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QoE-driven dissemination of real-time videos over vehicular networks

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ABSTRACT

Live video dissemination over Vehicular Ad Hoc Networks (VANETs) is fundamental for several services, e.g., roadside video emergency, advertisement's broadcast, and smart video surveillance. All these applications face many challenges due to stringent video quality level requirements, dynamic topologies, and broadcast environments. To cope with these challenges, as well as reduce network routing overhead, geographic Statistical Routing Protocols (SRPs) have been proposed as a suitable solution for the distribution of video flows in VANETs, usually by using positioning and Quality of Service (QoS) parameters. However, rather than only these parameters, a satisfactory video dissemination from the user's perspective also requires video and human-awareness issues. In real situations, due to different requirements and hierarchical structures of multimedia applications, network level and position parameters alone are not enough to select the best relay nodes and build up reliable backbones to multi-hop video dissemination with satisfactory reachability and Quality of Experience (QoE) levels. This article focuses on improving the disseminated quality of on-road live videos in VANETs. Thus, we propose the cross-layer QoE-driven REceiver-based (QORE) mechanism, which is modularly coupled to SRPs to offer QoE-aware and video-related parameters for the relay node selection and backbone maintenance. Thus, nodes decide for themselves to retransmit further the video sequences, enhancing the capacity of the system in delivering videos with better QoE assurance. On top of this, an application-level Error-Control (EC) scheme, namely Interleaving, allows mitigating the effects of frame loss by spreading out the bursty losses. We added QORE to a straightforward SRP built using the Distance method, named DQORE protocol. Results show the gains of DQORE compared to SRPs, achieving video dissemination with QoE support, less routing overhead, and satisfactory reachability, in V2V topologies.

1. Introduction

Vehicular Ad Hoc Networks (VANETs) are targeted to apply information and communication technology to improve and ease transportation problems. Vehicles can cooperate among themselves to disseminate not only simple scalar data, e.g., text messages, but also live multimedia content, e.g., videos of dangerous situations, allowing users and authorities (such as firefighters and paramedics) more meaningful information. This has encouraged industries and manufacturers to provide drivers and passengers with a wide scope of novel real-time multimedia services, ranging from safety and security traffic warnings to live entertainment and advertising video flows [1]. As reported by Cisco, the traffic generated by video-based services already exceeds 50% of mobile network traffic, and it will represent over 90% of the global IP data in a few years [2], where thousands of users will produce, share, and consume multimedia services ubiquitously, including in their vehicles. In this way, efficient on-road live video dissemination support in VANETs has become a market trend and, at the same time, part of the future of the Intelligent Transportation System (ITS) [3].

In general, to accomplish the task of dissemination of content (multimedia or not) over VANETs, vehicles employ flooding approaches extensively. Unfortunately, this simple flooding of data within the network, leads to an explosive growth of traffic resulting in collisions and congestions, i.e., the broadcast storm problem [4]. In case of dissemination of multimedia flows, due to the large amount of data associated with video-based applications, to the ad-hoc nature of the VANET, and to its highly dynamic topology, when neighbor vehicles decide to transmit the same packets, they can interfere with each other. It can lead to the broadcast storm problem, causing different impacts on the video quality and wasting network resources.

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Thus, the design of a reliable and robust dissemination approach for real-time video transmission over VANETs is not a straightforward task [5]. Most of the current approaches aims only high packet delivery rates and low end-to-end delay levels, without addressing the subjective acceptability of users when watching the video sequences. While these Quality of Service (QoS)-based metrics focus only on packet-based management and delivery statistics, the evaluation of received videos while maximizing the user's Quality of Experience (QoE), becomes an intricate task. It has not been taken into account in main VANET approaches [6,7], the latter being key to the success of the broadcasted safety and traffic warning videos [8]. Thus, the multi-hop routing service must be aware of QoE requirements and network conditions to recover or maintain video quality with a low overhead and with high reachability for the nodes in the flooding area.

A variety of backbone-based solutions has been proposed to provide users with continuous transmission of applications with medium-long duration, such as multimedia flows in VANETs [5–7,9–11]. Most of them use information exchanged by neighbor vehicles to make routing decisions and build up sender-based backbones. However, end-to-end routes suffer from frequent interruptions, and the currently available local topology is not always accurate [12]. Statistical Routing Protocols (SRPs) allow improvements on the network performance by making a distributed hop-by-hop routing decision [4,13]. In SRPs, the selection of relay nodes (backbone creation process), is carried out by receivers (receiver-based), without requiring static end-to-end routes, and allowing continuous transmission even in case of topology changes. However, the existing SRPs do not efficiently explore vehicle positioning, network, and QoE-aware parameters into an integrated proposal. Thus, a QoE-driven mechanism, that employs key video and human-awareness information, such as hierarchy of frames [14] and estimation of video distortion (caused by probability of loss and loss burstiness) [15] can be coupled in current SRPs as a QoE-pointer to support a self-organized real-time monitoring and forwarding decision at the routing level [16].

On top of this, at Application layer, Error-Control (EC) schemes can also enhance the advantages of SRPs due to its suitability for video transmissions in wireless environments and the nature of error coding at the application layer [9,17]. Schemes, such as MDC (Multiple Description Coding), ARQ (Automatic Repeat Request), FEC (Forward Error Correction), or NC (Network Coding), support multimedia dissemination even in the presence of dynamic topologies since they employ information from the application-layer (video characteristics and requirements) to minimize the effects of packet loss and achieve better video distribution [18,19]. The problem about these approaches is that they rely on redundant information or retransmission of packets, which requires additional bandwidth and causes even more packet losses in case of crowded links [20]. Despite of this, the Interleaving EC scheme improves the QoE levels of live video flows by merging frames of the original video sequence without increasing packet redundancy, thus reducing the broadcast storm problem [21]. Therefore, a straightforward SRP coupled with a QoE-driven mechanism and an appropriate application-level EC scheme (Interleaving) in a unified approach, assures the dissemination of real-time video sequences with better QoE in dynamic V2V topologies.

This article proposes the cross-layer QOe-driven REceiver-based (QORE) mechanism to support the delivery of real-time videos over V2V communications. This mechanism combines positioning and QoE-aware parameters (e.g., different frame importance, frame position, and video distortion estimation) at the routing level to establish trade-offs between perceived quality, reachability, and a lower number of hops. Further, at the application level, we added the Interleaving EC scheme to mitigate the effects of a sequence of frame losses (bursty losses) and improving the human experience while watching live videos. QORE can be easily integrated with SRPs allowing vehicles to build up self-organized backbones, maintaining the packet delivery ratio, reacting well to dynamic environments and enhancing or at least maintaining the QoE level of the disseminated videos when compared to non-QoE-driven approaches. For this work, we added the QORE mechanism to a straightforward SRP built using the well-known Distance-based method and we named it as DQORE protocol.

The main contributions of this article are the following: (1) design of a modular QoE-driven mechanism to create and maintain self-organized multi-hop backbones for real-time video broadcast, while assuring the disseminated video quality. Through QORE, vehicles can broadcast videos to all the surrounding cars within an interest zone. (2) Improvement of existent SRPs with the application-level error-control Interleaving scheme and a backbone-based forwarding operation mode. (3) An extended evaluation of DQORE and currents SRPs under dynamic V2V topologies. First, we evaluated the impact of the application-level EC Interleaving scheme. Next, we assessed the reachability in highway and urban scenarios with different density of nodes. Further, we measured the packet delivery rate and the average delay at different distances from the source vehicle. Finally, (4) we analyze the benefits and impact of SRPs on the video quality level through objective and subjective QoE-based metrics. Evaluation results show the gains of DQORE in relation to current SRPs when adding QoE-aware parameters for the relay node selection and backbone maintenance.

The remainder of this article is organized as follows. Section 2 presents the related work. Section 3 introduces the QORE mechanism and its coupling with the application-level EC Interleaving method and with the Distance-based SRP (DQORE). Simulation setup and results comparing SRPs and DQORE are presented in Section 4. Lastly, conclusions are summarized in Section 5.

2. Related Work

SRPs are a class of multi-hop broadcast protocols proposed to reduce the broadcast storm problem. In SRPs, the next relay nodes are chosen through a distributed backoff phase, by comparing a locally measured value with a threshold value, thus, nodes decide for themselves which ones will rebroadcast the video packets. Three fundamental methods that fit into the category of SRPs are Counter-based, Distance-based, and Location-based methods [4]. In the Counter-based method, nodes simply count the number of times that each packet is received during the backoff phase to count the number of neighbors that so far have retransmitted the packets. The Location-based method, in turn, employs sharing of positional information to promote retransmissions mainly in the uncovered area. Lastly, the Distance-based method selects relay nodes which have not received broadcast messages from another node nearby, i.e., during the backoff phase, nodes observe which of their neighbors are transmitting. When the distance from retransmitting neighbors is larger than a given distance threshold value, the node will retransmit the message. These methods have been used to design many protocols including some using hybridization with topological approaches.

In [22], authors published improved versions of the above statistical methods by adding parameters related to density to further reduce the broadcast storm problem. In [23], following the guidelines of the Distance-based method, authors proposed a broadcast mechanism that takes into account particularities of VANETs. Aiming for dissemination of emergency alerts in urban and highway scenarios, the latter uses information such as town layout to reach an adaptive flooding. In case of highway scenarios, the proposal does not significantly differ from the Distance-based method. In [24] authors proposed the Distribution-Adaptive Distance with