, instead of using the all-routers multicast address.

Once the IP configuration at the destination vehicle has been completed, the regular IPv6 control information related to ND is exchanged between the IP peers, i.e., between the vehicle and the AR. In order for this exchange of information to happen, the tunnel established at the geo-routing layer is always used for the multi-hop delivery of packets between the two peers. For the proper operation of PMIPv6 in the multi-hop scheme, and also for the prediction of handovers introduced in the next section, it is necessary to maintain state information at the entities involved in the exchange of IP packets. Here we describe the required data structures:

1) Neighbors Table: Nodes in VANET from which a link layer beacon has been received. Based on this information, every node executes the geo-routing protocol and locates the best candidate to forward packets to the destination;

2) IP Neighbors Table: IP neighbors announced in ND. At the vehicle, the table contains the AR serving its current area, and the candidate ARs available in the domain. At the AR, the table contains all the nodes in the connected VANET for which the AR is serving as the IP next-hop. This table could be integrated to that of the ND protocol by appending the additional fields for location information.

B. Handover mechanism

A moving vehicle in an urban scenario may experience different types of handovers: 1) when the vehicle detects another RSU and changes its connection; 2) when the vehicle changes its connection to a different intermediate vehicle; and 3) when the vehicle moves to the service area of a different AR. Given that this section addresses the problem of IP mobility, we focus mainly on the third case.

In order to take advantage of the location capabilities in VANET, we propose a prediction mechanism that allows for the pre-configuration at the AR/MAG of the IP settings of the vehicle before it moves to a new service area. The process is explained in detail as follows. Every node that has a valid IP prefix from the PMIPv6 domain, exchanges ND messages with the AR. Therefore, based on the information received from NeighborDiscovery/NeighborAdvertisement messages, the AR is able to update the location of a vehicle. In order to determine if the vehicle is about to leave the current service area, the AR first makes an estimation of the vehicle's location as $x_{est} = x_0 + s_x \times (T_1 - T_0)$ and $y_{est} = y_0 + s_y \times (T_1 - T_0)$ [7], where the coordinates of the vehicle (x_0, y_0) and the velocity vector $v = (s_x, s_y)$ were those received in the last ND message. T_1 is the time at the moment of the estimation, and T_0 is the time at the moment of reception of the ND message. We use the AR service area coupled with the estimated location and velocity vector of the vehicle to construct a coarse grained approximation of the estimated distance d_{est} and time t_{est} for the vehicle to reach the imaginary line, with coordinates (x_1, y_1) and (x_2, y_2) , that defines the edge of the service area.

$$d_{est} = \frac{|(x_2 - x_1)(y_1 - y_{est}) - (x_1 - x_{est})(y_2 - y_1)|}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}} \quad (4)$$

Based on d_{est} and $t_{est} = d_{est}/v$, we form a heuristic to make the following decision: if the time to reach the edge is lower than that determined by a threshold value, the AR predicts that the node is about to leave the service area and reports this event to the LMA. The LMA then chooses the next candidate AR based on the position and direction of the vehicle, and establishes an inactive tunnel with it. This means that the new AR/MAG has the IP prefix information for the vehicle that is about to enter its service area. However, the redirection of IP packets is kept to the old location until the node is actually reported to have entered to the new area.

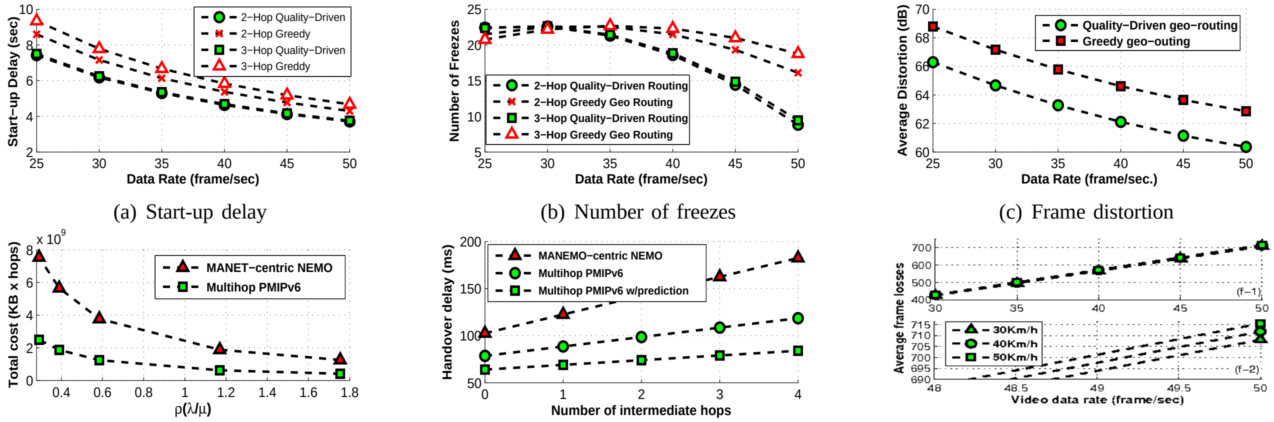
Once the vehicle experiences the handover to a new service area, it sets the entry for the AR in PROBE state in the ND table. The PROBE state forces the vehicle to send a NeighborDiscovery message to check the AR's reachability. The location of the new AR/MAG is known by the vehicle thanks to the list of candidate ARs stored in the IP Neighbors Table. When the AR receives this packet, it is used as a hint for the detection of the new connection, and allows the AR to set the pre-established tunnel with the LMA as active. Once the LMA receives the notification for the activation of the tunnel, it redirects the forwarding of IP packets to the new vehicle's location, and the handover process is terminated.

V. NUMERICAL RESULTS AND DISCUSSIONS

In this section, we analytically evaluate our integrated scheme. First, to evaluate the performance of the quality-driven routing scheme, we compare it to the traditional greedy georouting protocol [8] in terms of quality of streaming (start-up delay and number of freezes) as well as visual quality (PSNR of delivered video frames). Fig. 2(a) shows the start-up delay when the video streaming starts on a 2-hop and 3-hop path. An increment in the incoming data rate results in a lower start-up delay. Our protocol achieves lower start-up delay in both scenarios. The start-up delay difference between 2-hop and 3-hop scenario in our protocol is very small, which shows a high stability for our scheme. The small difference is due to two reasons: 1) faster delivery of packets due to a shorter path; and 2) lower packet loss (higher arrival rate at the destination) due to fewer number of hops. Compared to the greedy forwarding scheme, the quality-driven routing protocol has more computations per hop. In our method, the computation at each hop is limited to a few candidate nodes, by first selecting the cluster of candidates using greedy geographic. The protocol is applicable in polynomial time.

Fig. 2(b) shows the number of streaming freezes versus the incoming data rate for 2-hop and 3-hop connection scenarios, for 300s session length. For low data rates, the greedy algorithm achieves in slightly lower frequency of freezes compared to our quality-driven scheme. However, as the data rate increases, our method results in significantly lower number of freezes compared with the greedy algorithm. Our method guarantees a higher arrival rate by selecting links with lower loss probability. Lower packet loss is the main contribution of our routing scheme compared with the greedy scheme, and its impact on the arrival rate of packets at the destination increases as the input data rate is increased (above 30 frames/sec.). According to (1), for a higher arrival rate, the number of freezes decreases since the second derivative of (1) is negative. In Fig. 2(c), we compare the distortion of delivered video frames. The quality-driven algorithm always selects the next candidate hop that results in the minimum frame distortion given by (2). As expected, our method results in a lower frame distortion compared to the greedy approach.

Second, to evaluate our proposed multi-hop PMIPv6 scheme, we compare it with a MANET-centric NEMO scheme [9]. The scheme uses NEMO Basic Support and geo-routing to hide nested configurations in VANET, and allows one single tunnel formation from the vehicle to the Home Agent. The measures to analyze the schemes's performances are: 1) location update signalling cost C_{BU} (e.g., PBU/PBA messages); 2) packet delivery overhead cost C_{PD} (e.g., IP tunnel header); and 3) handover delay T_{HD} .



(a) Start-up delay (b) Number of freezes (c) Frame distortion

(d) Cost comparison (e) Handover latency comparison (f) Frame loss

Fig. 2. Numerical Results for the Seamless Quality-Driven Data Delivery Scheme

We follow the same methodology in [10] for cost calculations. An adapted fluid flow model is used to describe the transition of a node along different subnets, given a probability $\alpha(i)$ of crossing i subnets during an inter-session arrival time $1/\lambda$. Sessions lengths vary from 30s to 1800s. The subnet crossing rate μ_s is calculated as $\mu_s = vL_s/\pi A_s$, where average velocity v is 50Km/h, and L_s and A_s are the perimeter and area of the service area. The signalling cost C_{BU} (bytes transmitted per hop) is calculated as $C_{BU} = \sum_i i \times BU \times \alpha(i)$, where BU is customized for each scheme according to how many hops the signalling messages have to cross to reach the anchor point. C_{PD} is total overhead to deliver packets in one video session. The total cost T_C then is $C_{BU} + C_{PD}$. T_C is measured according to the session to mobility ratio $\rho_s = \lambda/\mu_s$. Video frame sizes are $7.7^{\exp 02} bytes$, and distances (hops) are: RSU_AR=1, AR_Anchor point=3, and anchor point_video server=8.

The sum of the different delays during a handover process is used to quantify the total handover delay T_{HD}. Therefore, $T_{HD} = t_{L2} + t_{MD} + t_{BU} + a$, where t_{L2} is the layer 2 connection delay (50ms including authentication), and t_{MD} is the movement detection delay (e.g., RS/RA or NeighborDiscovery/NeigborAdvertisement messages). Finally, t_{BU} is the binding update delay to the anchor point, and a is the anchor point's processing time. The transmission delay between vehicles is assumed to be 5ms, and between vehicle and RSU is 10ms.

Fig. 2(d) shows that our multi-hop PMIPv6 achieves around a 30% less cost to update the vehicle's location and to deliver the video packets. The location update cost is reduced due to the fact that PMIPv6 confines the protocol signalling to the infrastructure side. Although both schemes require some extra signalling to perform movement detection for vehicles in a multi-hop link, the tunneling for packet delivery in MANET-centric NEMO starts from the vehicle itself, whereas in multi-hop PMIPv6 the tunnel is required only between the MAG and the LMA. Similarly, Fig. 2(e) shows the performance in the compared schemes in terms of handover delay. The multi-hop PMIPv6 with the prediction mechanism allows for resuming the reception of video packets aprox. 1.6 $\sim$ 2.1 times faster than MANET-centric NEMO, thanks to the pre-established tunnel at the new MAG. The reduced handover delay then enforces the seamless transmission for a demanding service like video streaming.

Finally, we evaluate the performance for the integrated routing / mobility management scheme. Fig. 2(f) shows the impact of the vehicle's velocity in the average of lost frames during a video session, when our integrated scheme is applied to the routing and handover management. We consider a session length of 900s, and three different average velocities for the vehicle. We can see that the behavior of the integrated scheme is fairly stable under an increase in velocity. Fig. 2(f)-2 shows more detailed behavior for high data rate scenarios. The increase in losses are mainly due to the increase in the number of handovers during the session length.

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