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# CBTC VENDORS EVALUATION TECHNICAL REPORT

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# Introduction

A CBTC system is a continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits. According to the IEEE 1474.1 2004 standard, a CBTC system provides:

- continuous, high-capacity, bidirectional train-to-wayside data communications;
- train-borne and wayside processors capable of implementing automatic train protection (ATP) functions, as well as optional automatic train operation (ATO) and automatic train supervision (ATS) functions.

This document presents the available implementations of the CBTC system, as provided by the main vendors operating in the CBTC market, namely Alstom, Ansaldo STS, Bombardier, Thales, Invensys and Siemens.

The evaluation of each vendor is given according to the following aspects:

- **Operating Mode Management:** defines how the CBTC system behaves in different operating modes. The current operating mode of the CBTC system depends on the wayside equipment and on the on-board equipment. Contents related to this topic involve problems of transition from a CBTC equipped region to a non-CBTC equipped region and movements of non-CBTC trains in a CBTC region;
- **Safety and Failure Management:** this topic is ortogonal to the other topics and shall be traeated in relation with them. However, the focus here is in the identification of the vital functions and of the safety-related aspects of each topic;
- **System Architecture:** provides examples of reference architectures and implemented architectures;
- **Communication Infrastructure and Protocol:** provides examples of communication infrastructure and adopted protocols for wayside-onboard and onboard-wayside communication;
- **Interlocking and Wayside Information Integration:** defines how th e CBTC system is integrated with the interlockings at the stations. Involves also other wayside-related information such as broken rail detection, work-zone protection, grade crossing, etc.;
- **ATS Functions:** involves all those functions related to the train supervision;
- **Headways:** provide standard constraints for headways, and involves also end-of-track protection;
- **Braking Models and Speed Limit Protection:** involves also the zero speed detection criterion, the parted consist protection and the rollback control;
- **Train Speed and Train Location Determination:** involves all those functions related to the measurement of the train location and speed. This topic involves also the issues related to Cold Start-up. When the system is started again after a total system power-down, the CBTC Wayside System is unaware of the position of the trains. In earlier CBTC systems it was often necessary to have drivers board the trains and drive them manually to the next station in order for the CBTC system to ‘acquire’ the position of the trains in a safe way.
- **Door Management:** involves the functions related to door control;
- **ATO Functions:** involves all those functions related to the automatic train operation, such as, e.g., precision stopping (the accuracy of the train stopping position) ;

- **Service-Oriented Facilities:** involves all those functions related to the user services, such as passenger information displays, CCTV, public announcement and such.

At the end of the document we provide a summary table of the characteristics of each vendor.
Moreover, a table is presented that compares the implementations provided by the vendors with the Standard IEEE 1474.1-2004 requirements.

# BOMBARDIER

## *Introduction*

Bombardier Transportation has invested significant efforts in streamlining the products, technologies and capability; and has structured its signaling solutions in the most comprehensive, cohesive and upgradeable product lines. The products have been organized into two main classes: **Bombardier INTERFLO** for mainline solutions and **Bombardier CITYFLO** for urban needs.

The **INTERFLO** system offers complete **mainline solutions** individually tailored to the customer's need, encompassing integrated operations control systems and computerized interlocking systems, as well as automatic train protection and wayside equipment.

The **CITYFLO** system provides complete **urban railway solutions** for all types of mass transit such as trams, light rail vehicles and metros to suit various operating modes and customer's need. These include cab signalling, semi-automatic train operation, driverless and unattended train operation. The systems can be expanded to the customer's growing requirements and thus meet the operational demands for the entire life of the system.

The various solutions and applications are summarized below.

| | |
|---|---|
| INTERFLO 50 | GPS-based train location and information system |
| INTERFLO 100 | Conventional regional line system |
| INTERFLO 150 | Radio-based regional / industrial line, including ERTMS based system |
| INTERFLO 200 | Conventional main line system |
| INTERFLO 250 | ERTMS Level 1 e.g. Taiwan ATP contract |
| INTERFLO 350 | Continuous track based communication system |
| INTERFLO 450 | ERTMS Level 2 |

| | |
|---|---|
| CITYFLO 150 | Manual tram/LRV control system and onboard |
| CITYFLO 250 | Cab signalled mass transit system, non CBTC, fixed block |
| CITYFLO 350 | STO metro system, non CBTC, fixed block |
| CITYFLO 450 | STO CBTC, moving block |
| CITYFLO 550 | Automated (DTO/UTO) system, non CBTC, fixed block |
| CITYFLO 650 | Automated (DTO/UTO) CBTC moving block system |

The only CBTC systems provided by Bombardier are *CITYFLO 450* and *CITIYFLO 650*.

CITYFLO 650 supports driverless and unattended operation, while the previous version of the system, CITYFLO 450, does not provide these functionalities.

**CITYFLO 650** is now **operational in thirteen locations** around the globe, summarized in the table below. As highlighted in the table, the Madrid Metro Line 1 and 6 is the longest track (46,8 Km) where the system has been installed.

| **Customer Line** | **Type of Service** | **Operation** | **New Resignal** | **Award Year** | **Length Km** |
|---|---|---|---|---|---|
| San Francisco Airport | APM[1] | UTO | New | 1999 | 9.6 |
| Seattle Airport | APM | UTO | New | 1999 | 2.7 |
| Dallas/ Fort Worth Airport | APM | UTO | New | 2000 | 8 |
| Philadelphia SEPTA | LRT[2] | STO | Resignal | 2000 | 8 |
| Taipei Neihu Line | Metro | UTO | Resignal | 2003 | 25 |
| **Madrid Line 1&6** | **Metro** | **STO** | **Resignal** | **2004** | **46,8** |
| London Heathrow APM | APM | UTO | New | 2004 | 1.0 |
| Yong In | APM | UTO | New | 2004 | 18.0 |
| | | | | | |

In general, Bombardier provides a more complete documentation concerning CBTC installations and implemented system functionalities compared to the other vendors.

## *Operating mode management*

The CITYFLO 650 solution is a Communication-Based Train Control (CBTC) system that does not require track circuits or an onboard operator, making it an ideal choice for **new (green field) installations**.

CITYFLO 650 can also be used as an **overlay train control system** to upgrade existing fixed block (brown field) systems. It can be made to support mixed-mode operation and the graceful upgrade and expansion of any metro as the wayside and vehicle equipment are systematically upgraded through a retrofit program, eventually yielding improved transport capacity, permitting higher speeds and greater regularity, reliability and utilization of the rolling stock assets.

The management of transition areas in overlay installations is not detailed in the current documentation. This is possibly due to the strict dependency of the approach from the existing system configuration. Indeed, the approach will be different, if the new CBTC system has to interact with, e.g., a continuous signalling system or a discontinuous one and *ad hoc* solutions are expected.

Furthermore, no information is provided concerning degraded modes (e.g., ATO system failures) , or lower degrees of automation (e.g., ATP system with a driver) , which we expect, however, to be supported. In this case, we expect the approach not to be dependent from the previously existing system, though some dependency would be required if degraded modes are supported by the existing system.

1 APM = Automatic People Mover
2 LRT = Light Railway Transit

## *Safety and failure management*

**Backup system**

Bombardier proposes a **full secondary signalling system using the conventional track circuits**, interlockings and wayside signals. The solution is based on the Bombardier EBI Lock 950 Computer Based Interlocking (CBI) and TI21 jointless track circuits.
Should the CITYFLO system fail, the affected trains will still be able to operate using the movement authority generated by the EBI Lock 950 interlocking and conveyed by means of the wayside signals. For this back-up mode, it is possible to choose longer track sections in order to reduce the number of track circuits. Therefore the headway in fall-back mode will obviously be much higher than with the CBTC system [7].

**The Train Registry System**

One of the **drawbacks** of CBTC systems is at **'cold' start-up**. When the system is started again after a total system power-down, the CBTC Wayside System is unaware of the position of the trains. In earlier CBTC systems it was often necessary to have drivers board the trains and drive them manually to the next station in order for the CBTC system to 'acquire' the position of the trains in a safe way.

The CITYFLO 450/650 systems offer the **Train Registry System (TRS)** feature, which registers the identity of the trains as they pass in and out of the regions independent of the regions.
In case of a 'cold' start or after a brief communication failure, the TRS system will provide the train IDs for each region to the CBTC Wayside System so that the communication can be re-established instantly thus making any start-up a matter of minutes [7].

**Train Occupancy in *CITYFLO* 650**

In moving-block systems, train occupancy is generated by the train and sent back to the wayside control system. This train-generated occupancy is based upon the worst-case braking of the train.
The trainborne ATC is responsible for calculating the location and occupancy of the train. The trainborne ATC is programmed with the worst-case performance parameters of the propulsion and braking systems and uses these parameters to calculate the worst-case stoppoing distance.
The trainborne ATC generates the train's occupancy using the worst-case stopping distance and transmits this "virtual occupancy" to the wayside ATC.

During each task cycle, the **emergency braking distance** is calculated for a final speed of zero utilizing the emergency braking rate.

The **service braking distance** is the braking distance that is applied when coming to a normal stop utilizing the service braking rate. The service braking calculation is based on ride comfort and is therefore a jerk-limited, acceleration-bounded braking scheme. The service braking distance is calculated for the purpose of determining the distance required to allow the trainborne ATO to stop the train at a comfortable rate to prevent the trainborne ATP from having to initiate an emergency brake stop**[4].**

The information reported concerning the emergency and service braking are common to any railway system. No additional information is provided concerning the implementation of such functionalities.

## *System architecture*

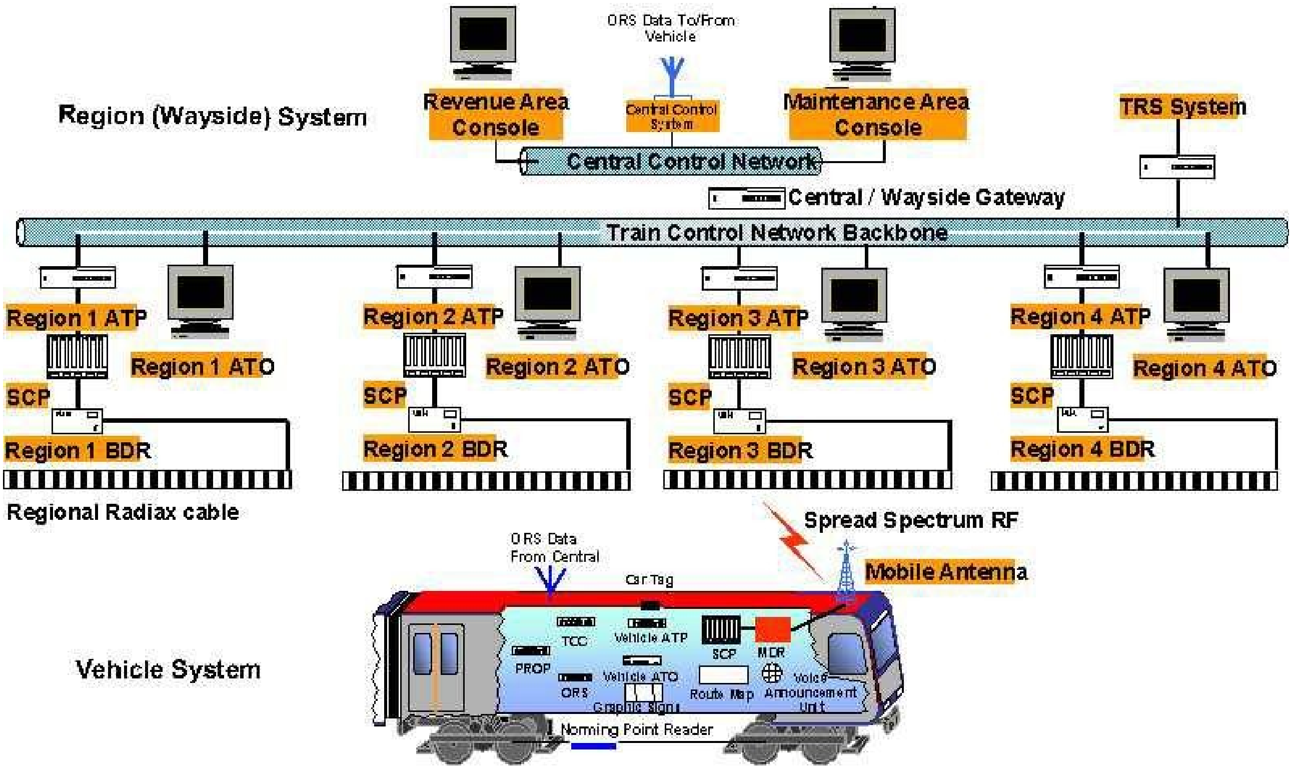


*Figure 1: Block Diagram of CBCT system*

Like most modern train control systems, the CITYFLO 650 ATC is divided into various sub-systems, based upon function and modular hardware and software. The Figure 1 illustrates the Train Control System Architecture for a typical metro installation.

With reference to Figure 1, the CITYFLO 650 is divided into the following distinct elements:

| | **Safety Level** | **Subsystem** |
|---|---|---|
| **ATS** | Non-vital | Central Control |
| **ATO** | Non-vital | Vehicle ATO/Region ATO |
| **ATP** | Vital | Vehicle ATP/Region ATP |
| **TWC**[3] | Non-vital | RF Infrastructure |

The wayside equipment is distributed along the line and divided into parts, called *Regions*. Each region is responsible for safe movement of trains within its boundary of control and safe handover of the trains to adjacent regions.
The size of each region depends on the length of the line controlled by it and the maximum number of trains that need to be handled within the region.

The regions contain the ATP and ATO parts of the CBTC system responsible for issuing Movement Authorities and communicating train positions to the Central Control System.

3 TWC = Train-wayside Communication

The Wayside System components are operationally redundant.

The ATS system is located in the Central Control System (CCS) , which has direct interface with the Central Operator.

The ATS system communicates with the different regional wayside systems through the Central Wayside Gateway. This is basically a port to access the Train Control Network Backbone, which is the communication backbone linked to both the regional systems (ATP and ATO) and the CCS.

As one can notice from Figure 1, there are two ways for the CCS to communicate with the train:

1. Through the link: Central/wayside Gateway → ATP → Serial Communication Processor → Base Data Radio (BDR)
2. Directly through the ORS data antenna

From the documentation it is not clear which kind of information is sent through link 1 and through link 2, respectively. We can expect that information processed by the ATP (link 1) is the vital information, while non-vital information is sent through link 2.

According to the documentation, the Region ATP is responsible for formatting all data to be transmitted to the trains. It receives information from the CCS through the Region ATO and transmits that data along with data of its own to the trains.

System status and control data associated with each Region ATO are processed and sent to the CCS where the current status of the system is displayed.

The Region ATO units are also operationally redundant with a Master and Standby unit. Each independent primary and backup ATO system operates in conjunction with the Region ATP primary and backup systems. Both the primary and backup Region ATO collect data from their own region, but only the primary system issues commands and requests [4].

## *Communication infrastructure and protocol*

Communication between the trains and wayside for train control is provided by the Train to Wayside Communications (TWC) subsystem. The TWC is a radio frequency (RF) subsystem that uses a Spread Spectrum Code Division Multiple Access (CDMA) modulation technique at 2.4 Ghz.

**The RF communication uses either a leaky coaxial cable or Line of Sight (LOS) antenna network along the wayside that transmits data to the trains via their onboard mobile antennas**. The trains and regions communicate through the TWC “link” every COMM Cycle. The trainborne ATC continuously receives messages from the wayside ATC as long as the communication link is maintained. When a train loses communications, the wayside ATC creates a protection block around the lost-communication train and, at the same time, the trainborne ATC equipment applies the service brakes. Upon restoring the communication, the wayside ATC removes the blocks associated with losing communication with that train.
The TWC not only supports the transfer of train control data between trains and wayside but also supports the two-way transfer of ATP/ATO maintenance data between the trains and the Centralized

Maintenance Office.

The radio connection is achieved through the use of base data radios (BDRs) and mobile data radios (MDRs) . These spread spectrum radios have been designed to meet the unique demands of CBTC systems. The BDR and MDR operate at 2.4-GHz to 2.4835-GHz. This can also be adapted to suit specific requirements or standards associated with non-licensed low power transmission in the 2.4GHz or higher frequency bands per the national legislation adopted within the ITU recommendations.

The TWC equipment includes the Radiax, BDR, Distribution Amplifiers (not shown on the overview in Figure 1) , Mobile Antennas (on board the trains) , and the MDR (Mobile Data Radio on board the trains) . Data is transferred through the MDR to and from the Vehicle ATP (VAT P) .

Note that “Line of Sight” antennae can be used instead of the Radiax to provide RF distribution. The decision to use one system or the other is determined during the design process based on the application and specific site/customer requirements.

When the company designed this early version of the system, the preferred **onboard communication device** was the Mobile Data Radio developed *ad hoc* by the Andrew company. Taipei underground is currently using this solution.
Afterwards, for cost reasons, the company has chosen to move to the commercial off-the-shelf radio provided by Safetran, named **Safetran S3 Link** [5].

The train has also an internal communication network, which uses the IEEE-1473 protocol [2].

## *Interlocking and wayside information integration*

The CITYFLO 650 built-in interlocking function is located with the regional wayside ATP.

The CITYFLO 650 solution can either use the built-in interlocking function or add optional EBILock computer-based interlocking for fall-back system capability or adherence to local norms.

It is not clear which is the channel that let the interlocking communicate with each other (i.e., if the communication is directly through the backbone or through the CCS) .

## *ATS functions*

In Bombardier system ATS functionalities are carried out through the EBI Screen Automatic Train Supervision.

The ATS system is the operator interface to the system and provides control centre functionalities such as [4]:

- Centralized Maintenance System, which uses TCP/IP connection with Ethernet for the remote uploading of configuration data;
- Transmission of ATP/ATO maintenance data, data logging, archival and report generation;

- Manual override requests (when the central operator substitutes the automatic system ATP or ATO) ;
- Train initialization;
- Management of fleet reductions and build-up (initiation and termination of service)
- Management of train schedules including dwell and headway control (with anti-bunching, which means achieving a proper distribution of trains)
- Management of route assignments for normal operations (train dispatch) and failure modes
- Train management (including train or fleet hold, skip station or station close)
- Remote set or reset of emergency brakes (assuming safety criteria are satisfied)
- Implementation of failure management strategies
- Other Central Control (CC) functions such as voice communication with the train and supervision
- Control of any power distribution system (the adopted system is called SCADA)

### *Headway*

CITYFLO 650 is capable of less than 75 second headway [9].
Metro Madrid: 101/111 seconds headway (avg. dwell + margin) [8].

### *Train speed and train location determination*

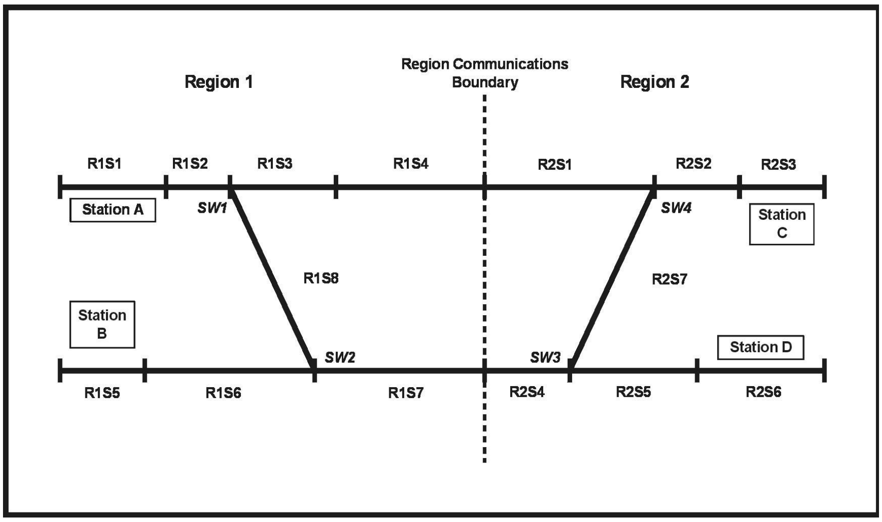


*Figure 2: How region and segments are used for train positioning*

In Communication-Based Train Control, Moving- Block systems, as well as in all “contactless” train control systems, there are no track circuits to provide information to the trains or occupancy from the trains. CITYFLO 650 models the tracks using the entity called a “CITYFLO Segment”, which is defined to be a section of track that is defined by a set of unique values in:

- Grade
- Speed
- Platform Location
- Switch Location
- Region Boundary
- End of Line
- Emergency Walkway Location
- Underlying Fixed Block Locations

Each segment has a name associated with it that includes its Region Number and Segment Number (within that Region) . The segment layout provides for the determination of location which is handled through what is called the "**Moving Block Coordinate System**" (MBCS) , which defines the location of a Region Number, Segment Number, and Offset into that segment.

For **example** (see Figure 2) suppose that a train was 25% through segment R1S4 which is, say, 100 m long, then the location of the train in MBCS is R1, S4, O25; for Region 1, Segment 4, and Offset 25.

**Norming Points**
A Norming Point is a **"Passive Tag" containing "Location Data"**. These tags are situated along the track and contain their own location data in the form of the MBCS.
When a train passes over a tag, the tag is "energized" by the RF energy from the train's tag reader antenna. The tag in turn transmits its location to the train. The tag location is used by the train for two important elements within its train control system:

1. Verification of the train's location
2. Normalizing the train's positioning error

As the train travels along its route it incurs a Norming Point. **The train reads the location information embedded within the Norming Point Tag and verifies the tag location with its calculated location.**

The second purpose for which **Norming Points are used is the "re-normalization" of the train's accrued position error**. As the train moves along its route, it continuously calculates its location using its onboard positioning system. This system is made up of tachometers that have an associated error. This error is accrued as the train continues its movement along its route. The Train Control System places a maximum on this position error accrual and the Norming Points are used to "reset" this positioning error to a minimum.

In the event of a faulty or missing norming point, the train just continues past that point without having "normalized" its error until the next norming point where the error is finally normalized. This usually does not have any influence on the operation or on the headway.

**Conflict Points**
A **Conflict Point is defined as the end of movement authority**, i.e. the location along the track beyond which is a train is not permitted.

The Region ATP uses these Conflict Points to properly and safely manage the movement of trains throughout the railway network. Typical Conflict Points include Rear of Train in Front, End of Line, A point not set or End of route for a particular train.

### *Braking models and speed limit protection*

The documents analyzed did not reveal any information on these topics.

### *Door management*

Door control requests are issued by the ATO system (both onboard and wayside) . We argue that such requests are processed also by the ATP system, since the opening/closing of the doors are vital functions. The ATO system allows **precision stopping by the train at stations with a typical accuracy of +/- 15 cm** [1].

### *ATO functions*

The EBI Cruise ATO system is responsible for the “non-safety” operation of the train control system within the CITYFLO 650. The ATO system also has both the region and train components - the Region ATO (RATO) and the train or Vehicle ATO (VATO) .

Each Region ATC has an independent ATO designated as Region ATO. The Region ATO performs all non-vital functions related to directing train movement and station operation. In support of these functions, the Region ATO is responsible for the generation of various non-vital train movement controls and commands for the respective elements located on the wayside such as:

- Ride Comfort Control, e.g. jerk limiting (controlled by the VATO)
- Stopping accuracy (VATO)
- Train operation according to commanded speed profile (acceleration and deceleration, including performance levels, e.g. coasting, energy saving, etc.) (VATO)
- Door Control Requests (RATO and VATO)
- Onboard triggers for audio announcements and dynamic displays (VATO)
- Wayside Passenger Announcement triggers to platform display systems (RATO)

### *Service-oriented facilities*

The CITYFLO 650 solution allows for integration of auxiliary systems such as:

- Passenger information displays (PIDs)
- CCTV (Closed Circuit TV)
- Public announcement (PA)
- Radio
- Telecoms

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## ALSTOM

### *Introduction*

Alstom has developed URBALIS Mass Transit System Control, which is a complete and flexible system for integrating a communication network System Based Train Control (CBTC) . Users benefit from a wide range of high performing functions needed to operate subways and suburban commuter trains profitably. URBALIS provides higher passenger throughput, better journey times, accurate station stopping and can deliver multimedia content onboard.
Main features:

- Driverless & Unattended operations;
- Optimized train speeds and line capacity to meet transport objectives;
- Guaranteed short lead-time delivery to achieve service date targets;
- Reliable operations from day one to ensure passenger satisfaction;
- Automated operations & easy maintenance to reduce operating costs [5].

Today, URBALIS is in revenue service in many countries, including Switzerland, Brazil, China and Singapore; this enables to cover major metro lines. In addition, URBALIS is a solution that Alstom will support for the next 30 years.


*Figure 3: Metros that have chosen Alstom CBTC*

The Alstom's driverless URBALIS system has been chosen by Lausanne Transport Authority to transform and extend its M2 line into a high performance "backbone" for public transport in the city. The Alstom solution of rubber-tired trains and advanced Automatic Train Control (ATC) are adapted to the line's specific geographical constraints: 12% slopes and tight 40-meter curves. Stations have platform screen doors and trains feature real-time video surveillance for a fully secure and supervised environment.
In 2008, the State of São Paulo selected Alstom to renovate lines 1, 2 & 3 of its metro with no

disruption to service. A sizeable challenge for the world's busiest metro lines. Alstom is installing its URBALIS CBTC as an upgradeable driverless-ready system to give operator CMSP (Companhia do Metropolitano de São Paulo) greater efficiency and transport capacity. Passenger service began in 2010 on the extension of line 2, and will continue with the other sections, for operations with platform screen doors on some stations and 3 fully automated depots. In a separate contract, Alstom is also modernizing the rolling stock.

Finally, Alstom has been chosen to supply the radio CBTC system to Singapore's Land Transit Authority (LTA) for its 20 km, 16-station North East Line and as part of a turnkey project for its 33 km, 29-station Circle Line. With these two lines, Singapore has a fully automatic metro. Thanks to URBALIS, the network meets operator LTA's high standards for availability, safety and service quality. For Circle Line, Alstom also provided rolling stock, track work, system engineering and integration in a turnkey contract.

## *Operating mode management*

Urbalis allows:

- fully automatic Unattended Train Operation (UTO) . It is possible to have UTO with customer service staff more station-based or with roving service staff often on-board train [1] [2];
- driverless Train Operation (DTO) with attendant.

Furthermore, Urbalis supports train operations in degraded mode and ensures protection of non-equipped trains through secondary detection devices (digital track circuits and LED Signal) [3].

## *Safety and failure management*

Urbalis includes:

- an ATC train system that applies, once a safety condition is no longer validated or respected, the emergency brake until the train comes to a complete stop [4];
- a maintenance support system (MSS) which allows to automatically notify maintenance team about the failure occurred [5];
- a special program to cut off the power supply to the track in case of an emergency that would require the evacuation of passengers, who would need to be able to walk on the line in total safety (Singapore Circle Line) [6].

## *System architecture*

Urbalis is built on three systems:

- Trackside System, with:
    - Automatic Train Control (ATC) functionality
    - Automatic Train Supervision (ATS) functionality (provided by ICONIS module)
    - Maintenance Support System (MSS)
    - Interlocking functionality (provided by SMARTLOCK module)
    - Passenger Information System (PIS)
    - Platform Screen Doors (PSD) functionality;

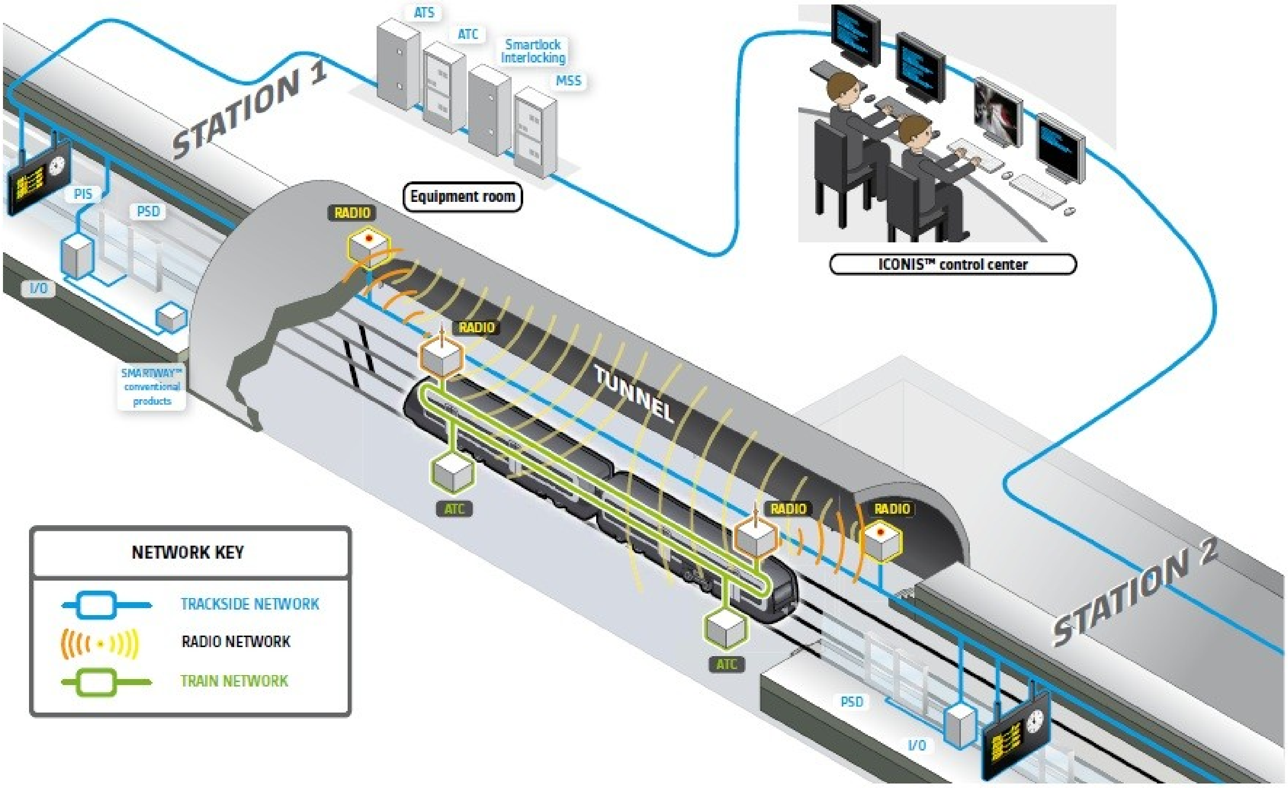


*Figura 1: Architecture of Urbalis*

- Data Communication (DCS) ;
- Train System, with:
  - Automatic Train Control (ATC) functionality
  - Passenger Information System (PIS) [5].

## *Communication infrastructure and protocol*

The three subsystems form three integrated networks compliant to international standards from IEEE (Institute of Electrical and Electronics Engineers) :

- Backbone (trackside) Network on SDH (Synchronous Digital Hierarchy) Multi service network;
- Radio Network on IEEE 802.11 g/a with OFDM carrier at 2.4 GHz or 5.8 GHz;
- Train Network on ETHERNET [7].

The interfaces are IEEE 802.3 and UDP/IP. Standard radios are used with a choice of propagation medium: Free Propagation, Leaky Feeder or Wave Guide (IAGO system) [8].
Each of the three networks is fully redundant.

## *Interlocking and wayside information integration*

The interlocking functions are provided by SMARTLOCK module [9]. Its main features are:

- provides a Computer-Based Interlocking system that implements the interlocking functions for the main line and depot and includes the ability to call routes and control switches;
- its modular architecture (centralised or decentralised) adapts to all types of networks, whatever their size, and can be applied to new installations or to renovate

existing installations;

- is compliant with CENELEC (European Committee for Electro-technical Standardization) , Euro-Interlocking and compatible with ERTMS (European Rail Traffic Management System) standards.

## *ATS functions*

The ATS functions are provided by an integrated control and information system (ICONIS control center). This system supervises all aspects of a network. It monitors entire urban arrangements, thereby giving operators the most reliable way to anticipate situations and enhance efficiency [7].

ICONIS can be scaled to network's size and complexity, and can integrate Supervisory Control and Data Acquisition (SCADA) , on board/in station passenger information (PIS) , security system and maintenance support system (MSS) [5].
The ATS functions provided are:

- supervision/sending commands to the signaling devices/trains;
- train runs tracking based on detection devices, primary (ATC) and secondary;
- identification of trains and their destination in accord with the hourly chart;
- automatism of Automatic Route Setting (ARS) for all trains in line, on the junctions and at the terminals;
- automatism of Automatic Traffic Regulation (ATR) in accord to the hourly chart;
- sending information to the PIS [10].

## *Headways*

Urbalis works with Moving Block principle to ensure train operating headways as short as 85 seconds, resulting in the highest possible line capacity [5].
Real headways obtained: 90 seconds (Singapore's North East Line (2003) ) , 120 seconds (Beijing's Line 2 (2008) ) , 90 seconds (Milano's Line 1 (2006) ) .

## *Braking models and speed limit protection*

The ATC train system continuously updates the ATC trackside system on the position of the train and receives a detailed description of the line and movement authorities [4][5]. Therefore, the ATC trackside system monitors train positions and controls a line section (up to 20 km long) based on Moving Block principle, with a zone controller. The two basic function provided by ATC trackside system are:

- locating the trains on the track and creating a protective zone around these trains;
- sending authorizations of movement to the trains. These authorizations must be established and transmitted safely in order to eliminate all risks of accident.

The ATC train system (ATP component) :

- controls the speed and position of the train;
- checks the condition of overspeeding;
- verifies the safety context of the train (doors closed outside of the passengers exchange zones) ;
- verifies the validity of the authorizations of movement for the train;
- ensures that the train is driven respecting the safety rules (verify that the train will be able to stop upstream from the security points) .

Once a safety condition is no longer validated or respected, the ATC train system (ATP component) applies an emergency brake until the train comes to a complete stop.

### *Train speed and train location determination*

The train location function is provided by ATC train system (ATP component) [5]. This system uses EUROBALISE on track as beacons for the train location function: an onboard controller uses train location information read from the EUROBALISE beacons on tracks [8]. The train position is sent to the ATC trackside system via radio.

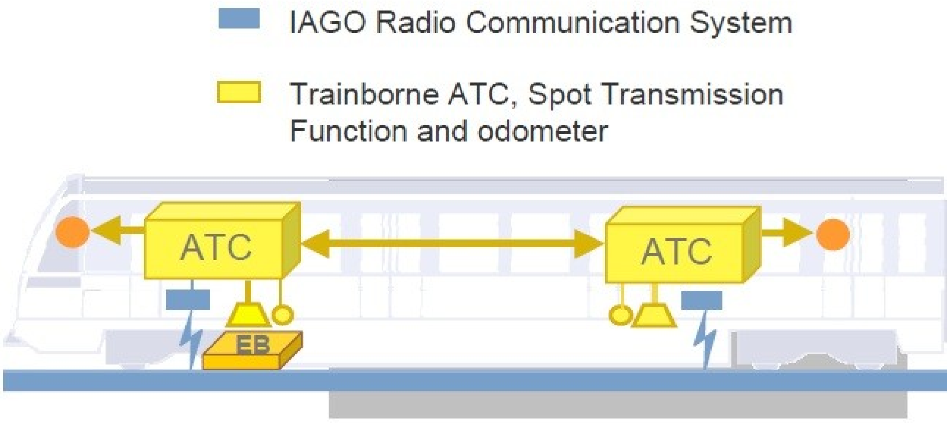


*Figura 2: Train location determination (Lausanne m2)*

The kinematic measure (displacement, speed, acceleration) is done by train system through a sensor called odometer installed on the axles of train [4][10].

### *Door management*

Urbalis ensures:

- Automatic train doors opening (Milano's Line 1 (2006) ) ;
- Management of platform edge doors (Milano's Line 1 (2006) ) [10].

### *ATO functions*

The ATO functions are provided by ATC train system (ATO component). These functions allow for fully automatic piloting of the train (full Unattended Train Operation (UTO)) or providing assistance to the driver [4].
The assistance system displays to the driver the speed guidelines which allow the former to stick to the trip time of the train.
The full automatic piloting is defined and conceived by prioritizing different achievable performance in this strict order of priority:

1. Optimize the driving of the train within safety limits
2. Control the performance of stopping at a station
3. Controlling the time taken between stations
4. Control the intervals between trains
5. Optimize driving such that energy is conserved.

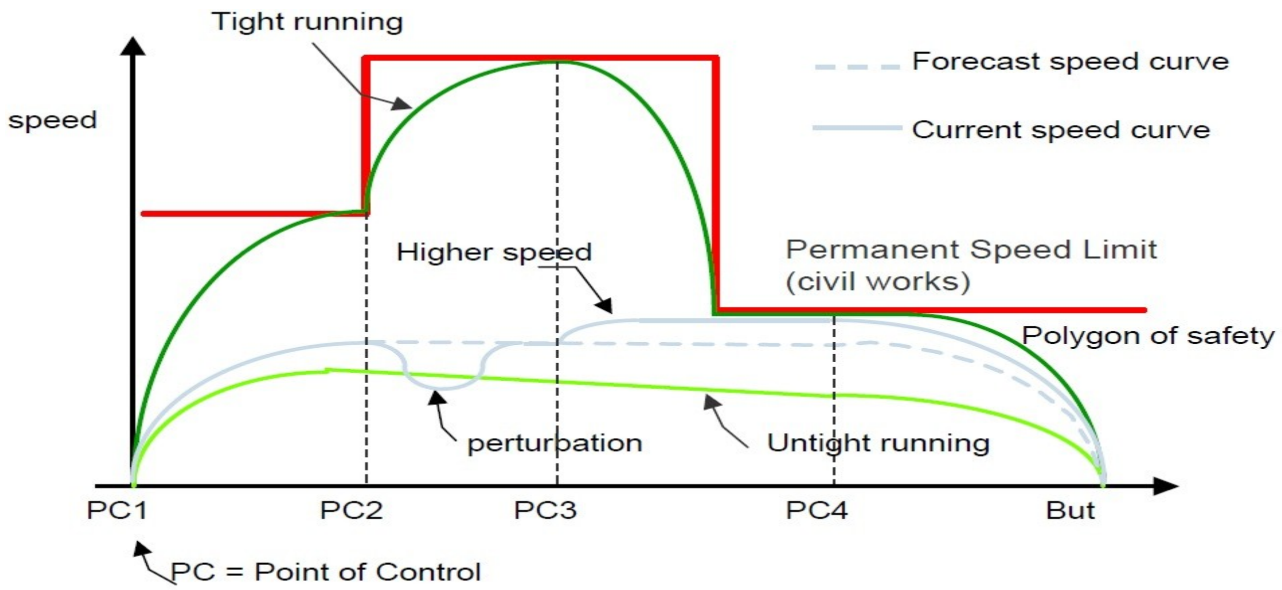


*Figura 3: Principle of ATO regulation (Lausanne m2)*

The full automatic piloting can take or leave the responsibility of driving the train to the driver.
The ATO functions provided are:

- movement train control in Automatic Run mode
  - in order to respect the arrival time given,
  - with separated and combined order of the traction and breaking,
  - with advanced management of departure (taking off) ;
- automatic Repositioning in station (the system can control movements between 10 cm and 6m by driving both the traction and the braking) ;
- correct stop management in station/platform;
- automatic reverse management in terminal;
- automatic train doors opening (Milano's Line 1 (2006) ) ;
- automatic platform edge doors (Losanna m2 (2006) ) .

## *Service-oriented facilities*

Urbalis can be integrated with:

- Passenger Information System (PIS) through ICONIS control center;
- Supervisory Control and Data Acquisition (SCADA) through ICONIS control center;
- Supervision and Control of Telecommunications through ICONIS control center;
- real-time CCTV (Closed Circuit Television) monitoring;
- alarms (in trains and on platforms) , fire detections, emergency calls and intercoms [7][11].

## *Technical features Urbalis CBTC*

The technical features of some projects are summarized in this table [3] [10] [12][13].

| METRO LINES | HEADWAY | MAX SPEED | LINE LENGTH | CAPACITY | SCHEDULE ADHERENCE | STOPPING ACCURA |
|---|---|---|---|---|---|---|

| | | | | | (last 6 months average) | CY |
|---|---|---|---|---|---|---|
| Singapore North East Line | 90 sec | 100 km/h (design) | 20 km | 25 trains | 99.42% (Departure) 98.67% (Arrival) | +/- 30 cm |
| Singapore Circle Line | 90 sec | ND | 32 km | 40 +10 trains | ND | ND |
| Beijing's Line 2 | 120 sec<br><br>90 sec (design) | ND | 23 km | 48 trains | ND | ND |
| Beijing's Airport Express | ND | 110 km/h | 28 km | 10 trains | ND | ND |
| Lausanne m2 | 120 sec (middle section)<br><br>240 sec (between end terminals) | 60 km/h | 6 km | 15 trains | ND | +/- 30 cm |
| Milano's Line 1 | 90 sec | ND | 26.8 km | 45/48 trains | ND | +/- 30 cm |

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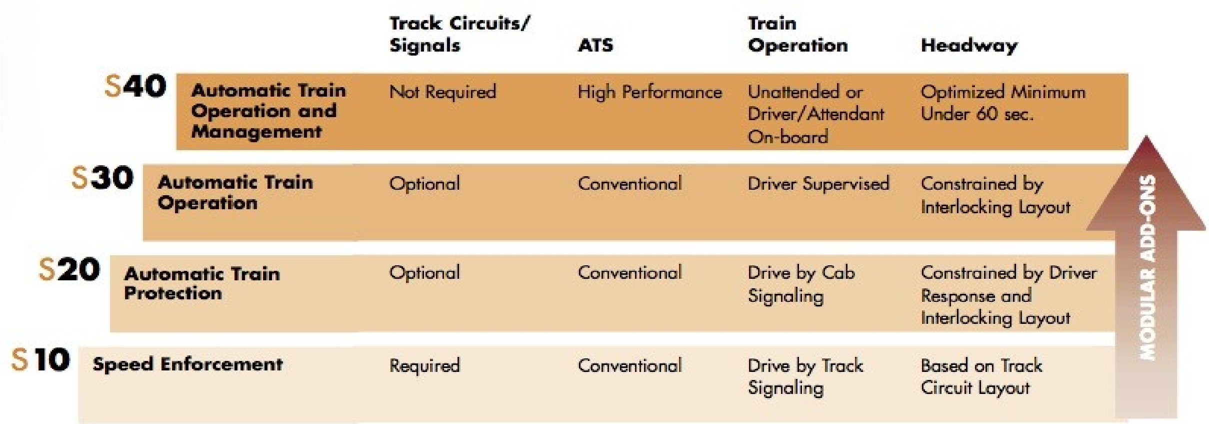
## THALES

### *Introduction*

SELTrac is a digital signalling technology used to control the movements of rail vehicles originally developed by Standard Elektrik Lorenz (the "SEL" in the name) . It was originally developed for the Krauss-Maffei Transurban automated guideway transit system developed in the 1970s, and moved to the ICTS vehicle when the Transurban efforts were taken over by an Ontario consortium.

SelTrac was primarily sold and developed by Alcatel, through a Toronto subsidiary. SelTrac is now sold by Thales, after it purchased many of Alcatel's non-telephony assets.

SelTrac family provides complete **railway solutions** for all types of mass transit such as trams, light rail vehicles and metros to suit various operating modes and customer's need. These include cab signalling, semi-automatic train operation, driverless and unattended train operation.
The various solutions and applications are summarized below.




The only CBTC system provided by Thales is SelTrac S40, that supports driverless and unattended operation and it is optimized for minimum headway of 60s.
SelTrac CBTC system has been installed in the world since 25 years, the first revenue operation having taken place in Vancouver into 1985. The main achievements of Thales [12,13] are:

| **Customer Line** | **Type of Service** | **Operation** | **New or Resignal** | **Award Year** | **Length Km** |
|---|---|---|---|---|---|
| Toronto Scarborough | Metro | STO | New | 1981 | 6.4 |
| Vancouver Sky Train | Metro | UTO | New | 1981 | 49.7 |
| Detroit APM | APM | UTO | New | 1983 | 4.7 |
| London DLR | Metro | DTO | Resignal | 1992 | 31.0 |
| San Francisco MUNI | LRT | DTO | Resignal | 1992 | 11.0 |
| Ankara | Metro | STO | New | 1993 | 14.6 |
| Kuala Lumpur | Metro | UTO | New | 1995 | 29.0 |

| | | | | | |
|---|---|---|---|---|---|
| Hong Kong KCRC West Rail | Metro | STO | New | 1998 | 30.5 |
| New York City JFK | Metro | UTO | New | 1998 | 13.0 |
| Las Vegas Monorail | APM | UTO | New | 2000 | 6.4 |
| Hong Kong KCRC Ma On-Shan | Metro | STO | New | 2001 | 11.4 |
| Wuhan LRT | Metro | STO | New | 2002 | 10.2 |
| Hong Kong MTRC Disney Resort Line | APM | UTO | New | 2002 | 3.2 |
| Paris RATP Line 13 | Metro | STO | Resignal | 2002 | 26.0 |
| Seoul KNR Bundang | Metro | STO | Resignal | 2003 | 18.3 |
| Guangzhou Metro Line 3 | Metro | STO | New | 2003 | 36.0 |
| London LUL Jubilee | Metro | DTO | Resignal | 2003 | 35.0 |
| London LUL Northern | Metro | DTO | Resignal | 2003 | 67.0 |
| Washington Dulles Airport PM (Ph I) | APM | UTO | New | 2004 | 3.6 |
| Shanghai Yangpu Line (M8) | Metro | DTO | New | 2005 | 23.0 |
| Dubai Light Metro - Red Line | Metro | UTO | New | 2005 | 49.0 |
| Vancouver Canada Line | Metro | UTO | New | 2006 | 18.0 |

Characteristic of THALES CBTC :

- Standard network and radio based communication system based on the Internet Protocol (IP) Standard.
- Remote train monitoring in real time
- Constant high-speed connectivity between train and trackside
- Centralized network management
- A flexible network architecture
- Detection of train location, speed and direction
  - Transponder tags, tachometer,
  - Accelerometer,
  - Switch/route info
- Route and switch interlocking
- Safe train separation using Progressive Movement Authority
- Work Zone protection
- Train handover between neighboring Zone Controller
- Emergency Stop Device response

## *Operating mode management*

The Thales company declares to have much flexibility, since SelTrac addresses the different requirements of operators, from simply replacing existing signalling, to improving the headway performance of an existing fixed-block system, or to overlay on an existing system [1]. No additional information is provided concerning the implementation of such functionalities. The only information has been found about the **Migration strategy** concerning **London Undergroud (LU):** Special functionality has had to be developed for the Control center (SMC), Zone controller **(**VCC) and Vehicle On-board Controller (VOBC) to support the migration strategy, in particular to ensure:

- Trains retain there existing protection system during the migration phases so that they can continue to operate in London Underground territory.
- Trains are inhibited from using their existing protection system in the Transmission[4] Based Train Control (TBTC) territory (since the track side components, trainstops, will have been removed)
- The trains are passively monitored by TBTC as they approach the migration boundary to ensure that communications are established.
- The new control system exchanges information with the existing control system at the control center.

From an operational perspective the migration strategy adds a further complication to the transition from existing LU signaling to the new TBTC system. Trains are also required to operate under both systems for several years and during this time the boundary between the two systems will change location as more and more of the railway becomes TBTC. For these reasons, each line has its own Dual Fitted Area (DFA) as a predecessor to the main migration phases.

The DFA is an overlay of TBTC onto the existing fixed block signalling in the area. In this way TBTC "spies" on the signal relay and trainstop status, and only advances the Limit of movement authority when both are clear [8].

***Safety and failure management***

Seltrac S40 uses fully redundant computer systems to run large areas of their transmission-based train detection systems. Of course, the system is designed to stop all the lost trains immediately but, to recover, it then has to poll each train to find out where it is and which way it is facing and then calculate the relationships with other trains before it can restart the system. This effectively shuts down the whole line. In a recent incident on the Jubilee Line, a VCC glitch required it to be 'rebooted' to clear its memory of a virtual train. This meant clearing the area under its control of real trains too. This took half an hour. After rebooting, a test train had to be sent through the area to test the system and reset the axle counters used in the back-up system. This took another hour [2].

4 Transmission because of use of inductive loop into communication subsystem

*System architecture*

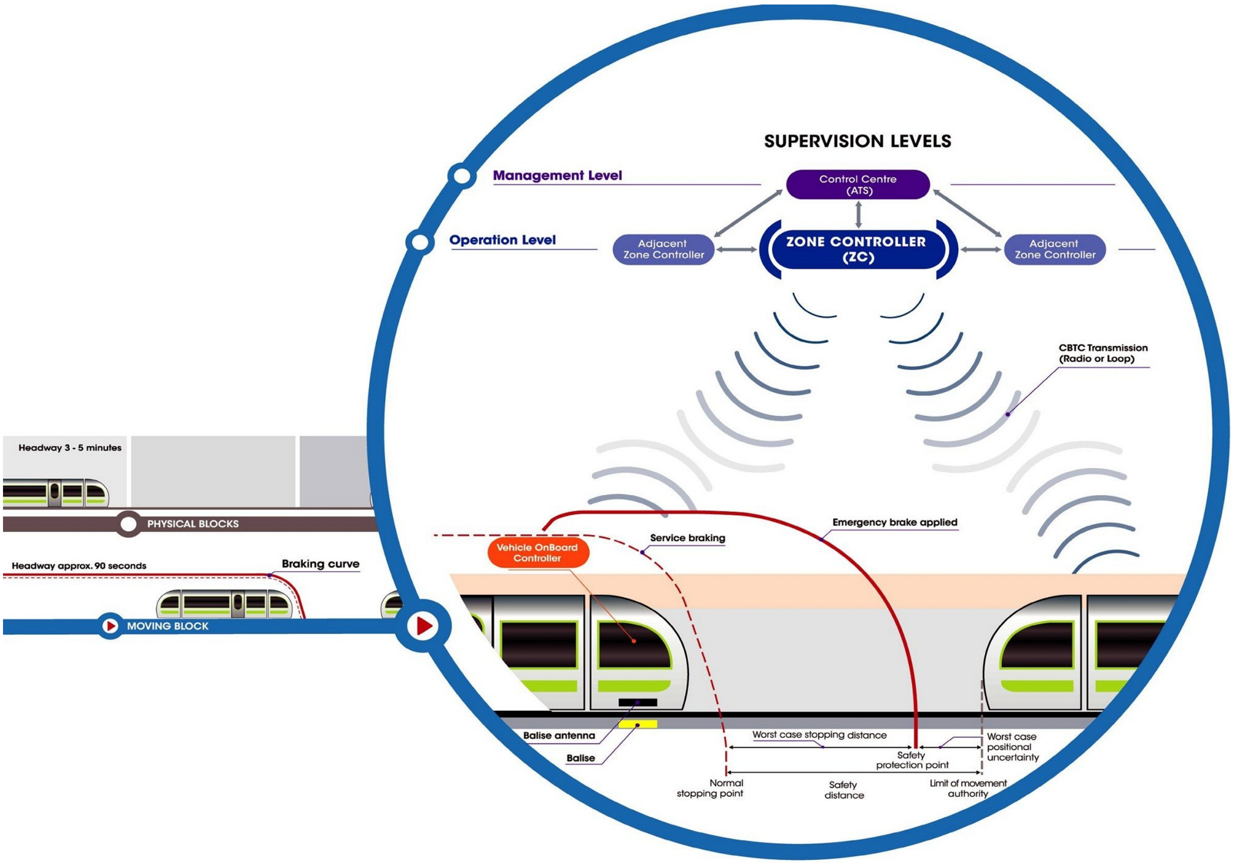



*Figure 4: Thales Seltrac S40 CBTC System Overview*

- **Vehicle Control Computer** (VCC) or **Zone controller** (ZC) : to monitor & track vitally the trains along the tracks. Zone Controller on the trackside is the recipient for all position messages sent from the trains within its region of control and the status of the obstructions such as axle counter blocks, signals, switches, floodgates, guideway intruder detection. The ZC is responsible for route setting based on the commands received from the Central control subsystem. It supports fully bidirectional operation.
- **On-Board Equipment** to supervise the speed & automatic control train. The vital component of the system is a Vehicle On-board Controller (VOBC) on the train. The Vehicle On-board Controller establishes the position of the train on the guideway by detecting transponders located in the track bed, and uses the transponder data to extract information from the database. The database on the Vehicle On-board Controller contains all relevant guideway information, including station stops, gradients, civil speed limits, switch locations, axle counter blocks locations and trackside signal locations.
- **Control center** or **System Management Center** (SMC) for automatic train supervision (ATS) , management of overall line system, overview of tracks and train positions and status, headway and schedule regulation and automatic and manual train routing and scheduling.
- **Communications Subsystem** (Inductive Loops or Radio) to allow communication with trains and network between all sub-system. The VCC and vehicle onboard computer (VOBC) are linked by low-frequency inductive transmission via loop cable or by high-frequency digital spread-spectrum radio.

**System with Inductive Loop**

This system is implemented in London Undergroud. Each loop segment can be up to 3 km long, but is typically limited to 1.5 km. Each 'side' of the loop has an opposite phase. The loop is crossed every 25 m to improve signal quality [3].

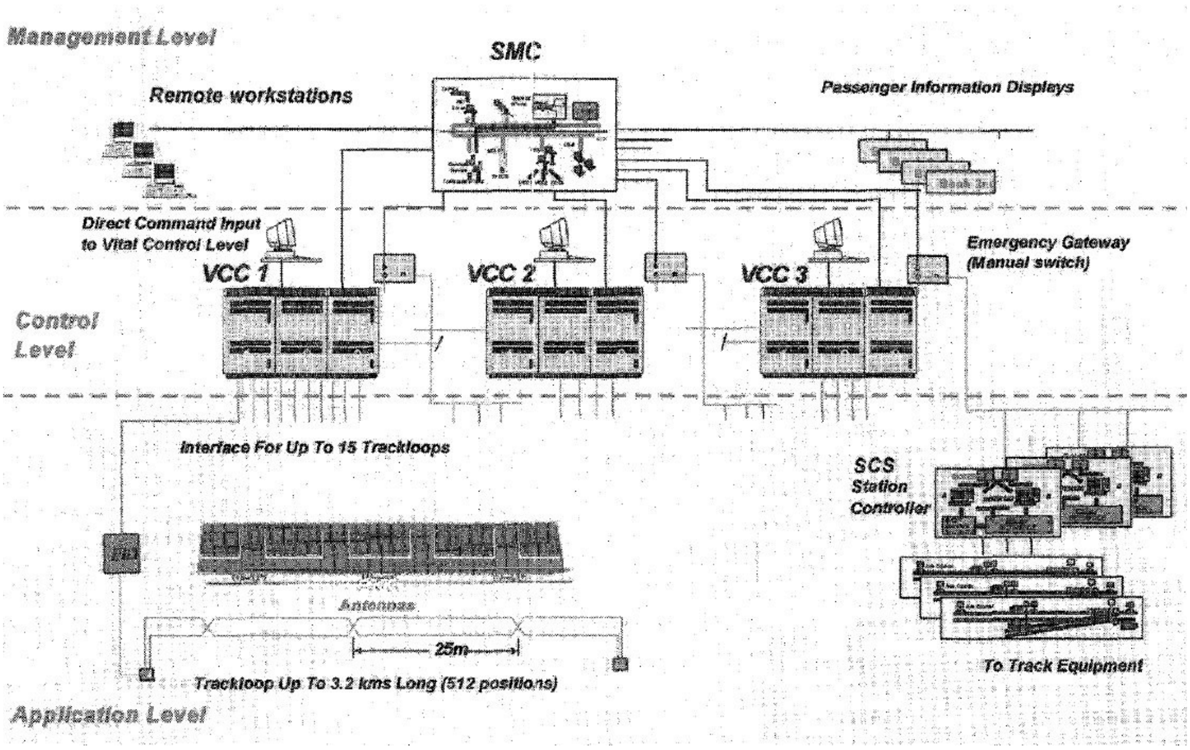



*Figure 5: S40 System with Inductive Loop*

**System with Radio-based**

Seltrac S40 communication subsystem use a radio link which relies on free-standing antennas or leaky coaxial-cable antennas. Trackside transponder tags assist in train positioning [10].

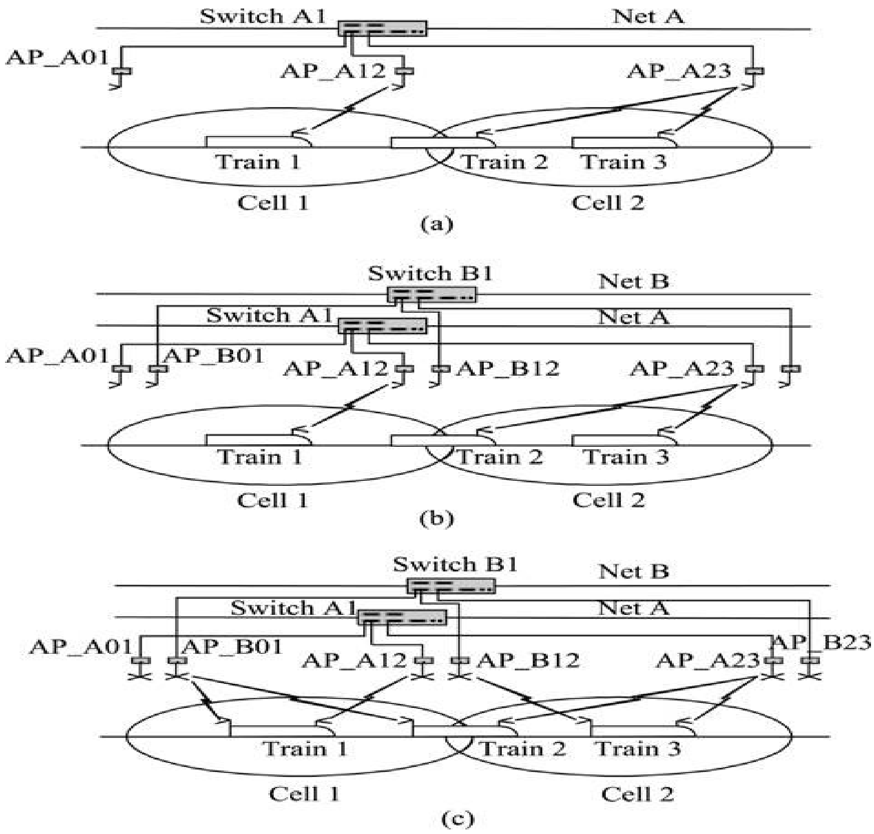



*Figure 6: Radio data communication systems (DCS) architecture in communication based train control (CBTC) systems. (a) No-redundancy; (b) semi-redundancy; (c) full-redundancy configuration*

In order to overcome possible unreliability of wireless portions of Zone controller, three configurations are considered, which differ in how the redundant APs and train's antenna realize. We shall refer to these three configurations as "no-redundancy", "semi-redundancy" and "full-redundancy", respectively (see figure 3). In simplicity, we call the antenna at the head of train as "head antenna", and the antenna at the end of a train as "tail antenna".

1) No-redundancy. One AP with directional antenna is employed in each radio cell. The head directional antenna of the train is connected with in-vehicle data communication equipment, which is depicted in Figure 3 (a).

2) Semi-redundancy. Two APs with directional antenna are employed in each radio cell. They connect with two different networks (i.e., Net A and Net B) via Ethernet switches, respectively. In semi-redundancy configuration, only the train's head antenna is used to connect with in-vehicle data communication equipment. The train's head antenna communicates with two APs simultaneously, as depicted in Figure 3 (b).

3) Full-redundancy. Two APs each using one uni-directional antenna (facing in opposition directions) are serviced in each radio cell, which are respectively connected to two wireline networks (i.e., Net A and Net B) via Ethernet switches. The redundancy APs and wireless network

form a double ring network. Two directional antennas, i.e., head antenna and tail antenna, are connected with independent communication equipment at each end of the train. The additional requirement is described as follows: (i) The AP connected to Net A communicates with the train's head antenna; (ii) The AP connected to Net B communicates with the tail antenna, as depicted in Figure 3 (c) [16].
How much is the distance from an access point to another? How much is the position accuracy provided by the system? How much train can be travel in same the area? These questions are not answered.

### *Braking model and speed limit protection*

The system allows four service brake rates ranging from 0.4$ms^{-2}$ to 0.8$ms^{-2}$.
The brake rate for a specific train or track section can be adjusted manually from the control center, and the lowest brake rate is used at start of service on wet mornings.
Safety calculations are based on an emergency brake rate of 0.9$ms^{-2}$, which is applied if an overspeed exceeds a specified tolerance that varies between 2km/h and 5km/h. The target point for a train is always a safe distance behind the train in front, this distance being calculated to allow an emergency stop with the worst-case trip speed [6].

### *Communication infrastructure and protocol*

The control center is connected to the devices associated to the zones through a communication backbone. The configurations of the communication system are fully redundant.

**Train-wayside protocol:**

- **Radio Frequency:** IEEE 802.11
- **Inductive Loop:** proprietary but based upon LZB & 56 kHz carrier. The VOBC in the vehicle uses ferrite coil antennas to receive data telegrams at 36 kHz and to transmit data telegrams at 56 kHz. The data is encoded using frequency shift keying. The protocol used in Alcatel's loop communication has the VCC transmitting an 83-bit telegram to the VOBC at 1200 baud; the VOBC responds with a 43 bit telegram at 600 baud [5].

**On Board Communication sub-system in RF version**: The on-board communication system has two antennas, one on the front, and one on the rear of the train. Each onboard network device connected to the antenna is a modular component, with two IEEE 802.3 interfaces, as well as one CAN[5] bus interface. CAN bus is provided for data transfer through the couplers. It requires only a single twisted pair wire and can operate in poorer transmission environments than Ethernet [14].

### *Interlocking and wayside information integration*

The interlocking functions are provided by LockTrac 6131 ELEKTRA is an electronic interlocking

5 Controller Area Network (CAN or CAN bus) is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer.

system that provides the highest levels of safety and availability. It has a modular system architecture and is based on modern microprocessor technology. Besides basic interlocking functions, additional features include local and remote control, automatic train operation, integrated block functionality, and an integrated diagnosis system. This entire system can be upgraded to the features of a management operation system and is approved according to CENELEC standards with safety integrity level 4 (SIL4) .

### *ATP Functions*

Automatic Train Protection functions on Seltrac System:

- Train integrity monitoring;
- Emergency brake control and monitoring;
- Over-speed monitoring;
- Vehicle positioning and overshoot monitoring;
- Supervision of train rollback;
- Detection of motion obstruction;
- Correct Side Door Enable and Door Status supervision; and
- Vital communication with the wayside VCC.

### *ATS functions*

Automatic Train Supervision Functions on Seltrac System:

- Train departure, destination assignments and identification assignment.
- Train routing functions.
- Modification of the system operations parameters in response to system delays and Control Room commands.
- Control of communications subsystem, displays and interfaces to assist the Control Room Staff.
- Collection and analysis of data for management reports.
- Station platform information display (PID) control
- Station platform announce

### *Headways*

SelTrac has proven that it can deliver **headways of under sixty seconds** [1]**.** In Dubai Metro to permit fully-automated operation, Thales Rail Signalling Solutions is supplying its SelTrac CBTC. This is configured for a minimum headway of 90 sec. Maximum speed of the trains will be 90 km/h, giving a round-trip time of 2 h 23 min for the Red Line and 1 h 23 min for the Green Line [7].

### *Train speed and train location determination*

With the inductive transmission version, loops are laid between the tracks and transposed every 25 meters (82 feet) for ground reference calculations. For speed determination the system uses tacho-generators, two per train end, used to measure speed, direction and distance in conjunction with an accelerometer. SELTRAC train position detection system - a transmission based, moving block system - provides a 6.25 meter resolution [8].

The system uses the trackside transponder tags to assist in train positioning [10].

### *Door management*

[No information for this function]

### *ATO Functions*

Automatic Train Operation Functions on SELTRAC System are:

- Regulation of train speed within imposed by the ATP subsystem and to provide passenger ride quality as established by operating policy.
- Control train movement with regard to speed, acceleration, deceleration, and jerk.

### *Service-oriented facilities*

Seltrac integration of auxiliary systems [9,15] such as:

- Passenger information displays (PIDs)
- CCTV surveillance
- Public announcement (PA)
- Audio and video recording
- Phone system and emergency
- Advertising information system audio / video
- Supervisory Control and Data Acquisition (SCADA) these systems are used within the transport network to provide a network wide view of the electrical and mechanical systems within the network, including ventilation, lighting, vertical transportation, access control, fire detection, communications and fare collection.
- Emergency call points allow direct communication with passengers from centralized Operational control center.
- Access control: used to detect and warn in the event of unauthorized access to particular areas of the network

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## INVENSYS

### *Introduction*

SIRIUS is Invensys Rail's Communication Based Train Control (CBTC ) solution for all types of Mass Transit and Suburban Railways – conventional, driverless or fully automatic/unmanned.
SIRIUS is based on moving block principles, and uses the latest state-of-the art digital radio transmission techniques.
SIRIUS is a high performance Moving Block Communications Based Train Control system. The basic operating principle of SIRIUS is that each train is granted at every moment its own Limit of Movement Authority (LMA).
SIRIUS has been specifically designed for high density lines. By optimising headway the operator is able to reach maximum transport capacity and optimise rolling stock usage.
SIRIUS offers the following key features:

- Automatic Train Supervision to GoA 3 and GoA 4
- High Performance
  - High speeds
  - High capacity
  - Smart driving strategies
- Digital, bi-directional, track to train communications using spread spectrum radios
- Latest generation technology platform
  - separation of application software from hardware operating system
  - highly open interfaces
  - common components with the IRG FUTUR (ERTMS) product line
  - reduced lifecycle costs
- Ultra high availability architecture
- Common hardware - Trackside and Onboard
- Ability to overlay SIRIUS onto existing systems
- Integration with external and/or legacy systems

The SIRIUS system was originally developed for the Madrid Metro Este Line. Most recently IRG has been awarded the Down Town Line (DTL) project by the Land Transport Authority in Singapore. This project is in three phases. Involves the signalling for 33 stations (plus a depot) over a distance of 40km and includes fitting 73 trainsets.

### *Operating Mode Management*

SIRIUS can operate in lines equipped with "Speed Codes" and "Distance to go" systems.
In case of non fully automatic lines, a train attendant on board, not necessary in the driver's cab, will control the train doors and train start functions through a touch-screen device acting as Driver Machine Interface (DMI) [1].

### *Safety and Failure Management*

SIRIUS includes a centralized Maintenance Aid System (MAS) to facilitate the diagnosis works, both on board and track side. All information concerning faults or incidents is saved in the onboard equipment and transmitted to the central maintenance facilities through a non-vital radio.
For the information classified as vital, SIRIUS uses a powerful bi-directional data transmission system using digital radio based in Spread Spectrum technology and IP protocols.
Seamless fallback in case of a major system failure:

- No manual intervention required
- Fast journey completion - minimising any possibility of passengers being stranded for any significant period, perhaps in a tunnel

Any loss of train reporting via the radio system is dealt with by the CBI (Computer Based Interlocking) using track circuit occupation information and reversion to conventional signalling control for the failed train or section.
Vital functions:

- Train speed supervision
- LMA supervision

### *System Architecture*

SIRIUS is based on a 2 out of 3 voting architecture. This configuration together with the high level of reliability of the chosen components results in availability figures above 99.99%.

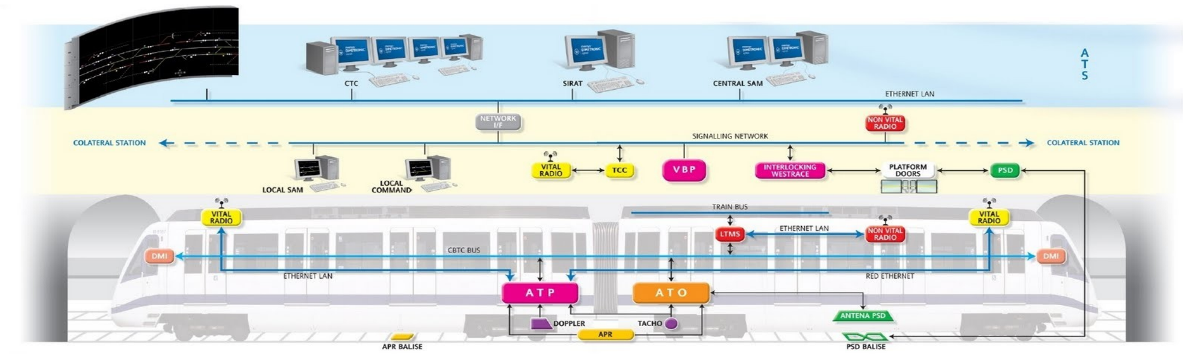
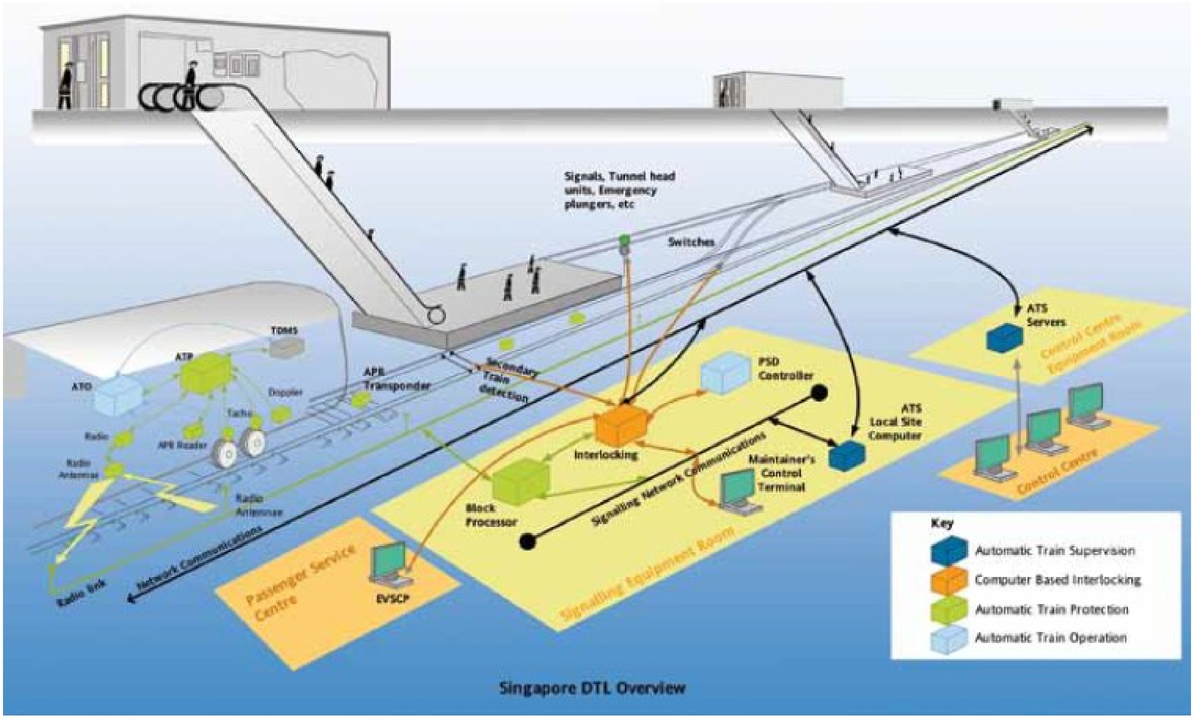



Figura 1: SIRIUS general architecture

TCC = Trackside Communications Controller
MAS/SAM = Maintenance Aid System
PSD = Platform Screen Doors
APR = Absolute Position Reference (Train Location Determination)
VBP = Virtual Block Processor
TACHO = Tachogenerators (Train Speed Determination)



Contract 952 - DTL Signalling System and Platform Screen Doors

Figura 2: Singapore DTL architecture

**Trackside equipment**: redundant architectures in the vital subsystems, Signaling Command and Control is done by electronic "hot stand-by" Interlocking, the Block Processor calculates the MA by using the route status provided by the interlocking and according to the locations reported by the trains, the geographical data of the line is stored in the BP and transmitted to the trains by radio, Ethernet communications among the ATS, Interlocking, BP's and Radio equipment using IP protocols, passive beacons are used for the accurate location of trains [6].
**On board equipment**: ATP subsystem provides train protection functions, assuring the train doesn't exceed the MA received from the BP; ATO subsystem provides automatic driving following the commands received from the ATS, Synchronized Train and Platform Door Control, odometry, Driver Machine Interface based in PC, transmission of events through the radio to the ATS.
**Communication equipment**: use of digital radios with spread spectrum modulation techniques, redundant configuration of equipments, redundant communication, use of antennae or leaky feeder.

## *Communication Infrastructure and Protocol*

SIRIUS uses a digital radio system to grant a continuous, high capacity, bi-directional train-to-wayside data communication (Safetran Radio 2.4 GHz radio system) . Each train reports its position continuously through the digital radio to the Virtual Block Processor (VBP) in the track. The LMA is sent via radio through the Trackside Communications Controller (TCC) [1].
For the information classified as vital, SIRIUS uses a bi-directional data transmission system - using digital radio based in Spread Spectrum technology and IP protocols.
SIRIUS uses PROFIBUS (PROcess FIeld BUS) and TCN standards in the train-carried equipment

and IP protocols for the track equipment and the track-train communications.
PROFIBUS is a communication system created to connect several digital field devices and/or elements with poor performance as transmitters, actuators, controllers, etc.. It is a distributed system based on token [3].
The Train Communication Network (TCN) is a hierarchical combination of two fieldbus systems for digital operation of trains. It consists of the Multifunction Vehicle Bus (MVB) inside each coach and the Wire Train Bus (WTB) to connect the MVB parts with the train control system. The TCN components have been standardized in IEC 61375 [4].
Redundant communication (spatial y spectral) is offered through leaky feeder or free space transmission.

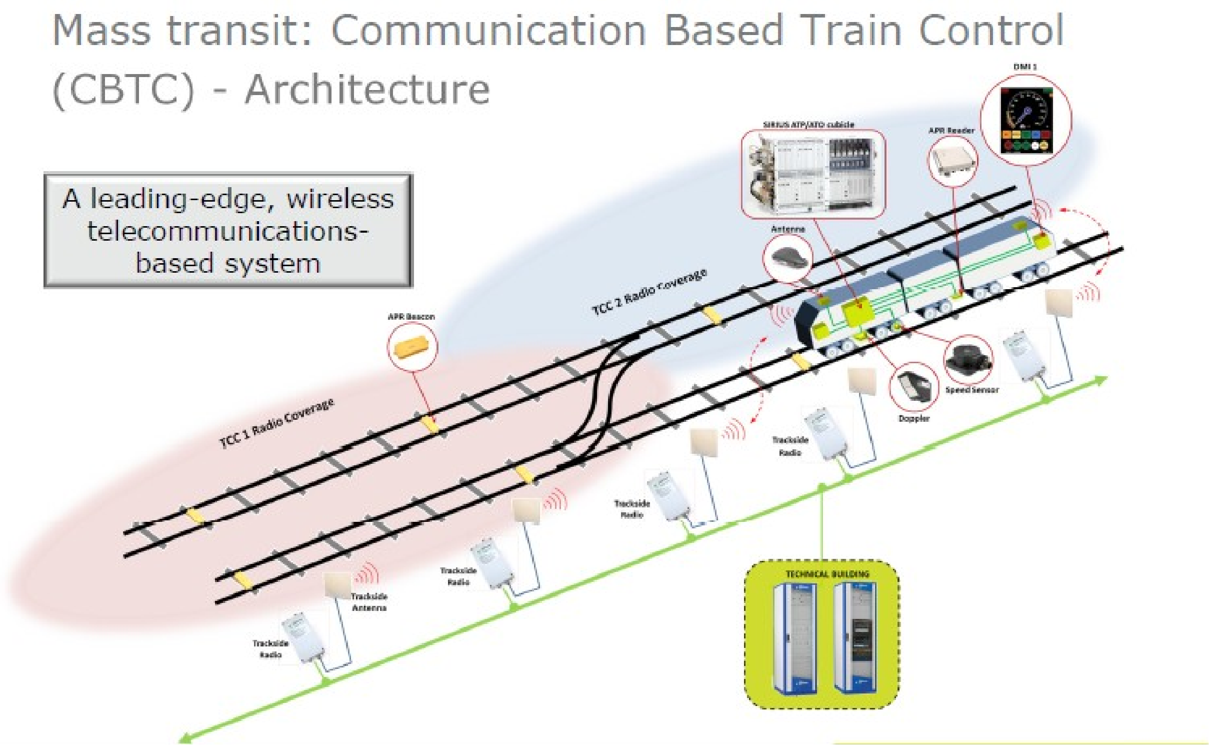


Figura 3: Communication Infrastructure

## *Interlocking and Wayside Information Integration*

The heart of Invensys signalling solution, the latest generation of WESTRACE CBI, interlocks train movements relative to the location of all other trains and switch settings. The CBI also handles the functionality required for emergency stop plungers, civil defence doors, tunnel head units and so on.
WESTRACE Mk2 electronic Interlockings [5] provides:

- Modular and scaleable
- IP based network interfaces
- Selectable levels of redundancy, down to I/O level if required
- Hot swappable modules in case of failure

## *ATS Functions*

SIRIUS includes an Automatic Train Supervision system based on the "Urano" platform. The ATS encompasses a set of programs and tools including a wide variety of functionalities, among which

handling traffic control, depot management, train awakening, automatic regulation, integrated maintenance, operation simulators, incident report and replay... The ATS works in an open architecture which allows to integrate in a simple manner other railway control systems such as Traction Power Control, Passenger Information Systems, Building Management, Environmental Control or any kind of Telecommunication system - telephone, radio, CCTV, etc.
Main functions:

- Core Traffic Control
- Advanced regulation and optimisation
- Dynamic Temporary and Permanent Speed Restrictions
- Remote train control e.g. Creep, Jog, Sleep and Wake functions
- Integrated maintenance support

The SystematICS platform features:

- Integrated Control and Communications Systems platform
- Designed for business critical rail applications, to CENELEC SIL 2
- Inbuilt maintenance, simulation and reporting functions plus an extensive library of external system interfaces (e.g. to legacy systems or corporate business systems)
- Advanced Train Control application suite including dynamic scheduling, optimisation and automation, in addition to feature rich conventional Automatic Train Supervision functionality
- Applications for traction power control, passenger information display, public address systems, voice/radio communications, closed circuit TV and other Electrical & Mechanical system control

### *Headways*

Headways below 80 secs are achievable [5].

### *Braking Models and Speed Limit Protection*

From the information contained in the LMA, the on-board equipment continuously supervises train speed, to safely ensure that the LMA cannot be exceeded. In order to do this, each train continuously reports its position over the digital radio to the trackside Block Processor (BP) . The BP uses the position information from the trains and track status information from the interlocking to recalculate the LMA for each train.

### *Train Speed and Train Location Determination*

Absolute Position Reference (APR) passive balise located along the track are activated when the train passes through. They provide information which allows the trains to be located with maximum precision within the line.
Speed and distance will be measured by devices driven by the trains wheels or gearbox, with supplementary information from Doppler radar units. Location information is derived from these sensors and calibrated upon passing reference beacons in the track.
Track circuit secondary detection is used to ensure a very robust and highly available system [2].
Odometry is based on tachogenerators and Doppler effect devices [6].
The FS3000 is a digital track circuit suitable for secondary detection on CBTC systems. The FS3000 series of track circuits will operate on any rail gauge – using AC, DC – or its own internal power supply. And each track circuit operates from a single, configurable transceiver. Multiple

receivers ensure full train detection over all point legs without complex serial or parallel bonding. Transceivers plug install for simple maintenance, with all configuration maintained on the rack-mounted socket [7].
A train entering (or powering up from cold in) the system must acquire definitive knowledge of its position before it can enter full CBTC operation. Without a positive track code indicating that the track ahead is clear and it is safe speed to proceed, the train must creep at very low speed until it reaches the next beacon. At that point it positively confirms its absolute position, and can proceed under full CBTC control. The physical track circuit remains a pragmatic solution if fast system start up and fast recovery after a failure is a requirement.

## *Door Management*

SIRIUS is also capable to interface with a Platform Screen Doors (PSD) System by means of a bi-directional data exchange between the trains and loops located at the station points of the stations.

## *ATO Functions*

The bi-directional data exchange between the trains and loops located at the station points of the stations provide an accurate stopping function.

## *Service-Oriented Facilities*

Integration with external and/or legacy systems [5]:

- Roller shutter interface and ventilation system interface, with Train Control interlocks, for handling fir/smoke scenarios
- Dynamic scheduling and timetable optimisation
- Integration with station management, CCTV, HVAC, Escalation/evacuation control, voice communications, Passenger Information Display Systems

Systems that will be integrated include:

- traction power supply;
- tunnel ventilation;
- electrical and mechanical monitoring;
- CCTV;
- public address;
- passenger information display;
- passenger counting;
- voice communications;
- passenger alarm and the fibre optic transmission systems.

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# ANSALDO STS

Ansaldo STS is developing the CBTC, which, in line with the international standards, bases the urban railway traffic control activities on Radio communications, in order to allow for the full interoperability on the metro lines between different system/technological operators in the case of maintenance or expansion of existing lines, The control systems installed on board calculate the position of the vehicle and adjust its movement to the authorized limits. Thanks to the communications between the control systems placed in the adjacent area, at the interlocking points and on board, it is possible to safely manage the headways of vehicles and the capacity of the line, Additional advantages relate to:

- the complete systems for central control rooms, on board and round that can be of a "stand alone" type or can be integrated with the existing systems;
- optimization of the headways of vehicles, only 60 seconds (introduction of the concept of "moving block") ;
- reduction or elimination of the requirement for track circuits or any other devices to calculate the position of the trains.

Ansaldo STS has already installed this technology on line 3 of the Paris metro, on line 1 of the Chinese metro of Shenyang and Chengdu, while other systems are being designed and, in some cases, are being installed such as the Ankara metro, the Taipei metro and the Copenhagen metro (the last two projects will manage the driverless mode) [1,2,6,7,8].

| Customer Line | Type of Service | Operation | New or Resignal | Award Year | Length Km |
|---|---|---|---|---|---|
| Taipei Circular Line | Metro | DTO | New | 2009 | 15,4 |
| Copenhagen Cityringen | Metro | DTO | New | 2011 | 16 |
| Shenyang Metro Line 1 | Metro | STO | New | 2006 | 28 |
| Chengdu line 1 | Metro | STO | New | 2010 | 18,5 |
| Hangzhou Metro Line 1 | Metro | STO | New | 2010 | 53,6 |
| Paris metro line 3 | Metro | STO | Resignal | 2009 | 11,7 |
| Ankara Metro | Metro | | Resignal | 2008 | 55 |
| Napoli Line 1 / 6 | | | | | |
| Linea Alifana *Piscinola-Aversa* | Experimental | | Resignal | | |
| Milano Metro 4 | | DTO | | 2011 | 15 |

### *Operating mode management*

Ansaldo STS CBTC solution is a scalable solution that matches the needs of any operator should they require an overlay system or a brand new line.
When used as an overlay solution Ansaldo STS' CBTC allows simultaneous CBTC and non-CBTC equipped vehicles to share the same tracks. In this way the upgrading of non-equipped vehicle can be staged to fit the operator needs without causing disruptions and maintaining the highest levels of safety.
Migration Strategy:
• New Wayside Communication will be implemented first
• The Existing traffic control system will be replaced by a new one (ATS) as soon as possible
• The existing relay interlocking as to be replaced by new CBI
• TC's and Code Generators are to be maintained as long as there are still train not yet equipped with the new on-board ATC.
• New on-board ATC installed progressively on trains, in parallel with existing ATC.
• The entire line could be operated with "Mixed mode", the entire path is transferred to CBTC but may be still operated with legacy system
• At the end of the migration, Track Circuit will be replaced by Axel counter.

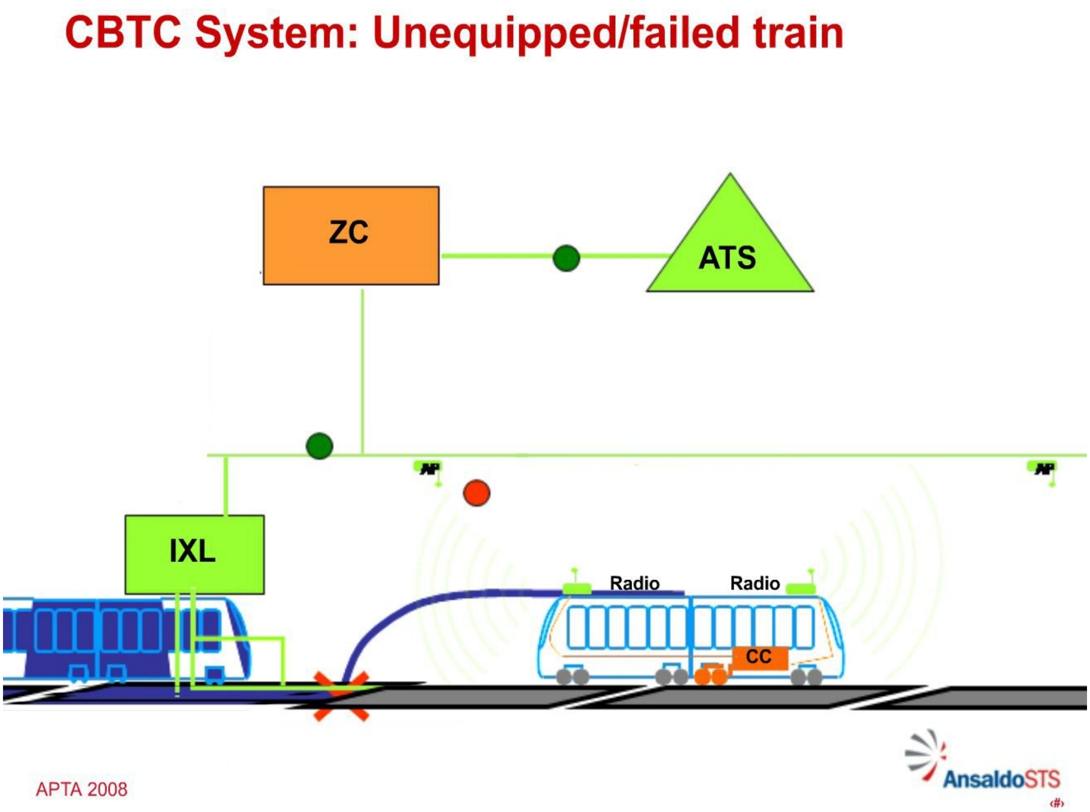


*Figure 7: Unequipped/failed train*

The unequipped train does not communicate but it occupies the track circuits. The interlocking (IXL) detects the track circuit occupation and send this information to the Zone Controller (ZC) . The Zone Controller places the Moving Authority Limit (MAL) behind the last track circuit occupied and sends it to the equipped train and to the Automatic Train Supervision (ATS) . The train receive the Moving Authority Limit (MAL) form Zone Controller and the Carbone

Controller (CC) calculates its braking curve based on the MAL see figure 1.

### *Safety and failure management*

[Information]

### *System architecture*

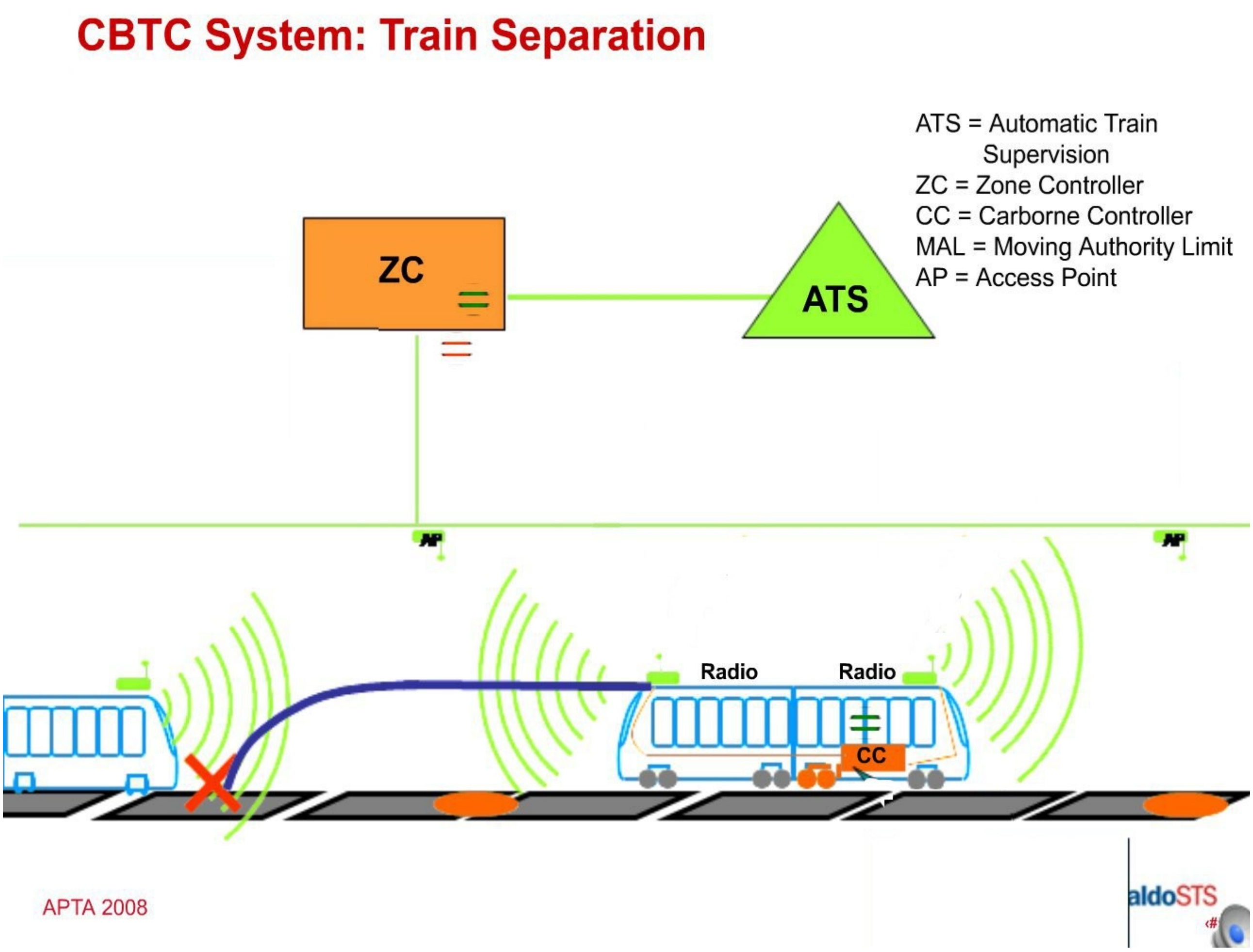


*Figure 8: Train separation*

In normal operations the Carborne Controller calculates the position of the train using track side beacons and the train's odometer. The position is sent by radio to the Zone Controller (ZC) . The Zone Controler, based on the information received from all trains, calculates the Moving Authority Limit (MAL) (the X red in figure 2) and sends it to the vehicles. Zone Controller also sends the position of all trains to the ATS to be displayed. The train receive the Moving Authority Limit (MAL) form Zone Controller and the Carbone Controller (CC) calculates its braking curve so that the MAL is never exceeded.

### *Communication infrastructure and protocol*

**Train-wayside protocol:** **RF:** IEEE 802.11

**Fully redundant** configurations**.**

## *Interlocking and wayside information integration*

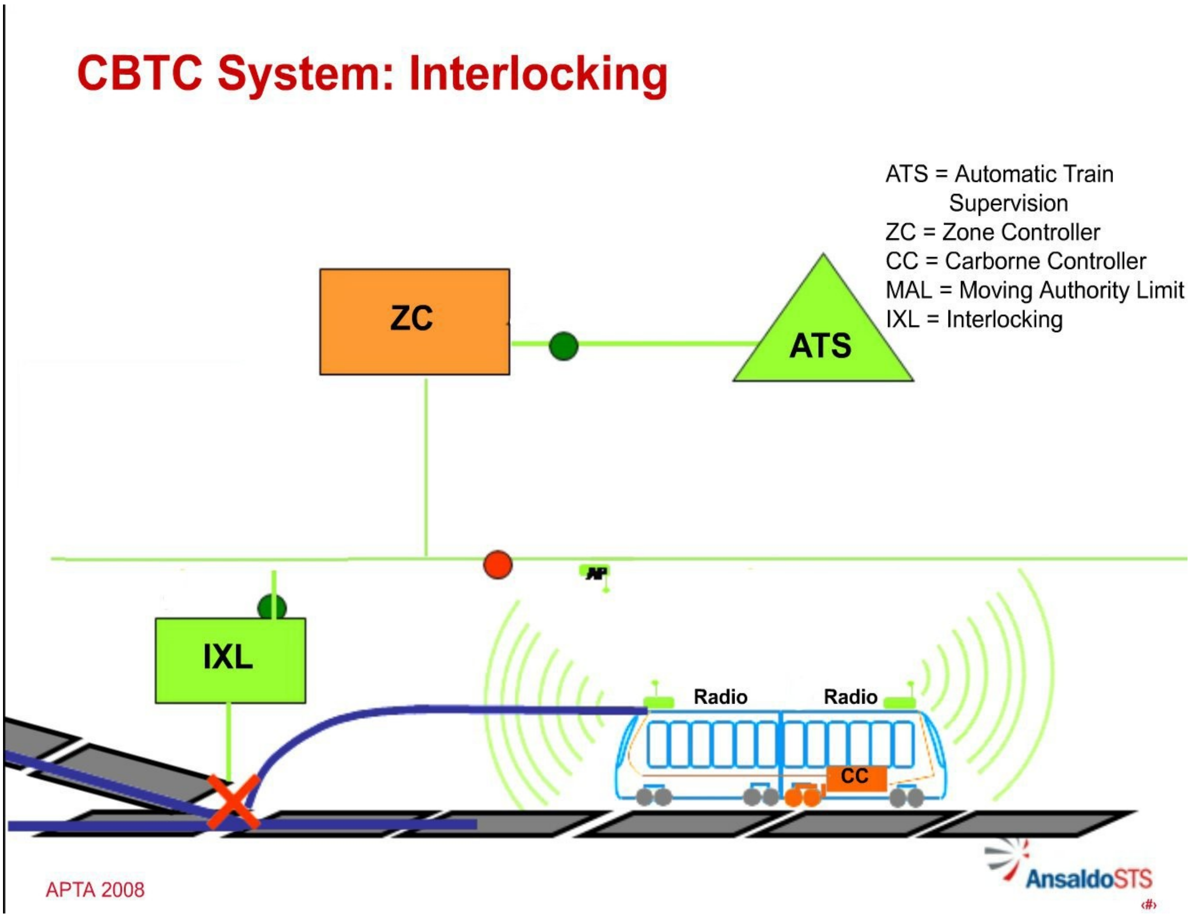


*Figure 9: Interlocking*

The position of the switch is controlled by the interlocking (IXL) that sends the track status (free or not) to the Zone Controller (ZC) . The Zone controller based on route of train and the position of the switch sends Moving Authority Limit to the vehicle and the status of switch to the Automatic Train Supervision (ATP) . The train receives the Moving Authority Limit (MAL) from Zone Controller and the Carbone Controller (CC) calculates its braking curve so the MAL is never exceeded (see figure 3) .

## *ATS functions*

ATS functions will provide system status information, monitor system operations, and implements the automatic control for various functions of the system [6].

## *Headways*

In brochures headway is declared down to 60 seconds [3].
Copenhagen Metro headway: 90s/100s minimum in normal condition[4,5]
Taipei Circular Line headway: 90s minimum [5].

### *Braking models and speed limit protection*

[No Information]

### *Train speed and train location determination*

The maximum train speed is 80km/h in Copenhagen and Chengdu [4].
The position train is determined using track side beacon, to receive the absolute position, and the on board odometer system.

### *Door management*

Door control functions is assigned to ATP
The system ATO functions allows the train to make small forwards and reverse movements to center doors
(Undershoot recovery / Overshoot recovery)

### *ATO functions*

ATO supports the following functionality:

- Speed regulation
- Programmed stops management
- Platform Screen doors management
- Skip Stop
- Overshoot ad undershoot management
- Vehicle retention
- Driving mode management
- Automatic turnbacks
- Automated coupling & decoupling
- Energy consumption management and optimization
- Routine maintenance reporting can be provided directly to the interlocking technician terminal.

### *Service-oriented facilities*

- Closed Circuit TV.
- Obstacle detection system
- Loudspeakers in stations and trains.
- Information displays in stations and trains.
- Emergency Call Points in stations and trains.

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# SIEMENS

## *Introduction*

The modular and scalable Trainguard MT train automation system is Siemens' answer to the comprehensive requirements of urban transport today and offers the latest standard in automation at different levels. Trainguard MT is a Moving Block CBTC solution offering:

- **High level of safety** thanks to continuous speed supervision, full enforcement of speed limits, flexibility to define temporary speed limits, and proven "fail-safe" system components;
- **Cost-effectiveness** expressed in terms of high availability, reliability, and maintainability. Reduced life cycle cost (LCC) thanks to more accurate train regulation, energy savings, and less trackside equipment;
- **Reduced size of train-borne equipment** for easier integration into the rolling stock;
- **Reduced maintenance-demanding equipment** thanks to Airlink, the wireless track-to-train data communication solution based on free-propagation;
- **Upgrade to driverless operations**. Trainguard MT CBTC has been designed to accommodate both driver-attended and driverless operations. Its modularity guarantees the ability to plug in additional modules and to implement functions requested when upgrading to driverless solution, without changing existing modules;
- **Interoperability and interchangeability;**
- **Mixed fleet operations**. Trainguard MT CBTC equipped trains and unequipped trains can both operate safely on a CBTC-equipped line.


*Metros that have chosen Siemens CBTC*

Trainguard MT is installed in many countries, including [2]:

- New York City - Canarsie line: NYCT awarded the CBTC Joint Venture lead by Siemens the contract for resignalling the line and equipping new trains with its CBTC. The contract includes designing, furnishing and installing CBTC equipment for mixed fleet operations, upgrading existing interlockings to be CBTC-ready and providing six completely new CBTC-ready interlocking systems. Trainguard MT CBTC equips fifty steelwheeled trains, the 17 km long line and the yard. It is in revenue service since January 2006;

- Paris - Ouragan: The resignalling program currently undertaken by RATP to upgrade to CBTC lines 3, 5, 9,10 and 12 aims at:
    - Improving safety by ensuring continuous train speed control.
    - Improving the quality of the service offered to passengers by reducing the headways from 105 to 90 seconds;
- Budapest - line M2: To upgrade line M2 to full CBTC operation, BKV awarded Siemens the signalling contract. Trainguard MT CBTC will equip a fleet of 26 driver-operated trains running on the 12 km long line;
- Algiers - line 1: To equip the first line of its metro, EMA (Algiers Transport Authority) has chosen Trainguard MT CBTC. The CBTC system will equip a fleet of 14 driver-operated trains running on the 9 km long line.

### *Operating mode management*

Trainguard MT can handle mixed fleets of trains on the same line with different train control equipment at the same time in the same network [1]. The different train control levels operated by Trainguard MT are:

- **Interlocking train control** allows unequipped trains to operate on the line;
- **Intermittent train control (ITC)** allows fixed-block operation with continuous supervision and already offers automatic train operation (ATO) functionality;
- **Continuous train control (CTC)** uses a bi-directional WLAN transmission channel providing full moving-block functionality in combination with comprehensive ATO capabilities. Color light signals can be reduced to a minimum or even completely omitted.

Depending on the chosen train control method, Trainguard MT can implement the following levels of automation:

- "**Automatic Train Protection**" mode (**GOA1**) : the driver follows the instruction supplied by the CBTC
- "**Automatic Train Operation**" mode (**GOA2/GOA3**) : the CBTC controls the train automatically; the driver needs only to give the command to start the train
- Fully automatic, or "**Unattended Train Operation**" mode (**GOA4**) : the train can run without a driver on board.

Operators can transfer from one mode to another without having to change existing modules.

### *Safety and Failure Management*

In New-York Canarsie line, Airlink uses three kinds of diversity [3]:

- **Spatial diversity**: 2 antennas per train installed on each end, with two independent propagation ways
- **Time diversity**: data transmitted twice in two adjacent radio cycles, in case of poor

transmission quality

- **Frequency diversity**: radio cycle uses alternatively two different frequencies for each cell

To guarantee the availability-reliability of the communication system, Airlink uses directional antennas, in order to minimize jamming effect, and the implementation of equipment redundancy in order to mask failure during operation and maintenance operation. The proven message error rate is $10^{-8}$ per train.

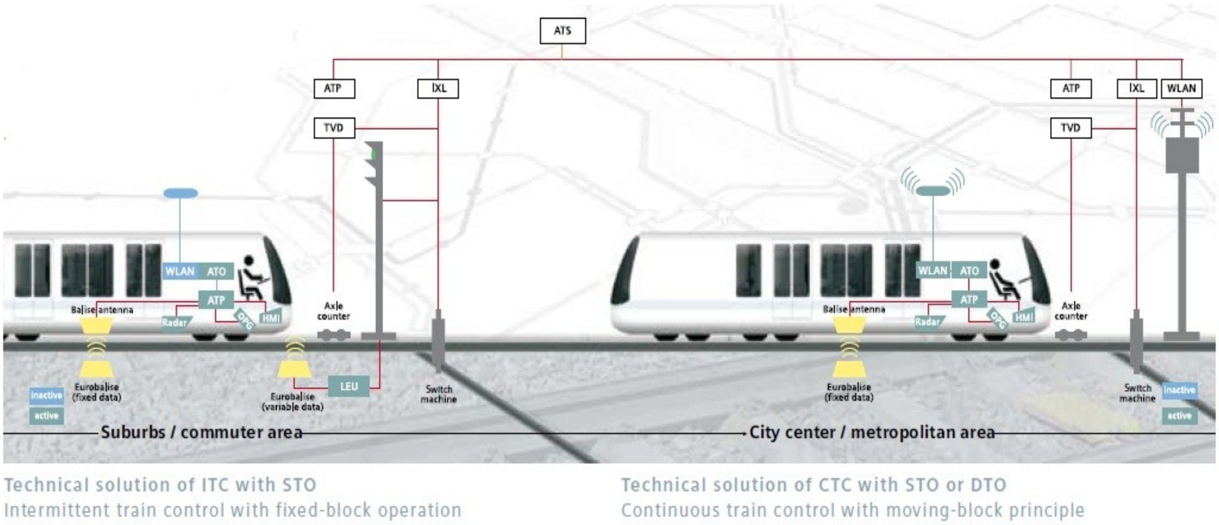
Passenger protection in the stations: platform doors are provided to prevent any fall on the tracks.

Safe emergency evacuation: for instance, when a vehicle emergency handle is pulled by the passenger, whenever possible, the train will proceed to the next station for safe and convenient alighting of the passenger.

### *System architecture*

The key subsystems are [1][2]:

- Train-borne CBTC subsystem for Automatic Train Control (ATC = ATP+ATO) ;
- Way-side CBTC subsystem for Automatic Train Control (ATC = ATP+ATO) . This subsystem includes:
  - ACM axle counting system (TVD)
  - Eurobalise S21 (COM) ;
- Data communication subsystem for a bi-directional, high-capacity and continuous track-to-train data transmission. The free propagation radio solution designed by Siemens is Airlink.




Overview of the subsystems

Instead, the optional subsystems are:

- Auxiliary wayside sub-system (AWS) , comprising:
  - signalling
  - interlocking (provided by Sicas) .

  In addition to its interlocking function, it also controls lineside signals to protect the movements of unequipped trains;

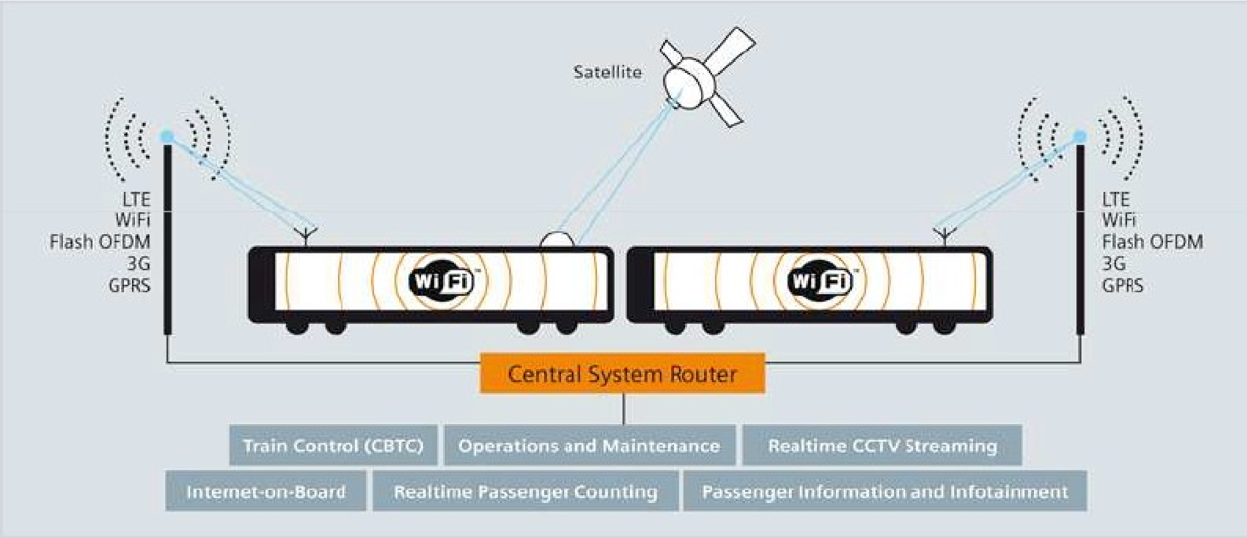
- Automatic Train Supervision (ATS) subsystem (provided by Vicos® OC 100 and Vicos OC 501) ;
- Passenger protection sub-systems such as platform screen doors which prevent passengers from falling onto the track, or other devices based on optical technology. These systems detect obstacles on the track and interact with the train-borne and wayside systems to stop trains at specific locations.
- Traction power sub-system.
- Audio-visual sub-systems, allowing full duplex voice communications between operators at the Operations Control Centre (OCC) and passengers. Video cameras installed on board trains and on platforms enable operators at the OCC to monitor any incident.

### *Communication Infrastructure and Protocol*

Requirements for CBTC applications [4]:

- Bidirectional and continuos transmission, including yard area
- Adaptable to various line configurations and topologies
- Compliant with various train operations
- Line operation for up to 30 years
- Using adpatable frequency bandwidth, licensed or not (from 2 to 6 GHz)
- With low data rate: CBTC needs < 50Kbits/s
- With fully transparent handover management (Seamless roaming = 0ms)
- With high availability level: (Train stop without transmission > 3s)
  - Train frame error rate < $10^{-8}$, taking account of system architecture
  - No transmission loss over 3s with one train, no more than three times per year
  - No transmission loss over 3s with all trains, no more than once per 10 years
  - Support railways environment (EMC, T°, Vibrations)

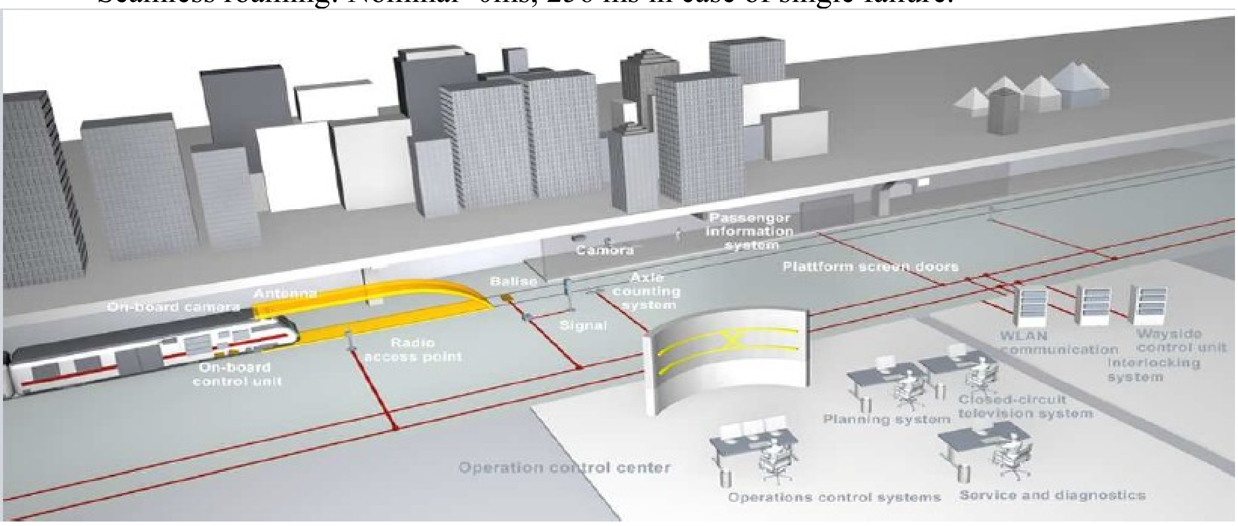
Siemens has developed and put into operation a radio system called Airlink. This product, initially based on a proprietary DSSS based transmission, is now being extended using 802.11 standards. Airlink is a system that provides transparent IP-based communication between wayside and onboard equipment with one or more standard Ethernet interfaces. It is a flexible platform with ability to support a variety of applications concurrently [3].




General Airlink Communication System Concept

Main features of application of Airlink in New-York Canarsie line are [4]:

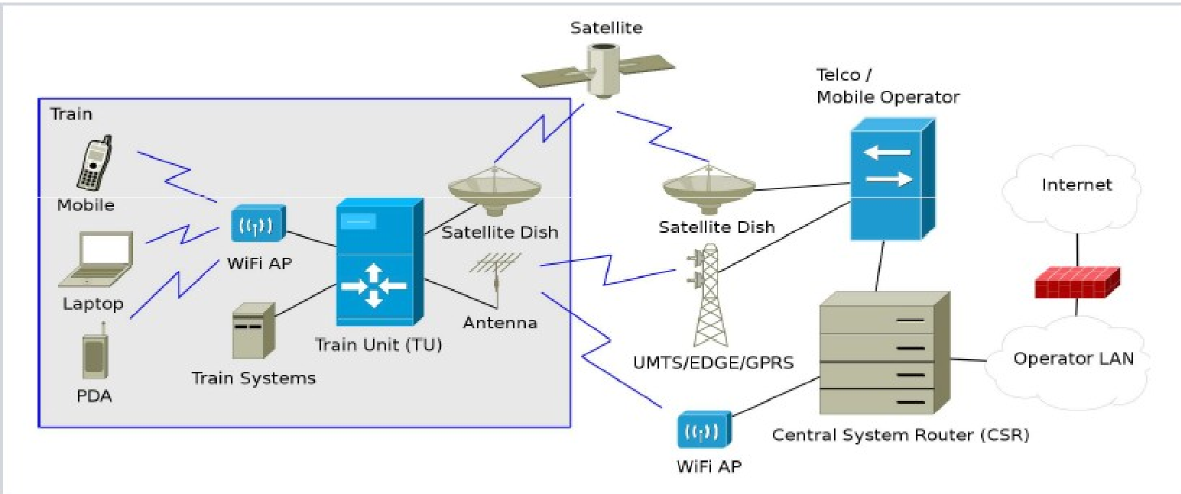
- Communication based on radio transmission in the 2.4 GHz ISM Band (Possible adaptation in the range 2 GHz to 6 GHz (5.9GHz used in Paris metro)
- Use of Direct Spread Spectrum Sequence modulation (DSSS) , with long spread sequence (128 chips) , optimized CRC and specific modulation-demodulation (ASIC ICARE) to optimize management of tunnel multipath propagation
- Transmission organized in geographical cells and time sharing (TDMA: synchronized cycles composed of communication slots)
- No jamming between wayside transmitters within a cell, and with the adjacent cells and no jamming between trains
- 64 Kbits/s data rate
- Data encryption
- Dynamic signing management
- Seamless roaming: Nominal=0ms, 256 ms in case of single failure.




System Overview

Airlink media features[3]:

- Wireless Passenger Internet
  - No special setup required
  - In-train caching for improved performance
- Custom Networks
  - Routed to the land side
  - Possible applications:
    - Maintenance Data
    - Passenger Information System
    - CCTV
    - Passenger Counting
    - Public Address
- Each network usage is kept separate
  - prioritized delivery to land side
- GPS
  - In-train units can subscribe to Train Unit GPS data
- Scalability
  - New Train Units can easily be added to the system, even after launch
- Maintenance
  - Train Unit software can be updated remotely
- Adaptation
  - The Train Unit can be extended with new functionality




Airlink Media System Architecture

## *Interlocking and wayside information integration*

Sicas is an electronic interlocking system that offers sophisticated functionality. Sicas electronic interlockings monitor, set and control signals, switches and routes.
Several interlocking computers can be interconnected and positioned centrally or decentralized. Furthermore, the fail safe connection of outdoor components and interfacing to operations control and train control system is possible. It uses a 2-out-of-3 configuration or 2x2-out-of-2 configuration to ensure highest availability.
Main functionalities:

- Control and detection of switches, signals and other outdoor components
- Route setting and releasing
- Connection of intermittent and continuous train control systems
- Relief operations and cancellation of operator actions
- Locking and unlocking of individual elements

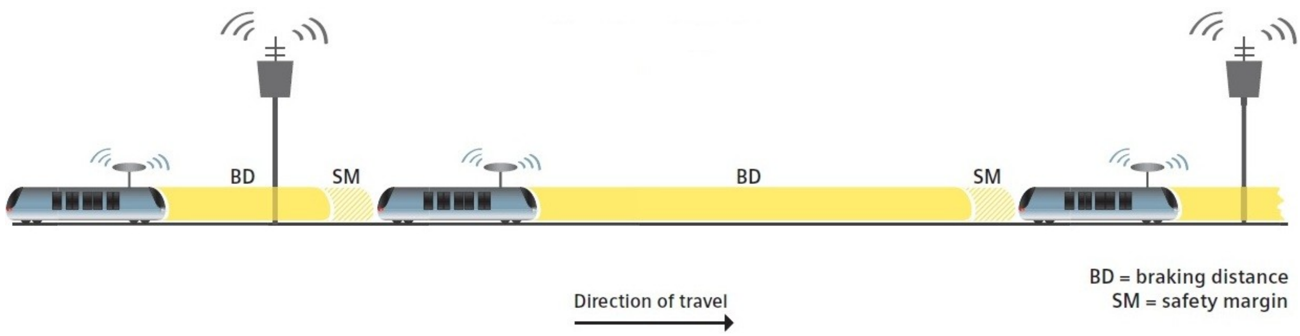
### *ATS functions*

The main functions implemented include [5]:

- Controlling and supervision of power supply
- Monitoring and supervision of trains and wayside equipment
- Regulation of traffic
- Enforcement of the schedule
- Route Setting
- Train tracking
- Mission management
- Automatic train storage, insertion and removal
- Audio and visual monitoring of trains and platforms
- Management of remote diagnostic, preventive maintenance

### *Headways*

Optimised headway by the use of moving blocks whose size is adapted to the characteristics of each single train. The required distance between two trains is calculated by taking the braking distance of the rear train at the current speed and adding a safety margin. This margin is constantly recalculated during the journey [14].




Moving block

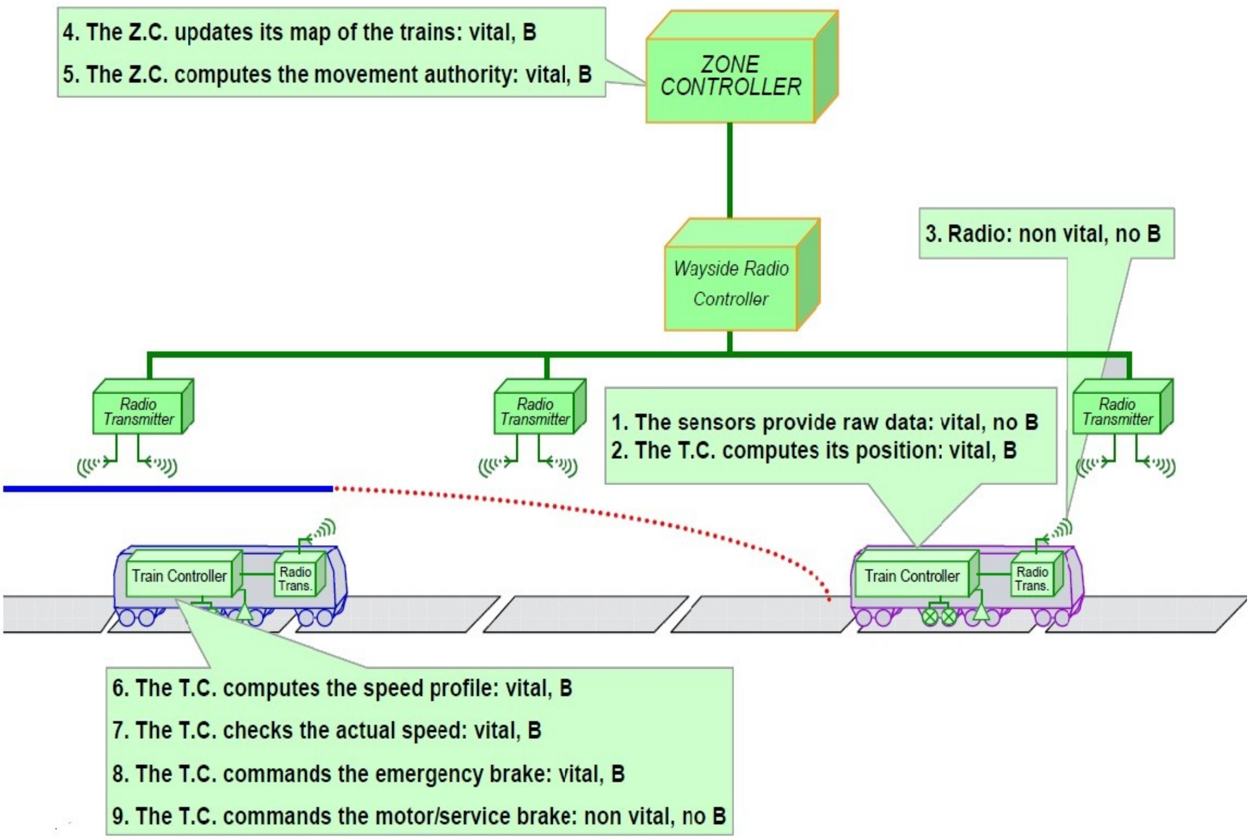
### *Braking models and speed limit protection*

Train-borne CBTC subsystem, CC (Carborne Controller) : every train unit is equipped with a CC which [13]:

- computes the speed profile;
- checks the actual speed;
- commands the emergency/service brake.

Wayside CBTC subsystem, including a ZC (Zone Controller) : the equipped network is divided into one or several zones, each one equipped with a ZC. The ZC:

- protects train movement;
- is the central point where the track data base of the ZC controlled area is inserted in the system and provides this track data base to the trains;
- is the central point where the speed restrictions are managed for the ZC controlled area;
- Vital tracking of trains;
- Authorized movement direction management;
- Moving Blocks anti-collision;
- Supervision of wayside equipment and report failures;
- Compensation of signaling failures.




Train protection

## *Train speed and train location determination*

The precise train location is ensured by on board CBTC system using radar and odometer pulse generator [1]. The doppler radar sensor measures the train speed over ground by applying the Doppler effect, while the odometer pulse generator measures the distance by counting the pulses derived from wheel rotation. Trainguard MT uses intelligent sensor fusion algorithms for ensure precise detection of the train speed and distance.
The ACM axle counting system is used by Trainguard MT as a reliable track vacancy detection system. Nevertheless, Trainguard MT also allows using other kinds of track vacancy detection

systems (e.g. track circuits) .

### *Door Management*

Train doors and platform screen doors management are provided by the on board CBTC system.

### *ATO Functions*

The ATO functions provided are [14]:

- automatic train supervision;
- automatic driving between stations: using the stored route profile, the ATO component calculates how it should accelerate and brake before bends or switch points in order to arrive at the next station on time while using the minimum amount of energy;
- automatic stopping (in station) and opening of doors;
- automatic turn back of the trains at any point on the line enabling a flexible management of traffic (Alger, Line 1) [7].

### *Service-oriented facilities*

- CCTV
- Passenger Information System
- Internet-on-Board
- Entertainment
- Media Content Platform
- At-seat Audio
- Enhanced Cellular Coverage

### *Technical features Trainguard MT*

The technical features of some projects are summarized in this table [6][7][8][9][10][11].

| METRO LINES | HEADWAY | SPEED | LINE LENGTH | CAPACITY | DATA COMUNICATION |
|---|---|---|---|---|---|
| Paris, Ouragan | 90 sec | 97 km/h (MAX) | 17 km | 50 trains | free propagation radio |
| Alger, Line 1 | 110 sec | over 28.5 km/h (OPERATIONAL) | 10 km | 22 trains | free propagation radio |
| Budapest, Line M2 | 94 sec | 32 km/h (OPERATIONAL) | 11 km | 26 trains | free propagation radio |
| New York | 94 sec | 97 km/h | 17 km | 53 trains | free propagation radio |

| | | | | | |
|---|---|---|---|---|---|
| City, Canarsie Line | | (MAX) | | | |
| Barcelona, Line 9 | 80 sec | 33 km/h (OPERATIONAL) | 44 km | 50 trains | free propagation radio |
| Paris, Line 14 | 85 sec | ND | 8 km | 45/48 trains | inductive loops |

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# COMPARATIVE TABLE OF CBTC SYSTEMS

| *CBTC TOPIC* | **ALSTOM** | **ANSALDO STS** | **BOMBARDIER** | **INVENSYS** | **SIEMENS** | **THALES** |
|---|---|---|---|---|---|---|
| **Operating mode management** | Fully UTO, DTO | Fully UTO, DTO | Fully UTO, DTO<br>Mixed mode | Compatible with “Speed Codes” and “Distance to go” systems | Interlocking train control, Intermittent train control (ITC) , Continuous train control (CTC) | Fully UTO, DTO<br>Mixed mode |
| **Safety and failure management** | Maintenance Support Sytem (MSS) , digital track circuits | Interlocking to secondary systems. | full secondary signalling.<br>Solution based on the EBI Lock 950 Computer Based Interlocking (CBI) .<br>‘Cold’ start-up | Maintenance Aid System (MAS) , Track Circuit, 2 out of 3 voting architecture | Communication: spatial diversity, time diversity, frequency diversity; Safe emergency evacuation | redundant computer systems |
| **System architecture** | WS: ATS, Zone Controller, Maintenance Support Sytem, Interlocking, Eurobalise,<br>PSD, Communication Equipment<br>TS: ATP, ATO, PIS, Odometry, Communication Equipment | WS: ATS, Zone Controller, Beacon Tag<br>TS: Carborne Controller Mobile Antennas, Beacon Tag Reader | WS: Central Control System, Central Control Network, Region ATP, Region ATO, Region BDR, Region Radiax Cable, Norming Point<br>TS: VATP, VATO, Norming Point Reader, Mobile Antenna. | WS: ATS, Interlocking, Passive Beacon,Trackside Communication Controller, Maintenance Aid System, Virtual Block Processor, Radio Equipment<br>TS: ATP, ATO, Train and platform Door Control, Odometry, Driver Machine Interface, Mobile Antenna | WS: ATS, Interlocking, Eurobalise, Radio equipment, ATC, Axle Counter<br>TS: ATP, ATO, Mobile Antenna, Balise Antenna, Doppler radar, Odometer Pulse Generator, HMI | WS: Control center or System Management Center (SMC) , Vehicle Control Computer (VCC) or Zone controller (ZC) , Communications Subsystem (Inductive Loops or Radio) , Balise<br>TS: Mobile Antennas (for RF o IL) Vehicle On-board Controller (VOBC) , Balise reader |
| **Communication infrastructure and protocol** | IEEE 802.11 g/a with Free propagation/Leaky Feeder/Wave Guide | Train-wayside protocol: RF: IEEE 802.11<br>Fully redundant configurations. | RF leaky coaxial cable or Line of Sight (LOS)<br>To train IEEE-1473 protocol. | Digital Radio System with Spread Spectrum technology and IP protocols | Radio System with Spread Spectrum Sequence modulation | Train-wayside protocol: IL Proprietary but based upon LZB & 56 kHz carrier.<br>RF: IEEE 802.11<br>On board RF: CAN and IEEE 802.3 |
| **Interlocking and wayside information integration** | SMARTLOCK system | | Built-in interlocking function is located with the regional wayside ATP or add optional EBI Lock computerbased interlocking | WESTRACE Mk2 | SICAS system | LockTrac 6131 ELEKTRA |
| **ATS functions** | commands to signaling devices/trains, train tracking, automatic route setting, automatic traffic regulation | | Manual override requests, Management of train schedules and route assignments,Remote set or reset of emergency | traffic control, speed restriction, remote train control | traffic control, route setting, train tracking, remote diagnostic, control of power supply | Train departure, destination assignments and identification assignment, Train routing functions, Modification of the |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | brakes, Control of any power distribution system, voice communication with the train and supervision | | | system operations parameters in response to system delays and Control Room commands, Data logging, Station platform information display (PID) control, Station platform announce |
| **Headways** | 90 s | 60s | 75s | 80 s | 80 s | 60s |
| **Braking models and speed limit protection** | | | | | | The system allows four service brake rates ranging from 0.4 to 0.8 ms^ (-2) . Safety calculations are based on an emergency brake rate of 0.9ms^ (-2) |
| **Train speed and train location determination** | EUROBALISE, odometer on the axles of train | track side beacon to receive the absolute position and on board odometer | “Moving Block Coordinate System” (MBCS) and “Passive Tag” containing “Location Data”.<br>max speed 80km/h | Odometry based in tachogenerators and Doppler, Absolute Position Reference passive balise | Doppler radar, odometer pulse generator, ACM axle counting system<br><br>97km/h | IL: tacho-generators, used to measure speed, direction and distance in conjunction with an accelerometer. SELTRAC train position detection system<br>- a transmission based, moving block system - provides a 6.25 meter resolution<br>RF: use the trackside transponder tags assist in train positioning |
| **Door management** | Train and platform doors management provided by ATO | The system ATO functions allows you to make small movements to center doors<br>(Undershoot recovery Overshoot recovery) | Door control requests are issued by the ATO system (both onboard and wayside) . Stopping by the train at stations with a typical accuracy of +/- 15 cm | PSD management: loops located at the station points of the stations | Provided by the onboard CBTC system | |
| **ATO functions** | Movement train control, repositioning in station, correct stop management, reverse management, doors management | Speed regulation, Management of programmed stops, Management of Platform Screen doors, Skip Stop, Management of overshoot ad undershoot, Automated coupling & decoupling, Energy consumption management and optimization, Routine maintenance | Ride Comfort Control, Stopping accuracy, Train operation according to commanded speed profile, Door Control Requests, Onboard and Wayside Passenger Announcement | N/A | Automatic train supervision, automatic driving, automatic stopping and opening of doors, automatic turn back | Control train movement with regard to speed, acceleration, deceleration, and jerk. |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Service-oriented facilities** | PIS, CCTV, Supervisory Control and Data Acquisition, alarms, fire detections, emergency calls | Closed Circuit TV, Obstacle detection system, Loudspeakers in stations and trains, Information displays in stations and trains, Emergency Call Points in stations and trains. | Passenger information displays (PIDs) ,<br>CCTV (Closed Circuit TV) ,<br>Public announcement (PA) ,<br>Radio,<br>Telecoms | Traction power supply, tunnel ventilation, CCTV, passenger information, passenger counting, voice communications, passenger alarm | CCTV, PIS, Internet-On-board, entertainment, Media Content Platform, At-seat audio, Enhanced Cellular Coverage | CCTV, Public announcement, Audio and video recording, Phone system and emergency, Advertising information system audio / video, Supervisory Control and Data Acquisition (SCADA) , Emergency call points allow direct communication with passengers from centralised Operational control centre, Access control |

# COMPARATIVE TABLE OF CBTC SYSTEMS *vs* IEEE 1474.1-2004 STANDARD

| **Standard IEEE 1474.1-2004** | **Requirements** | **Alstom** | **Ansaldo** | **Bombardier** | **Siemens** | **Invensys** | **Thales** |
|---|---|---|---|---|---|---|---|
| **4. General Requirements** | operating modes, management of transition areas, management of degraded modes | | | | | | |
| **4.1 Characteristics of CBTC systems** | train location determination independent of TC, continuous communication, vital processor | | | | | | |
| **4.2 Categorization of CBTC systems** | ATP functions mandatory, ATO-ATS optional | | | | | | |
| **4.3 Range of applications** | heavy rail, light rail, commuter rail, people mover, etc. | Heavy rail (?) | Heavy rail (?) | Madrid and Taipei | Heavy rail (?) | Heavy rail (?) | Heavy rail (?) |
| **4.4 Train configurations** | fixed/variable length, uni/bi-directional | fixed/variable length (?) | | fixed/variable length (?) | fixed/variable length (?) | fixed/variable length (?) | fixed/variable length (?) |
| **4.5 Train operating modes** | zero/single/multi-person (door attending) crew; driverless (crew for failure modes recovery) /unattended (no crew) ; CBTC/mixed-mode (non-CBTC equipped trains or for fall-back plan with auxiliary system or procedure - REQUIRED) | fall-back with TC and signals | fall-back with TC and signals | fall-back with TC and signals | fall-back with TC and signals | mixed-mode (?) - driverless/unattended (?) | fall-back with TC and signals |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **4.6 Entering/exiting CBTC territory** | checks before entering CBTC territory and on-board/ATS notification; on-board notification before exiting | (?) | (?) | (?) | (?) | (?) | dual-fitted area |
| **4.7 Train operating speeds** | decided by the authority, ensure no conflict with the standard requirements | | | | | | |
| **5. Performance requirements** | headyways, trip times, RAMS | | | | | | |
| **5.1CBTC factors contributing to achievable headways** | interferred/uninterferred headways (preceeding train affecting/not affecting speed profile of the following train) ; factors affecting headways are location, speed, communication delay, CBTC equipment reaction times, performance limitation (e.g., max num of trains) , ATO algorithm | quantitative headways, no formula/factors explanation | quantitative headways, no formula/factors explanation | quantitative headways, no formula/factors explanation | quantitative headways, no formula/factors explanation | quantitative headways, no formula/factors explanation | quantitative headways, no formula/factors explanation |
| **5.2 CBTC factors contributing to achievable trip times** | same as headways' factors; minimum trip time for uninterferred headways | (?) | (?) | (?) | (?) | (?) | (?) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **5.3 System safety requirements** | System Safety Program Plan (SSPP) shall be issued for each CBTC application; Preliminary Hazard Analysis (PHA) and Risk Assessment for (minimum) train-to-train collision, train-to-structure collision, derailment, highway vehicles collision, hazard to work crew and passengers, hazard related to objects along the track; MTBHE = 10^9 hours; protection against hardware failure | (?) | hazards to passenger control, obstacle detection | (?) | (?) | (?) | (?) |
| **5.4 System assurance requirements** | 3 types of failures (and associated quantitative evaluation) : (1) affecting on-time performance (MTTRS - mean time to restore service) (2) affecting functionalities (MTBFF) (3) no impact (MTBF) ; design life of 30years required; MTTR (1) = 30min; MTTR (2) = 2h | (?) | (?) | (?) | (?) | (?) | (?) |
| **5.5 Environmental requirements** | Train-borne IEEE Std 1478-2001; Wayside IEEE P1582/D1.0 | (?) | (?) | (?) | (?) | (?) | (?) |
| **6. Functional requirements** | functions in ATP, ATO and ATS | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **6.1 ATP functions** | train speed/location determination (self-initializing, no manual intervention) ; secondary train location determination; safe train separation (MA) ; safe braking model; overspeed protection and brake assurance (monitoring) ;rollback;end-of-track; coupling/uncoupling of trains and parted consist protection; zero speed detection; door control monitoring; emergency braking; route interlocking; train reversal interlock; workzone protection; broken rail detection; grade-crossing | all functions implemented, no detail on grade-crossing, train reversal, broken rail and others | all functions implemented, no detail on grade-crossing, train reversal, broken rail and others | all functions implemented, no detail on grade-crossing, train reversal, broken rail and others | all functions implemented, no detail on grade-crossing, train reversal, broken rail and others | all functions implemented, no detail on grade-crossing, train reversal, broken rail and others | all functions implemented, no detail on grade-crossing, train reversal, broken rail and others |
| **6.2 ATO functions** | automatic speed regulation; platform berthing (also for multiple trains) ; door control; | | | | | (?) | |
| **6.3 ATS functions** | display data and user information according to IEEE Std 1474.2-2003; user can override any functionality of ATS; train identification and tracking; train routing; schedule regulation; energy optimization; stop trains; workzones; interface to passengers; fault-reporting | No info about interfaces conformance to the standard | No info about interfaces conformance to the standard | Passenger information implemented by the ATO system. No info about interfaces conformance to the standard | No info about interfaces conformance to the standard | No info about interfaces conformance to the standard | No info about interfaces conformance to the standard |
| **6.4 Interoperability interface requirements** | authority dependent | (?) | (?) | (?) | (?) | (?) | (?) |

Legend:

- The gray color indicates: No information about that function.
- The green color indicates: Functionality is implemented.
- The orange color indicates: Functionality is implemented, but a few  information about that function.