ANALYSIS OF SATELLITE AND TERRESTRIAL TELECOMMUNICATION LINK AVAILABILITY TO IMPROVE SECURITY AND ATTRACTIVITY IN URBAN BUSES

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Abstract

Mobility is still growing and the key challenge for sustainable mobility, in urban areas, is how to match the increasing demand for transport and the need to reduce the impact of the use of private vehicle on the physical, social and human environment. It is urgent to promote the use of collective means of transport by improving the security feeling inside public transport and proposing new attractive services for passengers such as multimedia information. Such services require wireless radio link transmissions in bi-directional with high data rate.

The main problem is that, nowadays, terrestrial communication systems such as GSM/GPRS[1] have a limited data rate and flow decreases significantly in case of mobility and transfer of data in full safety. Moreover, for such urban transports application, UMTS[2] is not available now and satellite systems are not used yet.

This paper aims at demonstrating that a satellite-based system radio link can answer this problem with the use of terrestrial wireless communication systems as a complementary solution, in bad satellite coverage areas. We study along urban Bus lines, the availability of satellite and terrestrial systems, which is one of the conditions that make it possible to guarantee the continuity of radio link communication along these ways.

Keywords: Satellite systems; GSM-GPRS; Availability; Wireless; Radio link; Bus; Sub-urban areas
Topic area: B2 Telecommunication and Advanced Information Systems

1. Introduction

The development of Intelligent Transport Systems rely on new information and communication technologies particularly with the provision of new services, which aim at improving the quality of public transport and the security feeling. " Research has shown that 30 percent of travellers would choose a more convenient or quicker way to travel if they had better advance information about their options" [ERTICO, 2003]. The information could contain for example tourist information relative to areas crossed by the traveller (museum, cinema, opera…) or multimodal information such as connections, perturbations on the other transport modes (bus, tram metro, train…). This suppose, sharing of information between different transport operators and the development of multimodal platform applications [Uster, 2001].

Among the various new attractive services that could be offered to customers and operators of public transport, we focus our work on:

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[1] GSM/GPRS: Global System for Mobile communications/General Packet Radio Services
[2] UMTS: Universal Mobile Telecommunication System

- real-time audio-video monitoring from the inside of the vehicle, which is sent to the Operator Centre in order to improve security feeling,
- multimedia information available for passengers using wireless network: mobile phones, pocket PC, PDA[3], laptops or on-board PC that become a popular way to retrieve tourist information or transport time table in order to increase multimodal behaviour,
- localization of the vehicle for fleet management, security applications, and refreshment of multimedia information according to vehicle position.

These services required telecommunication links that rely on existing infrastructures such as satellite systems like Globalstar, Inmarsat or terrestrial wireless radio links such as GSM-GPRS. These systems are deployed in West-Europe but none of them is able to support high data rate for bi-directional radio links. Broadcasting satellite like Afristar of the Worldspace system, offers high data rate information at downlink with no return link. Maximum throughput with GSM/GPRS is limited to 20 kbits/s in Uplink and the future UMTS will provide a maximum of 384 kbits/s in Downlink with speed lower than 200 km/h.

The aim of this paper is to demonstrate that the continuity of communication services can be achieved with satellite and terrestrial systems as complementary solutions. We will present an experimental and simulation evaluation of the availability of both satellite and terrestrial telecommunications system mentioned along several buses trajectories, in urban and suburban areas. Another paper accepted in this conference [Marais, 2004] will focus on GPS satellite availability for localization and navigation applications in the same context.

In the first part of this paper, we will describe the general context of the study performed in the framework of the TESS (Transport ESpace et Société) project. Then, the different telecommunication systems and some technical specifications required will be given. In the second part, we will present simulations results on signal availability obtained along two representative Bus Lines using the Globalstar constellation and Afristar, which is a broadcasting satellite of the Worldspace constellation. In the third part, we will present on site measurement results along the Bus lines mentioned, using the Afristar satellite and the terrestrial communication system GSM-GPRS. Finally, we will conclude on the use of satellite-based system completed by terrestrial one to ensure the continuity of communication services for public transports applications.

2. General context of the TESS project and system architecture

The work presented in this paper was performed in the framework of the TESS[4] project of the French national research program RTE[5]. This project aims at demonstrating that a satellite-based system can answer to the high data rate audio-video recording data transfer requirements and to the fleet management needs with the use of terrestrial systems as a complementary solution in bad satellite coverage areas. The solution developed in the project addresses the field of urban/suburban buses and international freight trucks. It includes the on-board equipment installed inside buses or trucks and the fixed equipment in a Control Centre in order to deploy: vehicle localization, trip data board, general information broadcasting, high data rate multimedia transmission, security management, alarm on the vehicle or goods states, fleet management related to traffic [Gransart, 2003].

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[3] PDA: Personal Data Assistant
[4] TESS: Transport ESpace et Société (Land Space and Society Project)
[5] RTE: Réseau Terre et Espace (Land and Space Network)

As illustrated on Figure 1, the telecommunication system used in the project relies on a two-links architecture:

- the first link between a “super mobile” inside the bus and the operator Control Centre. The downlink is used to broadcast multimedia and other information services inside the Bus while the uplink is used to send audio-video monitoring and travellers requests from the inside of the bus. The broadcasting or communication systems considered are: GSM-GPRS, Globalstar and Worldspace.
- The second link between the “super mobile” and the inside of the bus, supported by a Wireless Local Area Network (IEEE 802.11b- Wi-Fi), is used to send information between the “Super mobile” and different equipments like GPRS phones, Pocket PC or PDA, laptops or on-board computer, on-board display devices.

The “super mobile” inside the bus is composed of two main sub-systems. The first one, inside the bus, managed the communication between the “super mobile” and the PDA. The second one managed the communication between the “super mobile” and the control centre. From a software point of view, the first sub-system uses a CORBA middleware (ORBacus) [Gransart, 2003]. The communication protocol between the “super mobile” and the Mobile Object in the Bus is based on an IP multicast layer. Furthermore, at any time, both satellite and terrestrial links could be cut because of coverage problem or obstacle masking. In order to solve this problem, the communication between the bus and the Operator control centre is based on a MOM (Middleware Oriented Messages) called iBus. This device provides messages waiting system during network connections losses. The messages are then delivered when the link is established again.

The main sensors used inside the buses are cameras and microphones for audio-video monitoring, the “super-mobile” for management of communication and local database information. To retrieve information needed locally, travellers in the bus could be equipped with “Mobile Object” such as GSM-GPRS phones or PDA. The Bus is also equipped by positioning and communication satellites receivers – such as GPS for navigation, Globalstar for bi-directional communication or Afristar for multimedia broadcasting in Europe.

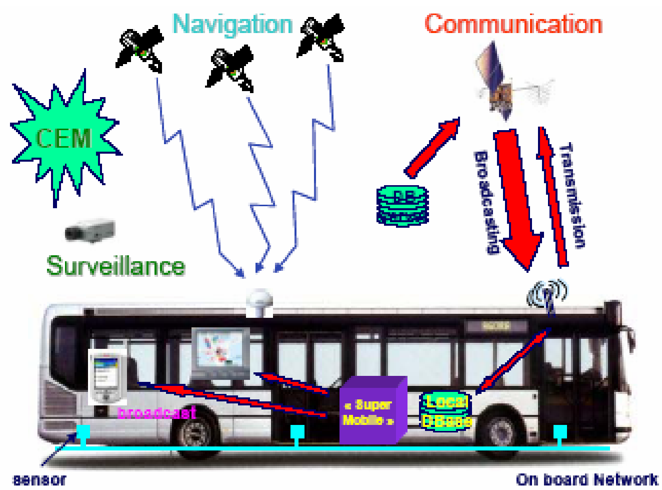

Figure 1: The Intelligent Bus concept [origin: TESS project presentation]

2.1 Telecommunication systems description and availability requirements

The multimedia information is broadcasted using the geostationary Afristar, satellite from the Worldspace constellation available in West-Europe. Its position is fixed for a terrestrial observer and the elevation is around 30°. The data rate available is 128 kbits/s in downlink. The other satellite system considered is Globalstar, which is a LEO constellation with 48 defiling satellites. The data rate available is situated between 9.6 and 56 kbits/s. The link can be supplemented by GSM-GPRS in certain areas when satellite signals are no more available.

The real-time audio-video data of all the scene monitored inside the bus should be recorded, processed and transmitted to a Control Centre via a wireless link with a minimum data flow of 25 kbps per sensor, which is composed with a camera and the associated microphone.

The availability of a satellite constellation depends on visibility and geometry of the satellites received. As illustrated on figure 2, three satellite states are generally considered to define the visibility of a satellite:

- a Line of Sight or LOS: the satellite is visible in direct path by the receiver,
- a blocked case for which the satellite is not visible for the receiver,
- a shadowed case for which the satellite signal reaches the receiver by alternate path reception with no direct signal -Non Line Of Sight or NLOS-.

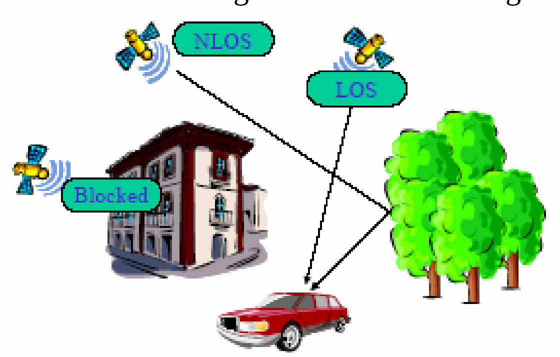

Figure 2 : satellite states illustration [origin : LOCOPROL[6]-2002]

In urban or suburban areas, the number of satellites above the “horizon line” -relative to the mask height- is very small. Therefore, the receiver can take into account some satellites situated below the mask. A compromise is generally made between multipath errors and the choice of the geometric configuration.

3. Simulation results

The software used, to simulate the availability of Globalstar or Worldspace satellite systems, is called STK[7]. This software is able to predict at every position and at any time along a given way, the elevation and azimuth angles of the satellites that could be received. STK uses updated information of ephemeris of the satellites constellation [STK-2001] that could be downloaded from the [Celestrak] website.

Unfortunately, this prediction result, according to STK release and the 2D map used, doesn’t take into account the masks elevation around the receiver. To perform it, three methods can be considered:

- use a 3D release STK and a 3D map with the good file format for STK,

[6] LOCOPROL : LOw COst satellite based train location system for signalling and train PROtection for Low density railway lines

[7] STK: Satellite Tool Kit

- use current releases STK, 2D map and then develop a tool that takes into account 3D environment around the receiver,
- use current releases STK and map, apply a mean mask elevation value obtained in urban or suburban area and then, evaluate the availability as probabilities versus the time and distance.

The 3D STK module and 3D map tools are too expensive for the application, thus this solution is not convenient.

A tool, developed in our laboratory, considers real mask elevations and azimuth along a given way, by performing video records of the 3D environment around the receiver [Marais, 2002]. Then results are combined to STK predictions in order to evaluate the availability of any given satellite constellation. However, this process includes managing great database in case of long trajectories. In a first approach we does not retained this solution.

The third method mentioned consists in using a permanent mask elevation around the receiver and considering only two states of reception, as proposed in classical satellite signal models [Lutz, 1991]:

- satellite visible or received in LOS when satellite is above the mask,
- and satellite not visible or blocked when it is under the mask.

This is the approach retained in this paper to evaluate the number of satellites that could be received in LOS in some simple configurations.

Among several urban Bus lines available in the city of Lille, in the north of France, two representative trajectories, regarding mask elevations, were chosen for the application: Bus lines n° 3 and n° 12. They are respectively about 8 and 12 kilometres long. A great part of the trajectory of the line n° 3, is located in dense urban environment in the old part of the city of Lille. The half part of line n° 12 is in suburban area. The other half is in dense urban environment.

It was shown in [Locoprol, 2002] that the mean mask elevation value in suburban areas is about 20 degrees and reaches 40 degrees in dense urban environment. We chose 30 degrees elevation value corresponding to an intermediate mask elevation value between urban and suburban areas.

Figures 3 and 4 illustrate two examples of simulation results obtained with the Globalstar system, along the two Bus lines using a continuous mask elevation of 30 degrees, for a given time of departure of the Bus.

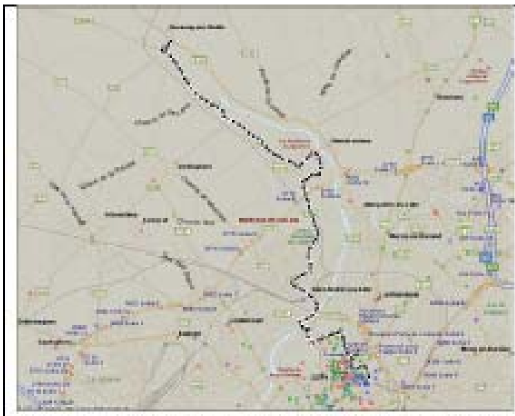

Fig 3.a: Trajectory with a GPS receiver

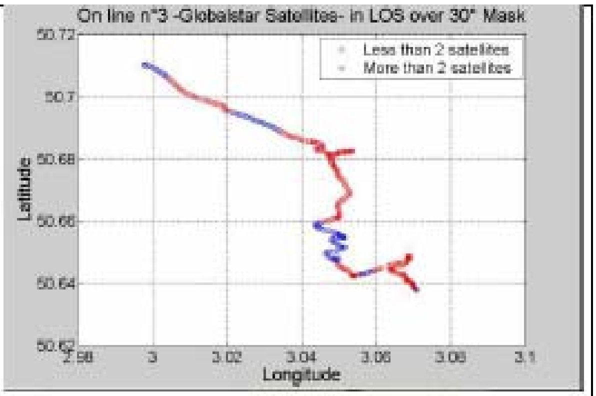

Fig 3.b: Simulation result along Bus line n°3

Figure 3 : Globalstar availability with a continuous 30°mask elevation along Bus line n° 3 in Lille (France).

On figures 3.a and 4.a, each position of the receiver along the line was obtained using a differential GPS with 10 metres accuracy. Then the trajectory issued is applied into STK for calculations. The Globalstar system is considered available, at each position of the trajectory, if at least two satellites reach the receiver at this position either by direct or indirect path.

Figures 3.b and 4.b present simulation results obtained along the trajectory. Red colour indicates the areas where less than two Globalstar satellites could be received and blue colour, the areas where more than two Globalstar satellites could be received in LOS.

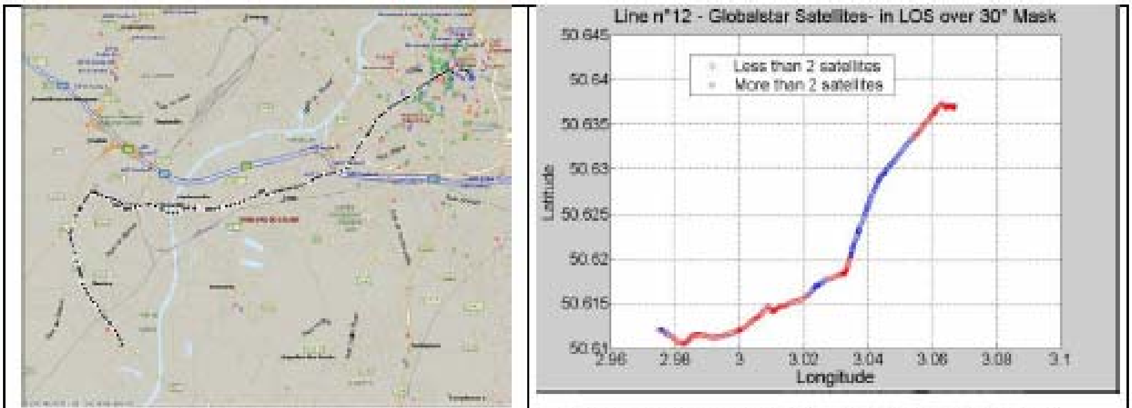

Fig 4.a: Trajectory with a GPS receiver | Fig 4.b: Simulation result along Bus Line n°12

Figure 4: Globalstar availability, using a continuous 30°mask elevation along BUS line n° 12 in Lille in France.

On figure 4.b, the simulation trajectory is a part of line 12 shown on figure 4.a. The simulation results show that Globalstar is available 100 percent of the time if environments around lines 3 and 12 are free of mask that is to say if there were no obstacles or buildings on both sides of the whole way.

Table 1 resumes the main simulation results obtained using respectively mask elevation values equal to 10°, 20°, 30 and 40 degrees on lines 3 and 12 for a given time departure of the Bus.

Table 1: Globalstar availability on lines 3 &12 using mask elevation values equal to 10, 20, 30 and 40 degrees

	Bus Line 3	Bus Line 12
Mask elevation	Percentage of time of availability	Percentage of time of availability
10 degrees	99%	98%
20 degrees	70%	70%
30 degrees	32%	31%
40 degrees	7.6%	10%

Using a mean mask elevation of 30 degrees on both sides of the road, the availability of the Globalstar system is about 32 percent of the time for both lines. At least two Globalstar satellites could be visible in direct path along line 3 and 12 at 32 percent of time if we assume that there is a mask of 30 degrees along all the way. However, greater availability percentages should be obtained, in each case, if we consider also satellites received in NLOS.

The availability is greater than 70 percent of the time in suburban areas where masks elevation due to obstacles and buildings are lower than 20 degrees. At the opposite, the availability decreases to less than 10 percent of the time in dense urban areas where masks elevations are often greater than 40 degrees.

These results were obtained for a given time of departure of the Bus. Many others simulations were done for different times of departure of the Bus on both lines in order to obtain a statistical analysis. The availability distribution along the way is uniform. The availability is around 10 percent of the time for a permanent mask elevation of 40 degrees, about 30 percent of the time for 30 degrees mask elevation and 70 percent for 20 degrees mask elevation. Globalstar system availability is better in areas where masks are less than 20 degrees than in urban areas where masks effects can reach 40 degrees and more.

These statistical values are then used as inputs for the Probability Density Functions of being in state k in a Lutz like two-state satellite behaviour model. The fast fading associated to state k is Rayleigh or Rice distributed regarding the environment characteristics.

The Worldspace constellation system availability was characterized along the two same Bus lines with the same method. As said before, the Afristar satellite is geostationary, thus, from a position on a given Bus line, the angular elevation of the satellite is quite the same at anytime. Moreover, The Worldspace system is considered available, at each position, if the broadcasting satellite reaches the receiver at this position either by LOS or NLOS. In our study, we consider only the pessimistic case for which the satellite is received in direct path or LOS to evaluate percentage of availability.

Figure 5 shows an example of simulation results obtained with the Afristar system, along the two Bus Lines n° 3 and n° 12 using a continuous mask elevation of 30 degrees along the line. The simulation approach predicts that Afristar satellite couldn't be visible at all in LOS if we consider a mask elevation of 30 degrees on both sides of lines 3 and 12. This result was predictable due to the Afristar satellite angular elevation measured from the Bus lines, which is about 30 degrees. In the case of a geostationary satellite, the simulation approach doesn't give very accurate information. The probability analysis of satellites being visible needs to be completed by measurements performed with a Worldspace receiver system. These results are presented in the following paragraph.

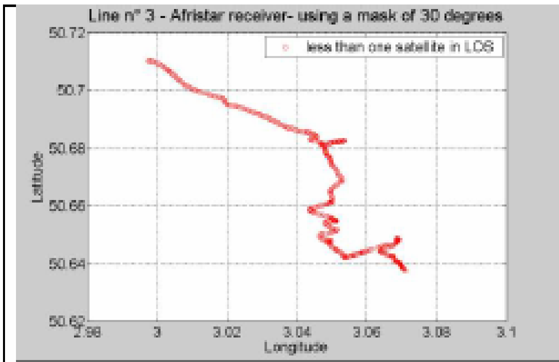

Fig 5.a: Simulation result along Bus Line n° 3

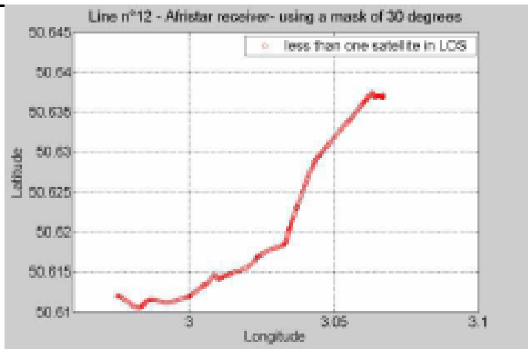

Fig 5.b: Simulation result along Bus Line n° 12

Figure 5: Afristar availability, using 30°mask elevation, along Bus Lines n°3&12 at Lille in France.

4. Experimental results performed with Worldspace system

A Worldspace receiver combined with a bench test is installed inside the laboratory car. A differential GPS is used to locate the position of the vehicle along the Bus line. The Worldspace antenna is placed on the roof of the car. Signal frames are sent continuously from the Afristar satellite while the car is moving along the Bus line n°12 -extended to the suburban area- which represents about 14 kilometres long. The car moves with an average speed of 35km/h or 21 mph and a speed limit of 50 km/h or 31 mph. A tool was developed to determine the data lost between two intervals where data have been received correctly.

On figure 6, positions for which Afristar satellite was received or not, on the trajectory, are represented respectively with green and red markers. Data lost are evaluated visually on this road using different variable colours of round on the trajectory.

The analysis of the data received show that, during the travel on the whole line 12, Afristar satellite is visible during 54 percent of the time. We can see that, in dense urban area, the amount of data lost is greater than in suburban area. The quality of service decreases from a suburban area to a dense urban environment.

The results show also that the broadcasting service can be available in urban areas with a greater probability of loss of data information than in suburban areas. The quality of service is bad if masks elevations are greater or equal to the broadcasting satellite elevation (in this case between 25 and 30 degrees).

The measurements on the Worldspace satellite system show that it is necessary to complement the satellite system with a terrestrial one in case of high mask elevation areas in order to guarantee the continuity of service required in the TESS project. For this reason, we have analyzed the terrestrial GSM/GPRS radio-electric coverage available along the two lines in the downlink frequency band. This characterisation will indicate in which conditions it is possible to exploit GSM-GPRS as a complementary system for the satellite constellation in areas where satellite signals are not received.

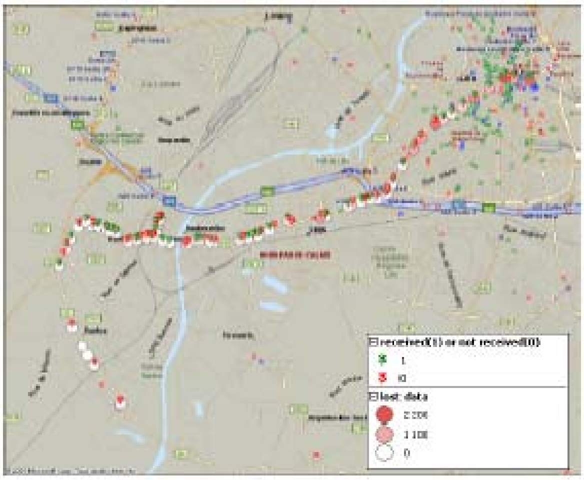

Figure 6: Measurements performed with a Worldspace receiver: data lost estimation.

5. Signal level measured in the whole downlink band of GSM-GPRS system

In this paragraph, the coverage of the GSM-GPRS system is characterized along the Bus lines 3 and 12. The signal level is measured, at each position of the Bus line, on each frequency inside the whole GSM-GPRS downlink band while the car is moving. The average speed is about 40 km/h, measurements are performed with an spectrum analyzer connected to a GSM antenna. Each 20 metres along the Bus line, signals levels are acquired on frequencies from 932 MHz to 962 MHz.

Figure 7 shows an example of measurements performed on line 3. Fig 7.a represents the coverage with different colours according to signal level. Figures 7.b and 7.c represent respectively the maximum and the minimum signal level received on each frequency of the downlink band along the whole line 3. A low noise amplifier of 15 dB is insert between the antenna and the spectrum analyzer, thus 15 dB must be cut off from measurements obtained and presented on figures 7.b and 7.c.

If we consider only frequencies of the downlink band that is to say between 935 and 960 MHz, we can see that on the whole line 3, the maximum of signal level received varies between –5 and –45 dBm while the minimum varies between –70 and –90 dBm.

The same measurements were performed along the Bus line n° 12. The maximum of signal level received, along the whole line n° 12, varies between –15 and –50 dBm from 935 to 960 MHz and the minimum, between –70 and -90 dBm.

The results obtained are quite the same on both lines. We measured good coverage of the GSM system.

However, this coverage measurement is related to GSM coverage but not to GPRS. Only a few base stations among the one measured are enhanced with GPRS services and the exact locations of those base stations need to be known to evaluate the GPRS availability on line 3 and 12. The measurements must be completed with effective transmission and evaluation of GPRS performances while the car is moving along the two Bus lines considered.

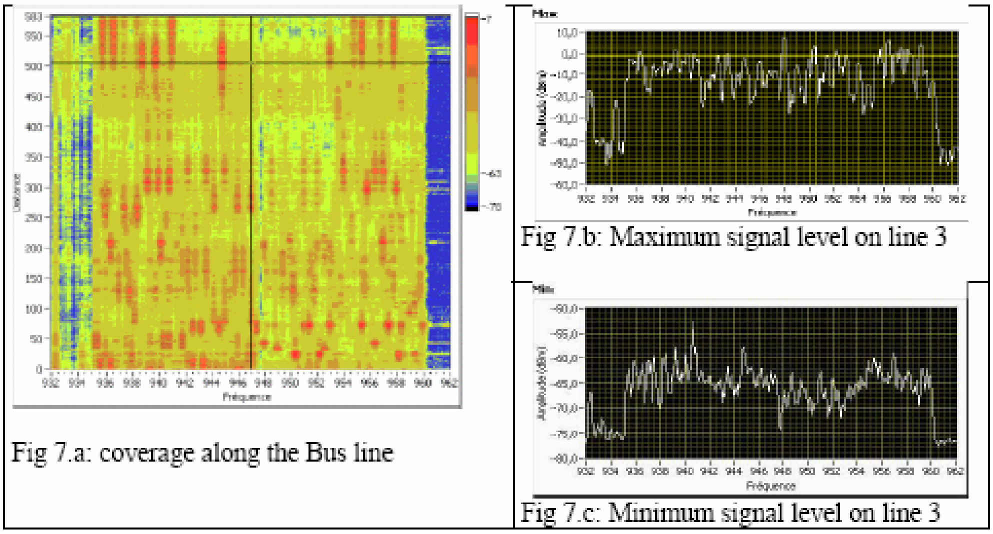

Fig 7.a: coverage along the Bus line

Fig 7.b: Maximum signal level on line 3

Fig 7.c: Minimum signal level on line 3

Figure 7: Line 3 coverage -Signal levels measured in the downlink band of GSM system

6. Conclusion

The work presented in this paper was performed in the framework of the TESS project, which aims at demonstrating that a satellite-based system can answer to high data audio-video transfer needs with the use of terrestrial system as a complementary solution in bad satellites coverage areas.

Our study focuses on wireless telecommunications links used in the context of project, which addresses the field of urban/suburban buses and international freight trucks. These telecommunication systems are Globalstar satellite system for bi-directional communications, Worldspace satellite system for broadcasting information and GSM-GPRS as the complementary terrestrial communication systems. The study consists on evaluating the availability of these systems along urban/suburban bus lines. The satellite system is available, if at least two satellites could be received in LOS or NLOS in the case of Globalstar and if one satellite is visible in the case of Wordlspace system.

Simulations and measurements were performed on two representative trajectories in the north of France, regarding mask elevations. Simulations results showed that availability of Globalstar or Worldspace systems are better in suburban areas where masks elevation are lower than 20 degrees than in urban areas where masks effects can reach 40 degrees and more. Using a continuous mean mask elevation of 20 degrees on both sides of the Bus lines, at least two satellites of the Globalstar system could be received in LOS during about 70 percent of the time. This availability decreases to about:

- 32 percent of the time for a mask elevation of 30 degrees,
- 10 percent of the time for a mask elevation of 40 degrees.

The Afristar satellite is a geostationary one with a constant angular elevation around 30 degrees for a terrestrial observer in Lille in the north of France. The availability is 100 percent of the time for a mask elevation lower than 30 degrees and the satellite is not available for mask elevations greater than 30 degrees.

Measurements in situ were performed along both lines to evaluate the data which could be lost along the line in case of broadcasting information. The analysis of the data received shows that, during the whole line, Afristar satellite is visible during 54 percent of the time. We have seen also that the broadcasting service can be available in urban areas with a greater probability of loss of data information than in suburban areas.

The simulations results and measurements performed on satellite systems confirm that, if we want to guarantee the continuity of telecommunication service required in the TESS project, it is necessary to use terrestrial system as complement in case of high mask elevation.

We have then analyzed the terrestrial GSM/GPRS radio-electric coverage available along the two lines in the downlink band. The minimum signal level received, along the whole lines, varies between –70 and -90 dBm on each frequency from 935 to 960 MHz. It is sufficient to assure a good coverage along Bus lines. However, this coverage measurement is related to GSM-data but not to GPRS. Only a few base stations among the one measured are enhanced with GPRS services. The exact locations of those base stations need to be known in order to evaluate the GPRS availability on Bus lines. Measurements need to be completed with effective transmission and evaluation of GPRS performances while the car is moving.

This preliminary availability analysis confirms that the complementary approach promoted in the TESS project between terrestrial and spatial solutions are the only one able to answer the requirements for fleet management or safety applications in public transports or international freight trucks.

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