TECHNOLOGY WHITE PAPER

Open Standards for CBTC and CCTV Radio-based Communication

Train control places high demands on effective wireless roaming because of the high-speed mobility. Unlike a home or office environment, where roaming is rare and deferred communication is tolerated, Communication-Based Train Control (CBTC) demands continuous communication in an environment where roaming is a certainty and often occurs at very high speeds. The authors explain the concept of continuous wireless scanning and seamless roaming handover to provide reliable and sustained communication for smooth CBTC operation. They also take a brief look at CCTV trials in Hong Kong and commissioning of the Las Vegas Monorail.

ALCATEL

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OPEN STANDARDS FOR CBTC AND CCTV RADIO-BASED COMMUNICATION

Alcatel's CBTC and CCTV radio-based systems incorporate commercial off-the-shelf components using open standard wireless local area network technology.

Introduction

Alcatel is pioneering the implementation of an open Radio Frequency (RF) communication technology, based on the Institute for Electrical and Electronics Engineers (IEEE) 802.11 Frequency Hopping Spread Spectrum (FHSS) standard, for trains moving in excess of 120 km/h. Whether it is used for Communication-Based Train Control (CBTC) or Closed Circuit Television (CCTV), IEEE 802.11 is the preferred choice as it is the only standard that supports mobility and protects against obsolescence. Alcatel adopted the 802.11 FHSS technology in 1999, since then it has carried out several trials and demonstrations.

There are several benefits from adopting radio technology for CBTC, including:

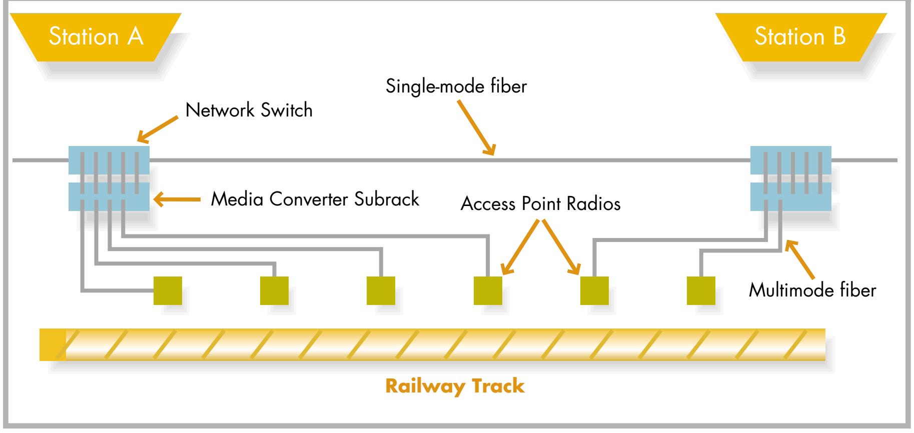
- Complete link redundancy, typically not found in other systems.
- Less overall equipment.
- High data throughput available for other services.
- Easily upgradeable.
- Straightforward expandability.
- Radios located adjacent to the track, with the equipment protected from trains.
- Simplified fault detection.

As pioneers in the use of open standard radio technology in the harsh railway environment, Alcatel has attracted its fair share of skepticism from competitors and rail operators alike. However, a major milestone will be the start of commercial operation of the driverless Las Vegas Monorail project, the first train control system to be based on open communication standards. Alcatel is so convinced that open standard technology will be proven in service, that two of its divisions are collaborating on several proposals and trials in which this technology will support CBTC, CCTV and/or Internet access within an urban rail environment. In the realm of CBTC, radio is a free space communication medium used as an alternative to inductive loops for the transmission of train control data between operation control and trains. CCTV provides security; cameras onboard trains transmit video to operation control via the radio link.

Integrated Network

The Data Communication System (DCS), which provides communication between all the major CBTC subsystems, is an integrated seamless Ethernet-IP (Internet Protocol) network that includes both a wireline and a wireless component. Although simple in concept, the DCS is a complex mix of network equipment and RF wireless components, all protected by a robust security system using the open IP Security (IPSec) protocol. The DCS uses only commercial off-the-shelf components and open standard software and protocols.

Fig. 1 Wired network



An important distinction between Alcatel's open standard DCS and other proprietary systems lies in its future migration capability. It is comprised of three distinct elements: a radio link, a wayside network (running adjacent to the track and providing a link between wayside applications and trackside radios) and a security system which can be modified/upgraded independently as technology advances.

The wired component of the DCS is a combination of Ethernet hubs/switches and fiber-optic cabling, as shown in *Figure 1*. The Ethernet hubs/switches, which are installed inside station equipment rooms, not only aggregate the interconnection of numerous radio Access Points (AP) and wayside control units, but also form a high-speed Ethernet backbone. The numerous APs are interconnected by connecting them to the network switches via media converters, using multimode fiber optic cabling to establish ground radio connectivity. The high-speed Ethernet backbone is realized by interconnecting the Ethernet switches together using single mode fiber-optic cabling.

The wireless component consists of APs and Station Adapter (SA) radios. APs are typically placed at fixed locations and serve as the access interface between the wireless coverage area and the wireline network. Because the APs can be subjected to damp and/or dusty conditions in tunnels and to harsh weather conditions, these radios are housed in National Electrical Manufacturers Association (NEMA) enclosures, which meet established railway standards (e.g. American Railway Engineering and Maintenance of Way Association, AREMA) for thermal and vibration resistance.

The SA is the mobile component of the wireless solution; it is installed as an integral part of the train's communications/control subsystems.

Located at both ends of a train, each radio is connected to two antennas to ensure diversity. Using antenna diversity, two independent wireless signals can be received and compared by the SA; the better of the two signals is then used. This is especially important in harsh environments where noise, obstacles, bad weather and multi-path reflections exist.

Wireless Technology

The main reason for choosing a wireless radio solution based on the IEEE 802.11 FHSS standard is because it:

- Supports mobility.
- Ensures a stable future migration path.
- Comes with an abundance of professional published documentation, which is freely available.
- Provides universal IEEE 802.3 (Ethernet-IP) interfacing.
- Uses IEEE 802.11 radios, which are commercial off-the-shelf components.
- Uses an accepted standard, thereby reducing costs as a result of economies of scale.
- Offers additional bandwidth, which is available for growth.

IEEE 802.11 supports three physical layers: FHSS, Direct Sequence Spread Spectrum (DSSS) and infrared. All incorporate a common Medium Access Control (MAC) layer. Alcatel chose to use FHSS in preference to DSSS because it is a robust technology whith little influence from noise, reflections, radio stations or other environmental factors. In addition, the number of simultaneously active systems in the same geographic area (collocated systems) is significantly higher than for DSSS systems.

DSSS radios operate using 22 MHz of bandwidth per channel; if the receiver picks up a narrowband interference signal anywhere in the 22 MHz operating band, the entire band is affected. Thus only three discrete channels or up to seven overlapping channels can be collocated.

In contrast, FHSS radios only use 1 MHz channels, so the presence of a narrowband interference signal on a specific frequency will only affect one hop. If the FHSS receiver is unable to operate on a specific hop, the radio will only transmit on the next hop and the receiver will receive it on that hop.

Since FHSS radios are less sensitive to signal delays, they are more tolerant of noise and multi-path reflections than are DSSS radios. FHSS uses both time and frequency diversity, so any retransmissions use a different hop frequency to ensure successful execution. In addition, FHSS systems are more secure than DSSS systems as they can use up to 79 available frequency channels and a unique hopping sequence, and can accept and apply customized dwell times.

All these features make FHSS technology the best choice for installations designed to cover wide areas where a large number of collocated systems is required.

Wireless Performance

Designing uniform wireless coverage is the foundation for delivering uninterrupted wireless communication. The fundamental principle for maintaining consistent wireless performance is a strategy based on a balanced combination of the following:

- interference;
- antenna selection;
- antenna diversity vs coverage;
- station adapter threshold settings;
- access point location and signal strength.

Any unbalanced combination of these will produce erratic behavior within the wireless coverage area, including irregular mis-associations, an excessive number of retransmissions, an unacceptable number of dropped packets and/or unpredictable sporadic SA resets.

Interference

The interference/noise floor is the basis for wireless signal strength requirements as the operation of IEEE 802.11 is based on efficient signal-to-noise ratios. The minimal operational signal strength threshold for an SA-AP association should be between 12 dBm (decibels referred to 1 milliwatt) and 18 dBm above the identified interference/noise floor.

When the level of interference is not uniform across the frequency spectrum, defining the interference/noise floor warrants some additional consideration (see *Figure 2*). A single 22 MHz WiFi channel within the 2.4 GHz spectrum will block approximately 30% of the spectrum, thereby causing retransmissions and potential packet loss. This potential for WiFi interference may expand to three discrete WiFi channels in the same coverage area. In time it could quite possibly increase to full overlapping of collocated coverage areas consisting of 14 WiFi channels.

Each mobile SA is configured with a roaming and joining threshold value. An AP signal level lower than the roaming threshold places the mobile SA in roaming mode and an AP signal level above the joining threshold directs the mobile SA to join that AP. Therefore, values for either the roaming or joining thresholds with less than a 15 dBm differential from any interference peak lead to a high probability of interference affecting roaming and data transmission throughout the wireless spectrum.

Fig. 2 WiFi signal spectrum

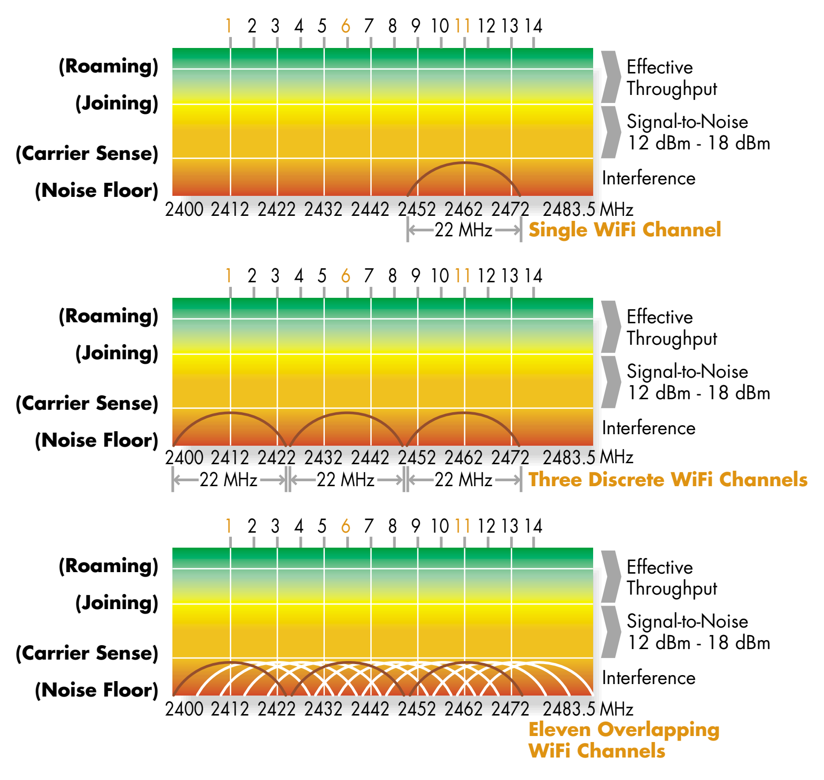
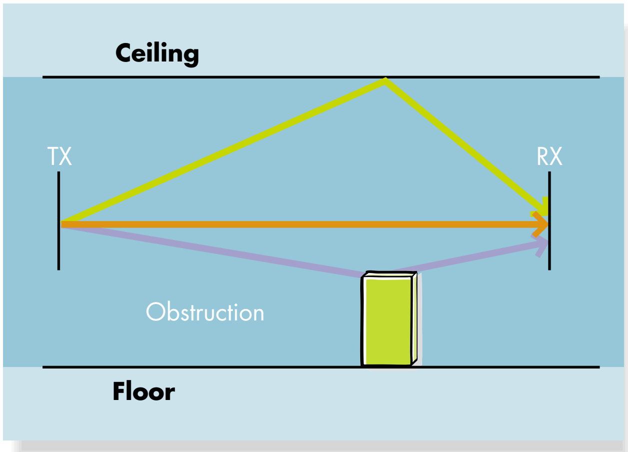


Fig. 3 Multipath interference



Multipath interference

Multipath interference (see *Figure* 3) occurs when a wireless signal traverses more than one path between a receiver and a transmitter. These multiple signals combine in the receiving antenna and the receiver and distort the signal.

The effects of receiving multiple signals as a result of the signal traversing several paths are analyzed in both the time and frequency domains. The paths along which the transmitted signal travel differ in length, so the signal propagation time is different for each path, resulting in multiple signals arriving at the receiver at slightly different times.

FHSS radios generate a very low rate, 330 ns wide transmission signal, which is less sensitive to delays than the narrow 90 ns pulses employed in DSSS. Consequently, FHSS systems are more robust against multipath effects.

FHSS systems use time diversity to retransmit lost packets, until the receiving part acknowledges that they have been received correctly. They also use frequency diversity whereby packets are retransmitted on different frequencies (hops).

Even if some frequencies encounter multipath effects or noise, others will not, so the FHSS system will transmit the information successfully.

As the mobile SA is continually moving, another type of diversity merits consideration. Positional diversity occurs when the wireless RF signal quality differs from one instant to another as the SA moves towards or away from the signal from the associated AP.

Antenna selection

An antenna gives the wireless system three fundamental properties: gain, direction and polarization. Gain is a measure of the increase in power, direction is the shape of the transmission pattern and polarization relates to the orientation of the antennas. Each type of antenna has different coverage capabilities. As the gain of an antenna increases, there is some tradeoff to its coverage area. Usually high gain antennas can cover longer distances, but only in a particular direction.

Omni-directional antennas

An omni-directional antenna (see *Figure* 4) is designed to provide a 360-degree radiation pattern. This type of antenna is used when coverage in all directions is required.

Directional antennas

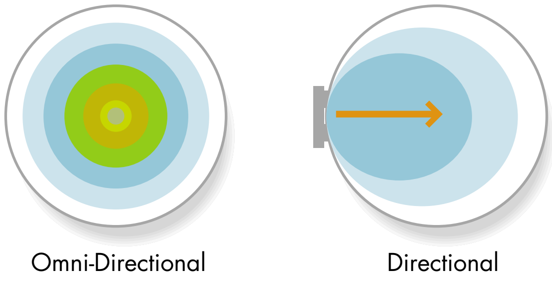
Directional antennas (see *Figure* 4) come in many different designs and shapes. An antenna does not add any power to the signal; it simply redirects the energy it receives from the transmitter. By redirecting this energy, it effectively provides more energy in one direction, and less energy in all other directions. As the gain of a directional antenna increases, the angle of radiation usually decreases, increasing the coverage distance at the expense of reducing the coverage angle. Directional antennas include Yagi antennas, patch antennas and parabolic dishes.

Diversity antenna systems

Diversity antenna systems are used to overcome a phenomenon known as multipath distortion or multipath fading. Two identical antennas are located a short distance apart to cover the same physical area.

A diversity antenna system can be compared to a switch that selects one antenna or the other, but never both at the same time. The receiving radio switches continually between the two antennas listening for a valid radio packet. When the radio receives the start sync of a valid packet, it evaluates the sync signal of the packet on that antenna, then switches to the other antenna and evaluates that signal. The radio then selects the best signal and uses only that antenna to receive the remaining part of that packet. When transmitting, the radio selects the same antenna as it used the last time it communicated with that particular radio. If a packet fails, it switches to the other antenna and retransmits the packet.

Fig. 4 Wireless antenna coverage



Antenna diversity vs antenna coverage

The path taken by a radio signal between two antennas is seldom a straight line; the reality is that there are many elevation changes and curves. A good example illustrating antenna diversity at the expense of antenna coverage is when the SA approaches a curve on the pre-determined path and where the existing and/or next AP is not visible to the SA's directional antennas.

Diversity antenna systems with a full overlay of their 120 degrees of spatial coverage (see *Figure* 5) make it highly likely that the SA will lose contact with both the existing AP and following AP as the SA approaches curves along its path. As the SA approaches a curve with APs located before and after the curve, the SA potentially loses contact with the next AP just after passing the previous one. This will result in unnecessary beacon loss, retransmissions and possibly lost packets.

An alternative worth considering is to angle the diversity antennas outwards by as little as 15 degrees each to widen the SA's coverage area (see *Figure 5*). This can improve the total coverage by as much as 30 degrees while still maintaining a 90 degree angle of antenna diversity. Widening the coverage area in this way will lessen the probability of losing communication between the SA and AP on curved sections of the track.

As the SA approaches a curve with APs located before and after the curve, the SA establishes contact with the next AP just after passing the previous AP. This approach provides the potential for a more continuous SA-to-AP association, which will result in minimal beacon loss, few retransmissions and insignificant packet loss.

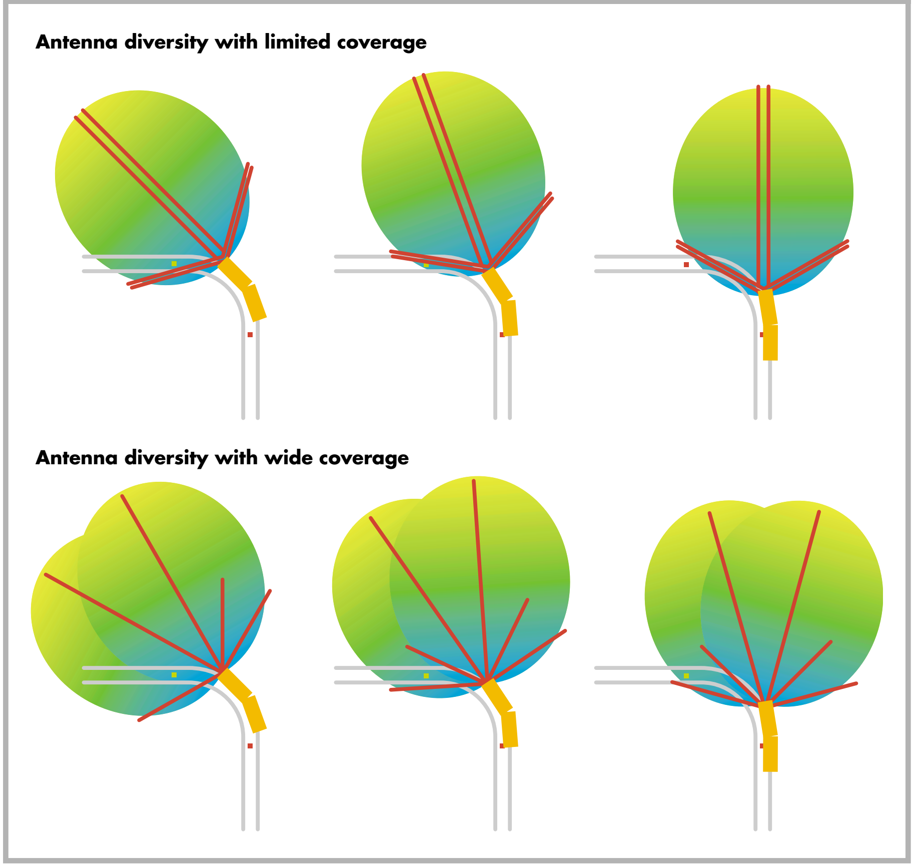
SA threshold settings

The mobile SA roaming/joining thresholds must be set to maintain the appropriate signal-to-noise differential with respect to the interference/noise floor across the entire spectrum.

A roaming threshold set below the appropriate signal-to-noise ratio may cause a prolonged AP association to the extent that the SA loses the signal altogether as it passes the AP. This condition will produce intermittent beacon loss disconnects, rescans and re-associations, resulting in excessive retransmissions and/or dropped packets.

A joining threshold below the appropriate signal-to-noise ratio can potentially result in an association with a downstream AP that provides a low signal strength and poor signal-to-noise differential, choking the effective throughput of the AP-SA association and causing excessive retransmissions and/or dropped packets.

Fig. 5 Antenna diversity schemes



AP Location and Signal Strength

AP locations and the associated wireless coverage must ensure a uniform end-to-end signal strength to guarantee seamless roaming handover. The distribution of APs along the path of the mobile SA will depend on the SA's roaming and joining thresholds, which in turn are based on the interference/noise floor.

APs must provide full track coverage with a consistent minimum signal level above the measured noise floor. FHSS radios can operate with a signal-to-noise ratio as low as 18 dB. A site survey establishes the noise floor within a given environment and includes interference measurements taken from other operators using the same frequency band. Once the noise floor has been established, it is possible to determine the minimum signal coverage required throughout the system; this in turn aids in AP positioning.

Wireless Roaming

The concept of wireless roaming involves a series of SA-to-AP associations, disconnects and re-associations (see *Figure 6*). During the roaming process, only the SA is responsible for initiating an association with the AP. A disconnect between an SA and an AP occurs when an existing association is terminated in one of two ways: a roaming disassociation or beacon (signal) loss disconnect. A disconnect may be initiated by either the SA and/or the AP. Re-association occurs when the SA either re-associates with a new, or the previously associated, AP.

An SA can only be associated with one AP at a time to ensure that it maintains only one connection to the network. In contrast, many SAs can be associated with the same AP at the same time.

The IEEE 802.11 specification provides for roaming from the coverage area of one AP to that of another. The conventional roaming logic implemented in 802.11 devices is based on an election process, where the premise for association with the next best AP is based on moving towards a stronger signal while the existing signal is reducing in strength. While in the roaming mode, the mobile SA selects the next best AP from a list of neighboring APs, at least one of which will have a signal level above the SA joining threshold. This roaming logic ensures robust and seamless handovers in omni-directional cell-based topologies where the SA can move in any direction and where there is more than one AP to roam to.

Omni-directional antenna topologies

Mobile wireless environments utilizing omni-directional antennas that provide AP coverage based on a pre-determined path, such as a road or rail track, create a more predictable roaming pattern based on direction and speed. This type of linear roaming moderates the need for a multi-destination, election-based AP selection process; if properly designed, only one AP should qualify as the next best AP to roam to.

An omni-directional wireless RF coverage profile will present a gradual increase in signal strength as the SA approaches each AP. There is a slight dip in signal strength while the SA is adjacent to the AP, followed by a gradual decrease in signal strength as the SA moves away. This result is based on the notion that when using an omni-directional antenna, the SA can “see” in all directions – a full 360 degrees.

Conventional hysteresis (LOW-to-HIGH threshold roaming)

The conventional theory of operation for omni-directional roaming handover is for the mobile SA to ‘Roam LOW’ and ‘Join HIGH’ (see *Figure 7a*). This is based on the notion that as the mobile SA moves away from its currently associated AP, the signal level will gradually drop to below the SA’s roaming threshold. Here the SA enters into roaming mode.

While in roaming mode, the SA selects an AP from a list of neighboring APs and attempts to associate with the next AP that has a signal level at or above the joining threshold. The new AP will now have a stronger signal level than that of the previous AP; the SA continues in the specified direction until the roaming process is again triggered at the next AP-to-AP coverage boundary.

This type of operation is best suited to omni-directional wireless coverage designs where AP signal levels might vary between each of the APs. However, in the case of uniform wireless coverage, an attempt should be made to provide a signal of consistent strength between AP coverage areas.

Analogous hysteresis (EQUAL threshold roaming)

Analogous hysteresis implies equal roaming and joining thresholds (see *Figure 7b*). As the mobile SA moves further away from its currently associated AP, the signal falls below the SA’s roaming threshold and the SA enters the roaming mode. While in this mode, the SA selects the next best AP from a list of stored neighboring APs, each of which has a signal level above the SA’s joining threshold and equal to the existing AP’s signal level. In this case, the new AP has an equivalent to or stronger signal level than that of the old AP, and the SA continues in the specified direction until the roaming process is triggered again.

Fig. 6 Wireless coverage and roaming

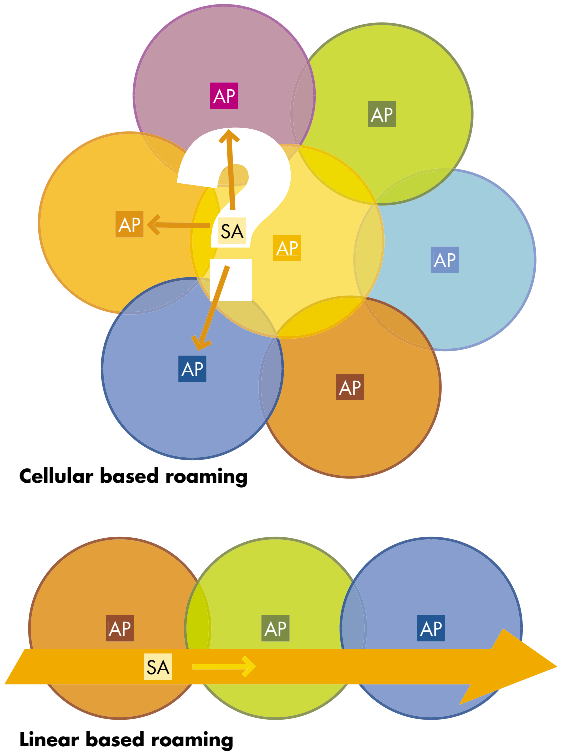
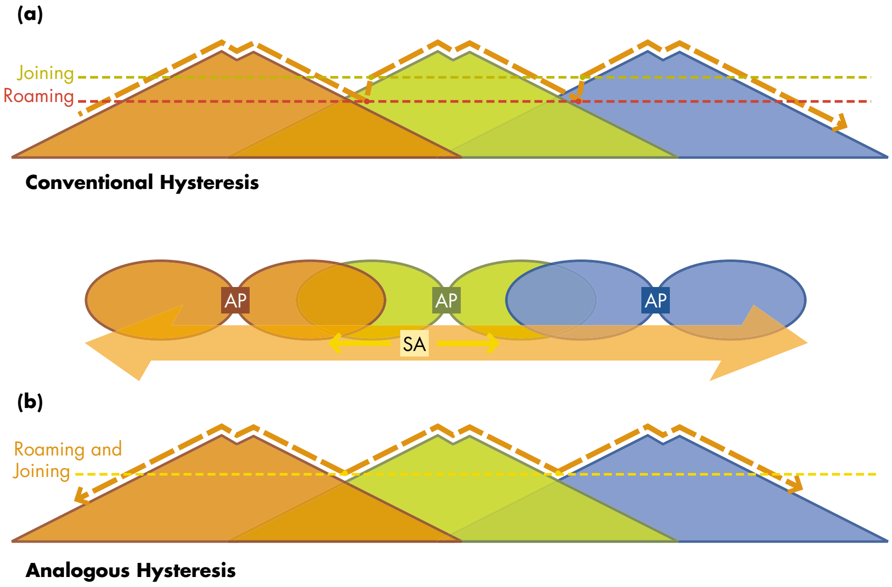


Fig. 7 Wireless roaming



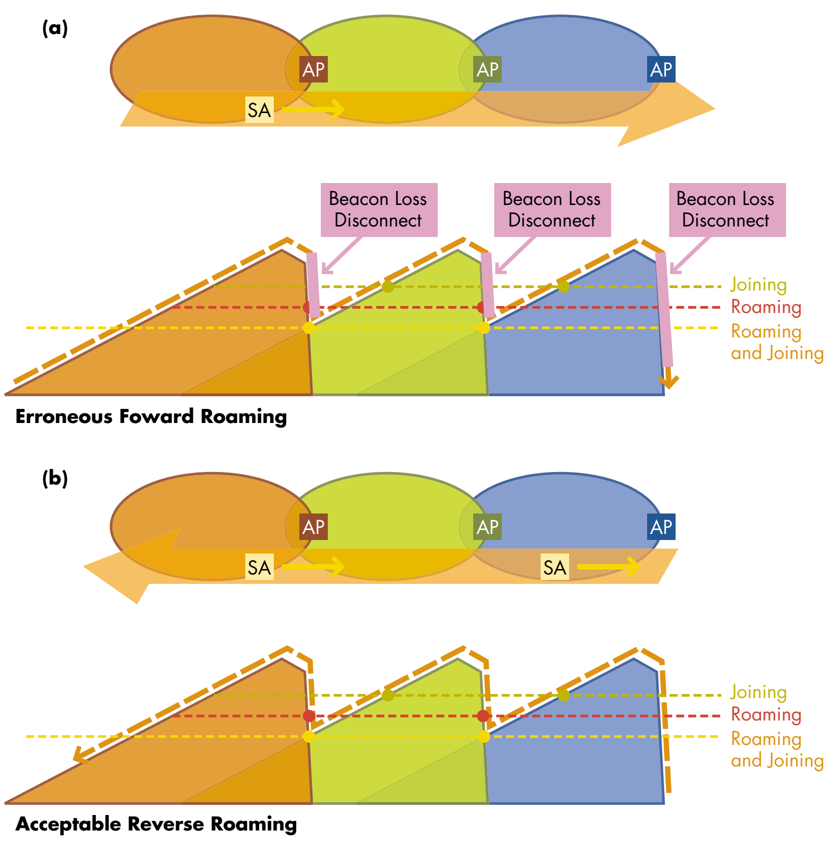


Fig. 8 Faulty roaming characteristics

This type of operation relies on a common roam/join signal level intersection between the AP coverage areas, and is therefore less tolerant of unbalanced wireless coverage designs. Consequently, measures must be taken to ensure uniform AP signal levels between each of the APs in order to support continual seamless handover.

Uni-directional antenna topologies

Reducing the number of APs required to provide wireless service for a specified distance requires the use of two uni-directional antennas (facing in opposite directions) per AP. These antennas are either narrow beam, high gain antennas that cover long sections of straight track, or are sectored antennas that are best suited for areas of curved track. The combination of two antennas per AP provides a wireless service to a specific area known as the coverage area.

Uni-directional antennas installed in a mobile environment where trains operate along a track introduce many challenges to wireless roaming. While the roaming pattern is still linear and predictable, based on direction and speed, the wireless RF coverage profile is dramatically different from an omni-directional signal profile. Although each AP will have two coverage lobes in opposite directions, a mobile SA with uni-directional antennas can only associate with the coverage lobe that it is facing.

Roaming takes on a whole new dimension in a railway environment; movement is not a mere possibility, but is a reality, and may occur at very high speeds. APs are positioned at specific intervals alongside the railway track. Trains are equipped with two SAs, one at each end. Each SA is equipped with uni-directional antennas for the following reasons:

- Directional antennas offer a much stronger signal in a single direction than omni-directional antennas.
- Directional antennas are suited to a linear path, such as a rail track.
- Omni-directional antennas are more susceptible to adjacent interference sources, especially in stations where there is a strong possibility that WiFi hotspots will be present.
- Directional antennas can be mounted inside trains and will not be damaged by train washing equipment.

The wireless coverage signal profile resulting from the use of uni-directional antennas imposes uncompromising challenges for the delivery of seamless roaming handover. Although directional antennas working with the SA onboard a moving vehicle dramatically extend the wireless “reach” between the SA and APs, they also result in rapid signal drop-off once the SA passes the associated AP.

The uni-directional wireless RF coverage profile is characterized by a gradual increase in signal strength as the SA approaches each AP, with a slight dip in signal strength while the SA is adjacent to the AP, followed by an acute drop-off in the signal immediately after the SA passes the AP. When using uni-directional antennas, the SA can only see in one direction – limited to the antenna’s spatial range (e.g. 90-120 degrees). SAs moving at high speeds don’t help this situation, as the signal will drop-off in less than half a second in the case of an SA moving at 130 km/h.

Since the SA can only associate with an AP within its antenna’s field, it is essential to properly overlay the

AP's coverage area to achieve a seamless roaming handover environment between the APs positioned along the predetermined path.

The application of either conventional or analogous hysteresis in uni-directional wireless environments results in a high probability of producing erratic and unreliable wireless behavior. Roaming in the forward direction, with respect to the orientation of the uni-directional antennas, may produce unreliable roaming handover conditions; the SA might hold it's association with the existing AP for too long then disconnect abruptly as the SA passes the AP (see *Figure 8a*). Such abrupt disconnects can result in a high probability of retransmission and packet loss.

With the SA configured to Roam LOW and Join HIGH, or to Roam/Join at an EQUAL threshold, the SA will be satisfied with the existing AP's connection and maintain its association with that AP until it passes and subsequently loses that AP's signal.

Roaming in the reverse direction, with respect to the orientation of the uni-directional antennas, presents a functionally stable roaming handover condition for both normal and analogous hysteresis. Movement in the backward direction allows the SA to observe a gradual degradation in the wireless signal strength and roam to the next AP when the appropriate threshold conditions are met (see *Figure 8b*).

However, when the mobile SA must support roaming operation in both the forward and backward directions, neither conventional nor analogous hysteresis is suitable.

Inverse hysteresis (HIGH-to-LOW threshold roaming)

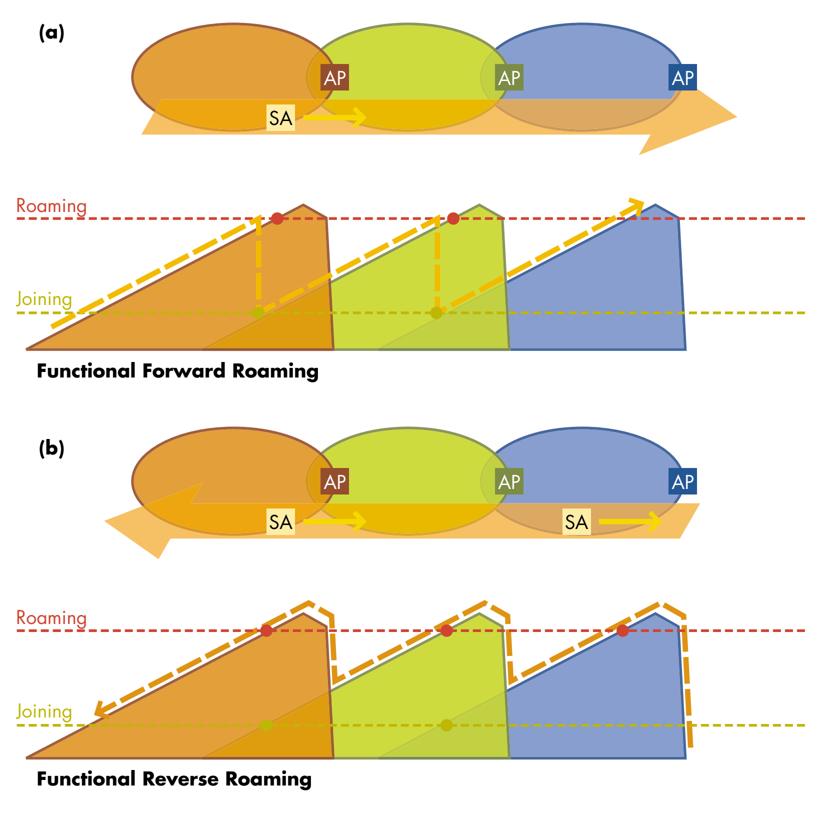
To overcome the challenges of two-way roaming operation imposed by uni-directional wireless roaming, a new theory of operation is recommended. This proposed alternative implies inversing the conventional hysteresis roaming logic by configuring the SA to Roam HIGH and Join LOW (see *Figure 9*). In this case, the SA will be in a constant state of pro-active roaming to ensure seamless roaming handover as the SA moves between AP coverage areas.

In a train control environment, mobility is a certainty with uninterrupted data communications across the wireless network being essential for continued operation. Pro-active roaming assures that the uni-directional mobile SA will roam to the next AP before losing the signal of the existing AP while traveling in either the forward or backward direction. Since the SA is continuously moving, the previous AP will probably not qualify for re-association after a short period of time as it's signal strength will either abruptly disappear or gradually fall below the joining threshold.

Setting the SA roaming threshold parameter to a high value will ensure that the SA is never satisfied with the current signal level. Consequently it will always be in a roaming state in which it will examine the table of neighboring APs and attempt to select the most suitable one. Setting the joining threshold parameter to a low value allows the SA to associate with the next AP at a lower signal level, knowing that the next AP's signal will continue to improve. As the SA approaches the next AP's coverage area, the signal strength of that AP will increase to above the roaming threshold and the SA will associate itself with the next AP. This demonstrates proactive scanning and roaming along the pre-determined path in a seamless fashion.

When moving in the forward direction, the SA will associate with the next downstream AP, even though it has a lower signal, before abruptly losing the existing AP's signal as the SA passes that AP.

Fig. 9 Seamless hand-over roaming with inverse hysteresis



Hong Kong CCTV Trial

The Hong Kong CCTV trial took place in two phases; the first included a site survey and installation, while the second involved optimizing the system and concluded with a successful customer demonstration.

The main objective of the CCTV trial was to use wireless radio technology to provide smooth streaming IPvideo transmission from moving trains. The customer expectation was to witness IPvideo streaming with a quality of no less than 4 frames per second (fps) with the train traveling at speeds in excess of 120 km/h.

The site of the trial was the existing Airport Express tunnel located under Victoria Bay between the Kowloon and Hong Kong subway stations. The signal coverage survey led to the installation of five APs over a distance of approximately 1.5 km.

Phase One

Fiber optic cabling was used to connect the five APs to an Ethernet network switch at Kowloon station. The IPvideo feed was to be transmitted from the SA on the train to the APs as the train moved through the tunnel beginning at the Hong Kong station. The IPvideo feed would then reach the centralized network switch at Kowloon station. A laptop connected to the switch would record the video feed.

Noise and interference measurements were low and meant that the noise floor settings in the radios did not require modification. Several signal measurements were made during the first phase and were later used during simulation testing.

Simulation Testing

Simulation testing in the Toronto lab took place between the two phases of the trial. The objective was to determine how to perform seamless radio roaming, ensuring smooth video streaming without data loss. Simulation equipment included a roaming simulator, AP and SA, cameras and a digital video recorder. The roaming simulator was configured with signal level profiles as measured on site and proved invaluable in configuring the radios.

Simulation testing revealed that it can take up to two seconds for an SA to disconnect and re-associate with a new AP when using the site data representing sawtooth signal coverage. As the SA on the train passes the AP to which it is currently connected, it no longer receives beacons from that AP. The SA is configured to disconnect from an AP if it receives 15 beacon losses. The APs were also configured to send a beacon every 32 ms. The beacon loss disconnect process therefore takes 15 x 32ms = 480 ms. The mobile unit can then take a further one and a half seconds to associate with the next AP. The resulting two second communication gap could extend to over three seconds if additional latencies are experienced in the network, resulting in train stoppages.

It was found that optimizing the radio settings could reduce these gaps but not eliminate them. Since the decision to roam comes from the SA, the roaming and joining values are only configured in the SA. Several alterations to these settings were considered, but during simulation the idea of reversing the roaming logic of the SA by inverting the roaming and joining values (inverse hysteresis) was introduced; inverting these values resulted in continuous video streaming.

Phase Two

After a few unsuccessful attempts using conventional hysteresis, the concept of inverse hysteresis was applied to the radios used in the Hong Kong trial. A train carrying passengers was equipped with two cameras, both of which were connected to a digital video recorder; in turn the recorder was connected to the SA. The final configuration was such that the video signal from both cameras was set to transmit at 15 fps. After some minor tweaking, successful results began to appear; smooth streaming IPvideo was transmitted from the train to the track-side network and back to the station where it was recorded on the laptop.

Phase two concluded with a successful demonstration to the customer, who is very pleased with the results.

Radio Network commissioning in Las Vegas

The concept of inverse hysteresis was also applied to the radio network in Las Vegas during the commissioning phase of the communication system. Since the Las Vegas Monorail site is above ground, there was the additional challenge of interference. A site survey resulted in the detection of WiFi interference levels as high as –50 dB in one of the DSSS 22 MHz channels, with the future possibility that all channels would become occupied.

In order to mitigate against this interference, the noise floor of the radios was set to –60 dB; the carrier sense level was set to –49 dB, providing an 11 dB carrier sense differential, as required by the radio. FHSS requires an 18 dB signal-to-noise ratio, which means the signal coverage for the entire system had to be above –35 dB. Further testing in Las Vegas later revealed that the FHSS radio operated nearly flawlessly where APs are spaced in such a way that the signal level coverage was at least –35 dB. Operating above this threshold resulted in less than 10% retransmissions, whereas operating below this level resulted in retransmission rates as high as 75%. Ensuring a minimal signal coverage of –35 dB and configuring the SA to operate between –25 dB and –35 dB has resulted in continuous communication between the control center and the trains operating over the wireless link.

In the reverse direction, the SA will join the next AP with an equal to better signal. Because the SA is moving towards the next AP, its signal will improve very quickly and then slowly weaken, while the signal of the existing AP will gradually degrade down into interference levels.

In either direction, since the SA is continually moving, the previous AP will not qualify for re-association after a very short period of time as its signal strength will either abruptly disappear or gradually fall below the joining threshold.

Implementing inverse hysteresis with a joining threshold set to at least 15 dBm above the highest level of interference, and setting a roaming threshold above the joining threshold, assures pro-active roaming and seamless handover with effective throughput throughout the wireless coverage area.

For both forward and backward operations, the Roam HIGH and Join LOW ‘inverse hysteresis’ roaming method has been proven to provide a very stable and effective wireless communication environment with seamless roaming handover, including minimal beacon loss, few retransmissions and insignificant packet loss.

Conclusion

The use of open standard wired and wireless network technologies provides numerous benefits ranging from the use of universally accepted protocols (Ethernet and IP) to the use of a well developed architecture and documented standards. It is recognized that the use of an open standard data communication system offers a stable future migration path as any of its three distinct elements can be independently modified/upgraded as technology advances.

FHSS is more robust and better suited to a rail environment where roaming is a certainty and where noise and multipath interference are often present. FHSS radios are also more secure as they use frequency hopping and customized dwells.

CBTC, CCTV and the wireless environment in which they are deployed, each present unique challenges. However, as explained in the article, these can be readily overcome using the same equipment and methodology. It is evident that three major factors continue to contribute to the success of Alcatel’s DCS deployments, namely the performance of interference measurements, ensuring that roaming parameters are set well above interference levels, and establishing uniform signal coverage throughout the system.

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Abbreviations

AP	Access Point
AREMA	American Railway Engineering and Maintenance of Way Association
CBTC	Communication-Based Train Control
CCTV	Closed Circuit Television
DCS	Data Communication System
DSSS	Direct Sequence Spread Spectrum
FHSS	Frequency Hopping Spread Spectrum
fps	frames per second
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISD	Integration and Services Division
MAC	Medium Access Control
NEMA	National Electrical Manufacturers Association
RF	Radio Frequency
SA	Station Adapter
TSD	Transport Solutions Division