FIFTH Project Solutions Demonstrating New Satellite Broadband Communication System for High Speed Train

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Abstract - **Currently the broadband access service in mobility condition, from a very large part of INTERNET users is growing. At same time the mobility telecommunication technology proposes new and challenging solutions to reach the users everywhere. FIFTH (Fast Internet for Fast Train Hosts) Project, co-founded by European Commission in the 5th Framework IST, proposes a new and challenging network solution to make available the INTERNET access through broadband geo-satellite access, to high speed train passengers. A new mobile satellite terminal technology has been studied and a prototype has been designed and developed for a practical implementation in suitable demonstrator scenarios. The present paper aims to describe the end-to-end geo-satellite network designed and implemented in Demonstrator framework of FIFTH Project and installed in a suitable railway coach to execute experimentations on the Italian Railway Network.**

I. TRAIN NETWORK PROTOTYPE IMPLEMENTATION

In the FIFTH Project, the Demonstrator activity framework specifies, designs and implements suitable network prototype to validate, in a significant and actual environment, the main objectives of the Project stated in its Study Phase. To satisfy this goal and in following the prototype implementation, a validation strategy and test campaigns are defined, organised and executed. Finally data elaboration and results assessment will produce significant recommendations to the overall proposed network architecture contributing also in standardisation bodies where applicable.

To satisfy the activity goals, two main objectives have been pursued:

Definition and design of a suitable Broadband Satellite Network Prototype to test new technological solutions for the implementation in moving train environment.

Characterisation of the radio channel and telecommunication link in the railway environment studied under the dynamic and static profile from a train (in motion and motionless).

In the Project, the Demonstrator activity has been carried out exploiting the huge experience gained in the frame of the other related EC Projects as SECOMS/ABATE and particularly SUITED. The first one has contributed in the frame of radio channel characterisation, the second one for what concern the communication aspects (data link, services, etc.).

As in Fig. 1, FIFTH Demonstrator Prototype infrastructure is based on two main sub-systems: the Mobile Train Terminal Prototype (MTTP) and the FIFTH – Access Network Infrastructure (FANI). The MTTP is not only a satellite gateway installed in a train to interface the satellite access network

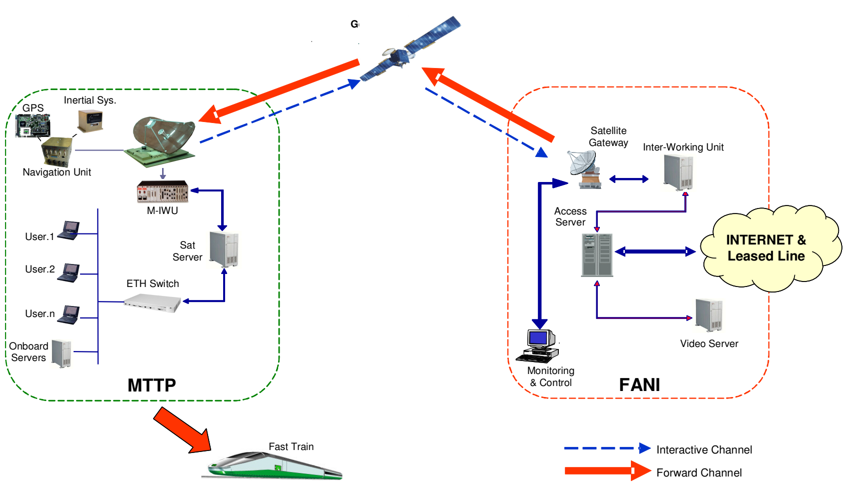

Fig. 1: FIFTH Demonstrator Layout

but it comprises also the entire sub-network, defines Train User Local Area network (TU-LAN), deployed into the train and composed by servers and user terminals towards the passengers-users. At same time FANI is not only a simple ground gateway to link, through a satellite connection, the MTTP but it is also a Network Operation Centre (NOC), providing inter-working capabilities to link the terrestrial networks and access point for the Content Providers of services towards the passengers-users in the railway context (Railway Service Content Provider – RSCP).

II. Demonstrator Specification And Design

More attention has been devoted in specifying and designing the MTTP hosted into the train coach. As anticipated above the MTTP specification activity consist in identifying each sub-system constituting the end-to-end terminal prototype architecture, and making available all the elements to have a fine design of it. The specification definition has not avoided considering the environment where the complete terminal is integrated and installed (railway environment).

The MTTP is composed by two main entities:

- SAT (Satellite Access Terminal) is the section providing the satellite access front-end.
- TU-LAN (Train User - Local Area Network) constitutes the LAN deployed into the train. It hosts all the train servers and the harnesses allowing the connection of the user-passengers to the LAN through wired or wireless links.

A low radome profile antenna system has been specified and designed taking into account not only the train mechanical constraint but also regulatory aspects strictly related to the train safety and currently regulations for what concern the EM items and railway specific standards for what concern the ETR500 train characteristics.

Four main blocks have been specified and designed for the MTTP starting from previous high level description: radio frequency front-end (RF); NTU; M-IWU and TU-LAN.

The *RF* manages physical radio-link access to FANI by means a suitable broadband geo-satellite access. Initially main configurations have been proposed: a Ku band TX/RX access, labelled GEO-SAT and a hybrid one based on Ku band access for the RX and L band fro the TX from the MTTP, labelled HYB-SAT. Practically only first configuration has been designed and implemented, because more significant to respect the second one. Fig. 2 shows a block diagrams describing the main sub-systems composing the MTTP.

The *M-IWU* interfaces the SAT section with the TU-LAN. It manages the handover between segments (satellite, gap-filler, W-LAN) evaluating the local conditions (signal strength) and the information received from FANI. This entity also hosts the processor managing all the strategy to reduce the fading effect on the data stream passing in a railway tunnel.

The *NTU* manages the antenna satellite tracking and pointing operations, it is based on the combination of a GPS navigation system and an inertial one (gyro system) supported by a proprietary software accessing to a database providing the railway characteristics to respect the train position information.

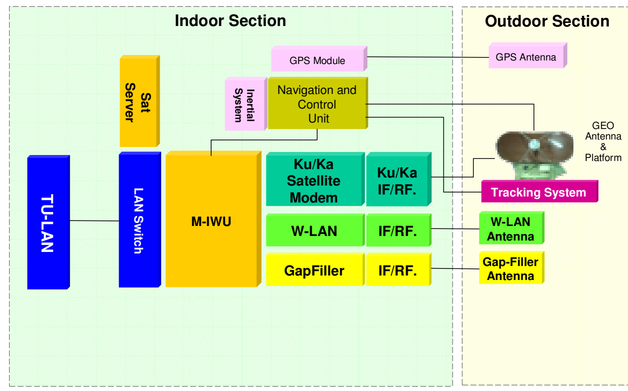

Fig. 2: MTTP SAT layout for GEO-SAT type

The *TU-LAN* constitutes the Local Area Network in the train; it is based on a group of concentrated or distributed servers (it will depend from the railway Operator exigencies), the user distribution sub-systems (hubs, switches, access points) and all the necessary harnesses (optical fibers, wires, connectors, sockets). TU-LAN foresees two user access method configurations: wired, based on UTP ver. 5 LAN physical connection and wireless, using IEEE802.11a or b access points distributed in the coach and in the entire train.

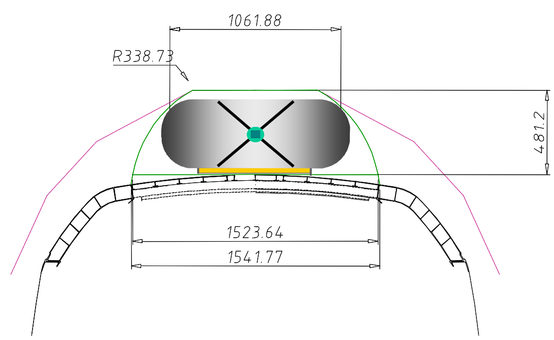

Fig. 3: ETR500 Roof Cross Section with the Antenna

The specification and design of the FIFTH MTTP has considered as target train the Italian ETR500. The infrastructure of the ETR500 adopts an aeronautical technology 15 years old; this choice has been necessary to design a train reaching a maximum speed of 320 Km/h and, at same time, guarantying all the safety regulations and a comfortable journey to the passengers. Practically the adopted technology makes available a train made completely in aluminium extrusions without a rigid framework and having an aerodynamic shape, these details are very important designing an antenna system (defines as antenna, the cover radome and the moving platform) suitable for the external installation without interfering to the train and railway regulations. These assumptions have imposed to design an antenna system hosted on the top of the train roof not in a suitable hole made on it; this has been an important and challenging constraint in designing the antenna system. Fig. 5 depicts implemented solution, where a radome (green line) having an aerodynamic shape with a maximum high of 481.2 mm and a base width of 123.64 mm has been designed. As in Fig. 3 the radome maximum dimensions impose several constraints in designing the target antenna and its platform, for this reason a passive shaped main reflector antenna technology having a Cassegrain geometry has been adopted.

Practically, final prototype has been installed in a suitable train coach not in an ETR500 because it is an operative train not immediately usable for strong and critical experimentations. The railway Project Partner has provided a UIC-Z1 Baggage Van and an electric train ALE-601 constituting the FIFTH Demonstrator train. In the baggage van all the MTTP subsystems with the measurement equipment are installed. The details on the sub-systems constituting the MTTP are as in following.

Antenna System - Carbon Fiber Reinforced Polymer (CFRP) constitutes the material used for the antenna main reflector. It has been deployed in a Cassegrain configuration with an aluminium made sub-reflector, suitably shaping two reflectors to optimise the radiated energy in a reduced volume in conjunction wit the circular feed. The feed is mechanically fixed to make available the linear polarisation configuration: horizontal or vertical. Antenna Radiation Pattern Envelops (RPE) in the azimuth and elevation planes, have been obtained by means simulations executed on the final antenna design shape. Both patterns have been compared with the recommended side lobe envelope mask as foreseen by the ETSI EN 301 427 and M EESS 502 standard by Eutelsat for fixed station.

Antenna Platform - Initially optimising the Demonstrator activity time allocated in the Project and also to take advantage from the current commercial technology, after a market survey, the idea to design and implement the antenna platform has been addressed to some off-the-shelf product technology solutions also SECOMS/ABATE and SUITED. A commercial antenna platform has been selected and purchased, following it has been tested considering the FIFTH Demonstrator requirements, the railway environment and some fundamental stability characteristics coming from suitable measurements executed on a high-speed train.

In a second time, due to the particular constraints above described and having available the final antenna it has been taken the decision to design a proprietary antenna platform, recovering also some sub-system from the purchased one (motors and gears).

Navigation and Tracking Unit – Mission of the NTU is to maintain best antenna pointing during the train journey also during satellite fading condition. The applied strategy has considered three main information sources: a GPS (or a EGNOS system when it will be available) sub-system giving information on the train location and the possibility to calculate the train motion vector; a inertial sub-system based on a Fiber Optic Gyro (FOG) for the heading reference information supporting the azimuth pointing and an inclinometer giving the horizontal plan reference for the roll and pitch angles correction, supporting the elevation pointing. Finally a data base system with Geographic Information System (GIS) on the railway track gives the possibility to have a predictable pointing system reducing the error probability and speeding up the pointing procedures. A suitable Pointing Acquisition and Tracking (PAT) algorithm has been designed and implemented to manage all the NTU sub-system operations.

Mobile InterWorkin Unit - The M-IWU functionalities can be grouped in three main group represented by three sub-system:

QoS Management Module (QoSMM), responsible for the execution of specific capabilities for the end-to-end QoS support (e.g. admission control, compensations against channel degradation, etc.). In particular the QoS module implements functionalities performing interworking between the access segments specific protocols and the mechanisms envisaged to support QoS at IP level.

Mobility Management Module (MMM), which hosts functionalities dealing with the execution of registration and authentication procedures, functionalities in charge of interacting with the segment specific terminals in order to set-up a wireless connection and functionalities in charge of executing inter-segment handover between different access links.

Fading Reduction Module (FSSM), which implements a all the algorithms composing the technical strategy to reduce fading effect in particular train situation as the tunnel or urban canyon crossing. It also supports the particular coding solution implemented to reduce the effect of the train power infrastructure on the satellite link.

Train User-Local Area Network - TU-LAN constitutes the LAN network cabled into the train. Two definitions characterise the TU-LAN: the Coach LAN (C-LAN) and Train LAN (T-LAN). C-LAN is the network cabled into a coach; the interconnection between each C-LAN constitutes the T-LAN. This detail describing the TU-LAN it is necessary to explain well the question that the SAT access is present only in a particular coach and, at same time, some coaches are non cabled

Fig. 4: Final antenna and platform

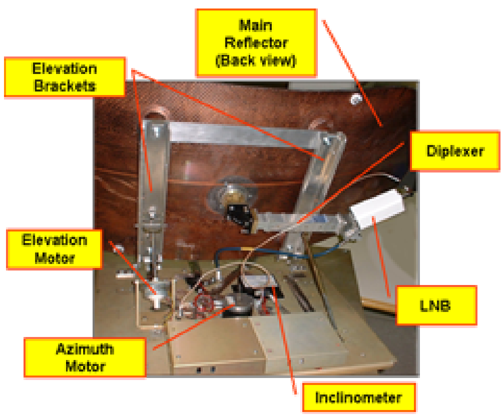

Fig. 5: Platform mechanical detail

because they do not host passengers (baggage van, mail van) but the in train network backbone passes through. Another important technical item considered is the method to interconnect the backbone between coaches, considering the strong regulations on this matter. For the Demonstrator Prototype objectives only one coach has been cabled. The TU-LAN integration has been done at two levels: at physical level (1st layer of the ISO/OSI Stack) and at logical level (all the upper layers to respect the physical one in the ISO/OSI Stack). Cabling system (active and passive components) support storage temperature from -20 to +70° C (commercial specifications). TU-LAN backbone allows the plug and play connections at each access point. On the SAT sub-system gateway also a coax "F" connector is present to provide direct connection of a digital decoder to watch the satellite digital TV on several distributed and collective video displays. This capability is also supplied through IP Multicast protocol utilising a Media Server located in the train, capable to acquire video streaming on MPEG protocol and coding these on IP Multicast streams. In this way also on the normal passenger notebooks or on the collective PC made available by the Railway Operator Partner, the video streaming are available.

The IP flows are sent to Ethernet switches, each one serving a group of sites in the coach and adopting a cascade configuration: every device has an entering flow coming from the previous switch, and an outgoing connection to the following one. Also a Wi-Fi connection distribution has been implemented to access the TU-LAN through a wireless system.

III. Train Terminal And Access Network Implementation And Deployment

Prototype development has been executed in three defined phases: i) the procurement and single elements development and test phase, ii) the sub system integration and test in laboratory and iii) finally target coach preparation and integration of the MTTP with final tests connecting it with the FANI access (see Fig. 1 layout).

The i) phase has been a crucial one in the Prototype development and implementation, particularly for what concert the MTTP development. During this phase, the development of three elements required more attention consuming a large amount of Project time: the antenna system, the platform and the NTU. Fig. 4 and 5 show the final developed antenna. As written above also the platform has required a complete new design and development, spending a lot of time to develop the mechanical structure and interfaces. As in Fig. 4 the platform is compliant with the requirements coming from the ETR500 roof layout; all gimbals, motors and driving cards are hosted on the mobile plate optimising the available volume.

Fig. 6: Antenna and platform on test car

The elevation and azimuth motors are located behind to respect the antenna. The total height of the base plates is about 2 cm comprising the separation gear and the total weight (antenna plus platform) about 22.5 Kg. In the NTU the inclinometer and gyro, are located separately: the inclinometer is on the platform, behind the antenna and the gyro is fixed outside the platform.

During this phase activity the necessary software modules have been developed, particularly for what concern the platform driving and for the implementation of the Pointing Acquisition and Tracking (PAT) algorithm. The software operative environment used to run platform and PAT software is LINUX "MANDRAKE" distribution version 9.1 with the Kernel 2.4.18, each module has been development by KDEVELOP version 2.1 and GCC 3.1, designing and implementing a group of demons made in C++. After an initial debugging session the software has been finalised to be operative on the field.

Fig. 7: Antenna and platform on the coach roof

Fig. 8: Final radome installation

The ii) phase has been executed at ALS premises using for the dynamic tests a car where, on the roof, the antenna system has been installed as in Fig. 6. At same time the UIC-Z1 baggage van has been rightly prepared for the MTTP integration. More attention has been devoted designing the radome installed on the coach roof where a hole has been made as shown in Fig.7. Fig. 8 shows the UIC-Z1 baggage van with the radome on the roof.

The indoor SAT section and the TU-LAN equipment installation into the UIC-Z1 baggage van have completed the integration phase of the MTTP. Fig. 11 shows the rack installed into the coach, it hosts part of the SAT system equipment as the modulator and the Demodulator/IP-Decapsulator (DVB-S standard fro the forward link connection and transparent for the return one) and servers and harnesses constituting part of the TU-LAN core.

IV. Conclusions

At the time of the present paper finalisation, the FIFTH validation campaign are in progress on a suitable Italian Railway Network path, demonstrating the radio link robustness in the hard railway environment and showing the possibility to implement broadband services. More test activities have been carried out before to start the validation campaign execution, demonstrating the robustness and reliability of the proposed technology for railway applications.

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