Feasibility study of ring topology CBTC system with information sharing among onboard and switch controllers

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1. Introduction

Background

• A lot of projects are planned to expand railway networks worldwide.
• In those project, reduction of Infrastructure cost is strongly desired.
• Most signalling equipment still has a complex structure.
• In particular, the cost of trackside central controllers is relatively high.

We propose

• a new cost-effective CBTC system without trackside central controllers.

We provide

• clear solutions to the identified problems of the proposed system through feasibility study for ensuring the technical validity.
2-1. Existing signalling systems (1/2)

Traditional ATP system

- Before CBTC, many pieces of field equipment were required for signalling.

These many devices were centrally-controlled by trackside central controllers in an effective way.
Conventional CBTC system

• Track circuits and signals were eliminated by radio transmission of train position and movement authority.

To control only onboard and switch controllers, the central control logic was still unchanged.
We think a central control architecture is no longer effective for signalling.

**Concept**

- Onboard and switch controllers work autonomously with information sharing by circulating telegram containing necessary information for signalling instead of central controlling by trackside controllers.

![Diagram showing onboard and switch controllers with information sharing](image)
Fundamental principle: Traditional token block logic

- Traditional token block logic will be applied to virtual blocks on train routes.

When train enters virtual block, it must have exclusive right (electronic token) of that block.

If train can acquire the exclusive right of block, it is allowed to extend limit of movement.
Fundamental principle

✓ These exclusive rights (electronic tokens) of virtual blocks are controlled on one telegram, ‘circular safety telegram’, circulating among onboard and switch controllers via radio, just like traditional token exchange between train driver and station staff.

+ Control and status information of switches is included into that telegram so that the train can control switches, when it has the exclusive right to the block containing the switches.
Onboard controllers can recognise the limit of movement in accordance with the exclusive rights to the blocks on the telegram.
4-2. System functionalities (2/2)

Route control (Interlocking)

Onboard controllers can control switches and confirm those status by the instructions and status information on the telegram.

Circular safety telegram

<table>
<thead>
<tr>
<th>Instruction to Switch</th>
<th>Status of Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>#11 Reverse</td>
<td>Unlocked</td>
</tr>
<tr>
<td>#11 Reverse</td>
<td>Reverse Locked</td>
</tr>
</tbody>
</table>

✓ The proposed system can perform these signalling functions without trackside central controllers (ATP and interlocking).
5-1. System benefits (1/2)

Simple architecture

• **Onboard controllers** update limit of movement and braking pattern within the acquired blocks, and control the train’s speed based on the braking pattern in the same way as the conventional CBTC system.

• **Switch controllers** turn and lock the switches according to the instructions in the telegram, and update the status of the corresponding switches on the telegram.

• **ATS system** provides traffic management instructions to each controller on the basis of the timetable and dispatcher’s order.

• **Radio system** provides wireless data transmission among the above 3 sub-systems.

The proposed system is realized through only 4 sub-systems, and this configuration can facilitate system deployment and migration.
5-2. System benefits (2/2)

Cost reduction

So far, the cost of trackside central controllers accounted for a major proportion of the total equipment cost of the existing systems, because high-performance failsafe hardware and software were needed to centrally-control the system.

The total equipment cost of the proposed system is expected to be approximately 1/3 that of a conventional CBTC system.

*estimated from cost reference data
*(Price and Costs in the Railway Sector, Baumgartner, J. P. 2001/1)
Measures against telegram loss

Telegram loss is critical failure mode of the proposed system because it is the key to reliability and safety.

- The high-confidence telegram transmission methods commonly used in a conventional CBTC system, should be implemented.
- Against unavoidable telegram loss, ATS assigns one healthy SIL4 controller as a temporary data collector to restore the telegram.

**Circular safety telegram**

**Redundant architecture**

Telegram

- user data
- CRC code

**Error-detecting code**

**Reliable retransmission protocol**

**System resumption procedure in conjunction with ATS system**

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Measures against increase in train headway

Train and switch control may be delayed because each controller receives the new information only by telegram circulation.

- The number of controllers circulating one telegram is minimized by dividing line into small sections and circulating a telegram for each section.
- Reservation system for exclusive right and control instruction is introduced so that switch controllers can recognise the instruction as soon as possible.

**Section partitioning**

**Reservation system**

1. Release
2. Instruct
3. Recognize

(1) Release & Activate
(0) Reserve in advance
(2) Recognize
(3) Recognize

Delete its ID from member list

Request to join
7-1. Case study (1/2)

Case study: train headway at intermediate station

Conventional CBTC:

\[ T_{\text{headway}} \geq (28.5 + 30.0 + 1.5) \times 1.1 = 66.0 \text{ s} \]

Ring topology CBTC:

\[ T_{\text{headway}} \geq (29.5 + 30.0 + 1.5) \times 1.1 = 67.1 \text{ s} \]

\( \checkmark \) No problem

Assumptions

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train length</td>
<td>54 m</td>
</tr>
<tr>
<td>Acceleration</td>
<td>3.6 km/h/s</td>
</tr>
<tr>
<td>Service braking deceleration</td>
<td>2.4 km/h/s</td>
</tr>
<tr>
<td>Emergency braking deceleration</td>
<td>3.6 km/h/s</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>60 km/h</td>
</tr>
<tr>
<td>Limited speed within station area</td>
<td>30 km/h</td>
</tr>
<tr>
<td>Train separation margin</td>
<td>20 m</td>
</tr>
<tr>
<td>Virtual block length</td>
<td>5 m</td>
</tr>
<tr>
<td>Switch turning time</td>
<td>5 s</td>
</tr>
<tr>
<td>Station stoppage time</td>
<td></td>
</tr>
<tr>
<td>- intermediate station</td>
<td>30 s</td>
</tr>
<tr>
<td>- terminus station</td>
<td>60 s</td>
</tr>
<tr>
<td>Data transmission time (radio/wired)</td>
<td>0.5/0.25 s</td>
</tr>
<tr>
<td>Headway margin</td>
<td>10 %</td>
</tr>
</tbody>
</table>
7-2. Case study (2/2)

Case study: train headway at terminus station

Conventional CBTC:  
\[ T_{\text{headway}} \geq (77.3 + 0.0 + 5.0) \times 1.1 = 90.5 \text{ s} \]

Ring topology CBTC:  
\[ T_{\text{headway}} \geq (77.3 + 0.0 + 24.0) \times 1.1 = 111.4 \text{ s} \]

[Based on the worst-case scenario for telegram circulation]

- Physical restriction
- Operational restriction
- Information transmission
- Margin factor

For middle level line
✓

For high-density line
✗

Fixed telegram circulation order causes delay due to unnecessary information transmission.

Sometimes the telegram is not circulated to an appropriate controllers, such as an approaching train, a departing train, and instructed switch controllers, in a timely manner.

We will investigate

algorithms for changing the circulation order dynamically, to transmit the telegram to the appropriate controller in a timely fashion.
We proposed the new cost-effective signalling system, ‘ring topology CBTC’.

It provides signalling functionalities equivalent to those in existing signalling systems without trackside central controllers.

Through feasibility study about reliability and capacity, solutions to some concerns were devised, i.e. high-confidence telegram transmission, system resumption by temporarily assigning a data collector, section partitioning, and reservation of exclusive rights to virtual blocks and control instructions to switches.

A result of case study of train headway showed that the proposed system can be applied to many middle level railways (headway $\geq 120s$) except to high-density mass transit systems (headway $\leq 90s$) in megacities.
8-2. Future works

We will develop

a prototype controller, and

algorithms for changing the circulation order dynamically in conjunction with ATS system for applying the proposed system to high-density mass transit.

Thank you very much for your attention.