Smart traffic calming measures for smart cities - a pre-study

Ghazwan Al-Haji

Scott Fowler

Tobias A Granberg

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Linköpings universitet
581 83 Linköping
www.liu.se/forskning/carer

LINKÖPINGS UNIVERSITET

Kontaktadress:

Ghazwan Al-Haji
ghazwan.al-haji@liu.se

Scott Fowler
scott.fowler@liu.se

Tobias A Granberg
tobias.andersson.granberg@liu.se

Linköpings universitet
SE - 581 83 Linköping

Center for Advanced Research in Emergency Response (CARER)

Centrum för forskning inom respons- och räddningssystem (CARER)

URL: http://www.liu.se/forskning/carer

E-Post: carer@lists.liu.se

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Abstract

Traffic calming measures, such as speed bumps and elevated crossing points, are used to reduce speed, to prevent overtaking and generally contribute to a safer traffic situation. However, they might also cause increased response times for rescue vehicles (e.g. ambulances or fire trucks). An alternative to the conventional traffic calming measures is so-called smart traffic calming measures. These can determine when a vehicle approaches, whose journey should not be hindered, and adjust to allow for free passage for this vehicle.

This report gives an overview of the problem, and some examples of smart traffic calming measures are discussed. Special focus is put on the wireless communication necessary to detect emergency vehicles. Furthermore, existing challenges and possible solutions for traffic calming measures and the communication needed to make them smart are discussed.

Svensk sammanfattning

Trafiklugnande åtgärder, såsom vägbulor och förhöjda övergångsställen, används för att minska hastigheten, hindra farliga omkörningar och generellt bidra till en säkrare trafiksituation. Dock kan de också bidra till att insatstiderna för räddningsfordon (t.ex. ambulanser eller räddningstjänstens släckbilar) förlängs. Ett alternativ till de konventionella trafiklugnande åtgärderna, är s.k. smarta trafiklugnade åtgärder. Dessa kan avgöra när ett fordon närmar sig, vars färd inte bör hindras, och anpassa sig så att fri färd för detta fordon tillåts.

I denna rapport ges en översikt av problemet, och några exempel på smarta trafiklugnade åtgärder diskuteras, med fokus på sådana som hämtar information och styrs med hjälp av trådlös kommunikation. Vidare diskuteras existerande utmaningar och möjliga lösningar för trafiklugnande åtgärder och den kommunikation som krävs för att göra dem smarta.

Table of contents

1 Introduction

The rapid growth of cities generates challenges for road transportation in terms of congestion, traffic accidents, emissions, energy consumption, delays, etc. Smart Cities provide modern, smart systems that integrate Information and Communication Technology (ICT) on the roads and in the vehicles. Smart Cities has been proved in many EU countries to offer effective applications for solving current and future transportation problems and challenges.

Delays in the response time for emergency vehicles (e.g. ambulances or fire trucks) to incidents may cause deaths, injuries and financial losses. In Ireland, 700 fatalities every year are due to inadequate ambulance response [1]. In the case of cardiac arrests, every lost minute reduce the chances of survival with 10% [6].

Most accidents occur in urban areas and most victims are Vulnerable Road Users (VRUs; e.g. pedestrians and cyclists). To increase the safety for this group, many cities have implemented Traffic Calming Measures (TCMs) on urban streets for reducing speed, deter overtaking and adjust driver behaviour.

TCMs can be divided into two parts. The first part includes vertical measures such as speed humps, speed tables, raised crosswalks, raised intersections, textured pavements, etc. The second part includes horizontal measures such as road narrowing, roundabouts, chicanes, chokers, traffic circles, etc. Each TCM gives different effects on mobility, accessibility, safety, cost, etc.

TCMs are successful in reducing speed, travel volume, overtaking, and consequently, traffic accidents. However they also create unwanted negative effects, such as increased energy consumption, emissions, noise, and increased travel times for emergency vehicles.

Improving traffic safety, mobility, accessibility and emergency response time on roads with TCMs is a major challenge for traffic planners, engineers and policy makers. Smart Cities, in particular smart transportation services, constitute an ideal platform for implementing ICT-based solutions that can help provide quicker response to an emergency; some of these can be performed at dispatch time whereas others must be performed dynamically while the emergency response vehicle is en route.

The aim of this pre-study is to formulate the problem of how TCMs can be adapted to allow a hinder-free passage of emergency response vehicles, using ICT-based solutions – and to provide a literature review. Specific focus is placed on the wireless communication enabling the smart TCMs, including vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication as well as road side units (RSU). The goal of the study can is to serve as a base for further development in this particular subject area.

The report is organized in as follows. The second section describes the problem formulation, while the third section presents smart TCMs. The forth section presents challenges in implementing V2V and V2I, and the fifth section discusses RSUs. Finally, conclusions and a discussion can be found in Section 6.

2 Problem formulation

The positive effects of TCMs include reducing the average traffic speed 20-40%; reducing the number of accidents by 50-70%; reducing the number of overtakings and maneuvers; reducing the need for enforcement measures; etc [2]. Furthermore, they are relatively inexpensive. However, TCMs are also responsible for an extra 40-50% in fuel consumption [3] and generate increases in exhaust emission rates of CO, HC, and CO2 between 20% and 60% [4]. This can be explained by the need for deceleration and acceleration before and after a TCM and the decreased capacity on the roads leading to longer travel times. TCMs may cause traffic diversion to neighbouring streets result long travel time.

There is a clear conflict between TCMs and ERT in terms of:

- Depending on which type of TCMs that are used and what type of vehicle that the emergency services utilizes, there will be delays in the response time. Studies shows that trucks in the fire department can experience a delay of up to 10,7 seconds per calming measure encountered [5]. The same effect has been observed for ambulances where delays can be as high as 9,6 seconds. An ambulance may also have to take a different route, extending trip with up to 1 km, or 40 seconds, when having a patient in the vehicle, due to the risk of severing the patient's condition [6].

- There is another aspect, related to the damages to the emergency vehicle that follows when driving in high speeds over speed humps and bumps. The exact cost of the impact that TCMs has on vehicles has not been found, however, the fire department in Linköping confirms they had heavy vehicles on repairs due to the continuous strain on the vehicle's suspension [7].

- TCMs creates a problematic ride for patients and severe pain for people with certain disabilities [11].

It is however possible to construct TCMs that do not cause the disadvantages described above. One such improvement is the replacement of speed humps by speed cushions. The speed cushions are designed as one smaller hump per lane, while the traditional speed hump stretches over the whole road. Larger vehicles, such as emergency service vehicles or busses, can pass without increasing the travel time, because they have a wider wheelbase, and thus can pass over the speed cushion without being severely affected. The delay experienced by the emergency services might vary between no delay and a few seconds delay after the implementation of speed cushions [8]. This can be compared to speed humps, raised crosswalks and raised intersections which might give delays between 1-20 seconds [41]. The main advantage of speed cushions is that the traffic calming still works for passenger vehicles, while emergency service vehicles can pass without delay [41].

The speed cushion is one example of how it is possible to make TCMs that have a minimum adverse effect on emergency response times, but being designed for large vehicles, they might still be troublesome for police cars, fire commander vehicles, first response vehicles or even ambulances. Thus, there is a need for smarter TCMs.

3 Smart TCMs

Traffic calming measures can have a negative effect on emergency vehicles, with reduced travel times, increased repair costs, and inconvenience while transporting patients. However, we can see recent trends in the development of IT solutions that can improve the response times and minimize the inconvenience for emergency services. These are based on communication with other vehicles (V2V, vehicle to vehicle) and communications between the emergency response vehicle and the infrastructure (V2I, vehicle to infrastructure).

In Spain and England, new types of speed bumps have been developed, which change their characteristics according to the drivers' speed. The Swedish National Road and Transport Research Institute (VTI) defines these types of speed bumps as dynamic [12]. They use some form of detection to identify the speed or the vehicle type of the approaching road user. This is normally done by some form of detection system, such as loop sensors in the road, or radar. If a speeding road user is detected, the speed bump will perform actions to reduce the speed, but if the driver is complying to speed limits, the speed bump will not perform any action. There are also possibilities to modify vehicles and the speed bumps, for example emergency vehicles or buses, to not be affected by these types of calming measures.

The Acti Bump is a dynamic active speed bump that consists of a hatch that is integrated in the road, which activates and opens when a speeding driver is detected. It also collects driver statistics and can be adjusted to different speed limits [13]. The Acti Bump can also be fitted with a transponder to recognize, for example, emergency vehicles, and will then remain inactive when these types of vehicles approach. A recent study in Linköping showed that the average speed was reduced by 11 km/h after the introduction of the Acti Bump. The Acti Bump also increased the number of drivers that gave way for pedestrians [14]. Other studies in Linköping have also proven that the number of speeding drivers on a 30 km/h road could be reduced from 50 to 30% [12].

4 Vehicular networking

It may be possible to improve emergency response time by exchanging relevant safety information via Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications (these will hereafter be referred to as Vehicle-to-X (V2X)). Today, V2X communication is based on two main technologies: Dedicated Short Range Communication (DSRC) and cellular networks. Although there is no globally agreed definition on DSRC, it is generally referred to as a wireless technology that can enable short range exchange of information between DSRC devices, e.g. onboard units (OBUs), road-side units (RSUs) or hand-held devices. There is variety of off the shelf solutions for V2X communications, which are able to provide wide coverage, high bandwidth capacity, widely deployed infrastructure and services that require stringent real-time safety.

Several wireless communication systems have been considered to support ITS services via V2V and V2I communications. Among them, LTE and DSRC technologies are front-runner candidates, and both are considered well suited for providing ITS services under the condition of low vehicle density [15], [16]. However, with an ever increasing number of vehicles, LTE networks are easily overloaded. Moreover, work in [15] shows that DSRC in conjunction with IEEE 802.11p[1] exhibits poor performance in the event of a large number of vehicles. Due to the high mobility of vehicles and the dynamic topology changes of the vehicle environment, it is problematic to present a suitable ITS services by means of a single wireless network. Consequently, by considering various wireless access networks such as LTE and DSRC it may be possible to meet the various demanding communications requirements of ITS services. Let's first start with the underlining architecture framework of V2X.

The framework of a Vehicular Network is illustrated in Figure 1; a V2X topology is composed of three main components, namely a Radio Access Network (RAN), a Core Network (CN), and a Service Center (SC). The RAN is the telecommunication part of the V2X topology. Service providers can often supply a variety of services to vehicular users through the SC. The CN is a key component of the V2X topology because it provides many important functions, such as aggregation, authentication, switching and so on. In a V2X topology, there are two types of communications links; V2V and V2I [17], [18]. V2V allows for short and medium-range communications among vehicular users, offering low deployment costs and supporting short message delivery with low latency. V2I enables vehicles to connect to a network infrastructure, e.g. the Internet, for information dissemination and infotainment via a roadside base station. Various candidate wireless access technologies can be used to support V2X communications depending on specific requirements. Thus, it is a challenging task to select an efficient and suitable radio access method that meets all the distinct quality of service (QoS) requirements of the vehicular users.

The idea with V2I communications is to provide a connection with the infrastructure located along the roadside. With the extensive cellular network infrastructure having been deployed in the past decades, it is reasonably to make use of the cellular networks to support V2I communications [16],

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[1] It defines approved amendment to 802.11 (specifications of the basis of products marketed as Wi-Fi) required to support Intelligent Transportation Systems (ITS) applications.

[19]. Another possible is to use DSRC, which is based on the IEEE 802.11p/1609 Wireless Access in Vehicular Environment (WAVE) protocols [20].

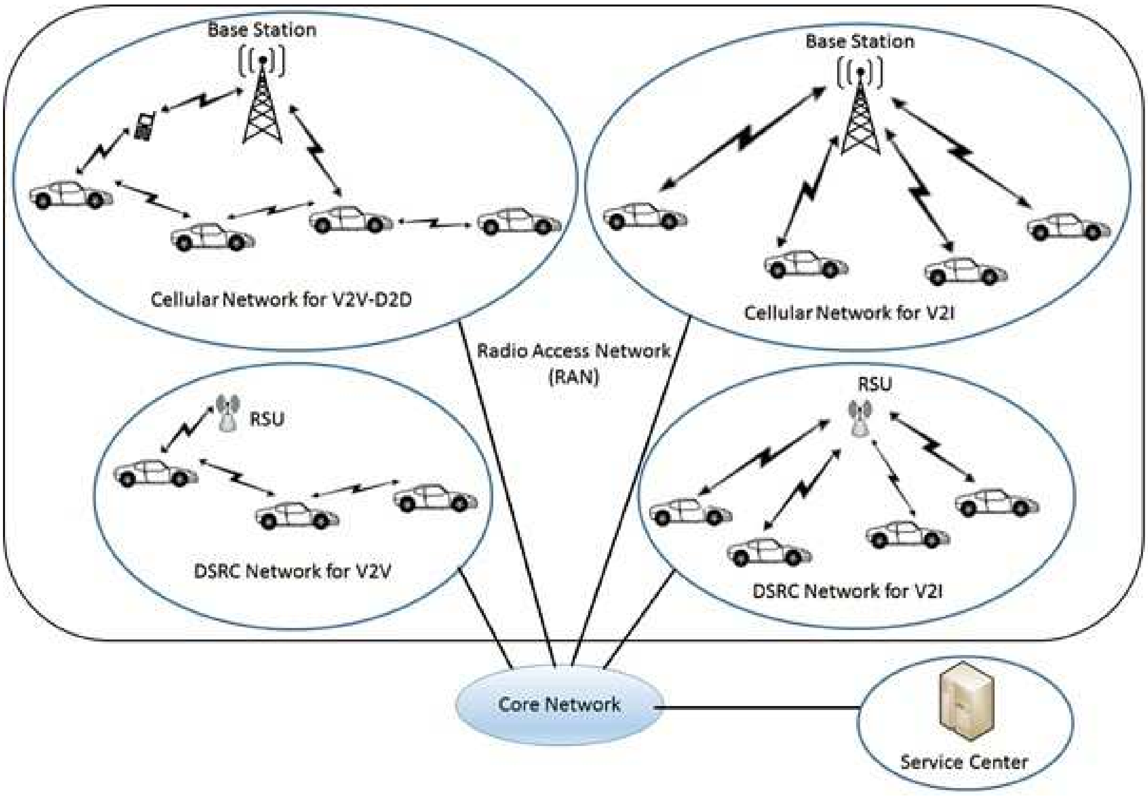

Fig. 1: *Generic Framework Topology of V2X.*

V2I is able to utilize two forms of cellular networks modes of transmission, particularly unicast and multicast/broadcast. Unicast is a point-to-point communication between a vehicle and the base station (also known as the Envolved NodeB (eNB)) which can be used for both uplink and downlink message distributions. Multicast/broadcast is used for the distribution of downlink messages, in other words point-to-multipoint transmission.

LTE is envisioned to well support V2I communications. LTE is able to provide uplink data rates up to 50 Mbps, and downlink data rates up to 100 Mbps with a bandwidth of 20 MHz, and vehicle mobile speed of 350 km per hour. The low transmission latency is credited to the flat architecture of the LTE infrastructure, e.g., the theoretical round-trip time is lower than 10 ms, and the transmission latency in the radio access network up to 100 ms. In general, LTE networks are able to provide high capacity with wide coverage. For instance, LTE can support up to 1200 vehicles per cell in rural environments with an uplink delay under 55 ms. Experiments of trialing LTE in vehicles to support various applications such as infotainment, diagnostics and navigation, have been carried out. The results show that the LTE system is able to provide a data rate of 10 Mbps with a speed up to 140 km per hour [21]. LTE can be particularly helpful at intersections by enabling a reliable exchange of cross-traffic assistance applications. Thus, it is essential to design lightweight joining/leaving procedures for dynamic groups of vehicles. The challenge is how to ensure transmission efficiency while reducing the overhead and to design lightweight joining/leaving procedures for the dynamic behavior of vehicles. Several problems need to be addressed before LTE systems is able to be widely used for V2I communications [22].

Our description on DSRC is based on the WAVE (Wireless Access in Vehicular Environment) protocol. A well-known WAVE technology for vehicular communication is the IEEE 802.11p which is able to execute a robust and quick setup connection. Another feature is possibility to minimize overhead, and thus avoiding packetization operating costs. The DSRC networks is able to perform well in a sparse nomadic environment with static channels. Yet, vehicular communications may take place over severe frequency-selective multipath and fast fading channels, in conjunction with densely populated environments. Hence, there is need for improvement and enhancement in DSRC. In relation to V2I communications, four problems have been identified:

1) Widely spaced pilot layout: The highly mobile dynamic V2I environment produces the problem of Time- and Frequency in a wireless vehicular communication channels. As a result, accurate wireless channel estimation (known as sparse channel estimation) is difficult to be achieved due to wireless propagation. Traditional sparse pilot design are inadequate to accurately estimate the channel state information. Such as problem can only be addressed by increasing the complexity of the receiver.
2) Channel congestion: The Carrier Sense Multiple Access (CSMA) mechanism is employed at the MAC layer of the DSRC network. In this, a node verifies the absence of other traffic before transmitting on a shared medium, in order to avoid collision. However, when there is a large number of vehicles, the probability of collision increases rapidly, resulting in large end-to-end latency and low channel utilization [15], [24]. Despite the method offered, channel congestion has to be dealt with, especially when it comes to QoS requirements of vehicular services [23], [42].
3) Unbalanced link: The coverage capacity of the OBUs and the RSUs are different, which gives rise to the "unbalanced link" problem. For example, a RSU radio communication range to an OBU is up to 1100 meters, whereas from the OBU to RSU it is only up to 400 meters. The specific deployment strategy of the RSUs in a specific area and channel fading are issues that remains challenging from the overall wireless link quality point of view.
4) Service selection: The problems only occur when there exist overlapping coverage areas by multiple RSUs. When an OBU arrives into an overlapping area, it will encounter various services being provided by different RSUs. The OBU may generate a WAVE Basic Service Set (WBSS) with the first RSU in its range. The OBU may change to a different RSU if that RSU offers broadcast service with higher priority. If the services from the other RSUs have lower priorities compared with the first RSU, the OBU does not create a WBSS with any other RSUs, resulting in the possibility to miss any service channel messages or services offered by the other RSUs [25].

The advantages and challenges with V2I are summarized in Table I.

While V2I offers one possibility for emergency vehicles to communicate with TCMs, some of the current challenges might make it impossible to establish a robust connection in time for the TCM to react. Another possibility is then to use V2V in combination with V2I, in order to establish a connection link from the emergency vehicle through a set of other vehicles, to the TCM.

The idea of V2V communications is to have direct connection between vehicles. V2V communications encompasses a wireless network where vehicles transmit data to each other with information. The data would comprise of speed, location, direction of travel, braking, loss of stability and other data [26]. In this subsection, two candidate techniques forV2V communications are discussed in detail.

TABLE I: *Advantages and Challenges in V2I*

Communication Method	Advantages	Challenges
LTE	• Wide geographical coverage. • Better performance when the received signal power is weak. • Low transmission latency. • Design as centralized architecture. • Support a maximum mobile speed of 350 km per hour. • Data Rate of 100 Mbps and Uplink 50 Mbps.	• Data is usually bursty and comprise small chunks, causing it to frequently switch between the connected and idle states. • Excessive amount of signaling overhead is generated, resulting in possibility heavy congestion in the control channels. • Inadequacy scheduling methods for vehicle environments. • Easily to have high signaling overhead.
DSRC	• Able to execute robust and quick setup connection. • The DSRC networks is able to perform well in a sparse nomadic environment with static channels. • Appropriate for local message broadcasting e.g. traffic signal.	• The traffic density of a synchronized flow is much higher, meaning that broadcast messages are likely to be flooded. • Widely space pilot layout. • Channel congestion when in a highly dense environment. • Unbalanced link.

Cellular network has been proposed for V2V (sometimes refer to as device-to-device (D2D)), more specially, taking advantage of the physical proximity of communicating devices in LTE systems [27], [28]. In the LTE-D2D mode, User Equipment (UE)s in close proximity can directly communicate with each other. LTE have serval advantages over DSRC [29]: a) Better Coverage: provide better performance when the received signal power is weak, b) Multiplexing Capacity: provides frequency domain multiplexing of multiple device transmissions, compare to DSRC, where only one device it able transmit for a given channel. However, D2D communications in LTE face several challenges. In LTE, the links share the same radio resources with other links, in D2D environment for other cellular UE whether it is the Uplink or Downlink. Likewise, the interference from neighboring cells is another problem facing for LTE-D2D communications. LTE is a centralized architecture, which means it is not natively support V2V communication.

Generally, D2D in LTE systems by and large are static or of low speed mobility. In a vehicular, vehicles move in medium or high speeds, resulting in severely lower performance of D2D communications. To more precise, the present peer and service discovery of D2D communications does not operate well in V2V environments. For any two vehicles be able to communicate with each other, they have to discover each other, a time consuming procedure. As identified in [30], the discovery period normally is set to 1, 2, 5, or 10 s. Thus, the existing D2D discovery mechanism have a difficult time to meet the strict QoS requirements of safety services.

DSRC has been shown to be effective in supporting services in V2V communications [31]. The physical layer of DSRC has embraces most of the same orthogonal frequency division multiplexing (OFDM) modulation, is able to support a data rate of 3-27 Mb/s on a 10 MHz channel and the performance of DSRC physical layer has been well understood. In a V2V system deploys a decentralized approach, in which DSRC is able organize itself into a mesh network with no external infrastructure required. Since DSRC use different frequency bands than cellular, it will not interfere with cellular networks. However, using DSRC in V2V system presents several challenges [29], [32]. For instance, collisions repeatedly occur in a crowd vehicular environment due the shortcoming of the CSMA design, resulting in comprehensive performance deterioration. Other limitation of DSRC intermittent, and short-lived connectivity. Also, the standard is only able to support a data rate of 3-27 Mb/s on a 10 MHz channel.

TABLE II: *Advantages and Challenges in V2V*

Communication Method	Advantages	Challenges
LTE	• Efficient utilization of the spectrum. • Effective resource scheduling techniques. • Provide better performance when the received signal power is weak. • Multiplexing Capacity.	• Severely lower performance of D2D communications due to service discovery of D2D communications. • Takes time to discover each other. • Interference from neighboring vehicles.
DSRC	• Easy deployment. • Is able organize itself into a mesh network. • Will not interfere with cellular networks.	• Several channel collisions in dense environment. • Only support 3-27 Mbits. • Widely space pilot layout. • High flooding of broadcast messages. • Hidden Node problem.

We can see that recent trends of IT solutions can improve availability for emergency services, communication with other vehicles and infrastructure, besides reducing the travel time. Whether DSRC or LTE communication network is used, they cannot satisfy the QoS requirements for vehicle services. A summary of the advantage and disadvantage wireless communication candidate, DSRC and LTE cellular networks, are presented in Tables I-II. The combination of V2V and V2I or not, wireless technologies enable vehicles to share warning messages with other vehicles. Part of the warning message broadcasts to vehicles are Road Side Unit (RSU). Hence in the next section we will discuss about RSU.

5 RSU

Concerning V2I communications, RSUs act similarly to wireless LAN access points, and can provide communication with the infrastructure. RSUs can collect road information (e.g. speed of vehicle, traffic flow) as well as broadcast warning messages. In our case, this may provide information to city planners in order to improve the safety for vulnerable road users (VRUs, e.g. pedestrians and cyclists). Taking in consideration that RSUs are typically very expensive to install [38], the amount and location of RSUs is a challenge for the planning authorities, especially in suburbs and areas of sparse population. Despite the problem, the planning authorities desire to have a majority of the vehicles be connected to some RSU during its trip [38].

With respect to V2I communications, Wu et al. [33] proposed a method to improve the efficiency of communication between vehicles and RSUs. They proposed that each vehicle determines its own priority of communication, in order to reduce the time required to compete and obtain a wireless channel. Furthermore, vehicles are able to change their priorities as they move away from the communication coverage area from the RSU.

Strategies for content download between RSUs and vehicles were analyzed [34], [35]. The objectives were to reduce the delays of the data being delivered. The use of existing network infrastructures was also Investigated [36], [37]. Other authors studied how to place RSUs. In [38], the RSUs are uniformly located on the map, preventing an unbalanced RSU deployment (i.e., too closely or too sparsely). Other authors [39] propose deployment strategies to deal with the maximum coverage problem (cover as much demand as possible, given a limited set of RSUs). However, the deployment strategy of the RSUs in a specific area is an issue that remains a challenge.

6 Conclusions and discussion

Traffic calming measures (TCMs) can have a negative effect on time critical emergency vehicles travel, including increased response times and repair costs. However, utilizing new, innovative ICT solutions, it is possible to develop TCMs, which will let emergency response vehicles pass, relatively unhindered. One example is speed bumps that are only active when a vehicle is speeding, and that can be adapted to not activate when an emergency response vehicle in approaching. For the wireless communication between the TCMs and the vehicles, LTE (cellular networks) and DSRC (Dedicated short range communication) are two suitable technologies. However, there are still challenges that have to be addressed. Examples of open issues are:

- Handover: It is desired that a vehicle always keeps connected with the most suitable network. With traditional handover methods in cellular networks are mostly centralized, which are not well suited for the hybrid-distributed vehicular architecture. Also, the handover of vehicular users is more frequent than cellular users, resulting in an excessive signaling overhead.

- Big data: All participants in a vehicular environment generators huge volumes of data, e.g., beacon messages, warning messages, and so on. With millions of miles of roads, the sheer number of data points is extraordinary. To achieve an effective balance between information processing and data transmission, advanced data processing and mining techniques are required to find, collect, aggregate, process, and analyze information.

- Cooperation: Due to vehicle mobility, wireless links for vehicular communications are unreliable with limited capacity. Thus, minimizing end-to-end latency and maximizing throughput is important issue. Cooperative communications help address these important issues [35]. Schemes such as link adaptation, relay selection and radio resource management in cooperative communications are important for improving system performance [32, 40]. However, the optimization problem in cooperation is usually NP-hard and computationally intractable. The main issue is how to balance between performance and complexity of the environment.

- Vehicular cloud computing: As computing and communication technologies have been rapidly developed, the vehicles with powerful computing abilities are advocated to be regarded as service providers rather than being only service consumers. As a result, the concept of Vehicular Cloud Computing (VCC) has been proposed, that jointly makes use of computation, communication and storage resources in vehicle equipment [40]. The VCC system has its unique features, for example, one of them is the variability of the available computation resources in Vehicular Clouds (VCs). Due to the uncertainty of the vehicle behavior, i.e., vehicles may randomly join or leave VCs, the resources in VCs are time varying.

Another calming measure that may affect response times is the roundabout, mostly due to the sharp turns that have to be made by the driver when entering and exiting the circulation point. However, this is not the case for mini and small roundabouts as the island can be slightly elevated and constructed with a material that allows vehicles to go straight through. There is also the option of choosing tangential entry and exit points instead of radial, allowing vehicles to have a higher speed when entering and exiting the roundabout.

An alternative to adapting the TCMs to accommodate emergency response vehicles, is to set up emergency routes in the city, with few or no TCMs. In Sweden, there is a handbook for implementation from the Trafikverket (The Swedish Transport Administration) called TRAST (Trafik för en attraktiv stad), which aims to help municipalities to plan traffic infrastructure include TCMs [9]. Moreover, there is a guide, called VGU (Vägar och gators utformning) at Trafikverket that can be used for the geometric design of roads and streets. In this guide, safety and delay times are considered in the geometric design. Additionally Lugna gatan [10] is a planning tool and recommendations for the municipalities, without being national regulations. Hedström and Svensson [7] present a long list with the most common TCMs applied in Sweden. No national guidelines for the implementation of TCMs in Sweden exist to the best of our knowledge. The impression is that each municipality has the possibility to create their own guidelines and implement the kind of TCMs that they think is appropriate.

In Sweden, it is common to evaluate TCMs based on decreased speed instead of delayed travel time, making it difficult to evaluate the effects of emergency response times, based on document and literature studies. When installing TCMs, the municipalities prioritize traffic safety and accessibility for vulnerable road users, which is correct from a safety point of view. However it may be argued that it would be more valuable to choose TCMs with the least impact on several aspects altogether (safety, energy, environment, ERT, etc.).

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