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# High Availability Train To Wayside Communication System For Subway Application Using 802.11X

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**Abstract:** Wireless transmission for train to wayside communication is now a reality, including for the train control application.

However subway applications entail specific constraints, such as environment, high speed mobility, need for a rugged data communication system with very high availability of the links and specific requirements in terms of quality. In addition, the operation of such system requires more throughputs for offering additional new services such as video or other data communication for other sub-systems. Finally, the life of the system shall be at least of 30 years.

The challenge is to design a whole system and an architecture integrating products from the 802.11 family (WiFi). These products should be available on the market and they still have to meet all the requirements mentioned above.

The present approach focuses on modularity, redundancy architecture and control of the link budget. Dedicated optimized algorithms address mobility features.

**Keywords:** Communication Based Train Control, WiFi

## 1. Introduction

In advanced automatic train control systems such as Communications-based Train Control (CBTC), the safety of train movements, including collision avoidance, no longer relies on the detection of the occupancy of track circuits, but rather on the onboard computer's knowledge of the track layout, of the location and of the relative speed of trains.

Indeed, a CBTC system relies on the three following features:

- High-resolution train location determination, independent of track circuits;
- Continuous, high-capacity, bi-directional track-to-train data communication;
- Onboard and wayside processors performing vital functions.

A reliable bi-directional transmission system offering high availability is therefore essential for achieving CBTC performances.

The information exchanged between wayside and onboard equipment is of various types:

- Track layout information is sent to the onboard equipment. This information includes fixed data describing the geographical features of the track and varying data such as the occupancy status of the track circuits ahead of the train, position of switches, speed limits etc.
- Necessary information for computation of the "Movement Authority Limit" such as position and speed of the trains on the track and stopping points. The refreshment rate is rather high in order to meet the safety requirements and the headway requirements.
- Remote control and monitoring data exchanged between the onboard equipment and the OCC (Operations Control Center) to support operation and maintenance.
- Critical information for driverless train operation, sent to the CBTC to execute safety functions such as authorizing train departure from stations, passenger transfer at the station and train evacuation management in case of failures, functions normally performed by the human driver.

Since the early Automatic Train Control (ATC) systems, there has been a constant trend to transfer intelligence from wayside systems to onboard systems, putting even more emphasis on the data transmission system.

In the very first generation of ATC systems, there was no need for data transmission as the safety of train movement was ensured by the train driver himself through compliance with line-side signals. The location of trains was detected by wayside equipment. The second generation of ATC systems relied on minimal track-to-train transmission. Speed codes were calculated by the wayside equipment and transmitted to the onboard equipment. An alternative design was for onboard equipment to

read speed profiles inscribed in the transmission lines installed in the track. In the latest generation, track-to-train transmission is more sophisticated. Information about track circuit states is transmitted from the wayside to the onboard equipment. Then, the onboard control unit estimates its own speed curve.

In the CBTC generation, continuous and bi-directional transmission is fundamental. The train estimates its own location and speed which is sent to the wayside equipment. The wayside equipment then transmits to each single train its target point. The first CBTC relied on data communication systems based on transmission lines installed in the track. Advances in free-propagation radio technology, particularly in the military field, provided the opportunity for significant progress in the transportation field.

## **2. High Availability needs**

As said above, ATC needs a continuous transmission of data, in time and in space to achieve safe operation and meet system performance requirements.

-In time by guarantying that the data communication is uninterrupted and current. In case of lack of communication between train controllers and wayside equipment, all trains of the area shall be stopped to preclude any safety hazard, which makes a great loss of system availability.

-In space by guarantying good communication coverage between train controllers and wayside equipment over the entire line. A train can potentially stop anywhere along the line. Safe operation cannot rely on an approximation, but on the precise position of each train, especially with very short vehicle headway,

The CBTC has been developed for guarantying the high safety level and the high performance required in terms of headway and system availability. To avoid any weak point on the system architecture, the data communication system shall be very reliable using proven transmission technology. The main goal is not to maximize the throughput but rather to optimize a given channel for very low packets losses and guarantied data transmission.

Another aspect of the availability is to offer, for each message, latency small enough to meet message refresh rate requirements.

These types of requirements might appear in contradiction with the use of a radio channel, as the radio propagation is a probabilistic phenomenon.

As it is now well documented, in railway environments, in tunnels, due to reflections and diffractions on the environment (wall, floor, obstacles...) free propagation of radio air create multipaths between the transmitter and the receiver. Recombination of these paths on the receiver side is more likely to impact negatively on the level of the received signal. Mathematic models can help predict the mean level of the radio signal received. That prediction takes into account not only the transmitter and receiver position as well as the description of the environment. The impact of fading however can't be described more precisely than by using a probability law.

Radio propagation in the metro is highly variable, due to the train's motion and crowd movements in the stations... It's obvious that all the operational situations lead to various and unpredictable scenarios of propagation. In such condition it's almost impossible to define a precise model that can be verified by measure or computation.

In addition, to provide the continuity of the transmission services, we have to deal with the reliability of any piece of equipment. The availability of the system shall be preserved including with the -inevitable- breakdowns of the hardware used.

## **3. Other specifics constraints**

### **3.1 High speed and high speed mobility**

One advantage of wireless equipment is to be free of any physical link and therefore the mobility is drastically improved. But when mobility is used in this context, it's more or less a convenient way to get connectivity from one location to another; one can imagine someone in an office, moving from a place to another with his/her personal computer.

Such wireless equipment installed in a train will move at higher speed! Therefore impact of the velocity on the quality of the transmission has to be verified.

Moreover, the radio coverage of a wayside radio equipment is limited to a few hundred meters. Consequently a large part of the time is lost while the train radio is switching from a wayside radio to the next.

And, last but not least, since a train must be reached anywhere along the line, the routing process must be seamless. As the train is moving, the network routing has to be dynamically updated in accordance with the actual configuration of the network.

In summary WLAN are currently designed for a “nomad” use of wireless equipment. Nevertheless, thanks to dedicated configuration settings it is possible to achieve our application requirements and to have a reliable and fast mobile use.

### 3.2 Life duration of the system

A subway system is designed to be used during a very long time. The oldest subway networks are more than one hundred years old...

Of course it doesn't mean that each particular device has to be in operation during all this time. Hardware failures are inevitable. But it means that it must be possible to repair or to exchange a device when necessary. And when exchange becomes impossible because of hardware obsolescence, the function must be still fulfilled when the defective part is replaced.

This lifetime duration is clearly not the one of the WLAN technology.

Radio standards are still in a fast evolution phase. Since the first publication of the 802.11 standard in 1999, three amendments about the physical layer have been published or are to be published in the next months (802.11a/h, 802.11b, 802.11g, 802.11n). The data rate has been dramatically improved, and a new bandwidth has been allocated for the RLAN application. In addition some amendments about the protocol have been published.

### 3.3 High availability requirements

Every hardware device, even the most reliable can - and will- fail. The equipment reliability is characterized by its MTBF (Mean Time Between Failure). This figure is the result of the assessment based on tables giving the reliability of each individual component in several environmental conditions (temperature, vibrations...). These elementary figures are derived from the past experience.

The more devices are used in a transmission chain, the more often this chain should be interrupted by a failure.

If a function needs N equipments to be performed, the MTBF of the whole function will be (assuming that equipment failure are independent) :

$$1/MTBF=1/MTBF_1+1/MTBF_2+...+1/MTBF_N \quad [1]$$

For the data communication system of the subway, a failure in a single train or in a single wayside radio, even for a few minutes, has often operational consequences for all the line, and for a long time.

The system architecture must thus guarantee that a single failure won't have any functional consequences.

## 4. The answers to these constraints

Regarding all of these constraints, the choice of the radio technology for providing an answer to the point to point link is important but not sufficient in itself to comply with all requirements.

### 4.1 Individual physical link

Even if the propagation condition can't be totally controlled, the knowledge of the typical parameters to be taken into account allows to take the right level of margin in the transmission in order to guaranty a very high rate of successful transmission.

These parameters include:

- the different environments of propagation (tunnel or outside tracks) governing the attenuation laws,
- the specific influence of the curves in tunnels,
- the fading repartition, depending on the bandwidth used,
- the influence of the location of the other trains, including when they are “blocking” the tunnel.

The figure below shows the typical level of received signal by 2 onboard radios installed at both ends of the train, while the train is moving from one side of the wayside radio to the other.

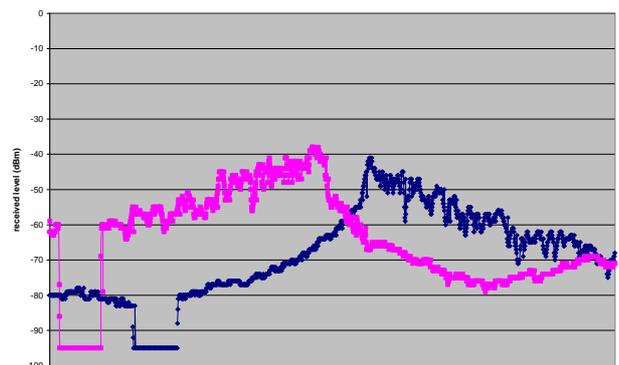


Figure 1 : Received signal level by a radio at each end of a train

In addition, the behaviour of the different type of modulations may have an impact on the propagation conditions (speed, multipath pattern in tunnel...). Therefore introducing a new type of modulation requires some verification.

## 4.2 Seamless handover and roaming

In order to optimize the radio coverage, one WLAN client is used at each end of the train. Only one is transmitting at any given moment. The transmitting WLAN client is qualified as Active. The other WLAN Client exchanges management frames with Access Points along the track, in the frame of the “Association Process”, but is not used for communication purposes.

The Trainborne Router controls this diversity, and Wayside Routers have to update the Wayside Network routes accordingly.

The Active WLAN client is the one who has the higher RF signal quality. This signal quality is quantified by the RSSI obtained through SNMP (Simple Network Management Protocol) periodic requests (for instance every 300ms). The RSSI based routing algorithm handles as follows:

- The Trainborne Router sends SNMP periodic requests to both WLAN Clients.
- The Trainborne Router chooses as the Active WLAN the one that has the best RSSI.
- In order to deal with RF fading and avoid unnecessary route changes, it is possible to take into account several successive RSSI reports and to apply an algorithm (e.g. hysteresis law) before making the decision to switch from an active WLAN client to the other .

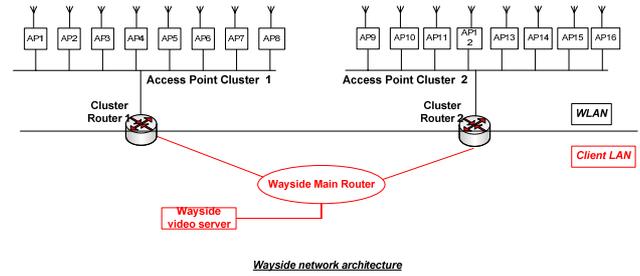
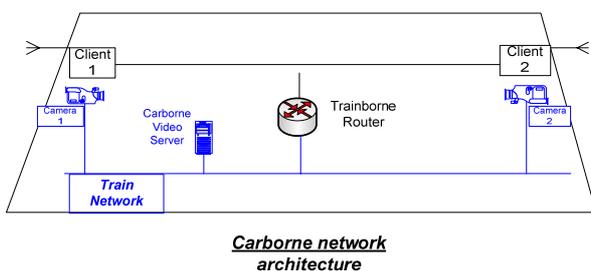


Figure 2: Carborne and wayside architecture for a seamless handover and roaming

This client diversity provides several benefits:

- The transmission loss of one client during its roaming from one Access point to another has no impact on the Network performance since another Active client is typically used at this time. One can say that there is an overlap on the assigning process.
- The radio coverage is significantly improved so the distance between the Access Points on the line can be increased.
- Due to clearance issues in Mass Transit tunnels, it is typically impossible to fit an antenna above the train roof for increasing the radio coverage. The antennas are installed at each end of the train. The client diversity is a good design solution to address this issue.

## 4.3 Redundancy

To answer to the high availability requirement, each hardware device has to be doubled, but it is not enough. The redundancy question is to determine how both redundant equipments will work together. A simple solution is to have two independent chains side by side. One is used at a time, and if a failure is detected, traffic is switched on the other chain. But this doesn't provide a correct answer to our problem because failure detection time and reconfiguration process will last too long time to be considered as fully transparent.

To achieve the redundancy switching in a full transparent mode, the redundancy architecture principle has to be tolerant to a single failure. Our preferred solution is to provide 2 independent chains transmitting in parallel two copies of each message (at least for the CBTC traffic which communication availability is a must, video and voice application require lower availability).

## 4.5 Built in test equipment

The redundant architecture allows being tolerant to a single failure. The probability of a second failure at the same place, before the first one has been fixed, is assumed to be very low, so the MTBFF (mean time between functional failure) is high, and the availability figure specified can be reached

But this assumption is correct only if the first failure is detected in order to be fixed. As this failure has no functional consequence, it had to be done by a specific function of supervision and alarm. This function has to be precise enough to allow efficient corrective maintenance. As the hardware equipments (especially the radio) are distributed all along a subway line, and in order to be efficient, that function determines exactly the location of the broken-down equipment. Thus, the time to fix the failure is optimized and the time to repair goals might be adjusted accordingly.

But this type of built-in test equipment is quite specific and doesn't exist natively in the products.

## 5. Conditions for a controlled evolution

### 5.1 Architecture modularity

To manage obsolescence of some part of the system, and benefit from the constant evolutions of the radio technology, it is necessary:

- ⇒ To define elementary functional blocs with standardized interfaces. It must be possible to change the way to implement a functional bloc without changing its interfaces, in order to allow independent evolutions of the blocs. This evolution can be done with the same performances or with enhancement of performances (for example, for the radio link : higher throughput...) In that case, the other blocs of the chain must be well dimensioned to be able to draw part of this enhancement (typically, if the radio link throughput is increased, the wired link at both side must also support higher throughput...)
- ⇒ To determine precisely which features and performances are completely described in the standards: they should be met in every implementation. Other characteristics should vary from one supplier to another.

- ⇒ To be able to add or remove some wayside radio without modifying everything.

### 5.2 Test plan

Since off the shelf devices are used and evolve frequently, it's important to determine a comprehensive test plan to be sure that all the functions of the whole system are still meet the requested performances

## 6. How WIFI radio can be used?

The various criteria listed here-below can be checked:

-Is radio technology suited for a transmission with trains (regarding multipaths, speed ...)? It has been tested and the results have been found suitable up to the 802.11g family. The 802.11n seems to bring also new and very interesting features.

-Are interfaces well defined by standards in order to get more flexibility in the choice of supplier? The answer is yes, as the WiFi alliance goal is to assure the interoperability between suppliers. On the other end, the use of specific feature not governed by standards shall be done knowingly and always after deep analysis

- Are performances clearly guaranteed in all cases? What are the impacts on the other parameters, as implementation might have influence, for example, on the sensibility of the receiver, or the time it takes to perform the association... Comprehensive tests have to be carried out, and some parameters of the system have to be adjusted.

-Is there a stable and well defined functional breakdown? Yes and no. Functions are well described in the standard, but the different amendments have progressively added new functions. Typically some "quality of service" functions have been introduced in the standard by the 802.11e. It's possible that the future 802.11r amendment will solve the seamless handover and roaming question...

## 7. Conclusion

As a conclusion, we would like to point out the fact that building a radio communication system with the specific constraints of the train to wayside subway application is much more than to choose a radio

technology well suited for propagation in tunnels. Since radio technology is quickly evolving, it might be interesting to draw part of these evolutions by upgrading only some components without having to replace the whole communication system. For that, two necessary conditions are highlighted:

- The modularity of the architecture of the system, with a clear function breakdown of the system, using standardized interfaces between elementary functions,
- The definition of a comprehensive non regression plan to be able to assess the impact of the change of one piece of the puzzle on the overall performances required at the system level.

## **8. Acknowledgement**

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## **9. References**

## **10. Glossary**

*AP* : Access point  
*ATC* : Automatic Train Control  
*CBTC*: Communication Based Train Control  
*IP* ; Internet Protocol  
*MTBF* : mean time between failure  
*MTBFF* : mean time between functional failure  
*WLAN* : Wireless Local Area Network