Challenges and Research Directions in Vehicular Traffic Modelling and Uplink In-Car Scheduling

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***Abstract*—Vehicular communications could be realized with LTE. However, an uplink channel bottleneck problem has to be tackled first. In this technical report, we identify the in-car traffic modeling and scheduling challenges. Finally, we propose our approach to these challenges.**

I. INTRODUCTION

Vehicular communications aim in the first place at improving road safety. One of the promising technologies for vehicle communications realization is LTE [1]. It has a number of advantages from bounded delays and high data rates to fast market penetration. However, one of the possible bottlenecks is uplink transmission, e.g., [17], [18]. In order to guarantee that critical messages are delivered in time to the processing node, an in-car traffic specific scheduling algorithm has to be developed. The scheduler has to be evaluated against a realistic in-car traffic mix. Thus the second part of the work has to be in-car traffic modeling.

In this technical report, we analyze related work on two defined topics. First, we show the state-of-the-art research on in-car traffic modeling, list existing models and discuss their advantages and drawbacks. Then we show the related work on in-car scheduling. Finally, we describe the challenges in in-car traffic modeling and scheduling as well as our approach to it.

II. RELATED WORK: CHALLENGES

This section addresses the related work for the two main directions in focus. In Subsection A, we discuss the existing traffic models for M2M in general and ITS specifically. We show the existing approaches, their primary goals and problems, when applying to ITS. Subsection B deals with the related work on in-car congestion control. It outlines the state-of-the-art work and its drawbacks.

A. ITS Traffic Modeling

The state-of-the-art on Machine-to-Machine (M2M) and Intelligent Transport Systems (ITS) has limited work on traffic modeling due to vague information on the real deployments of M2M and ITS. The first massive measurements on M2M traffic patterns ware made by Shafiq et al. in [2]. The measurements were conducted in a US tier-1 network for a week period in 2010. The authors identified and confirmed the general trends in the M2M traffic. One of the key findings of the measurements was that the M2M traffic uses mostly the uplink, whereas in the Human-to-Human (H2H) the downlink transmission dominates. Although these measurements are suitable as a general guideline, they do not capture the behavior of the ITS-specific applications as they are not widely deployed yet.

Research on traffic modeling for M2M so far has concentrated on a generic use case, when all the services were modeled together. A good introduction to M2M traffic modeling can be found in [3]. Standardization bodies tackle M2M traffic from a planning point of view, e.g., aggregate traffic models from 3GPP [4]. [4] presents two separate models: non-synchronized and highly synchronized. The non-synchronized arrival rate is assumed to be uniformly distributed and the synchronized obeys the beta distribution over an abstract time interval T. These models, although valid for their use case, provide very limited detail on a traffic pattern and are not connected. Al-Khatib O. et al. in [5] merge correlated and uncorrelated traffic models. The main contribution of their merged model is an analytical expressions for mean buffer lengths, mean queuing delays and blocking probabilities for a single base station. The model captures temporal correlation of the traffic as well as the event-triggered traffic and is non-Markovian. Generally, aggregate models are simple and therefore scale well. However, they are not precise as they are not capable of modeling the individual behavior of each source and every application.

Source models as in [6], or provide more precision and flexibility at a cost of higher complexity. For example, Nikaein N. et al. [6] derive a Markov Chain model based on the on-off structure. The parameters of this model have to be fitted to the individual applications as it was shown in [3] for auto-pilot and sensor-based alarm. Although this model is precise and flexible (can be fitted to many applications), it is computationally heavy with the growing number of devices to be modeled, as requires complex matrix-vector multiplication in each time slot [7]. A Coupled Markov Modulated Poisson Processes (CMMPP) was introduced in [8]. CMMPP captures the space and time correlation of M2M traffic due to two master processes. It preserves the source modeling precision due to the individual Markov-models per UE. IT is a compromise model in terms of precision and complexity.

3GPP and ETSI in [9] define the Machine Type Communication (MTC) or M2M features as follows:

- Low mobility

- Small data transmissions
- Infrequent mobile terminated

The measurements in [2] confirm these features for generic M2M traffic. However, the future and current ITS services differ significantly from it and thus shall be treated separately. Generally, ITS traffic consists of a combination of M2M, e.g., safety, and H2H, i.e., infotainment. Furthermore, it ITS foresees many delay-critical event-triggered up-link transmissions. Finally, ITS UEs are more mobile than humans. So far as it was also shown above, the research state-of-the-art concentrates on either generic M2M traffic modeling, e.g., [8], or on a typical M2M application, e.g., Smart Grid as in [10].

In the vehicular traffic area, to the best knowledge of the authors, there are no clear communication traffic models. This is mostly due to absence of standardized ITS implementations for safety and traffic efficiency applications. ETSI in [11] provides a mapping of the Traffic Class IDentification (TCID) and the intended use for the prioritization at transport and networking layer.

TABLE I
TCID MAPPING TO INTENDED USE [11]

TCID	Intended Use
0	High-priority Decentralized Environmental Notification Message (DENM), event-triggered
1	DENM, event-triggered
2	Cooperative Awareness Message (CAM), periodic
3	Multihop DENM, event-triggered; other data traffic

The use cases defined in Table I are partially described in [12]. There are three communication directions defined:

- Vehicle-to-Vehicle (V2V) or direct communication between cars
- Vehicle-to-Infrastructure (V2I) or communication to the base station or road side unit
- Infrastructure-to-Vehicle (I2V) or communication from the base station or road side unit

The communication requirements are defined for the ad-hoc networks, i.e., Vehicular Ad-Hoc Network (VANET) based on, for example, 802.11p. However, delay requirements and nature of the messages (periodic or event-triggered) are independent of the underlaying network and can be related to the LTE-based ITS. Delay requirements vary from 50 ms, e.g., pre-crash sensing warning, to 500 ms, e.g., co-operative traffic management. Most of the applications require maximum delay of 100 ms. Periodic messages shall be sent with the frequency from one to ten Hz. In [3] that for high speeds the CAM frequency can increase to 40-50 Hz, however, it is not mentioned in [12]. For these applications the positioning precision also varies depending on a concrete application from less than 1 m (pre-crash sensing warning) to at least 20 m (co-operative glare reduction). Event-triggered messages are described in [12] also in terms of period. When an event triggers an application, e.g., pre-crash sensing warning, it retransmits the same DENM message for a certain duration, e.g., 10 Hz for 5 s.

[12] does not provide a way to simulate the overall traffic generation in a single car and how to map it to the classification in Table I. Since there are also no real communication traffic traces for these applications, a flexible traffic model based on the ITS application requirements has to be developed. This model shall include the conservative and progressive traffic growth.

B. In-car Congestion Control

Network resources are limited and with the growing number of users they become even more scarce. This is why if the users, e.g., cars, send all the generated data, the network becomes congested and nothing can be delivered. For the VANETs ETSI introduced a Decentralized Congestion Control mechanism (DCC) [13]. Most of the proposed in the research methods are based on the channel probing to obtain the channel status and adjust the transmission accordingly. For example, transmission rate [14], power [15], or both [16] can be adapted to avoid the network congestion. These methods cannot be directly applied to LTE due to fundamental differences in technologies.

For LTE the connectivity is guaranteed by the infrastructure. [17] and [18] show that for CAM transmissions the LTE uplink becomes a bottleneck. Transmitting CAMs in a dense scenario with 10 Hz results in average delays of seconds for already ten cars per cell. Yet, according to [11] CAM is only one of four use classes and even not with the highest priority.

Authors in [19] propose to use a separate centralized server, i.e., so-called GeoServer [20], to adapt the transmission rate to the available resources. The GeoServer has centralized knowledge about the resources in the network, processes the incoming uplink messages and takes control over the downlink transmissions (from the network to the vehicles). Authors in [19] use the centralized knowledge of the GeoServer for the CAM message scheduling. The goal is to maintain the most accurate information at the GeoServer, e.g., changing position and speed, while not overloading the network. However, there are several drawbacks. First, the analysis for the event-triggered DENMs is missing. Second, the influence of the in-car traffic processing (shaping and scheduling) is neglected. [21] investigates CAM transmission rate adaptation based on the GeoServer information and vehicle speed. The DENM analysis is missing as well.

III. IN-CAR SCHEDULING: RESEARCH DIRECTIONS

At the moment [12] defines the traffic generation rules primely for the VANETs. In VANET connectivity depends on communication capable vehicle number and density [22] as well as on their relative position. This makes V2V communications unreliable. This is why event-triggered messages have to be repeated in order to guarantee their delivery to all the possibly affected vehicles.

In our set-up, we focus on the uplink, as it was shown to be a bottleneck. We assume that the GeoServer knows, which rate each vehicle has to use in order not to congest the network. The GeoServer realization is out of the scope

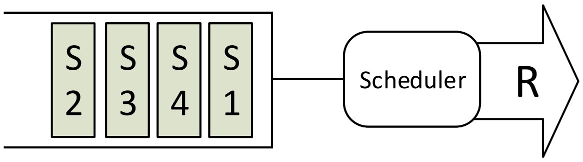

Fig. 1. Schematic of the scheduler

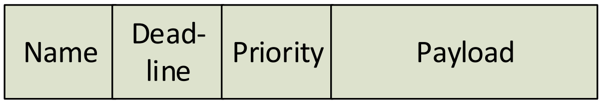

Fig. 2. Schematic of a service

of the work. As a vehicle receives from the GeoServer a recommended rate it has to adjust its sending rate accordingly. So the vehicle-originated traffic has to be scheduled in order to get the most important messages through even under the constraint of limited transmission rate and delay requirements. The following subsections present our research directions and ideas on the in-car traffic generation and on the in-car traffic scheduling.

A. In-car traffic generation

As it was mentioned in the introduction to the Section, not all of the information generated by the vehicular applications has to be sent. Thus there shall be defined a method to discard the some messages to obey the suggested by the GeoServer transmission rate. At the same time the transmitted information must provide the best possible under the resource limitations data precision at the GeoServer, e.g., position of the vehicle.

We shall review entire message generation process and provide a mathematical model of it. As the underlying network is cellular and it is more reliable in terms of coverage as VANET, the application shall generate less messages.

B. In-Car Scheduling

The goal of in-car scheduling is to send enough information under minimal possible data rate and respecting the requirements on the delay. Delay in the first approximation is defined as the buffering delay. So we assume that the respective vehicular application provides the information.

In-Car Scheduling is based on the assumption that we have a reliable communication channel. Therefore we do not need to send massages multiple times to deal with packet loss. A scheduling algorithm can run at specific data rate provided by the GeoServer.

As in Figure 1 shown a time based scheduler (Least Laxity First or Earliest Deadline First [23]) served by a data rate provided by the GeoServer. A service consists as illustrated in Figure 2 of a name, a deadline, a priority level and its payload. The deadlines of each service (S1 - S4) are an application input. Based on the data rate (R) and the load in queue it is possible to perform online schedulability analysis. If this analysis indicates an overload situation a priority based drop mechanism drops as many low priority services till schedulability is reached. The priority levels could be configured like the definition of the TCID levels. To improve the accuracy of the transmitted data we introduce two service types. A static payload service and a dynamic payload service. The static payload service is used to transmit data which does not change over time. This could be the point of time of a full break. The dynamic payload service transmits mainly status updates like the car velocity. To improve the accuracy of this data the payload will be generated just before the scheduler is able to transmit the information. This leads to a more accurate system state at the remote site.

IV. CONCLUSION

In this technical report, we have shown two challenges in in-car traffic modeling and scheduling. First, there is no realistic in-car traffic model. Second, there is a need in tailored for the automotive use case in-car scheduler to be able to send all the relevant information under delay and bandwidth constraints. This outlines our future work.

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