Architecture concepts

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TECHNICAL CHALLENGES FOR NETWORK AND APPLICATIONS
General situation

• **Growing traffic demands**
  – Operational (Voice, Video, Maintenance...)
  – Internet for passengers
  – High QoS and availability expectation (CBTC)

• **Quick evolution of technologies**
  – ~ 1 generation every 10 years

• **High CAPEX and OPEX of dedicated professional networks**
  – Eg. GSM-R
General trend

Today

• 1 service <-> 1 infrastructure
• Scaling issues
• Technology dependent

Tomorrow

• N services <-> M infrastructures
• Mutualisation
• Technology agnostic
Applications needs

• **Mixed Quality of service (QoS) needs**
  – Mission critical (CBTC, ERTMS)
  – Operational traffic (Data, Voice, Video)
  – Passengers (Internet, Entertainment, Mobile Office)

• **Seamless**
  – Radio perturbations
  – Hand overs (intra and inter RAT)
## New Possible Services Requiring High Data Rates (see D3.1 & D3.2)

<table>
<thead>
<tr>
<th>Traffic Type: UL (UpLink) or DL (DownLink)</th>
<th>Service Type (examples)*</th>
<th>Minimum Total Traffic for All Services (except normal user access)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-board Internet Access (business access only, during peak periods)</td>
<td>On-board Internet Access (normal user access only, during peak periods)</td>
<td>Train Video Surveillance (e.g. Closed Circuit TV or CCTV)</td>
</tr>
<tr>
<td>UL Minimum Required Traffic</td>
<td>2 Mbits/sec</td>
<td>90 Mbits/sec</td>
</tr>
<tr>
<td>DL Minimum Required Traffic</td>
<td>7 Mbits/sec</td>
<td>800 Mbits/sec</td>
</tr>
</tbody>
</table>

* Other additional services might exist, e.g. for train control purposes (for operating the train) – but this would require very low data rate with very high priority.

**Current minimum required throughput needs are not satisfied by current technology.**

LTE might be the answer but LTE has not been designed for high speed platforms and has to be evaluated and modified accordingly.
### QoS Requirements/Service (see D3.1 & D3.2)

<table>
<thead>
<tr>
<th>QoS Requirements</th>
<th>Service Type (examples)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-board Internet Access (business access only)</td>
<td>Train Video Surveillance (e.g. Closed Circuit TV or CCTV)</td>
</tr>
<tr>
<td>Semi-Embedded Video Transmission (TVSE Application) – for controlling doors.</td>
<td></td>
</tr>
<tr>
<td><strong>First Connection Establishment Time</strong></td>
<td>&lt; 5 sec.</td>
</tr>
<tr>
<td></td>
<td>&lt; 5 sec.</td>
</tr>
<tr>
<td></td>
<td>&lt; 2 sec.</td>
</tr>
<tr>
<td><strong>Connection Delay</strong></td>
<td>&lt; 5 sec.</td>
</tr>
<tr>
<td></td>
<td>&lt; 5 sec.</td>
</tr>
<tr>
<td></td>
<td>&lt; 300 ms</td>
</tr>
<tr>
<td><strong>Delay Variation</strong></td>
<td>&lt; 1 sec.</td>
</tr>
<tr>
<td></td>
<td>&lt; 40 ms (1 image Tx time)</td>
</tr>
<tr>
<td></td>
<td>&lt; 40 ms (1 image Tx time)</td>
</tr>
<tr>
<td><strong>Availability of Data Rate</strong></td>
<td>Inside or outside tunnels, on all 4 TGV branches</td>
</tr>
<tr>
<td></td>
<td>Inside or outside tunnels, on all 4 TGV branches</td>
</tr>
<tr>
<td></td>
<td>Video cameras installed on the station platform</td>
</tr>
<tr>
<td><strong>Packet Loss</strong></td>
<td>Yes (Allowed)</td>
</tr>
<tr>
<td></td>
<td>No (Not allowed)</td>
</tr>
<tr>
<td></td>
<td>No (Not allowed)</td>
</tr>
<tr>
<td><strong>Required Speed</strong></td>
<td>Up to 320 km/h</td>
</tr>
<tr>
<td></td>
<td>Up to 320 km/h</td>
</tr>
<tr>
<td></td>
<td>0-10 km/h</td>
</tr>
<tr>
<td><strong># of Users Sharing the Same Connection</strong></td>
<td>100-150 users/train</td>
</tr>
<tr>
<td></td>
<td>Minimum 1 user/train (if only 1 camera is used at the time)</td>
</tr>
<tr>
<td></td>
<td>6 real-time video cameras/train</td>
</tr>
</tbody>
</table>

* Other additional services might exist, e.g. for train control purposes (for operating the train) – but this would require very low data rate with very high priority, so throughput is not a problem for other additional services. However, the prioritization and the differentiation of data flow should be reconsidered.
Network constraints

- Variable radio link quality
  - Radio perturbations
  - Coverage variability
  - Doppler...
- Mobility
  - Handovers
- Heterogeneous Radio Access Technologies
  - Multi homing
  - RAT Aggregation
  - Multi service, infrastructure sharing
- Integration with existing solutions
  - End to end transparency
  - Data collection / integration with applications
CHALLENGES AT PHY AND SYSTEM LEVELS
Necessary Adaptations

- Possible Issues at PHY & System Level

- (CORRIDOR) System Architecture:
  - Options for Radio Cognitive repartition functionality
  - CORRIDOR architecture choice (user centric) – to reduce OPEX & CAPEX
  - Cognitive Manager using a DataBase and Media Independent Handover (MIH)

- (CORRIDOR) Mobility and Spectrum Management:
  - Intra-RAT HandOver: New Handover algorithm (UE side) for Intra-RAT HO (LTE to LTE) – description on separate slide
  - Inter-RAT HandOver: New Handover algorithm (UE side) for Inter-RAT HO (LTE to WiFi and viceversa) – description on separate slide
  - Advantages of using Knowledge DataBase approach

System Architecture, Mobility and Spectrum Management are overlapping aspects
Normally we start presenting the System Architecture, but since we present the results, I propose to start with Mobility and Spectrum Management First, and then with the architecture.
Doppler Shift as viewed by UE side (1/2)

<table>
<thead>
<tr>
<th>Carrier Frequency</th>
<th>(Worst Case) Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200 km/h</td>
</tr>
<tr>
<td></td>
<td>Max Doppler Value [kHz]</td>
</tr>
<tr>
<td>750 MHz</td>
<td>0.138</td>
</tr>
<tr>
<td>900 MHz</td>
<td>0.166</td>
</tr>
<tr>
<td>2 GHz</td>
<td>0.370</td>
</tr>
<tr>
<td>2.6 GHz</td>
<td>0.481</td>
</tr>
</tbody>
</table>

Standard provides resistance to speeds up to 500 km/h: at 2 GHz carrier frequency, this corresponds to maximum 925 Hz Doppler Shift. [http://www.ee.columbia.edu/~roger/LTE_PHY_fundamentals.pdf](http://www.ee.columbia.edu/~roger/LTE_PHY_fundamentals.pdf)

Subcarrier spacing = 15 KHz;
Doppler Shift as viewed by UE side (2/2) - Impact of Carrier Frequency Offset on SINR

A residual carrier frequency offset (CFO) of 0.138 kHz (0.92x10^{-2} normalized to the subcarrier spacing) may reduce the SINR value with maximum 5 dB.

Intra-RAT HandOver Description – Issues & Necessities

1. UE is connected to eNB A, receives the signal on the frequency $f_{1,DL} - f_{1,D1}^{max}$, but compensates it to $f_{1,DL} => OK$

2. eNB A receives the signal on $f_{1,UL} => OK$
   Then, eNB A configures UE to measure eNB B.

3. UE « sees » the pilots from eNB B with a frequency offset => NOK

4. UE measures the pilots of eNB B and underestimates received power from eNB B => NOK

5. UE reports to eNB A incorrect eNB B power measured values (& maybe too late.. because conditions were not met in time) => NOK

6. eNB A decides HO to eNB B => NOK (HO might be too late)

7. UE performs synchronization on eNB B; UE is no longer connected to eNB A, UE compensates $f_{2,DL} + f_{2,D1}^{max}$ (received frequency) to $f_{2,DL} => OK$

8. UE performs RACH and attaches to eNB B; eNB B receives the signal on $f_{2,UL} => OK$
Few Notations..

- $f_{1,DL} =$ eNB1 transmission (Tx) frequency carrier (in DL)
- $f_{1,UL} =$ eNB1 reception (Rx) frequency carrier (in UL)
- $f_{2,DL} =$ eNB2 transmission (Tx) frequency carrier (in DL)
- $f_{2,UL} =$ eNB2 reception (Rx) frequency carrier (in UL)
- $f_{1,D1}^{max} =$ Maximum Doppler Shift on Tx frequency carrier (DL) from eNB1
- $f_{1,D2}^{max} =$ Maximum Doppler Shift on Rx frequency carrier (UL) towards eNB1
- $f_{2,D1}^{max} =$ Maximum Doppler Shift on Tx frequency carrier (DL) from eNB2
- $f_{2,D2}^{max} =$ Maximum Doppler Shift on Rx frequency carrier (UL) towards eNB2
Doppler Shift value perceived at UE side (or eNB) (1/2)
(without and with compensation with respect to serving eNB)

Remarks:
For Doppler Shift what really counts is the radial speed! -> in reality a maximum of 200 km/h radial speed, taking into account system network & eNB distribution;

At 750 MHz & 300 km/h, maximum expected Doppler Shift is < 150 Hz, equivalent to $1 \times 10^{-2}$


ISD=1732 m (or ISD=500 m)
UE max speed: 300 km/h
Distance between eNB & railway: 1732 m
Doppler Shift value perceived at UE side (or eNB) (2/2)
(without and with compensation with respect to serving eNB)

**Remarks:**
For Doppler Shift what really counts is the radial speed! -> in reality a maximum of 200 km/h radial speed, taking into account system network & eNB distribution;

At 750 MHz & 300 km/h, maximum expected Doppler Shift is < 100 Hz, equivalent to 0.6x10^{-2}


ISD=1732 m (or ISD=500 m)
UE max speed: 300 km/h
Distance between eNB & railway: 2 x 1732 m
Inter-RAT HandOver Description – Issues & Necessities

1. UE is connected to eNB A, UE is not supposed to report WLAN measurements

2. eNB A configures UE to measure eNB B

3. UE « sees » WLAN, but does not connect => NOK

4. Inside the tunnel, UE disconnects from any available service => NOK

5. Outside the tunnel, UE re-synchronizes and RACH eNB A => NOK

6. UE reports to eNB A measured values

7. eNB A decides HO

8. UE performs synchronization on eNB B; UE is no longer connected to eNB A

9. UE performs RACH and attaches to eNB B

10. UE is connected to eNB B, UE is not supposed to report WLAN measurements
MOBILITY ARCHITECTURE
Inter RAT mobility: Mobile IP

- **Home Agent (HA)**
  - Located on the Internet
  - Maintain a unique IP address for the mobile
  - Route traffic to appropriate RAT

- **2 implementations**
  - Host based
  - Network based
Inter RAT mobility: Mobile IP, 2 solutions

Host based (MIPv6)
- Tunnel between host and HA
- Long negotiation during hand over
- Complexity lies in host

Network based (PMIPv6)
- Tunnel handled by Mobility Access Gateway (MAG)
- Complexity lies in network
Network Mobility (NEMO)
- Normalised (RFC 3963)
- Mobile network
- MR -> HA
- Solution for CALM

Mobile IPv6 (MIPv6)
- Normalised (RFC 6275)
- Single user
- Host -> HA

Proxy Mobile IP (PMIPv6)
- Normalised (RFC 5213)
- Single user
- MAG -> LMA

Proxy- NEMO (P-NEMO)
- Proposal
- Mobile network
- MAG -> LMA

Architecture for mobility

Host based mobility

Network based (proxy)

Single mobile user

Mobile Network

MR: Mobile Router
HA: Home Agent
MAG: Mobility Access Gateway
LMA: Local Mobility Anchor
SYSTEM ARCHITECTURE
Towards a **MR-oriented** architecture

- Mobile Relay (MR) Centered Architecture
- Intermediate Mobile Relay (MR) Architecture

Towards a **NW-oriented** architecture

- NetWork (NW) Centered Architecture
- Intermediate NetWork (NW) Architecture

(CORRIDOR) System Architecture

Towards a Pure-oriented architecture

Towards a Hybrid-oriented architecture

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## (CORRIDOR) System Architecture Choices

<table>
<thead>
<tr>
<th>Architecture Type</th>
<th>Impact on Legacy Network Architecture</th>
<th>Cognitive Manager CM Position</th>
<th>Handover Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR Centered</td>
<td>High</td>
<td>MR</td>
<td>MR side</td>
</tr>
<tr>
<td>Intermediate MR</td>
<td>Low</td>
<td>MR</td>
<td>MR side for WiFi NW side for LTE</td>
</tr>
<tr>
<td>Intermediate NW</td>
<td>Low</td>
<td>MR &amp; NW</td>
<td>MR side for WiFi NW side for LTE</td>
</tr>
<tr>
<td>NW Centered</td>
<td>High</td>
<td>NW</td>
<td>NW side</td>
</tr>
</tbody>
</table>

The intermediate-MR architecture has been finally selected, for lower operational expenditure (OPEX) and capital expenditure (CAPEX) reasons.
MR-Centered HandOver

PoA  Point of Attachement  
PoS  Point of Service  
MIH  Media Independent Handover  
MIHF  MIH Function  
MIIS  MIH Information Service
MR-Centered HandOver (2/2)

- Warn the TCP layer

- Not necessarily at the same time

- MIH Mobile to Network Handover commands

- There must be an Application Manager in the HA too
Intermediate-MR HandOver (1/2) – for WiFi

- Warn the TCP layer
- CR parameters (MIH events)
- Mobile to Network Handover command
- Periodic or commanded reports
Intermediate-MR HandOver (2/2) – for LTE
Intermediate-NW HandOver (1/2) – for WiFi

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Intermediate-NW HandOver (2/2) – for LTE

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NW-Centered HandOver

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NW-Centered HandOver (2/2)

Warn the TCP layer

TCP warning message

PoA Wifi

PoA LTE

PoA LTE user

MIHF

3GPP, LTE stack

802.22 stack

802.11 stack

MR

Management Plane

Data Plane

Transport

Network

Position Tracker

Sensing Engine

Cognitive Manager (MIH user)

Radio Cartography DB

RAT use Rules

QoS Rules

RRM

PoS (MIH user)

L3 Layer

PoS (MIH user)

L3 Layer

PoS (MIH user)

L3 Layer

Cognitive Manager

Home Agent

Localization Server

Position Computer

802.3 stack

L3 Layer

Cognitive Manager

802.3 stack

L3 Layer

MIHF

802.3 stack

MIHF

802.3 stack

802.3 stack

802.3 stack

802.3 stack

Database

MIH Network to Network Handover command

Home Agent

802.3 stack

Position Computer

MIHF

802.3 stack

802.3 stack

802.3 stack
Available data

• **Link state**
  – Availability (ON/OFF)
  – Low level information (cell ID, signal quality...)
  – Quality (data rate, delay...)
  – Cost...

• **Localisation and speed**
  – Not only freq policies as commonly understood for CR
  – Availability duration (radio coverage)
  – Other trains crossing

• **Many others**
  – Doppler shift
  – Maintenance data (temporary works/failure),
  – application needs announcements (eg, non delay critical data offloading...).
  – ...
CONCLUSION
What does CR enable?

• **Better links**
  – Anticipation of intra RAT HO, radio losses...
  – Inter RAT HO (pre-configuration)
  – Seamless integration for applications

• **Mutualisation**
  – Heterogeneous networks => better coverage and availability
  – QoS => mission critical deployment cost partially assumed by commercial services
  – Possibility of partnership with network operators (carriers)

• **For infrastructure and rolling stock managers**
  – Permanent supervision / Detection of infra “aging issues”
  – Possibility to co-found infrastructure (multi-service, RAT mutualisation)
What’s next?

- Other applications
- Interface with applications
- Smart monitoring
- Usage prediction
- Common, opened databases
- New carriers business models
- ...

Thank you for your attention

QUESTIONS ?