

Advanced Mobility Solution

Vehicular Broadband Wireless Communications for
Trains, Boats and Cars



Abstract

This paper presents a brief overview of RAD's turnkey mobility solution for in-motion broadband communications enabling passenger Wi-Fi, public information systems, real-time security cameras, management and control, staff VoIP, and more for trains, highway patrol cars, and harbor/canal boats.

The complete solution consists of a unique radio system, a flexible and secure networking device, and project management services (planning, testing, implementation and provisioning).

We look forward to discussing your project's unique needs.

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1 Executive Summary

RAD's broadband solution for real-time vehicular communications is based on multiple technologies, including a broadband radio system, networking components and end-to-end project management.

The heart of the solution is the Airmux-5000/ Broadband Mobility wireless radio solution: A field-proven technology enabling a network operator to achieve high throughput to and from a moving vehicle, with uninterrupted service even in harsh and high-interference environments.

RAD's Airmux-5000/Mobility enables an operator to leverage the same infrastructure for current and future services (real-time CCTV, management and control information, passenger information systems (PIS), and public WiFi) for trains, cars and vessels while providing the required quality of service and security.

Due to its interference mitigation mechanisms, Airmux-5000/Mobility provides coverage superior to that of other solutions and technologies, working inside tunnels and open-air routes and enabling substantial CapEx and OpEx savings in the associated infrastructure.

In addition to the radio solution, each project requires complete networking design and implementation, based on an available network or a new deployment. Cameras, WiFi systems, video management, and command and control applications, are all taken into consideration. RAD offers project management from planning through execution, including site survey, network design, deployment, optimization, and maintenance.

2 High Level Solution Description

RAD's advanced mobility solution is based on three main elements:

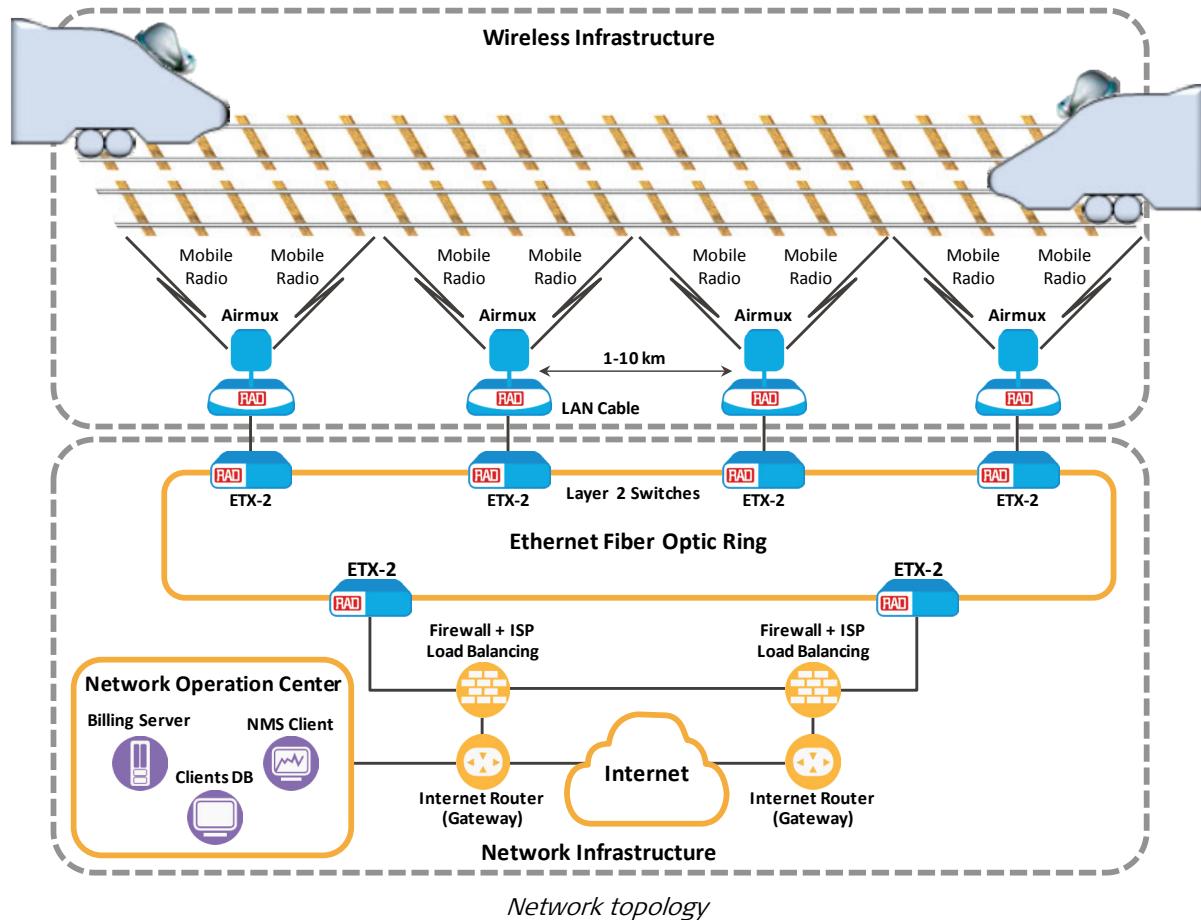
- RAD's Airmux-5000/Mobility radio system:
 - Radio home base stations (HBS) deployed along the trackside, providing continuous coverage and connectivity to the moving trains/metros in that route.
Each HBS is deployed with two antennas in diversity mode (depending on the requirements and topology)
These base stations are deployed typically at intervals of approximately 1 km underground, or up to 10 km aboveground (depending on topology and country regulations)
 - Mobile radio units (HMU – High-capacity mobility subscriber unit) installed on-board the vehicle, with two antennas on top
The HMU aggregates traffic to/from the different units and services on-board and communicates continuously with the nearest relevant base station (HBS). Optionally, a dual HMU configuration is installed on-board to enhance resiliency and coverage
- A communications and backhauling network connects the HBS to the operator command and control room, as well as to fixed cameras along the route, sensors, IT systems, and so on. This network may consist of an existing SDH/SONET/PSN network and will be specifically adapted to the networking and implementation requirements of each project.
The solution should support the bandwidth, distances, available infrastructure, QoS, and clock synchronization requirements of each project

- Turnkey – RAD offers planning, testing, supply, integration, provisioning, and support of all above elements of the project

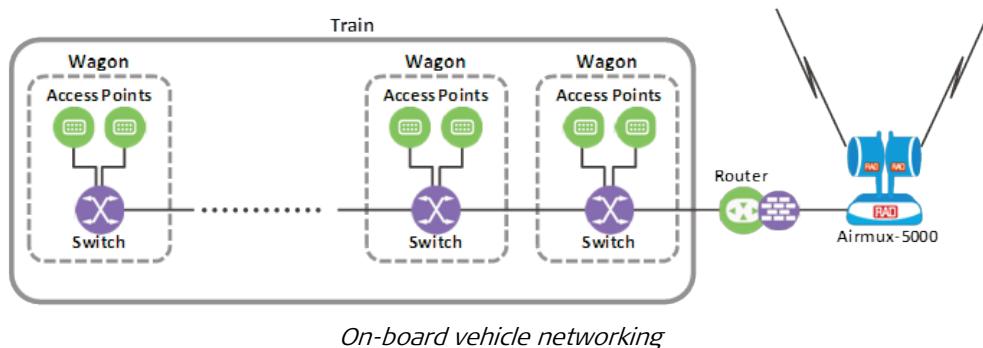
2.1 Trackside Backhaul Networking

HBSSs are installed along the track/route at distances of 500 m to 10 km, depending on terrain and the type of application (e.g., underground or aboveground trains) and are connected by communication switches over FO or radio links to the network operations center (NOC).

Routers and clock synchronization devices are implemented to support security and networking requirements on a case-by-case basis.



2.2 On-Board Vehicle Networking



HMUs are installed on top of the vehicle connecting local network appliances such as WiFi users, IP Cameras, passenger information systems, and others to the radio link to support bidirectional traffic to and from the vehicle.

2.3 Airmux-5000/Mobility Radios

RAD's Airmux-5000/Mobility vehicle-to-ground radio system is specifically designed to meet the needs of the transportation market. Designed to work in high-interference, near/non-line-of-sight (Near-LoS/NLoS) scenarios, Airmux-5000/Mobility includes the following advantages:

Performance

- High-capacity, up to 100 Mbps per HBS or HMU
- Extended coverage per base station, reducing the number of required trackside installations and substantial infrastructure costs (e.g. poles, electricity, network), as well as ongoing maintenance.
Infrastructure requirements are reduced by a typical ratio of 1:5 (underground) to 1:15 compared to conventional Wi-Fi based solutions
- Supports trains/metros at speeds of up to 200 km/h (designed for higher speeds)
- Seamless handover between base stations (handover time of under 50 msec)
- Fully synchronized network that operates on a common time base for all the base stations, thus avoiding potential mutual radio interferences. This capability is essential to maintain a consistent, high throughput along all the routes and operation scenarios.
- Low, fixed service latency and jitter – essential for delay-sensitive applications such as video and VoIP
- QoS over the air, enables prioritization and assured service level of different services

Architecture

- Distributed architecture with no single point of failure (no controller is required)
- Configurable uplink/downlink bandwidth ratio, enabling flexibility and variety of services over the same infrastructure
- Multiband radio – support of 4.9 to 6.0 GHz over a single platform. Other frequency bands also available, as well as special customization options for additional frequency bands
- Very simple and easy installation

Reliability

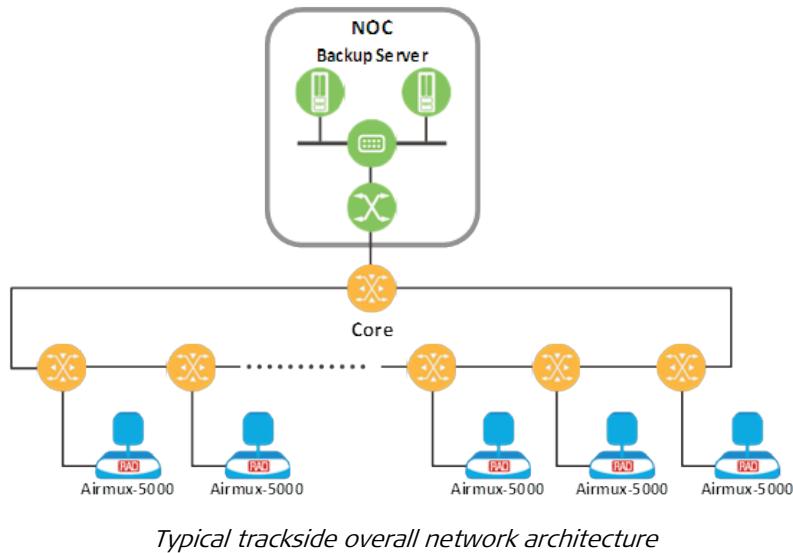
- Operates in harsh outdoor conditions and complies with IP-67 standard
- Complies with railway standards, including EN50155 and EN50121
- Optional redundancy for both base stations and mobile units
- Integrated 128-bit AES encryption for data security

3 Detailed Solution Description

3.1 Trackside Architecture

General Trackside Network Architecture

- The network consists of a layer-2 access network that connects and synchronizes the radio base stations (HBS) along the trackside, and backhauls the traffic through an existing core network to the NOC



Backhauling Considerations

- 1/10 Gbps connectivity over fiber or radio links is deployed along the tracks or the designated coverage area
- The interface to the network operation center is located at one of the stations. The BW of the interface is 1Gbps; the type of the optical interface is Single Mode
- A router with firewall capability is located at the interface to the NOC
- No single point of failure (NSPF) network topology design
- The network is based on RAD's ETX-2 and ETX-5 Carrier-Grade Ethernet switches, featuring advanced clocking, QoS and traffic management tools
- The network is managed end-to-end by RAD's RADView SMS
- If an existing network, based on SDH/SONET or PSN technology, is deployed along the tracks, a dedicated design is required in order to utilize this network for the operation of the mobility solution

Radio Base Station Synchronization

Synchronization between the radio base stations is necessary to avoid interference (TDD – Time Division Duplex operation)

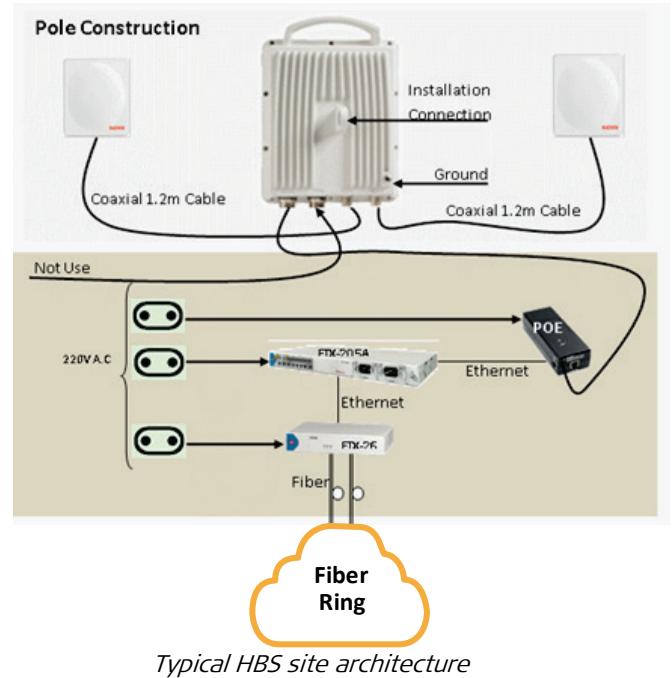
In aboveground projects, an external GPS unit will be attached to each of the HBSs to supply the required synchronization.

However, in metro projects (underground trains), synchronization distribution from the network operations center to all radio base stations will be through the Ethernet network, using the 1588v2 standard, for which a designated VLAN with high priority QoS is necessary. In the NOC, an external and redundant Grandmaster clock, based on RAD's ETX-5 connected to an external GPS unit, will distribute time to the nearest ETX-205A connected to a base station. The ETX will convert the synchronization signal to a physical port and output 1PPS (phase and frequency) to the base station.

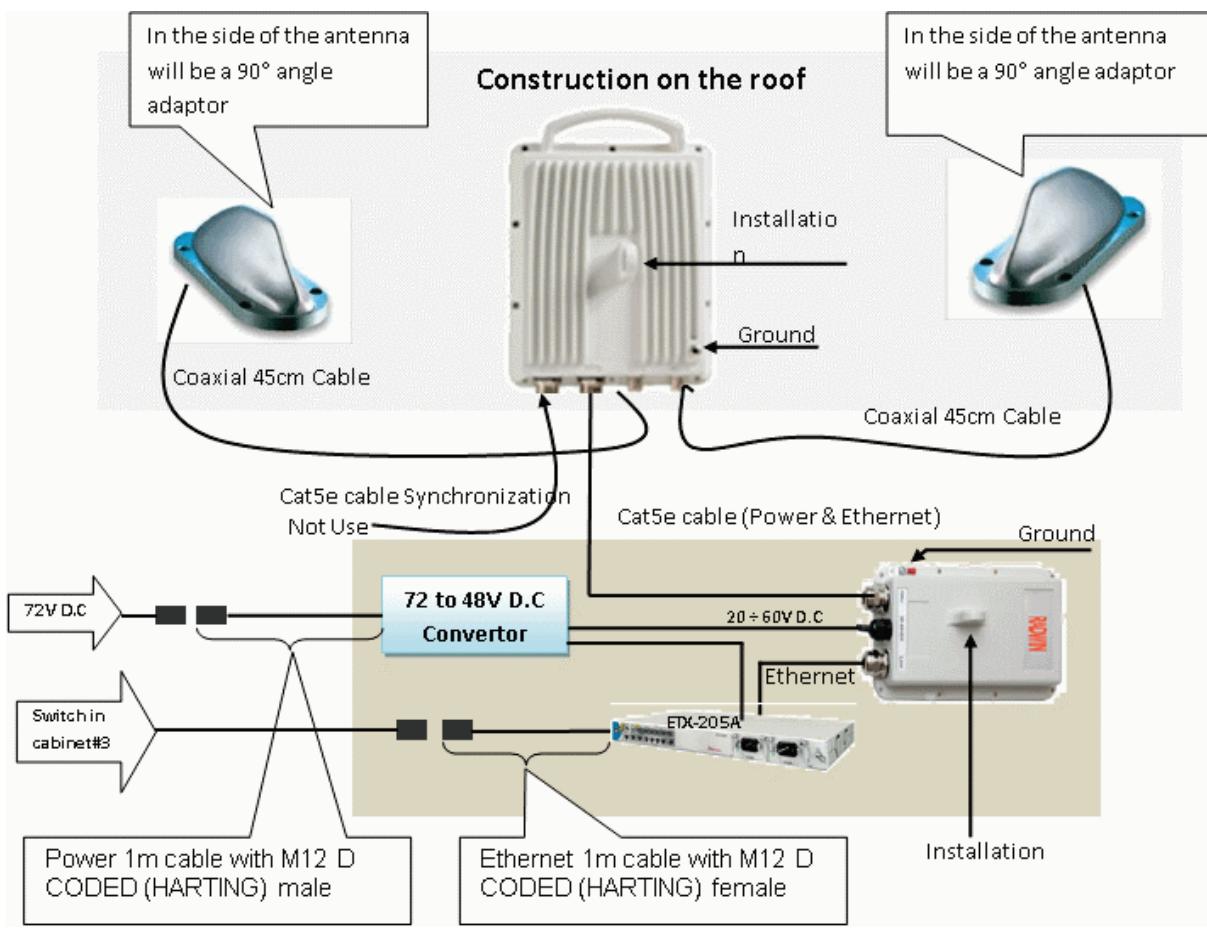
HBS Site Architecture

The trackside radio base station includes:

- Outdoor HBS radio unit (with an option for multiple units per site architecture)
- Two flat panel 18 dBi diversity sector antennas
- Two RF cables
- CAT5e cable
- PoE unit, and optional Fiber/Copper termination unit (TU)
- Cabinet (assumed to be provided by the SI)
- RAD's ETX-2, with or without 1588v2 clocking capabilities – local backhauling over a fiber optic switch
- To address inter-site interference in large-scale deployments, an external GPS, Airmux-GSU/Outdoor GPS will be added by connecting to the HBS units



3.2 On-Board Architecture



- On-board GbE network inside and between the carriages to connect all the different on-board services is assumed to exist/ provided by the SI
- A mobile radio unit (HMU) is installed on top of the vehicle and connected to an existing switch via PoE
- RAD's ETX-2 is used as the local switch
- For train projects:
 - Two mobile radio units are deployed at both ends of the train and are connected to each other for synchronization, as well as to an existing switch via PoE. O-board redundancy and improved performance is ensured using an intra-train handover mechanism (ITHO)
 - The system automatically selects the HMU providing the highest throughput (only one HMU at a time provides the required capacity, while the other is in HSB configuration, and only control bits are transferred via wireless)
 - The on-board network should support a dedicated VLAN between the two HMUs to enable the ITHO mechanism

- Four directional antennas (12 dBi each) are installed on top of the train, two on each side, connected via RF cables to the HMU. The distance between the antennas should be at least 60 cm



An example of a train antenna installation

3.3 Seamless Handover Support

The RAD Airmux-5000/Mobility solution implements a unique mechanism which guarantees seamless handover (as low as sub-50 msec), as well as high availability of the service along the route. The handover principles are as follows:

- As the on-board radio (HMU) connects to a specific radio base station (HBS), it receives the frequency channel list of its neighboring HBSs
- That HMU performs regular “peeping” to these neighboring HBS stations, while still connected to the same HBS, and maintains the service level of that link
- As the HMU identifies an RSS trend from one of the neighboring HBSs which is constantly improving, while its own is degrading (meaning that the train is getting further from the existing HBS and closer to the other one), it will switch the connection to the new HBS once its RSS threshold is achieved
- The HMU will then initiate a re-learning message in order to refresh the network topology and update the relevant addresses of the new information route
- In addition to this process, an on-board dual HMU system may optionally provide another layer of resiliency and availability, as it implements a unique ITHO (intra-train-handover mechanism) developed by RAD
- The ITHO mechanism is based on dual on-board HMUs, connected to the internal train network. Each HMU is connected to a trackside HBS – one HMU is active and the other is in idle mode
- The throughput of each HMU is constantly evaluated. If the idle HMU can have a better throughput, then there will be an internal switchover, and it will become the active one, while the other HMU will turn to idle mode

- This mechanism ensures best performance, based on both the received signal strength indication (RSSI) and the maximum throughput

4 Specific Design Principles

4.1 Design Parameters to be Provided by the Customer

Each project is designed and planned according to the applications and environmental requirements.

Following is an example of a questionnaire for railway mobility projects:

| Parameter | Value |
|---|---|
| Railway length | TBD |
| Number of stations | TBD |
| Average distance between stations | TBD |
| Number of tracks in a single tunnel | TBD |
| Number of simultaneous trains crossing at the same tunnel | TBD |
| Max number of trains in a section (e.g. between 2 stations) | TBD |
| Train speed | TBD |
| Train length | Top of the tunnel / side of the tunnel |
| Location available for trackside base stations & antennas | TBD |
| Handover | XX Uplink / YY Downlink |
| Assigned Frequency [MHz] | TBD |
| Regulation obligation | Real-time video surveillance Remote control & monitoring (unmanned) Passenger information systems (PIS) Broadband Wi-Fi Level crossing monitoring Cellular offload |
| Number of tunnels/stations without clear sky view | TBD |

4.2 Link Budget Analysis – Typical Example

| Parameter | Value |
|------------|--------|
| Channel BW | 40 MHz |

| | |
|----------------------|---------------------------------|
| Rate | 90 Mbps (16 QAM $\frac{3}{4}$) |
| Rx Sensitivity | -74 dBm |
| Tx Power | 21 dBm |
| Base-Station Antenna | 18 dBi |
| Train Antenna | 12 dBi |
| Antenna Polarization | Vertical |
| Range | 1000m |
| Capacity* | 78.1 Mbps |
| RSS/Fade | -62 dBm/12 dB |
| Service Type | Ethernet |

*The capacity of 78 Mbps is supported for longer range. An analysis for 1000m verified that there is a margin in the link budget to assure such a range and to maintain high availability.

4.3 Link Performance Rate 90 Mbps (16 QAM $\frac{3}{4}$) – Typical Example

| Parameter | Value | Comment |
|------------------|---------------------------------|-----------------------|
| CBW | 40 MHz | |
| Rate | 90 Mbps (16 QAM $\frac{3}{4}$) | Fixed Rate |
| Rx Sensitivity | -74 dBm | |
| Tx Power | 21 dBm | |
| BS ANT | 18 dBi | See antenna spec |
| Train ANT | 12 dBi | See antenna spec |
| Antenna Polarity | Vertical | |
| Capacity | 75 Mbps | Net aggregate per HBS |
| RSS/Fade | -59 dBm/15 dB | |
| Service Type | Ethernet | |
| Distance | 1 km | 14 dB fade margin |

4.4 Link Performance Rate 120 Mbps (64 QAM $\frac{3}{4}$) – Typical Example

| Parameter | Value | Comment |
|------------------|----------------------------------|-----------------------|
| CBW | 40 MHz | |
| Rate | 120 Mbps (64 QAM $\frac{3}{4}$) | Fixed rate |
| Rx Sensitivity | -69 dBm | |
| Tx Power | 19 dBm | |
| BS ANT. | 18 dBi | See antenna spec |
| Train ANT. | 12 dBi | See antenna spec |
| Antenna Polarity | Vertical | |
| Capacity | 100 Mbps | Net aggregate per HBS |
| RSS/Fade | -61dBm/8 dB | |
| Service Type | Ethernet | |
| Distance | 1 km | 8 dB fade margin |

5 Railway Applications

Bi-directional broadband connectivity between trains and a sidetrack network, either underground or on-ground, metro or river ferries, supports a variety of standalone and simultaneous applications. Popular applications utilizing bi-directional broadband are:

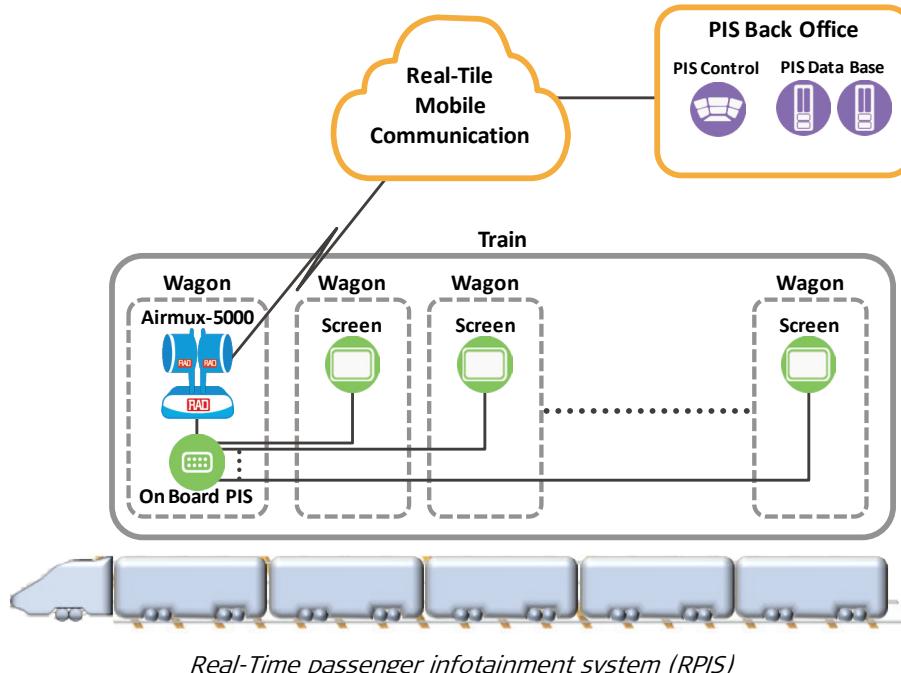
- [Real-time passenger infotainment systems \(PIS\)](#)
- [On-board internet and cellular services](#)
- [Real-time video surveillance from moving trains](#)
- [Enhanced video solution for level crossings](#)

5.1 Real-Time Passenger Infotainment Systems (RPIS)

Enhance Your Passengers' Experience

RAD RPIS solution keeps your passengers informed and entertained in real time and throughout their commute. Its high-bandwidth connectivity was designed for fast-traveling rolling stock and enables real-time content update. With flexible programming options, both online and offline content can be displayed per a specific schedule and/or route locations. Operators benefit from an easy-to-use and automated content management system (CMS), which dynamically distributes operator content as required to the edge devices.

RPIS Solution



Advantages

- Single system comprising several functionalities: Digital signage, CMS and online/recorded content (video, PA, games, and external feeds)
- Flexibility through pushing and/or streaming content in real-time
- Advanced information management tools and editors allow you to maximize the system for a variety of uses
- Automatic vehicle location services enable the relevant and timely delivery of location-based information

Solution Highlights CMS options

- On-demand controllable content displayed passenger devices
- Live TV broadcast distribution on the move
- Premium Billing for video on demand (VoD) content
- External Feed handling (ads, news, trip information)

Video Options

- Full-screen quality movies and newscasts
- Split-view support for VoD and/or live content
- Displayed information can include route maps, promotional videos, timetable information, advertising, and much more
- Multiple, single or double-sided screens can be connected using a video distribution unit

Audio Options

- Controlled announcements
- GPS-triggered announcements
- Door-triggered audio (door open/door closed, as well as door opening and closing tones for use on light rail)
- Several PA zones (internal / external / driver's cabin and additional outputs)

Summary

Today, in medium/large metropolitan transportation services there are millions of daily commuters. Currently, passengers are not exposed to real-time infotainment while on-board. RAD's solution provides a way of addressing large numbers of passengers, presenting advertisers the possibility to create intelligent and strategic campaigns that align with their marketing goals through messages programmed at specific times and locations while generating revenue for transit authorities.

5.2 Onboard Internet and Cellular Services

Solution Description

By leveraging RAD's advanced mobility solution, high bandwidth (up to 100 Mbps) provides the extreme reliability for on-board service delivery. The solution's synergy increases when the following functional elements are combined:

On the Rolling-Stock and Platforms

WiFi APs are distributed along the coaches and are connected either by an Ethernet cable or by a dedicated WiFi channel. The APs provide public WiFi services and cellular data offloading.

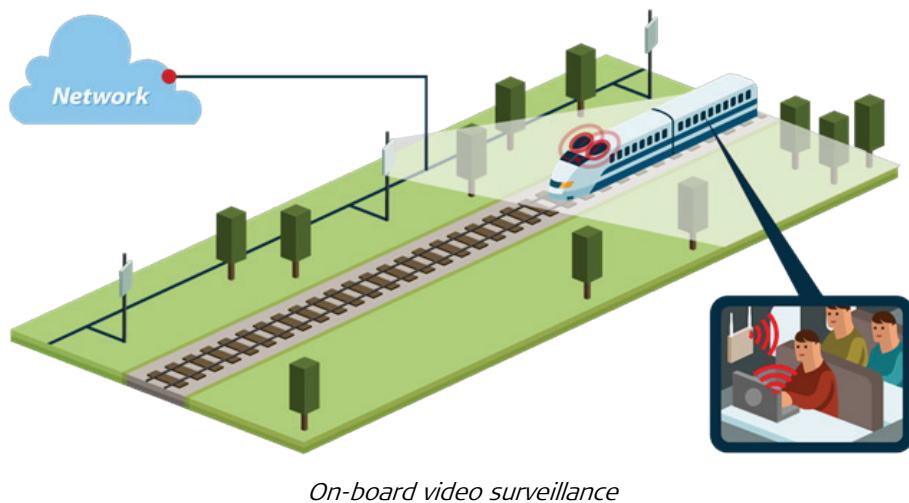
Femto cells provide cellular connectivity inside the coaches to prevent black holes in coverage while providing a better user experience without disruption.

In Network Centers

Secure network connections – RAD's solution addresses all aspects of connectivity to local ISPs.

Billing and walled garden – The billing layer is based on the RADIUS protocol which communicates with the policy enforcers to provide free, pre-paid and post-paid broadband services. It also integrates with e-ticketing, vouchers and scratch card providers and/or pay-as-you-go online clearing house services.

TELCO gateways and enablers – RAD offers all the communications equipment required to interconnect the train Femto cells with cellular providers.



5.3 Real-Time Video Surveillance from Moving Trains

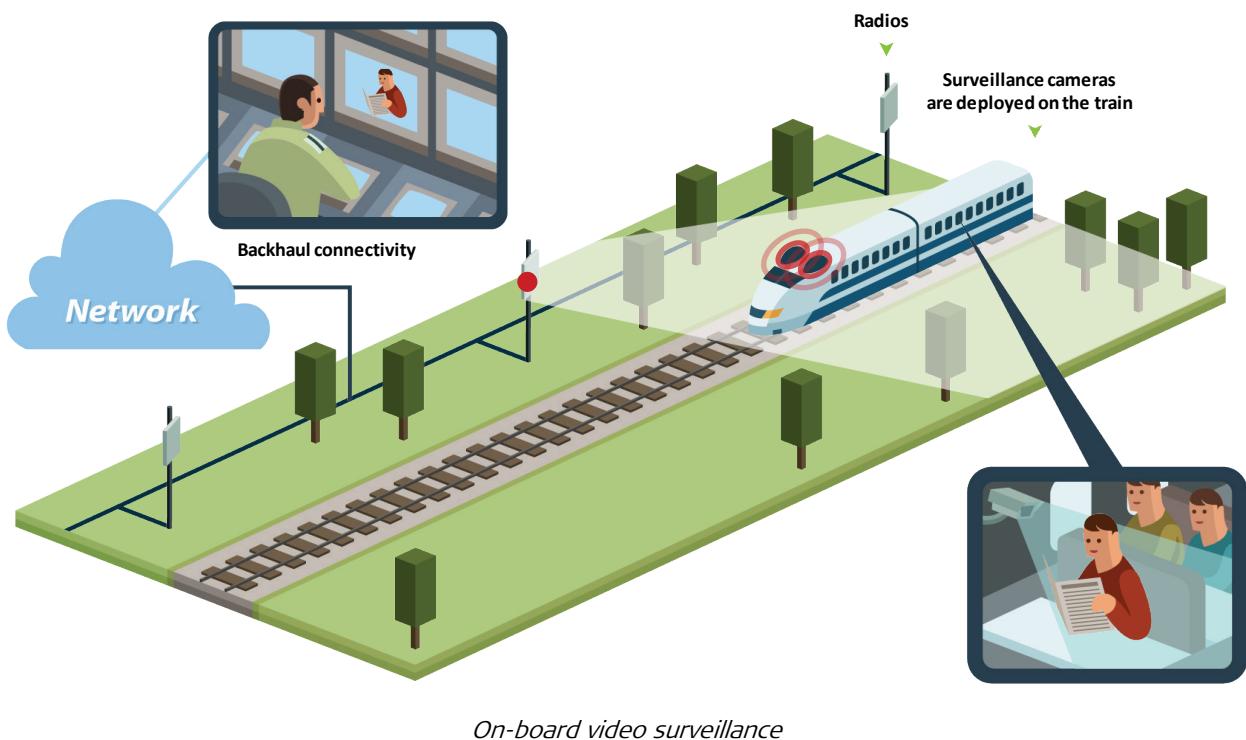
RAD's mobility solution transmits HD video in real time from multiple CCTV cameras deployed onboard trains and from station platforms back to a control center. This enables transport authorities and operators to monitor passengers' activity 24/7 and detect and respond to events in real-time, thus boosting travelers' security and safety.

The mobility solution guarantees dedicated bandwidth per train and supports seamless handover to ensure a high quality of service as well as service continuity.

Train Operator Benefits

- Boost passenger safety and security via real-time video transmission from CCTV cameras on board trains and stations
- Improve safety measures by transmitting real time video from station platforms to the driver's console
- High speed internet access for passengers
- Quick response to train vandalism

On-board VoIP services for real-time public address (PA) systems and emergency intercommunications



5.4 Enhanced Video Solution for Level Crossings

Overview

Level crossings can pose a significant risk to rolling stock in the event of an obstruction, or from the unexpected crossing of a variety of elements. Ensuring the safety of both those attempting to cross and the individuals on-board is a primary concern for all transportation operators. This means that trains must be given sufficient notice to allow for braking, which is enabled by control room connectivity to isolated junctions.

RAD's enhanced video solution for level crossings is a value-added service for public and operational safety. The solution provides real-time video and video analytics (VA) delivered directly to train operators and command and control centers (CCC), by using RAD's advanced mobility solution. With it, both operators on-board and in the CCC have full visibility into what is happening at level crossings.

Solution Capabilities

- Built-in stopping, slowing, dwelling and virtual fence VA, real-time alerting for incoming trains and backhauling to the CCC via wireless/cellular/fiber, optics API to junction systems video/audio, dispatch from CCC to engine drivers
- Integration with local barrier and signaling systems

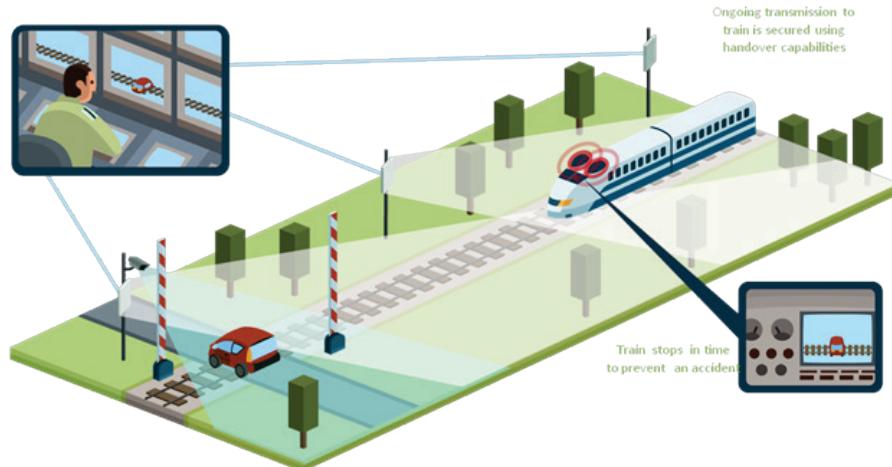
RAD's Video Analytics CCTV and Mobility Solution

When there is no line of sight to an oncoming level crossing or junction, you'll be able to cost effectively ensure safe passage by eliminating the need for manned crossing or grade separations. Here's how it works:

- An obstacle is found on the tracks
- A CCTV camera armed with VA capabilities identifies the potential threat
- The video is relayed to the control center
- For remote locations, a localized video can be sent directly to the approaching train driver using RAD's advanced Mobility solution
- 'Stop' signals are sent to the driver

RAD's simple solution for all level crossings can be rapidly deployed anywhere. It can be used:

- With all traction types
- In urban or remote areas
- With rolling stock traveling at speeds of up to 200 km/h
- Whenever there is no line of sight from the train to the junction



Level crossing concept

Summary

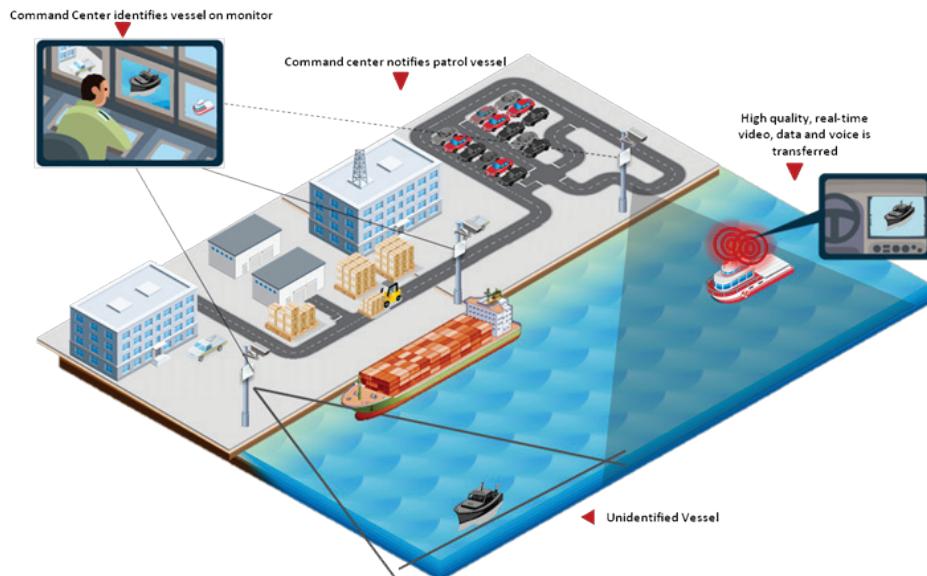
RAD's Level Crossing Solution is a unique, readily-available and mature solution providing safety and smart CCTV control. It benefits from both worlds: A robust, high-capacity wireless link dedicated per level crossing, with video surveillance incorporating advanced video analytics that deliver real-time video when it matters the most.

6 Oil, Gas and Maritime Applications

- Delivering real time video, internet access (WiFi), data and VoIP to vessels:
 - Police patrol boats
 - Ferries
 - Cruise lines
 - Fire and rescue vessels
- Port machinery – video connectivity to cranes
- Airports – maintenance and control

The implementation of the mobility solution in such environment is similar to manner described for transportation/railway networks:

6.1 Broadband Communications in Ports and on Rivers



Broadband communications in ports and on rivers

Many bodies are active in the port area – customer and port authorities, police boats, cruise and cargo operators and port services, as well as industrial cranes and automation devices.

Each has its own communications needs, all of which are characterized by one common denominator – mobility.

RAD's mobility solution provides the communications needs for all of the above:

- HBSs are installed in the port area or along the river, and are connected over fiber optics and/or microwave links to supply pre-defined coverage to cranes and boats



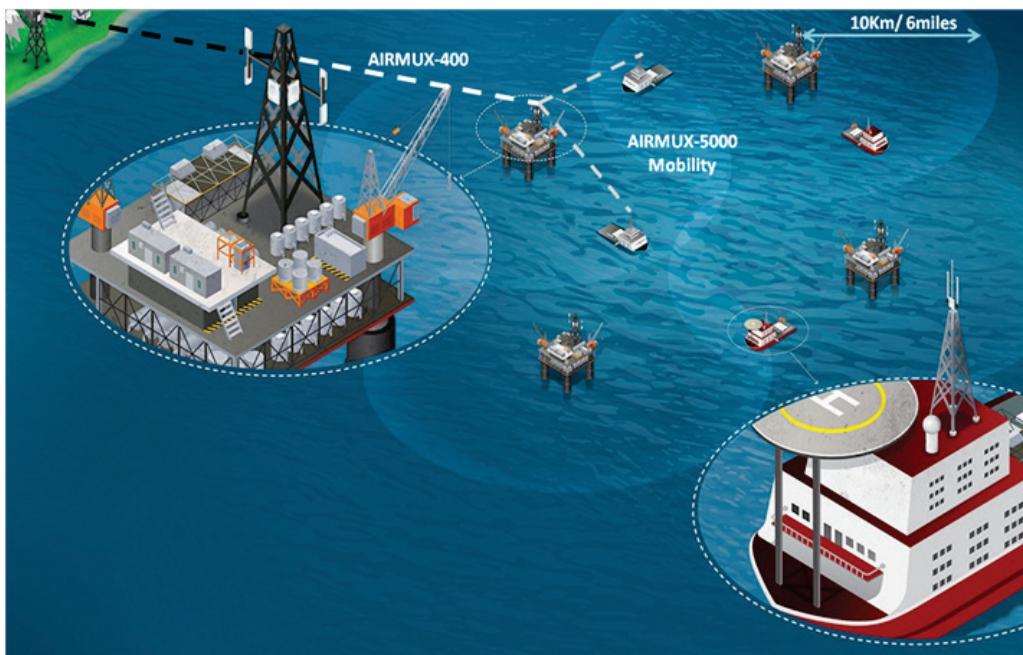
- On each boat, two omni-antennas are installed to supply the connectivity for video and audio.

6.2 Oil Fields – Wireless Broadband to Vessels

Oil rig communications with boats and the shore, using microwave and underwater fiber optic links.

Service vessels sailing in the rig area require real-time and secure, broadband communications supporting voice, data and video. RAD's mobility solution meets this requirement.

HBSSs are installed on top of the oil rigs and supply 360-degree coverage at distances of up to 10 km from approaching vessels (based on specific conditions for each case).

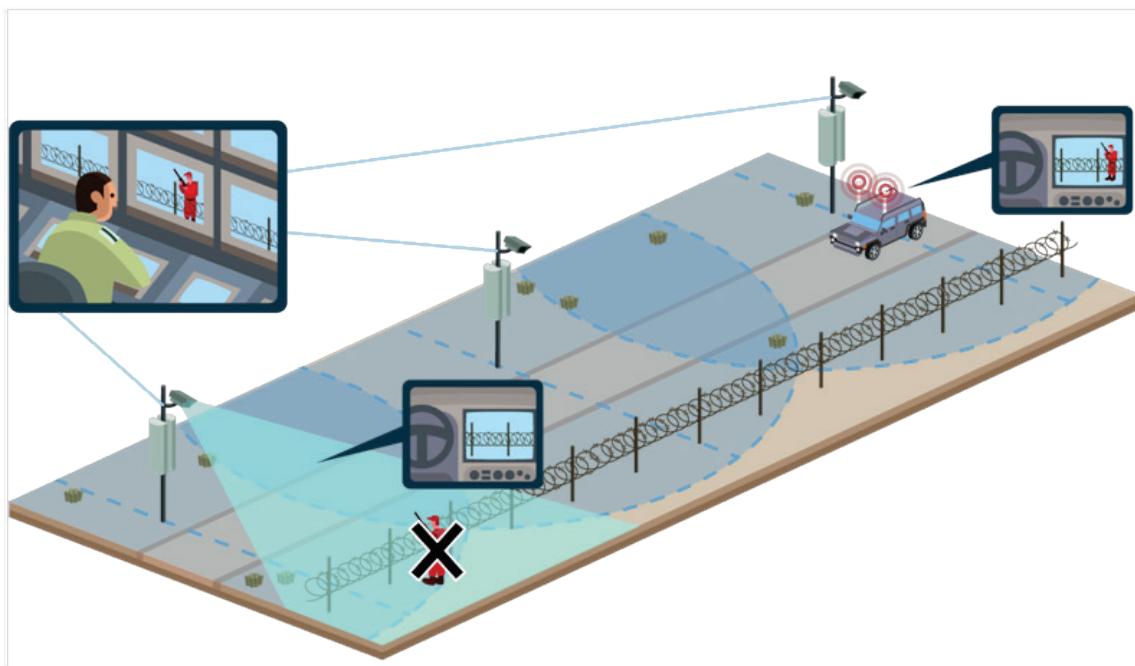


Wireless broadband to vessels

7 Patrol Vehicle Applications

Police, security forces and highway patrol cars along highways and the perimeter of critical assets deal with law enforcement, speed control, intelligence, accidents, license plate recognition applications, and others.

RAD's mobility solution enables real-time video streaming from cameras installed along highways or patrol routes to a terminal in the police car. Simultaneously, a video can be transmitted from the car to the control center.



Mobility communications to patrol vehicles – application concept

8 Summary

Broadband communications is becoming a life necessity today. It is expected by people on-the-go when commuting in public transit and is a mandatory tool for efficient and safe modern transportation.

RAD's advanced mobility solution enables affordable and secure broadband in motion for modern transportation needs. Afield-proven solution, it is deployed worldwide by numerous transportation and security agencies, leveraging over 30 years of telecom experience with deep understanding of customer needs.

RAD's advanced mobility solution is a turnkey offering with state-of-the-art radios, flexible networking and end-to-end project management. RAD's solution is customized to the specific reliability, security and safety needs of the transportation market.

We look forward to discussing your unique mobility needs.

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