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Investigating VANET dissemination protocols performance under high throughput conditions

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A B S T R A C T

The use of Vehicular Ad-Hoc Networks (VANETs) for the dissemination of data flows to mobile highway vehicles has gained recently attention. For this purpose, vehicle-to-vehicle multi-hop communications are employed. For the effective networking of packets among highway vehicles, it is necessary to implement efficient algorithms that vehicles use to elect themselves as relay nodes to forward packets that they receive from other vehicles. In this work, we investigate the behavior of distributed relay node election protocols. In particular, we consider a class of such protocols whose actions are determined at time instants induced by the expiration of properly calibrated timers. We then investigate the high throughput regime of dissemination protocols. We show that a key factor that limits the achievable throughput rate is the occurrence of spurious forwarding events. These events are shown to lead to message duplications and consequent throughput degradation. We characterize this phenomenon by considering a VANET system that is configured to disseminate a single message flow along a road, as well as a scenario that involves the dissemination of two data flows that are originated by two distinct source nodes. We propose the integration into the protocol of a probabilistic decimation logic, with minimal impact on the protocol complexity. We show that, combined with the use of timers, the probabilistic mechanism serves to alleviate the occurrence of spurious forwarding events and consequently enhances the system's throughput rate and packet delivery ratios. The results of our study provide key guidelines for the design and calibration of such high performance networking protocols for VANET systems.

1. Introduction

Communications networking to, from and among highway vehicles is a task of essential importance for a wide range of applications involving vehicles traveling along highway systems. Applications involve a wide range of services that relate to highway safety, public safety announcements and control in reaction to occurrences of disasters, guidance to first aid units, including police, medical and fire public safety entities. Of much interest are also applications that provide for the autonomous operation of highway vehicles, for personal communications and for infotainment services. A key role undertaken by Vehicular Ad-Hoc Networks (VANETs) is to disseminate information flows to a wide set of vehicles on travel. This can be achieved through the use of vehicle-to-vehicle multi-hop communications, enabling the extension of the road span covered by Road Side Units (RSUs) or On Board Units (OBUs) generating the data flows.

The dissemination function is of interest for a wide range of safety and infotainment applications [1]. A dissemination protocol can be implemented within a layer that is separate from the MAC one [2]. It can reside above it, or it can be merged with the MAC protocol itself [3,4]. The latter approach however implies modifying the MAC logic and designing new firmware, thus possibly inducing inter-operability issues with legacy MAC versions. An alternative approach envisages merging the dissemination functionality into the networking layer. This is the approach selected by ETSI in its definition of the GeoNetworking protocol [5,6].

In this paper, we consider dissemination protocols that are based on the use of distributed beaconless mechanisms. Such a technique is an attractive choice for its simplicity, robustness and effectiveness in the propagation of isolated messages.[1] Our aim

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[1] Notably, the GeoBroadcast component of the ETSI GeoNetworking protocol falls into this category.

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in this paper is to investigate to what extent those dissemination protocols can be employed to sustain high rate message flows. Specifically, we address the following points:

i. we evaluate, by simulation analyses, throughput and message delivery performance of beaconless dissemination protocols in a high throughput regime under various networking scenarios;
ii. we demonstrate that a key factor that serves to limit the attainable value of the throughput rate is the occurrence of spurious forwarding events, which lead to message duplications and consequent throughput degradation; we characterize this phenomenon by considering a VANET system that sustains a single message flow as well as a scenario that involves the transport of two flows, generated by distinct source nodes, whose spatial spans geographically overlap;
iii. we show that the spurious forwarding phenomenon depends on the level of the mean vehicular traffic density (λ) and of the offered bit rate (R_o);
iv. we determine the corresponding data rates beyond which the system performance degrade in a significant manner; we provide explanation of the impact of the spurious forwarding phenomena on the system performance;
v. we present and analyze decimation based mechanisms that alleviate the spurious forwarders problem.

In our work in [7] we set up a model to identify the interplay between MAC procedures and dissemination protocols that may give rise to spurious forwarding and to analytically quantify this phenomenon at low data rate regime. Differently from the paper [7] we here quantify how the data dissemination performance exhibit collapse under heavy load due to these spurious retransmissions (also known as unsuppressed message duplicates); to this aim we investigate then performance limits of timer-based dissemination protocols under heavy load. Moreover, we also extend the study to the case where multiple nodes are responsible for generating flows that must be broadcasted across the network system. To the best of our knowledge, no other studies published to-date carry out performance evaluations of techniques used for high data rate dissemination of message flows across a VANET system. The results of our study are of essential importance for the design and calibration of such a VANET system: they enable it to sustain efficiently high data rate broadcast flows across a vehicular highway system.

The rest of the paper is organized as follows. Section 2 surveys related work. Section 3 describes the logic of the analyzed dissemination protocols. The interplay between the operations undertaken by the MAC layer and the network layer, which arises during the dissemination process, is analyzed and evaluated in Section 4, including the impact by the level of the achievable data throughput rate. Conclusions are drawn in Section 6.

2. Related work

The key element of a dissemination logic is the criterion to elect a sub-set of vehicles traveling along the road to act as message relay nodes. The idea is rooted in the extensive studies investigating MANET systems that aim to solve the broadcast storm problem [8,9]. We can classify the dissemination approaches for VANETs on the basis of the basic rule that is used to select relay nodes. A more extended survey on the information dissemination mechanisms for VANETs can be found in [10]. We identify three cases:

1. timer based packet by packet dissemination: without any prior consensus reached on a node in the neighborhood that will act as a relay node, each vehicle decides autonomously to elect itself as a Relay Node (RN) for each packet that is receives, on the basis of its position (i.e., its distance from the sender of the received packet); these schemes are classified as beaconless location-based relaying;
2. probabilistic timer based packet by packet dissemination: such a scheme is similar to the one used in previous case, but it uses an additional probabilistic rule that serves to reduce the number of RNs;
3. clustering/signaling based dissemination: a forwarding logic that requires an exchange of messages before the start of the data transfer phase, or that requires the conduct of a pre-established coordination dialog between vehicles that reside in the same geographical area; each cluster is managed by a dedicated cluster head node (identified as the corresponding RN), in charge of forwarding messages for the entire cluster.

2.1. Timer based dissemination

The mechanisms analyzed in this paper are based on the selection of vehicles that are located at preferred positions to act as Relay Nodes (RNs), while inhibiting others. This can be done in a distributed manner through the activation at each candidate vehicle of a timer expiration mechanism. In this regard, a key development is the Distance Defer Transmission (DDT) scheme presented in [11]. The DDT approach is based on a simple but quite effective way for reducing redundant rebroadcasts and the consequently ensuing medium contentions and collisions. It assigns the task of relaying messages in each neighborhood solely to the receiver that is located farthest away from the sender.

The paper in [12] proposes the Urban Multi-Hop Broadcast (UMB) protocol that selects the farthest node from the transmitter to relay a message, and uses repeaters at intersections to retransmit messages, and to overcome the problem of large buildings obstructing a message path. The mechanism is also used to speed up the dissemination of message flows oriented toward certain directions and to avoid retransmissions due to collisions. A drawback of UMB is an extensive infrastructure requirement for the deployment of repeaters.

The Road Oriented Dissemination (ROD) protocol [13], data disseminates separately in each direction, aims to optimize data dissemination at an intersection. To fulfill these goals, these mechanisms make use of vehicular GPS positions, which are inserted in the header of broadcasted messages and used to locate the node in the road map. The ROD protocol includes data encoding the coordinates of intersections, hence it requires a considerable amount of side information, that is location specific.

The Timer-based Backbone Network dissemination protocol (TBN) [14] is based on the use of local (vehicular) timers. The key idea is that each vehicle receiving a message starts a timer, whose timeout duration is set to a value that decreases the closer the vehicle is located to a nominal relaying position. The nominal positions are spaced out by a distance range that is chosen so as to provide each receiving relay node with a Signal to Interference plus Noise ratio (SINR) level that can support the intended packet transmission rate. The vehicle that is residing closest to the nominal relay position is elected as a relay node; other nearby vehicles would then cancel their plan to act as forwarders of the same message. Therefore, TBN aims at coupling the simplicity of DDT and the effectiveness of properly placing the RNs to achieve good performance of the relay radio link.

2.2. Clustering based dissemination

In a second group of protocols, instead of employing a rule governing the selection of RNs, the formation of clusters is guided by