Studying Reliable, Cost-effective and Interoperable Communications for High Speed Passenger Trains in the US using 5G-NR and LTE

(Develop and Test 5G-NR/LTE-A Integration for US passenger trains: Challenges and Prospects)

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Objectives

• Establishing long-term relation with OAI

• Planning field testing of 5G-NR T2X for US passenger trains

• Understanding challenges in interoperable 5G-NR/LTE-A T2X Deployments
Overview

• Introduction
• Challenges and Opportunity of Implementing 5G-NR/LTE-A for the US-High Speed Trains
• Wireless Challenges
• Testbeds and Test Plans
• Verification and Validation
• Deployment Goals with OpenAirInterface5G
• Challenges of OAI-5G-HST Deployment
• Conclusions
Introduction

• By 2030, High Speed Trains (HST) will connect 12,000 miles in the United States

• Reliability of this vast operation depends on an ultra-reliable communications backhaul

• Communication support (wireless)
  – Train-Related Services
  – Passenger-Centric Services

• Guaranteeing seamless communication in train control operation along with high achievable throughput for on-board passengers can be challenging

• Therefore, identifying next-generation network demand for high speed passenger trains is crucial
Introduction
Introduction

- High speed train environment is challenging due to railroad infrastructure and architectures
- Rigorous testing of 5G-NR/LTE-A performance in various railroad specific environment is a requirement
- Early field-testing of 5G-NR/LTE-A in railroad environment before commercial radio infrastructure setup is therefore planned
- Verify and validate field testing with in-house and commercial simulators/channel emulators
# Roadmap Towards Deployment

<table>
<thead>
<tr>
<th>Phase</th>
<th>Funded by</th>
<th>Field Tested</th>
<th>Goals</th>
<th>Tasks Delivered (to be delivered)</th>
<th>RATs Identified/Tested/Simulated</th>
<th>Timelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earlier efforts</td>
<td>FRA</td>
<td>Yes (Crete testbed)</td>
<td>Identify capabilities of WiMax with railroad microwave base stations</td>
<td>WiMax network Simulator, field-test results and validations</td>
<td>WiMax</td>
<td>2009 – 13</td>
</tr>
<tr>
<td>I</td>
<td>FRA</td>
<td>No</td>
<td>Identify wireless/wired technologies to support seamless in-train and Train-to-Ground (T2G) control/passenger communication</td>
<td>• Detailed comparative analysis of technologies, identified commercial core technologies, • limitations and challenges of technologies in high speed trains, • overall present maximum achievable throughput/passenger in-train</td>
<td>LTE-R, GSM-R (UIC), LCX, ROF, Satellite, WiMax,</td>
<td>2015 – Mid 2016</td>
</tr>
<tr>
<td>I</td>
<td>FRA</td>
<td>No</td>
<td>Propose network solution for V2X (T2G) communication to solve mobility related challenges in high speed train: handover, small-scale fading, etc.</td>
<td>Massive MIMO, distributed antenna and femto-cell based user and control plane-separation to design high speed-train in-train and T2G network architecture: UPWARC</td>
<td>LTE-A, 5G-mmwave,</td>
<td>2016 - Mid 2017</td>
</tr>
<tr>
<td>I</td>
<td>FRA</td>
<td>No</td>
<td>Identify Wireless-Digital Train Line (WiDTL) requirements and find offloading radio-access technologies</td>
<td>In-train network architecture, LTE-A/5G PHY end-to-end simulation, achievable throughput per passenger for next-generation network services</td>
<td>LTE-A/5G</td>
<td>2017 - Mid 2018</td>
</tr>
<tr>
<td>I</td>
<td>FRA</td>
<td>No</td>
<td>NS3 end-to-end simulation for LTE and 5G-mmwave (LTE-EPC) to model different railroad environment, architectures, etc.</td>
<td>• In-train network traffic model, • NS3-simulation for environment-specific achievable throughput and base station deployment, • handover performance • End-to-end delay • Maximum number of UE support</td>
<td>LTE-R/5G</td>
<td>Mid 2018 – Late 2019</td>
</tr>
<tr>
<td>II</td>
<td>FRA</td>
<td>Upcoming</td>
<td>Test and verify end-to-end simulation with field-testing results, identify core technologies before commercial deployment</td>
<td>1. Lab S1 test results with two USRPs (B210, X300) 2. Lab channel emulator testing results of two USRPs (S1) 3. Vehicular testing results of OTA USRP(eNB + EPC)-USRP(UE)/COTS(UE) 4. Field testing results of OTA communication</td>
<td>LTE/5G</td>
<td>Throughout 2019</td>
</tr>
</tbody>
</table>
Roadmaps Towards Deployment (TextCloud)
Challenges & Opportunities in the US-HST with 5G and LTE-A

Train Consist Interconnect still requires comprehensive network infrastructure
Challenges & Opportunities in the US-HST with 5G and LTE-A

[Diagram showing various components and systems related to train technology]
Comparison of throughput at different train velocity for GSM/GPRS-900MHz
Predicted Demand in HST-Wireless
Reliable Throughput with UPWARC

Conventional 5G Implementation

5G with UPWARC

Realtime Simulation of mmWave 5G-NR-28Ghz

Comparison of throughput for UPWARC at different velocities
General Challenges in 5G-NR/LTE-A Implementation

• LTE-5G-NR interoperability
  – Handover performance (between 5G-mmWave/sub-6GHz base stations and assisting LTE base stations)
  – Maximum allowable delay for handover
  – Packet error rate during handover
  – Separate user and control channel performance
• Maximum achievable throughput for 5G-NR for different velocities for allowable bit-error-rate.
• 5G-NR standard specification dedicated to railways
• LTE-A for railways standard specification
• Femto-cell assistance specification in tunnel
• mmWave and sub-6GHz 5G-NR frequency interoperability specification
• Channel measurements for mmWave and sub-6GHz in the US railroads and different environments.
Available and Accessible Testbeds
Collaboration Plan with OAI

TEL-UNL joining as Associate Member

Channel emulation and over-the-air (OTA) testing with OAI-5G-NR/USRP for vehicular channel models

Identify challenges and limitations if any for OAI-5G-NR development. Propose fix. Validate testcases and identify core parameters for V2X testing

V2X environmental testing: railroad tunnel and viaduct

Observe handover latency and corroborate with OAI for optimizing fast-handover.

Participate in COTS-UE testing for OAI-5G-NR

As an associate member identify core challenges and participate in Git commits

Follow and participate in LDPC-integration with GPU for portability
Test Plan with OAI

Hardware

- eNB CPU: Intel i9960X Skylake X 16 core 3.1 GHz (4.4 GHz turbo) + Nvidia GTX-2080
- EPC CPU: Intel i9960X Skylake X 16 core 3.1 GHz (4.4 GHz turbo)
- UE CPU: Intel i7-7700

Openairinterface

- LTE: openairinterface5g-master + openair-cn
- 5G: openairinterface-5gnr (develop) [currently under consideration]

Testplans

- Lab1.a: S1: USRP-B210(eNB+EPC)->USRP-B210(UE)
- Lab1.b:S1(emulator):USRP-B210(eNB+EPC)->USRP-B210(UE)
- Lab1.c:OTA: USRP-B210(eNB+EPC)->COTS
- Veh1.a:OTA:USRP-B210(eNB+EPC)->COTS
Verification and Validation

Simulation Parameters:
- No. of railcars
- No. of users per railcar
- No. applications per user
- Distance profile
- Velocity profile
- Track environment (bridges, viaduct, tunnels, etc.)
- Landscape (hills, rural, urban, etc.)
- Selectable radio technology

Simulation Reports:
- Aggregate throughput
- Handover performance
- Latency and packet loss rate
- Performance/application/user
e tc.
LTE and 5G-NR SINR Simulation Comparison

**LTE**

![Uplink/Downlink SINR Stats for v=300 mph](image1.png)

**5G-NR (fast handover)**

![Uplink/Downlink SINR Stats for v=300 mph](image2.png)
The Results to be Compared

- **Lab 1.a**: throughput, RSRP, bit error rate, delay
- **Lab 1.b**: throughput, SINR linear, RSRP, bit error rate for pedA, pedB, vehA, vehB channel and channel delay
- **Lab 1.c**: throughput, RSRP, SINR linear, bit error rate, delay, handover if multiple device available
- **Veh 1.a**: Velocity vs throughput, RSRP, SINR linear, bit error rate, delay, handover if multiple device available
Deployment Goals and Challenges with OAI-5G

• Contributing to 5G-NR development and test with verification and validation for V2X implementation
• Handover emulation or simulation during 5G/LTE field testing
• 5G COTS testing for V2X/T2G communication
• LTE-A UE performance in extreme V2X scenario (fast handover, high velocity, hilly terrain, tunnels)
• Femto-cell implementation during handover.
• LTE-EPC handover challenges in 5G-NR
• Emulate PDCP in GPU to increase portability during field testing
Conclusions

• Follow develop-nr branch in github
• Follow implementation challenges in develop-nr and openairinterface5g
• Follow PDCP emulation in GPU thread
• Verify and validate simulator and field test measurements with each other
• Field test COTS UE in extreme HST environment
• Understand 5G-NR’s potential to handle train control traffic.
• Collaborate and communicate OAI about field test results and performance further down the road.
• Working towards standardizing 5G-NR for railways.