Link Performance for a Satellite-Based Communications System for Fast Trains: Analysis of Trials and Measurements

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Outline

- Overview of the FIFTH Project
- FIFTH Demonstrator and Measurement Setup
- The Railroad Satellite Channel
- Results of Measurements and Trials
- Conclusions
FIFTH (Fast Internet for Fast Trains Hosts) Objectives

- Specify and evaluate the FIFTH System, i.e. a multi-segment network infrastructure for the provision of high quality Internet (IP and MPEG over IP) and digital TV services to passengers of top-class, high-speed trains (the extension to other categories of trains and passengers is also envisaged).

- Study and design a robust satellite radio link which reacts to the impairments caused by obstacles located along the railway.

- Identify proper Gap fillers for shadowing areas (e.g. railway tunnels or large train stations).

- Study and design a wireless LAN (W-LAN) based system to distribute the signal inside the train coaches.

- Complement the study and design phase for all involved radio links with an exhaustive measurement campaign on-field utilising real railroad infrastructures and high speed trains.

- To design and develop a Ku band demonstrator
FIFTH Terminal Functional Blocks

- **Train Distribution Network**
  - **T-IWU**
    - **Router 4-7**
      - **IEEE802.3 card**
      - **Modules:**
        - Mobility Support
        - QoS Support
        - Protocol Conversion
        - Admission Control
  - **T-IWU Interface Bus**
  - **Mobile Surrogate Server**

- **Navigation Unit**
  - **GPS Module**
  - **GPS Antenna**
  - **Antenna Driver**
  - **SaT**
    - **SaT Antenna**
  - **W-LAN STA**
    - **W-LAN Antenna**
  - **GF STA**
  - **GF Antenna**

**Abbreviations:**
- GPS: Global Positioning System
- SaT: Satellite Terminal
- STA: Station
- T-IWU: Terminal Inter-working Unit
- TE: Terminal Equipment
- GF: Gap Filler
**FIFTH Demonstrator General Prototype Layout**

- **Train's LAN**: Inertial System, GPS, Navigation Unit, User.1, User.2, User.n, Onboard Servers, Supporting Workstation, Switch, Fast Train
- **Service Centre**: Satellite Gateway, N-IWU, Access Server, Firewall, Local Service Servers, Monitoring & Control
- **INTERNET & Leased Line**: Forward Channel, Interactive Channel
- **N-IWU**: Network Interworking Unit
- **M-IWU**: Mobile Interworking Unit
- **ETH**: Ethernet
Considering the satellite link geometry (elevation and azimuth) to respect the Italian Railway Network, a suitable adaptation of the UIC-Z1 baggage van roof has been designed and implemented to host the final antenna and platform subsystem under the roof.
Demonstrator Target Train

FIFTH Demonstrator Train Composition

Baggage Van (Target Coach)  ALE-601 Ballast Coach  ALE-601 Electric Train
Antenna & Platform Details

Maximum elevation angle
Maximum antenna high

104.8 cm
45.0 cm

50.0 cm
Integration Phase in the Target Coach

Antenna Installed Under the Target Coach Roof before the Radome Installation

Final Antenna Installation under the Radome

Detail of the Radome on the Target Coach Roof

Radome Installed on the Coach Roof

Wi-Fi Base Station

Configuration PC

Indoor Equipment Arrangement into the Coach Lab. Section

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Mobile Train Terminal Prototype (MTTP) Layout

- **Satellite front-end**
  - Antennas, LNB
  - RF/IF Downconv.
  - Modems

- **NTU**
  - PAT algorithm based on GPS, gyro and a railway database

- **M-IWU**
  - Manages the handover between different segments

- **TU-LAN**
  - Allow both wired and wireless access
Ku Band Measurement Setup

- Ku Geo-Satellite
- Micro Camera
- RF Splitter (-5dB)
- RS232 Acquisitions
- Workstation
- PAL Video Signal
- SAT Decoder
- Digital Display
- Video Combiner
- Video Recorder
- Antenna Control Unit (ADCU)
- Spectrum Analyser
- GPS
- Gyro Sensor
- RS232
- Acquisitions Workstation
Stationary / Slow Motion Measurement Results

**Suspension Bracket**

**Electric Line Post**

**Electric Trellis Bridge**
The Railroad Satellite Channel

- Extremely challenging environment for mobile satellite communications
- Nearly ON-OFF behavior of the propagation channel at Ku-band
- Peculiar obstacles typical of the railway environment:
  - Electrical Bridges / Trellises
  - Electrical Posts with Brackets
  - Catenaries

<table>
<thead>
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<th>Environment</th>
<th>A</th>
<th>Dg [s]</th>
<th>Db [s]</th>
<th>c [dB]</th>
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<td>6.2</td>
<td>0.8</td>
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<td>Rural</td>
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<td>3.9</td>
<td>0.7</td>
<td>18</td>
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<tr>
<td>Suburban</td>
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<td>4.7</td>
<td>0.8</td>
<td>19</td>
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<td>Urban</td>
<td>0.56</td>
<td>7.6</td>
<td>9.5</td>
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Results for the Land Mobile Satellite Channel at Ku-Band (downlink)
Impairment Effect Due to the Power Line Infrastructure

![Impairment Effect Diagram]

- Visible Obstacle
- Spectrum Analyser Display
- Post with Bracket
- Trellis
- Video output

**Graph Details:**
- X-axis: Acquisition time (sec)
- Y-axis: Signal level (dBm)

**Graph Notes:**
- Good
- Corrupted
- Post with Bracket

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Trials in Motion

• Test Itinerary:
  Firenze <-> Campiglia Marittima

• Firenze <-> Pisa, mainly E-W oriented
• Pisa <-> Campiglia M., mainly N-S oriented

• Approx. Length: 200 km
• Max Speed: 160 km/h
Trial Results: First Order Statistics

Reception threshold for a DVB-S signal with rate 3/4

**Blocked state**

**“Shadowed” state**

LOS
Trail Results: Second Order Statistics I

TSC \((T_c, x)\) is the probability that an arbitrary time instant belongs to a connection of duration \(T_c\).

A connection is a time interval where the signal level remains above a given threshold \(x\).

TSF \((T_f, x)\) is the probability that an arbitrary time instant belongs to a fade of duration \(T_f\).

A fade is a time interval where the signal level remains below a given threshold \(x\).
## Trial Results: Second Order Statistics II

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<th>LCR(^{-1})</th>
<th>AFD</th>
<th>TSC (T(_c) = 2 min)</th>
<th>TSF (T(_f) = 10 sec)</th>
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<td>Florence -&gt; Campiglia</td>
<td>-67 dBm</td>
<td>-74 dBm</td>
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<td>-67 dBm</td>
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<td></td>
<td>350 m</td>
<td>600 m</td>
<td>90 m</td>
<td>15,5 %</td>
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<td></td>
<td>20 sec</td>
<td>40 sec</td>
<td>5 sec</td>
<td>37,8%</td>
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<td></td>
<td></td>
<td></td>
<td>4.5 sec</td>
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<td>-72 dBm</td>
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<tr>
<td></td>
<td>325 m</td>
<td>500 m</td>
<td>72 m</td>
<td>21,3 %</td>
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<td></td>
<td>16 sec</td>
<td>25 sec</td>
<td>3.4 sec</td>
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<td>2.2 sec</td>
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<td>9,7 %</td>
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<td>4,5 %</td>
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Diversity Techniques

– Space Diversity
  • 15 m  + 4 %
  • 300 m  + 9 %

– Time Diversity
  • 5 min  + 14 %
  • 10 min  + 16 %
  • 5 & 10 min  + 20 %
Conclusion

- A statistical analysis of the satellite radio link in the railway environment has been performed using the data gathered during direct measurements.

- Although the results confirm that the railway scenario is extremely challenging, diversity techniques can lead to significant improvements.
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THANKS FOR YOUR ATTENTION!!!