1. INTRODUCTION

The purpose of this document is to present a commercial solution, based on satellite communications technology at Ku-band, to offer broadband Internet access to train passengers.

In the high-demanding environment of railway operation it is increasingly becoming a must and an advantage to provide services such as internet browsing, e-mail and TV. However, it is not always readily available or is not economically feasible to deploy the proper terrestrial communications infrastructure for those services.

The railway environment has quite specific characteristics, e.g., the signal is blocked when in tunnels or stations, as well as heavy and unpredictable fading is present due to buildings, mountains and bridges, in a similar way of what happens in standard mobile voice telephony. Hence, the final overall technical solution will necessarily embrace both satellite communications and other terrestrial-based communications technologies (that will act as gap-fillers) in order to cope with minimum service availability requirements. Such combination of different communications paths between the train and the rest of the world implies the adaptation of the satellite technical solution in order to work together with other terrestrial mobile communication solutions to guarantee data traffic continuity along the railroads.

The system developed is an innovative and easily deployable solution based on satellite communications technology that offers broadband interactive services to train passengers. The system is capable of locking to the signal and of tracking the satellite regardless of train speed or position, providing passengers with internet access, e-mail,… Additionally, the system can overcome satellite loss-of-visibility situations, e.g. railway stations or tunnels, by automatically switching between wireless terrestrial networks and the satellite link.

This solution is based on a big experience in communications system technologies (SCPC, spread-spectrum, DVB,...) and product development such as antenna, modems and hub stations. The product can be adapted, if necessary, to customer specific needs in order to offer the best solution in a case by case basis.

2. SYSTEM OVERVIEW

WLAN technology has experienced an enormous deployment in public and private spaces due to its easy-to-install and use intrinsic characteristics and low cost of installation and operation. This technology has also potential commercial interest within the rail transport sector, particularly when access points are deployed inside airports and railway stations in order to provide Internet access to passengers waiting for travelling to their destinations.

Within this context, extension of the service in order to provide it to passengers while travelling has also been found interesting in terms of market demand. Particularly, passengers of long-haul trains spend a minimum of two or three hours. During that time, internet access could be provided covering at the same time both professional and entertainment demand. Even more, passengers travelling on high-speed trains (which are a subset of long-haul trains) do normally correspond to business travellers, who are prone to pay for internet access if at a reasonable price.

By deploying WLAN technology along train coaches and building thus a distribution network up to each passenger seat, the solution to one part of the problem is tackled. A solution for the establishment of a communications pipe from the mobile train to the terrestrial internet backbone can be provided for most of the cases at competitive cost by means of satellite technology at Ku-band without incurring in huge costs due to the deployment of costly terrestrial dedicated infrastructure along the railway.

However, due to the specific characteristics of the train environment in which satellite signal can be blocked when going into tunnels or rail station areas, a diversity strategy including other access technologies need to be used and, hence, interoperability between satellite technology and those terrestrial-based radio links shall also be foreseen on trains.

3. NETWORK OVERVIEW

The satellite network described is a one-way or two-way communications system, which uses a very efficient DAMA access scheme in order to optimise the use of satellite bandwidth. Terminals are allocated bandwidth automatically depending on their actual needs on a real-time basis. It is not necessary thus to define a fixed configuration since the control centre will reallocate resources as needed.

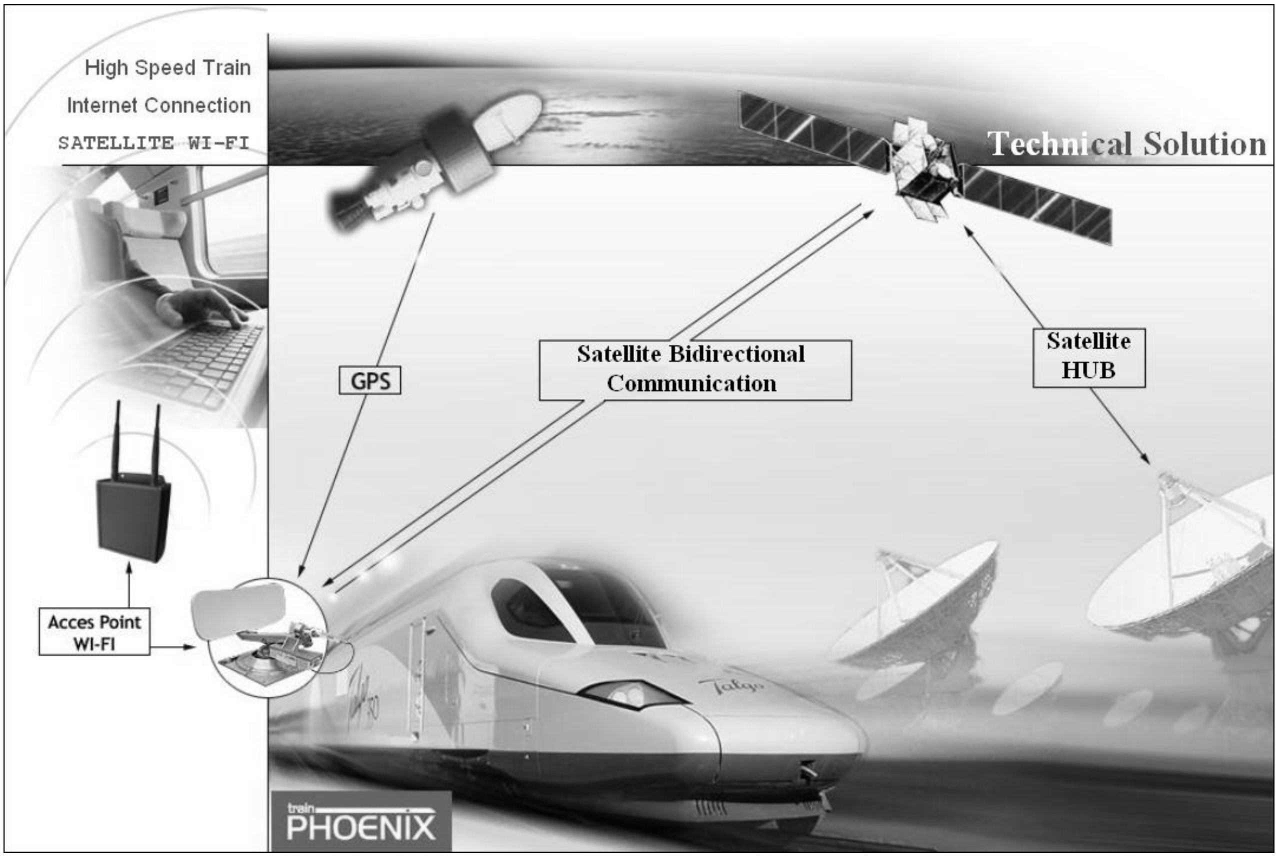
Therefore, the overall communications system is composed by:

- Network Management Station (NMS): there exists a single NMS responsible for the overall management of the network, including resource management (resource allocation and control for the DAMA functionality) and monitoring and control of the different network components. To improve network reliability, another NMS can be added and configured as a backup, in the same or other physical location; such backup NMS would automatically become active after a failure of the nominal NMS. Different sizes of NMS are available for better scalability.
- Gateway Hub Earth Station (GHES): it provides the interface with external networks (e.g., IP WAN and voice POTS through ISDN), as well as user (voice

and data) satellite traffic channels. There can be one or more GHES's, depending on the network configuration, and for not-complex nor big networks it is usually located beside the NMS or even within the same rack for a small network. GHES stations can also be configured with rerouting and backup capabilities.

- Mobile Terminal (MT). Remote terminal installed in the train to provide passengers with broadband interactive services through an in-train communications network based on Wi-Fi and 802.3 LAN standards.
- Satellite. Responsible of providing the communication link between MTs and HUB for the desired geographical area of coverage.
- On-board Multichannel Gateway. Integrated in the MT architecture, this element provides flexible multiroute communications by choosing on a realtime basis the best route available for each location and circumstance (e.g., GPRS in a tunnel, Wifi in underground stations, and satellite in the field); the gateway can also be loaded with a well of different applications, such as user access control, traffic shaping, billing platforms, video streaming server, etc.

Typically, a small hub for a few terminals will be a few units-high small rack with one or two computers, power supply and channel units, whereas for a big redundant network with redundant terrestrial interfaces the hub would be a distributed infrastructure with several racks and hundreds of channel units. In this document, for the sake of clarity and generality, both logical entities (NMS and GHES) are described separately in the following sections, though they could be delivered in the same rack.



There are two different networks inside the train:

<u>*Satellite Network*</u>: Thanks to the best guidance system, a bi-directional satellite antenna fixed to the roof of the train, a link can be established with a satellite. The maximum capacity of this link is:

- 26 Mbits downstream
- 2 Mbits upstream

The satellite system has been tested several times in Europe achieving this bandwidth. Once the satellite link is established, a CPU acts as bridge to connect the satellite bandwidth to the internal Wi-Fi network.

The satellite connection is point-to-point connection, so it cannot be sniffed or interfered by any person. Once the signal is received in the Satellite hub (Satellite Main Station), it is connected to the Internet.

<u>*Wi-Fi Network*</u>: On each car train, a Wi-Fi access point is installed. These access points have dual functions -- one part is in charge of the backbone connection, keeping

bandwidths over 100 Mbps with the rest of the access points. The other part acts as an access point repeater. This configuration allows 250 connections per Access Point installed on the train, so the Wi-Fi network in a five-car train can allow up to 900 clients.

The CPU bridge will host the hotspot management system and other applications, including:

- Local video streaming, films, videos or music.
- Games
- Latest news
- Video on Demand
- Telemetry
- CCTV

The public access bandwidth will be divided into:

a. ***Local Access (Train Wi-Fi LAN)***: Inside the train WLAN, clients have access to different services.

b. ***Remote Access (Satellite/Wi-MAX/others)***: The remote access will be divided into:
   - For the public access, WLAN-connected passengers will have a level of access of 250 kbps uplink and 750 kbps downlink with a contention ratio of 20.
   - 1.5 Mbps will be reserved for the CCJPA train operations.
   - The maximum downstream with the satellite communication will be 4 Mbps.

Wi-Fi / Wi-Max support: The system balances the bandwidth needed with different system supports. The satellite can achieve up to 4 Mbps downstream, but when more public bandwidth is needed other systems act as routers to maintain the quality of service.

4. NETWORK TECHNOLOGIES

The services are provided by three different satellite technologies, namely: bidirectional CDMA satellite connections, one-way or two-way SCPC QPSK, and oneway DVB-S. CDMA and QPSK are implemented in the same modem (switch from one technology to another is a configuration option) whereas DVB-S is implemented separately in order to allow combined configurations (i.e., QPSK + DVB-S, and CDMA + DVB-S).

Terminals can operate in CDMA or QPSK mode, and can be installed with or without DVB-S reception capability. Terminals can be configured for CDMA or QPSK, and for those with the DVB-S hardware platform installed the DVB-S reception service can be enabled or disabled. All services configurations can be made locally (through the monitoring and control port of the terminal) or remotely (through the configuration window in the operator post HMI in the hub).

The performance of the terminal (measured in kbps) strongly depends on the satellite used and the coverage of that satellite in the geographical area where the train operates. The figures provided below assume that there is no such limit or constraint and correspond to maximum performance of the modem. A detailed scenario case is provided in another section below for a specific satellite and location, for information purposes.

CDMA mode

The CDMA mode is useful for meeting international regulations related to off-axis radiation, since the process of spreading the signal reduces spectrum power density. In order to do not waste valuable satellite resources, different signals from different users share the same bandwidth and can be distinguished at reception because each user uses a different and orthogonal sequence.

In this mode satellite resources are broken down and assigned along two different "dimensions", namely orthogonal codes and frequency slots; thus, the system is in fact a combination of CDMA and FDMA. The spectrum allocated to CDMA is split in different frequency slots or chunks of spectrum, all of them equal in bandwidth (Hz).

Within each slot different terminals are given different orthogonal codes. The allocation and release of a combination of slot and code is done automatically by the hub upon request by the terminal for satellite capacity.

The policy used by the hub for allocating slots and codes, as well as the number of users (codes) per slot is configured depending on the maximum spectrum density allowed for a specific location (or satellite), and other considerations.

Two different spreading factors (code length) are available and different configurations in terms of coding and symbol rates are available:

Symbol rate (baud)	User Data Rate per carrier (bps)					Max. number of carriers per modem	Total per modem (bps)
	VIT 1/2 RS	VIT 3/4 RS	VIT 1/2	VIT 3/4	UNCODED		VIT 1/2 RS
16.000	14.313	21.125	15.375	23.250	31.125	8	114.500
32.000	28.625	42.250	30.750	46.500	62.250	8	229.000
64.000	57.250	84.500	61.500	93.000	124.500	8	458.000
128.000	118.250	177.750	126.750	190.500	254.250	8	946.000
256.000	236.500	355.500	253.500	381.000	508.500	4	946.000

The terminal, when used in CDMA mode, can receive and transmit more than one carrier and aggregate the resulting capacity at its IP interface in a transparent way to the user. This allows providing users with scalable capacity without needing to excessively spread the signal.

QPSK mode

In this mode the terminal is like any other IESS-308/309 compatible QPSK satellite modem, with the advantage that can be managed by and through the Network Management System.

Modulation	QPSK
FEC	Convolutional to 3/4, 1/2 Block Reed-Solomon (126,112,7) – configurable
BW/carrier	From 83.2 up to 1996.8 KHz
Roll-off	0.3
Symbol rate (1 carrier)	From 64 up to 1536 Kbauds
User bit rate	64, 128, 256, 512, 1024, 2048 Kbps

The QPSK mode can be enabled for transmit or receive, independently, an each one at different user bit rates (asymmetrical links).

DVB-S complement

The basic terminal can be complemented with a DVB-S reception module that provides the system with the capability of:

1) Broadcasting information to all or to a subset of trains.
2) Standard DVB-S IP encapsulation.

Technology	DVB-S (adapted to movile environment)
Modulation	QPSK
FEC	Convolutional 7/8, 5/6, 2/3, 3/4, 1/2 Block Reed-Solomon(204,188,8)
Roll-off factor	0.35
Bandwidth	Up to 36 MHz
BW/train	Typically ≥ 3 MHz
Bit rate/train	Typically 2 Mbps, up to 26 Mbps
BER en reception	QEF

5. TERMINAL PERFORMANCE

The Mobile Terminal offers broadband Internet access service to train passengers by means of using a hybridized satellite communication system. The terminal can work in different technologies (CDMA, SCPC and DVB-S) permitting a high degree of configurability for each terminal on an independent basis, coexisting all the terminals in the same network and being managed from a single Network Management System.

On the other hand, different options are also available for the antenna. Selection of the most suitable one depends on the targeted performance (kbps), geographical area and satellite used, and mechanical (height) constraints.

The proposed terminal is based in the following aspects:

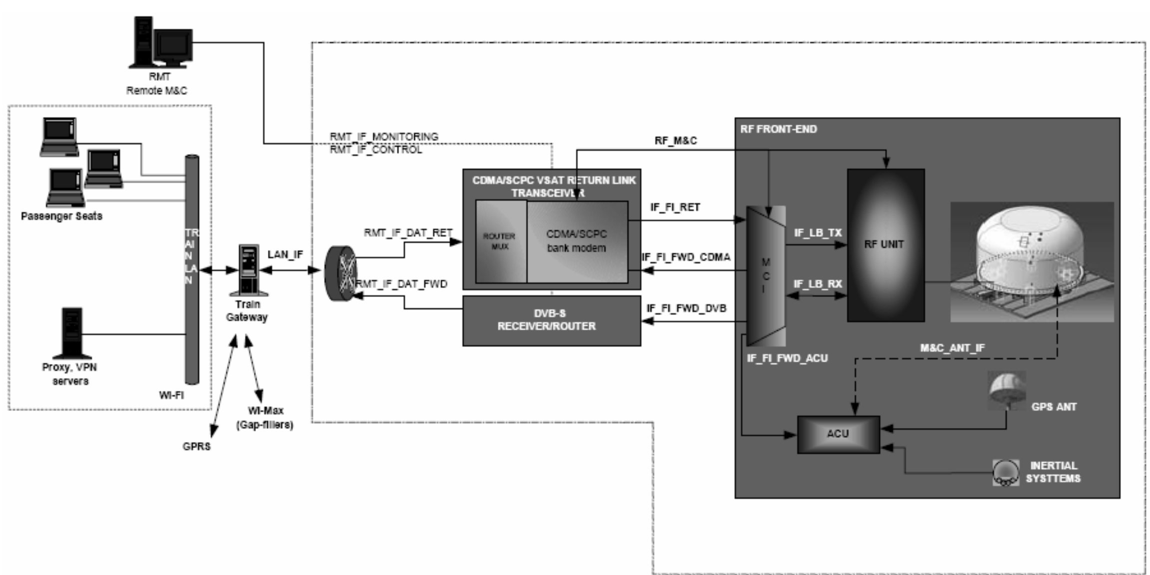
- Satellite search and tracking: the MT is capable of tracking the satellite regardless of train speed or position.
- Configurability: the MT supports CDMA and SCPC and complemented with DVB-S technology, being possible to switch from one to another when needed.
- Small terminals: adapted to the railway environment in terms of height, and also capable of overcoming the potential problem of off-axis radiation international regulations by providing spread-spectrum technology (CDMA). These way terminals can transmit at broadband rates while still meeting international regulations.
- Fading: The satcom subsystem counteracts against unpredictable non periodic fading due to obstacles (bridges, trees, buildings,..) and periodic fading due to the presence of equally spaced metallic structures such as the overhead wire.

- Integration with other networks: The satcom subsystem notifies upper layers of the network the event “signal lost” when traversing tunnels and urban areas in order to allow the system to switch-over to another access technology.
- Access time: channel Access time at start-up and after crossing tunnels or stations is less than 20 seconds.
- Recovering time: channel recovering time is less than 2 seconds.
- Operability: the MT can work unattended, robust and easy to configure.
- The system offers all capabilities for complete network management in a centralized way at the hub station, e.g., user handling, priorities, call routing, backup routes, QoS management, etc.

6. MOBILE TERMINAL

The satellite user Segment, named the Mobile Terminal (MT), encapsulates IP traffic coming from the train passengers on-board local LAN interface (LAN_IF), perform Segmentation of IP traffic and signaling packets and modulate data streams in the corresponding CDMA carrier(s) or through an SCPC carrier. In the same manner, it demodulates one or more CDMA carrier(s) or an SCPC carrier depending on the working CDMA/SCPC modem mode.

In addition, the MT is in charge of demodulating, from the DVB-S forward carrier, high rate DVB-S data, extracting the IP traffic addressed to it from the rest of stream contents, and providing respectively IP packets to the train LAN through LAN_IF interface. At the same time, when working in CDMA mode, the MT demodulates low rate CDMA VSAT signaling to extract synchronization and M&C packets for remote control purposes.



The main components of the MT are:

- Antenna subsystem front-end:
    i. Low profile antenna.
    ii. RF unit: HPA and LNB.
    iii. Antenna control unit (ACU).
    iv. Multiplexing & converter interface module (MCI).
- DVB-S receiver/router.
- CDMA/SCPC VSAT transceiver.

7. OUTDOOR SUBSYSTEM

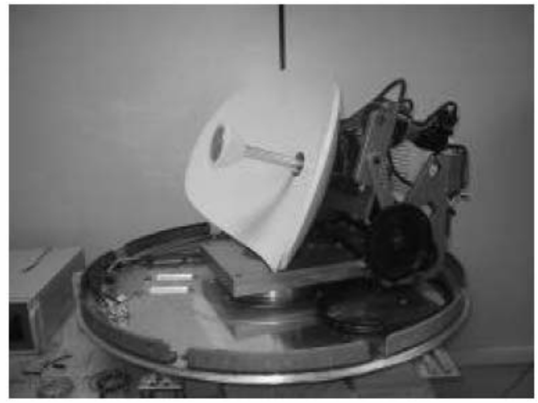
Under this subsystem, the following elements are included:

- Low profile antenna, composed by:
    - Antenna.
    - Antenna stabilizer, when applicable.
    - Radome
- RF unit, to provide up/down conversion from the Ku-band frequency to a suitable intermediate frequency for the CDMA/SCPC VSAT transceiver and DVB-S receiver equipments. It has also an HPA in TX to feed the antenna, and a LNB in RX to receive signal at suitable levels of C/No.

The main characteristics of the ODU 700 are detailed in table below:

Outdoor Subsystem 700		
	RX	TX
RF parameters		
Frequency Band	10.7 to 12.75 GHz	13.75 to 14.5 GHz
Instantaneous bandwidth		
Gain (at RF interface)	>35 dBi (10.7 GHz)	>36.5 dBi (13.75 GHz)
EIRP		44.2 dBW max ITU-R S.728-1
G/T ratio at antenna terminal	14 dB/K min	
Antenna Type / Pattern	Double reflector Cassegrain / ITU-R 580-5	
Polarization	Linear	Linear
Cross-polarization	30 dB	
Elevation scan range (relative to horizon)	Elevation: 17º to 62º Azimuth: unlimited	
Size		
Dimensions (mm)	850 x 546 (diameter x height)	
Weight	110 Kg.	

Outdoor Subsystem 700		
	RX	TX
Pointing system		
Spatial pointing / Tracking accuracy	0.5º RMS	
Tracking speed	Elevation: 15º/seg Azimuth: 20º/seg	
Acquisition & tracking	Automatic (step track mode)	
Max. motions	Roll: ± 10 deg/s Yaw: 1 deg/s Speed: 300 km/h Acceleration: 5.5 m/s2	
HPA Power		
HPA power	Up to 8 W (SSPA)	



8. INDOOR SUBSYSTEM

Under this subsystem, next elements are included:

- Antenna control unit (ACU).

This is the Antenna Control Unit in charge of providing stabilized signals in pitch-roll axes at the output of the RF Unit, mitigating the movement effects due to the railway environment. ACU implements some stabilizing algorithms based on the received signal, GPS signal and inertial sensors. The output of these algorithms results on some mechanical actions over the antenna equipment. Automatic polarization adjustment is also included in the ACU functions. Depending on MT model, ACU is integrated in the outdoor subsystem or Indoor subsystem.

- Multiplexing & converter interface module (MCI).

This module is in charge of interfacing the CDMA/DVB base-band equipment and the Antenna subsystem. The main functions to perform are:

- The distribution and conversion of L-band Rx signal to ACU, DVB receiver and CDMA/SCPC modem
- the multiplexing of power requested by the RF equipment part of the antenna subsystem
- RF M&C interface

- DVB-S receiver/router.

This is a DVB-S receiver/router (COTS) which implements the base band processing of the DVB-S standard. It receives broadcast IP traffic (also video/audio if requested) from IF_FI_FWD_DVB packet into DVB-S Transport Streams and delivers it to the MTS_IF_DAT_FWD in the form of IP datagram. The DVB-S receiver is set (based on system topology) to receive those DATA packets with a given PID and MAC address and, optionally, to receive those TS (AUDIO/VIDEO) packets of a given PID. These PID and MAC match with those sent from the HUB and are useful to associate a range of IP addresses with a single PID-MAC address, avoiding massive reception of IP traffic that is sent to other IP networks (in our case, other MTs).

DVB-S Reception at MT	
Technology	DVB-S (adapted to mobile terminals)
Modulation	QPSK
FEC	Convolutional to 7/8, 5/6, 2/3, 3/4, 1/2 Block Reed-Solomon(204,188,8)
Roll-off factor	0.35
Overall System Bandwidth	Up to 36 MHz
Bandwidth per train (satellite dependent)	Typical ≥ 3 MHz
Bit rate per train	Typical 2 Mbps, up to 26 Mbps
BER in Reception	QEF

- CDMA/SCPC VSAT transceiver.

This component manages the CDMA and SCPC VSAT base band transmission and reception. In the steady state, when an IP connection is established, it supports the framing and merging of return IP traffic received from the on-board LAN, as well as channel access control and monitoring protocol messages over the TX path. In addition, some control information is received over the RX path for remote monitoring and control purposes of the station.

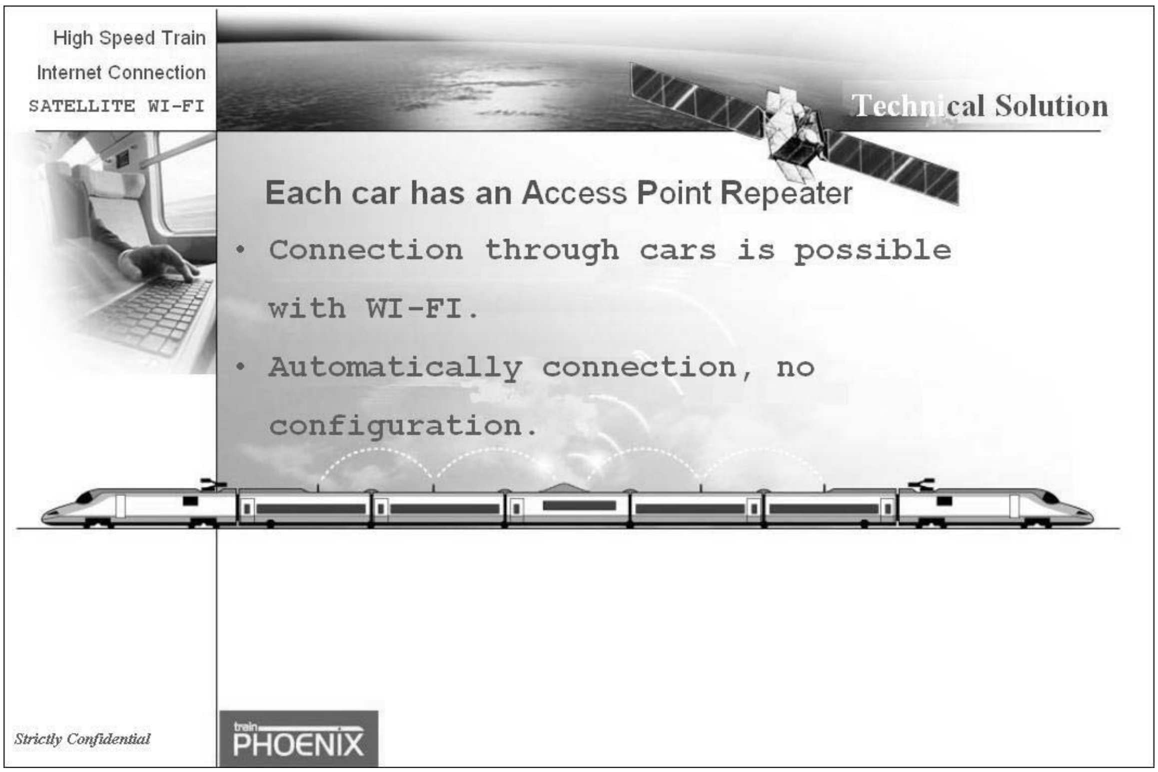
The CDMA/SCPC VSAT equipment constituents are:

- A CDMA/SCPC modem (or bank of modems, for multichannel terminals), each one supporting bidirectional channels with a configurable traffic bit rate according to the table below and the operation mode.
- The router (when applicable), in charge of streaming a single IP traffic flow over one or several of the above channels (multiplexing and demultiplexing function at IP level).

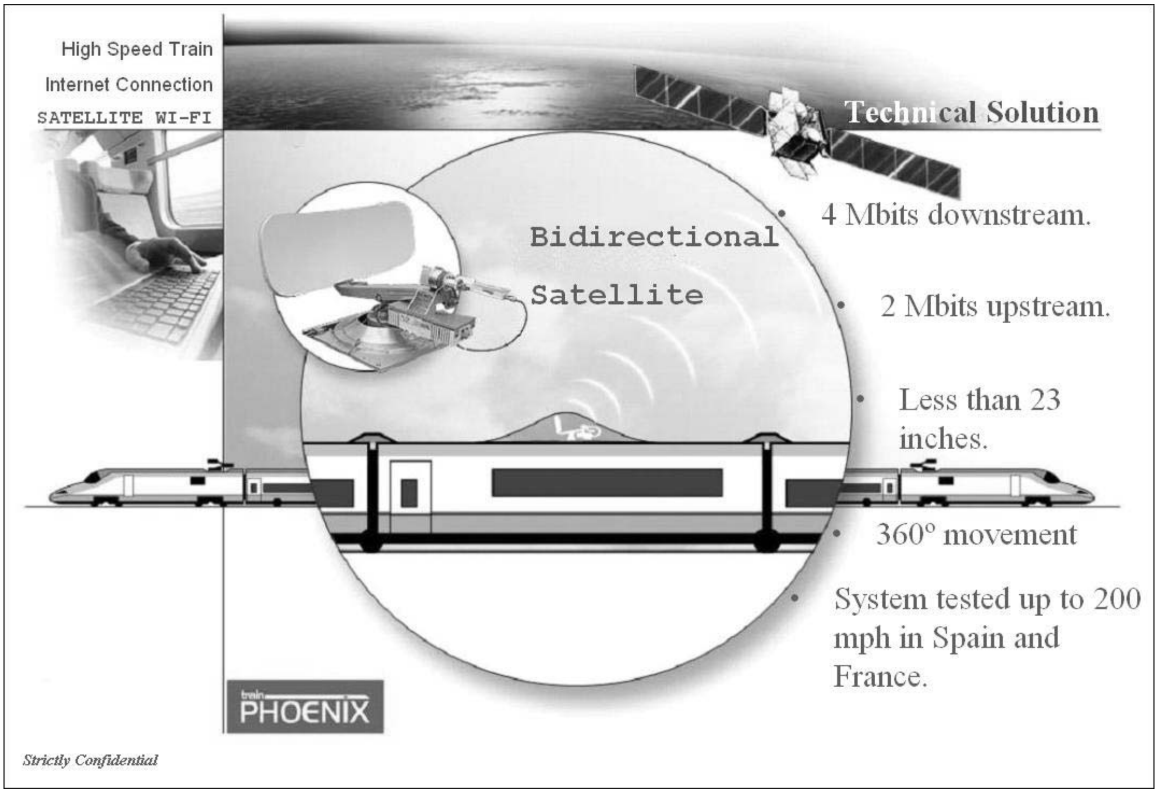
CDMA/SCPC VSAT Transceiver	
CDMA Mode	
Access technique	BLQS-CDMA (Band-Limited Quasi-Synchronous Code Division Multiple Access)
Modulation/Dem. Type	DS/Dual BPSK (QPSK)
IF Tx/Rx center frequency	70 MHz
Number of Tx/Rx Channels	1 – 8 (NB) or 1 – 4 (BB)
Spreading/despreading sequence	GOLD
Code Length/Spreading factor (SF)	31, 63 and 127 - configurable
FEC	Convolutional to 3/4, 1/2, 1/3, 1/4 Block Reed-Solomon (188,172,8) / (251,235,8) / (254,238,8)
Roll-Off factor	0.22 / 0.4
Symbol rates (per channel)	16 / 32 / 64 / 128 / 256 kbaud
Bandwidth	0.6 / 5 / 10 MHz
Bit rate - CC 1/2 + RS (254,238,8)	14.3 / 28.6 / 57.2 / 118.2 / 236.5 kbps
SCPC Mode	
Access technique	SCPC (Single Channel Per Carrier)
Modulation/Dem. Type	QPSK
IF Tx/Rx center frequency	From 50 to 90 MHz
FEC	Convolutional to 1/2, 3/4 Block Reed Solomon (126,112,7)
Roll-Off factor	0.3
Symbol rates	From 64 to 1563 kbaud
Bandwidth	From 83.2 to 1996.8MHz
Bit rate (CC 1/2)	64 / 128 / 256 / 512 / 1024 / 2048 Kbps

9. GLOBAL VISION

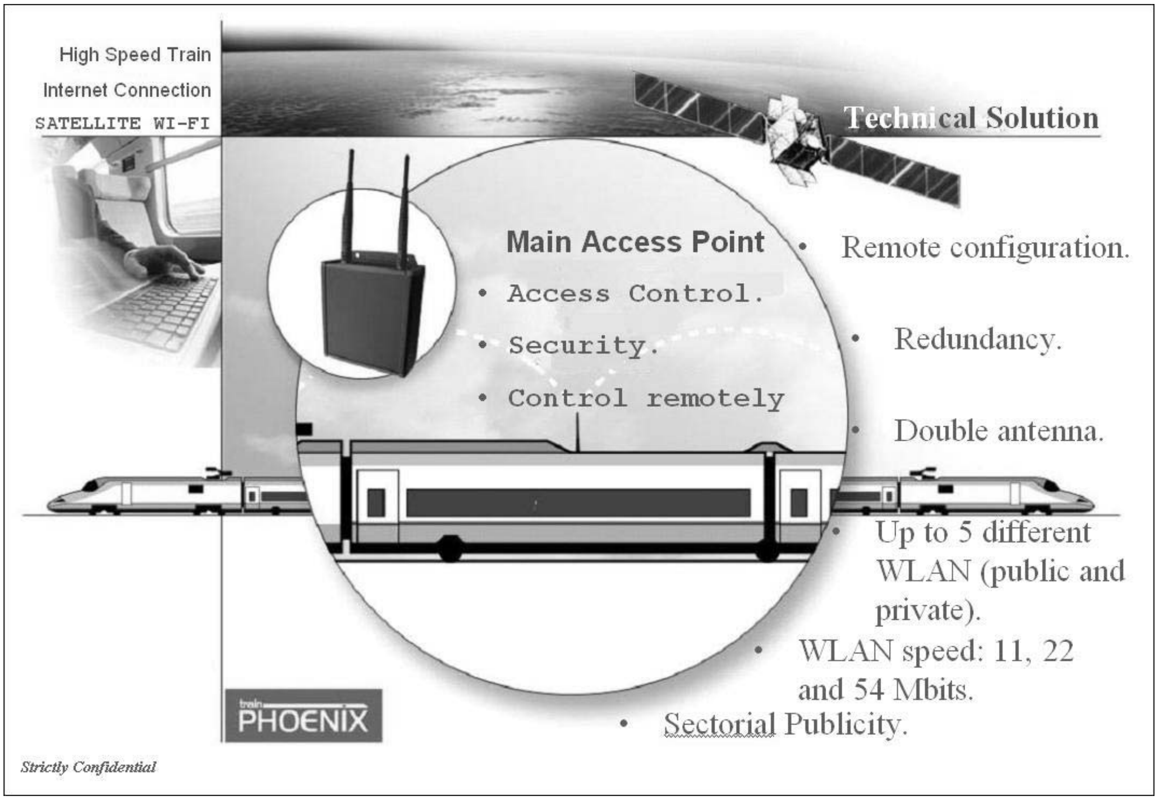
Functional specification of the network elements to be deployed.



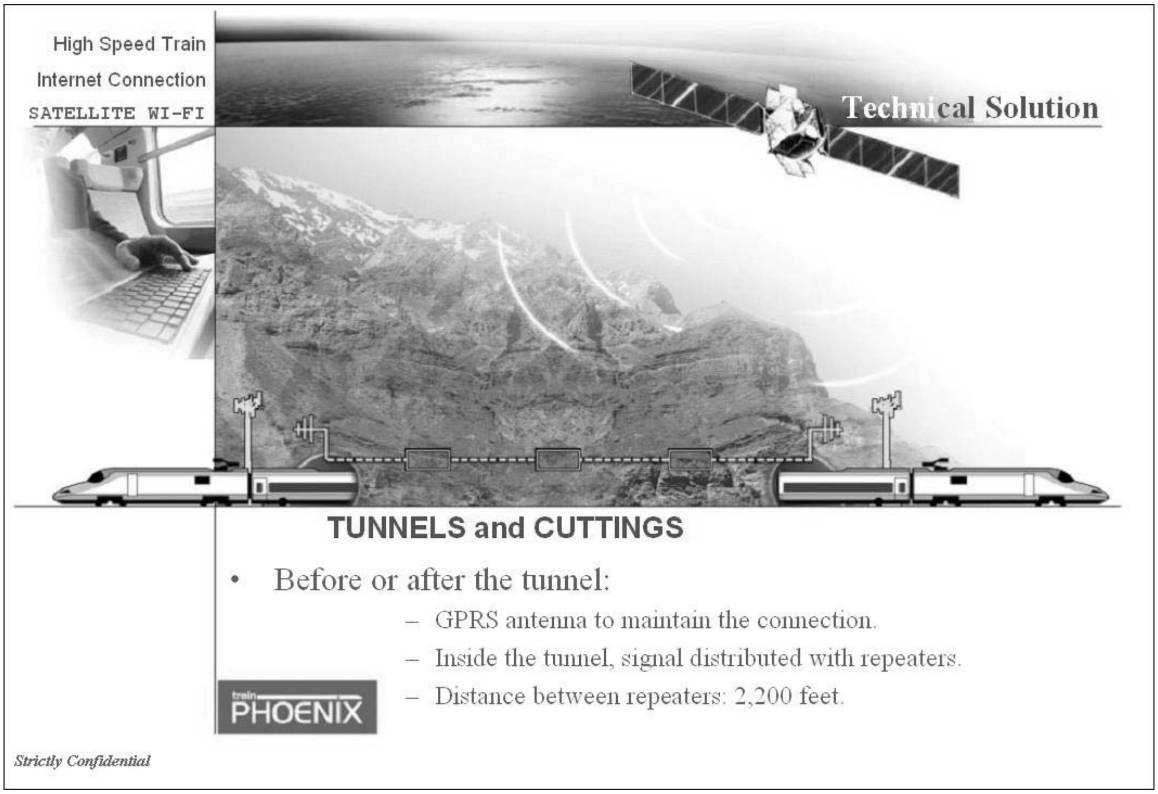
The connection between car trains is made with Wi-Fi. It can also be done with UTP cat.6 cable. There is no need for any kind of preconfiguration, because the Wi-Fi system already connects automatically. In the future, if train cars must be changed for maintenance, the system will configure automatically.



The train's middle cars include a radome covering the satellite antenna. This antenna is connected to the in-car WLAN, so users can access the Internet.



On each car train, a Wi-Fi repeater is installed. These Access Points allow access to 250 users per car train, and can also can be configured for up to five different WLANs, for public (passengers) and private (railway operator) use.



In tunnels, stations and cuttings, the system can use other infrastructures already deployed, like GPRS, 3G, WI-MAX, WI-FI or others.