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IMPROVING THE EFFICIENCY OF TRAFFIC AND TRAVEL INFORMATION SERVICES

Marius MINEA[1]

The paper focuses on studying the effects of the communication chain in the total transmission time for systems employing mixed communications (mobile and fixed), for transmitting traffic and travel messages. The communication chain is divided in several components, each of those being analyzed from several points of view.

The final part of the paper is trying to evaluate the amount of energy and/or fuel consumption reduction that a better traffic/travel information service is able to produce on an urban road network, considering the contribution of the communication efficiency. Different elements and physical delays of the signal are modeled and explained. The author takes also in consideration some measurements performed with data collected from Bucharest Traffic Management system.

Keywords: mobile data communication, delay, jitter, energy efficiency. emissions

1. Introduction

Reducing stress and travel time when transiting congested road networks is nowadays depending more and more on information. There are now several methods for route guidance employed onboard of most vehicles, even particular ones, but the efficiency of these solutions rely mostly on the accuracy of static information, such as the configuration of the road network, road signs and static restrictions. More evolved systems employ the RDS-TMC[2] for actuating the information ahead on the route traveled by a vehicle, thus being able, if necessary, to perform corrections if the route is too congested, or if a bottlenecking is envisaged. These devices and services allow for a smoother travel along a congested network, but they rely much on the information collection and on the accuracy of it, as well as on the efficiency of the communication chain. In this paper we evaluate the main constraints in the information chain, to estimate the delay introduced by communication and the efficiency of the real-time traffic and travel information services in terms of fuel consumption and/or energy efficiency.

Technical literature presents now new advances in vehicular ad-hoc networks (VANETs) [1] and several studies and experiments are performed

[1] Assoc. Prof., Dept.of Telematics and Electronics for Transports, University POLITEHNICA of Bucharest, Romania, e-mail: marius.minea@yahoo.com

[2] RDS-TMC – Acronym for Radio Data System – Traffic Message Channel – a technology using FM radio carriers to transmit traffic and travel relevant information on dedicated channels

worldwide to achieve rapid, efficient and secure communication among the vehicles participating in a cluster of information exchange [2]. Until this will become a proven technology, with solid results, the vehicular communication remains still a side that has not yet been addressed by the mobile real-time traffic and travel information services (MRTTI). While for a normal user, such a person driving his/her own car and employing real-time traffic and travel information, the efficiency of the communication network is not crucial, this becomes critical when it comes to special appliances such as emergency vehicles and *e-CALL* services. The author has previously investigated such cases in several papers [3]. [4] and came to the conclusion that for critical services a smooth operation of all factors involved in information transmission is very important. Traffic congestion has an impact on both the speed of travel and on the reliability of travel conditions and it is crucial to collect relevant information of congestion and bottlenecking points for delivering them to mobile users. Congestion in traffic may be *recurrent* in case of factors that act regularly or periodically in the transportation system such as commuters, daily flow to work etc., or *non-recurrent,* when atypical events occur on the road network (traffic accidents, civil works, large meetings etc.). One important element in the information chain is the correct collection of relevant information, and because we speak about automatic data collection, this component is the responsibility of the traffic management system (TMS). In other words, if this information is trustful and available at the output of the TMS in due time, then only the mobile communication chain will be responsible with the correct and on-time delivery of relevant information to emergency vehicles that need route guidance. In the case of *e-CALL* services, the communication depends on the coverage of the GSM network, because the concept refers to all the systems and services that allow a vehicle involved in an accident to automatically connect to a safety authority employing this kind of communication. The vehicle opens a voice channel in a GSM channel and sends over a data link selected information to identify itself, its position and the severity of the accident. In this case, the efficiency of the communication relies primarily on the GSM signal availability. Because *e-CALL* and MRTTI services rely on mobile communication networks that employ fixed base stations, the efficiency of the communication and the delay experienced are dependent on the load of the networks. If in cases of congested GSM networks, complementary VANET communications could be used, the efficiency could be probably improved, but this approach has not been yet addressed. The following section of the paper will focus on the analysis of the information transmission chain.

2. Case Analysis

Considering the elements of a data communication chain between information collection and delivery, and the quality of information delivery service, a model for the information flow can now be imagined. The information chain contains the following reference points:

- Data collection and interfacing with third-part systems that provide data;
- Processing of relevant data, filtering and formatting of messages in the central node of the MRTTI system;
- Communication chain via mobile and fixed networking;
- Local processing and information delivery.

Let's consider now that the MRTTI system is collecting relevant information from two types of sources: a Traffic Control System (TCS) and a Car Fleet Control System (CFC-AVL[3]). The latter has the ability to collect *floating-car* data, such as time to travel a certain segment of a route, thus collecting relevant traffic congestion information.

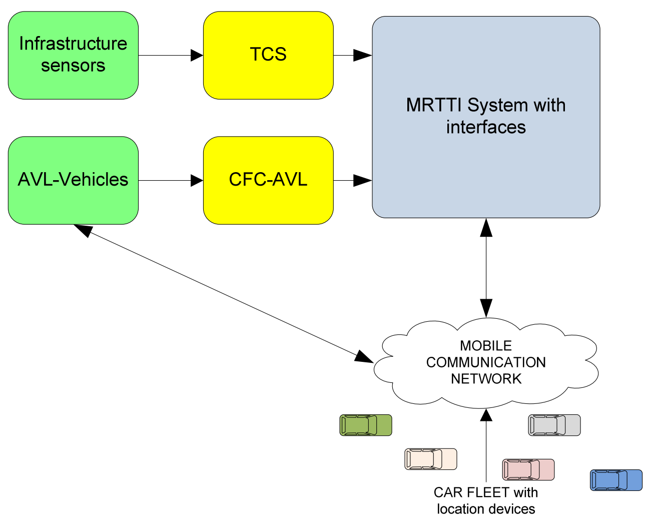

Fig. 1 A structure for the information Chain

In Fig. 1 above, the MRTTI data is collected employing the two technologies simultaneously. This involves that in the real-time traffic and travel information system the information will need specific processing (contents

[3]AVL – Automatic Vehicle Location – a system with the ability to collect relevant information regarding a vehicle's position and dynamic parameters, such as speed and bearing, travel time etc.

correlation, computing, map matching and formatting). In such a system there is also embedded a certain degree of redundancy, as similar information is expected to be collected both from the UTC and the CFC[4] subsystems.
Considering the chain where information is processed, the following relationship expresses the delay experienced by data, as presented in [4]:

$$T_{id} = max\{(T_a^{TCS} + \delta_1^{cn}), (T_a^{CFC} + \delta_2^{cn})\} \quad (1)$$

if multiple sources of information are used by the MRTTI service or, in case of a single source, one of the following:

$$T_{id}^{TCS} = T_a^{TCS} + \delta_1^{cn} \quad (2)$$
$$T_{id}^{CFC} = T_a^{CFC} + \delta_2^{cn} \quad (3)$$

In the equations above, T_{id}^{xx} denotes the moment where relevant MRTTI information becomes available at the interface of the traffic control centre, respectively car fleet control centre interfaces commonly or independently, in the second and third cases. The factors T_a^{xx} represent a measure of the quality of service offered by the information provider, i.e., the traffic control centre or the car-fleet management centre. This quality of service relies on several aspects:

- A flawless operation of all sensors and internal communication network for the TCS;
- Availability of traffic data in appropriate format at the output interfaces of the TCS and CFC subsystems;
- Delay produced by data conversion to appropriate external/internal formats (here, especially for the GSM coordinates and reference geodetic system employed, conversion to different map formats for web transmission, such as WFS[5] and WMS[6]);
- A low influence (in terms of delay) produced by the protective measures such as firewalls, anti-virus software etc.

The terms δ_i^{cn} denote the global delay that a communication network, either fixed or mobile, used for data transmission, produces to the relevant message. Considering the quality of service (QoS) produced by such a communication network, the following components may be relevant in a data transmission:

[4] CFC – Car Fleet Control system – an automatic vehicle monitoring system employing GPS and communication techniques, installed onboard fleet vehicles
[5] WFS – Web Feature Service interface standard – a specific interface allowing requests for geographical features across the web
[6] WMS – Web Map Service – a standard protocol for serving georeferencd map images over the internet

- The *throughput* due to varying load produced especially in crowded network communications:
- The number of *dropped data packets* due to the failure of some routers in delivering information. The receiving application may ask for a retransmission, inferring a delay;
- *Latency* due to longer routing or queuing of data packets;
- *Jitter*, producing different delays arriving to destination to different data packets, when lengths of packets' routes vary unexpectedly;
- Employing supplementary correction protocols for cases when disorder in package contents is expected to occur, that may also induce delaying in message delivery.

Considering the above, the term δ_i^{cn}, representing the delay introduced in message delivery by the communication network may be formulated as:

$$\delta_i^{cn} = D_d + \xi_l \cdot \delta_l + \xi_j \cdot \delta_j + \delta_{pp} \tag{4}$$

$$D_d = \sum_{d=1}^{N} \{\xi_d \, n_d t_d\} \tag{5}$$

The D_d term models the total delay in case of lost data packets, where ξ_d is the probability of a packet to be lost in a transmission, n_d is the identity of a lost packet, *N* the total number of lost packets and t_d the delay induced by the retransmission of a single lost packet.
The delay introduced by latency is modeled with $\xi_l \cdot \delta_l$, where ξ_l represents the probability of packet queuing and δ_l the delay introduced by the queue.
The delay introduced by jitter is contained in the term $\xi_j \cdot \delta_j$, with ξ_j the probability of experiencing jitter in a congested communication network and δ_j the delay introduced by jitter. The term δ_{pp} refers only to cases when specific additional software induces more delaying in data processing.

As presented in [4], if a MRTTI service involves mobile communication, this segment has also to be analyzed in terms of QoS. This behavior of the network in different scenarios has been previously discussed in literature. In [5], the authors take into account the PAL[7] model for the mobile communication network load produced by vehicular technologies. PAL model can be also considered as a load model that enables description of key factors such as the density of calls in a crowded network, handoff rate, density of originating calls, density of terminating calls, thus formulating a global estimator of latency in delivering a specific traffic message. Considering the ideas presented in [5], we can further consider that traffic involved by a MRTTI service in a mobile

[7] PAL – Poisson Arrival Location modelling of a common approach between mobile communication network load and vehicles arrivals in a measurement zone

communication network employed for emergency vehicles may occur in the following situations:

- Requested mobile communications with EVs for establishing their position on the network; these involve communications with non-calling vehicles;
- Communications with EVs for delivering route guidance; these represent communications with calling vehicles, or vehicles that need intense data traffic for route guidance or additional communications.

This type of modeling is useful when there is need to establish traffic and QoS in a typical GSM cell, in order to determine if the cell is able to handle communications with the requested level of QoS.

We can consider the time non-homogeneous deterministic model presented in [6]. Starting from here, $I(\mathrm{x}, \mathrm{t})$ and $A(\mathrm{x}, \mathrm{t})$ represent the total number of inactive (non-calling vehicles), respectively active (calling) vehicles at position (0, x] at moment t (Fig. 2).

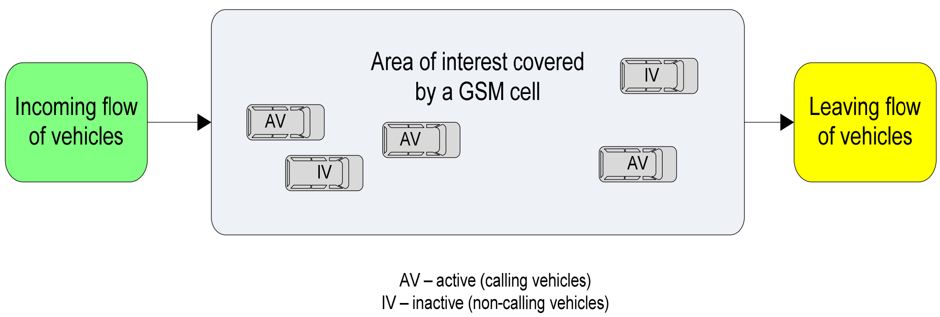

Fig. 2 Area of interest for the PAL model

Space density of the active and inactive EV can therefore be deduced from:

$$i(x,t) = \frac{\partial I(x,t)}{\partial x}, \; a(x,t) = \frac{\partial A(x,t)}{\partial x} \tag{6}$$

Let's now consider $V_i^+(x,t), V_i^-(x,t)$ the number of inactive vehicles entering and respectively exiting the location *(0, x]* and $V_a^+(x,t)$, $V_a^-(x,t)$ the correspondent number of active vehicles (Fig. 2, from the incoming flow of vehicles and the outgoing flow, respectively). The rate densities are then:

$$v_i^+(x,t) = \frac{\partial^2 V_i^+(x,t)}{\partial x \partial t}, \; v_i^-(x,t) = \frac{\partial^2 V_i^-(x,t)}{\partial x \partial t} \tag{7}$$

and

$$v_a^+(x,t) = \frac{\partial^2 V_a^+(x,t)}{\partial x \partial t}, v_a^-(x,t) = \frac{\partial^2 V_a^-(x,t)}{\partial x \partial t} \quad (8).$$

Considering that, in this case, the system uses a polling reporting technique, equation (4) needs also to be modified for multiple requests/answers involved in this process:

$$\delta_i^{cn} = \xi_{lr} \sum_{i=1}^{n} \delta_i^{cnr} + \xi_{la} \sum_{j=1}^{n} \delta_j^{cna} \quad (9),$$

where δ_i^{cnr} (requesting data) and δ_j^{cna} (answering) represent mobile communication delays experienced on each of the n steps of the polling process. The terms ξ_{lr}, ξ_{la} represent the probabilities of experiencing jitter and packet losses on the vehicle-infrastructure (request of data – r) path and on the infrastructure-vehicle (answer – a) path.

Now it can be considered that equation (9) may be further developed taking into account the number of active (communicating) vehicles by combining it with the results obtained in (7) and (8):

$$\delta_i^{cnr} = \sum_{a=1}^{m} \left(\int_{-\infty}^{t} v_a^{+}(x,t) \right) + \sum_{a=1}^{n} \left(\int_{-\infty}^{t} v_a^{-}(x,t) \right) \quad (10)$$

$$\delta_i^{cna} = \sum_{a=1}^{p} \left(\int_{-\infty}^{t} v_a^{+}(x,t) \right) + \sum_{a=1}^{q} \left(\int_{-\infty}^{t} v_a^{-}(x,t) \right) \quad (11)$$

in which *m, n, p* and *q* denote the total number of polling active vehicles entering, respective exiting the geographical area *(0,x]* covered by a GSM base station.

Considering space and time for this case, the total delay in delivering the data from/to a vehicle is dependent on the density of active communicating vehicles, but also on non-active communicating vehicles, because the latter also need to report their positions regularly.

For the case of an emergency situation, it also should be considered that in these calculations an important factor may contribute to the network congestion: the number of active calls made by private public. This case is particularly possible when large disasters occur, and people use their cellular phones to make calls. On the contrary, in case of less major emergencies, such as traffic crashes, fire etc., this situation may not influence the normal behavior of the cellular network, in terms of latency an QoS.

As stated in previous research [4], it becomes clear that the emergency services should not use for vehicle route guidance and location public cellular networks or usual public channels, unless they employ virtual private networking with priority channels.

Also, envisaged vehicular technologies might contribute to reduce GSM load with traffic messages if new developments will consider integration with MRTTI services. The vehicular communication technology involves a larger and more dynamic set of nodes in a communication network topology, delivering more room to messages. However, employing such kind of communication for

MRTTI services designed to serve emergency vehicles might not incur the security level needed.

4. Environmental Protection Induced by MRTTI Services

Some research activities [7] and implementation of services across Europe has tried to demonstrate the benefits of mobile real-time traffic and travel services in inducing different drivers' behavior in traffic, with benefits in reducing fuel consumption, emissions and stress. It is a known fact that modal shift towards public transport reduces the traffic demand of passenger cars, which have a considerable environmental impact in urban areas. Therefore the possible effect of mobile real-time traffic and travel information is of particular importance.
The case considered is for Bucharest Traffic Management System, where some data has been collected in several tests between 2009-2011.

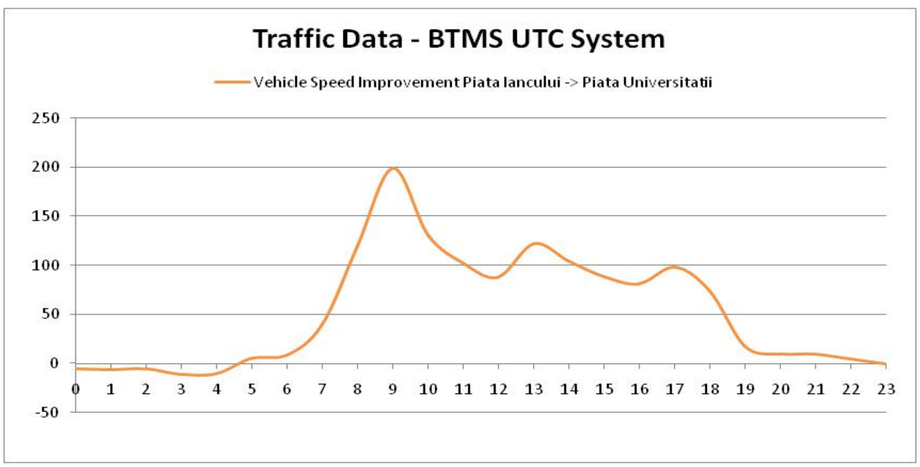

Fig. 3 Vehicle speed improvement on a traffic sector analyzed (source: *In-Time project,* [7])

Usually, fuel consumption of a vehicle is computing employing the following formula [7]:

$$C_f = 1.609(d \cdot v)k_1 + 3.9 \cdot 10^{-4} \cdot v^2 \qquad (12)$$

where d denominates travel distance in km, $k_1 = 0.07523 - 0.00411 \cdot v^2$, v is the speed of the vehicle in km/h.
Correct service and usage of a MRTTI service assumes increasing the vehicles' speed on a guided route, also increasing the level of particles and gas emissions per individual vehicle. This behavior is, however, more intense for specific pollutants, such as PM10, than for others, such as NOx, where the dependency

with vehicle speed is relatively limited. Recent studies in the environmental impact revealed that, for very high or very low speeds of vehicles, a relatively small modification of the speed produces major changes in pollutant emissions. For example, when increasing the average speed of the vehicle from 5 km/h to 10 km/h (increase of speed gained by reducing traffic jams, the case usually obtained with mobile real-time traffic information systems), the pollutant emissions observed decrease with a percentage of up to 20%.

$$\begin{gathered}\textit{Equivalent no. of vehicles/h} = 35067/24 = 1461{,}125\ [\text{veh/h}] \\ \textit{Average speed} = 1161/24 = 48{,}375\ [\text{km/h}] \\ \textit{Fuel consumption}\ (10/100)*7=0.7\ [\text{l}] \\ 0.7 *1461 = 1029.7\ [\text{l}] \\ CO_2 = (1029.7 * 69.9)/1461\ \text{g/l} = 49.26\ [\text{g}] \\ NOx = (1029.7\ \text{l} * 13.6)/1461\ \text{g/l} = 9.5\ [\text{g}] \\ VOC = (1029.7\ \text{l} * 16.2)1461\ \text{g / l} = 11.41\ [\text{g}]\end{gathered} \tag{13}$$

Of course, the case considered above is not real, as there is also an improvement in vehicle flowing due to the centralized command of traffic signs.
It is essential to consider that, in order for a mobile real-time traffic information service to be effective, the number of users employing it should be as large as possible. This allows for a change in drivers' behavior, reducing congestion and increasing speed. The amount of emissions is envisaged to be decreasing, because even if the vehicles travel faster and produce more emissions, their density becomes lower.

5. Conclusions

The recent development of high-speed data transmission over GSM and LTE networks allow for an expansion of mobile real-time traffic and travel information services. In this paper, a model for the elements that produce delay in data transmission has been provided, with focus on the communication link. However, it results that only for critical cases, such as major disasters, when communication channels are over-saturated with calls for emergency, the communication link may fall in delivering on-time messages. In these cases an important factor may contribute to the network congestion: the number of active calls made by private public. Such case analysis is useful especially for emergency services route guidance. On the other hand, if MRTTI is used by a large amount of drivers, this may result in reducing travel time, modifying the behavior in traffic, with positive results in what concerns the emissions and traffic congestions. In a near future, it may be possible to integrate MRTTI also with vehicular networks, allowing for a better usage of bandwidth in an integrated communication networking. Concluding, it appears that for a MRTTI service to be more effective, it needs:

- To use reliable sources of information (TCS in combination with car-fleet management systems, allowing for data collection by the *floating-car* method from its own users);
- To employ different communication channels, or even integrated communication networks;
- To use separate channels from public traffic, thus avoiding delaying the messages due to network congestion;
- To employ standards accepted for map requesting and delivery over the Internet, to allow for up-scaling the system;
- To be cheap and public friendly, in order to expand its usability to as many as possible drivers.

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