SUV: Related Work and Performance Evaluation

F. Soldo†, C. Casetti‡, C.-F. Chiasserini‡, Pedro Chaparro⋆
† University of California at Irvine, USA
‡ Politecnico di Torino, Italy
⋆ Technical University of Catalonia, Spain

I. RELATED WORK

The problem of medium access control and traffic dissemination in vehicular networks has attracted a great deal of interest, however most of the proposals that have appeared in the literature deal with either delay-tolerant or safety/emergency applications.

An example of MAC scheme is in [1], where vehicles are synchronized and transmit into time slots according to their position: spatial cell resolution and temporal slot schedule are centralized and notified through an out-of-band control channel. In [2], [3], the use of rate-less codes and nodes cooperation are exploited to ensure fast and efficient dissemination of delay-tolerant traffic or single messages, in highly mobile networks. The work in [4], instead, focuses on driving an information piece from a source to one or multiple home zones, where the information is then maintained and provided to interested users. Such tasks are performed by exploiting periodic messages, broadcasted by each vehicle and announcing its future route: the knowledge of future movements, both its own and those of its neighbors, allows a vehicle carrying a content to decide whether to keep the information or to hand it to a neighbor with a lower estimated time-to-home zone. A broadcast protocol, specifically addressing the problem of intermittent connectivity, has been presented in [5]. There, using the solution in [6], each node determines to which connected dominating set (CDS) it belongs, based on the local position information received from its neighbors through periodic beacon messages. Beacons also include acknowledgments of broadcast messages. Upon receiving a broadcast message, a node decides whether to forward it or not, depending on the information acquired through its neighbors’ beacons, so as to reduce the number of retransmissions and ensure reliability. A survey on routing and data dissemination in vehicular networks can be found in [7].

Focusing on the support of streaming media in VANETs, few works have addressed the problem of channel access and traffic forwarding [8], [9], [10], [11] and the majority of them consider a highway scenario. In particular, the network architecture in [8] aims at propagating video streaming through forwarding nodes; however, unlike our case, the solution is tailored to traffic delivery in a highway scenario from multiple sources to a single receiver. The study in [9] proposes to improve video quality, while reducing bandwidth consumption, by applying frame skipping and frame rate reduction in 802.11-based VANETs. The work in [10] proposes an application-layer approach to deliver live video streaming, by exploiting a cluster-based network topology that however requires high cluster-formation overhead. We consider a similar network architecture as in [11] (i.e., synchronized broadcasting performed through forwarders), but we deal with an urban environment, which poses several additional challenges with respect to the highway case. Unlike our solution, [11] does not leverage the application characteristics.

Finally in the context of sensor networks, the solution in [12] builds a virtual grid of forwarders and implements a TDMA schedule through a vertex coloring algorithm. In particular, [12] assumes a static, dense network and presents a distance-2 coloring heuristic with performance \(O(1)\) from the optimum. As for channel access, traffic recovery is achieved through an RTS-CTS-DATA-ACK mechanism. Although related to our study, we remark that the work in [12] differs from ours in many aspects. In particular, we address a highly dynamic scenario and we do not require high node density. We define a distance-\(k\) coloring, where \(k\) can be any positive integer, which is optimal and has the same asymptotic complexity as the algorithm in [12]. Furthermore, we design a channel access scheme by leveraging the specific characteristics of video sources, such as variable bit rate and video encoding.

II. SIMULATION SETTINGS

To analyze the performance of SUV, we collect two kinds of results using the ns-2 simulator on a city section, where nodes move according to a realistic mobility model. The first set of results are derived from snapshots of the VANET at different time instants, thus corresponding to different network topologies. These experiments allow us
to compare the performance of SUV against the theoretical results for broadcast capacity in [13]. The second set of results instead provides a broader set of statistics (including the PSNR of received video streams) obtained using the urban topology in Fig. 1, and the realistic vehicular mobility traces provided by the VanetMobiSim mobility simulator [14].

More in details, we consider a network area size of $1 \text{ km} \times 1 \text{ km}$ and assume that there is a fixed gateway node located at the center of the area. The gateway node acts as a source of the streaming video, which has to be distributed to all vehicles in the network. The transmission rate on the data channel is equal to 2 Mb/s, the time frame periodicity is the same as the one of video frames. We point out that, although only one gateway node is considered, the original video stream splits and merges again at several points in the network area, thus yielding the same situation as the one occurring in the multisource case.

We simulate propagation according to the well-known two-ray ground reflection model, which has been shown to be suitable for vehicular environments [15]. We point out that the two-ray ground reflection model implemented in ns2 gives results that are equivalent to the ones obtained through more accurate models, as the one presented in [16], [17], for transmitter-receiver distances greater than 80 m and that, in our vehicular scenario, transmitter-receiver distances are greater than 100 m with very high probability. We also consider the presence of buildings blocking the propagation of radio signals and that each vehicle keeps updated knowledge of its actual 1-hop neighbors through HELLO messages, which are transmitted on the data channel with periodicity of 0.5 s. By requiring an average packet error rate of at most 0.0802, we obtain a maximum transmission range of 250.77 m. Finally, by relaying on the studies in [16], [18], we set the value of $P_{rx}^{(th)}$ to $-58 \text{ dBm}$, and $f_{out}$ and $f_{in}$ to 4 dB and 12 dB, respectively.

The road topology for the city section is shown in Fig. 1. It includes several road intersections regulated by traffic lights or stop signs, where vehicles are allowed to queue up. Vehicles movements are generated using VanetMobiSim with microscopic-level traffic dynamics regulated by the IDM-LC car-following model, which accounts for cars interactions, overtakings, and road signaling [14]. Each vehicle in the topology is initially assigned a desired speed, uniformly chosen in the interval [10,20] m/s. Depending on road traffic conditions and regulations, each vehicles tries to maintain its desired speed, slowing down and picking up speed again if required. In our simulations, we observed that such realistic vehicular mobility led to spotty network connectivity.

III. COMPARISON AGAINST UPPER BOUNDS TO BROADCAST CAPACITY

Our goal is to place the performance of our scheme within theoretical upper bounds. We exploit the results in [13], which provide upper bounds to the maximum achievable throughput, when the network topology is represented by an arbitrary connected graph. The maximum achievable throughput is the maximum rate at which all nodes can successfully receive the broadcast transmission. Specifically, we proceed as follows. We look at two upper bounds defined in the following way:

1) in a topology with a predefined backbone, the ratio of the size of the Maximum Independent Set (MIS) to the number of backbone nodes;
2) in a general topology, the ratio of the size of the MIS to the size of the Minimum Connected Dominating Set (MCDS).
The MIS size represents the maximum number of relay nodes whose transmissions can be received by at least one node. As predefined backbone, we consider the one identified by SUV, whose size can be at most $5/3$ larger than the MCDS size. Indeed, the number of SUV relay nodes per radio range is upper bounded by 5 (i.e., the relay node, its parent node and three children nodes). In the case of the MCDS, instead, 3 nodes belonging to the MCDS fall within a node radio range (i.e., the relay node along with its parent and child nodes). Then, to make a meaningful comparison, we consider snapshots of a realistic VANET simulation taken at random times, each corresponding to a different topology. For each topology, we compute the two aforementioned ratios and multiply them by the channel capacity. The throughput achieved by SUV instead, is computed as the average throughput at receiver nodes and, for consistency with the theoretical results, the gateway is assumed to broadcast CBR traffic saturating the channel capacity.

In Fig. 2(a), we compare the SUV throughput with the two upper bounds computed as described above. Each comparison was carried out for a different number of nodes $N$ in the VANET and the throughput values were obtained by averaging over ten snapshots. As noted in [13], we observe that the theoretical broadcast capacity decreases with increasing $N$, since, due to the node interference, both the size of the MCDS and that of the backbone grow much faster than the size of the MIS. Surprisingly, however, in a VANET with a small number of nodes, this effect is mitigated by the fact that increasing $N$ corresponds to widening the geographical area covered by the connected network (i.e., the area where the service is provided). Thus, the node density on the actual network area grows more slowly than the number of nodes.

As for the SUV performance, it should be pointed out that a small number of nodes (namely, 80 nodes) results in fewer nodes that can be selected as relay nodes. Also, since SUV is tested under urban mobility, the choice of relay nodes is less than ideal due to vehicles following the road layout. These factors result in an incomplete, askew grid; hence, in a lower throughput for small values of $N$. When $N$ increases, SUV achieves an excellent performance. Furthermore, unlike the findings by Grossglauser and Tse [19] on the increased unicast capacity warranted by mobility, it is interesting to note that here realistic vehicular mobility negatively affects the throughput of live video streams. Indeed, due to their stringent delay requirements, there is no allowance for store-and-forward. These shortcomings are however offset by SUV trump cards: namely its distributed scheduling mechanism and its low communication overhead.

Fig. 2(b) compares the number of relay nodes selected by SUV with the size of the MIS, for increasing number of nodes in the VANET. The number of SUV relay nodes is computed by selecting the maximum number of transmitters per slot, averaged over all ten snapshots. It can be observed that topologies with few nodes result in a larger number of relay nodes per time slot (i.e., simultaneously transmitting) with respect to the size of the MIS. Again, the reason is to be ascribed to the poor distribution of vehicles, which forces the selection of ill-placed, interfering relay nodes. As the number of nodes in the VANET grows, the larger set of candidates allows a better selection of relay nodes so that the locations of the forwarders selected by SUV resemble a regular grid. Under this condition, the constant-step coloring optimally solves the distance-$k$ coloring problem. It follows that, for a large number of nodes in the VANET, the SUV relay nodes do not interfere with each other and are therefore bounded
IV. VIDEO STREAMING AND BEST-EFFORT DATA

Here, we use video YUV sequences provided by [21]. Using the technique described in [22], the video sequences are encoded into 3 descriptors in the Quarter Common Intermediate Format (QCIF) resolution \(176 \times 144\). Each descriptor is associated to a constant video rate of 8 frames/s, a mean bit rate of 55.3 kb/s, and a peak rate of 259.3 kb/s; this yields a total mean and peak bit rate associated to the video stream equal, respectively, to 166 kb/s and 778 kb/s. Nodes are also assumed to attempt the transmission of best effort data, whenever possible. The size of the SAR layer header is set to 26 bits [23], while the MAC and physical layer headers are of 26 and 24 bytes, respectively. At the MAC layer, we fix the maximum payload size to 1236 bytes and the minimum payload size (useful for best-effort data transfer) to 200 bytes. The RTS and CTS size, as well as all other parameters and timings used for best-effort data transfer, are set to the default values as specified by the 802.11b technology.

Figs. 3(a) and 3(b) plot the results obtained at the node experiencing the best and worst performance, as well as the performance averaged over all network nodes, as functions of the number of nodes \(N\). Fig. 3(a) also carries the average throughput for aggregate video and best-effort data traffic, and highlights the efficient bandwidth usage obtained through SUV.

The curves in both figures make a strong case for denser topologies as far as the received video rate is concerned. Likewise, they suggest that sparser topologies provide a better jitter, while the delay is just slightly affected by the network density. The number of nodes (hence the density of the network) affects the received rate in a quite predictable fashion: fewer nodes translate into poorer choice of forwarders (i.e., relay nodes chosen farther from the sector center). The unbalanced grid structure thus accounts for overlapping coverage at the cost of more collided slots. Furthermore, a high number of relay nodes increases the chance that a neighboring node is exposed to more than one copy of the forwarded video stream. Surprisingly, when delay and, especially, jitter are observed, there is an adverse behavior. It turns out that, being exposed to more than one copy of the forwarded video stream, a SUV node in a dense topology can replace a collided video frame with one of its copies, broadcast at a later time in a neighboring sector. Losses are reduced (hence the throughput increase), but the jitter is negatively affected. The effects of high jitter can however be mitigated using a properly dimensioned playout buffer.

\(^1\)Note that typically hand-held wireless devices have a screen size that corresponds to the QCIF video format.
The good performance is further confirmed by the mean received video PSNR, whose best, average, worst performance are plotted in Fig. 4(a). Some nodes, namely those whose route keeps them closer to the gateway, achieve excellent performance (close to the ideal, no-loss PSNR equal to 34 dB). The average performance starts at about 6 dB below the ideal mark and closes in as the number of nodes grows. Such good performance is yielded by our cross-layer synergies between multi-description video coding and transmissions scheduling on the physical channel. It is worth pointing out that, in our performance evaluation, no playout buffer was introduced at the receiver; its presence might have further boosted the PSNR values, by enhancing the chances of packet reordering and mitigating delay losses.

Finally, in Fig. 4(b) we plot the difference between the original video rate and the video rate received by a sample vehicle, chosen so as to correspond to the average performance, with $N = 250$, and whose route is highlighted in Fig. 1 by a checkered pattern. The sample video as would be seen by the receiving vehicle is available at [24]. The hop distance of the sample vehicle from the gateway changes over time as marked in the strip at the top of Fig. 4(b) (e.g., at the outset, the hop distance is equal to three). The rate difference, presented as a function of time, is mostly below 15 kb/s, except for a few spikes, that correspond to the change of relay node from which the stream is received. As can be expected, the best performance is experienced one hop away from the gateway: this is due to the absence of scheduling conflicts, since the gateway is the only relay node scheduling its neighbors. As the distance from the gateway increases, so does the chance that neighboring nodes are chosen as children by different parents, thus increasing the number of collisions.

### Table I

<table>
<thead>
<tr>
<th>$N$</th>
<th>80</th>
<th>160</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>0.60</td>
<td>0.58</td>
<td>0.56</td>
</tr>
</tbody>
</table>

In Table I, we report the access efficiency (i.e., the ratio of throughput to available bandwidth) for what concerns best effort traffic. We point out that SUV allows best effort to pick up what is left by the streaming video and that every relay node acts as a “hot spot”. As expected, the access efficiency decreases with the increase of the number of network nodes.

**REFERENCES**


[24] https://webfiles.uci.edu/fsoldo/public/newsReceived.mp4?uniq=tqn38k