8th International Conference of Modeling and Simulation - MOSIM'10 - May 10-12, 2010 - Hammamet - Tunisia
"Evaluation and optimization of innovative production systems of goods and services"

SAVE TIME: A SMART VEHICLE TRAFFIC INFORMATION SYSTEM

N. COTTIN, C. DUMEZ, M. WACK, J. GABER

University of Technology of Belfort-Montbeliard / Systems and Transports laboratory
Rue Thierry Mieg, 90010 Belfort Cedex - France
nathanael.cottin@yahoo.fr, dchris@gmail.com, maxime.wack@utbm.fr, gaber@utbm.fr

ABSTRACT: *This article introduces SAVE TIME, a SmArt VEhicle Traffic InforMation systEm designed to overcome current vehicles guidance limitations due to traffic information and routes planning shortcomings. This informative system contributes to safer driving conditions in collecting, elaborating and disseminating real-time local traffic information. Different architectural designs based on specialized Location-Based Services and Spatial Registries are proposed and discussed.*

KEYWORDS: *SAVE TIME, Traffic Information System, Location-Based Service, Spatial Registry.*

1 INTRODUCTION

Official estimates presented at the European Conference of Ministers of Transport (ECMT, 1999) demonstrated that "road congestion costs, including commuting and leisure traffic as well as business and freight traffic, amount to an average 1 percent of gross domestic product (GDP) in the European Union, with Britain and France at 1.5 percent". This represents a 126 billion euro waste. As one would expect, ECMT concludes that reducing traffic congestions is an important concern for economical, environmental and social reasons.

Latest mobile navigation devices integrate impressive technologies to contribute to safer transportation. These technologies intend to provide drivers with a better quality of service, including 3D maps, lane placement assistance, realistic motorways junctions, road signs indications, speeding warning and traffic congestion information. However, it remains difficult to keep vehicles informed of their near future driving conditions, especially when traffic congestions occur. Existing systems, mainly motorway traffic information radio channel and information boards, suffer from information inaccuracy (latency, erroneous or incomplete information), availability (information is not given when needed) and relevancy (useful information is spread in a huge amount of information which do not concern drivers itineraries). Conforming to visual or vocal indications given by navigation devices leads to regularly bring drivers straight into congested roads. Suggested itineraries also either invite drivers to take closed roads or, on the contrary, dissuade drivers from taking re-opened roads, even when traffic information is received by these navigation devices. In both cases, drivers are not able to determine whether the suggested itineraries are optimal or could be improved.

This paper introduces SAVE TIME, a traffic information system specialized in real-time local traffic supervision used to perform route planning. This innovative system relies on two main complementary components: (1) specific Location-Based Services (LBSs)[1] called Traffic Information Services (TISs) and (2) registries specialized in LBSs registration and discovery, called Spatial Registries, introduced in (Cottin and Wack, 2009). Thus vehicles receive fresh and relevant traffic conditions information which can be integrated to optimal itineraries computation processes. Wischoff et al. point out in (Wischoff et al., 2003) that most traffic information or management systems are based on centralized architectures. These systems need to filter a huge amount of information coming from all involved vehicles and sensors, independently from their location. On the contrary, SAVE TIME is a scalable system which relies on a distributed architecture thanks to dynamically discovered LBSs to process local traffic information.

The remainder of this work is organized as follows: next section covers an extensive related work and emphasizes traffic information shortcomings; section 3 presents SAVE TIME's operations and deconges-

[1] The OpenGeospatial Consortium defines a LBS as "any application service that exploits the position of a mobile terminal". Complementary definitions of LBSs structural and behavioural properties are described by Bakhouya and Gaber in (Bakhouya and Gaber, 2008) and mathematically expressed by (Cottin and Wack, 2009).

tions benefits. The internal architecture and components are described in detail in section 4. Section 5 is dedicated to TISs selection and handover procedures. Next section reports common security considerations. Finally, conclusions draw the benefits of this system and outline future improvements.

2 RELATED WORK

Compared with many existing traffic information and management systems, SAVE TIME particularities and innovations are highlighted.

2.1 NOTICE

A secure, privacy-aware architecture for the notification of traffic incidents called NOTICE is suggested in (Abuelela et al., 2008). This solution involves sensor belts embedded in roadways. Traffic-related messages or advisories are disseminated from one belt to another by passing vehicles. Decisions regarding this information are taken by the infrastructure rather than vehicles.

Although this approach is secure and guaranties drivers privacy, its main drawback lies in the necessary investment required to equip roadways with sensor belts. Moreover, data transportation between belts is assured by vehicles. This induces latency and reduces reliability (Wu et al., 2004). Indeed, this system is dedicated to two-way roads and the collected information will not be disseminated upstream unless there are vehicles going on the other way.

Compared with this system, SAVE TIME does not need any road sensor to collect information, although sensors could be integrated in our architecture. Traffic information is primarily sent by vehicles directly to the infrastructure (i.e. TISs components) in real-time.

2.2 StreetSmart Traffic

This traffic information system, introduced by (Dornbush and Joshi, 2007), combines GPS driving assistance with peer-to-peer wireless communication to discover and disseminate traffic congestion information using vehicle ad-hoc networks (VANETs). This solution is based on vehicle-to-vehicle (V2V) communication using 802.11 or 802.15 wireless technologies.

Unfortunately, one could challenge the reliability of the system due to difficult communication conditions, such as high velocity, bad weather conditions, obstacles (e.g. buildings) and wireless interferences. Another issue is that the VANET is regularly disconnected when not enough vehicles take part in the network, which may render data dissemination difficult and unreliable.

To overcome these issues, SAVE TIME primarily relies on vehicle-to-infrastructure (V2I) communication to collect and disseminate traffic information. Use of V2V communication is also considered in the sole case the infrastructure cannot be reached directly. Thus information is passed between vehicles until the infrastructure is contacted.

2.3 TraffCon

An intelligent traffic management system for wireless vehicular networks called TraffCon is proposed by in (Collins and Muntean, 2007). This system focuses on travel links, i.e. road segments located between two junctions. TeaffCon makes use of the IEEE 802.11p Wireless Access in Vehicular Environments (WAVE) being standardized. The authors describe mainly three important steps: data harvesting (which associates a delay with a travel link), data processing (which basically computes average delays for road links) and decision making (a WAVE-compliant server makes use of genetic algorithms to adjust routes and communicate re-routing results to vehicles). A strong feature of WAVE is that it allows both V2I and V2V communication, rendering the system more robust.

Although TraffCon reduces information redundancy, a possible shortcoming of this system is that there is no traffic congestion detection on the vehicle side. The vehicles simply communicate the time it took them to travel links (i.e. sections of road between two junctions). This can decrease the system reactivity when vehicles are stuck on a link.

SAVE TIME suggests to regularly disseminate information, independently from vehicles locations, rather than punctually send information when specific checkpoints are reached.

2.4 SOTIS

Being part of the FleetNet project, SOTIS is a self-organizing traffic information system put forward by (Wischoff et al., 2003). This system solely relies on inter-vehicle communication using GPS receivers and digital radio equipments to send traffic information. Each participating vehicle communicates every 5 seconds a periodic report to surrounding vehicles. This report encloses the issuing vehicle's current position and traffic information. In addition to periodic reports, emergency reports are sent as soon as an emergency is detected. Complementary to their geographic information systems (GISs), vehicles store reports in their local knowledge database. Traffic information distribution is performed by three embedded components, namely "Receive", "Analyze" and "Send": "Receive" integrates received reports, "Analyze" elaborates relevant information from reports and "Send" determines the delay before sending the next report to close vehicles.

V2V communication drawbacks (such as unreliable communication channels, vehicle failure, high mobility and network partitioning) have been pointed out by (Wu et al., 2004). Furthermore, decision making is achieved by vehicles based on their close traffic information. This lack of a global view of the current traffic conditions may lead to generate non-representative reports and new traffic congestions. Vehicles may also generate conversing reports.

The two main differences with SAVE TIME are (1) the primary use of a V2I architecture and (2) the notion of adaptive reporting: the delay between reports is updated by each TIS at run time.

2.5 CarTel

This traffic regulation project described by (Bychkovky et al., 2006) is currently being tested by the MIT's Computer and Artificial Intelligence Laboratory on a 50 vehicles fleet (including 40 taxis). This system is used to create traffic models and predict traffic congestions. CarTel combines Quick WiFi, 30 times faster than traditionnal WiFi, Internet communications and Pothole Patrol (P2) technologies. The latter is used to automatically detect roads surfaces drivability and holes. The MIT also designed an algorithm able to synthetize up to 600 information per second for the sole purpose of this project. CarTel basically decomposes a wide area into small square pieces and calculates the average delay to get from one square segment to another. Vehicles equipped with client-side components of this system connect to a central server via the Internet to collect information.

Contrary to SAVE TIME, this system lacks direct relation with a geographic information system which could be helpful to refine the elaborated information, such as roads names and both-way roads directions concerned by congestions.

2.6 Dash GPS system

This traffic information system proposed by (Dash) is officially available in the United States only. Each vehicle periodically transmits its current position and speed information to Dash servers using anonymous V2I communication (using WiFi or GPRS technologies). This way, Dash servers can compute each road segment's average speed and use predictive algorithms to estimate near future traffic flow on that segment. It disseminates this information to all vehicles in the network every few minutes. Dash suggests up to three different routes to a destination and uses its traffic information to calculate the Estimated Time of Arrival (ETA) for each route. The driver then decides which route to follow. Dash differentiates stop-and-go traffic, moderate congestion, relatively unobstructed and free-flowing roads to help vehicles take re-routing decisions.

As many existing systems, Dash incorporates road sensors information and traffic flow history. On the contrary, SAVE TIME does not need specific infrastructure components (mainly road sensors) to mine information sent by participating vehicles.

2.7 TMC

The Traffic Message Channel system (TMC), supported by the Traveller Information Services Association (TISA), formerly known as TMC forum, is available in Europe. This traffic information system allows devices get access to near real-time traffic information. Information is disseminated (either in clear or encrypted) by means of a Traffic Information Center (TIC) on FM radio frequencies through the Radio Data System (RDS) by means of National Marine Electronics Association (NMEA) 0183 alarms. TMC Compendium specifies in (TMC Compendium, 1999) that each TMC message encloses information expressed in Alert-C (ISO 14819 set of standards). Alert-C messages exchange protocol conforms to ENV 12313-1 up to ENV 12313-3 standards.

Broadcasting traffic information by means of radio stations may be efficient. However, many TMC technical disadvantages, such as information inaccuracy, are highlighted in (Wischoff et al., 2003). The most important drawbacks lie in the 20 to 50 minutes effective delay before information distribution (although the TISA mentions TMC messages dissemination every 3 or 5 minutes) and the large number of sensors needed to monitor traffic states.

Contrary to TMC, SAVE TIME manipulates real-time and accurate traffic information sent directly by vehicles without requiring road sensors nor human intervention. As previously mentioned, information is regularly sent by vehicles to the infrastructure to either update (modify) traffic information or confirm existing information. A simple request-response protocol can be used to make sure that each vehicle sending its local traffic information gets fresh information in return.

2.8 SAVE TIME specificities

Compared with the previously mentioned research and commercial projects, our approach is mostly inspired by CarTel and Dash projects as it manipulates vehicles average speed, which appears to be a simple and valuable indicator. SAVE TIME also relies on the periodic reporting principle introduced by SOTIS.

The main difference with the existing literature lies in the fact that SAVE TIME is completely distributed. It also takes advantage of Spatial Registries and LBSs to collect and disseminate local information in real time. As previously mentioned, our system does not necessarily require road sensors to operate, although sensors could be part of the infrastructure components. However, information issued by sensors, such as vehicles count, may advantageously complete raw information sent by vehicles. SAVE TIME is designed to be a lightweight and scalable system thanks to adaptive local information reporting and dissemination (i.e. reports and notifications issuance frequencies are adapted at run time to stabilize infrastructure components loads) by TISs. Robustness is achieved by preferring a V2I architecture to a V2V system. V2V communication is solely used to propagate information between vehicles and the infrastructure in the particular case the latter is not directly reachable. A V2I design intrinsically provides more accurate information due to a higher-level view of the system, compared with very local information exchanged between vehicles. Finally, SAVE TIME's ability to dynamically integrate external LBSs can contribute to provide more accurate traffic information.

3 OPERATION OVERVIEW

3.1 System classification

According to the classification proposed by (Collins and Muntean, 2007), SAVE TIME is a distributed traffic information system which primarily makes use of V2I communication. It automatically elaborates local relevant information in real-time and disseminates this information by means of notification messages. This information derives from raw information sent by reporting vehicles.

3.2 Messaging

Each vehicle involved in SAVE TIME contacts a Spatial Registry to discover one or more suitable TISs. A vehicle receiving a network reference to a TIS periodically transmits status reports comprising location, direction and speed (velocity) indicators. It may also submit punctual alerts (e.g. slippery roads) to this TIS independently from reports deliveries. From the infrastructure perspective, TISs periodically compute average speeds per road segments from collected reports (as previously said, based on CarTel and Dash improved principles) using data mining techniques. This mainly allows detecting forming traffic congestions, as shown by figure 1. Such relevant information is then regularly disseminated to vehicles located in TISs coverage areas. Each vehicle is thus periodically notified of latest local traffic information. This information can be used to update its current itinerary in real time and optimize travel time.

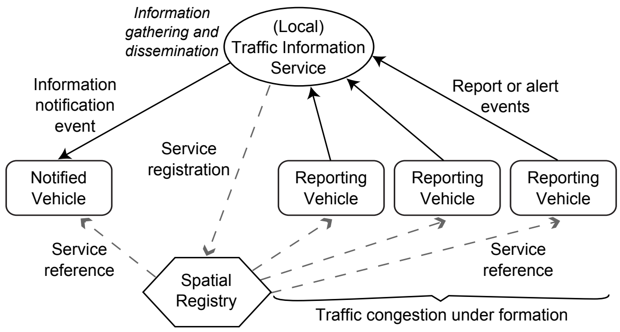

Figure 1: Components behaviour

3.3 Itineraries computation and re-routing

SAVE TIME does not directly interfere with itineraries computation but notifies navigation devices of their local traffic conditions. Combined with global traffic information systems (such as TMC), SAVE TIME real-time local traffic information allows to determine optimal itineraries on long distances. Itineraries can be updated in real time using re-routing techniques based on TISs notifications.

SAVE TIME contributes to limit new congestions generation without requiring V2V exchanges when vehicles are re-routed. A group intelligence between close vehicles is intrinsically created as each participating vehicle's current position and average speed is integrated in reports sent to TISs. Vehicles taking a similar alternative itinerary will necessarily reduce their average speed as far as this road segment becomes loaded. Indeed, a future TIS notification will propagate this load information to close vehicles. Therefore, their navigation devices will privilege other alternative itineraries.

4 ARCHITECTURE

4.1 System actors

As depicted by figure 2, SAVE TIME defines the following system actors:

- Local *Traffic Information Services* (TISs), which gather and provide local traffic information to requesting vehicles located in their coverage areas. A simple request-response protocol may be used to ensure that participating vehicles get fresh traffic information each time they send their local information to a TIS;
- *Vehicles*, which periodically send their own local information (including traffic reports and alerts) and receive traffic information notifications from their selected TISs;

- *Spatial Registries*, which register and publish TISs references. They also allow optimal TISs discovery based on vehicles locations.

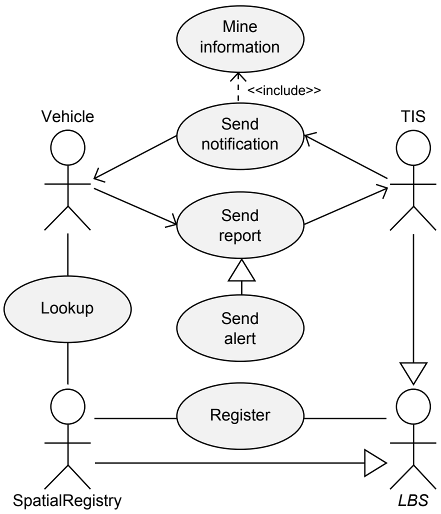

Figure 2: SAVE TIME functionalities

In this model, vehicles are considered in place of drivers or navigation devices, although drivers could manually generate alerts.

Both TISs and Spatial Registries are defined as particular LBSs. Extending this model to integrate external LBSs so that TISs can refine their traffic information is straightforward.

4.1.1 Services providers

SAVE TIME currently specifies LBSs specialized in traffic information known as TISs. Each TIS collects raw information from vehicles located in its coverage area and periodically informs vehicles about their local traffic conditions in return. TISs' coverage areas, as defined by (Cottin and Wack, 2009), are expressed using roadmaps to minimize uncovered areas while avoiding redundancy. Ideally all TISs should partition the global geographical coverage area so that a given vehicle needs to be in contact with a single TIS at a time. Although the number of TISs may evolve at run time, the optimal number of TISs is determined by the global coverage area (which corresponds to the union of all TISs' coverage areas) and the average load of each TIS. One could also assign a TIS per political region.

Fault-tolerance can be supported by means of spare TISs: vehicles are in contact with a primary TIS. A secondary (i.e. spare) TIS may replace the primary TIS in case it unexpectedly shuts down. In order to maintain a coherent state between primary and secondary TISs (during primary TISs activity), an inter-TISs communication protocol must be defined. This protocol basically forwards latest results mined by primary TISs to their corresponding spare TISs.

As previously mentioned, many other LBSs (i.e. services providers) could be integrated to provide TISs with more accurate and complementary information, such as meteorology, roadworks or local events (sports, music concerts, etc.) in order to more precisely predict congestions.

4.1.2 Vehicles

Referring to figure 1, SAVE TIME manipulates different kinds of vehicles which may be declined as follows:

- A *reporting vehicle* denotes a vehicle participating in the information collection process. It makes the infrastructure (i.e. TISs) aware of its latest local driving conditions;
- A *notified vehicle* obtains local traffic information (i.e. notifications issued by TISs) elaborated from close vehicles reports.

After selecting the most appropriate TIS using a Spatial Registry, each vehicle periodically sends fresh traffic reports to its TIS. Vehicles punctually become notified vehicles when asking the infrastructure for traffic conditions around their current location. Such vehicles are either unaffected by their current TIS notifications or re-routed (in case their embedded navigation devices suggest alternative itineraries, mainly to avoid traffic congestions). Thus, depending on the impact of the received information on the current vehicle's itinerary, a *notified vehicle* is either:

- A *re-routed vehicle*: refers to a notified vehicle which follows an alternative itinerary based on its received information from its local TIS;
- An *unaffected vehicle*: a notified vehicle which is not re-routed; traffic information notifications from SAVE TIME do not lead to update this vehicle's current itinerary.

4.1.3 Spatial Registries

Traditional registries, such as UDDI (OASIS, 2004), intend to register services and provide services references to requesters. Even if LBSs may be registered within traditional registries, efficient registration and discovery requires specific registries. LBSs specificities (such as coverage areas) and efficient LBSs retrieval based location-based requests processing are highlighted by (Cottin and Wack, 2009) to introduce Spatial Registries and motivate their need.

The LBS abstract actor specializations in figure 2 illustrate, from the infrastructure perspective, that each key component manipulated by SAVE TIME (i.e. Spatial Registries and TISs) is primarily a LBS.

4.2 Functionalities

According to the use cases of figure 2, SAVE TIME offers the following functionalities to vehicles:

- *Register*: used by a LBS, such as a TIS, to register within a Spatial Registry. Selection of the most suitable registry is discussed in (Cottin and Wack, 2009);
- *Lookup*: used by a service requester (i.e. a vehicle) to get an access point to a service provider (a TIS) by means of a Spatial Registry, based on the requester's current location;
- *Send report*: a vehicle regularly submits reports to inform TISs of its current local driving conditions (e.g. current location and average speed);
- *Send alert*: defined as an extension of the reports submission procedure, this use case indicates that a vehicle may punctually send an alert in case of an unexpected event, such as abnormal traffic conditions (car crash, etc.). Alerts can also be manually submitted by drivers;
- *Send notification*: each TIS regularly disseminates traffic notifications participating vehicles to keep them informed of their traffic conditions;
- *Mine information*: to populate traffic notifications content, TISs need to compile all reports information issued by vehicles to produce relevant traffic information.

5 EXCHANGED MESSAGES

SAVE TIME manipulates messages to exchange information between vehicles and the infrastructure (i.e. TISs). To remain distant from messages synchronous or asynchronous delivery alternatives and keep a high abstraction level, events (i.e. asynchronous messages) are specified whenever possible.

Then, both synchronous and asynchronous possible alternatives of a simple request-response protocol based on the proposed messages are provided for discussion and validation purposes.

5.1 Vehicles events

Events sent by reporting vehicles to their local TISs, depicted by figure 3, are described as follows:

- `REPORT`: this event is periodically sent by vehicles to inform the infrastructure of their current driving conditions (i.e. location, direction, average speed, etc.). The direction is expressed in degrees and refers to an angular deviation from the north. In case no TIS is available, vehicles periodically keep attempting to find an eligible TIS from a Spatial Registry. In case the underlying protocols support synchronous messaging, reporting vehicles may receive a callback from the contacted TIS when the latter is no more appropriate. In the case a request-response protocol is used, the callback refers to the response from the TIS;
- `ALERT`: this particular event is generated by vehicles when a potentially dangerous situation is encountered or predicted (abrupt deceleration, airbags activation, etc.). Each alert is raised independently from report events and may indicate either critical information or a previous alert update. Depending on the nature of the alert, vehicles itineraries may be modified or a simple warning message may be displayed.

Figure 3: Vehicle reporting principle

Each TIS holds its own adaptive delay between sucessive reports. For each TIS and depending on the underlying synchronous or asynchronous protocol used, this delay can be adjusted per vehicle or shared by all vehicles located within this TIS coverage area.

Complementary to adaptive periodical reporting, SAVE TIME distinguishes automatic and manual alerts issued by vehicles. Embedded sensors may be used to detect drivers unusual reactions and generate automatic alerts. Providing drivers with a simple user interface allows SAVE TIME to integrate situations which would be difficult to be automatically detected otherwise (e.g. accidents, slippery roads, obstacles on roads, drivers faintness). The Coyote GPS alert system (Coyote), which indicates mobile speed cameras location, testifies to the effectiveness of involving drivers in collecting traffic information.

5.2 Infrastructure messages

In return to vehicles events, the infrastructure, by means of TISs, interacts with vehicles using the following messages:

- `NOTIFICATION`: this event is periodically disseminated to vehicles to keep them informed about their local traffic conditions. The enclosed traffic information refers to the issuing TIS's coverage area. It also includes the expected delay between reports based on the TIS current load and the average reports frequency;
- `OUT_OF_RANGE`: this optional warning message is specific to synchronous messaging. This message

is a reply to a submitted report. It indicates that the recipient TIS is not concerned with this report as the latter contains a location out of this TIS's coverage area. The vehicle has to select another TIS the coverage area of which contains the report location to (optionally) re-submit this report and send future reports to.

Each `NOTIFICATION` event integrates an indicator, expressed in $]0;1]$, which reflects the confidence the infrastructure grants to its traffic information content. This value is proportional to the number of concordant reports. It may equal 1 (highest trust degree) in case of reports sent by "trusted vehicles" (please refer to section 7.2) which avoid mining on erroneous data. Navigation devices may use a minimum confidence threshold to decide whether to integrate or discard these notifications when calculating itineraries.

Depending on the actual messaging, vehicles are kept informed by TISs notifications either individually or collectively. In case a synchronous messaging protocol is used, traffic conditions notifications can be added to TISs acknowledgements (i.e. TISs replies to vehicles reports) or send separately. When synchronous messaging is not supported, TISs have to regularly disseminate common traffic information to all vehicles by means of broadcasts.

5.3 Events exchanged between TISs

The inter-TIS communication protocol aims to make secondary (spare) TISs aware of primary TISs mined results. Primary TISs send an `UPDATE` event to their secondary TISs each time a significant change operates in their mined results. This is mostly the case when the confidence degree associated to a report modifies the currently known confidence degree of the associated traffic information. The impact of this indicator will be discussed in section 7.2.

6 TIS SELECTION AND HANDOVER

Selection of the most appropriate TISs is performed by Spatial Registries. This process is based on vehicles locations and TISs' coverage areas. In the particular case that more than one primary TIS is eligible to inform a vehicle, the latter may concurrently invoke multiple TISs and merge their traffic conditions information. Merging algorithms are out of the scope of this paper as it is recommended that primary TISs realize a geographic partitioning of the global coverage area of the system.

Vehicles movements lead to dynamically update their selected TISs. This TIS handover process is based on the vehicles locations. Two alternatives arise, depending on the underlying communication protocols used, namely synchronous and asynchronous handover procedures described hereafter.

6.1 Synchronous selection and handover

Assuming that the underlying communication layer supports synchronous messaging, a vehicle leaving the coverage area of a TIS is informed by an `OUT_OF_RANGE` response to its last report sent to that TIS. This warning response indicates that next reports sent to this TIS are likely to be discarded again. The reporting vehicle then needs to contact a Spatial Registry to receive a list of newly eligible TISs which cover its current location. This report may be either cancelled or re-submitted by the vehicle if it has not expired yet. It is recommended to re-send alerts as they reflect unpredictable traffic conditions.

A possible implementation of this synchronous handover principle is illustrated by the sequence diagram of figure 4. As recommended, each vehicle contacts a single TIS at a time to send its reports to. For simplification reasons, a unique Spatial Registry which holds all registered TISs references is available.

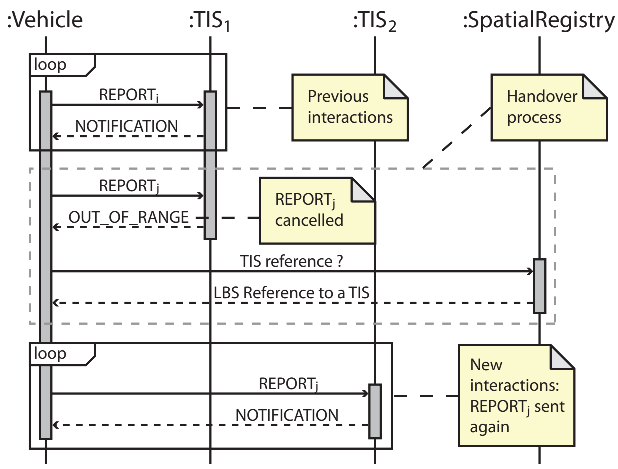

Figure 4: TIS synchronous handover process

Figure 4 mentions that report$_j$ is re-submitted to TIS$_2$. As briefly explained hereafter, the adopted synchronous messaging protocol implies more reports discarding by TISs than its asynchronous alternative.

6.2 Asynchronous selection and handover

Considering that the underlying protocols support asynchronous messaging, the `OUT_OF_RANGE` event has no effective meaning because callbacks are not supported to preserve vehicles (and drivers) privacy (privacy will be discussed in section 7.3).

Vehicles must be kept aware of TISs' coverage areas to determine the most appropriate moment to switch TISs and do not send useless events (i.e. events which will be discarded by TISs because of inappropriate issuing vehicles locations). Although a possible inter-

TIS communication protocol may propagate reports and alerts to appropriate TISs, the aim is to minimize such communications to avoid reports resubmissions. Indeed, it is the vehicles responsibility to obtain TISs' coverage areas and decide the most appropriate moment to initiate the handover process.

This asynchronous handover process is depicted by figure 5.

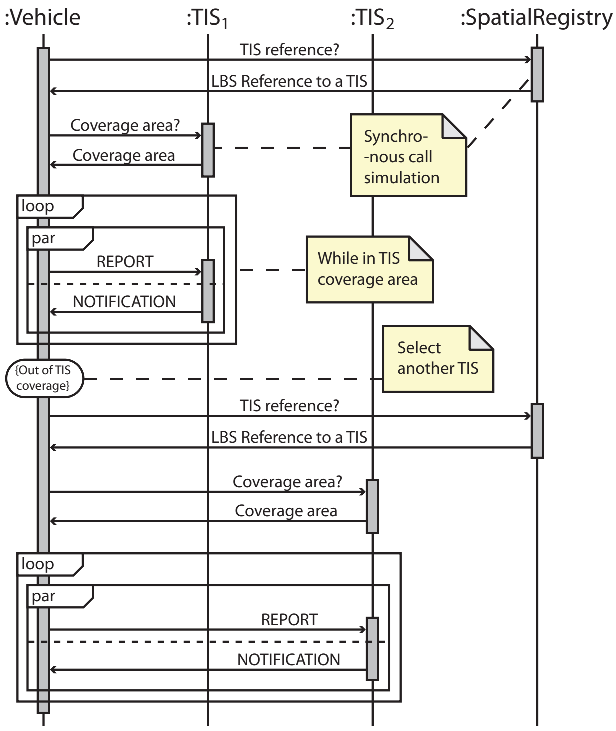

Figure 5: TIS asynchronous handover process

The diagram of figure 5 clearly demonstrates that less reports are discarded than in the synchronous architecture: no inter-TIS forwarding protocol or reports resubmission is required. This can be explained by the handover process initiation which comes from vehicles rather than TISs. Indeed, compared with the synchronous architecture, an extra step is required before a vehicle sends its first report to a TIS. This step consists in asking for the TIS's coverage area to determine the most appropriate moment for initiating the handover process.

Furthermore, the asynchronous handover process requires to ask a Spatial Registry to obtain the network reference of a new TIS. As no synchronous communication is allowed, the vehicle has to wait until the Spatial Registry answers. This exchange implies that the registry is able to either bind on a given vehicle or make all reachable vehicles informed of the most appropriate TISs.

Finally, an asynchronous system is less reactive to services shutdown than a synchronous system: vehicles are aware of a TIS crash when they do not receive an expected notification from this TIS.

7 SAVE TIME SECURITY

Security in an important concern as far as it impacts the system design and protocols (including data structures and information transmissions). To address common security issues, SAVE TIME infrastructure components send authenticated information to vehicles. On the contrary, vehicles messages must be kept anonymous in respect with drivers privacy.

7.1 TISs messages authentication

First step to authenticate TISs messages is to get confidence in LBSs references published by Spatial Registries. Spatial Registries may digitally sign their provided information and make Public Key Certificates (PKCs) (Housley et al., 2002) available so that destinatories are able to authenticate received messages (Cottin and Wack, 2009).

TISs messages authentication implies that each TIS owns a PKC used by vehicles to verify its digital signatures. This PKC may be provided by Spatial Registries along with the corresponding TIS reference.

In the case of synchronous messaging, messages security and authentication may rely on secure exchange protocols, such as TLS (Dierks and Rescorla, 2008). These protocols guarantee messages confidentiality and parties authentication.

7.2 Vehicles messages forgery

Malicious information may be sent by attackers so that TISs receive contradictory information (assuming that other vehicles send correct information). In the particular case that a given TIS receives more forged messages than valid messages, it would primarily mine on forged information and disseminate invalid notifications to vehicles.

An efficient protection against this attack consists in:

- Assigning a confidence degree indicator (in range $[0;1]$) which expresses the trust level TISs attribute to the reports they receive. This confidence degree increases along with the number of correlated reports: punctual forged reports will be discarded as they would lower the confidence degree of the previously mined information;
- Integrating "trusted vehicles", such as traffic patrols. Each trusted vehicle owns a (trusted) PKC used to digitally sign its reports (including alerts). These reports may either confirm or invalidate previous information received by TISs and directly impact the confidence degree of their

previous information. TISs are able to grant such notifications a maximum confidence degree (of 1) as long as they verify the validity of the digital signatures on the signed reports.

7.3 Drivers privacy

As previously mentioned, trusted vehicles reports must be authenticated so that TISs are able to grant these reports a maximum confidence degree. On the contrary, common drivers privacy, including vehicles anonymity, must be preserved. The system is not allowed to keep track of a vehicle without its driver's consent. Yet the system can manipulate localization information as far as it is not bounded to a particular vehicle's identity. This localization information is therefore integrated within (anonymous) vehicles reports.

Information required for messages transmission, such as IP addresses, must neither be used by the system. Indeed, asynchronous callbacks should not be permitted (even if such contact information is versatile). This constraint may invalidate the suggested asynchronous design alternative where Spatial Registries are able to bind on a specific vehicle and broadcasting should be used instead.

7.4 TISs overloading

As for many systems, SAVE TIME is potentially subject to denial-of-service attacks. Such attacks intend to overload TISs which would not be able to properly collect reports, mine information and send notifications to vehicles. This issue has not been solved yet, apart from queuing techniques and specific architectures which physically separate TISs messaging and internal mining services. Moreover, vehicles may not follow TISs recommendations on adaptive delays between reports submissions, hence contributing to TISs overloading.

8 CONCLUSIONS

SAVE TIME is a decentralized prospective system dedicated to local real-time traffic information. It relies on Spatial Registries and LBSs called Traffic Information Services (TISs) to notify vehicles (or eventually any other requester) of local relevant information automatically generated from traffic reports. The accuracy of this system is based on the assumption that an increasing number of vehicles will be equipped with navigation devices able to connect to the Internet and exchange information with close vehicles in a near future. In case of too few equipped vehicles, our system will not be able to gather enough information; integrating road sensors may provide valuable and trusted complementary information.

Different architectural alternatives being suggested in this article, a prototype based on GPRS communication, web services and distributed Spatial Registries is currently under development. This prototype will help validating the proposed synchronous architecture and suggesting practical solutions to TISs discovery and handover, messages formats and delivery, TISs failures as well as information mining. A web-based traffic supervisor will also be studied to display traffic conditions in real-time, including more complete and accurate information than the newly available TomTom HD Traffic widget (TomTom, 2009).

SAVE TIME information collection and dissemination procedures primarily use V2I communication schemes. This system may benefit from complementary support for V2V communication to forward vehicles reports. Such communication would be enabled in the sole case direct communication with the infrastructure is defective (i.e. the infrastructure is not directly reachable by the original issuer). Integrating V2V communication may also ensure better alerts propagation to close vehicles, thus improving road safety. Communications security is another important concern as the proposed system must ensure messages authenticity, not only from the vehicles perspective but also when integrating external information. Systems such as CARAVAN (Sampigethaya et al., 2005) and anonymous authentication schemes (Xi et al., 2008) will be investigated in detail. System failure is currently handled by means of a single secondary (spare) TIS for each primary TIS and a simple inter-TISs communication protocol to forward mined information results. A possible extension could consist in integrating duplicated primary TISs. Balanced communications between duplicated TISs and vehicles would increase the global system response time and stabilize primary TISs average loads.

The current system capabilities can be extended thanks to Spatial Registries as any external LBS can be dynamically discovered and invoked by TISs. Extended traffic information may integrate services such as meteorology and special events (concerts, sports events, etc.). Other traffic information systems (such as TMC) can also complement local traffic information collected by TISs by means of complementary LBSs dynamically invoked. This offers tremendous perspectives in terms of traffic congestions prediction.

New optimization and information relevancy checks algorithms dedicated to SAVE TIME will be designed to integrate GNSS evolutions as well as innovative information discovery and exchange technologies. Mathematical definitions of optimal adaptive delays between reports submissions for each TIS to avoid TISs overloading will be investigated. Proofs of concept using model checking and Higher Order Logic (Shapiro, 2001) techniques will also be performed.

Finally, simulations will indicate the optimal number of TISs to partition a given geographical area. V2V routing algorithms, such as (Collins and Muntean, 2008), will complement the existing V2I architecture.

ACKNOWLEDGMENT

This work is partially supported by the 7th EU's Framework Programme for Research and Technological Development (http://ec.europa.eu/research/fp7) through the ASSET project (http://www.project-asset.com), 2008–2011.

Abuelela M., Olariu S. and Weigle M.-C., 2008. NOTICE: An Architecture for Notification of Traffic Incidents. *68th IEEE Vehicular Technology Conference - Spring (VTC'08)*, Singapore, p. 3001-3005.

Bakhouya M. and Gaber J., 2008. Approaches for Ubiquitous Computing. *Wireless Ad hoc and Sensor Networks*, Singapore, p. 111-142.

Bychkovky V., Chen K., Goraczko M., Hu H., Hull B., Miu A., Shih E., Zhang Y., Balakrishnan H. and Madden S, 2006. Data Management in the CarTel Mobile Sensor Computing System. *ACM Special Interest Group On Management Of Data (SIGMOD'06)*, Chicago, USA, p. 730-732.

Coifman B., Beymer D., McLauchlan P. and Malik J., 1998. A real-time computer vision system for vehicle tracking and traffic surveillance. *Transportation Research Journal*, vol. 6, issue 4, p. 271-288.

Collins K. and Muntean G.-M., 2008. A Vehicle Route Management Solution for Wireless Vehicular Networks. *27th IEEE Conference on Computer Communications (INFOCOM'08): Mobile Networking for Vehicular Environments (MOVE'08), Phoenix, USA.*

Collins K. and Muntean G.-M., 2007. TraffCon: An intelligent traffic control system for wireless vehicular networks. *International Conference on Information and Communications Technologies (CIICT'07)*, Dublin, Ireland.

Cottin N. and Wack M., 2009. Dynamic Registration and Discovery of Location-Based Services using Spatial Registries. *3rd workshop on Agent-oriented software engineering challenges for ubiquitous and pervasive computing (AUPC'09)*, London, p. 33-38.

Coyote Working Group. Coyote GPS Alert System. *Available online at http://www.coyotesystems.co.uk.*

Dash Consortium. Dash Express. *Available online at http://www.dash.net.*

Dierks T. and Rescorla E., 2008. The Transport Layer Security (TLS) Protocol Version 1.2. *IETF Request For Comments 5246.*

Dornbush S. and Joshi A., 2007. StreetSmart Traffic: Discovering and Disseminating Automobile Congestion Using VANET's. *65th IEEE Vehicular Technology Conference - Spring (VTC'07)*, Dubin, Ireland, p. 11-15.

ECMT's Economic Research Centre, 1999. OECD Round Table on Transport Economics - Traffic Congestion in Europe, vol. 110.

Housley R., Polk W., Ford W. and Solo D., 2002. Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile, *IETF Request For Comments 3280.*

OASIS, 2004. UDDI Spec. *Draft.* Version 3.0.2.

Sampigethaya K., Huang L., Li M., Poovendran R., Matsuura K. and Sezaki K., 2005. CARAVAN: Providing Location Privacy for VANET. *Embedded Security in Cars (ESCAR'05).*

Selhofer A., Gruber T., Putz M., Schoitsch E. and Sonneck G., 2007. RAMSS Analysis for a Cooperative Integrated Traffic Management System. *Lecture Notes in Computer Science*, vol. 4680, p. 87-92.

TISA. Traffic Message Channel. *Available online at http://www.tmcforum.com.*

TMC Compendium, 1999. *Alert-C Coding Handbook*, ref. F02.1, 600-W804.D07.

TomTom, 2009. HD Traffic Live. *Available online at http://www.tomtom.com/hdtraffic/.*

Wischoff L., Ebner A., Rohling H., Lott M. and Halfmann R., 2003. SOTIS - A Self-Organizing Traffic Information System. *57th IEEE Vehicular Technology Conference - Spring (VTC'03)*, Orlando, USA, vol. 4, p. 2442-2446.

Wu H., Fujimoto R., Guensler R. and Hunter M., 2004. MDDV: a mobility-centric data dissemination algorithm for vehicular networks. *1st ACM international workshop on Vehicular ad hoc networks (VANET'04)*, Philadelphia, USA, p. 47-56.

Xi Y., Sha K.-W., Shi W.-S., Schwiebert L. and Zhang T., 2008. Probabilistic Adaptive Anonymous Authentication in Vehicular Networks. *Journal of Computer Science and Technology*, vol. 23, p. 916-928.

Shapiro S., 2001. *The Blackwell Guide to Philosophical Logic*, Lou Goble.