HUGHES

White Paper

Communications on the Move (COTM) for Railways

For centuries, rail travel has been an essential mode of transportation throughout the world. Today, the rails offer a distinct advantage over often-congested travel by air or car. Rail is a more relaxing mode of travel that affords more leisure time which can be put to use for a myriad of purposes. Travelers today welcome that extra time to catch up on reading or emails at their leisure, surf the Web, or do other tasks that require high-speed Internet or Virtual Private Network (VPN) access. The foundation of all these activities is broadband connectivity.

This paper addresses the challenges of providing broadband connectivity on trains and assesses the most comprehensive and cost-effective solutions employing satellite-based technology.

More than Just Internet Browsing

Broadband data requirements on trains generally cover two broad areas—railway operations and passenger services—as illustrated in Figure 1.

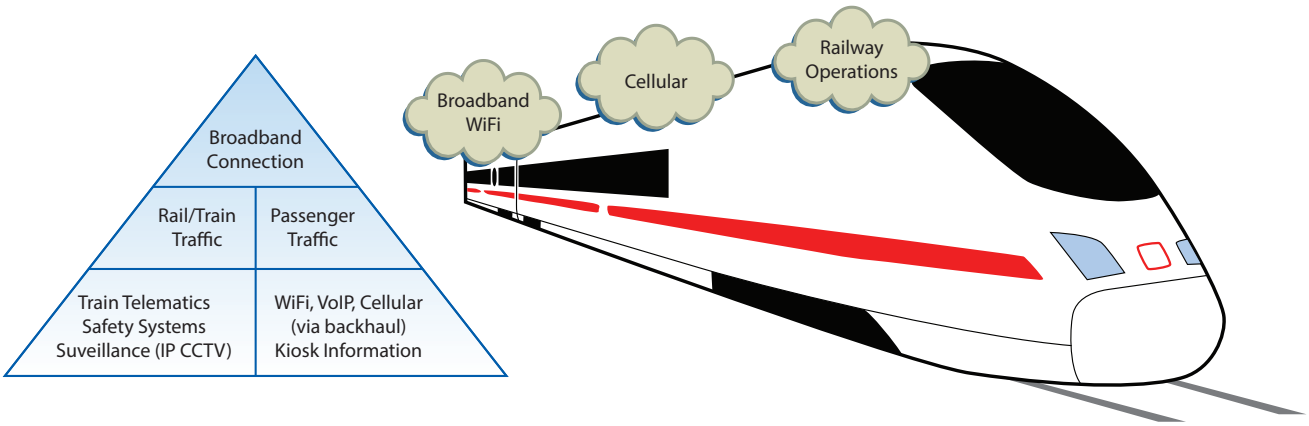

Figure 1. Broadband Requirements for Passenger Railways

Railway operations may include the exchange of critical data, including operational safety data like systems status and emergency information, video monitoring using IP-based CCTV systems, telemetry data, and command and control. This type of traffic is typically high priority.

Passenger services are composed of the data and voice connectivity that today's passengers expect. This type of Internet traffic includes activities like Web surfing, downloading videos and files, online gaming, and VoIP traffic. As illustrated in Figure 2, forecasts show land mobile bandwidth utilization growing at a steady pace across both conventional Ku-band and High-Throughput Satellites (HTS), which are typically Ka-band.

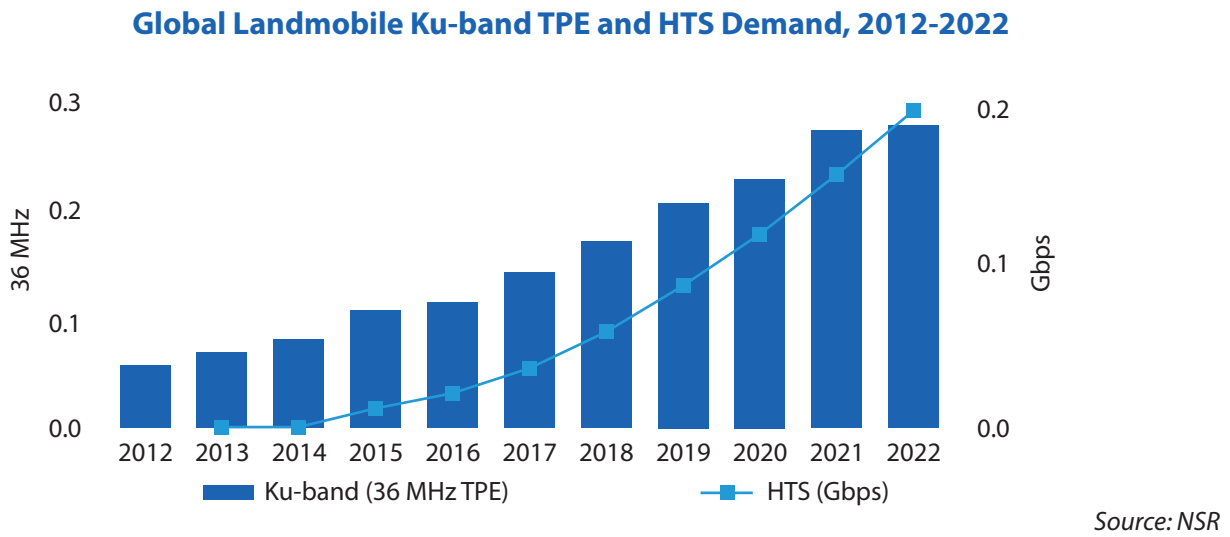

Figure 2. Global Land Mobile Demand

A significant part of this growth will be on passenger rail transport, similar to the surge of airborne broadband. And in both cases of rail and air, the universal networking technology available for both environments is satellite. Cellular 3G/ 4G services are a possible but incomplete option in the case of rail, especially for long-haul rail. Because of the high traffic requirements and typical gaps in terrestrial cellular coverage over the route of a long-haul train, a direct connection to cellular systems alone cannot meet the consistent quality expected by customers for the duration of a journey. Only satellite-based solutions can address these challenges in a comprehensive and cost-effective way.

Even in areas where no cellular coverage exists, rail passengers still expect coverage. In this case, onboard cellular connectivity for passengers may be provided employing a hybrid solution of microcells or picocells connected to 3G/4G cores via a broadband satellite link.

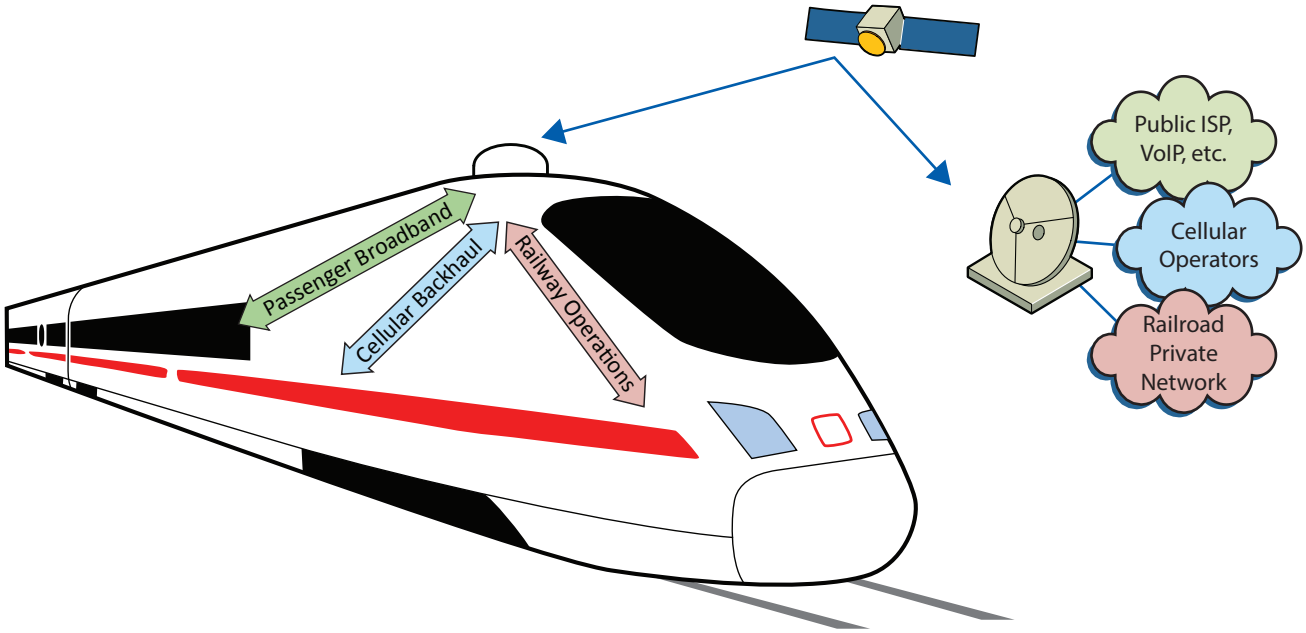

Figure 3. Satellite Connectivity for Railway Broadband

The Unique Challenges of Mobility

All mobility applications—airborne, maritime, and land-mobile alike—face similar challenges related to signal interference caused by physical line-of-sight (LoS) obstructions. However, of these, land-mobile is likely to face the most extreme and unpredictable obstructions.

Specific challenges unique to rail and ground-based vehicle mobility include:

- LoS blockage from buildings, trees, tunnels, and other structures
- Crossing of national and service provider boundaries
- Harsh physical environments, such as heat, vibration, and electro-magnetic interference

Compounding these issues are additional challenges on high-speed trains:

- Doppler shift
- Changes in signal levels due to movement within coverage beams
- Crossing satellite footprints and beams
- Limits in antenna size

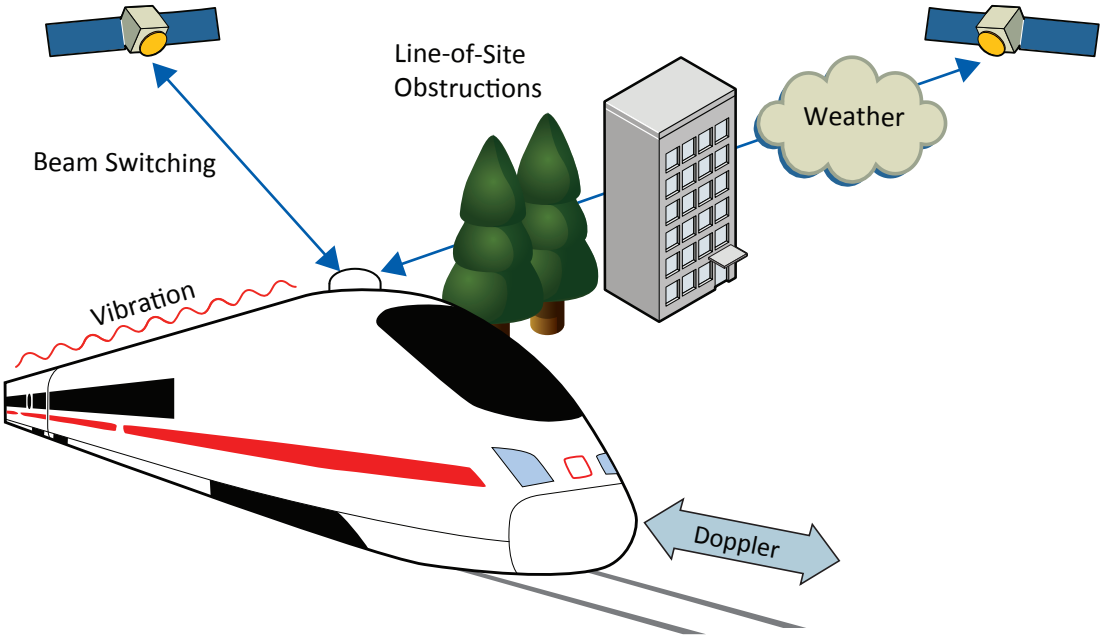

Figure 4. The Challenges of Land-Mobile (COTM)

Synchronization

In a fixed satellite installation, the modem or router locks onto a synchronization signal received from the satellite, which is then used to synthesize the transmit clock. The transmit clock serves two purposes: it ensures that the transmit center frequency is correct, and it ensures that the burst timing is synchronized. In Time Division Multiple Access (TDMA) systems, this synchronization is crucial. Without it, bursts from different modems will not be aligned and can interfere with each other.

In rail mobility applications, the clear reception of a signal is not guaranteed due to the aforementioned obstructions. Therefore, the regeneration of the clock required for the transmission must be derived from another source if interruptions occur for more than several seconds. In the case of short interruptions, typically less than 30 seconds, the modem's own internal clock can "free-wheel" or "fly-wheel" in order to bridge the gap. However, this free-wheeling is not sufficiently accurate over longer periods; hence, in the absence of an external clock reference, the modem must turn off the transmitter in order to prevent problems with the transmissions of other terminals.

Effects of Changing Position and Weather

As a train moves across the footprint of the satellite beam, the receive signal level may vary, especially towards the edge of the beam. In addition, changing atmospheric conditions may cause receive and transmit signal degradation. In order to maintain a high-quality service, the satellite modem and hub must take these factors into account by dynamically changing the modulation and coding used in both directions, and by changing the transmit power in the satellite inroute direction.

Effects of Speed

The modem must also account for Doppler shifts in the signal. Doppler shift causes changes in symbol timing, which has a worsening effect in the modem as modulation complexity increases. Therefore, it is crucial that the speed and direction of the train be known, so that algorithms can be applied to correct for the frequency shift.

Beam Switching

In certain cases, a train may cross from one satellite's coverage area to another. This is the norm for the newer HTS satellites operating in the Ka-band when trains move from one spot beam to another. In either scenario, the satellite system must be able to seamlessly hand off traffic from one beam to another.

The Ideal Mobility Solution

The Hughes HX System is a good example of an innovative IP broadband satellite system specifically designed and optimized for a broad range of applications, including mobility.

The HX System provides advanced bandwidth management capabilities that enable operators to custom-design various Quality of Service (QoS) features and Service Level Agreements (SLAs) on a per-terminal basis. As a completely IP-based solution, the HX System incorporates a robust set of IP functions and features, including full IPv6 support. Leveraging the DVB-S2 transmission standard on the outbound channel, the HX System achieves high spectral efficiency. In addition, while the HX System allows operators to dedicate inbound/outbound bandwidth per remote, the Aloha-based inbound TDMA channels provide the capability to dynamically allocate bandwidth based on usage and need—thus enabling operators to develop a wide range of service plans for their customers. The highly advanced Network Management System (NMS) includes HTTP access, which can be located remotely and shared with end users.

Hughes Mobility Feature Set

Hughes has optimized its satellite broadband products and services to directly address the key requirements found in many mobile applications, and these features have been fully integrated into the HX System:

- **DVB-S2/ACM** — The use of Adaptive Coding and Modulation (ACM) of the outbound channel enables the remote terminal to continually monitor the received signal level of the outbound channel and to dynamically request changes to the combination of coding and modulation. This allows the downstream channel to be continually optimized as the train terminal travels through the various contours of the satellite footprint.

- **Adaptive Inroute Selection (AIS)** — With the AIS feature, the TDMA uplink from the mobile device is continually monitored by the hub, and the remote terminal is thus continuously advised of its optimal TDMA transmission coding and power levels. Similar to the DVB-S2/ACM capability for the outbound channel, this feature means that the TDMA channel is also continually optimized as the train travels through various contours of the satellite footprint, or under varying weather conditions.

- **TDMA Channel Spreading** — To overcome issues with off-axis emissions, the HX System supports spreading of the TDMA channel by two and four times the nominal channel bandwidth. A 256 ksps TDMA channel with a nominal channel spacing of 320 kHz can be spread to either 640 kHz (2x spreading) or 1280 kHz (4x spreading). This feature enables the use of very small antennas as it mitigates adjacent satellite interference.

- **Doppler Compensation** — The HX System continuously calculates and applies a Doppler compensation to counterbalance frequency shifts.
- **Outbound Flywheel and Fast Reacquisition** — As land mobile units frequently encounter obstructions, such as trees or bridges, which prevent receipt of the outbound channel, Hughes has implemented a flywheel for the timing synchronization of the outbound channel. The flywheel can spin for as long as 30 seconds, during which time the reacquisition of the outbound channel occurs immediately upon receipt of the first superframe marker.
- **External 10 MHz Reference** — To ensure fast TDMA transmission capability, the HX remote unit is capable of accepting an external 10 MHz reference. This eliminates the need for frequency stability to be derived from the outbound carrier, which is not accurate during the flywheel period, and enables the remote terminal to transmit the TDMA carrier immediately upon reacquisition of the outbound channel.
- **IP Steady State** — The HX System maintains the IP session during even prolonged periods of link outages, such as when a train travels through a tunnel. Even if the signal is lost for longer than 30 seconds, the link is restored, and users do not have to re-establish IP connectivity.
- **Ruggedized Chassis** — HX remote terminals are configured with a ruggedized chassis that permits mounting in a 19-inch rack and is able to withstand environments of high heat, humidity, dust, and vibration.
- **Automatic Beam Switching** — Using a standard Application Programming Interface (API), the HX remote terminal interfaces to an Antenna Control Unit (ACU) to determine location and timing to command the antenna to switch to a new satellite.
- **Configurable Demodulator** — The Wideband Configurable Demodulator Subsystem (CDS) supports a special mobility mode that increases the ability to detect received bursts.

Linking it All Together

The basic satellite infrastructure required on board the train includes a stabilized very small satellite terminal (VSAT) antenna, a GPS receiver, and the Hughes HX System. A typical installation block diagram is shown in the Figure 5.

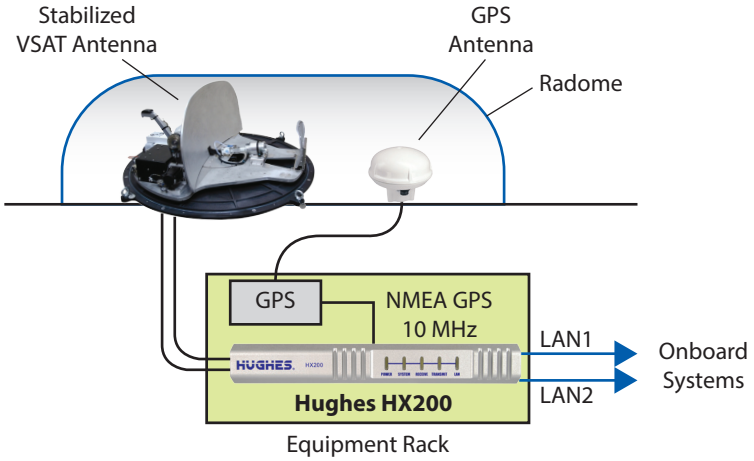

Figure 5. SatCom Connectivity Onboard the Train

In Figure 5, the major subsystems include:

- VSAT antenna systems – Various vendors supply three axis-stabilized, autotracking antennas. Hughes systems have been integrated with mobility antennas from Raysat, Orbit/OrTes, Seatel, Intellian, Aerosat, and others.
- GPS antenna and receiver or stable 10 MHz reference clock – Depending on the antenna used and the specific application, a GPS reference may be required; otherwise, a 10 MHz reference may be used.
- Power systems

Figure 6. Stabilized Antenna Without Radome (Photo Courtesy of OrTes)

Inside the train, the various systems are integrated with the Hughes HX series satellite router. Because the traffic shares a single transmission path, it is vital that the services be differentiated. The HX satellite routers fully support VLANs, QoS, and rules-based routing in both the outroute and inroute directions. This allows the highest-priority traffic, such as train telematics and voice traffic (including both VoIP and cellular), to take priority over lower-priority traffic, such as passenger Internet access.

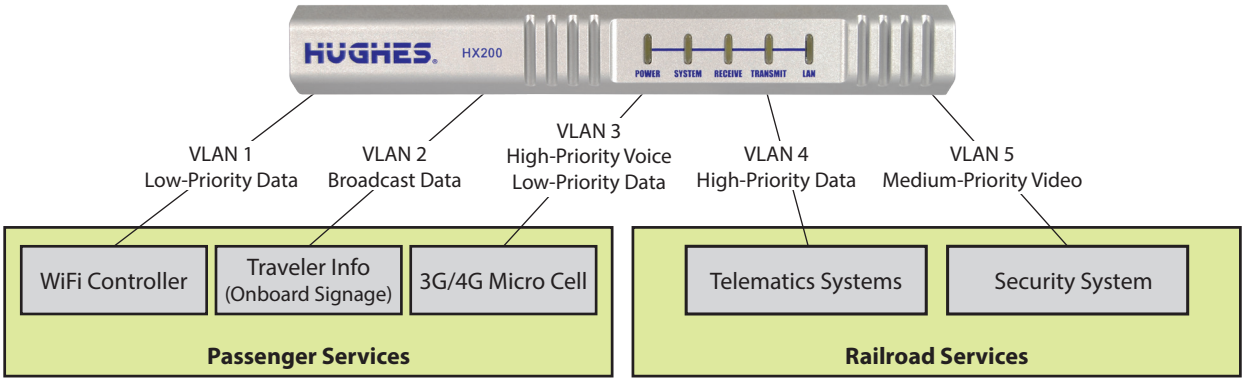

Figure 7. Multiple Services – Single Modem

For rail consists that are not frequently reconfigured, fiber interconnection between the rail cars is ideal. However, some trains require frequent reconfiguration during or between journeys. The addition and removal of cars from a rail consist prohibits the use of a wired (LAN) infrastructure due to the reliability and limited connection cycles of the connectors. Therefore, a WiFi mesh controller is required in order to implement the onboard LANs (VLANs). Connectivity is illustrated in Figure 8.

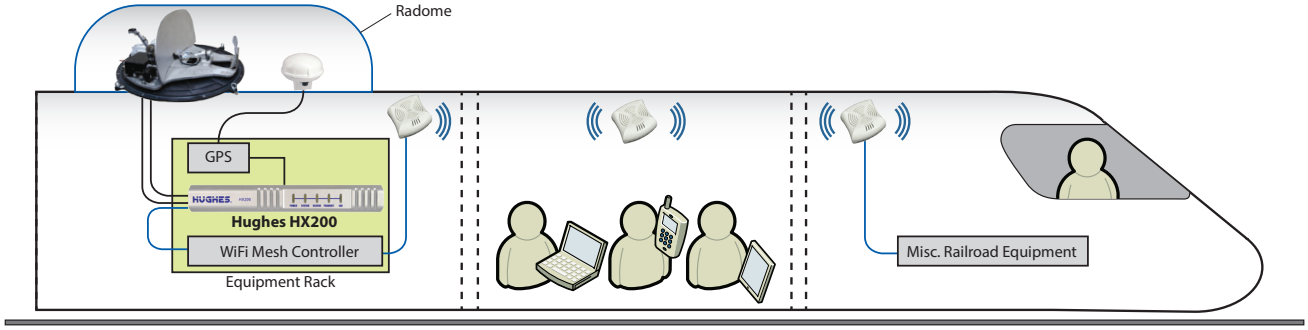

Figure 8. Connectivity Between Railcars

Commercial or enterprise-grade WiFi mesh systems support multiple (VLANs) and Service Set Identifiers (SSIDs), connectivity for hardwired devices, and other features necessary to implement this architecture.

Hughes has extensive experience in integrating the necessary components together as a complete, high-quality system.

Additional Connectivity Options

Continuous connectivity onboard a train may be desired when entering and exiting stations. As users board, they may desire to start working immediately and continue to do so without interruption when the train leaves the station. Similarly, when a train arrives at a station, users who are not disembarking may desire uninterrupted connectivity.

Many rail stations, especially in cities, are located in areas that are blocked by buildings, or even located underground. In order for the rail service operator to provide coverage in these areas, an alternative method of connecting data must be offered. This poses a challenge, especially if a seamless handoff is required.

One solution is to use a fixed VSAT terminal at each station and switch the onboard connectivity to the fixed VSAT. The system then hands off the WiFi users from the onboard access points to those located in the stations. (Fixed VSAT installations can also be used to provide coverage via WiFi relay in tunnels.) Onboard 3G/4G/Satellite bandwidth bonding technology may also be used to provide uninterrupted coverage.

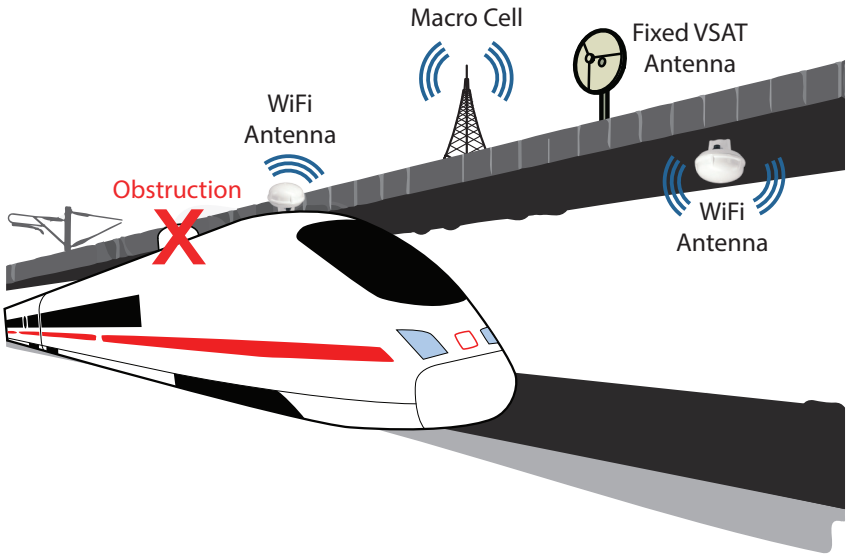

Figure 9. Connectivity at the Station

Cellular handoff would not require any additional infrastructure from the rail operator; however, the handoff from the onboard microcells or picocells to the macrocells in the rail stations may not be completely seamless to users. Dropped calls may occur when calls are handed off from the relatively high-latency backhaul provided by the satellite connection to the relatively low-latency connection that the macrocell uses.

Successful Implementation

Hughes has successfully completed several rail-based VSAT installations, including deployments in India and Russia. In the Russian program, broadband connectivity via VSAT was demonstrated on a 1900+ km journey from Moscow to the city of Nazran (See Figure 10).

Using a low-profile, three-axis stabilized antenna on the roof of the train and the HX200 satellite router, connectivity was maintained for the duration of the journey. Users were able to browse the Web and maintain secure HTTPS connections during the journey, even when signal interruptions occurred.

The Russian rail project is currently expanding to more trains and providing broadband connectivity to thousands of rail customers.

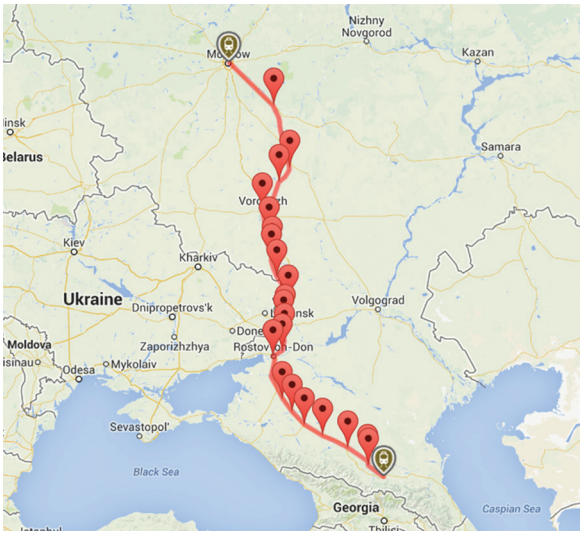

Figure 10. Long Haul Rail in Russia

Figure 11. SatCom Antenna Radome on Railcar

Connect to the Future

The Hughes HX System provides unparalleled capability and powerful tools to manage satellite bandwidth on-the-move by utilizing advanced features specifically tailored for mobility. The Hughes HX System is widely used in mobility applications around the world, including airborne, maritime, and land-mobile. Contact Hughes for more information on how we can connect you to the future.

Proprietary Statement