Broadband Communication Architectures for Train to Ground Communication Services

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Outline

- Context & Motivation
- Research goal
- Research Methodology
  - Railway Communication Context Characterization
  - Survey on Train to Ground Communication Architectures
  - The WiMAX opportunity and limitations
- The WEWBRA architecture (Description & Performance Evaluation)
- Enhancing the handover process
- Conclusions and contributions
- Open Research Lines & European Related Research Projects
- Our Lab
Increasing demand for environment-friendly transport modes such as the rail transport, including metro, light rail and heavy rail

ERRAC vision
European Research Advisory Council

Rail transport in 2020 will double its share in freight and passenger markets

Safety
Efficiency
Competitiveness
Sustainability
Context II

Safety
Efficiency
Competitiveness
Sustainability

Traffic Management
System

Railway Communication
Technologies and
Architectures

Traffic Management Centre

Remote Control Centre

Interlocking

Railway Communication
All kind of voice and data communication

Traffic Management
- Strategic Management, Planning

Signalling System
- Control of level crossings
- Control of Switch points
- Control of line side signals
- etc..

Train Control-command
- Automatic train command with in-cabin signalling
- Train-side location based block control
- etc..
Context III

Mobile Communication Generation

Railway Communication Technologies and Architectures

Traffic Management Information System & Train Control System

Mobile Communication Generation

Mobile Technology Evolution

GSM, IS-95

TETRA versión 2

3GPP, 3GPP2

GT800 (Huawei)

UIC751-3

end of 1970s

end of 1980s

middle of 1990s

end of 1990s

beginning of 2000s

Railway Technology Control Evolution
Motivations I: ERTMS – European Railway Traffic Management System

ERTMS, the signalling and management system for Europe, enabling interoperability throughout the European Rail Network

**ERTMS = ETCS + GSM-R**

ETCS is the control-command system
GSM-R is the radio system for voice and data communication.

Diagram:
- ETCS Application
- Open Communication system GSM-R
- GSM-R radio transmission
- ETCS application protocol
- Radio protocol

Train-Side

Track-Side
Motivations II : ERTMS – European Railway Traffic Management System

European Railways, following the MoU, will use GSM-R as the "bearer service" for their communications (including ETCS).

However, future applications demand more capacity. Some national applications (already today, e.g. shunting) need higher data rate wireless technology.
Motivations III : GSM-R Limitations

- GSM-R is a 2G communication system
  Transmission data rate just 9.6 kbps
  Even considering immediate GSM-R evolution (HSCSD, GPRS, EDGE..)
  difficult to reach emerging and future railway communication services

- Limited frequency availability
  Current deployments present limitations for offering available traffic channels for high priority connections (ETCS services) at borders and congested crossing or busy junctions

- GSM-R deployments unaffordable or unsustainable for emerging countries, secondary or low density lines

Consequently, UIC (Union Internationale des Chemins de Fer) is initiating follow-up GSM-R deployment research projects towards an European Railway IP Infrastructure
Motivations IV: Emerging and future applications in the railway domain

Although traditionally narrowband technologies have supported signalling and control systems …

- Real-time access from the control centre to on-board telemetry information
- Optimal train operation (golden run), optimize energy consumption (green concern)
- On-route information about the proximity of other trains, their route, speeds, etc..
- Support for remote train approaches
- Visualization from the control centre of the route ahead the train, any emergency situation and yard congestion status
- **Video surveillance**, including identification and detection in real time of misleading behaviours that may affect passenger safety
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Opportunity

- Cellular
  - 1G
  - 2G
  - 3G
  - 4G
- Broadband Wireless
  - 802.16e
  - 802.16m
- Wireless LAN
  - 802.11a/b/g
  - 802.11n

All roads lead to OFDM & MIMO. Mobile WiMAX (802.16e) is already there.
Motivations IV: The need for a specific railway communication architecture

 Different philosophy:
  - Traditional public communication architectures designed for financial return
  - Railway communication architectures are designed to cater to the stringent performance requirements

  Train control systems and other information systems for operational goals are designed to meet very stringent safety standards (RAMS, SIL levels) & legislative requirements

 While in traditional public communication architectures **handover process** is a rare exception, in railway communication architectures is the rule

Railway context benefits:
- Highly predictive mobility pattern
- Low loaded telecom networks
- Pre-established data application profile
Research question

Which communication architecture for train to ground communication is currently a good candidate for supporting enhanced IT communication services in the railway context?

Understanding architecture

• as a radio access technology, network topology and protocols
• which is based on standardized and open broadband wireless communication technology

The research focuses on Train control systems and Information services for operational goals:

• ETCS service
• VoIP &
• Video surveillance service in uplink stream

We focus on train to ground bidirectional communication not in V2V or inside network…
Research Methodology

- Railway Context Characterization from the Telecom Point of View:
  - Functional Requirements
  - Performance Requirements

- Train to Ground Communication Network Reference Model

- Survey on RAT and on the Aggregation and Distribution Network

- End-to-End Proposed Architecture

- Performance evaluation of the Proposed Communication Architecture in different railway operation scenarios: busy junctions, two train crossing
The Railway Context

Railway trends regarding IT services

Suppress cables, open technologies, minimize obsolescence, well proven technologies

EIRENE specification & ITU Recommendations for IP and Ethernet services

EIRENE project, launched after the decision to adopt GSM-R, specifies the necessary requirements to cope with the ETCS data traffic, with special emphasis in the QoS parameters

General Requirements for communication technologies in the railway domain

Broadband Wireless Digital Access Support, high mobility support, high data rate support, low latency, end-to-end, advance security scheme, scalability, extensibility, coverage, operate at unlicensed and licensed exempt frequencies ....

Functional & Performance Requirements

ETCS service
Voice service
Video Surveillance Service
## The Railway Context

### Functional & Performance Requirements (KPIs)

<table>
<thead>
<tr>
<th>FIRENE ETCS &amp; Voice (KPIs)</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection establishment delay (CED)</td>
<td>&lt; 8.5 s (95%) ≤ 10 s (100%)</td>
</tr>
<tr>
<td>Maximum end-to-end transfer delay (30 byte data block) (TED)</td>
<td>≤ 0.5 s (99%) ≤ 400 to 500 ms</td>
</tr>
<tr>
<td>Average end-to-end transfer delay</td>
<td></td>
</tr>
<tr>
<td>Network registration delay (NRD)</td>
<td>≤ 30 s (95%), ≤ 35 s (99%), ≤ 40 s (100%)</td>
</tr>
<tr>
<td>Handover effective time (between BSS)</td>
<td>&lt; 300 ms</td>
</tr>
<tr>
<td>Transmission Data Rate</td>
<td>≥ 2.4 kbps</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CCTV QoS Parameter (KPIs)</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Throughput</td>
<td>&gt; 384 kbps</td>
</tr>
<tr>
<td>End-to-end transfer delay</td>
<td>&lt; 60 ms</td>
</tr>
<tr>
<td>Packet delay variation within a flow</td>
<td>&lt; 20 ms</td>
</tr>
<tr>
<td>Information Loss PER (Packet Error Rate)</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>One way Radio Access Network Transfer Delay</td>
<td>&lt; 25 ms</td>
</tr>
<tr>
<td>Handover delay</td>
<td>&lt; 50 ms</td>
</tr>
<tr>
<td>Bounded Packet loss during handover</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>
## General Requirements for communication technologies in the railway domain

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Satellite</th>
<th>GSM-R</th>
<th>HSPA</th>
<th>LTE</th>
<th>PMR</th>
<th>DVb-H</th>
<th>IEEE 802.11p</th>
<th>IEEE 802.16</th>
<th>HAPs</th>
<th>IEEE 802.22</th>
<th>IEEE 802.20</th>
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<tbody>
<tr>
<td><strong>High Speed Veh. Support</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>HR capability</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>High Data Rate Support</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Low Latency</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Wide Radio Coverage</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td><strong>Advanced Security Scheme</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>End2End QoS Support (MAC layer)</strong></td>
<td>NA</td>
<td>NA</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td><strong>Maturity</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Mesh Support</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Licensed exempt operation</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Wireless</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Full stack E2E Arch. (all IP)</strong></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td><strong>Data Rate</strong></td>
<td>Varies from two Mbps up to 48 Mbps</td>
<td>9.6 Mbps</td>
<td>Useful: 10/84.8 Mbps</td>
<td>Useful: 75/27.6 Mbps</td>
<td>7.2 Mbps</td>
<td>Downlink 99 Mbps</td>
<td>10-20 Mbps</td>
<td>1.56 Useful: 40/14 Mbps</td>
<td>1.56 Useful: 16/5 Mbps</td>
<td>varies</td>
<td>19 Mbps</td>
</tr>
</tbody>
</table>
Strategies in the aggregation/distribution network

The aggregation and distribution network aggregates the data traffic coming from the different BSs placed along the rail net

Main requirements:

• High Data Rate Support
• Wide Radio Coverage → maximize dwelling time/handover ratio
• End-to-end quality of service support
• Low latency
• Support for advanced security scheme
• Wireless versus a wired solution is promoted
• Mature, standardized, cost effective solution

<table>
<thead>
<tr>
<th>Access Network</th>
<th>Aggregation Network</th>
<th>Status</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERTMS (GSM-R)</td>
<td>GSM-R</td>
<td>ISDN</td>
<td>Exploitation</td>
</tr>
<tr>
<td>ICOM</td>
<td>Heterogeneous</td>
<td>Heterogeneous</td>
<td>Lab Demonstration</td>
</tr>
<tr>
<td>BOSS</td>
<td>IEEE802.16</td>
<td>Ethernet over Fibre</td>
<td>Testbed</td>
</tr>
<tr>
<td>FAMOUS</td>
<td>RoF</td>
<td>Ethernet over Fibre</td>
<td>Research Study</td>
</tr>
<tr>
<td>SWIFT</td>
<td>IEEE802.16m</td>
<td>Ethernet over Fibre</td>
<td>Research Study</td>
</tr>
<tr>
<td>OCEAN</td>
<td>3G</td>
<td>Unspecified (IP cloud)</td>
<td>Research Study</td>
</tr>
</tbody>
</table>
WEWBRA Scenario & Information Flow Representation

a WiMAX/IEEE802.16 based extension of a Metro area Ethernet network to a Wide Broadband wireless area Network for train to ground communication in the RAilway scenario.
Performance Evaluation Methodology:

- Field tests
- Simulation Tool Choice
- WEWBRA extensions implementation in the WiMAX official model
- Modelling the IT railway services under the thesis scope
  - ETCS service
  - VoIP and Video Surveillance application in Uplink stream
- Validating data traffic profile
- Devising challenging railway Use Cases:
  - Single train
  - Two train crossing
  - Busy junctions
- Last stage:
  
  To verify that the WEWBRA architecture meets the demanded KPIs for the different railway applications under study and in the different proposed railway use cases.
WEWBRA Performance Evaluation: Field Tests

**Alvarion BreezeNET B (2005)**
- OFDM, TDD technology
- Unlicensed 5Ghz bands
- Frequency 5.4Ghz, Band:
- Data communication 802.11
- Performance in NLOS env.
- Up to 54Mbps

**Motorola Canopy**
- Ethernet bridging & backhauling
- Outdoor radio
- Unlicensed 5 Ghz bands
- Frequency 5.4Ghz
- Useful (data) aggregate throughput from 6.8 upto 7.5Mbps.

Straight trajectory upto 60Km/h
2.05 MB data transfer rate

Upto 120Km/h
1.08 MB data transfer rate
WEWBRA Performance Evaluation: Simulation Tool Choice

Problem

In 2006 WiMAX equipment very expensive unstable & not certified

High speed scenarios are really complex testbeds

From the research point of view:

Need for implement and test in the simulation scenario specific protocols and devices not yet available in the market

Solution

belongs to the Academic Tier from the OPNET WiMAX Model Development Consortium since September 2006
WEWBRA Performance Evaluation: WiMAX Opnet Model current features

**MAC**
- IP convergence sub-layer
- Service flow configuration and mapping traffic to service flows
- Bandwidth request and grant mechanisms
- BS scheduler for uplink and downlink connections
- Scheduling service for UGS, ertPS, rtPS, nrtPS, BE
- Adaptive modulation and coding
- MSDU packing and fragmentation
- ARQ
  - In-order SDU delivery
  - Cumulative ACKs
  - Fragmentation and packing
- HARQ
- Scanning-based BS selection
- Handoff mechanisms for mobility
- ASN based mobility
- Power saving mode

**PHY**
- TDD
- OFDMA, SOFDMA
  - Preset values for SOFDMA (FFT 128, 512, 1024, 2048)
- Co-channel interference
  - Perm-base
  - Sub-carrier overlap computation
- 2x1 MIMO STC
- Multi-path fading
  - ITU models (Pedestrian A, Pedestrian B, Vehicular A, Vehicular B)
  - Finite state Markov channel models
- Path-loss modeling
  - ITU (Pedestrian, Vehicular)
  - Erceg (terrains A, B, C)
- Ranging (initial and periodic)
- Uplink power control
WEWBRA Performance Evaluation: Modelling the ETCS service

Source: Commercial ETCS application data log 50Km run

Identifying the main routines (standard based research):

- Connection established
- Validated Train Data
- Position Report
- General Message
- Movement Authority
- Movement Authority Request
- Disconnection

Building a new ETCS application using the ACE Whiteboard tool

Identifying and designing new statistics on simulation platform
Identifying the main routines

**Connection established:**
This routine takes place every time a new train initiates its mission and during the train handover procedure between RBCs.

Message 155: Initiation of a Communication Session  
Message 32: Configuration Determination  
Message 159: Session Established.

**Validated train data:**
This routine takes places every time the train connects to a new RBC and after the train passes through the first balise group.

Message 129: Validated Train Data  
Message 8: Acknowledgement of Validated Train Data  
Message 146: Acknowledgement
Identifying the main routines

**Position Report (PR):**

Each time a train passes through a balise group a message is launched from the train to the RBC reporting balise group identification and consequently train position.

**Movement authority (MA):**

The RBC sends the movement authority to the train and then this message is acknowledged by the train.
Identifying the main routines

**Movement authority request (MAR):**

This routine is initiated in the train. In our simulation we launch it periodically. The frequency introduced is such that the total number of messages matches with the one provided in the trace file.

Message 132: Movement Authority Request

**General message (GM):**

This routine is initiated in the RBC every 15 seconds sending a message type 26. The train then answers back with an ACK message.

Message 26: General Message
Message 146: Acknowledgement
Identifying the main routines

**Disconnection:**

This routine takes place whenever the train ends its connection to a RBC: end of mission or RBC handover procedure.

Message 156: Termination of a Communication Session
Message 39: ACK of Termination of a Communication Session
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBC_coverage</td>
<td>Double</td>
<td>40.000000</td>
<td>Distance covered by an RBC (km)</td>
</tr>
<tr>
<td>Balise_dist</td>
<td>Double</td>
<td>150.000000</td>
<td>Distance between balises (m)</td>
</tr>
<tr>
<td>RBC_overlap</td>
<td>Double</td>
<td>6000.000000</td>
<td>Overlap between RBCs (m)</td>
</tr>
<tr>
<td>path</td>
<td>String</td>
<td>Documents and Settings\op_models\</td>
<td>Trajectory files' path</td>
</tr>
<tr>
<td>subnet</td>
<td>String</td>
<td>Campus Network</td>
<td>Name of the scenarios' subnet</td>
</tr>
<tr>
<td>balise_range</td>
<td>Double</td>
<td>20.000000</td>
<td>Maximum range of a balise (cm)</td>
</tr>
<tr>
<td>max_speed</td>
<td>Double</td>
<td>200.000000</td>
<td>Maximum speed the train can reach (km/h)</td>
</tr>
<tr>
<td>MA_freq</td>
<td>Double</td>
<td>65.000000</td>
<td>Frequency of “Movement Authority” messages (s)</td>
</tr>
<tr>
<td>MR_freq</td>
<td>Double</td>
<td>170.000000</td>
<td>Frequency of “Movement Authority Request” messages (s)</td>
</tr>
<tr>
<td>GM</td>
<td>Double</td>
<td>15.000000</td>
<td>Frequency of ‘General Message’ sent by RBC (s)</td>
</tr>
<tr>
<td>units</td>
<td>Integer</td>
<td>1</td>
<td>kilometres (0) metres (1)</td>
</tr>
<tr>
<td>RBCs</td>
<td>Integer</td>
<td>5</td>
<td>Number of active RBCs in the scenario</td>
</tr>
<tr>
<td>Movement</td>
<td>Integer</td>
<td>1</td>
<td>Indicates whether a defined trajectory is declared for every train (1) or all trains will remain still (0)</td>
</tr>
<tr>
<td>log</td>
<td>Integer</td>
<td>1</td>
<td>Save the message log (1)</td>
</tr>
</tbody>
</table>
### WEWBRA Performance Evaluation: Modelling the ETCS service

#### Building an ETCS service on a general purpose Network Simulator

<table>
<thead>
<tr>
<th>ID</th>
<th>Source</th>
<th>Destination</th>
<th>Bytes</th>
<th>Tag Description</th>
<th>Subtask</th>
<th>Connection</th>
<th>Depends On</th>
<th>Processing Time</th>
<th>User Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Train</td>
<td>RBC1</td>
<td>32</td>
<td>Position Report</td>
<td>&lt;None&gt;</td>
<td>ID: 17</td>
<td>0.000000</td>
<td>0.000000</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Train</td>
<td>RBC1</td>
<td>32</td>
<td>Position Report</td>
<td>&lt;None&gt;</td>
<td>ID: 19</td>
<td>0.000000</td>
<td>0.000000</td>
<td></td>
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<tr>
<td>16</td>
<td>Train</td>
<td>RBC1</td>
<td>32</td>
<td>ACK</td>
<td>&lt;None&gt;</td>
<td>ID: 20</td>
<td>0.000000</td>
<td>0.000000</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Balle Group</td>
<td>Train</td>
<td>32</td>
<td>Position Info</td>
<td>&lt;None&gt;</td>
<td>ID: 23</td>
<td>0.000000</td>
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<td>0.450000</td>
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<tr>
<td>24</td>
<td>Train</td>
<td>RBC1</td>
<td>32</td>
<td>Position Report</td>
<td>&lt;None&gt;</td>
<td>ID: 24</td>
<td>0.000000</td>
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<td></td>
</tr>
<tr>
<td>25</td>
<td>Balle Group</td>
<td>Train</td>
<td>32</td>
<td>Position Info</td>
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<td>ID: 25</td>
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<td>0.540000</td>
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<td>27</td>
<td>Train</td>
<td>RBC1</td>
<td>32</td>
<td>Position Report</td>
<td>&lt;None&gt;</td>
<td>ID: 27</td>
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<tr>
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<td>32</td>
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<td>ID: 29</td>
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<tr>
<td>30</td>
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<td>32</td>
<td>Position Report</td>
<td>&lt;None&gt;</td>
<td>ID: 30</td>
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<tr>
<td>31</td>
<td>Train</td>
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<td>10</td>
<td>Termination of a communication session</td>
<td>&lt;None&gt;</td>
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<tr>
<td>32</td>
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<td>Train</td>
<td>10</td>
<td>ACK of a communication session</td>
<td>&lt;None&gt;</td>
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<tr>
<td>46</td>
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<td>RBC2</td>
<td>32</td>
<td>Position Report</td>
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<td>ID: 35</td>
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<tr>
<td>47</td>
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<td>Movement Authori</td>
<td>&lt;None&gt;</td>
<td>ID: 36</td>
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</tbody>
</table>
Scenario & Information Flow Representation

CSN - Connectivity Service Network

Operational Control Center Network
- Video Server
- Maintenance Server
- VoIP ...
- ETCS server

ASN - Access Service Network

WEWBRA Node A

WEWBRA Node B

WEWBRA Node C

On-board Network

Wireless Link
ETCS application log vs Commercial Real ETCS data log

<table>
<thead>
<tr>
<th>Time</th>
<th>Position</th>
<th>Origin</th>
<th>Destination</th>
<th>Id</th>
<th>Tipo de Mensaje</th>
<th>Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:33:30</td>
<td>1.50000</td>
<td>Winmax_train</td>
<td>RBC 0</td>
<td>146</td>
<td>Acknowledgement</td>
<td>22</td>
</tr>
<tr>
<td>12:33:30</td>
<td>1.60000</td>
<td>Winmax_train</td>
<td>RBC 0</td>
<td>136</td>
<td>Position Report</td>
<td>32</td>
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<tr>
<td>12:33:30</td>
<td>1.80000</td>
<td>Winmax_train</td>
<td>RBC 0</td>
<td>136</td>
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<td>12:33:30</td>
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<tr>
<td>13:00:00</td>
<td>2.00000</td>
<td>RBC 0</td>
<td>Winmax_train</td>
<td>24</td>
<td>General Message</td>
<td>18</td>
</tr>
<tr>
<td>13:00:00</td>
<td>2.02192</td>
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<td>146</td>
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<td>14:00:00</td>
<td>2.02192</td>
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<td>RBC 0</td>
<td>136</td>
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<td>32</td>
</tr>
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<td>14:00:00</td>
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<td>RBC 0</td>
<td>136</td>
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<td>15:00:00</td>
<td>2.50000</td>
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<td>Winmax_train</td>
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<td>General Message</td>
<td>18</td>
</tr>
<tr>
<td>15:00:00</td>
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<td>Winmax_train</td>
<td>RBC 0</td>
<td>146</td>
<td>Acknowledgement</td>
<td>22</td>
</tr>
<tr>
<td>15:00:00</td>
<td>2.500192</td>
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<td>136</td>
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<td>16:00:00</td>
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<tr>
<td>17:00:00</td>
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<td>Winmax_train</td>
<td>RBC 0</td>
<td>136</td>
<td>Position Report</td>
<td>32</td>
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</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Position</th>
<th>Speed</th>
<th>Source</th>
<th>RBC</th>
<th>Id</th>
<th>Tipo</th>
<th>Bytes</th>
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<tbody>
<tr>
<td>5:10:49 PM</td>
<td>866</td>
<td></td>
<td>TRAIN</td>
<td>2</td>
<td>146</td>
<td>Acknowledgement</td>
<td>22</td>
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<tr>
<td>5:10:53 PM</td>
<td>837</td>
<td>70719.5</td>
<td>TRAIN</td>
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<td>136</td>
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<td>32</td>
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<tr>
<td>5:10:58 PM</td>
<td>902</td>
<td>70886.2</td>
<td>TRAIN</td>
<td>2</td>
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<tr>
<td>5:11:03 PM</td>
<td>838</td>
<td>71052.8</td>
<td>TRAIN</td>
<td>2</td>
<td>136</td>
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<td>32</td>
</tr>
<tr>
<td>5:11:04 PM</td>
<td>682</td>
<td></td>
<td>RBC</td>
<td>2</td>
<td>24</td>
<td>General Message</td>
<td>18</td>
</tr>
<tr>
<td>5:11:04 PM</td>
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<td></td>
<td>TRAIN</td>
<td>2</td>
<td>146</td>
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</tr>
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<td>5:11:08 PM</td>
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<td>TRAIN</td>
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<td>136</td>
<td>Position Report</td>
<td>32</td>
</tr>
<tr>
<td>5:11:13 PM</td>
<td>886</td>
<td>71386.2</td>
<td>TRAIN</td>
<td>2</td>
<td>136</td>
<td>Position Report</td>
<td>32</td>
</tr>
<tr>
<td>5:11:18 PM</td>
<td>838</td>
<td>71552.9</td>
<td>TRAIN</td>
<td>2</td>
<td>136</td>
<td>Position Report</td>
<td>32</td>
</tr>
<tr>
<td>5:11:19 PM</td>
<td>682</td>
<td></td>
<td>RBC</td>
<td>2</td>
<td>24</td>
<td>General Message</td>
<td>18</td>
</tr>
<tr>
<td>5:11:19 PM</td>
<td>868</td>
<td></td>
<td>TRAIN</td>
<td>2</td>
<td>146</td>
<td>Acknowledgement</td>
<td>22</td>
</tr>
<tr>
<td>5:11:22 PM</td>
<td>199</td>
<td>71652.9</td>
<td>TRAIN</td>
<td>2</td>
<td>136</td>
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<td>32</td>
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<td>5:11:23 PM</td>
<td>949</td>
<td>71719.5</td>
<td>TRAIN</td>
<td>2</td>
<td>136</td>
<td>Position Report</td>
<td>32</td>
</tr>
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<td>5:11:28 PM</td>
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<td>71886.1</td>
<td>TRAIN</td>
<td>2</td>
<td>136</td>
<td>Position Report</td>
<td>32</td>
</tr>
</tbody>
</table>
Small differences due to:

- Frequency and MA size
- Handover Routine: backbone communication

<table>
<thead>
<tr>
<th></th>
<th>ETCS real data trace (40 min)</th>
<th>ETCS simulation data (40 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (sec)</td>
<td>2.400</td>
<td>2.400</td>
</tr>
<tr>
<td>Nº Message sent</td>
<td>1.017</td>
<td>981</td>
</tr>
<tr>
<td>Nº Bytes aplication</td>
<td>31.479</td>
<td>29.958</td>
</tr>
<tr>
<td>Message/min</td>
<td>25.42</td>
<td>24.52</td>
</tr>
<tr>
<td>Bytes/message</td>
<td>30.952</td>
<td>30.538</td>
</tr>
<tr>
<td>Bytes/sec</td>
<td>13.11</td>
<td>12.48</td>
</tr>
</tbody>
</table>
ETCS deployment
Use Case: Railway Operational Scenarios

- Scenario A: Single Train Scenario
- Scenario B: Two Train Crossing
- Scenario C: Busy Juctions
Scenario A: Single train & ETCS traffic

- Connection establishment delay
- Average end-to-end transfer delay
- Cumulative distribution Function vs KPI
- Handover delay and Serving BS id
- Transmission Data Rate
- Transmission Data Rate with heavy FTP
## Scenario A: Single train & ETCS traffic

<table>
<thead>
<tr>
<th>QoS Parameter</th>
<th>EIRENE Value</th>
<th>WiMAX based Arch. ETCS Aplication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection establishment delay of mobile originated calls (CED)</td>
<td>$&lt; 8.5s$ (95%), $\leq 10s$ (100%)</td>
<td>$&lt; 1.5$ s (100 %)</td>
</tr>
<tr>
<td>Maximum end-to-end transfer delay (30 byte data block) (TED)</td>
<td>$\leq 500ms$ (99%)</td>
<td>$&lt; 350ms$ (100 %)</td>
</tr>
<tr>
<td>Average end-to-end transfer delay</td>
<td>$\leq 400$ to $500ms$</td>
<td>$&lt; 130$ ms</td>
</tr>
<tr>
<td>Network registration delay (NRD)</td>
<td>$\leq 30s$ (95%), $\leq 35s$ (99%), $\leq 40s$ (100%)</td>
<td>No appliance</td>
</tr>
<tr>
<td>Handover effective time (between BSs)</td>
<td>$&lt; 300ms$</td>
<td>25 ms</td>
</tr>
<tr>
<td>Transmission Data Rate</td>
<td>$\geq 2.4$ Kbps.</td>
<td>Upto 10 Mbps</td>
</tr>
</tbody>
</table>
Busy Junctions

Scenario Details

40 trains supporting ETCS traffic
### WEWBRA Performance Evaluation: Validation Results

#### Use Case I: Single train scenario
- **Connection establishment delay (CED)**
  - EIRENE Value: ≤ 8.5s (95%) ≤ 10s (100%)
  - ETCS application in WEWBRA Arch.: ≤ 1.5s (100%)
  - VoIP application in WEWBRA Arch.: ≤ 0.17s (100%)
- **Maximum end-to-end transfer delay**
  - ≤ 0.5s (99%)
  - ≤ 400 to 500ms
  - Average end-to-end transfer delay:
    - ≤ 0.2s (100%)
    - ≤ 130 ms
    - < 90 ms (100%)
    - < 85 ms
- **Handover effective time (between BSs)**
  - EIRENE Value: ≤ 300ms
  - ETCS application in WEWBRA Arch.: 25 ms
  - VoIP application in WEWBRA Arch.: 25ms

#### Use Case II: 2 Trains crossing
- **ETCS application in WEWBRA Arch.**
  - < 1.3s (100%)
  - > 110 ms
- **VoIP application in WEWBRA Arch.**
  - < 0.095s (100%)
  - < 95 ms

#### Use Case III: Busy Junctions
- **ETCS application in WEWBRA Arch.**
  - < 1.9s (100%)
  - < 65 ms (100%)
- **VoIP application in WEWBRA Arch.**
  - < 0.5s (98.5%)
  - < 1s (100%)
  - < 90 ms (100%)
  - < 95 ms
  - < 0.5s (99.08%)
  - < 1.2s (99.91%)
  - < 0.2s (100%)
  - < 95ms

<table>
<thead>
<tr>
<th>QoS Parameter</th>
<th>Use Case I</th>
<th>Use Case II</th>
<th>Use Case III</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connection establishment delay</strong></td>
<td></td>
<td><strong>ETCS application</strong></td>
<td><strong>ETCS application</strong></td>
</tr>
<tr>
<td>EIRENE Value</td>
<td>≤ 8.5s</td>
<td>≤ 1.3s (100%)</td>
<td>&lt; 1.9s (100%)</td>
</tr>
<tr>
<td>(CED)</td>
<td>(95%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10s (100%)</td>
<td>≤ 1.5s</td>
<td></td>
<td>≤ 65 ms (100%)</td>
</tr>
<tr>
<td>ETCS application in WEWBRA Arch.</td>
<td>(100%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VoIP application in WEWBRA Arch.</td>
<td>≤ 0.17s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(100%)</td>
<td>≤ 0.2s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 130 ms</td>
<td>≤ 90 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 400 to 500ms</td>
<td>≤ 85 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average end-to-end transfer delay</td>
<td>≤ 0.5s</td>
<td>≤ 0.5s (98.5%)</td>
<td>&lt; 95ms</td>
</tr>
<tr>
<td>(30 byte data block) (TED)</td>
<td>(99%)</td>
<td>≤ 1s (100%)</td>
<td></td>
</tr>
<tr>
<td>Handover effective time (between</td>
<td>≤ 300ms</td>
<td>≤ 90 ms (100%)</td>
<td>&lt; 95ms</td>
</tr>
<tr>
<td>BSs)</td>
<td>25 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETCS application in WEWBRA Arch.</td>
<td>25ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VoIP application in WEWBRA Arch.</td>
<td>25ms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# WEWBRA Performance Evaluation: Video Surveillance Validation Results

<table>
<thead>
<tr>
<th>CCTV (KPIs)</th>
<th>KPI</th>
<th>100km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG Throughput</td>
<td>&gt;384Kbps</td>
<td>2412.9Kbps</td>
</tr>
<tr>
<td>ETE</td>
<td>&lt; 60ms preferred</td>
<td>34.44ms</td>
</tr>
<tr>
<td>Jitter</td>
<td>&lt; 20ms</td>
<td>0.46ms</td>
</tr>
<tr>
<td>PER</td>
<td>&lt; 1%</td>
<td>0.048%</td>
</tr>
<tr>
<td>WiMAX delay</td>
<td>&lt; 25ms</td>
<td>29.04ms</td>
</tr>
<tr>
<td>HO Delay</td>
<td>&lt; 50ms</td>
<td>23ms</td>
</tr>
</tbody>
</table>
WEWBRA handover considerations:

- a sequence of intratechnology, intrasubnet and intradomain handovers

- Low performance during handover in trajectories with a high handover ratio

  → end-to-end performance degradation
Handover Enhancement Techniques:

- Enhancing the handover process
  - In the scope of the IEEE802.16 standard

- Efficiently Scheduling or timing the handover process
  - Not in the scope of the IEEE802.16 standard
Handover Enhancement Techniques:

- Enhancing the handover process
  - Cell reselection stage: the disruptive effect of the scanning process
    (reducing the number of frequencies, adaptive channel scanning algorithm..)
  - Execution stage different strategies ..

![IEEE 802.16e Handover Execution Schemes](image)
Timing the handover process:

Efficiently Scheduling or timing the handover process
The RMPA Handover:  \textit{A Reliable Mobility Pattern Aware IEEE802.16 handover scheme for the railway domain}

The RMPA handover makes use of:

- A redundant neighbouring advertising policy
- A bi-neighbouring scanning strategy
- A \textbf{handover policy} based on location information and double checked for redundancy purposes with Received Signal Strength Indication (RSSI)
  
  \textit{This handover policy also makes use of dynamic distance threshold values that takes into consideration the expected scanning and handover initiation delay time, the train speed and the data traffic profile}

- Two \textbf{concatenated link triggers} for scanning and handover initiation
- A hard handover execution strategy (HHO)
RMPA cross layer interactivity:

- GNSS Receiver:
  - Location info (x,y,z) & speed

- Application Layer:
  - MAC: Performance measurements, QoS, jitter, delay

- PHY:
  - Link measurements: RSSI, Noise, Interference, Preamble counter, TDM Frame counter

- Non-Volatile Memory:
  - Current Train Program & Set of programmed BS IDs
  - Hyst Path & HO record
  - DL Frequencies
  - MS(x,y,z) & speed
  - Next BS target ID and location information

- Handover Policy

- IEEE802.16 Receiver

- Balise Reader

- General Data Base Management System with Operational Information

- Mobile Station

  - Handover Decision Making Engine
    - Generate SCI & LGD chained triggers
  - RMPA MOB_NBR-ADV message from BS
Contributions

- An alternative to GSM-R deployments: the WEWBRA architecture
- A railway specific enhanced handover technique: the RMPA handover

Related contributions:

- ETCS simulator on a general purpose network simulator
- Contributions to the Opnet WiMAX Model (support for ETH-CS & IEEE.16k)
- Survey on link layer handover enhancement techniques
- Survey on radio access technologies and architectures in the railway context
- WEWBRA suitability in other scenarios such as the vehicular and public safety
Open Research Line I

UIC GSM-R Projects 2010-2012

Work on introspecting Future Railways Telecommunications Systems. looking if LTE could be the GSM-R follower, and on Railways criterias when choosing a new technology. Technology survey

LTE communication technologies for the automated driving and control railway

**Objectives:** Analysis of the feasibility of adaptation of LTE and IP convergence railway environments, so they are applicable to railway signalling, automatic driving, communications and onboard train to ground communication for the purpose of contributing to the standardization and development.
Open Research Line II

VEGAS PROJECT

Towards a common platform for simulation based evaluation of both functional and telecommunication sub-systems of the ERTMS - Joint Rail Conference Proceedings 2012
Open Research Line III

SECRET PROJECT
SECurity of Railways against Electromagnetic aTtacks

The project SECRET aims to assess the risks and consequences of EM attacks on the rail infrastructure, to identify preventive and recovery measures and to develop protection solutions to ensure the security of the rail network, subject to intentional electromagnetic (EM) interferences, which can disturb a large number of command-control, communication or signalling systems.

The objectives are to:
- Identify critical scenarios of EM attacks and to evaluate the consequences thanks to risks analysis and attack experiment on railway infrastructure
- Develop equipment protection and resilient command-control and communication architecture to such attacks
- Produce technical recommendations to reinforce the railway infrastructure
SECRET PROJECT
SECurity of Railways against Electromagnetic aTtacks

the different wired and wireless systems which contribute to the management of a railway crossing zonE
1. New EURORADIO Protocol


*** Searching Doctorate candidate!!!
University of the Basque Country

- Public University of the Basque Country (Spain)
- 45,000 students and 4,000 lecturers and researchers
- Divided on three campus
- Multidisciplinary University:
  112 degree courses in 83 topics

http://www.ehu.es
ETSI – Faculty of Engineering

- A more than 100 years old Faculty
- Over 3500 students
- 350 lecturers and researchers
- Industry related and supported (Aula Robotiker, Ormazabal, Iberdrola .. )
- Graduation courses:
  - Industrial Engineering and Telecommunication Engineering
- PosGraduation courses:
  - MSc and PhD courses on IT & Mobile Communication Networks TICRM (www.ticrm.es)
  - MSc in Transportation Systems
I2T research lab  http://i2t.ehu.es