Application of communication based Moving Block systems on existing metro lines

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Abstract

The unique features of Communication Based Train Control (CBTC) systems with Moving Block (MB) capability makes them uniquely suited for application 'on top' of existing Mass Transit or Metro systems, permitting a capacity increase in these systems. This paper defines and describes the features of modern CBTC Moving Block systems such as the *Bombardier* CITYFLO** 450 or *CITYFLO* 650 solutions that make them suited for 'overlay' application 'on top' of the existing systems and gives an example of such an application in a main European Metro. Note: *Trademark (s) of Bombardier Inc. or its subsidiaries.
Keywords: CBTC, Moving Block, CITYFLO, TRS, Movement Authority, norming point, headway.

1 Introduction

The use of radio as a method of communication between the train and wayside in Mass Transit systems, instead of the traditional track circuits/axle counters and loops is gaining popularity. The radio based CBTC systems are uniquely suited for application 'on top' of existing Mass Transit or Metro systems for increased traffic capacity as CBTC systems normally do not interfere with the existing systems. This allows an installation of the CBTC system in a line in operation whilst maintaining full safety and capacity during the process.

The fact that CBTC systems also allow Moving Block operation adds to the possible increased traffic capacity that can be achieved with such systems.

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2 Definitions

2.1 Communication Based Train Control (CBTC)

Although the term Communication Based Train Control in theory allows for any 'contact-less' communication between train and wayside, in this paper the term is used to designate the more modern type of CBTC system using radio as the communication medium.

2.2 Moving Block (MB)

The traditional Mass Transit systems using track circuits or axle counters as a method for detecting the presence of the train are 'fixed block'; the block being defined as the fixed length of the track circuits and axle counters. In CBTC systems radio is used as the communication medium, enabling the position of the train to be sent by the train itself and in turn making it possible to have a 'moving block' operation (or more accurately a 'moving and variable block' operation) as there is no equipment with fixed lengths in the system.

A moving block system allows the trains to run closer to each other compared to a conventional fixed block system, thus reducing the possible headway.

However, CBTC systems may also operate within a 'fixed block' mode, if so desired, thus permitting increased compatibility with traditional systems, while compromising on the headway.

2.3 Movement Authority (MA)

A Movement Authority is defined as the authority for a train to safely proceed up to a certain point where it has to stop. In fixed block systems, the Movement Authority consists of a locked train route starting at a certain signal with a proceed aspect and ending at another signal with a stop aspect, passing through one or more track sections.

In a CBTC *fixed block* system the Movement Authority is set from the predetermined block point where the train is to a predetermined point on the track, normally the end of a track circuit or similar.

In a CBTC *moving block* system the Movement Authority is set from the exact point where the train is to a 'conflict point' in the track ahead of the train.

In a CBTC system with constant update of information about the train's position and constant renewal of the Movement Authority the train will be allowed to proceed without braking as long as there is no conflict point within braking distance ahead of it.

2.4 Conflict Points (CP)

A Movement Authority for a train always ends at a 'conflict point' ahead of the train. A 'conflict point' is defined as:

A location along the track beyond which a train *NOT* permitted.

A CBTC system utilizes these conflict points to properly and safely manage the movement of trains throughout any metro line. A conflict point can either be *static*, meaning that its location in the track is fixed or *dynamic*, which means that its location is a moving train. An example of a static conflict point is a buffer stop at the end of the line and an example of a dynamic conflict point is the end of the train in front.

Furthermore, a conflict point can have two states - *mutable* of *immutable*. A mutable conflict point can be either *active*, meaning it is a conflict point, or *inactive*, meaning it is not a conflict point. Immutable conflict points are always conflict points.

Examples of typical conflict points are:

Table 1: Typical conflict points.

Conflict Point	**Type of Location**	**State**	**Active/Inactive**
Rear of Train in Front	Dynamic	Immutable	always active
Buffer stop	Static	Immutable	always active
Point	Static	Mutable	active / inactive

3 Elements of a typical modern CBTC system

Broadly speaking, a modern CBTC system can be said to consist of four parts:

- the **Control Centre System** which controls the operation
- the **Wayside System** which receives train positions and issues Movement Authorities to assure the safe running of the trains
- the **Vehicle System** that generates the train position and receives the Movement Authorities and assures the compliance of the Movement Authorities and
- the **Communication System** which allows the transfer of messages to and from the train.

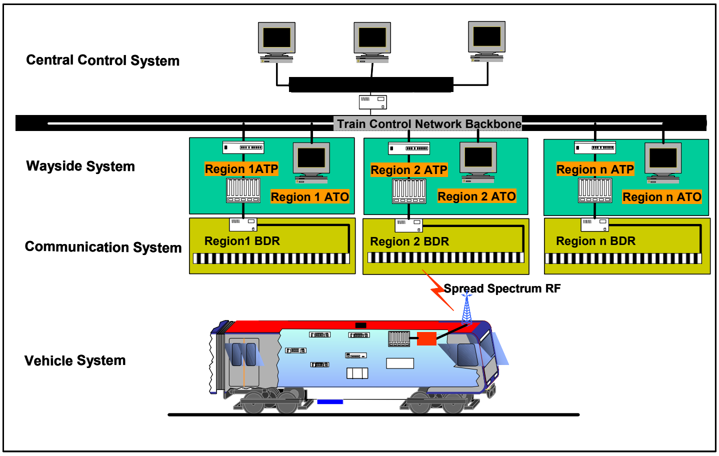

Figure 1: Block Diagram of a modern CBTC system.

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3.1 The Control Centre System

The Control Centre System normally consists of 'off the self' servers and operator's work stations that run the CBTC application. The Control Centre System allows operators to direct trains from one location to another, turn them around at the end stations, or in the middle of the line, and permits trains to leave and enter the depot(s).

All modern CBTC Control Centres also have programs for automatic driving of the trains without operator intervention, allowing either regulation by time table or by headway.

Furthermore a modern Central Control System also has control of auxiliary functions like Passenger Information Systems (PID), Telephone Systems and CCTV systems. In many cases the Central Control System also contains the SCADA systems for control of auxiliary systems such as traction, escalators and air conditioning.

The Central Control System is always duplicated in modern systems in order to achieve the availability needed.

3.2 The Wayside System

For Mass Transit lines of normal lengths, the wayside equipment is distributed along the line and divided into parts, often 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.

The Wayside System components are operationally redundant for the highest availability.

3.3 The Vehicle System

3.3.1 ATP and ATO System

The Vehicle System mounted onboard the train contains the equipment needed to acquire all the information from the train and the track, to process it and to transmit the train position to the Wayside System. It also contains the equipment that receives the Movement Authorities from the Wayside equipment and displays this information to the driver and controls the driving of the train through the ATP and ATO.

The Vehicle System is designed in such a way that the systems installed in each end of the train can be used as replacement for each other thus creating a duplication of equipment, in order to achieve the highest availability.

3.3.2 Train Position System

Since the train in a CBTC system is transmitting its position to the Wayside System, the train must know where it is in the network. This is achieved using the regions and then subdividing the regions into segments. Within the segments, the train is using its onboard tacho-generator and or other sensors to measure the distance from the start of the segment (offset). The figure below shows how regions, segments and offsets are used to define the train's position.

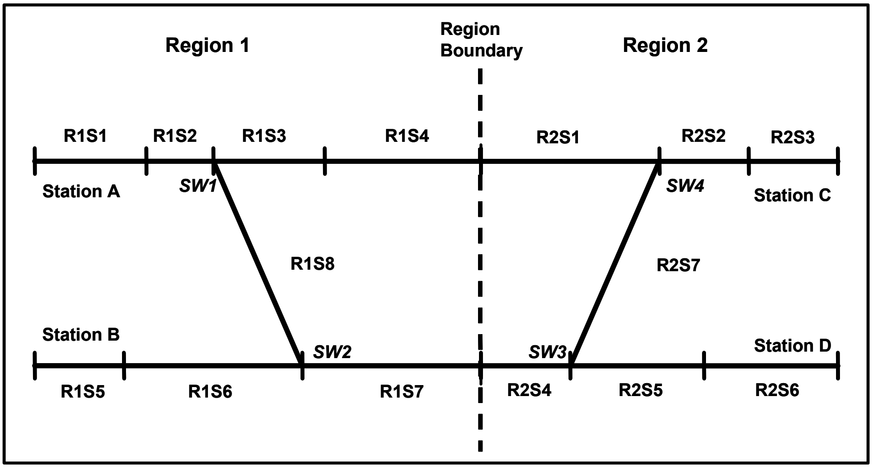

Figure 2: How regions and segments are used for train positioning.

In a *CITYFLO* 450 or *CITYFLO* 650 system, the train's position is sent to the Wayside System as region number, e.g. 'R1', segment number, e.g. 'S3' and offset from the start of the segment, e.g. 500m. The complete position would then be: 'R1, S3+500'.

To correct any errors in the position measurements made by the tacho-generator 'Norming Point' balises are used which are mounted along the track. When a train passes over such a balise it provides an exact location of the train and the Vehicle System can correct for any errors in the position of the rain. As the train moves away from the 'Norming Point', the position error will start to increase and this will again be corrected at the next 'Norming Point'.

3.4 The Communication System

The communication system in modern CBTC systems is based on radio transmissions, often in the 2.4 GHz ISM band and often using a spread spectrum technique to reduce the chances of interference from other systems.

The communication medium can be based on 'line of sight, or leaky coax using a RADIAX cable, or both depending on the application.

All communication system components, except the antennas or the RADIAX cable, are also duplicated.

3.5 The Train Registry System

One of the few 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. Although system stops in CBTC systems are unlikely due to the fact that nearly all components are duplicated, having to drive the trains manually could be very time consuming, sometimes taking an hour or more for larger metro systems.

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.

4 Application example, overlaid CBTC system for European Metro

4.1 Background

Most European metros were established some time ago and by now many of them will need a modern signalling system for one or several of its lines in order to increase their transport capacity. Normally there is in such a metro an existing fixed block, speed-step signalling system, with an older ATP and ATO which is working at full capacity and can not be upgraded.

Many such metros recognize that to install a moving block CBTC system is the only way forward. The solution they often arrive at is to overlay a CBTC moving block system ‘on top’ of the existing signalling system in order to achieve a ‘dynamic headway’ of down to 40 seconds, i.e. a headway calculated without the station dwell times, and to be installed without affecting the passenger safety or transport capacity in the process.

As this often is their first experience with CBTC systems, most metros would like to have a conventional system as ‘fall-back’, should the CBTC system fail. Finally, although often the proposed CBTC system would have a driver onboard, the system itself is more often than not required to be capable of being upgraded to a fully driverless system.

The selection of the *CITYFLO* 450 system from Bombardier Transportation to re-signal a metro line with these requirements will lead to the following system solution.

4.2 The system solution

The requirements of overlaying the CBTC system on the existing signalling system along with providing a fall-back system, to assure full safety and transport capacity during the installation and to be able to meet the dynamic headway requirement of 40 seconds lead to a system solution shown below, and which uses several of the unique features of the *CITYFLO* 450 system.

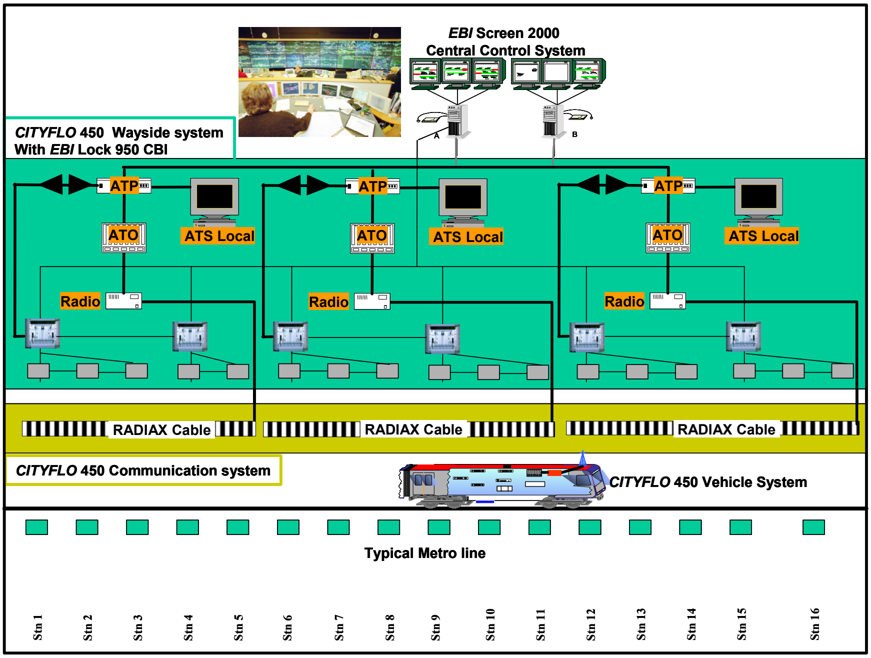

Figure 3: Typical Metro System solution.

4.2.1 Meeting the 'overlay' requirement

The *CITYFLO* 450 system uses radio for communication between wayside and train. The train position is determined by the onboard ATC equipment and communicated to the wayside ATC over the radio. The system does not need track circuits or other form of wayside interface for safe operation and therefore, can be easily 'overlaid' on top of an existing signalling system.

4.2.2 Meeting the 'fall-back' requirement

CBTC is relatively new technology and even though metros around the world are beginning to embrace this new technology for the obvious benefits it is likely to bring, the approach is cautious. Choosing to operate the system with drivers initially is a result of such caution even though there are a number of metros which already operate driverless trains using CBTC systems. Requirement for a 'back-up' signalling system is another example of such cautious approach. Even though modern radio systems are highly reliable, due to the nature of the CBTC systems, a single loss in the communication chain can bring any system to a grinding halt. Even though highly unlikely, metros often require the system to continue to operate under such a situation.

In such cases 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. *EBI* Lock 950 CBI was first introduced in 1976 and is currently in its fourth generation. The interlocking has certain special features that make it ideal for Mass Transit applications and especially for co-operation with the *CITYFLO* 450 system. Note: *Trademark of Bombardier Inc. or its subsidiaries.

In particular, as the interlocking allows the outputs to the wayside objects like signals, point machines and object controllers to be located at practically any distance from the central interlocking unit, it has been possible to use the capacity of each central unit in two to three metro stations using fibre optic cable as communication medium. This has allowed the number of interlockings needed for each line to be reduced.

The *EBI* Lock 950 CBI and the *CITYFLO* 450 systems communicate with each other over a safe serial link. While the *EBI* Lock 950 interfaces with the wayside objects, the *CITYFLO* 450 manages the communication between the trains and wayside ATC. The movement authority is generated as a safe and optimum balance between the trains' reported position and the actual track occupancies. In normal operation when the *CITYFLO* 450 system controls the operation of the trains, the computerized interlocking will act as little more than a conduit between the CBTC system and the object controllers controlling the wayside objects, with only basic functionality.

Should the *CITYFLO* 450 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.

4.2.3 Meeting the requirement to maintain safety and capacity during installation

The existing onboard ATP/ATO equipment in the trains will be removed when the *CITYFLO* 450 vehicle equipment is installed on a train. Therefore, it is necessary to choose a system solution that allows safe 'coexistence' between trains equipped with the old ATP/ATO and trains equipped with the *CITYFLO* 450 ATP/ATO without affecting the performance.

To this end, the *CITYFLO* 450 system will have information from the existing track circuits and will therefore distinguish between a train with the old ATP/ATO occupying a track circuit and a train with the *CITYFLO* 450 ATP/ATO occupying a track circuit. The latter train is also sending information via radio about its position while the former is not. This leads to four driving mode cases:

1. A train equipped with the old ATP/ATO equipment following another train equipped with the old ATP/ATO equipment will follow the existing rules and leave two un-occupied track circuits between them.
2. A train equipped with the *CITYFLO* 450 ATP/ATO equipment following a train equipped with the old ATP/ATO equipment can advance up to the end of the track circuit before the one occupied by the previous train.
3. A train equipped with the old ATP/ATO equipment following a train equipped with the *CITYFLO* 450 ATP/ATO equipment must also follow the existing rules and leave two un-occupied track circuit between them.

4. A train equipped with the *CITYFLO* 450 ATP/ATO equipment following another train with the *CITYFLO* 450 ATP/ATO can use the Moving Block capability in the CBTC.

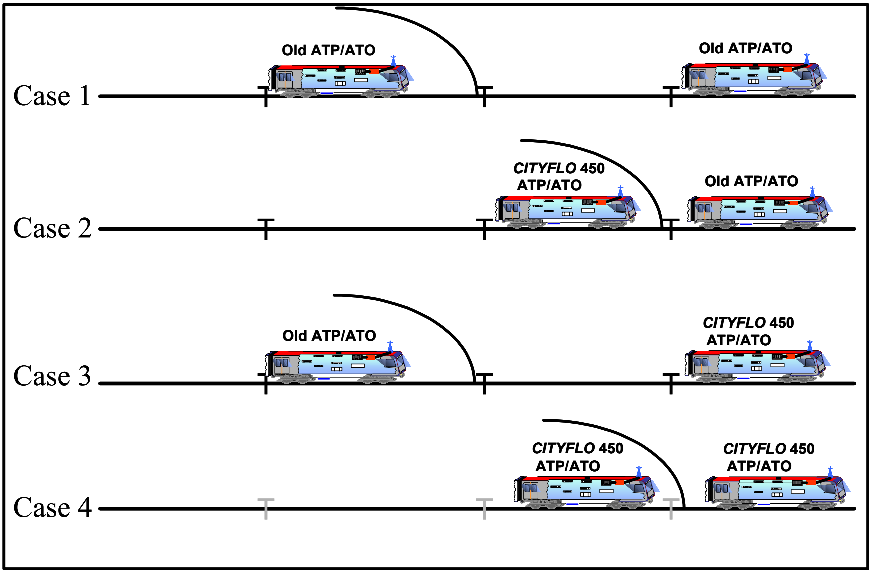

Figure 4: The four driving mode cases during system installation.

4.2.4 Meeting the headway requirement

If the dynamic headway requirement set up is 40 seconds, i.e. with a dwell-time of zero seconds in each station, the trains working in CBTC moving block mode would be separated by 40 seconds.

A modern CBTC system with moving block operation where the train 'footprint' or part of the track considered to be 'occupied' by the train is the train length plus a speed dependent 'buffer' area around the train. Moving and variable block, by its nature allows the trains to circulate closer to each other than fixed block system. The *CITYFLO* 450 system with its efficient radio communication has a demonstrated dynamic headway of about 15-20 seconds in other projects. Taking into consideration, the track and rolling stock characteristics of a typical metro it is nearly always possible to demonstrate in an operational simulation that the required dynamic headway will be met with *CITYFLO* 450 system.

4.2.5 Meeting the requirement for upgrading to a driverless system

The *CITYFLO* 450 CBTC moving block system with a driver is a version of the *CITYFLO* 650 CBTC moving block driverless system belonging to the same system family. It is therefore relatively easy to upgrade the signalling system itself to driverless operation.

Signalling systems have been capable of operating trains without driver for over two decades now. The issue is the compatibility of the infrastructure, i.e.

stations, tunnels and trains for driverless operation, especially the perceived security aspect and emergency procedures. Significant investment will be required for upgrading an existing metro system in order to adapt to the operational requirements of a driverless system.

5 Brown field Installations, a challenging implementation

For many European metros it will be their first experience in installing CBTC on an existing infrastructure although several CBTC systems have been installed in other metros in new lines. In such an installation we normally have to deal with a number of challenging issues such as:

1. The *CITYFLO* 450 system uses Radiax cable as a medium for train to wayside communication. The cable can be mounted between the tracks, on the tunnel wall or overhead. While mounting the Radiax hanging from the tunnel roof between the two tracks would be logical, in many cases it is not considered feasible due to access restrictions, and instead the location is often changed to the tunnel wall. This requires two sets of Radiax cables to be laid – one on each sidewall impacting the cost and schedule of installation.
2. During the proposal phase, it is often envisaged to interface the onboard ATC equipment to two, three or more different types of trains. On detailed survey, it is often revealed that the interfaces are not uniform even on each type of train, which certainly increases the scope and complexity of the adaptation task.
3. The biggest challenge that awaits a project team is implementation of the system without affecting the existing operation. Most metros, operates 20 hrs each day and therefore only a short time window is available to access the track to perform installation activities. A meticulous planning, rigorous project management and strict organisational regime will be necessary in order to exploit this short access effectively.
4. Our experience on delivering similar application of CBTC to the LRT project in Philadelphia (SEPTA), USA suggests that the driver training for any new system is an onerous task. While, the normal train drivers are familiar with ATP/ATO operation, they will have to be trained in using the new operator console. The effort required in educating the different operational modes of this implementation, i.e. driving under CBTC (without signals), and under 'fall-back' mode (with signals), can not be underestimated.

6 Conclusion

The paper has demonstrated that a modern CBTC system with moving block capability and using modern computerized interlockings can be 'overlaid' in order to increase the transport capacity (throughput) of an existing Metro or Mass Transit line while maintaining the safety and the capacity of that line during the installation process.