Use of Satellite Broadcast for ITS Applications

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***Abstract*-- This paper presents the SISTER (Satcoms in Support of Transport on European Roads) project which aims to study the feasibility of use of satellite communications in Intelligent Transport Systems (ITS). In particular, it details the architecture designed for the delivery of ITS files and alerts directly to vehicles on the road using an L-band GEO satellite. After describing the elements comprising the communication chain, an analysis of the critical factors affecting the performances of the broadcast is given. Finally, the paper presents an incremental attribute based map updating tool as an example of the ITS applications covered in SISTER.**

I. INTRODUCTION

Satellite communications can provide one-way broadcast service, two-way data transfer and two-way voice services. In particular, satellite broadcast at low frequencies has been used in the US and Canada for entertainment, weather and traffic information services. In Europe, it is mainly used for radio. The SISTER project makes use of one of these radio satellites at geostationary orbit (WorldSpace) to distribute ITS files over a data broadcast channel.

One class of systems that benefit from this broadcast solution are the Advanced Driver Assistance Systems (ADAS) which require highly accurate digital maps. The accuracy of the digital map in the On-Board Unit (OBU) has a significant effect on the functionalities of ADAS. Online map updates, i.e. receiving and processing updates when the vehicle is driving, have great advantages, such as improvement of the update efficiency and convenience for users. Strategies and mechanisms for the dynamic update of digital map databases have been developed by the EC-funded ActMAP [1] project (2002-2004) and have been further investigated in the EC-funded FeedMAP [2] project (2006-2008).

Currently, map updates are delivered to vehicles via GPRS or 3G, which demands a large number of dedicated unicast transmissions (one per vehicle). In contrast, satellite broadcast is able to deliver data simultaneously to a potentially infinite number of users in a wide area such as Europe, which reduces significantly communication costs.

II. SISTER SOLUTION

A. APPLICATIONS COVERED

In SISTER, three different applications have been implemented to demonstrate the feasibility of SatCom based broadcast for map update information:

1) Map updating in the classical sense, where map changes are delivered via satellite to an in-vehicle system. Demonstrators comprise two map update approaches: the updating of certain map attributes (incremental map updates as developed in the ActMAP and FeedMAP project) and replacement of parts of a digital map (tile based updates).

2) Customized Point of Interest (POI) updates, where POIs are broadcasted to trucks from a central server or back office to the on-board navigation systems of the customer's fleet.

3) Traffic Information together with Dangerous and Hazardous Goods Management information for safety and security enhancement in road transport business.

The Map Updating demonstrators in SISTER aim to demonstrate the advantages of the use of satellite communications compared to classical terrestrial means such as: cost savings for distribution of data to a high number of users, roaming issues and service centralization.

B. SYSTEM ARCHITECTURE

Figure 1 shows the end to end communication protocol stack in the SISTER architecture. The different back offices or clients (left side of the diagram) provide ITS files updates or alerts to the Data Distribution Server (DDS) which processes them for later broadcast distribution. At the indicated distribution time provided by the respective back offices, these files or alerts are forwarded to the WorldSpace gateway which incorporates them to the data broadcast channel.

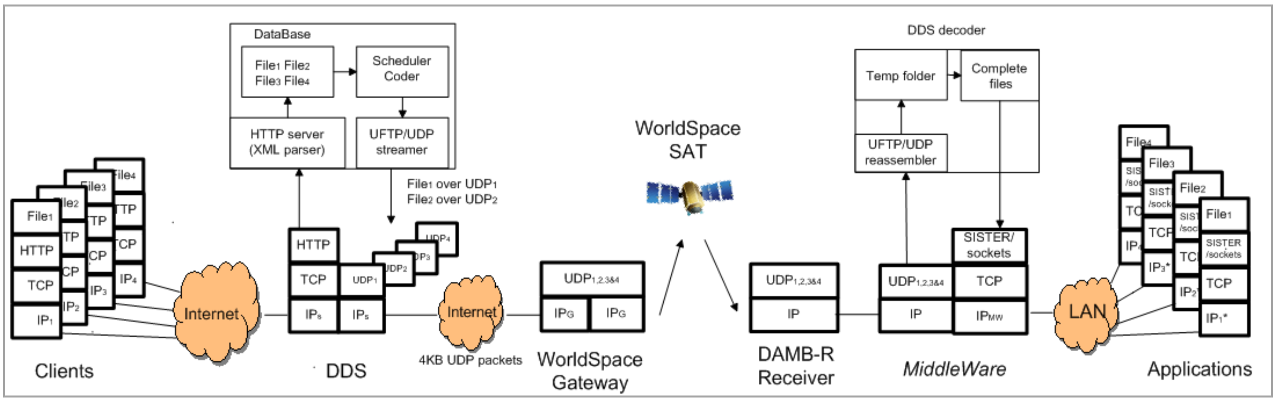

Figure 1 SISTER system architecture

Only those terminals with a valid encryption key registered in the multicast group will be able to decrypt these files. In the application end (right side of the figure), a dedicated middleware is in charge of reconstructing the files and routing them to the correct application.

The functionalities of the different elements that constitute the whole communication chain are detailed below.

B.1 File compilation

The generated update files or alerts are temporally stored in an http server at the back office side accessible by the DDS. Back offices can manually or automatically trigger a broadcast request to the DDS for a particular file or alert using a customized XML format message. In this XML message, the back offices specify parameters such as the file ID, start and stop time for the broadcast, repetition period or the percentage of the population that is requested to have received the file at the end of the broadcast window (in this case, the repetition period is estimated by the DDS as later described in the paper).

The DDS also offers the different back offices the possibility to check the current status of their broadcasting files, such as accumulated broadcasted time, repetition period, estimated population penetration percentage reached so far and scheduled stopping time.

B.2 File scheduling

The scheduling of the files is done dynamically at the DDS, incorporating new files and deleting obsolete ones. There are only two levels of priority distinguished in the SISTER solution: files and alerts. However, the back offices can configure their own prioritization policies within their files.

Alerts are scheduled with a constant repetition period provided by the back office whose value is set according to the importance of the alert. Reduced repetition times will have larger penetration amongst population in the same broadcasting interval. Alerts have higher priority against files and are served instantly.

Files are scheduled differently than alerts. The DDS makes use of three different parameters to estimate the repetition time or allocated bandwidth per file. These parameters are: the file size, the broadcasting time and the population penetration percentage to be reached in that period of time requested by the back office. The bandwidth estimation process is explained in detail later in Section D.

The DDS is also in charge of splitting those files that are larger than 4KBytes which is the most effective packet size for this satellite service. The extra headers necessary for later reassembly of these split files are also generated at the DDS.

B.3 File broadcast

Each application has a dedicated UDP channel in the broadcast link with a limited data rate capacity. In case of exceeding such limit, the DDS slows down the data flow of the current files in the broadcast for this particular application and informs the respective back office. This temporal data rate reduction is taken into account to re-calculate new broadcasting times or repetition times for those files that need to reach a certain percentage of the population.

Every receiver registered in the multicast group receives data from all the active UDP channels (although this can be restricted due to privacy, security or commercial issues).

B.4 File reception

The WorldSpace DAM-B receiver is integrated into a more complex transceiver that offers SISTER some other communication bearers such as WiFi, bidirectional satellite communications (Thuraya and Iridium), GPRS and GSM which are used by other ITS applications within the scope of the project. This transceiver hosts a middleware unit, which is in charge of queuing and routing all the communications taking place between the different vehicle applications and their respective back offices. The middleware is also in charge of storing and reassembling the broadcasted files and alerts. Once the file has been reassembled, the middleware routes it to the respective application making use of a customized socket communication protocol over the local area network where the applications belong.

It is important to mention that the SISTER transceiver and middleware were consciously designed following the CALM [3] standard. This standard defines a single interface and protocol to interconnect multiple applications to different communication channels releasing the applications from any direct management of the modems. The overall idea is to be able to connect new applications or modems into the system without modifying the existing architecture as long as they follow the CALM communication standard. The middleware allows the application to communicate to its back office or access the broadcasted data by standard TCP/IP connection with the middleware independently of the modem used.

C. CRITICAL FACTORS

There are several factors that affect the performance of the broadcast in terms of the files distribution efficiency and reception times amongst the vehicles. These parameters are the driving behaviour of the targeted vehicle, its driving environment, the broadcasting policy and bandwidth reserved for the file of interest as well as its size. The next sections give an insight of the impact of these parameters.

C.1 File Size

An ad-hoc simulation tool has been developed within the SISTER project in Matlab that allows a parallel analysis of the broadcast service for different file sizes and their allocated bandwidths, different environments with variable signal blockage statistics and different driving behaviours. This simulation tool generates a large sample of the specified driving behaviours and obtains the required driving time for each particular driver to complete the reception of the file under the specified conditions. This driving time can be obtained for different percentiles of the statistical sample. The term "driving time" refers to the time each driver accumulates on the road until reception of the complete file. In addition, for large files that have been split into different packets, the transmission efficiency is also obtained for each case, which is defined as the number of packets comprising the file divided by the total number of received packets until completion of the file (which includes repeated packets as well).

In theory, if there was a complete absence of signal blockages and there were no repeated packets at reception, the required driving time for reception of the file would be determined as the file size divided by its allocated bandwidth.

Figure 2 compares the performance of this theoretically perfect scenario and the simulated one wherein signal blockages interrupt the reception of the file and some of the received packets are repeated from cycled broadcasts. The bandwidth allocated to each file has been set according to its size, so that there is a homogenous repetition time of 71min for all file sizes.

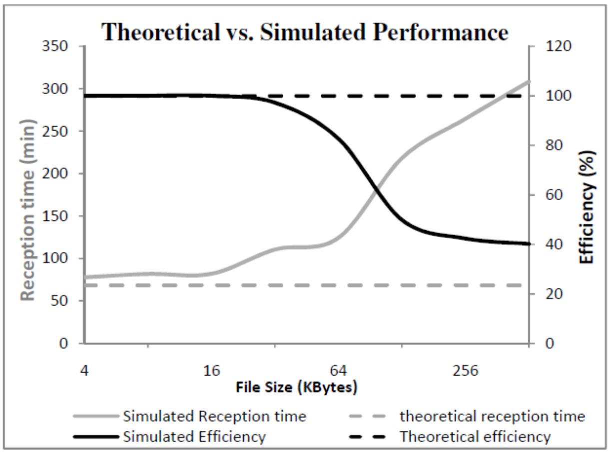

Figure 2 Theoretical vs. Simulated performance

It can be appreciated how the reception time increases and the efficiency drops as the file size increases. This is due to the growing number of packets of 4KB that the files are split into which raises the probability of receiving repeated packets in consecutive retransmissions of the file.

C.2 Driving behaviours

For simplicity, four different driving behaviours would be proposed:

1) A particular driver that only uses the car to make a 2h long return trip during the weekend.
2) A commuter that uses the car twice a day for an average of 20min each time.
3) A delivery van that realizes 10 journeys a day of an average of 20min each.
4) A truck driver that drives for an average of 4h twice a day.

These driving behaviours have been represented in the simulation tool which enables the user to generate a large number of samples for each type of behaviour. The duration of each trip is randomly calculated following a lognormal distribution around the specified average time while the starting times for each trip follow a normal distribution.

As an example, Figure 3 shows the required driving times of a 128KB file (32 packets of 4KB) for the above defined driving behaviours at different broadcasting data rates.

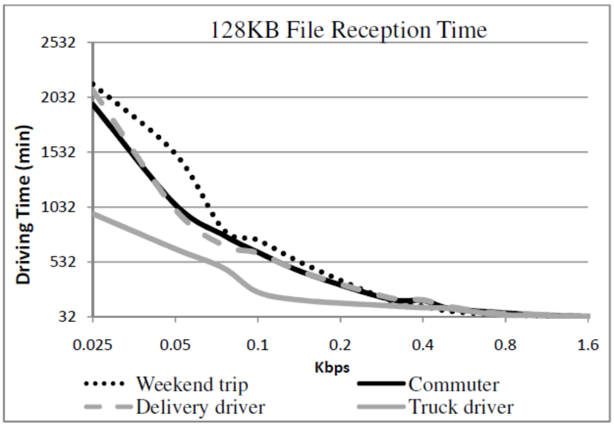

Figure 3 Impact of driving behaviour

It can be appreciated how a continuous drive (as the one shown by the truck driver) presents better performances than the rest for lower data rates. This is due to the increasing repetition period of the file as the data rate is reduced. For example, at 0.8kbps, the repetition period of the file is 21.3min, meanwhile at 0.05kbps it is 5.6h. For the former, the four drivers present similar results, as the average journey duration was set to 20 min. However, for the latter, there is a big difference in the required driving time as a larger number of trips will be needed to download the complete file due to the short duration of these trips. In this case, the probability of receiving repeated packets increases, dropping the efficiency in this way.

C.3 Driving environment

Signal blockage statistics vary with the environmental surroundings of the vehicle. For example, buildings in urban areas or trees in dense forests obstruct the satellite signal from the vehicle view which leads to loss of packets at reception, forcing the vehicle to wait until new repetitions of the file to complete the missing packets. In this manner, the efficiency drops and the required driving time for reception increases.

Figure 4 shows a combined histogram for consecutive lost packages in an urban and a rural environment for a 90min real journey. A total of 151 blockages of less than 40s were registered in the urban area and 158 in the rural one. However, it can be appreciated how most of the samples for the rural environment were accumulated into the first quarter of the figure, i.e. where the shortest blockages periods are registered. In the case of the urban environment, the samples are spread more homogeneously, reaching larger blockage duration values. In particular, there were 12 blockages larger than 40s (not shown in the figure) meanwhile there were only 2 in the rural area.

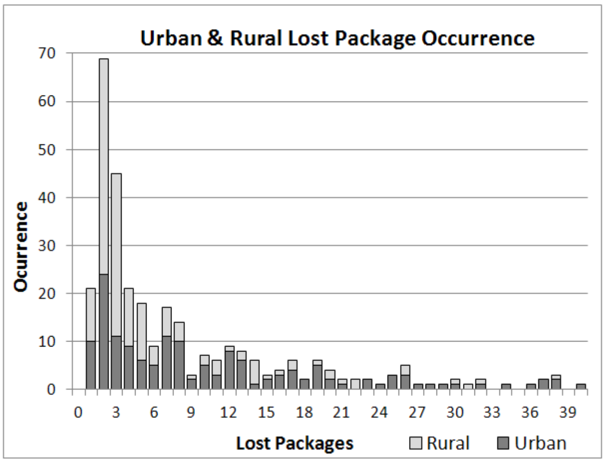

Figure 4 Urban & rural lost packages statistics

The results shown in the previous figure are used as an input for the above mentioned simulation tool, which allows the user to select the percentage of the journey carried out in urban and rural areas.

C.4 Distribution Policy

The way files are broadcasted during their repetition period also affects the performance of their reception. Figure 5 shows the required driving time for the reception of a 64KB file at various data rates using different distribution policies. The first one consists of transmitting the whole file “in one go” at the maximum speed available, waiting during a complete retransmission period to broadcast it again. The second one spreads the packets homogeneously during the repetition period of the file, so that they are equally distributed in time. Packets order can also be randomized.

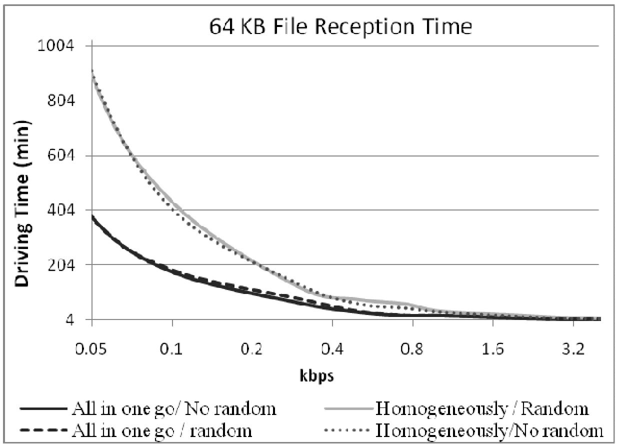

Figure 5 Impact of distribution policy

It can be appreciated how the former policy presents better performances for lower data rates (or higher repetition periods). This is due to the distribution of the signal blockages which is more likely to impair certain packets if they are spread in time rather than if they are broadcasted in a shorter time. These lost packets generate lower efficiencies as the vehicle needs more than one retransmission to receive the entire file.

In addition, the randomization of the packets has a negligible impact in the overall performance.

D. BANDWIDTH ESTIMATION

In order estimate the required bandwidth to be allocated to a particular file, the DDS takes into consideration the size of the file, the duration of its broadcasting period and the targeted population percentage that is requested to receive the file in such a period of time.

The daily driving time follows an exponential distribution represented in Figure 6. This daily driving time decreases as the targeted population percentage increases. As an example, only 20% of the population drives for more than 145min a day, meanwhile up to 80% drive at least for 21min.

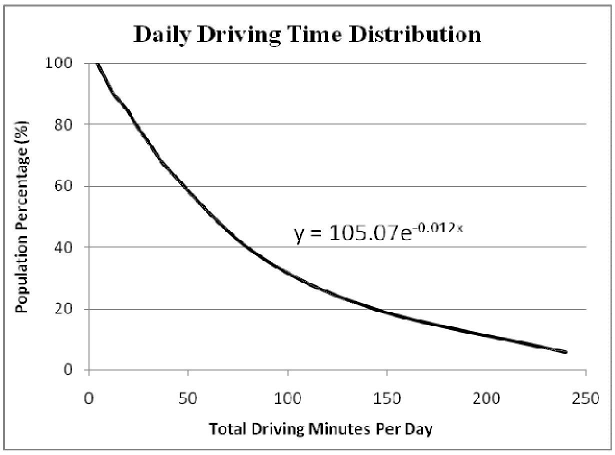

Figure 6 Daily driving time distribution

Under ideal conditions where files are received without repetition or loss of packets, the following formula would determine the required bandwidth:

$$BW = \frac{-1.6 \times 10^{-3} \times FileSize}{Airtime \times \ln(Population/105.07)}$$

where *BW* is the data rate in kbps, *Airtime* is the number of days that the file is broadcasted over the satellite, *FileSize* is expressed in KBytes and *Population* represents the percentage of targeted population.

However, the occurrence of packet losses and repetitions will incur higher required bandwidths. The new estimation formula for a 50% rural and 50% urban environment and a non-randomised "all in one go" transmission policy has been obtained using a curve fitting method to extrapolate the results of a number sample of simulations:

$$BW = \frac{-1.801 \times 10^{-3} \times FileSize^{1.208}}{Airtime \times \ln(Population/105.07)}$$

It is worth noting the potential dependency with the size of the file, as it was shown in section C.1

III. APPLICATION EXAMPLE

In SISTER, incremental attribute based map updating as developed in the EU research projects ActMAP [1][2] and FeedMAP [4][5] serves as a basis for the demonstrator developed by NAVIGON. For demonstration and validation purposes ADAS Horizon development platform (MapSensor) was extended to receive broadcasted map updates to demonstrate the benefits of SatCom in the context of advanced driver assistance applications based on up to date digital maps.

The ADAS Horizon (EU research project MAPS & ADAS [6][7]) comprises a solution for providing digital map information about the most probable path the vehicle will take to the vehicles CAN-bus. It is an extract of the digital map around the current vehicle position (Figure 7). Each street segment is assigned a probability value of being driven through. The Most Probable Path (MPP) is a connected set of segments, starting with the one where the vehicle is located and following the segments with the highest probability (Figure 8).

An ADAS speed limit warning application was developed based on the MPP and information contained in the map. SatCom provides one efficient mean to deliver map update information to the MapSensor application, so that it can be immediately integrated into the ADAS Horizon to warn the driver of changes ahead on the road.

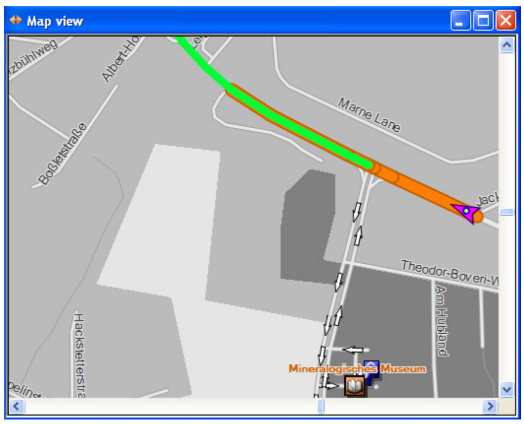

Figure 7 Map View Most Probable Path (orange) Map Update (green)

The Speed Limit Alerter (Figure 9) demonstrator reads legal speed limit information from the ADAS Horizon calculated by the MapSensor and informs the user about speed limits ahead of his track. If those speed limits are new or have been received by broadcasted map as new updates, the user is additionally warned. To increase driving safety the Speed Limit Alerter also advices the driver about when to slow down in time so that the vehicle is at an appropriate speed when entering the speed limit zone.

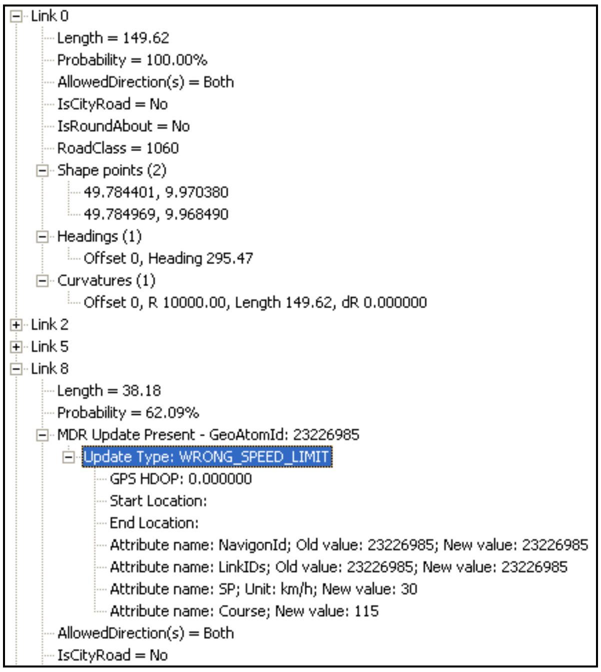

Figure 8 MapSensor: ADAS Horizon Information and Attribute Map Update

For SISTER demonstration tasks the ActMAP service centre functionality was extended to provide map updates to the DDS for satellite broadcasting. In particular, when updated information is provided by the in-vehicle itself (as already demonstrated in the FeedMAP project), the demonstration system actually forms a closed loop of deviation detection, update provision and reception. Thus SISTER is one effective mean to extend the FeedMAP framework making use of a satellite broadcast channel for fast delivery of ITS map updates.

IV. FIELD TEST

The entire end to end communication chain has been successfully tested over the WorldSpace satellite involving several back offices, the DDS and static receivers connected to several receiving applications.

Future trials will involve a considerable number of equipped vehicles driving on German and Dutch roads. The purpose of such trials is to analyze the practical performance of the system which will be then compared against the one anticipated during the simulations.

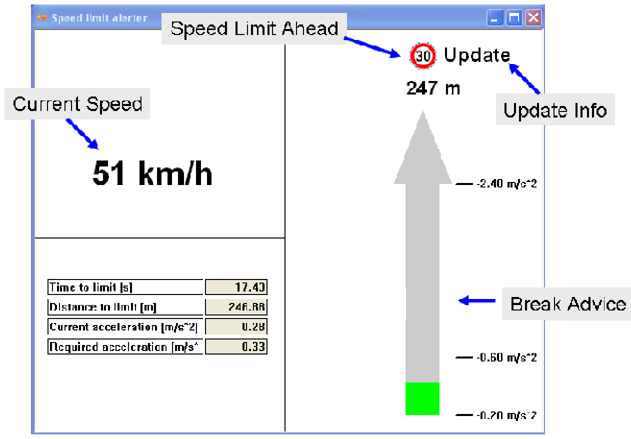

Figure 9 MapSensor ADAS Application Speed Limit Warner

V. CONCLUSION

This paper has presented the concept of ITS file broadcast over satellite developed within the scope of the SISTER project. A description of each element involved in the overall architecture has been given detailing its functionalities and interoperability within the others.

The impact of the file size, allocated data rate, broadcasting policy, driving environments and driving behaviours have been analysed and used to estimate the requirements in satellite capacity required for a particular file to reach a certain penetration level amongst the driving population.

One of the applications covered by SISTER, the ADAS horizon MapSensor, has shown the potential of this broadcasting platform which allows a unified pan-European media of simultaneous delivery of ITS related files or alerts to vehicles on the move.

References

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