A Rate Control Video Dissemination Solution for Extremely Dynamic Vehicular Ad hoc Networks


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Abstract

Video dissemination to a group of vehicles is one of the many fundamental services envisioned for Vehicular Ad hoc Networks, especially as a building block for entertainment applications. For this purpose, in this paper we describe VoV, a video dissemination protocol that operates under extremely dynamic road traffic conditions. Contrary to most existing approaches that focus exclusively on always-connected networks and tackle the broadcast storm problem inherent to them, VoV is designed to operate under any kind of road traffic condition. We propose a new geographic-based broadcast suppression mechanism that gives a higher priority to rebroadcast to vehicles inside especial forwarding zones. Furthermore, vehicles store and carry received messages in a local buffer in order to forward them to vehicles that were not covered by the first dissemination process, probably as a result of collisions or intermittent disconnections. Finally, VoV employs a rate control mechanism that sets the pace at which messages must be transmitted according to the perceived network data traffic, thus avoiding channel overloading. Therefore, VoV adapts not only to the perceived road traffic condition, but also to the perceived channel quality. When compared to two related and well-accepted solutions – ABSM and AID – under Manhattan grid and real city scenarios, we show that, overall, our proposal is more efficient in terms of message delivery, delay and overhead.

Keywords: VANETs, Video Dissemination, Broadcast Suppression, Intermittent Connected, Rate Control

1. Introduction

Vehicular Ad hoc Networks (VANETs) are finally leaving the labs and are gaining the streets [1, 2]. In these networks, vehicles are equipped with wireless networking interfaces for communicating with nearby vehicles and roadside units (RSU), thus enabling the development of traffic safety, management and entertainment applications. In this context, the scientific and auto maker communities envision video dissemination in VANETs as a fundamental service for both traffic management and entertainment applications [3, 4]. For instance, it is unquestionable that disseminating a video showing lines of cars stuck in traffic conveys a more compelling message to a driver deciding which route to take than a text message stating that there is a heavy traffic condition at a region of a city. Consider the example shown in Figure 1. After perceiving a traffic jam, the source vehicle produces a short video showing all nearby vehicles stuck in traffic and disseminates it to all vehicles in a region of interest (ROI) defined by the application. Therefore, when a vehicle receives the video and the driver notices the heavy traffic, it can avoid the problematic region and take an alternative route.

Toward this task, many solutions have been proposed in the literature [5–9]. Surprisingly, most of them were designed for always-connected networks, in which a path from the source vehicle to intended recipients is always guaranteed. Furthermore, relying on fixed infrastructures, such as roadside units and repeaters at intersections,
is common practice. However, it is common knowledge that VANETs are inherently intermittently connected networks, independently of the traffic density, due to non-uniform demographic distribution of vehicles, time variations in congestion conditions or simply traffic lights [10–12]. Besides, during the first years of VANETs deployments, the number of vehicles equipped with DSRC technology [13] and the availability of fixed infrastructure may not be enough for the proper functioning of existing video dissemination solutions.

With these issues in mind, in this paper we start from our previous work on video broadcasting [14] to propose the Video over VANETs (VoV), a video dissemination protocol for VANETs that works under the most diverse road traffic conditions inherent to these networks. For high traffic densities, VoV employs a geographic-based broadcast suppression mechanism that chooses vehicles inside high priority regions to rebroadcast. Therefore, vehicles inside these regions are assigned lower waiting delays to rebroadcast. Furthermore, after receiving a message, vehicles store it in a local buffer to be later forwarded to uninformed neighbors that failed to receive it in the primary dissemination process. We show that this increases the message delivery capability for our protocol not just for sparse road traffic scenarios, but also for heavy traffic conditions, since it works as a recovery mechanism for message losses caused by collisions. Due to the demanding nature of video dissemination, such as high bandwidth usage and strict time delivery requirements, here we extend our previous solution and propose a rate control mechanism that adapts the rate at which messages are inserted into the channel in order to avoid channel overload. Therefore, we argue that our new solution is adaptable not only to the perceived road traffic condition, but also to the available bandwidth on the communication channel. By means of simulations, we compare our proposal to two existing and well-accepted solutions – ABSM [?] and AID [5] – under Manhattan grid and real city scenarios, and we show that, overall, our protocol delivers more messages in the least amount of time by consuming less network resources. Finally, when compared to our previous work, the main contributions of this paper are the following:

- Like in [14], VoV also operates under diverse road traffic conditions. However, here, VoV employs a rate control mechanism, which turns this solution adaptable to the perceived network data traffic condition. We show that this increases the reliability and decreases the overhead of our proposed solution.

- Unlike in [14], here we assess the behavior of all protocols under Manhattan grid and real city scenarios. In particular, for the real city scenario, we rely on realistic mobility data from the city of Cologne, Germany [12] in order to increase the reliability of our results.

The remainder of this paper is organized as follows. In Section 2, we outline the related work and describe the two protocols used in our performance analysis. In Section 3, we describe in detail our proposed solution. Then, in
Section 4, we compare our proposed protocol to two existing solutions in the literature under different road traffic scenarios. Finally, in Section 5, we present our final remarks and discuss some future work.

2. Related Work

Video dissemination, and data dissemination in general, is a well-studied topic in VANETs. However, despite the fact that VANETs are intermittently connected by nature [10–12], most solutions focus exclusively on always-connected scenarios. Moreover, the solutions that do focus on both connected and intermittently connected scenarios either employ some kind of infrastructure, such as roadside units or repeaters at intersections, or a combination of GPS and street mapping information. Among the solutions that focus on both scenarios are DV-CAST [16] and SRD [17]. These protocols rely exclusively on local one-hop neighbor information and do not employ any kind of fixed infrastructure. However, both were designed to perform directional data dissemination and they are used solely for highway environments. Data dissemination protocols proposed for highways do not perform well when deployed in urban environments [?].

Korkmaz et al. [6] propose the Urban Multi-hop Broadcast protocol (UMB), a medium access layer (MAC) protocol designed to overcome the broadcast storm and hidden terminal problems. UMB defines a Request to Broadcast/Clear to Broadcast (RTB/CTB) handshaking procedure in which the vehicle positioned farther from the sender is selected to acknowledge the reception of the broadcast and also to rebroadcast the message to further vehicles. Moreover, UMB requires repeaters at intersections to help disseminate messages to other road directions. One of its main drawbacks, however, is the assumption that the network is always connected, which is not realistic. Korkmaz et al. [18] proposes an extension to UMB called Ad hoc Multi-hop Broadcast protocol (AMB), which eliminates another important drawback of UMB, i.e., infrastructure dependence. However, just like UMB, AMB also assumes an always-connected network.

Zhao et al. [9] propose the Data Pouring (DP) protocol to disseminate messages along roads in an urban environment. In this scheme, a static data center acts as the source for messages being disseminated. Initially, such data center chooses a road (axis road) and direction in which the messages must be propagated. It then chooses the farthest vehicle on such road to rebroadcast the messages. The protocol employs a request to send/clear to send (RTS/CTS) handshake mechanism similar to the one employed by UMB in order to guarantee message delivery reliability along the road. Finally, roadside units located at intersections are responsible for buffering the received messages and disseminating these messages along the roads crossing the axis road. Besides assuming a static source node and relying on a fixed infrastructure, DP also works only under dense networks.

Yi et al. [8] propose the Streetcast protocol, which, analogously to UMB, is a MAC layer solution. Under this scheme, RSUs are deployed at intersections to select the best relay vehicles to forward the messages. Moreover, the protocol employs a beacon control mechanism to avoid excessive periodic beacons at crowded intersections. Nevertheless, Streetcast operates only under dense networks. Wisitpongphan et al. [7] propose three probabilistic and distance-based broadcast suppression techniques – weighted-p-persistence, slotted-1-persistence and slotted-p-persistence – that do not require any neighbor information or special infrastructure. For instance, in the slotted-1-persistence technique, vehicles decide based on the distance to the sender when to rebroadcast a message. Vehicles farther from the sender transmit first, thus suppressing the transmission of other vehicles trying to rebroadcast. However, all three techniques assume a connected network environment.

Bakhouya et al. [5] propose the Adaptive Information Dissemination (AID), a distributed statistically-based broadcast suppression protocol for VANETs. Based on the inter-arrival time between message receptions, a vehicle decides whether to rebroadcast the message or not. For instance, in a high density road traffic scenario, after receiving some redundant retransmissions for a given message, a vehicle may decide not to rebroadcast it by assuming it was already transmitted by many other neighboring vehicles. The protocol does not require any neighbor information or any kind of infrastructure. However, it operates only on connected networks.

Among the solutions that guarantee message delivery under both dense and sparse urban network scenarios and that do not employ any kind of special infrastructure, Viriyasitavat et al. [19] propose the Urban Vehicular Broadcast (UV-CAST) protocol for both dense and sparse networks. In UV-CAST, when a vehicle receives a new message, it uses local one-hop neighbor information to determine whether it should operate under a broadcast suppression regime or under a store-carry-forward regime. If the vehicle determines that it should operate under a broadcast suppression
regime, it uses mapping information to verify whether it is at an intersection or not to properly calculate a waiting
time to rebroadcast. On the other hand, if the vehicle perceives that it should operate under a store-carry-forward
regime, it verifies whether it is a boundary vehicle or not. The protocol assumes that boundary vehicles have a greater
probability of encountering new neighbors. Therefore, these vehicles store and carry the message around until they
encounter uninformed neighbors. UV-CAST also uses implicit acknowledgements piggybacked in periodic beacons to
identify uninformed vehicles. Notice that, only boundary vehicles are responsible for storing, carrying and forwarding
messages to other vehicles. Moreover, when a vehicle receives a beacon from an unformed neighbor, it immediately
rebroadcasts the message without any explicit or implicit coordination with other vehicles in the neighborhood. This
lack of coordination leads to an increase in the number of redundant retransmissions, especially under dense network
scenarios [14].

[6] propose the ABSM, which uses the Connected Dominating Set (CDS) concept. ABSM relies on the fact that
the Minimum Connected Dominating Set (MCDS) provides the best-case solution for the broadcast data dissemination
problem in a connected network topology. The MCDS is the smallest set of rebroadcasting vehicles that are connected
to one another, and all vehicles that are not in MCDS are connected to at least one vehicle in the MCDS. Therefore,
assuming a connected network, if all vehicles in the MCDS broadcast a message, all vehicles in the network will be
covered. However, calculating the MCDS is a NP-Hard problem [7]. Hence, ABSM employs a heuristic that uses
local one-hop or two-hop neighbor information to determine whether vehicles belong to the CDS or not. Vehicles
in the CDS are scheduled first to rebroadcast the messages to other vehicles, thus suppressing the transmissions of
vehicles that are not in the CDS. Moreover, reception acknowledgements are piggybacked in periodic beacons to
guarantee message delivery under intermittently connected networks. In ABSM, when a new message is received
by a vehicle, it waits for implicit acknowledgements from its neighbors to compute its waiting time to rebroadcast.
Therefore, the latency to deliver messages depends on the periodic beacon frequency. ABSM proposes to achieve a
high message delivery ratio without a great overhead, however at the expense of an increase in the delay to deliver
messages.

3. Proposed Solution

Video dissemination is a demanding task for any kind of network because of high bandwidth utilization and
strict delay requirements. In VANETs, due to their intrinsically characteristics, such as the wireless medium and
high dynamicity, this task becomes even harder. Therefore, the main goals of our proposed approach is to perform
video dissemination in a reliable and efficient way without incurring a high load into the network. Toward these
goals, VoV selects a minimum set of vehicles to broadcast and also determines when the broadcast should take
place and at what pace. This way, the protocol tries to reduce the load sent to the link layer by decreasing the
amount of redundant retransmissions. Moreover, given that network partitioning is very common in these networks,
individually of the traffic density, received messages are kept in a local buffer to be later forwarded to uninformed
vehicles, i.e., vehicles that have not received the messages from the main “wave” of dissemination. We assume every
vehicle is equipped with a GPS and periodically broadcasts its < latitude, longitude, heading > information in
beacons known as Cooperative Awareness Messages [3, 21], which are used by many other applications in VANETs,
especially for traffic safety. Figure 2 shows the general architecture of our proposed protocol. As can be observed, our
solution operates immediately above the IEEE 802.11p MAC layer [13] and has three main components: the broadcast
suppression, store-carry-forward and rate control mechanisms.

In summary, once a vehicle receives a message for the first time, it executes the broadcast suppression part of
the protocol and calculates a waiting delay to rebroadcast the message. When such delay expires, the vehicle inserts
such message into an output queue, which is controlled by the rate control mechanism of the protocol. On the other
hand, once a vehicle receives a beacon from an uninformed neighbor and perceives that it does not acknowledge
the receipt of a given message, then the vehicle schedules a retransmission for the message (store-carry-forward) to
the uninformed neighbor. When such timer expires, the vehicle also inserts the message into the output queue for
proper transmission. Therefore, it is possible to notice that it is the rate control mechanism that decides based on the
perceived channel load when the message is sent down to the MAC layer to be disseminated. Hereafter, we provide a
detailed description to each of these components.
3.1. Broadcast Suppression Mechanism

The goal of any broadcast suppression mechanism is to avoid the well-known broadcast storm problem, which is caused by uncoordinated and redundant retransmissions, and is characterized by severe packet losses, high delay and ultimately, service disruption [7, 22–24]. To avoid these issues, we propose a new broadcast suppression mechanism that combines position and distance-based approaches (Algorithm 1). To the best of our knowledge, this is the first time that a solution combines both position and distance-based approaches in order to select the best relaying vehicles. At first, when a vehicle $v$ receives a broadcast with a new message $m$ (Line 6), it first verifies whether it is inside the ROI defined by $m$, and the time-to-live (TTL) for $m$ shows it is still a valid message. The ROI and TTL are defined by the application and their values are embedded in data messages. If $v$ is outside the ROI or $m$ is not valid anymore, then $v$ simply discards $m$ (Lines 7–8). Otherwise, assuming that $m$ is not a duplicate, then, $v$ adds $m$ to the list of received messages. This way, the next periodic beacons sent by $v$ will piggyback the ID of $m$ and all other messages previously received that are still valid (Lines 10–11). Thereafter, $v$ decides whether a rebroadcast is required or all vehicles in its neighborhood have already been covered by the broadcast. For that, the vehicle verifies whether there are any neighbor with a distance to the sender ($s$) of the message greater than the communication radius (Lines 12-15). If there are no such neighbor, $v$ will not attempt to rebroadcast, thus avoiding a redundant retransmission. Otherwise, $v$ determines whether it is inside a forwarding zone or not to calculate its waiting time to rebroadcast (Lines 16-23).

![Figure 2: General architecture of VoV](image)

![Figure 3: Illustration of the forwarding zone concept](image)
Algorithm 1: The VoV broadcast suppression algorithm

1 Initialize
2 \( N \leftarrow \) set of one-hop neighbors for this vehicle;
3 \( R \leftarrow \) communication radius;
4 \( \theta \leftarrow \) size of the forwarding zone;
5 \( T \leftarrow \) base delay;

6 Event data message \( m \) received from neighbor \( s \)
7 \( \text{if} \) vehicle is outside the region of interest specified in \( m \) or the time-to-live of \( m \) expired \( \text{then} \)
8 \( \text{discard} \ m; \)
9 \( \text{if} \) \( m \) is not a duplicate \( \text{then} \)
10 \( \text{add message to the list of received messages;} \)
11 \( \text{insert} \ m \text{ID in subsequent beacons;} \)
12 \( \text{everybodyCovered} \leftarrow \text{true;} \)
13 \( \text{foreach} \ n \in N \text{ do} \)
14 \( \text{if} \) distance\((n, s) > R \text{ then} \)
15 \( \text{everybodyCovered} \leftarrow \text{false;} \)
16 \( \text{if} \) everybodyCovered = false \( \text{then} \)
17 \( D \leftarrow \) distance to \( s; \)
18 \( \text{percentageDistance} \leftarrow \frac{D}{R}; \)
19 \( \text{if} \) vehicle is inside forwarding zone of \( s \) \( \text{then} \)
20 \( \text{delay} \leftarrow T \times (1 - \text{percentageDistance}); \)
21 \text{else}
22 \( \text{delay} \leftarrow T \times (2 - \text{percentageDistance}); \)
23 \( \text{schedule rebroadcast timer for } m \text{ to fire up at } \text{currentTime} + \text{delay}; \)
24 \text{else}
25 \( \text{if} \) rebroadcast timer for \( m \) is scheduled \( \text{then} \)
26 \( \text{cancel rebroadcast timer for } m; \)
27 \( \text{Event} \) scheduled rebroadcast timer for \( m \) expires
28 \( \text{Insert message } m \text{ into output queue;} \)

The **forwarding zone** is defined according to the direction of the sender, as outlined in Figure 3. Let the direction of a vehicle be a value in the interval \([0, 2\pi]\). Moreover, let the size of the forwarding zone be controlled by an input parameter \( \theta \) that lies in the interval \([0, \pi/2]\). When \( \theta \) is 0, there is no forwarding zone, and when it is \( \pi/2 \), all neighbors of the sender are inside the forwarding zone. Therefore, using the position and direction of the sender and its own position, a vehicle is said to be inside the forwarding zone of the sender if it lies in any of the four intervals \([0 - \theta, 0 + \theta], [\pi - \theta, \pi + \theta], [\pi - \theta, \pi + \theta] \text{ or } [\frac{3\pi}{2} - \theta, \frac{3\pi}{2} + \theta]\). The rationale is that vehicles inside these regions have a higher priority over vehicles outside it, i.e., vehicles inside the forwarding zone have a lower waiting time to rebroadcast. Notice that, the information required for a vehicle to determine whether it is inside the forwarding zone of the sender or not is embedded in received data messages. For instance, in Figure 3, vehicle \( E \) is inside the forwarding zone of the Sender, since it lies in the interval \([0 - \theta, 0 + \theta]\). Vehicles \( A \) and \( B \) also are inside it, since they lie in the interval \([\pi - \theta, \pi + \theta]\). However, vehicle \( C \) is outside it, since \( C \) does not lie in any of the four previously defined intervals.

The idea for defining a forwarding zone is to try to limit the amount of vehicles to rebroadcast a message. Moreover, vehicles lying on different intervals have a greater chance of not interfering in the transmissions of one another. For instance, if vehicles \( A \) and \( E \) rebroadcast at the same time, there is a greater chance of one not interfering in the other. However, if vehicles in the same interval perform a broadcast at the same time, a collision will probably happen. Consider, for instance, vehicles \( A \) and \( B \). Therefore, VoV combines the forwarding zone concept with a
distance-based broadcast suppression mechanism. In this scheme, vehicles are given a waiting delay to rebroadcast based on the distance to the sender of the message. The higher the distance to the sender, the lower the waiting delay to transmit. Moreover, a vehicle inside the forwarding zone always is assigned a lower delay than a vehicle outside it, thus giving the former a higher priority to broadcast.

Therefore, after determining whether \( v \) is inside the forwarding zone of \( s \) (Line 19), \( v \) proceeds to calculate its actual waiting time to rebroadcast (Lines 20 and 22). The waiting time is inversely proportional to the distance between the vehicle and the sender, i.e., the father from the sender the vehicle is, the lower the waiting time to rebroadcast. Moreover, vehicles inside the forwarding zone always have a lower waiting time than vehicles outside it. Therefore, when the farthest vehicle inside the forwarding zone rebroadcasts, it suppresses the rebroadcast of vehicles closer to the sender, both the ones inside and outside the forwarding zone (Lines 24-26). For instance, in Figure 3, vehicles \( A, D, E \) and \( F \) have the lowest waiting times to rebroadcast, since they are the farthest vehicles from the Sender that are also inside its forwarding zone. Therefore, when they rebroadcast, they will suppress the rebroadcast of vehicles \( B, C \) and \( G \), thus avoiding 3 redundant retransmissions. Finally, it is worth noticing that when the waiting time to rebroadcast fires up, the vehicle does not broadcast immediately. Instead, it places the message in an output queue (Lines 27-28), which is used by the rate control mechanism (c.f., Section 3.3).

### 3.2. Store-carry-forward Mechanism

Despite the fact that the aforementioned mechanism is intended to guarantee high data delivery to intended recipients by avoiding redundant retransmissions and consequently channel overloading, some message losses may still happen due to the demanding nature of video dissemination. Furthermore, as shown elsewhere [10–12], VANETs are naturally intermittently connected networks. This means that even if the channel is not overloaded and there are no message collisions, 100% data delivery cannot be guaranteed due to the lack of a lasting end-to-end path from source to intended recipients. Therefore, with this issue in mind, we propose a store-carry-forward mechanism (Algorithm 2) to increase the data delivery capability of VoV by serving vehicles that have lost some messages due to collisions and those that have failed to receive messages from the initial dissemination process (the main dissemination “wave”).

#### Algorithm 2: The store-carry-forward algorithm used in VoV

1. **Initialize**
2. \( R \leftarrow \) communication radius;
3. \( T \leftarrow \) base delay;
4. **Event** beacon \( b \) received from neighbor \( s \)
   5. **foreach** message \( m \) in the list of received messages **do**
      6. **if** \( m \) is not acknowledged in \( b \) **then**
         7. \( D \leftarrow \) distance to \( s \);
         8. \( \text{percentageDistance} \leftarrow \frac{D}{R}; \)
         9. \( \text{delay} \leftarrow T \times \text{percentageDistance}; \)
         10. schedule rebroadcast_timer for \( m \) to fire up at currentTime + delay;
6. **Event** data message \( m \) received from neighbor \( n \)
7. **if** \( m \) is a duplicate **then**
   8. **if** rebroadcast_timer for \( m \) is scheduled **then**
      9. cancel rebroadcast_timer for \( m \);
   10. **Event** scheduled rebroadcast_timer for \( m \) expires
11. Insert message \( m \) into output_queue;

When a vehicle receives a message for the first time, it stores it in a local buffer of received messages until the message’s time-to-live expires or the vehicle leaves the region of interest for the message. Notice that, both parameters are specified by the application that generated the message. For instance, the time-to-live for a message may be 2 minutes long and the region of interest may comprise all vehicles in a 1 km\(^2\) circular area around the source.
Besides storing the message, the vehicle needs to notify its neighbors about all the messages it has received so far that are still in its local buffer. This way, if a neighbor finds out that the vehicle has not received some already disseminated messages (uninformed vehicle), it will forward them to such vehicle. To accomplish that, the IDs of all stored messages are piggybacked in the periodic beacons exchanged among vehicles. For instance, if a vehicle A has received messages with IDs 1 and 2, then for every beacon it transmits, it will insert these IDs in the beacons to act as a list of received messages. Therefore, if a neighbor of A, say B, has received messages with IDs 1, 2, and 3, when it receives the beacon from A and notices the missing ID 3, it will forward this message to A. It is worth noticing that, the IDs piggybacked in periodic beacons act as an implicit acknowledgement mechanism for the messages received so far and that are still valid.

Assuming that the store-carry-forward mechanism is used not just for sparse traffic scenarios, but also for high traffic conditions, for instance, to recover from message collisions, some coordination must be employed when a vehicle decides to forward a message to an uninformed neighbor. For instance, imagine that in the scenario depicted in Figure 3, the Sender is the only vehicle that has not received a given message. Therefore, when it transmits a beacon that does not acknowledge the receipt of this message, all its neighbors will attempt to forward the message, probably leading to message collisions, contention and waste of network bandwidth. To overcome such issue, VoV also relies on a broadcast suppression mechanism similar to the one used for the normal dissemination process (Lines 4-10). When a vehicle receives a beacon from an uninformed neighbor (Lines 4–6), then, it calculates its actual waiting time to forward the message to the uninformed neighbor (Lines 7–10). Here, however, vehicles closer to the uninformed neighbor receives a lower waiting time than vehicles farther away (Line 9). Just like in the broadcast suppression algorithm, here, when the vehicle finally forwards the message, it suppresses the transmissions of other vehicles waiting to forward (Lines 11–14). For instance, going back to the example depicted in Figure 3, when all vehicles receive the beacon from the Sender, they calculate their waiting time to broadcast. Since vehicle B is the closest one to the Sender, it broadcasts first, thus cancelling the transmissions from all other vehicles, avoiding 6 redundant retransmissions. Notice that, if there is any other neighbor of B that also has not received the same message as the Sender, when B transmits it, such neighbor will also receive the broadcast.

3.3. Rate Control Mechanism

By employing both broadcast suppression and a store-carry-forward mechanisms, VoV is able to deliver messages to intended recipient under varying road traffic conditions, i.e., connected and intermittently connected networks. However, as shown in our performance analysis, as the road traffic density increases, so does the number of nodes competing to access the channel, independently of the effectiveness of the employed broadcast suppression algorithm. Therefore, we take a step further to make our proposed solution adaptable to the perceived available bandwidth. Hence, in VoV, when a vehicle notices that the communication channel starts to deteriorate, then it reduces the rate at which messages are transmitted.

Therefore, when the waiting delays defined by the broadcast suppression and store-carry-forward mechanisms for a message finally expires, such message is inserted into an output queue controlled by the rate control mechanism (see algorithms 1 and 2). It is the responsibility of rate control mechanism to determine how fast messages waiting in the output queue are sent down to the MAC layer for proper dissemination. In summary, such mechanism removes messages from the output queue at the same operational rate of the lower MAC layer. However, as messages are lost, the mechanism reduces the rate accordingly. Algorithm 3 shows the main steps taken by this mechanism. Initially, we define the data rate for this component to the operational bit rate of the MAC layer (Line 2).

It is worth noticing that the 802.11p MAC layer employed by VANETs relies on the use of multiple channels. The U.S Federal Communications Commission, for instance, reserved seven non-overlapping channels in the 5.85 GHz frequency range just for vehicular communication. One of these channels is designated as the Control Channel (CCH) and the remaining six as the Service Channel (SCH). Since the standard does not mandate the use of several antennas, a channel hopping scheme is proposed. Under such scheme, every 50 ms the transceiver is allowed to go from the CCH to the SCH, and then, after additional 50 ms, go from the SCH back to the CCH and so forth. It is assumed that beacon messages, mostly used by safety applications, will use the CCH, while general applications, e.g., video messages, will use one of the SCH. Given this channel hopping procedure, we assume that it is possible to calculate the number of messages lost due to collisions since the SCH became active (Line 3). Such information may be retrieved from the MAC layer.
Finally, when the timer used by the rate control component expires (Line 4), a message $m$ is removed from the front of the output queue (Line 5). Then, it is immediately sent down to the MAC layer for proper transmission (Line 6). The rate control mechanism must decide now when the next message in the output queue will be forwarded down to the MAC. Therefore, we first calculate the new operational data rate, which depends on the number of messages lost due to collisions (Line 7). Then, using this operational data rate, we calculate the transmission delay for $m$ (Line 8). Such delay is used to set up a timer for the next transmission (Line 9). We argue that by using this simple mechanism, VoV is able to adapt not only to varying road traffic conditions, but also to the amount of data traffic on the communication channel. It is worth noticing that an exact measurement of the data traffic on the communication channel is not used. Instead, the protocol retrieves the number of lost messages in the link layer as a means to infer whether the communication channel is overloaded. In this case, the protocol adapts the data rate at which new packets are sent down to the link layer in an attempt to decrease the load on the communication channel.

**Algorithm 3:** The rate control mechanism used in VoV

1. Initialize
2. $\text{datarate} \leftarrow \text{MAC layer bit-rate}$;
3. $\text{lost\_messages} \leftarrow \text{lost messages since SCH become active}$;
4. **Event** scheduled timer send\_data expires
5. $m \leftarrow \text{output\_queue\_front}()$;
6. send $m$ down to MAC layer;
7. $\text{op\_datarate} \leftarrow \text{datarate} \div \text{lost\_messages}$;
8. $\text{transmission\_delay} \leftarrow \text{m\_length} \div \text{op\_datarate}$;
9. schedule send\_data to fire up at $\text{currentTime} + \text{transmission\_delay}$;

4. Performance Analysis

To evaluate the performance of our proposed solution, we conducted a series of simulations using the well-established OMNet++ 4.2.2 network simulator [25] and compared it to two well accepted protocols – ABSM [?] and AID [5] – and to a simple flooding. Recall from our discussions on Section 2 that ABSM is a solution that employs the connected dominating set concept to determine which vehicles should rebroadcast. Moreover, ABSM operates under diverse road traffic conditions. AID relies on a statistically-based approach to determine whether a vehicle should rebroadcast or not. Such solution, however, focus on connected networks. Finally, Flooding is a simple implementation of a dissemination protocol in which all vehicles immediately rebroadcast received messages exactly once.

4.1. Simulation Setup

Aiming to show that VoV is a proper solution for video dissemination under varying road traffic conditions, we evaluated all protocols under different road traffic densities in a Manhattan grid and also under a real city street scenario. The Manhattan grid scenario comprises ten evenly-spaced vertical and horizontal double-lane roads in an area of 1 km$^2$. We also consider signal attenuation effects caused by buildings. For that, we assume that each block in the grid contains a 80 m x 80 m obstacle (80% of a block), representing a high-rise building. Moreover, we use the SUMO 0.17.0 mobility simulator [26] to build the street layouts and to generate realistic vehicle movements. To assess different road traffic conditions, we vary the density in the Manhattan grid from 20 vehicles/km$^2$ to 500 vehicles/km$^2$.

For the real city scenario, we rely on a two hour mobility dataset covering a 400 km$^2$ area of the city of Cologne, Germany [12]. According to Uppoor and Fiore [11], such dataset is realistic from both macroscopic and microscopic viewpoints. Besides an accurate mobility trace, information such as different types of roads, buildings and road signalization make this scenario much more realistic when compared to the Manhattan grid. To assess the behavior of the protocols under different road traffic conditions, we performed a data dissemination at five different times of the day (06:30, 06:45, 07:00, 07:15 and 07:30 a.m.). Notice that, as the time of the day increases, so does the road traffic, as shown in Table 1.
Table 1: Vehicle density for different times of the day for the real city scenario

<table>
<thead>
<tr>
<th>Time of the day (a.m.)</th>
<th>Density (vehicles/km²)</th>
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<tbody>
<tr>
<td>06:30</td>
<td>61</td>
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<tr>
<td>06:45</td>
<td>82</td>
</tr>
<tr>
<td>07:00</td>
<td>92</td>
</tr>
<tr>
<td>07:15</td>
<td>102</td>
</tr>
<tr>
<td>07:30</td>
<td>108</td>
</tr>
</tbody>
</table>

We also use the Veins 2.1 framework [27], since it implements both an obstacle model for signal attenuation effects and the IEEE 802.11p standard for vehicle communications. As parameters to our simulations, we set the bit rate at the MAC layer to 18 Mbit/s and the transmission power to 0.98 mW. This results in a transmission range \(R\) of about 200 m under the two-ray ground propagation model [28]. In VoV, we set \(\theta\) to \(\frac{\pi}{6}\) and the base delay \(T\) to 250 ms. Beacon messages are generated every 1 s and are transmitted only on the Control Channel. A vehicle approximately at the center of the network acts as the source for video dissemination. We use the well-known and widely used akiyou.cif, a MPEG video with a resolution of 360x486 and composed of 300 frames. These frames are packed up into 400 messages of at most 1024 bytes to be disseminated to all vehicles in the network in the case of the Manhattan grid scenario, and to all vehicles located in a circular region of interest (ROI) with a radius of 2 km and centered at the source vehicle. Moreover, the video messages are inserted into the network at three different data rates, 500 kbps, 1 Mbps and 1.5 Mbps. These messages are transmitted only on the Service Channel. All results represent the mean of 30 executions for each evaluated scenario with a confidence interval of 95%. Table 2 shows a summary of the main parameters used in our performance analysis.

Table 2: Simulation parameters used in our performance analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission power</td>
<td>0.98 mW</td>
</tr>
<tr>
<td>Transmission range ((R))</td>
<td>200 m</td>
</tr>
<tr>
<td>MAC bit rate</td>
<td>18 Mbit/s</td>
</tr>
<tr>
<td>Forwarding zone angle ((\theta))</td>
<td>(\frac{\pi}{6})</td>
</tr>
<tr>
<td>Base delay ((T))</td>
<td>250 ms</td>
</tr>
<tr>
<td>Beacon frequency</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Number of data messages produced</td>
<td>400</td>
</tr>
<tr>
<td>Number of runs</td>
<td>50</td>
</tr>
<tr>
<td>Confidence interval</td>
<td>95%</td>
</tr>
</tbody>
</table>

4.2. Evaluated Metrics

The metrics used to evaluate the reliability, scalability and efficiency of VoV are:

- **Delivery ratio**: the percentage of video data messages generated by the source vehicle that is actually delivered to intended recipients. It is expected that dissemination protocols must achieve a delivery ratio of 100%.

- **Transmitted messages**: total number of video data messages transmitted by all vehicles in the network. This metric is a strong indication of whether a protocol avoids redundant retransmissions, which may cause the broadcast storm problem under extreme road traffic conditions.

- **Delay**: the average time it takes for a video data message to travel from the source vehicle to intended recipients. This metric is important for time-constrained messages that must be disseminated as quickly as possible (e.g., accident warnings).
• **Collisions:** the average number of collisions per vehicle to disseminate all video data messages. A high number of collisions indicates that a given protocol is not able to avoid the broadcast storm problem.

### 4.3. Manhattan Grid Results

Figure 4 shows the delivery ratio for different traffic densities and for different transmission rates under the Manhattan grid scenario. Overall, we can see that VoV is the most reliable solution. In particular, looking at the results for the transmission rate of 500 kbps (Figure 4(a)), when the traffic density is low, ABSM possesses a slightly better delivery result when compared to VoV. Nevertheless, none of the protocols guarantee 100% delivery under lower densities. As the traffic density increases, both VoV and ABSM reach a delivery ratio of 100%. However, as the traffic density keeps increasing, VoV still guarantees 100% delivery ratio, while the performance of ABSM starts to deteriorate. For instance, at a traffic density of 500 vehicles/km², VoV delivers about 10% more messages than ABSM. This happens due to channel overloading, message collisions and, consequently, message losses. Notice that this pattern repeats itself at the other transmission rates (1 and 1.5 Mbps). It is worth noticing that, the delivery ratio performance of both VoV and ABSM is not much affected by the transmission rate. The explanation for such a fact is that, despite the rate control mechanism employed by VoV, both VoV and ABSM uses a store-carry-forward communication model. Therefore, it works as a recovery mechanism for messages losses caused by collisions. Looking to the performance of AID and Flooding, the low delivery results for these protocols can be attributed to the fact that these solutions do not rely on any store-carry-forward mechanism. As another consequence, their performance deteriorates with the increase of the transmission rate. For instance, for a traffic density of 500 vehicles/km², when the transmission rate increases from 500 kbps to 1.5 Mbps, AID’s and Flooding’s delivery performance decrease about 30%. Without any store-carry-forward mechanism, once a vehicle does not receive a message due to a collision, for instance, it will not have another opportunity to receive the message again. Finally, this result clearly shows that our proposed solution meets the strict delivery ratio requirement for video dissemination [29].

![Figure 4: Delivery ratio for the Manhattan grid scenario](image)

Figure 5 shows the total number of data messages transmitted for different traffic densities and for different transmission rates under the Manhattan grid scenario. Overall, we can notice that VoV is the protocol that induces the lowest overhead into the network when the vehicle density is high. When the vehicle density is low, VoV possesses a higher overhead. Notice, however, that the broadcast storm problem is not an issue at such lower vehicular densities. For instance, for a transmission rate of 500 kbps and a traffic density of 500 vehicles/km², VoV transmits about 38% less messages than AID, 50% less than ABSM and 70% less than Flooding. Moreover, VoV’s overhead is almost unaffected by the increase of the transmission rate. The same cannot be said to the other protocols. For instance, for ABSM, which employs store-carry-forward, as the transmission rate increases, so does the number of transmitted messages. That is, the increase of the transmission rate leads to an increase of the channel load and, consequently, more collisions and message losses. To keep up with the delivery ratio results, more transmissions are necessary. Recall that the store-carry-forward mechanism works as a recovery mechanism for such situation. For the protocols that do not employ store-carry-forward, i.e., AID and Flooding, as the transmission rate increases, the number of transmitted messages decreases. That is, as the channel load increases and more messages are lost, there will be no retransmissions, thus leading to a decrease of the delivery ratio and also the number of transmitted messages.
Figure 5 shows the total number of video data messages transmitted for the Manhattan grid scenario. The high delay for VoV and ABSM under lower traffic densities is due to the fact that these protocols employ store-carry-forward. As the traffic density increases, however, the delay for these protocols starts to decrease, since the broadcast suppression mechanism prevails over the store-carry-forward communication model under these scenarios. Notice that, at high traffic densities, VoV’s delay is more than one second lower when compared to ABSM. Moreover, as both the traffic density and transmission rate increase, so does the delay for ABSM, AID and Flooding. Indeed, at a transmission rate of 1.5 Mbps and a traffic density of 500 vehicles/km², VoV’s delay is even lower than AID’s and Flooding’s delay. Such increase of the delay with the increase of both the traffic density and transmission rate is a strong indication of high contention at the MAC layer, which is one of the symptoms of the broadcast storm problem.

Figure 6 shows the average delay for different traffic densities and for different transmission rates under the Manhattan grid scenario. The high delay for VoV and ABSM under lower traffic densities is due to the fact that these protocols employ store-carry-forward. As the traffic density increases, however, the delay for these protocols starts to decrease, since the broadcast suppression mechanism prevails over the store-carry-forward communication model under these scenarios. Notice that, at high traffic densities, VoV’s delay is more than one second lower when compared to ABSM. Moreover, as both the traffic density and transmission rate increase, so does the delay for ABSM, AID and Flooding. Indeed, at a transmission rate of 1.5 Mbps and a traffic density of 500 vehicles/km², VoV’s delay is even lower than AID’s and Flooding’s delay. Such increase of the delay with the increase of both the traffic density and transmission rate is a strong indication of high contention at the MAC layer, which is one of the symptoms of the broadcast storm problem.

Finally, Figure 7 shows the average number of collisions for different traffic densities and for different transmission rates under the Manhattan grid scenario. At higher traffic densities, it becomes clear that VoV generates a much lower number of collisions when compared to the other protocols. For instance, at a transmission rate of 500 kbps and a traffic density of 500 vehicles/km², the number of collisions for VoV is about 85% less than AID, 90% less than ABSM, and 92% less than Flooding. Moreover, the number of collisions for VoV is not much affected by the increase of the transmission rate. The same cannot be said about ABSM. For instance, when the transmission rate increases from 500 kbps to 1.5 Mbps, the number of collisions for ABSM increases about 28%.

4.4. Manhattan Grid with GPS Error Results

For the effective operation of our proposed solution, it is important to have accurate information about the neighborhood of a vehicle. Therefore, to show the resilience of the protocol to outdated or wrong information, we simulated VoV in the same Manhattan grid scenario as the one used in the previous section, considering a transmission rate of
1.5 Mbps, but now with the presence of GPS error. For that, when a vehicle broadcasts its position to its neighbors through periodic beacons, we add an error, chosen uniformly in the interval [0, 50] meters, to the reported position. Figure ?? shows the results for such scenario.

Figure 8: The performance results under the Manhattan grid scenario, a transmission rate of 1.5 Mbps and the presence of GPS error

As we can observe, regarding the delivery ratio (see Figure ??), the presence of GPS errors has a subtle effect on the performance of VoV under lower vehicular densities. Since in such lower densities the network is sparse, when a
vehicle receives a beacon from a neighbor that does not acknowledge the receipt of message, and such vehicle fails to forward the message to the neighbor, then it is possible that the neighbor will not receive the message from any other vehicle. In the presence of GPS errors, these failures are more common due to the wrong waiting time calculation for broadcasting a message (see lines 5–10 in Algorithm 2). At higher vehicular densities, such effect is not significant. Since the network in dense, if a vehicle fails to forward a message to a neighbor, there are many other vehicles that can still forward the message.

When considering the total number of messages transmitted (see Figure ??), we can observe a slightly increase on the overhead at higher vehicular densities. Due to the wrong position information, many vehicles believe they are the best choice to rebroadcast messages, thus increasing the number of redundant retransmissions. Such fact could lead to the broadcast storm problem. However, due to the rate control mechanism employed by VoV, vehicles still can share the communication channel effectively, without any negative impact on the delivery performance of the protocol.

Regarding the average delay and the average number of collisions (see Figures ?? and ??, respectively), no negative effect can be perceived. In fact, in the case of the number of collisions, there is a slightly improvement. Finally, these results show that VoV is resilient to GPS errors.

4.5. Real City Results

In this section, we present the results for the real city scenario. Figure 8 shows all the performance results for this scenario. Notice that, the transmission rate used in this assessment was 1.5 Mbps. Moreover, as we can observe in Table 1, the traffic density varies from 61 to 108 vehicles/km² according to the time of the day that the dissemination is performed, which can be classified as a low to normal traffic density. Therefore, under this scenario, the store-carry-forward communication model prevails.

Figure 8(a) shows the delivery ratio for the real city scenario. Similar to the Manhattan grid scenario, here, VoV also is the most reliable solution. For instance, for the dissemination performed at 07:30, VoV delivers about 20% more messages than ABSM, which is quite significant. Another interesting fact is that as the traffic density increases, the delivery results for VoV suffers a slightly increase, while ABSM’s performance suffers a slightly decrease. Notice the low delivery results for AID and Flooding. As already stated, in this scenario, the store-carry-forward communication model prevails, and neither solution relies on such communication model, thus explaining their poor performance.

Figure 8(b) shows the total number of data messages transmitted. As we can observe, VoV is the protocol with the highest overhead under the real city scenario. The reasons for such a fact are twofold. First, as shown in the previous result, VoV is the most reliable solution. Therefore, to deliver more messages under a store-carry-forward regime, more transmissions are necessary. Second, despite the fact that the store-carry-forward mechanism employed by VoV guarantees good delivery results, it does not avoid redundant retransmissions. Notice that, such fact can also be observed under the Manhattan grid scenario. Consider, for instance, the number of transmitted messages (Figure 5) for VoV under traffic densities below 150 vehicles/km². The low number of transmitted messages for AID and Flooding can also be attributed to their poor performance to deliver messages.

Figure 8(c) shows the average delay to deliver data messages to intended recipients under the real city scenario. The high delay for both VoV and ABSM is a strong evidence that these protocols are relying heavily on the store-carry-forward communication model under this scenario. For instance, to deliver more messages to intended recipients under an intermittently connected scenario, vehicles need to store and carry the messages for longer distances, thus increasing the overall delay. Notice that, as the time of the day increases, i.e., the traffic density also increases, the delay starts to diminish. The low delay for AID and Flooding can also be attributed to the fact that these protocols do not employ any store-carry-forward mechanism. Indeed, these protocols deliver data only to vehicles that are near the source, thus leading to a low delay.

Figure 8(d) shows the average number of collisions. As can be observed, VoV generates less collisions when compared to ABSM. However, when compared to AID and Flooding, VoV’s collisions are much higher. The low number of collisions for AID and Flooding is result of the low number of transmitted messages, which in turn is result of the characteristics of the real city scenario, i.e., the intermittently connected nature of this scenario. However, when focusing on the performance of the protocols suitable for such scenario, i.e., VoV and ABSM, we can argue that VoV is the solution that uses the communication channel most effectively. In summary, despite the more realistic nature of this scenario, we can notice that the performance of all protocols as quite similar to the one observed under the Manhattan grid scenario. Finally, from the results of both scenarios, it possible to argue that VoV clearly outperforms all the related protocols used in our assessment.
5. Final Remarks

In this paper, we proposed VoV, a video dissemination protocol for VANETs with diverse traffic conditions. For high traffic density scenarios, VoV selects vehicles in high priority regions to rebroadcast. This increases the delivery ratio of the protocol by avoiding redundant retransmissions and diminishing the load in the channel. Moreover, vehicles store received messages in a local buffer and immediately forward them whenever they encounter an uninformed neighbor. Our results showed that this increases the delivery capabilities for VoV under both low and high traffic density scenarios. A rate control mechanism is proposed in order to set the pace at which vehicles should transmit data messages into the communication channel. Therefore, VoV is adaptable not only to the road traffic density, but also to the perceived available bandwidth. When compared to two related protocols under Manhattan grid and real city scenarios, we showed that VoV delivers more messages in the least amount of time by conserving the available network resources. As future work, we intend to investigate network coding techniques as a possible means for increasing even more the current delivery ratio results. Moreover, we plan to work on a more effective store-carry-forward mechanism based on traffic prediction in order to increase the delivery results and to decrease the overhead.

Acknowledgments

This work was partially supported by CNPq, CAPES, FAPEMIG, FAPDEAL, NSERC DIVA Strategic Network, Canada Research Chairs Program and MRI/ORF Funds.