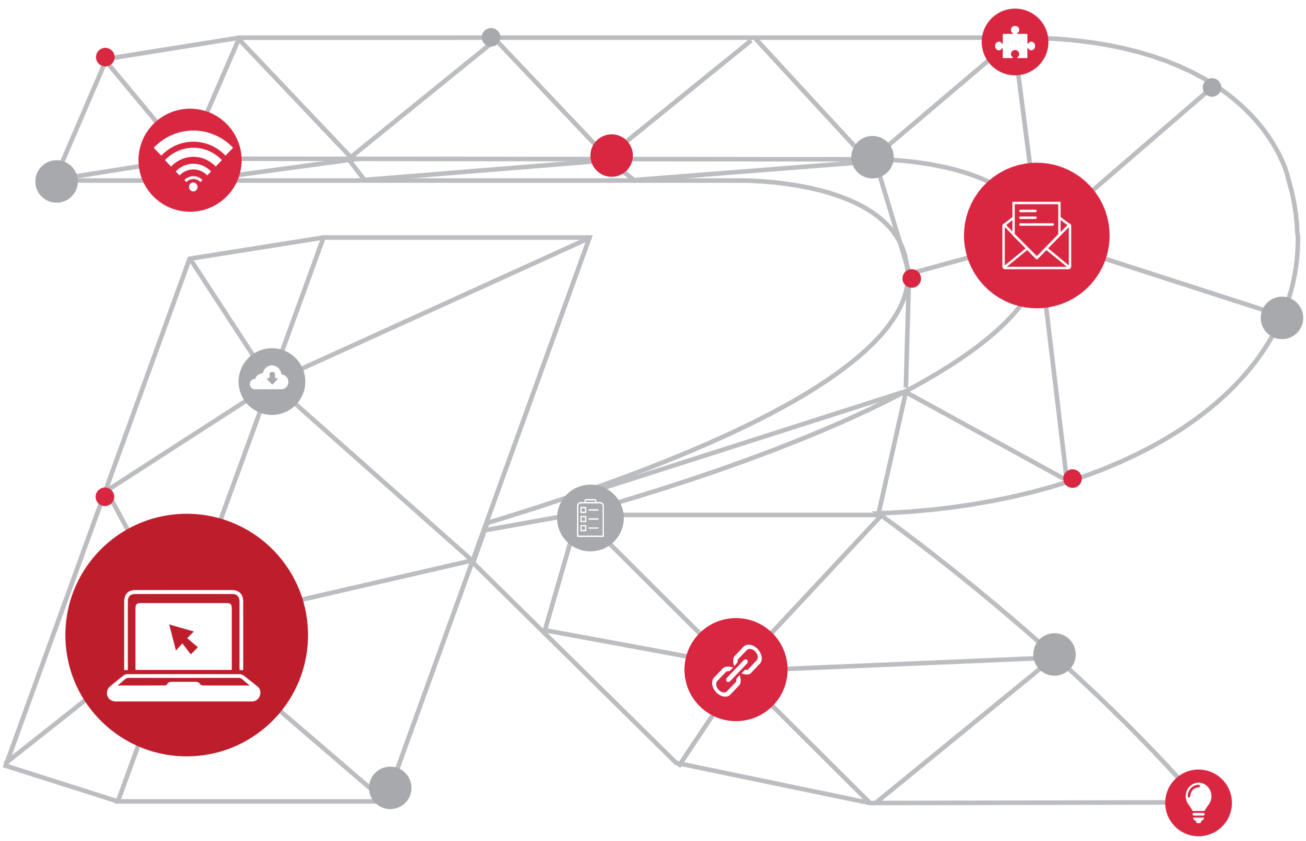
Ruijie Wireless Train-to-Ground

White Paper



Contents

Introduction

Metros are an outcome of high-speed development of cities. Cities constantly increase investments on the development and construction of the metro transportation system. The passenger information system is an important component of metro communication. Its modernized development and more reliable running are one of the focuses in metro construction and development. In comparison with wired network technologies, the reliability of wireless communication application in the metro passenger information system needs to be further studied and enhanced.

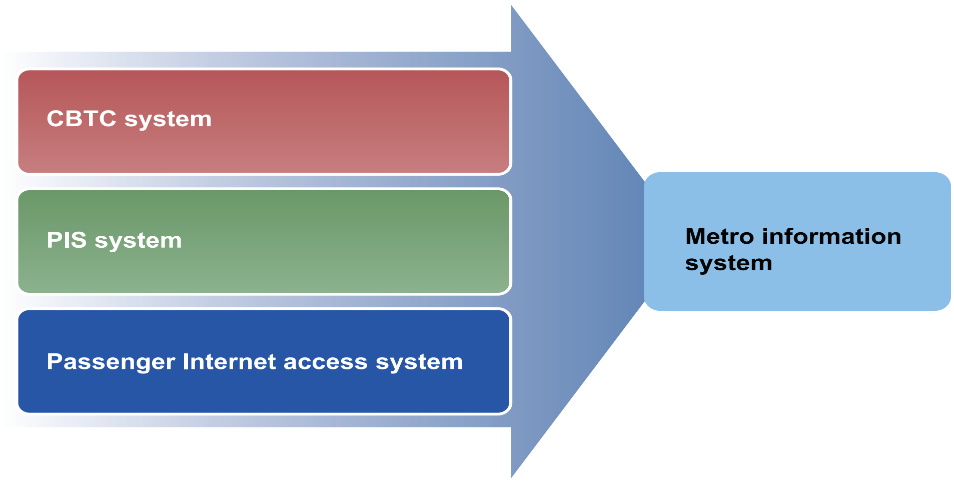
With the popularity of smartphones, more and more passengers use their smartphones to update micro-blogs and browse web pages. When trains pass through different areas, the smartphone signal strength fluctuates, affecting passengers' Internet access experience.

The train-to-ground communication solution based on Wireless Local Area Network (WLAN) gains increasing attention, to meet metro passengers' urgent needs for wireless Internet access and communication as well as wireless information, and raise the information-based metro construction and operation & service. In comparison with other solutions, the WLAN-based train-to-ground communication solution can provide higher bandwidth and more extensive access control to meet operators' multiple service requirements.

• Project Background

With the rapid development of urban public transportation, many second- and third-tier cities in China also start building metro network systems. The information technology development enables the metro network system to evolve into a comprehensive system that involves multiple fields and integrates numerous functions. Apart from the conventional transportation function, the metro system provides media communication. Passengers can learn about train running information, public information, and safety precautions from display STAs at metro stations. The metro information system can play weather forecast, news, and entertainment programs during train running.

Figure 1 Composition of the Metro Information System



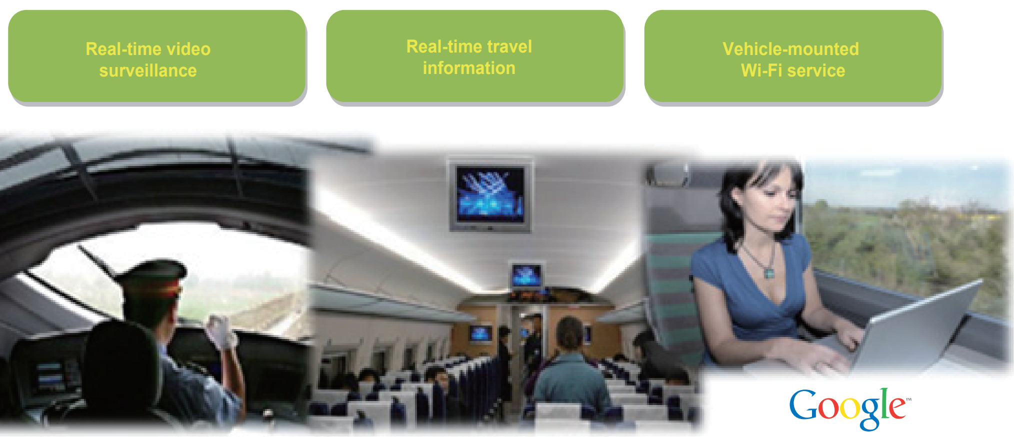
Development Trend of the Metro Information System

* **Real-time video surveillance: The images of the train head, cab, and compartments can be transmitted to the ground scheduling center in real time.**

* **Real-time travel information: Real-time dynamic advertisements, high-definition video programs, and event notifications can be transferred to passengers in a timely manner, to provide great convenience for passenger travel and make passengers feel at ease.**

* **Vehicle-mounted Wi-Fi service: Passengers can smoothly access the Internet, browse news, check emails, and handle business affairs conveniently even during high-speed train running. The vehicle-mounted large-capacity network devices and servers can store rich multimedia resources, providing splendid content services for passengers.**

Figure 2



CBTC System

In the metro transport system, the Communication Based Automatic Train Control (CBTC) system implements manual control, automatic control, and remote control to ensure train operation safety and control trains to run on railways.

It includes three subsystems:

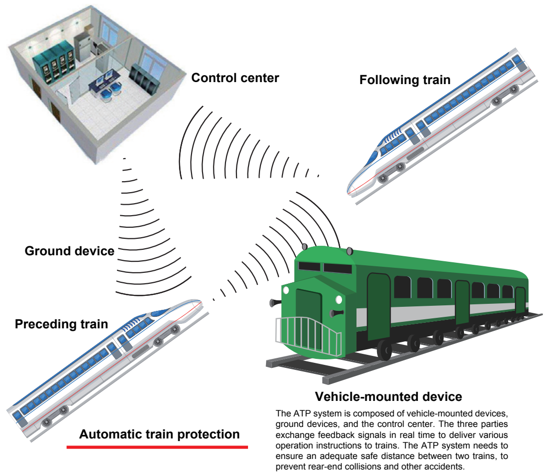
- Automatic Train Supervision (ATS) subsystem

- Automatic Train Protection (ATP) subsystem

- Automatic Train Operation (ATO) subsystem

The three subsystems constitute a closed-loop system via the information switching network and implement ground control and in-train control as well as field control and central control, thereby composing an automatic train control system that is based on safety devices and integrates train marshalling, running adjustment, train steering automation, and other functions.

Figure 3



PIS System

The Passenger Information System (PIS) is a service system that provides various types of information for passengers in trains.

The PIS relies on the multimedia network technology and centers on the computer system, to provide information services for passengers via media such as stations and vehicle-mounted display STAs.

Passenger Internet Access System

* **Vehicle-mounted Wi-Fi service**

-News: Passengers can browse latest news online.

-Business: Passengers can conduct Office Automation (OA), send emails, and invest in stocks.

-Leisure and entertainment: Passengers can listen to music, read e-books, view pictures, watch videos, and play games.

-Advertisement marketing: Media agencies can push advertisements.

Figure 4

Passengers in Need of Broadband in the Mobile Internet Era

Mobile STAs have outnumbered computers and become the major force of Internet, and smartphones will become the mainstream mobile STAs.

Mobile data services will grow exponentially, and services that require high bandwidth such as videos become mainstream services.

Figure 5

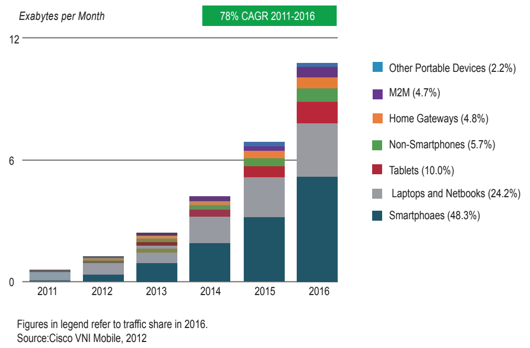
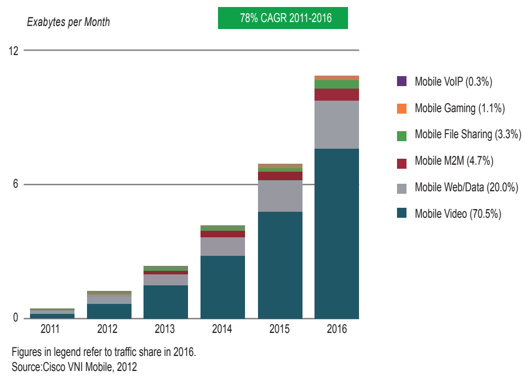


Figure 6



Mobile broadband Internet access services in trains are in strong demands.

On short-haul journeys, trains are crowded and laptop usage is not easily accommodated, so passengers would want Wi-Fi access primarily for smart phones.

On longer distance trains, 57% of respondents said they would use laptops if Wi-Fi is available and they would be willing to pay around 50₡ per trip for access.

• Products/Features Involved in the Solution

10GE AP Controller RG-WS5708

Figure 7

Features of the RG-WS5708 are as follows:

1. Adopts the latest MIP64 multi-core processor architecture in the industry, and provides 8 x 1GE SFP combo ports and 2 x 10GE SFP+ combo ports. It provides strong data transmission and service processing capabilities, and can manage up to 1024 Access Points (APs).

2. Supports deployment on a Layer-2 or Layer-3 network, with no need to alter the original network architecture. It can be used in combination with wireless APs to build an overall switching architecture, so as to conveniently control and process data switching on all APs.

3. Combines the embedded local user database and the embedded portal server to implement local authentication of wireless STAs in Web authentication mode.

4. Supports 1+1 or n+1 hot backup and seamless active/standby switchovers and provides dual power modules for redundancy to ensure stable running of the wireless network.

Vehicle-mounted Switch RG-IS2712G (P8)

Features of the RG-IS2712G (P8) are as follows:

1. Relies on the RG-IS2712 platform.
2. Supports extensible switch mode power supplies and supports 110 V DC power supply. It can be energized using the power supply in trains.
3. Adopts aviation captive connectors and conforms to the vibration specifications in IEC61373. It is applicable to trackside environments with strong vibration.
4. Provides EN50155-compliant Electromagnetic Compatibility (EMC). It can be energized using the power supply in trains and is applicable to environments with electromagnetic interference.
5. Delivers IP67 protection and supports the operation range from –40° C to +70° C. It can be installed in compartments.
6. Supports the bypass function for interfaces. When the device malfunctions in a linear networking topology, the bypass device will not affect communication of other devices.
7. Supports the output of four PoE+ ports.

Figure 8

Dedicated Trackside 802.11ac Wireless AP RG-AP530-I (S1)

The RG-AP530-I (S1) is a special metro trackside 802.11ac wireless AP released by Ruijie Networks. It supports three spatial streams, and a single-channel radio frequency (RF) unit can provide an access rate up to 1300 Mbps and the device can provide an access rate of 2600Mbps, which eliminates the rate performance bottleneck.

Wireless network security, RF management, mobile access, quality of service (QoS) guarantee, seamless roaming, and other important factors are fully considered for the RG-AP530-I(S1). It works with Ruijie WS series wireless controllers, to establish wireless bridges with vehicle-mounted APs, and transmit data via high-speed train-to-ground communication links.

The RG-AP530-I adopts the dual-radio 5G design and can also work in 802.11ac mode. It can be conveniently and safely mounted on the wall or poles. The RG-AP530-I (S1) can be energized by the local 220 V AC power supply and can be connected to an uplink device through an optical fiber, which reduces the components for trackside installation and lowers the device costs and maintenance costs.

Figure 9

Dedicated Metro Vehicle-Mounted 802.11ac Wireless AP RG-AP530-I (S2)

The RG-AP530-I (S2) is a special metro vehicle-mounted 802.11ac wireless AP released by Ruijie Networks. It supports three spatial streams and a single-channel RF unit can provide an access rate up to 1300 Mbps and the device can provide an access rate of 1750 Mbps, which eliminates the rate performance bottleneck.

Wireless network security, RF management, mobile access, QoS guarantee, seamless roaming, and other important factors are fully considered for the RG-AP530-I(S2). It works with Ruijie WS series wireless controllers, to implement user data forwarding, security, and access control.

The RG-AP530-I (S2) adopts the dual-radio dual-band design and supports 2.4G/5G dual-band output. It can work in 802.11a/n/ac and 802.11b/g/n modes. This compact product (180 mm x 100 mm x 40 mm) delivers a high protection grade (IP54), allowing to be installed in various positions in trains. The RG-AP530-I (S2) supports local 110 V direct power supply and remote Power over Ethernet (PoE) mode. Customers can flexibly select the power supply based on the field environment.

Figure 10

Technical Principles

• Overview

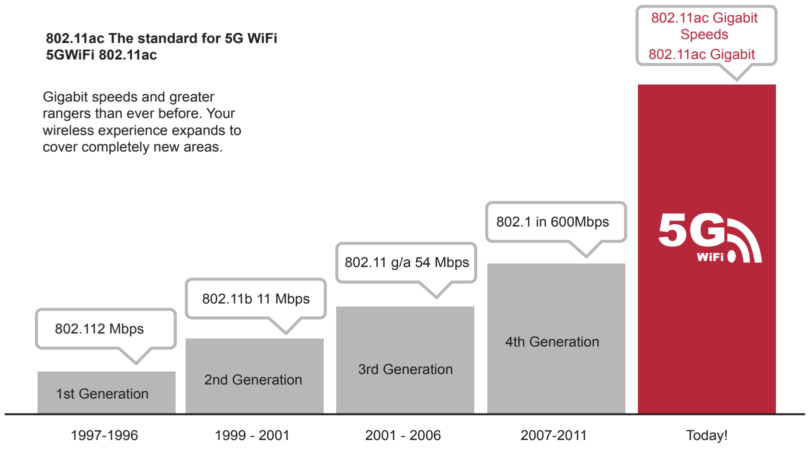
GE Performance

The train-to-ground link adopts the 5G Wi-Fi technology (802.11ac) as well as the 256 Quadrature Amplitude Modulation (QAM), carrier aggregation, deep frame aggregation, and other technologies, to implement a connection rate up to 1.3 Gbps. The actual effective throughput can reach 950 Mbps.

Transmission Distance

The APs use the advanced Multiple-Input Multiple-Output (MIMO), Transmit Beamforming (TxBF), Low-Density Parity-Check (LDPC), and Maximum Ratio Combining (MRC) technologies to achieve a transmission distance of 200 m.

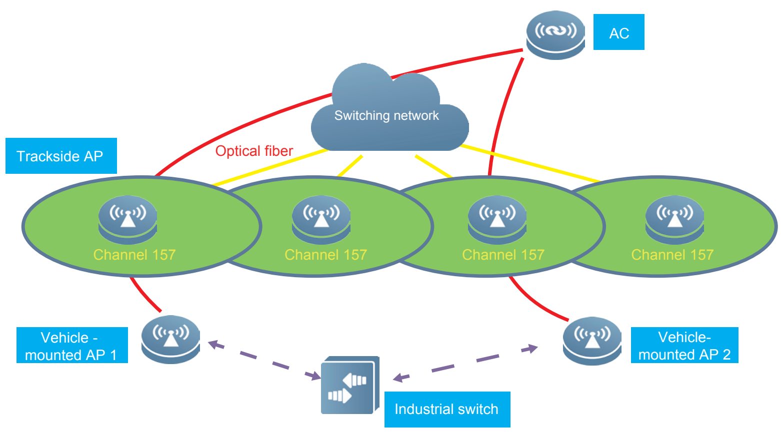
Figure 11



Single-frequency Networking

The Ruijie proprietary 802.11ac single-frequency networking technology enables all trackside APs to broadcast the same SSID at the same frequency. All data streams are transferred to the Access Controller (AC) for processing. No roaming handover occurs during train running and the performance is excellent without packet loss.

Figure 12



• Key Technologies

Virtual Cellular Technology

Trackside APs work at the same frequency and have the same BSSID. All packet processing and interaction are coordinated by the AC. All APs on the network can be considered as a virtual large AP for STAs.

Perception-free Handover

Based on the signal strength, connection rate, and other parameters of STAs, the AC automatically hands over the STAs to APs with better signal strength during STA movement. The handover involves only the update of AC entries, and does not need packet negotiation on the wireless device side. Therefore, the handover will not cause switching overheads or network packet loss.

Dual-link Aggregation

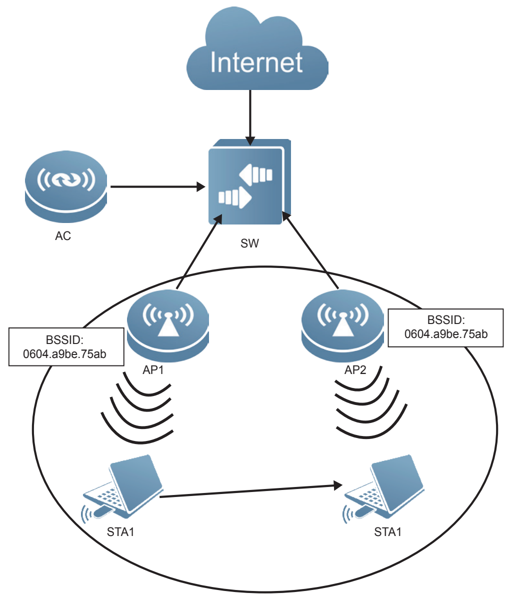
One train-to-ground communication AP is deployed at each of the train head and train tail and vehicle-mounted switches are used to implement dual-link load balancing. Typically, dual-link aggregation doubles the link performance, and ensures that the train-to-ground communication is uninterrupted if a link is disconnected.

Introduction to Key Technologies

In-train Switching Ring Network

One vehicle-mounted switch is deployed in each compartment, and the switches in compartments can be connected through network cables, to form a ring network. A switch in a compartment can be connected to the next but one switch in a compartment, to prevent excessive network cables, as shown in Figure 13.

Figure 13



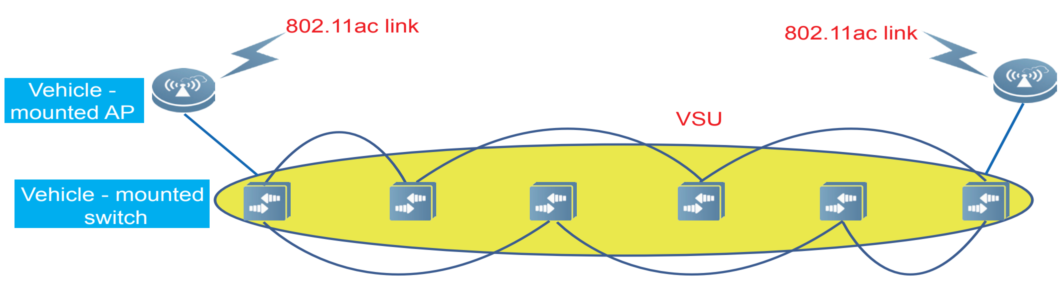
VSU Virtualization

Switches in all compartments are virtualized into one Virtual Switching Unit (VSU) for unified management and unified policy delivery. The switches can form a ring network to implement the redundancy backup of wired links.

Dual-link Load Balancing

The VSU has two uplinks, which can be configured to implement load balancing according to multiple policies (by IP address, MAC address, or port ID). When one link is interrupted, services and data can be switched to the other link within 20 ms.

Figure 14



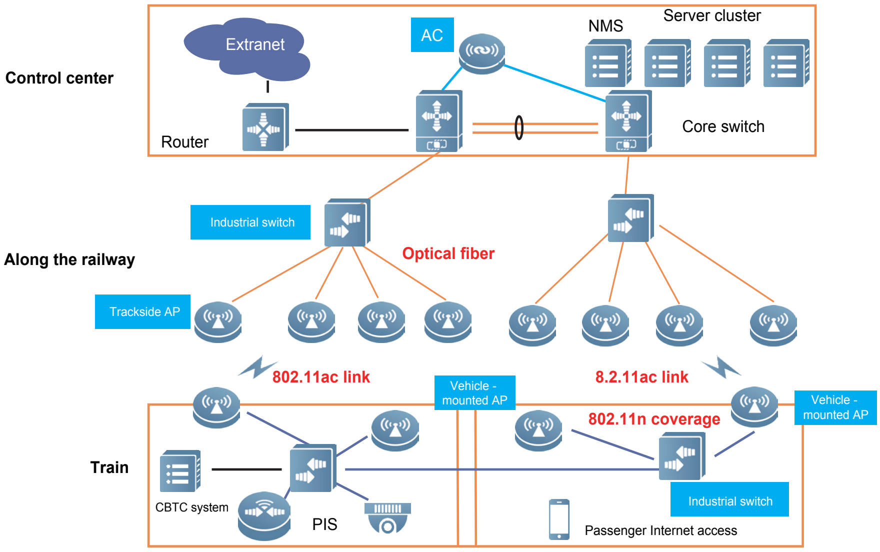
Wireless Access

In collaboration with Ruijie leading RF antenna technology and multi-user balancing and scheduling technology, the in-train coverage can support a maximum of 64 access users per radio while providing 2 Mbps bandwidth for each user. This can fully meet the video on-demand requirements.

Multi-system Interconnection

The in-train CBTC device, PIS display, and network cameras can be connected to the in-train network via vehicle-mounted industrial switches, to implement multi-system interconnection.

Figure 15



Features of Ruijie Train-to-Ground Wireless Communication Technologies

• Train-to-Ground Wireless Handover Mechanism

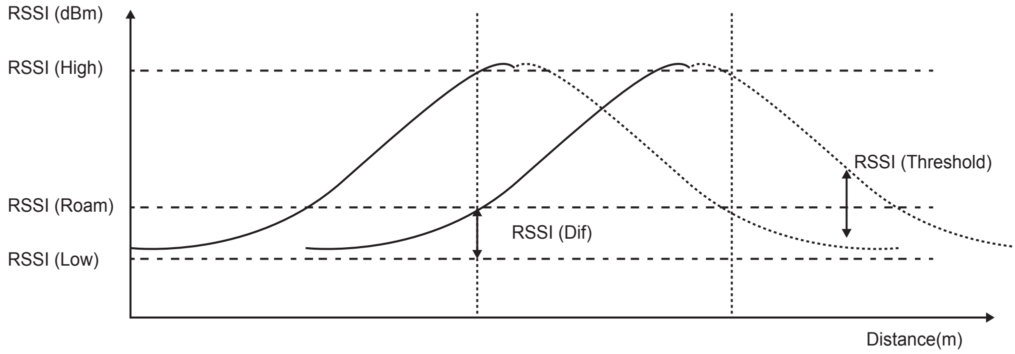
Handover Principle

Train-to-ground wireless links are channels that implement real-time communication between trains and the control center. They are critical to the safety of train running. Communication interruption, delay, and packet loss will affect the train running. Therefore, it is required that wireless links should be uninterruptible even if trains run at a high speed. When a vehicle-mounted AP moves from the coverage of one trackside AP to that of another, a handover will occur. A wireless handover between the coverage of APs is automatic and is transparent to train operations.

The handover time usually ranges from 500 ms to 2s in 802.11n work mode. Vehicle-mounted APs may be disconnected from trackside APs during the handover. This is unacceptable especially when trains run at a very high speed. Assume that a train runs at the maximum speed of 120 km/hour. The worst case is that the APs in the train may be disconnected from trackside APs at a running distance of about 65 m. The high-speed movement AP multi-link communication mechanism developed by Ruijie is adopted to achieve zero handover time, so as to prevent any data loss and ensure the communication quality during the handover. This communication mechanism establishes links and implements link handovers during train movement, and ensures no packet loss.

The difference between the multi-link communication mechanism of Ruijie APs and the standard 802.11n handover algorithm is that the multi-link communication mechanism allows a vehicle-mounted AP to establish a connection with a new trackside AP before being disconnected from the originally associated trackside AP (e.g., APn), that is, allows the AP to connect to a new trackside AP before services are interrupted. Moreover, the sufficient overlapped coverage areas between adjacent APs help achieve a seamless handover. In other words, all processing related to the handover will be accomplished when a train runs within the overlapped area of adjacent APs. The size of the overlapped area needs to be designed based on the maximum speed of trains. The minimum handover delay can be shorter than 10 ms and a handover with zero packet loss can be achieved.

Figure 16



When a vehicle-mounted AP accesses the in-train network for the first time, it scans all channels, records the Received Signal Strength Indicator (RSSI) values of different APs, and selects a trackside AP with the maximum RSSI value for access and a trackside AP with the second maximum RSSI value as a standby AP. In addition, the AC synchronizes its BSSID MAC tables (up_group and down_group) to uplink and downlink trackside APs. The vehicle-mounted AP classifies received RSSI values of neighboring trackside APs into the current uplink neighbor list (up_group_neighbor) and downlink neighbor list (down_group_neighbor) according to the MAC tables.

When the RSSI value is lower than RSSI_Roam, AP roaming is allowed. The vehicle-mounted AP compares the difference RSSI_max between the RSSI value of the standby trackside AP and that of the active trackside AP. From the neighbor list (up_group_neighbor or down_group_neighbor) in the trackside AP, the vehicle-mounted AP selects an AP with the maximum RSSI value difference RSSI_max and the maximum difference between RSSI_max and RSSI_Threshold (RSSI_max > RSSI_Threshold) as the standby AP. If such an AP exists, the vehicle-mounted AP roams to the coverage of the AP. If no such an AP exists and the current RSSI value is lower than RSSI_low, the vehicle-mounted AP selects an AP with the maximum RSSI_max as the standby AP from the uplink and downlink neighbor lists.

When the RSSI value is greater than RSSI_high, AP roaming is allowed. From the neighbor list (up_group_neighbor or down_group_neighbor) in the trackside AP, the vehicle-mounted AP selects an AP with the maximum difference RSSI_dif between the RSSI value and RSSI_low as the standby AP.

The preceding mechanism ensures that in open areas such as elevated railways, a vehicle-mounted AP always associates with a trackside AP in the same direction as the train heading direction, and will not associate with a trackside AP in the opposite direction to the train heading direction. In this way, the RSSI of trackside APs will not decrease sharply due to signal blocking during train crossing and no trackside AP handover will be incurred.

The handover can be accomplished within several milliseconds. A vehicle-mounted AP can extract the packet RSSI in real time from data packets used in current communication, and other APs in the neighbor list can extract the neighbor RSSI by periodically detecting the RSSI of beacon packets. Signal analysis is generally completed within 2 ms based on the current packet demodulation rate. A neighbor AP often transmits a beacon packet at an interval of 100 ms. In the time of a very short transmission distance (suppose that a train runs at 100 km/h, that is, the train moves 3 m within 100 ms, the RSSI basically keep unchanged within this period in long-distance signal transmission, and the RSSI of the previous period can be used as the RSSI of current period), the algorithm can compare the RSSIs in real time. A vehicle-mounted AP can accomplish roaming handover by exchanging only one beacon packet and the packet time is less than 1 ms. In theoretical analysis, the handover time does not exceed 5 ms. The actual test shows that Ruijie vehicle-mounted APs can accomplish handovers within 10 ms during high-speed train running.

Handover Reliability

Wireless APs are deployed in a linear manner in metros, and therefore, the coverage of the wireless network shows a linear pattern. Directional antennas need to be used to enlarge the effective coverage.

Conventional communication standard protocols use the automatic rate adjustment algorithm, that is, both parties use the highest rate supported by them in the initial communication. If the communication fails, a retransmission mechanism is adopted. After the transmission count reaches the maximum value, they continue to use a lower rate level for transmission until all data packets are transmitted successfully.

Signal fading is severe and the Signal-to-Noise Ratio (SNR) deteriorates significantly during high-speed train running. The data transmission of high-rate packets requires an SNR about 5 dB to 20 dB higher than that of packets at other rates. Therefore, the initial communication inevitably fails if the high-rate transmission is adopted.

By default, a maximum of 64 Operation, Administration and Maintenance Protocol Data Unit (AMPDU) packets can be aggregated when an AP sends packets. Data transmission requires a longer time if packets are large. The receiver performs channel estimation only in transmission of the packet header, and a longer transmission time will lead to a greater channel estimation error, which will cause a packet demodulation failure subsequently.

In addition, wireless communication uses a half-duplex contention communication mechanism. A longer transmission time will lead to a higher probability of interference, and hence a higher Bit Error Rate (BER) in an interfered environment. Retransmission will consume air interface resources, causing poor performance.

According to the switching communication principle, when a vehicle-mounted AP roams to the coverage of a new trackside AP, the trackside AP does not have the ARP entries of all STAs in the train and needs to broadcast an ARP request to learn their MAC addresses during the initial communication with STAs in the train according to protocol standards. Assume that a train runs at 100 km/h (30 m/s) and trackside APs are deployed at spacing of 200 m. A broadcast storm will occur every 6 to 7 seconds. If there are considerable STAs in the train, the broadcast storm will inevitably cause the network to break down or cause communication failures of certain STAs.

Ruijie train-to-ground communications system uses a private algorithm to resolve the issues above:

1. When a vehicle-mounted AP is ready for a handover to a trackside APn, it sends a handshake packet to notify the APn that the APn will be used as the next active trackside AP. The handshake packet is transmitted at a low rate. Upon receiving the handshake packet, the trackside AP returns a response packet at a low rate. After the successful handshake, that is, successful roaming, both parties use an auto-negotiated rate adjustment algorithm, and adjust the packet transmission rate in real time based on the current signal quality.

2. When a vehicle-mounted AP communicates with a new trackside AP for the first time, both parties use low-aggregated packets (short packets), and then use the automatic negotiation mode and adjust the aggregation depth based on the communication quality.

3. When a vehicle-mounted AP sends a handshake packet for a handover to a new trackside AP, the vehicle-mounted AP acts as a proxy of all the STAs in the train to synchronize the MAC address table to the trackside AP. The trackside AP updates the MAC address table to the access switch. Subsequently, all new packets are transmitted through the new train-to-ground link. Since the original trackside AP still has packets to be sent to the vehicle-mounted AP in the physical-layer buffer, the vehicle-mounted AP continues receiving packets from the original trackside AP but returns response packets via the new trackside AP of the new link.

The foregoing measures greatly improve the communication reliability during the handover, achieving zero packet loss.

Dual-link Load Balancing at the Train Head and Tail

VSU Virtualization

The switches at both ends of a train are virtualized into one VSU for unified management and unified policy delivery, thereby implementing redundancy backup of wired links.

Dual-link Load Balancing

The industrial switch virtualized using switches in the train head and train tail has two train-to-ground links, which can be configured to implement load balancing according to multiple policies (by IP address, MAC address, or port ID). When one link is interrupted, services and data can be switched to the other link within 20 ms.

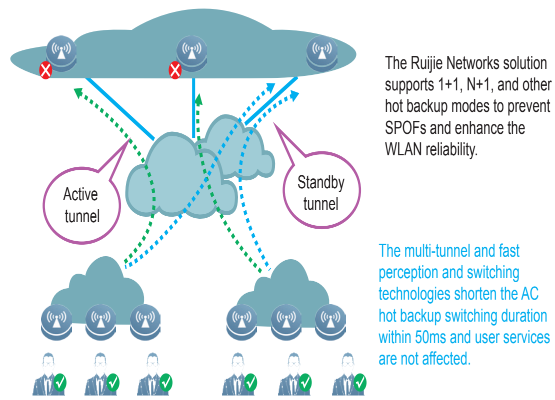
• Active and Standby ACs

In network design, network reliability is fully considered for the solution to provide 7 x 24 wireless network services. Two ACs are used to work in active/standby cluster mode. When the active AC malfunctions and breaks down, the standby AC takes over services and data within several milliseconds to ensure that the wireless Internet service is not interrupted.

The conventional AC redundancy backup is implemented as follows: A fit AP determines the work status of the associated AC by using the heartbeat handshake mechanism. When detecting that the AC drops out of the network or breaks down, the fit AP establishes a tunnel connection with the standby AC based on the locally stored standby AC address. Therefore, wireless STAs fail to receive packets before the fit AP establishes a connection with the standby AC successfully. The timeout duration of the heartbeat handshake between a fit AP and an AC is generally long, ranging from several seconds to dozens of seconds. That is, once the active AC drops out of the network or breaks down, the fit AP can identify the disconnection only after dozens of seconds. Then, the fit AP needs to establish a connection with the standby AC, which needs dozens of seconds at least. In this process, services will be interrupted for dozens of seconds and even several minutes, which is unacceptable to users.

Ruijie Networks ACs are developed based on the virtualized architecture by using the redundancy backup technology. The implementation is as follows: One AC serves as the master AC and another N ACs serve as slave ACs. Only the master AC accepts the registration requests of APs at wireless network initialization. When an AP registers with the master AC and establishes a Control and Provisioning of Wireless Access Points (CAPWAP) connection with the master AC, the master AC notifies each AP of information about the standby AC. The AP establishes a virtual CAPWAP link with the standby AC based on this information. Only the CAPWAP link established with the master AC is in the active state at a time. When the master AC breaks down, the heartbeat detection mechanism between the standby AC and the master AC can rapidly detects the status of the master AC, and instructs the AP to switch services and data to the standby CAPWAP tunnel. The switching will be completed within several milliseconds and user services will not be interrupted.

Figure 17



STAs are not affected during AC hot backup switching (cluster configuration can be performed on multiple ACs).

• Hot Backup at the Train Head and Tail

Vehicle-mounted wireless devices and vehicle-mounted switches with the same functions are deployed in a train's cabs at both ends of the train. Vehicle-mounted switches adopt the VSU networking mode. The VSU networking has the following advantages: unified management of multiple switches, master/slave hot backup, and binding of inter-device ports into an aggregate port.

Unified management enables multiple vehicle-mounted switches to share one management address, which greatly reduces the occupancy of IP resources and simplifies device management.

Master/slave hot backup can properly ensure the stability of the in-train network. When the master switch malfunctions, the slave switch becomes the master switch to manage devices. The vehicle-mounted wireless devices are disconnected from the original master switch and wireless devices in the train tail are connected to provide a train-to-ground link, to ensure that the system in the train functions properly.

Binding of inter-device ports into an aggregate port, in combination with wireless devices in the train head/tail, can double the wireless train-to-ground bandwidth. In addition, the wireless device signal detection function is available. When detecting that the train-to-ground wireless link is disconnected, the vehicle-mounted switch is notified to disconnect the link. The vehicle-mounted switch completes AP switching by using the aggregate port switching function, thereby achieving excellent switching performance.

• Trackside AP Maintenance-free Solution

Trackside APs are designed based on the physiology of zero configuration and maintenance exemption. The system startup process is as follows:

The CAPWAP protocol describes CAPWAP state machines comprehensively. The entire process is as follows:

Discovery—>Join—>Image data—>Configuration—>Data check—>Running

The establishment of a CAPWAP tunnel includes the following steps:

1. An AP obtains IP addresses of ACs by means of the Domain Name Service (DNS), Dynamic Host Configuration Protocol (DHCP), static configuration of IP addresses, and broadcast.
2. The AP discovers an AC.
3. The AP requests to join the AC.
4. The AP automatically completes an upgrade.
5. The AC delivers AP configurations to the AP.
6. The AP confirms the configurations.
7. The AP and the AC forward data through the CAPWAP tunnel.

The AC can implement device software download and batch configuration delivery on all trackside APs, with no need of field manual maintenance.

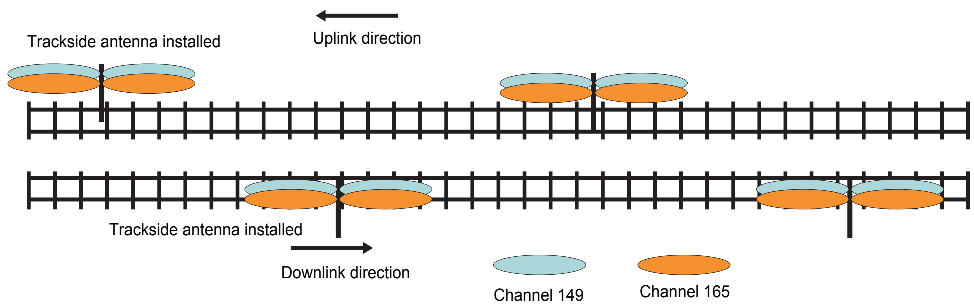
• Uplink and Downlink Anti-interference Solution for Elevated Railways

Interference is generated if co-channel signals are adopted for both the uplink and downlink because elevated railways are spacious. Moreover, the signal transmission effect of trackside APs on elevated railways is good. As a result, vehicle-mounted APs roam frequently. Signal blocking is severe when two trains head towards opposite directions cross each other, leading to poor performance.

The recommended deployment solution for elevated railways is as follows:

1. Deploy APs at spacing of 200 m in each driving direction in a staggered way, to eliminate signal coverage holes in case of SPOFs.
2. After deployment, properly adjust the AP transmit power to increase the beacon transmission rate and reduce co-channel interference.
3. Plan the uplink and downlink APs in different groups and synchronize the configurations of the uplink and downlink APs to vehicle-mounted APs. In principle, a vehicle-mounted AP roams among trackside APs only in one group. The purpose is to reduce frequent roaming of the AP or roaming to the coverage of other trackside APs, and avoid performance deterioration caused by signal blocking during train crossing.
4. When the RSSI of a vehicle-mounted AP is lower than RSSI_low, the AP is allowed to select one trackside AP with the best RSSI from all groups as the next AP for roaming.

Figure 18

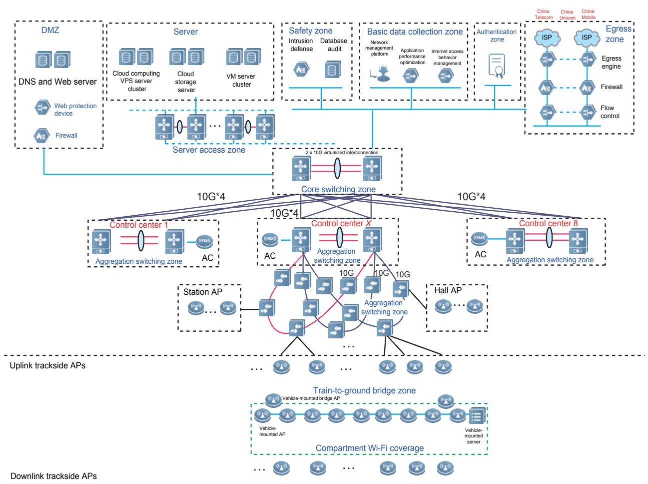


Typical Applications of Train-to-Ground Wireless Technologies in Metros

• Train-to-Ground Link Solution to WLANs in Metros

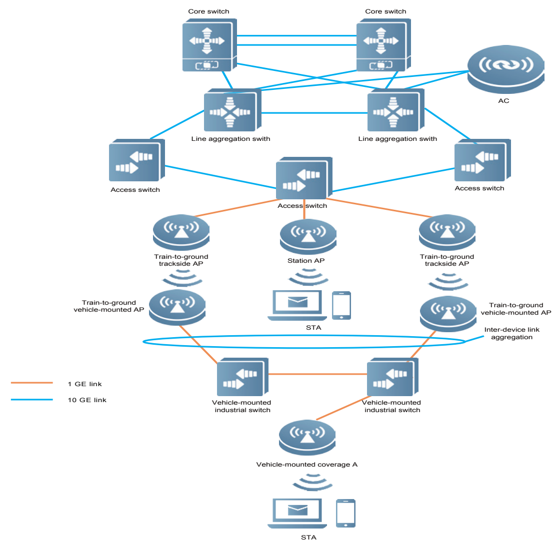
Overall Network Topology

Figure 19



Backbone Network Topology

Figure 20



Restrictions

	Restrictions	Remarks
1	The WDS bridging that uses both the fit AP and fat APs is not supported.	
2	When fit APs are used for bridging, the APs are required to automatically establish a CAPWAP tunnel via a Bridge Virtual Interface (BVI).	The WDS implements bridging only. Therefore, in fit AP bridging application scenarios, APs should be capable of establishing CAPWAP tunnels via BVIs. If APs do not support this function, the WDS cannot work in fit AP mode.
3	Pre-configuration is required before the fit AP nonroot-bridge is used.	
4	The same product using the same platform must be used at both ends of a WDS bridge.	
5	In nonroot mode, MAC attributes cannot be configured.	
6	In nonroot fit AP mode, ACs cannot deliver commands that shut down ports.	

Restriction		
7	The bridge can cover a maximum of 15 WLANs for BCM products.	
8	A single-hop WDS bridge supports one-to-many bridging while a multi-hop WDS bridge supports only one-to-one bridge.	
9	Fit AP local management does not support authentication roaming.	
10	The WDS cannot be configured to form a loop.	

Conclusion

The vehicle-mounted AC technology, 802.11ac GE link technology, train-to-ground wireless handover without packet loss, and train-to-ground wireless dual-link backup technology jointly compose the core of the train-to-ground wireless solution for metros. These technologies ensure ease of management, high bandwidth, low packet loss, and high reliability.

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