5G for Future Rail Operations – DB's ambitious Plans for the Introduction of the Future Rail Mobile Communication System (FRMCS)

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Digitale Schiene Deutschland
Realtime-Localization
Digital Interlockings
Smart infrastructure
Digital Command and Control Signaling (ETCS)
Data Exchange
Obstacle Detection
On track for the future
https://www.digitale-schiene-deutschland.de/index_en.html

Envisioned longer-term evolution of rail operation

	Today / Short- to Mid-Term	Longer-Term
Train Density	• Legacy: Compromise between fixed block sizes and cost • ETCS: Reduced block sizes without further field elements, moving block	• Possibly further increased density through move from absolute to relative braking distance → virtual coupling
Scheduling & Control	• Separate short-term dispatching and long-term planning • Large extent of manual optimisation	• Real-time steering and control of trains with centralised optimisation for entire time horizon
Automation	• Manual or assisted driving (GoA0-GoA2)	• Fully automated shunting, marshalling and general train operation (GoA4), and field element operation
Infra-structure	• Introduction of digital interlockings • ETCS: Replacement of line-side signals	• Cost-optimised minimisation of infrastructure elements (e.g., balises) • All-IP, Cloud-based

Target

- Significantly improved **reliability, capacity** and **cost efficiency** of rail operations
- **Sustainable competitive-ness** of rail transport

Technologies required to support this long-term vision

Management Systems

Managing of traffic and passenger flow in real-time, including incident response (e.g., based on Artificial Intelligence, Big Data)

Perception Systems

Flawless perception of environment (vehicle and trackside) through multi-modal sensing (cam, radar, lidar)

Localization Systems

Real-time location and train integrity based on multi-sensor input (e.g., GNSS, cellular communications) and Digital Map technology

Protection and Control Sys.

Simple and standardized safety core, dynamic detection of track occupancy

Operation Systems

Vehicle elements for automation of operative processes (e.g., door control, automated coupling), vehicle diagnosis

The fundament for future rail operation is a state-of-the-art and **future-proof communication and computation infrastructure**

Communication requirements related to future rail operation [1)]

Current requirement estimates

Protection & Control

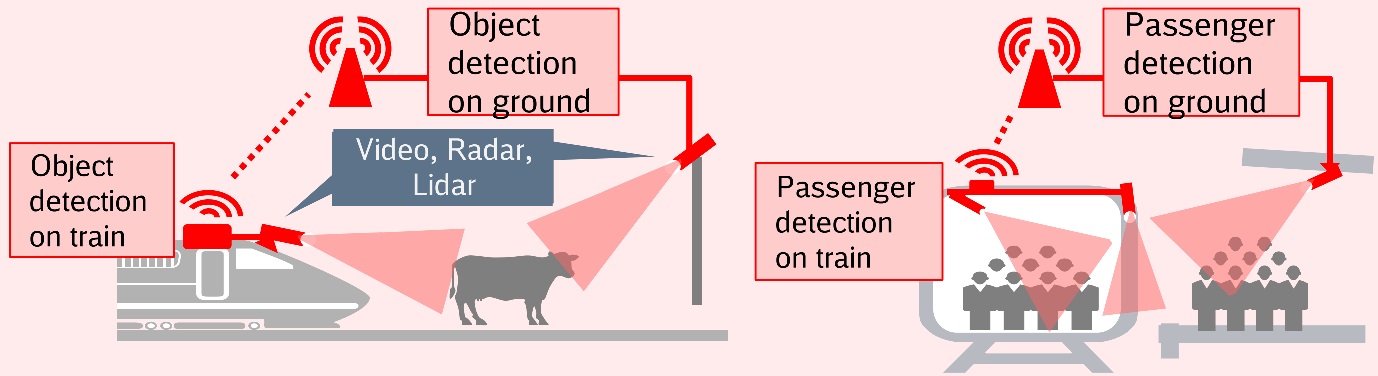
Communication of location, movement authorities, segment / journey profiles, etc.

	ETCS L3	Future
Downlink:	<6 kbps	<17 kbps
Uplink:	<3 kbps	<7 kbps
Latency:	<1 s	<100 ms

Intelligent Perception [2)]

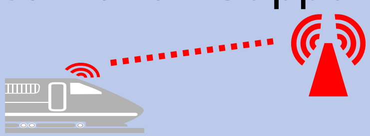
Automated detection of hazards

Automated monitoring of safe passenger (dis-)embarkation



2-3 Mbps/train at 99.999% reliability
Latency <10 ms for <40km/h, otherwise <100 ms

Localization Support

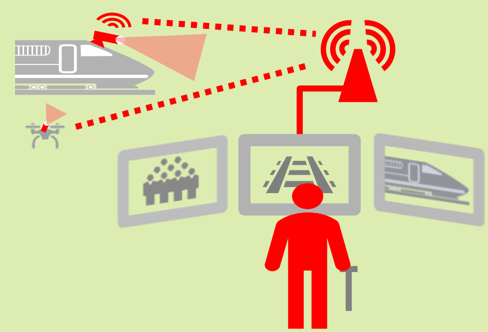


Provision of GNSS-RTK correction data and digital map data to trains

Downlink: 10 kbps at 99.9999% reliability
Latency <100 ms

Emergency Mgmt. [2)]

Video-based remote control of trains in degraded mode



Uplink: 6-7 Mbps/train at 99.99% reliability

Downlink: 200 kbps/train at 99.999% reliability

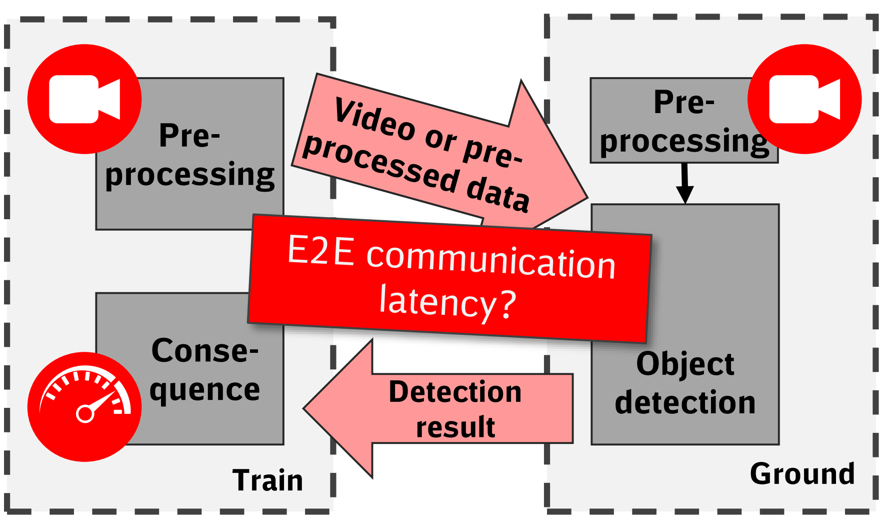
Latency <10 ms for <40km/h, otherwise <100 ms

1) Note that stated reliability requirements refer to what should be technically possible and do not imply that one will practically always operate at this point

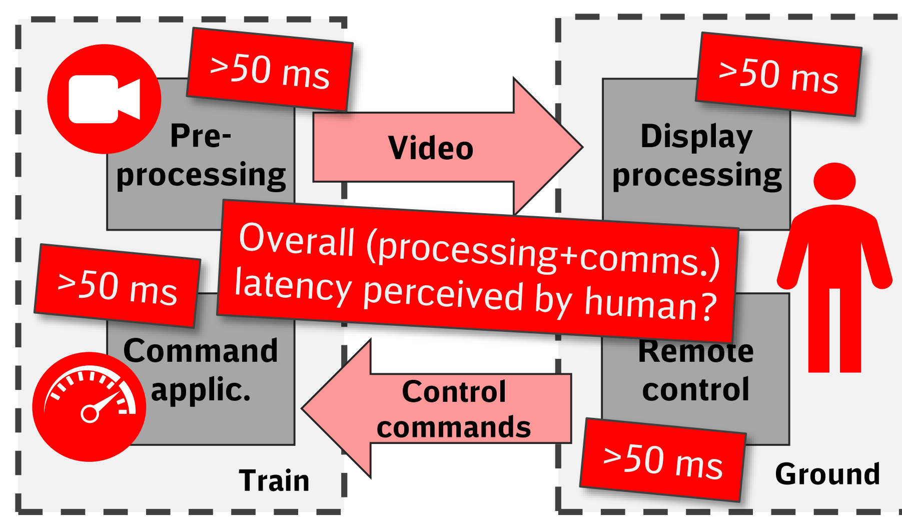
2) See details in UIC FRMCS FW-AT 3104, June 2018

Why latency matters in future rail operation

No human in the loop [1)]



Human in the loop [1)]



Main impact: Braking distance

At slow speeds, saving 200 ms of E2E processing / comm. latency has visible impact

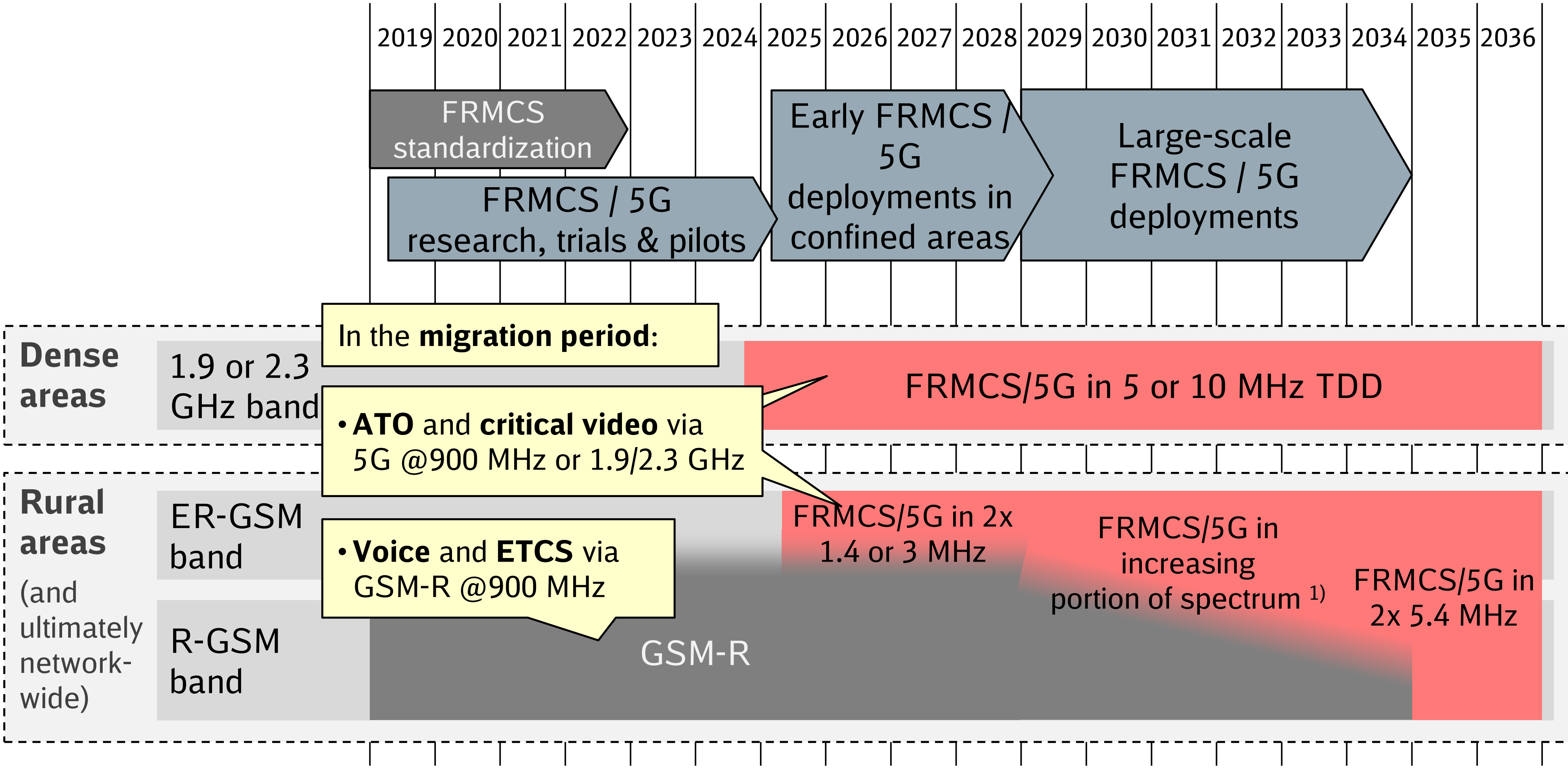
Main impact: Fidelity (and stopping accuracy)

According to various studies, fidelity of video-based control starts getting impaired for E2E processing / communication latencies beyond ~200-300 ms [2)]

Resulting requirements: **< 10 ms** one-way E2E comms. latency for **<40 km/h, <100 ms otherwise**

1) Strongly simplified for illustration purposes (e.g., transport network delay neglected)
2) See, e.g., Mellinkoff et al., „Quantifying Operational Constraints of Low-Latency Telerobotics for Planetary Surface Operations", January 2018

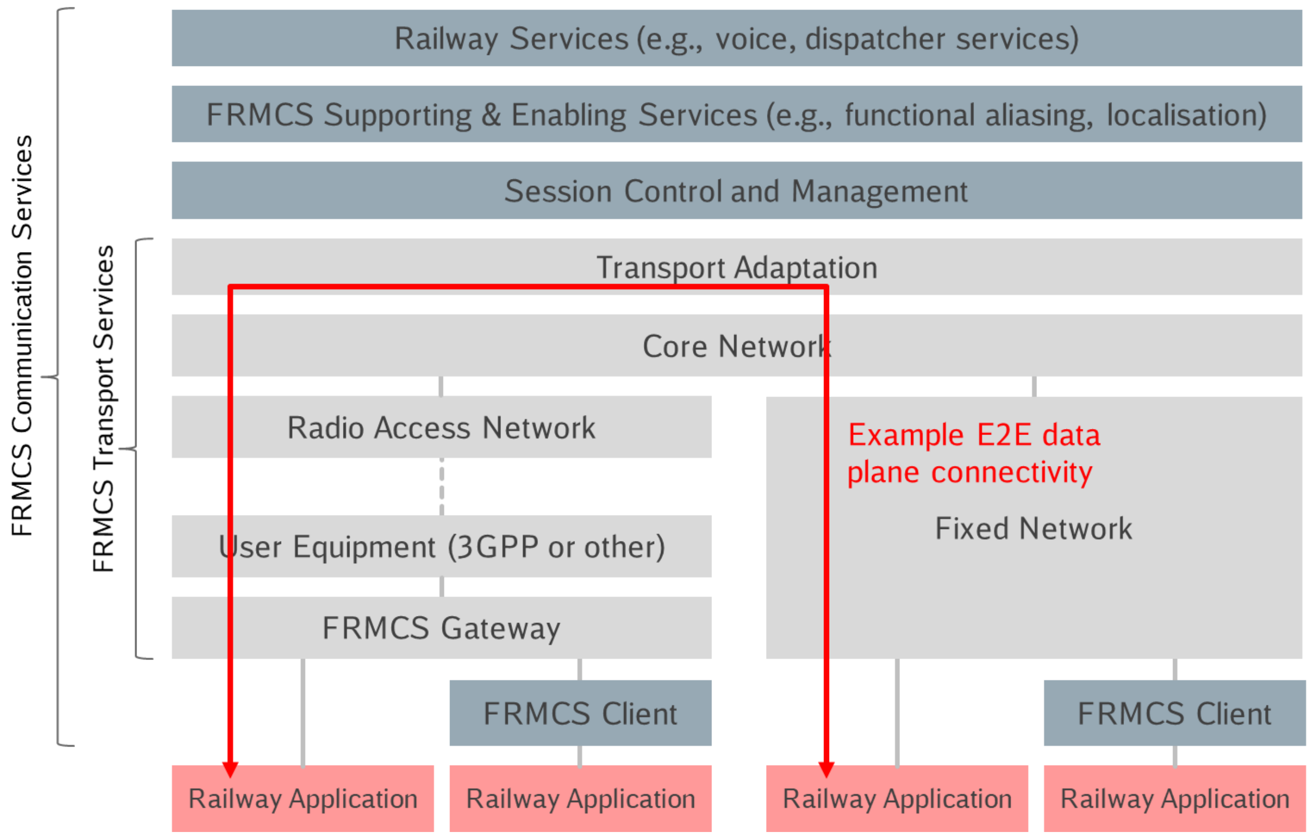
To address the needs, DB plans an early introduction of the Future Rail Mobile Communication System (FRMCS) based on 5G



1) Note that a step-wise refarming of (E)R-GSM bands of course has to well consider the remaining GSM-R connectivity needs, which are expected to remain high for a long period especially in dense areas

What exactly is FRMCS?

For international interoperability and market scale reasons, DB's 5G introduction will be compliant to the Future Rail Mobile Communication System (FRMCS) driven by UIC

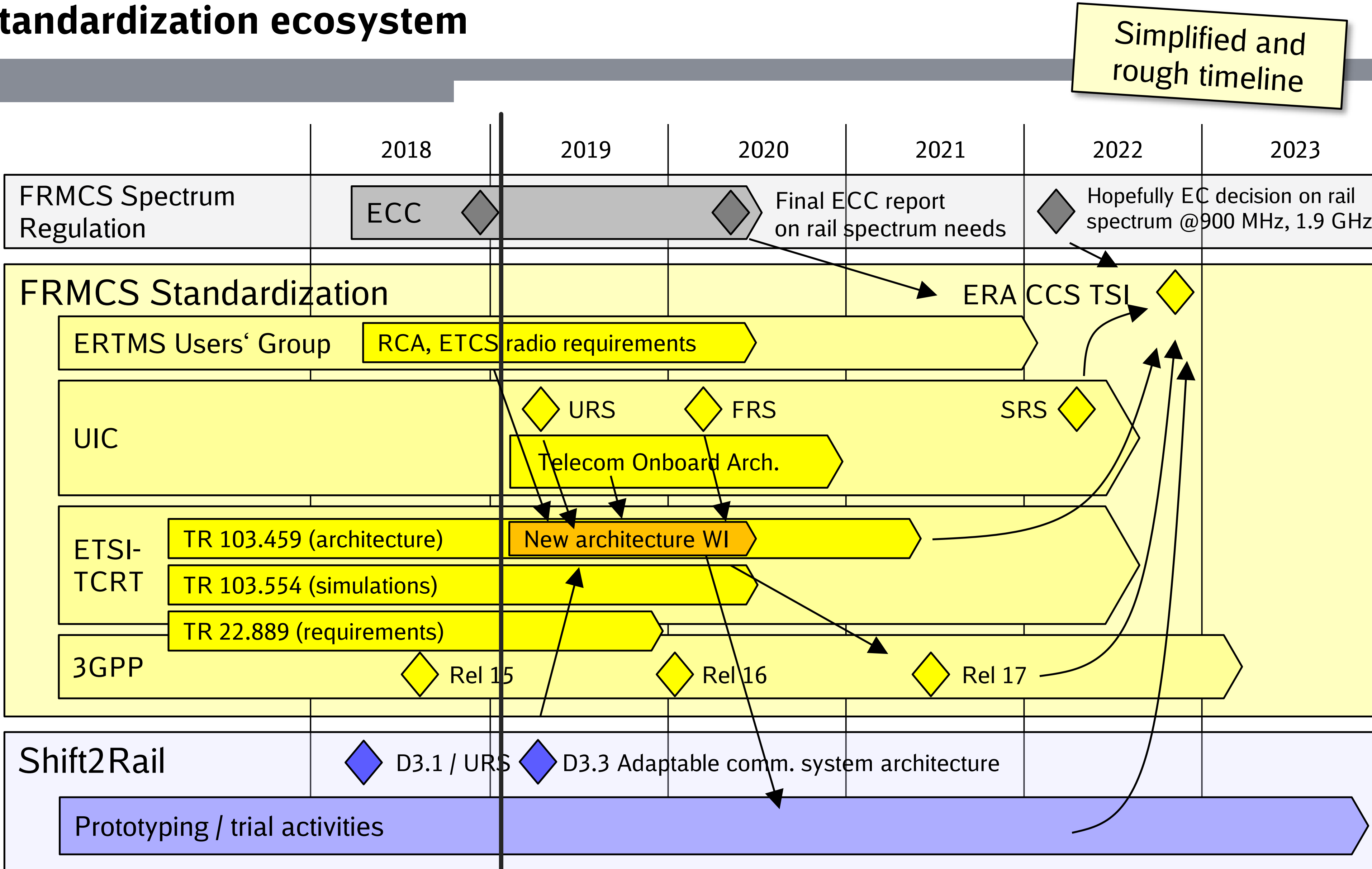


See details in ETSI TR 103 459

Points that are crucial to DB in the FRMCS standardisation:

- Maximally leverage „mainstream“ 3GPP technology and minimise rail-specific functionality
- No "one size fits all", but rather a differentiated support for diverse rail applications, e.g.,
  - MCX/IMS framework for applications requiring functional aliasing and point-to-multipoint (e.g., voice)
  - Lean handling of applications requiring point-to-point IP connectivity (e.g., future ETCS, ATO, critical video)

FRMCS spectrum regulation and standardization ecosystem



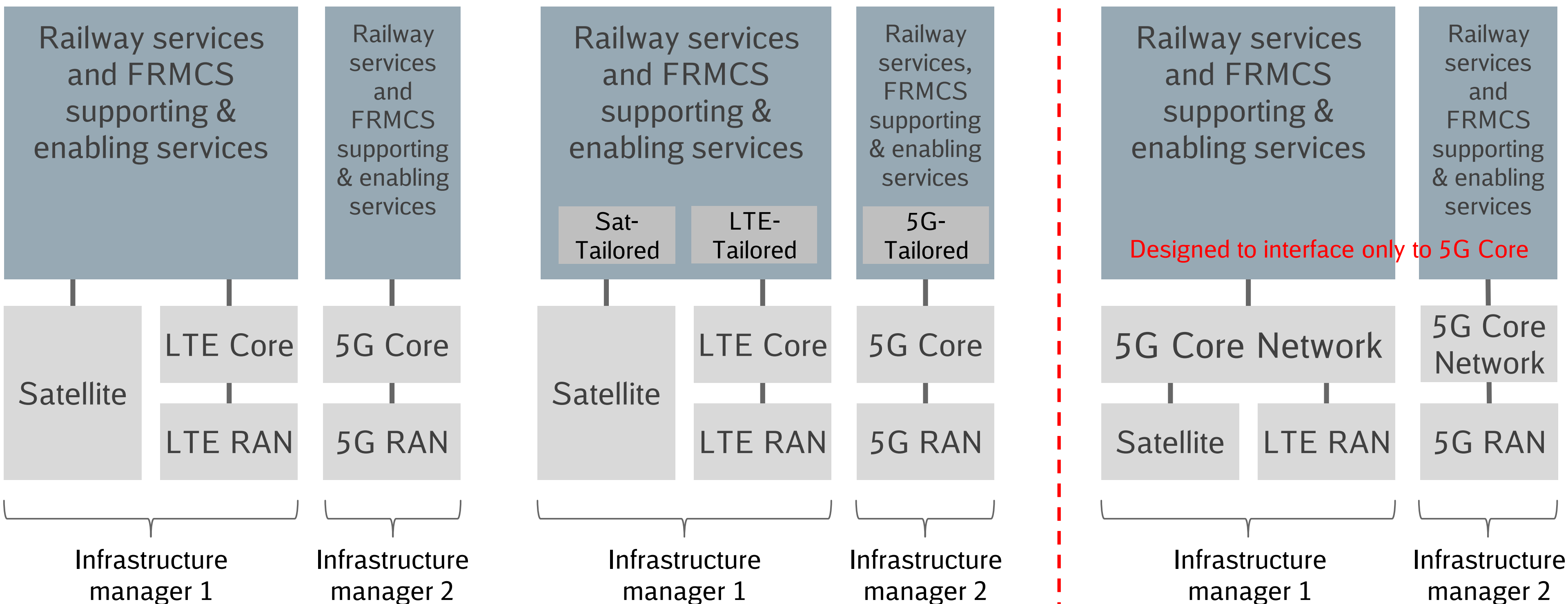
DB NETZE

FRMCS is expected to provide „bearer independence“, but DB expects that technology options should be well narrowed down

A **E2E bearer independence, with fully transport-agnostic FRMCS support services**

B **E2E bearer independence, FRMCS services tailored to comms. technologies**

C **Radio bearer independence, FRMCS support services optimized to leverage 5G core**

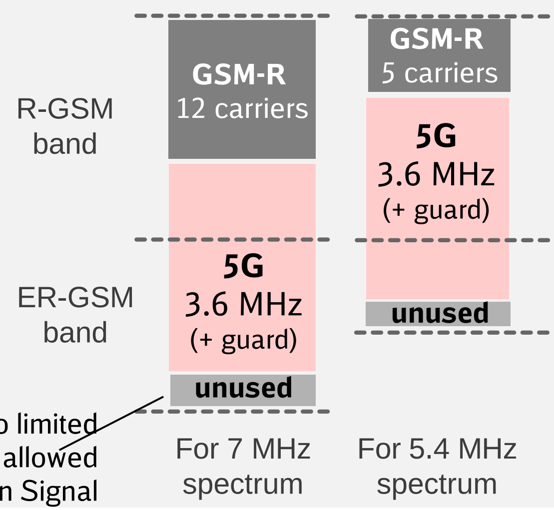


DB recommended

Challenge: FRMCS / GSM-R coexistence @ 900 MHz

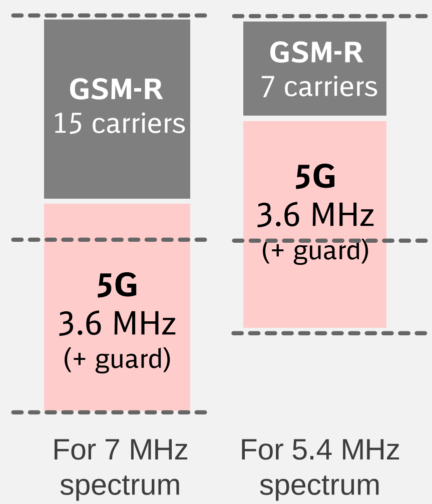
5G / NR radio is in principle designed for bandwidths ≥ 5 MHz, though a detailed view at the spec shows that the limit is actually 3.6 MHz (+ guard)

5G / NR as is (3GPP Rel. 15) allows for[1]:



Unused due to limited granularity of allowed Synchronization Signal Block (SSB) center frequencies

Minor standardization effort in 3GPP Rel. 17 could enable:



Any further reduction of NR bandwidth would require substantial changes in design of Synchronization Signal Block (SSB) and is **unlikely in coming releases**

Option would enable FRMCS/GSM-R coexistence where 7 or 15 GSM-R carriers are sufficient (e.g., in rural areas in Germany)

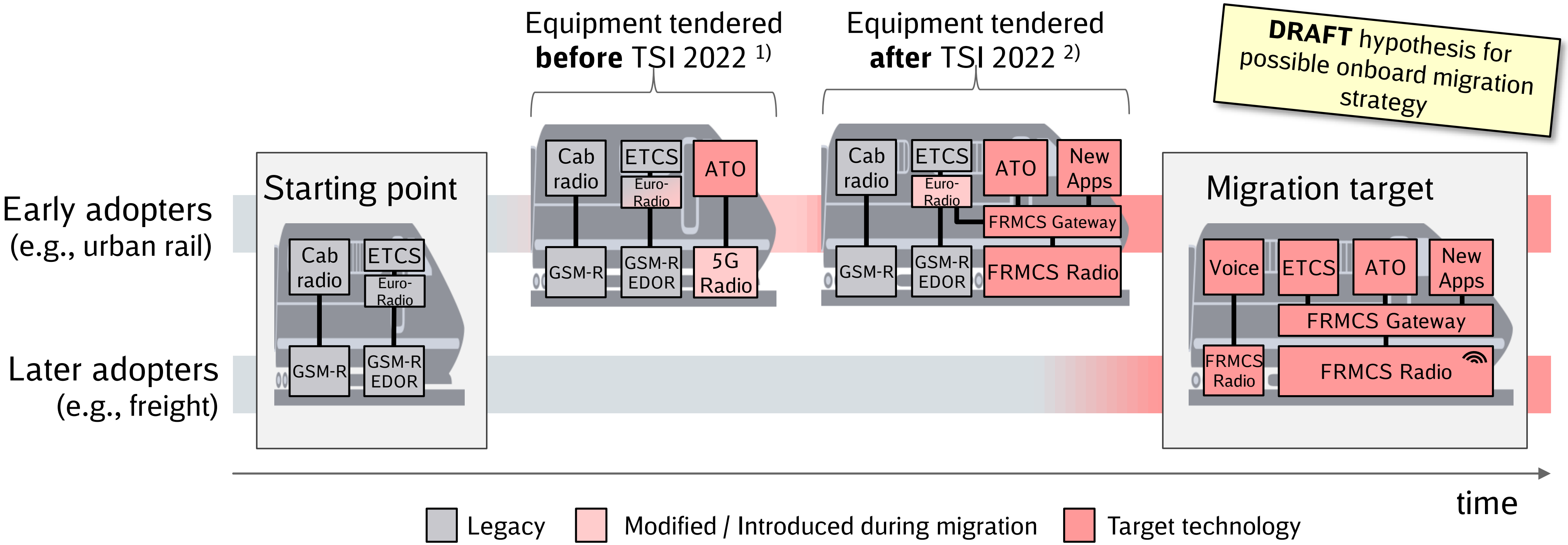
→ Possibly „low-hanging fruit“, but timely action needed

[1] From the perspective of the principle NR baseband design. Of course, for this solution, the (E)R-GSM bands as such have to be marked for NR usage.

Challenge: Onboard equipment migration

Key premises from DB perspective:

- Dual radio needed on trackside (in most cases) <u>and</u> train side (at least for urban / regional RUs)
- Number of onboard upgrade steps has to be minimzed
- Evolution of cab radio and its connectivity should be decoupled from that of ETCS and other applications



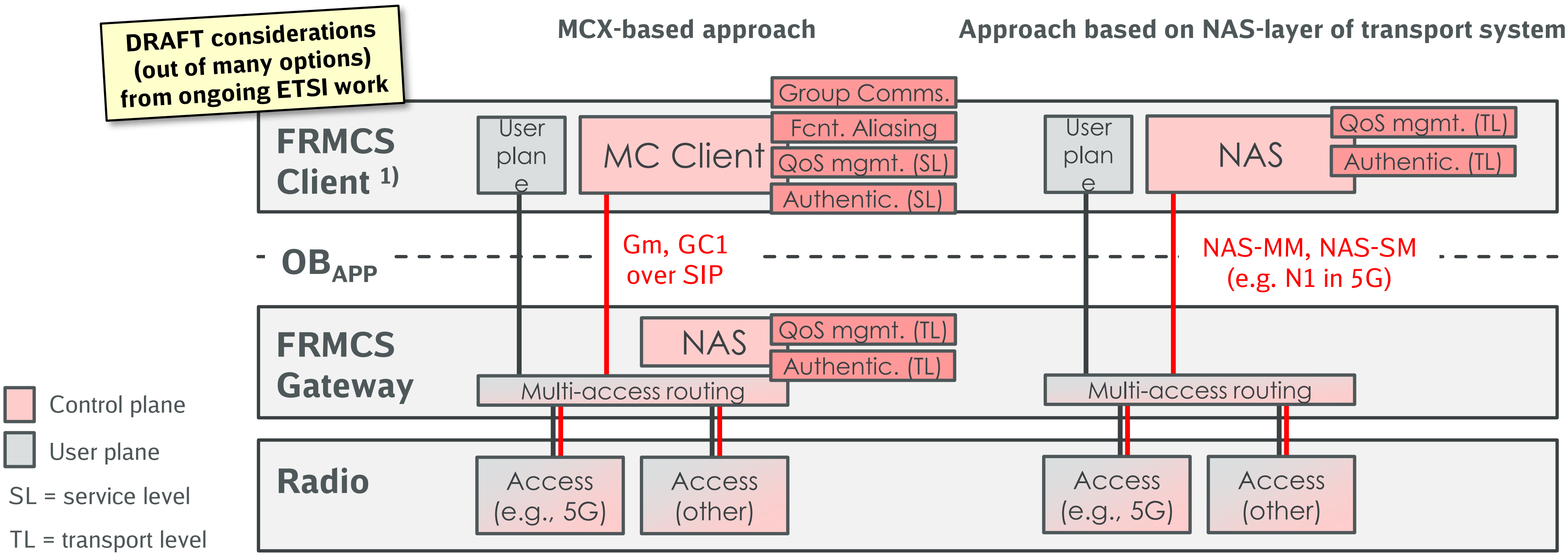
[1] e.g., involving EuroRadio implementation that is already physically prepared for later FRMCS interface

[2] for instance corresponding to UIC FRMCS TOBA variant 3 (see TOBA-7515) or similar

Current discussion in ETSI FRMCS standardization: Functional architecture and usage of 3GPP building blocks

Key needs from DB perspective:

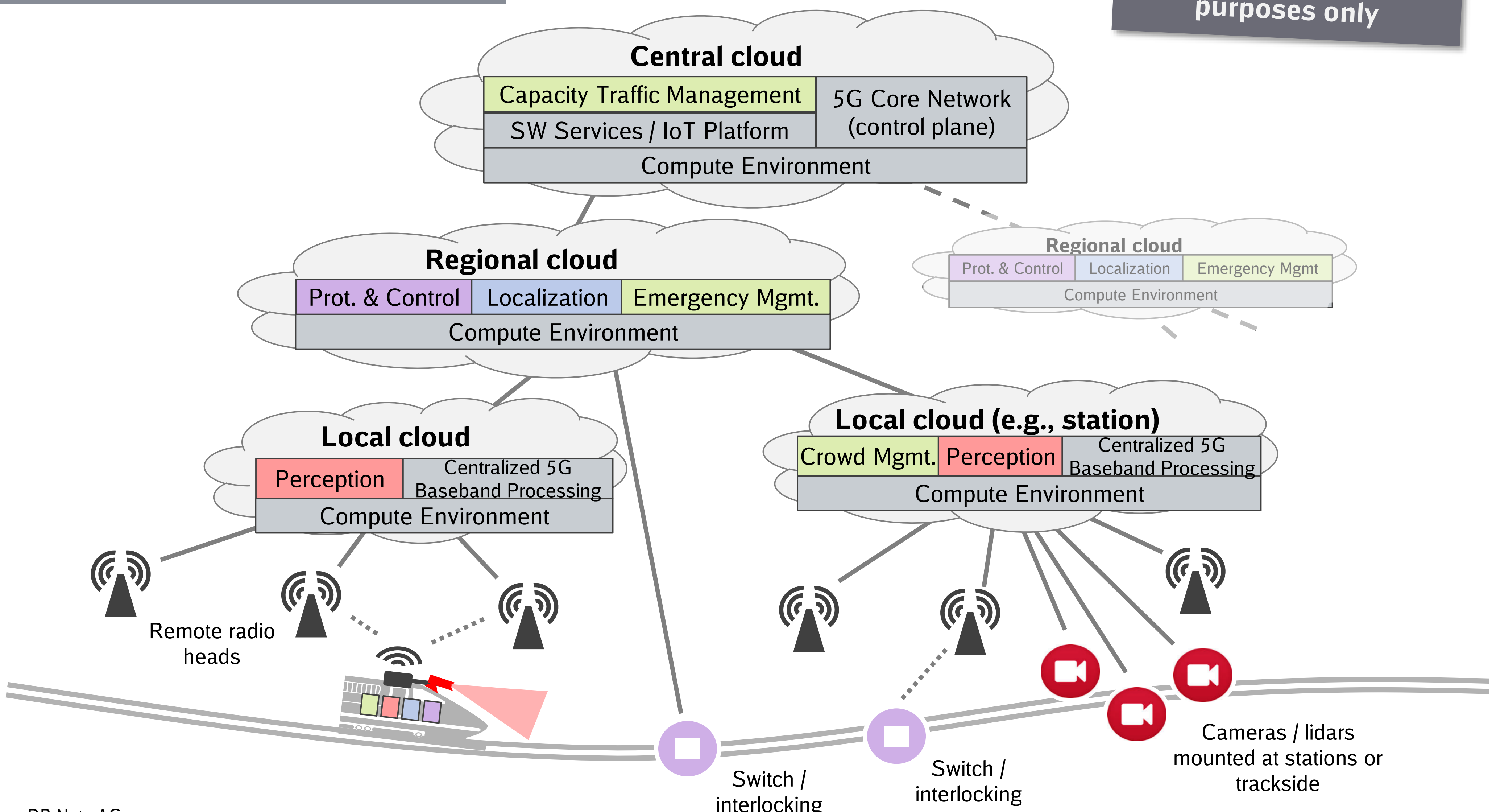
- Diversity of application needs should be taken into account (no „one-size-fits-all“)
- Application interface OB_{APP} needs to be finalized early, as relevant for signaling bodies / migration phase
- FRMCS supporting and enabling services shall be as lean as possible and leverage latest 3GPP advances



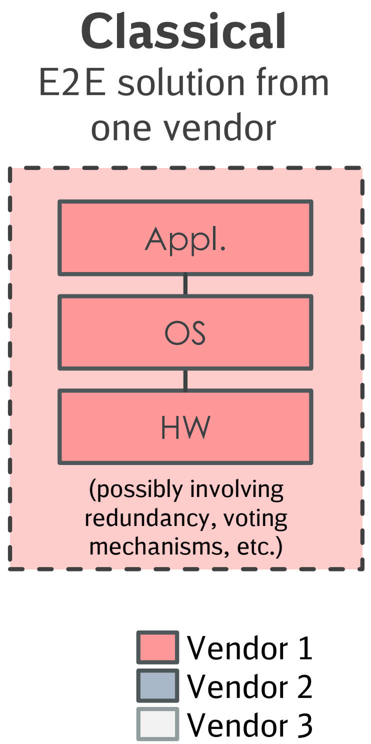
1) It is commonly assumed that the FRMCS Client is either included in the application, covered in a separate entity, or included in the FRMCS Gateway for applications which do not require a dedicated FRMCS entity and where static QoS management is sufficient

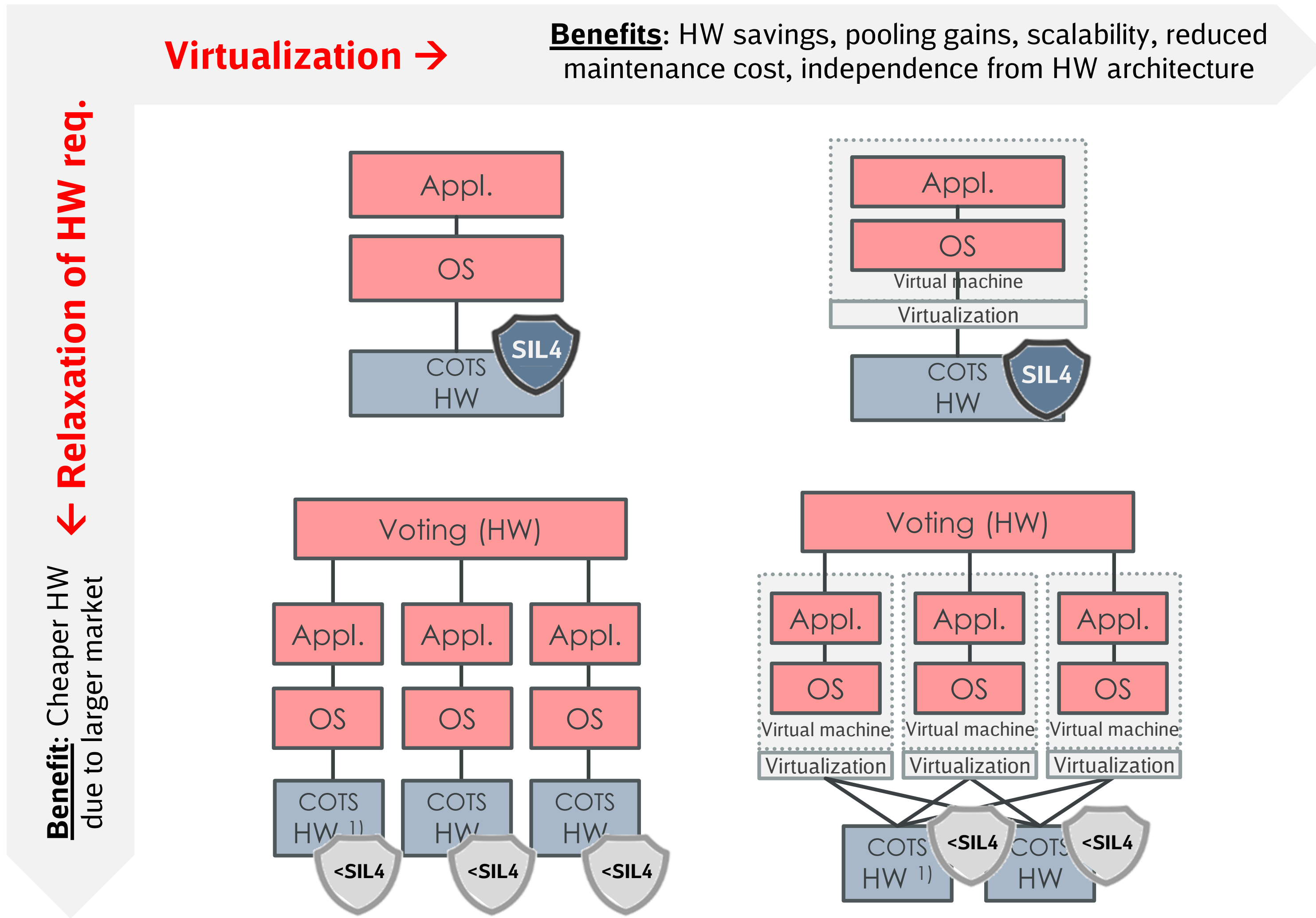
Ambition: A decently harmonized Cloud infrastructure for diverse rail applications and telco functionality

Example, for illustration purposes only



Challenge: How to realize safety-relevant (SIL4) applications in COTS Cloud environments?





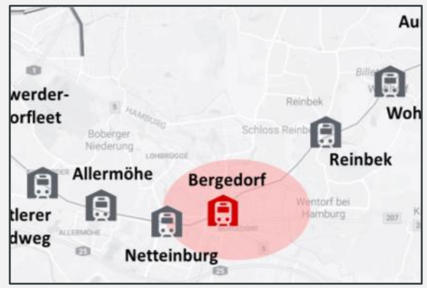
1) Note that HW from different vendors may be needed to mitigate systematic errors

DB‘s holistic approach to FRMCS development and introduction

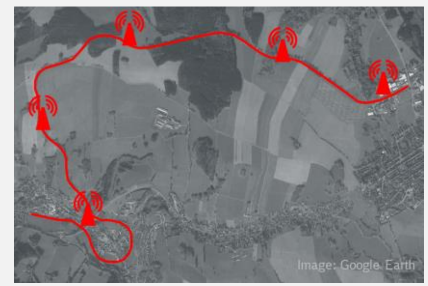
Research & innovation collaborations

- Perform broad technology scouting
- Tailor 5G /Cloud technologies to rail scenarios for maximum cost efficiency
- Trigger vendors to perform rail specific innovations they would otherwise not start themselves

Pilots and field trials



GoA2 / GoA4 pilot with 5G at ITS World Congress Hamburg 2021



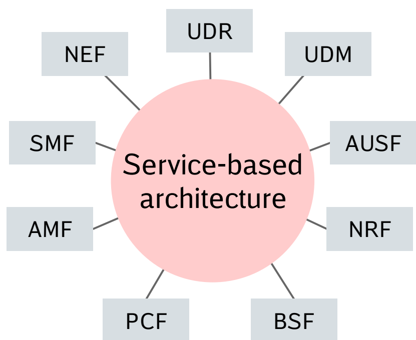
Digital Rail testbed Erzgebirge

Regulation and standardization

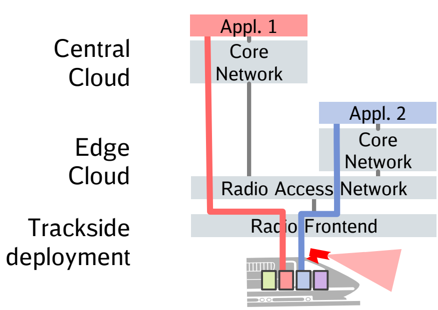
Strong involvement in UIC, EUG, ETSI, 3GPP (indirectly), Shift2Rail

Beyond standardization, there is a large potential in rail-specific 5G optimization & configuration

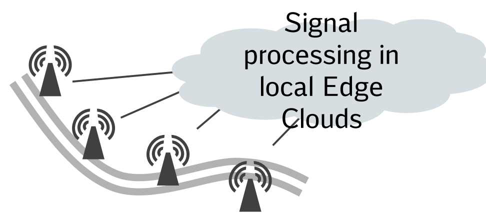
Railway-specific instantiation of service-based 5G core network



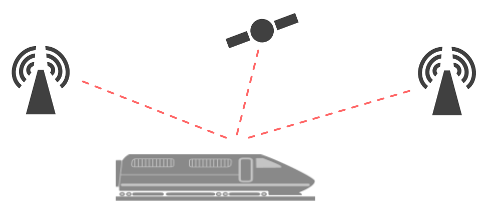
E2E differentiation of rail applications and QoS management



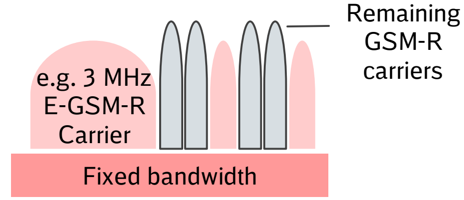
Centralized radio access network (C-RAN)



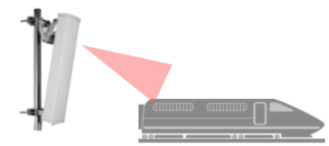
5G for positioning support



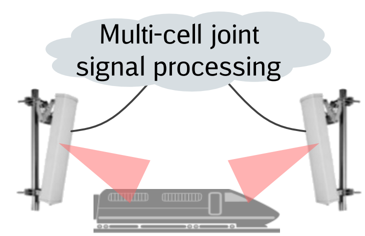
Flexible spectrum usage



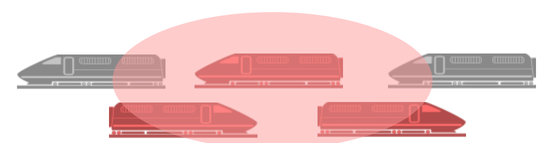
Multi-antenna technology („massive MIMO“)



Coordinated Multi-Point



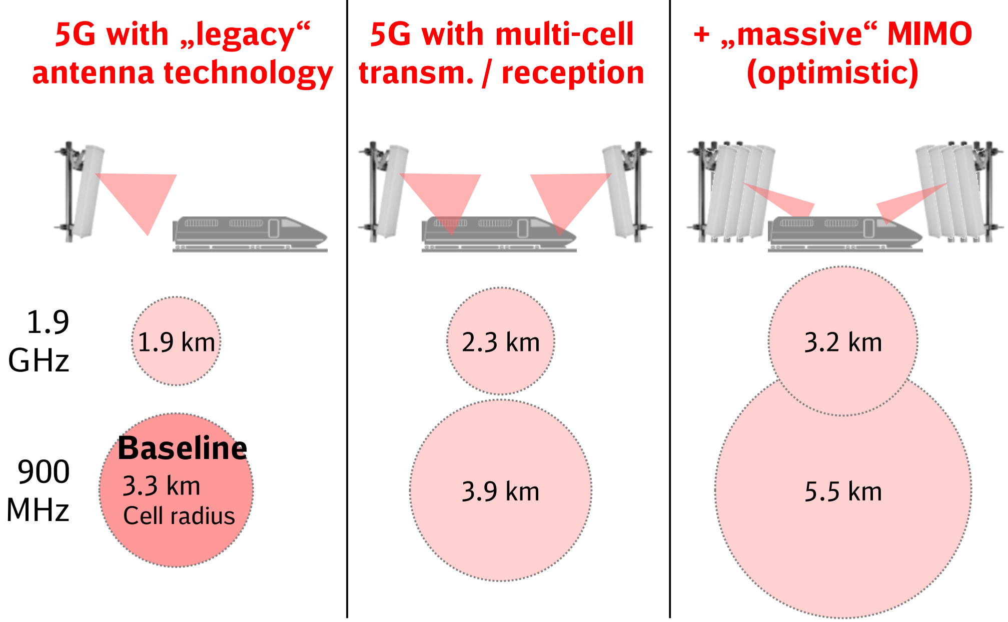
Location-based connectivity



Ongoing and planned research and innovation collaborations

Multi-Point Tx/Rx and „Moderate Order“ MIMO [1)]

Leveraging benefits of rail scenarios, such as limited set of locations in which trains can reside, high predictability of channel conditions, etc.

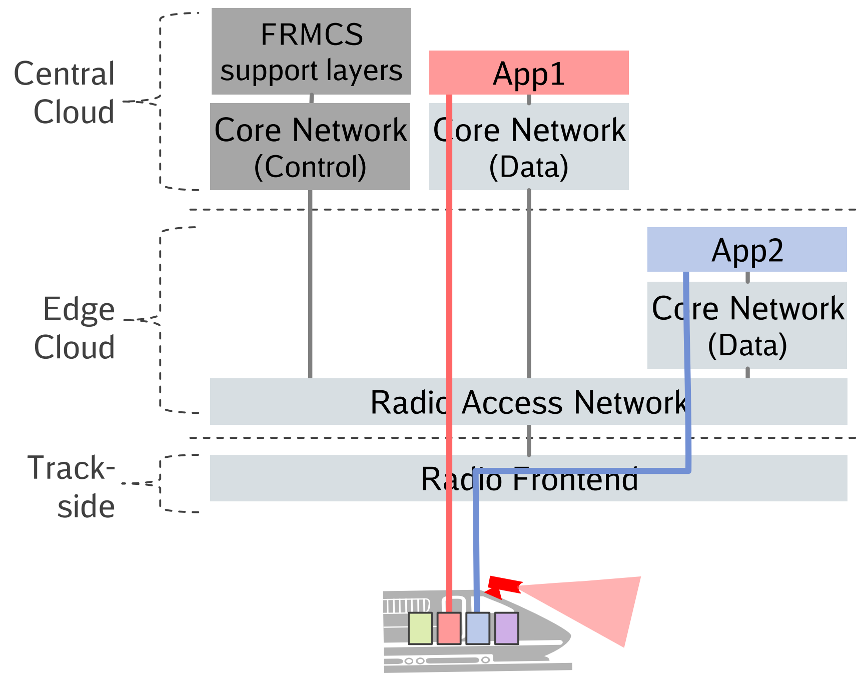


[1)] Note: Very rough estimates of cell size, for illustration only

Collaborations ongoing

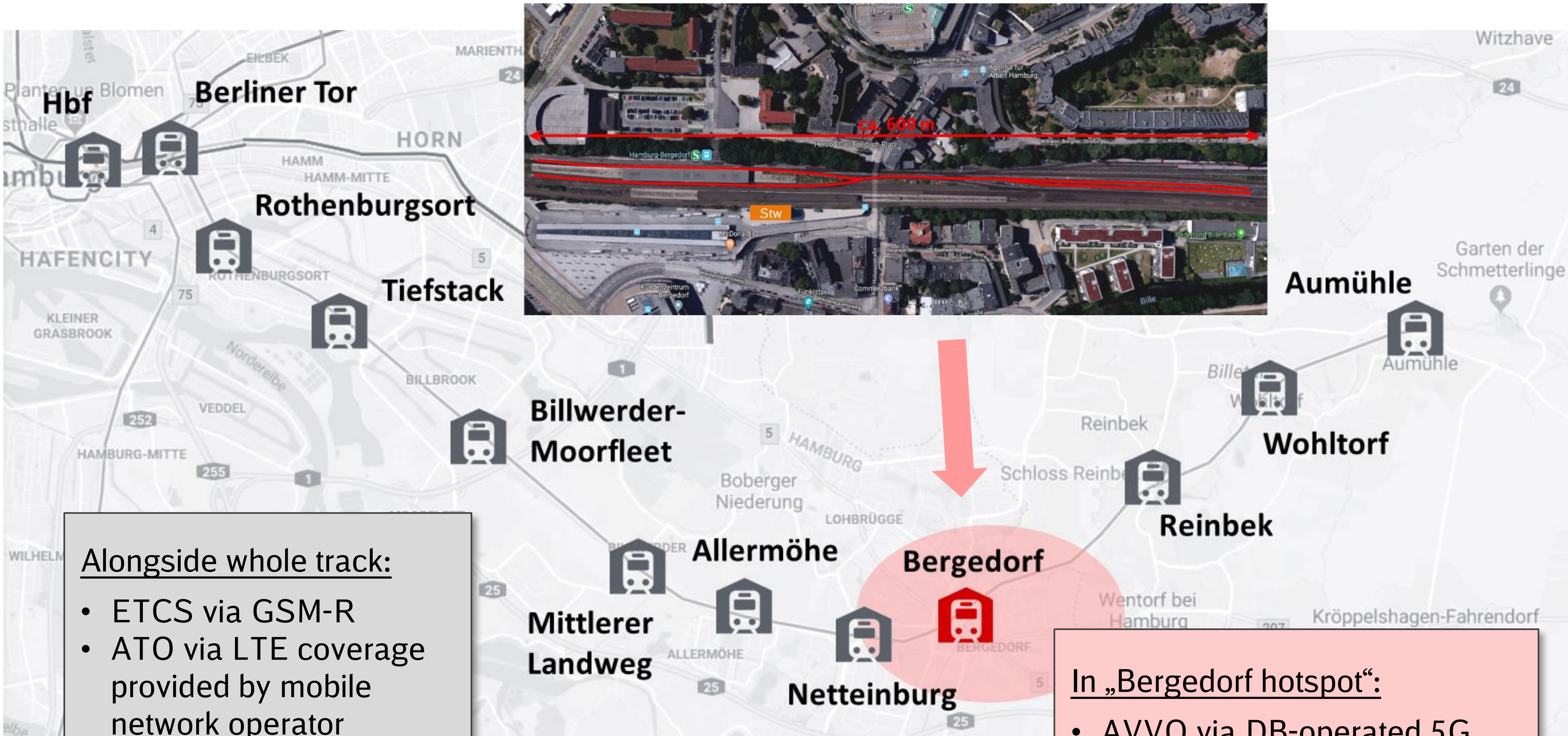
E2E Application Differentiation and Integration

Including specific instantiation of radio and core functionalities for railway needs, E2E QoS management, proactive application scaling based on prediction of channel quality, etc.



Tender planned

Pilot of GoA2 / GoA4 operation involving 5G planned for ITS Word Congress Hamburg in 2021



<u>Alongside whole track:</u>

- ETCS via GSM-R
- ATO via LTE coverage provided by mobile network operator

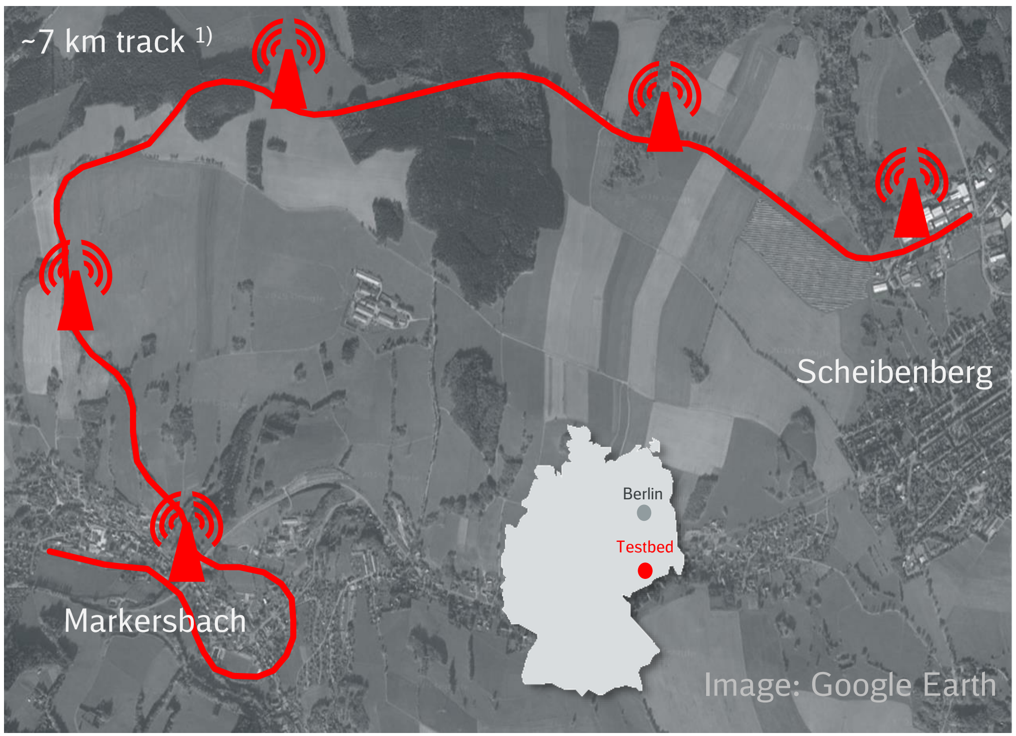
<u>In „Bergedorf hotspot“:</u>

- AVVO via DB-operated 5G core + 5G radio on DB-accrued spectrum @ 3.7 GHz

Planned Digital Rail testbed based on FRMCS/5G in Erzgebirge

Ambition: Comprehensive testbed alongside practically unused track for research & innovation, integration and verification of future rail operation applications on FRMCS/5G and Cloud technology

- **Core network:** 5G
- **Radio / spectrum:** Likely initially 5G @ 3.7 GHz and LTE @ 1.9 GHz, later also 5G @ 900 MHz and 1.9 / 2.3 GHz



Envisioned approach and tentative timeline:

Basic infrastructure setup

- *antenna masts*
- *fiber-optic conn.*
- *cabinets*
- *connection to DB test center Eschborn*

(DB-owned, vendor-neutral, well-dimensioned)

Setup and test of FRMCS / 5G and Edge Cloud

through tenders and collaboration with external partners

Integration and test of rail applications

through tenders and collaboration with external partners

2019 | 2020 | 2021+

[1] note that the exact number and locations of antenna sites are yet to be finalized (radio planning and measurements ongoing)

Thank you for your attention!