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Delay-sensitive content distribution via peer-to-peer collaboration in public safety vehicular ad-hoc networks

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ABSTRACT

Delay-sensitive content distribution with peer-to-peer (P2P) cooperation in public safety vehicular networks is investigated. Two cooperative schemes are presented and analyzed. The first scheme is based on unicasting from the base station, whereas the second is based on threshold based multicasting. Long Term Evolution (LTE) is used for long range (LR) communications with the base station (BS) and IEEE 802.11p is considered for inter-vehicle collaboration on the short range (SR). The first scheme is shown to outperform non-cooperative unicasting and multicasting, while the second scheme outperforms non-cooperative unicasting beyond a specific number of cooperating vehicles, when the appropriate 802.11p power class is used. The first scheme achieves the best performance among the compared methods, and a practical approximation of that scheme is shown to be close to optimal performance.

1. Introduction

Communication plays a critical role in disaster prevention and recovery. In critical situations such as earthquake, volcano eruption, terrorist attacks, and hurricanes, data transfer from a central command center, to rescuing mobile terminals such as ambulances, mobile medical treatment units, and police vehicles, needs to be done very fast and in the shortest possible time. Such critical information could include disaster related information such as electronic maps to support aid forces during their motion within a disaster area, weather conditions, nature and specifics of the disaster, and safety areas [1]. An example is considered in [2], where videos and information from an incident location are transmitted by a helicopter to a command center, which distributes this information to the public safety teams (police, fire, etc.) heading towards, or already located at the incident location.

In this paper, we propose cooperative techniques for short range (SR) collaboration to complement long range (LR) wireless transmission for public safety systems. The purpose is to ensure the transmission of the data in the shortest possible time. Clustering of moving vehicles is considered, and two different cooperative schemes, to be implemented in each cluster, are presented. The first scheme, which we will refer to as Scheme 1, consists of the base station (BS) unicasting the data at each fading realization to a single vehicle on the LR link, which in turn multicasts it to its peers on the SR links. The second scheme, which we will refer to as Scheme 2, consists of the BS multicasting the data using a pre-determined transmission rate. Vehicles with the best channel conditions and with successful reception on the LR would receive the data and multicast the data on the SR links to vehicles having achievable LR rates below the threshold rate. We consider a Long Term Evolution (LTE) network on the LR links and the Wireless Local Area Network (WLAN) 802.11p Vehicle-to-Vehicle protocol on the SR links. Both schemes

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are compared to non-cooperative scenarios including LR unicasting, where the BS unicasts the data to each vehicle on the LR LTE links, and LR multicasting, where the BS multicasts the data to the vehicles on the LR LTE links. LTE scheduling is considered and scenarios with different numbers of allocated LTE resource blocks (RBs) on the LR links are investigated.

The paper is organized as follows. Related work is reviewed in Section 2. The system model is presented in Section 3. Cluster formation methods are described in Section 4. The delay formulation and solution for the proposed schemes are derived in Section 5. Scheduling of LTE resources is presented in Section 6. Several simulation scenarios are studied and analyzed in Section 7. Finally, conclusions are drawn in Section 8.

2. Related work

Several studies in the literature focus on building public safety networks to ensure that critical information is delivered in case the existing communication is damaged by an incident. Law enforcement, fire department, emergency medical services, etc., require a reliable sharing of critical information which necessitates the need of employment of public safety wireless networks [1]. Incident Area Network (IAN) is studied in [3,4]. In case of a disaster, the IAN replaces the damaged existing communication infrastructure in order to guarantee communication of post-disaster operations such as ambulances, emergency vehicles and rescues. In [3], an anchor node plays the role of relaying the received multicast traffic from a UMTS interface towards its ad hoc neighbors. Radio resources, battery level, adverse context conditions (signal-to-noise ratio (SNR), high mobility) are exchanged with the anchor node which in turn sends them to local radio network control that will decide which cooperative terminal will be selected. In [4], a radio resource management policy monitors periodically the conditions of the network, terminals, and rescue team priorities to deliver multicast services to the team with major need. Simulations showed that HAP (High Altitude platform), which assists incident networks in offering broadcast/multicast services, can increase the number of multicast sessions when the terrestrial network does not exist.

In [5,6], a cooperative automatic repeat request (ARQ) is presented, where, after leaving the coverage of an access point (AP), vehicles communicate between each others to exchange the packets that were lost during the transmission from the AP to the vehicle nodes. In this way, retransmissions of packets can be avoided and packet losses decreased, thus improving the throughput and transfer delay. In [6], cars broadcast HELLO messages to know about the presence of other neighbor cars and to notify other nodes that they need to act as cooperator. A list of cooperators is contained in the HELLO message. After a vehicle finishes from downloading data from the AP, it identifies the packets lost and requests them from other vehicles.

Dynamic spectrum access is suggested in [7] for vehicles, where they sense the availability of spectrum before attempting to transmit. However, due to high mobility, shadowing, and other effects, spectrum sensing by a single vehicle may not lead to accurate information about the availability of the spectrum. Thus cooperative spectrum sensing is suggested in [7].

To implement optimized collaborative content distribution, signaling information needs to be exchanged between the vehicles themselves, and between the vehicles and the BS. Hence, the signaling overhead of any collaborative method should be taken into account. Other challenges incurred during device discovery and signaling include scalability, autonomous discovery, power efficiency and privacy. LTE Direct is being investigated as a possible device-to-device (D2D) communication platform addressing these challenges [8,9]. It is currently being standardized as a feature in 3GPP Release 12 of LTE. It allows the discovery of more than 1000 devices within ranges of several hundred meters while maintain the quality of service (QoS) requirements [8]. In LTE Direct, the network can authorize devices to communicate directly (a feature needed in public safety applications in the absence of the macrocell network). However, LTE Direct can allow an operator to authorize and control the direct connection setup between vehicles, and to determine the user traffic routing between the direct and network paths. This can provide more control in fast changing environments and allows to maintain QoS (minimize loss of information through network intervention and control).

In this work, cooperative content distribution schemes are developed in order to convey the critical information in public safety networks in the shortest possible time. The novelty in the proposed schemes is in relying jointly on LTE for LR communications and on IEEE 802.11p for SR communications, while taking LTE resource allocation into account. The same concept can be easily extended to LTE-Direct using D2D communications on the SR: in terms of adapting the simulation setup, this consists of selecting suitable LTE RBs for SR transmission instead of using 802.11p channels, and updating the simulation parameters accordingly. However, since IEEE 802.11p is standardized and widely used in the literature for vehicular communications, it will be used in this paper, especially that the implementation of LTE D2D in vehicular networks is not yet standardized (at the time of writing this paper).

In the non-cooperative case, LTE multicast and broadcast multimedia services (MBMS) [10–12] can be used to send the data to all the concerned vehicles. Using LTE MBMS/eMBMS for non-cooperative multicasting in this paper, we dedicate a single RB in the cell to multicast the data of interest to the set of interested vehicles. However, in the case of multicasting, transmission on a given RB is limited by the rate achieved by the vehicle having the worst channel conditions on that RB.

3. System model

The system model adopted in this work is depicted in Fig. 1. Vehicles of public safety teams progress in cooperative clusters. In a given cluster, K cooperating vehicles in the range of an LTE BS form a vehicular ad hoc network