Field Evaluation of MCX Implementations for the Future Railway Mobile Communication System

Friederike Maier*,Shirish Kendre* Maksym Tyrskyy*,Arne Weber*
Ulrich Geier†,Manfred Taferner†,Peter Beicht†,Kevin Wriston†, Endri Stefani†
Jens Koecher‡
*DB Netz AG, Berlin, Germany
†Kontron Transportation Deutschland GmbH, Immenstaad, Germany
‡Funkwerk Systems GmbH, Kölleda, Germany

***Abstract*—The Future Railway Mobile Communication System (FRMCS) will be the successor of GSM-R for mobile train-to-ground communication in railway operations. It will utilize 3GPP's Mission Critical Services (MCX) framework to add several railway specific functions, such as point-to-point and group calls, location based communication and prioritization of certain services, to the 5G-based transport stratum. While the standardization of FRMCS and MCX is still ongoing, first railway specific implementations of MCX over 5G are being realized and tested. Proof-of-concept experiments and field trials are a crucial part of the FRMCS system verification which is still at its beginning. The partners DB Netz AG, Nokia, Kontron Transportation and Funkwerk, as part of the sector initiative Digitale Schiene Deutschland have established an R&D cooperation and implemented a first FRMCS network in DB's Digital Rail testbed, which is located in the Erzgebirge region, Germany. This paper presents an early deployment and first measurement results of a FRMCS network, focusing especially on the MCX part of the system integrated with a 5G standalone network.**

***Index Terms*—FRMCS, MCX, Mission Critical Services, 5G, Field Evaluation, Railway Communication**

I. Introduction

The sector initiative Digitale Schiene Deutschland of DB Netz AG is working on a new level of rail operations by introducing modern technologies for enabling automation and digitalization for improved railway performance. The increased grade of automation comes with new use cases and demanding data communication needs. Data rates increase due to emerging services such as critical video and sensor information transfer in real-time between train and track infrastructure [1], [2].

To meet the upcoming connectivity requirements and due to the upcoming obsolescence of the 2G based GSM-R equipment used within railway operation today, the FRMCS will be based on 5G technology. In addition to the 900 MHz GSM-R frequency band, the European Commission has granted additional 10 MHz time division duplex (TDD) spectrum to the railway sector in the 1900-1910 MHz frequency band [3].

To evaluate innovative digital rail technologies in the field, DB Netz AG is operating a testbed in the Erzgebirge region, Germany, which is known as “Digitales Testfeld Bahn” (Digital Rail testbed). The testbed includes a 10 km long track which is covered by a private 5G transport network, provided by Nokia. On top of the transport network, an experimental FRMCS service layer is operated which includes features from the Mission Critical Services (MCX) framework of 3GPP. On the one hand it serves to evaluate the 5G and MCX implementations and configurations in the field and study different quality parameters as presented in this paper. On the other hand, it will be used as communication platform for upcoming automation and train control technology trials.

II. The mission-critical service (MCX) framework for 5G-based FRMCS

The European Commission has mandated ETSI TC RT (Technical Committee for Railway Telecommunications) to provide the normative technical specifications for FRMCS, based on the functional and system requirements specifications (FRS and SRS) which are published by the UIC (International Union of Railways) and based on latest standard releases of 3GPP. This set of documents define technical building blocks as well as interfaces and ensure the interoperability across countries. The FRMCS system architecture is based on the utilization of 3GPP 5G and Mission Critical Services (MCX). The MCX framework is being developed within 3GPP since Release 13 to add mission critical functionalities to the mobile broadband standards. While the initial focus of MCX services was public safety, more requirements as the railway related ones from FRMCS were taken on board in later releases [4]. FRMCS will require a set of functions from the MCX specifications:

- **Common Functions** defined in MCX specifications as functions which are used by different MCX services like MCPTT (Mission Critical Push-to-Talk), MCData (Mission Critical Data) and MCVideo (Mission Critical Video). They include registration and service authorization, configuration management procedures, affiliation/deaffiliation, policing and QoS handling, location management, functional alias (incl. operations such as activation, deactivation, interrogation and takeover) and security functions for end-to-end encryption [5];
- **MCPTT Functions** define all functions used specifically for the Voice Push-to-Talk service. They include Private Calls, Group Calls, Voice Media handling and Preemption [6], [7];
- **MCData Functions** define all functions used specifically for the Data transmission service. They include function-

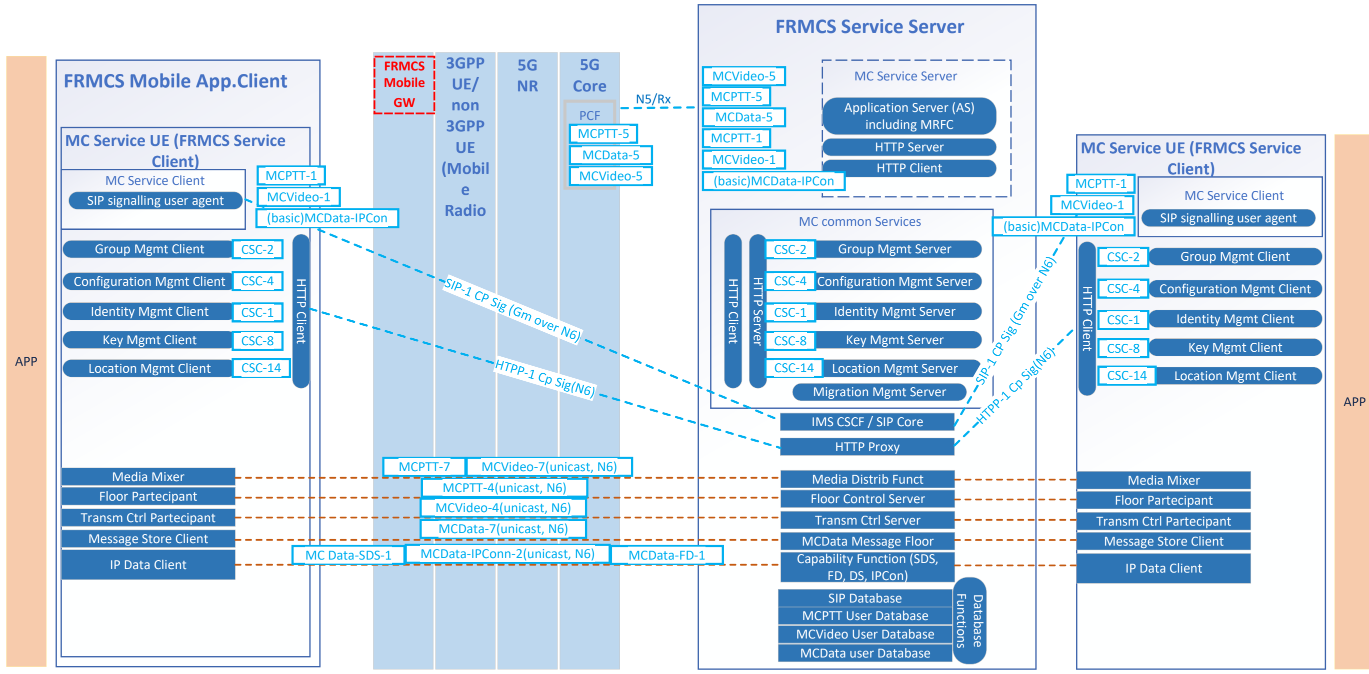

Fig. 1: MCX building blocks with reference points and connection to 5G Core

ality for IP connectivity, SDS (Short Data Service) and others [8], [9];

- **MCVideo Functions** define all functions used specifically for the video service, which are continuous accessibility, availability and reliability of service, low latency, prioritization and real-time operations in private and group communications [10], [11];

III. MCX Relevant Test Scenarios

In order to validate several MCX features, the following use cases have been tested within the R&D cooperation:

- Private MCPTT point-to-point calls with manual and automatic commencement mode and floor control option;
- Multi-user MCPTT group calls with pre-arranged groups;
- Railway emergency calls;
- MCData IPConn
- MCData file distribution (FD) in unicast and broadcast delivery method;
- MCData short data service (SDS) with text, binaries and hyperlinks as well as SDS with multiple messages (being interleaved within a single message payload), both over signaling or media plane.

IV. Functional Model of the MCX Service Architecture

The MCX architecture is used as vital building block for the FRMCS architecture [12]. Special focus needs to be put in addition on the interconnection of the MCX architecture to the 5G transport network. Fig. 1 aims to show the relevant MCX building blocks and reference points together with the interconnection to the 5G Core network elements. It shows the central core elements (FRMCS Service Server) and the connected clients ("FRMCS Mobile App.client" on the left-hand side for connections via the 5G network and "MC service UE" on the right-hand side for connected clients via a fixed network).

The functional model of the MCX service architecture can be divided in two separated planes, to allow further breakdown of the architectural description. The application plane and signaling control plane. Both of these functional planes can operate independently as standardized in [13]. The application plane uses the signaling plane via the MCX Application Server (MCX-AS) to achieve the desired services. From the end-to-end perspective, MCX AS acts as a server, while UE application obtains the role of client. To achieve this, both the MC server and MCX client make use of the application reference points also known as CSC (Common Service Core).

HTTP reference points (e.g. HTTP-1) are underlying signaling reference points used by Common reference points e.g., CSC-2, CSC-4 etc. MCPTT reference points MCPTT-x are used for MCPTT Services and have separate reference points for Session Establishment, SIP Database interface, Floor Control, MCPTT app and PCF for QoS and media over the N6 interface. Fig. 1 shows the signalling reference points and application plane reference points between the central MCX server ("FRMCS service Server") and the MC clients in detail. MCData reference points are used by MCData services for application signaling and SDS data transfer, file distribution and IPConnectivity services.

Although, MCX provides already a very complete framework for mission critical services, still many improvements are continuously included into the 3GPP MCX specifications. For further enhancements of the MCX framework in reference to FRMCS use cases and FRMCS deployments, the following topics are seen as items for additional future investigations:

- IPConn enhancements: Direct IP connection between clients and distributed IPConn capability/distribution function;
- More explicit separation between signaling plane and media plane for MCX connections and functional entities;
- Distributed Media Ressource Function (Processing Part, MRF-P) for MCPTT, in addition with interaction to 5G distributed deployment options (e.g. distributed UPF);
- MCX system interconnections and interaction with 5G deployment.

V. MCX SERVICES AND QOS WORKING PRINCIPLES

The FRMCS voice, data, and group communications services (MCPTT, and general MCX services) share commonly the air interface. The connectivity quality and throughput may be subject to fast changes due to the mobility of the train, therefore differentiated prioritization and QoS mechanisms are necessary. As described in Section IV, the MCX services consist of a control signaling plane (i.e. SIP/SDP signaling) establishing user plane Service Data Flows (SDFs), usually identified by 5-tuple (Source and/or destination IP address, Protocol and Source and/or destination Port). In general, a SDF is defined as the set of packets matching a single Policy & Charging Control (PCC) rule in the Policy Control Function (PCF and/or in SMF, UPF). Therefore, the 5G SA Core (SMF/UPF/PCF) needs to support the following tasks.

- Map SDFs to 5G QoS flows identified by N2 5QI (5G Quality-of-Service Identifier) and N3 QFI (QoS Flow Identifier);
- Bind one or multiple SDFs to that 5G QoS flow;
- Inform the UE of the QoS rules governing the mapping of uplink traffic to the correct 5G QoS flow;
- Verify that the UE respects the SMF-imposed or Reflective QoS rules for uplink traffic.

For the current MCX voice call and data scenarios the 5QI's in table I are recommended.

TABLE I: 5QI Mapping in 3GPP Rel. 17

	5QI	**Default Priority Level**	**Packet Delay Budget**	**Packet Error Rate**	**Example Service**
GBR	1	20	100 ms	10^{-2}	Conversational voice
Non-GBR	5	10	100 ms	10^{-6}	IMS signaling
Non-GBR	9	90	300 ms	10^{-6}	Video/TCP based data

In future releases (Rel. 18 and beyond), more MCX specific and standardized 5QI values will become available (e.g., 5QI 69 – Mission Critical delay sensitive signaling, 70 – MC Data, 65 – Mission Critical User Plane Push to Talk Voice, 67 – MC Video, 82-90 Delay Critical GBR).

VI. FIELD IMPLEMENTATION

A. Test environment

Fig. 2 shows DB's 24 km long testbed that is located between the towns of Schwarzenberg and Annaberg-Buchholz in a rural and moderately hilly part of the Erzgebirge region in Germany. The testbed includes a 10 km segment of railway tracks equipped with the basic infrastructure to operate mobile test networks, i.e. radio sites with antenna masts of 10 m height and fibre optic connectivity. The track is intended for experimental trials with a velocity of 50-80 km/h. The field trials have been performed with DB's ICE lab train "advanced TrainLab" and with a RF measurement van on a wagon as shown in Fig. 3. Both vehicles were equipped with several MIMO railway antennas on the roof and measuring equipment.

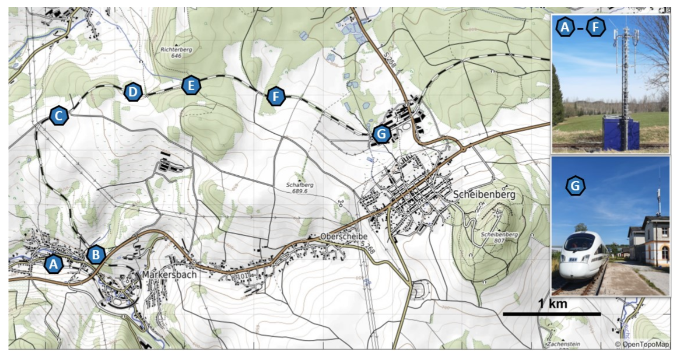

Fig. 2: Test site "Digitales Testfeld Bahn" in Erzgebirge, Germany. The radio sites used for the field trials are marked in blue

Fig. 3: Test vehicles used in the field trials

B. 5G network setup

Nokia provided the 5G standalone network, consisting of radio units with connected antenna systems, baseband units and a 5G SA core. The Remote Radio Heads (RRH, Nokia Airscale system) and antennas are deployed in seven container and tower sites along the railway track and at one rooftop site at the historic Scheibenberg train station. The 5G SA network operates at 3.7 GHz frequency range (band n78). The centralized access, IP and 5G core (Compact Mobility Unit, CMU) components are installed at Scheibenberg station.

A centralized and managed router 7250 IXR connects all IP based components and provides GPS time and synchronization functionalities. A Network Service Provider (NSP) provides the operation and management function for all the network elements. In addition, the radio units can be managed by local GUI (WebEM) on the provided service terminals.

C. MCX network setup

Kontron's mission critical service solution is used as MCX-trackside setup for the trial. It composes a converged IP Multimedia Subsystem (IMS) based virtualized 3GPP compliant system, capable of providing end-to-end mission critical services. The heart of this solution is an IMS-based SIP core with MC service servers, which is connected to the 5G-Core as shown in Fig. 4. The Server on which the IMS-based SIP core and the MC service application servers are running was installed in the railway station in Scheibenberg. Additionally a dispatcher application running on a laptop is installed and multiple MC service UEs hosting MC service clients.

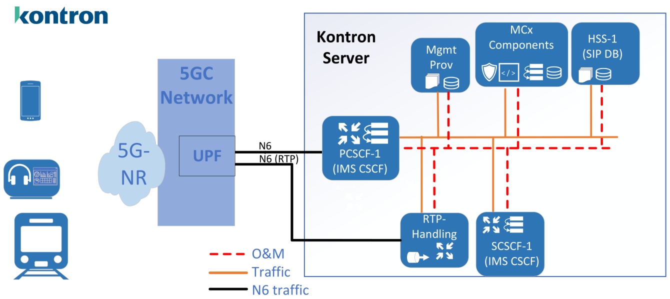

Fig. 4: Kontron MCX deployment and interconnection to 5G Core

The functional entities of the MCX solution are segregated and installed on several virtual machines on top of a small-scale datacenter infrastructure. Kontron's MC service solution provides all common services required for terminal authorization, user authentication, registration, configuration and security by hosting the following logical server functions:

- Media relay, distribution and conferencing;
- MCPTT server for private (point-to-point calls) and group communications, MCData server for IPConn, messaging and file distribution services, MCVideo server for video communications services (planned), Floor Control (FC) server;
- The IMS based SIP Core.

The SIP Core provides the capability to put Intelligent Application Servers (AS) in the loop, in order to "plug" additional services onto the IMS network and covers the following main functionalities:

- SIP registrar to UE;
- SIP Proxy;
- Service Selection;
- Security at the Gm Interface.

The IMS SIP Core consists of the Call Session Control Function (CSCF) components Proxy-CSCF (P-CSCF), Serving-CSCF (S-CSCF) and Home Subscriber Server (HSS) combined with a Real Time Protocol (RTP) proxy used for media.

The CSCF is the central element in SIP signaling between the UE and the IMS and it manages the UE's registration to the IMS and service session management. The CSCF is defined to have three different roles that may co-locate in the same node or separate nodes connected through the Mw interface. All are involved in the UE-related SIP signaling transactions.

The Serving CSCF (S-CSCF) is located in the user's home network and it maintains the user's registration and session. At registration, it interfaces with the Home Subscriber Server (HSS) to receive the subscription profile, including authentication information and it authenticates the UE. For the service sessions, the S-CSCF signals with the UE through the other CSCFs and may interact with the Application Servers or the MRFCs for setting up the service session properly.

The proxy CSCF (P-CSCF) is the first contact point to IMS node, the UE interacts with and it is responsible for all functions related to controlling the IP connectivity layer. For this purpose, the P-CSCF contains the Application Function (AF) that is a logical element for the IMS concept.

All Subscriber-related data (permanent or temporary) that corresponds to the individual IMS subscription is centrally stored in the HSS. This data is retrieved by using MCPTT-2 reference point, which exists between S-CSCF and the MCPTT user database (HSS). This reference point is used by the S-CSCF to obtain information about a specific user. The MCPTT-2 reference point utilizes a diameter management application protocol as defined in [13]. To access this data, the HSS provides a Cx interface to the S-CSCF.

In order to achieve Control and User Plane separation also known as CUPS, it was decided that a second N6 interface will be interconnected with 5GC. This second port will be a standard Gm interface from the 5G core point of view, but it will only carry RTP data in MCX implementation. The "connection information" in the SDP will contain the second N6 Interface IP so it will only add routing effort to the router interconnecting the MCX solution with 5G core.

D. UE setup

For the MCPTT measurements, a cab-radio setup by Funkwerk, as shown in Fig. 5 was used. The on-train cab radio is based on an Android operating system and equipped with railway typical frontend layout, e.g. Emergency button. On top of that a MCVoice application is running. 5G connectivity is provided by an external 5G Router.

For the MCData/IPConn measurements a test setup provided by Kontron was used as shown in Fig. 6. The MCData/IPConn client is integrated within the application laptop, which is tethered to a 5G modem. Another client is integrated within the dispatcher laptop, which is directly connected to the MCX network over Ethernet.

The MC Client laptop receives its IP address from the 5G modem, which is then a private IP address and unknown to the network to forwarding the SIP messages. In this case a NAT implementation in the MCX network side is required to support the SIP based call procedures.

In another IPConn test setup with a Funkwerk cab radio, not shown here in detail, the end-2-end IPConn call is arranged between two cab radios, which are connected to the MCX network over the 5G network. Here the MCData/IPConn clients

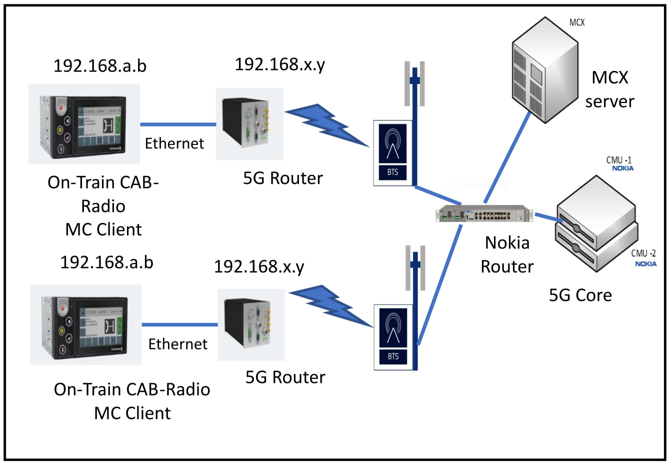

Fig. 5: Funkwerk cab radio setup for MCPTT measurements

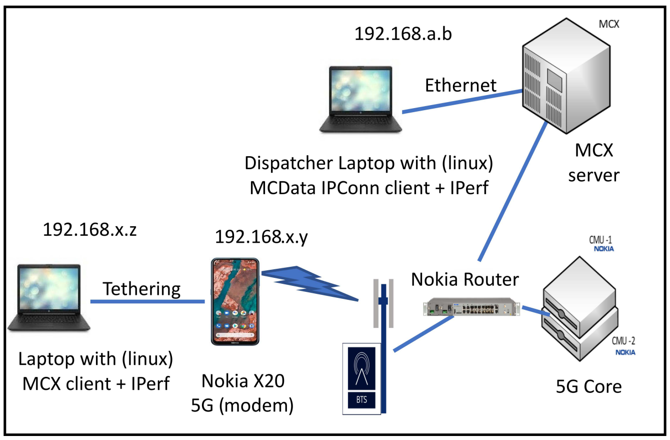

Fig. 6: Kontrons IPconn setup for MCData measurements

are integrated within the 5G modem, who's IP addresses are known to the MCX network, hence no NAT implementation in the MCX network is needed in this case.

VII. Evaluation Methodology and Results

The tests in the early phase of the project were aimed at basic verification of the installed system (5G and MCX) and first studies on how to assess quality parameters on different layers in the mobile environment for the end-2-end services.

A. MCPTT calls

Different types of MCPTT calls were tested as part of the testing strategy of the FRMCS system in the Digital Test Field in Erzgebirge:

- On-demand Private MCPTT Call in manual commencement mode with and without floor control;
- Floor management during a Group Call: Impact of user's priority;
- Upgrade of an on-going MCPTT Group Call to higher priority;
- Location reporting from MCPTT User to AS;
- Impact on system BW as measure of key performance indicator was also performed when using different codecs e.g., AMR-WB, G.711 a-Law.

The MCPTT Call analysis is based on SIP flow and RTP stream analysis. Therefore, the SIP/RTP stream is captured (traced) at the MCX AS and P_CSCF/S_CSCF at the RTP Proxy and at the UE/Modem side. As part of the SIP flow analysis the completeness of the different MCPTT procedures were analyzed:

- Registration success, de-registration;
- Affiliation, Floor Control;
- Call set-up Success, Call setup time and Call release.

As part of the MCPTT RTP analysis the following KPI's and Indicators were analyzed:

- Call duration;
- QoS stream (number of packets, lost packets, max, avg, min Delay and Jitter);
- Impact due to 5G network behavior, like cell change (Handover Procedures), loss of coverage or bad coverage.

Fig. 7 shows for example the packet delay of a recorded voice call affected by a coverage gap.

B. MCData tests

Along with the MC Voice service, MC Data (Short Data Service, File Distribution, IPConn) was also tested and verified. MCData IPConn is of special interest, as future railway applications mainly would be served using MCData IPConn. The MCData IPConn use case is characterized by one direct GRE (Generic Routing Encapsulation) tunnel between the two end user devices (e.g., terminal to terminal or dispatcher to terminal), which can be used by different applications as a direct "media flow tunnel" as can be seen in Fig. 8.

The SIP signaling procedures are used to set-up, maintain and at the end release the GRE tunnel between both end user devices, e.g., using for the setup procedure the SIP invite until SIP 200 ok messages. For the MCData (IPConn) the following KPI's were analyzed:

- Session setup success/time;
- Quality indicators per session (throughput, delay, packet loss);
- Session continuity (unexpected data session end indicator).

For MCData SDS, MCData FD the KPI's and Indicators are different.

- SDS successfully sent/received (one-to-one, group);
- FD request received/download succesful (unicast, broadcast).

Beside the MCX measurements also at the 5G network level, several QoS measurements have been conducted. Analyzing the dependencies between transport and service stratum quality and performance is a future topic of interest.

VIII. Conclusions

A successful installation and implementation of an early deployment FRMCS system over a 5G-SA network was done

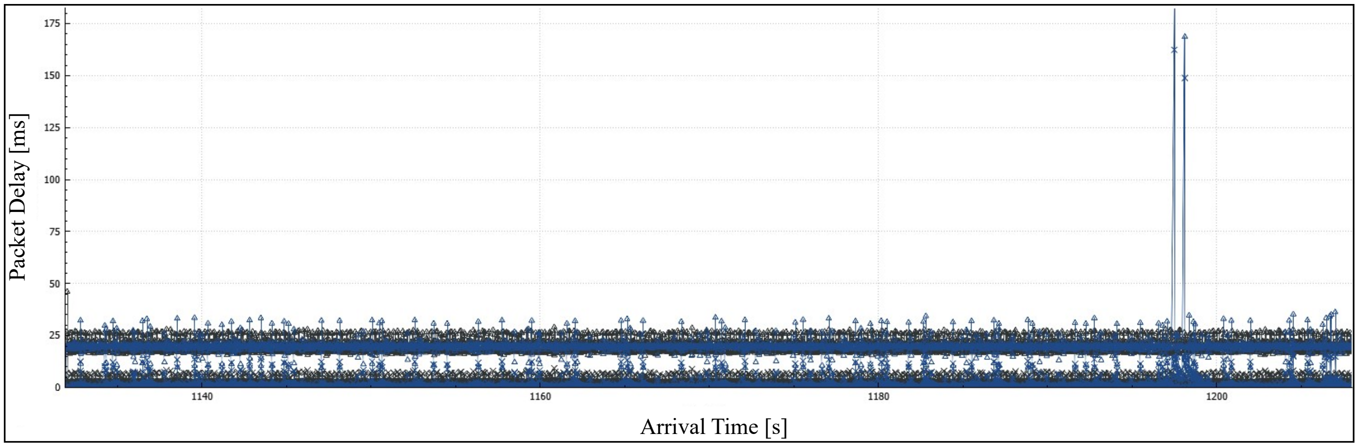

Fig. 7: Packet delay of a voice record measured during a drive test. Max. packet delay is below 50 ms with an exception occurred during handover processes in a coverage gap.

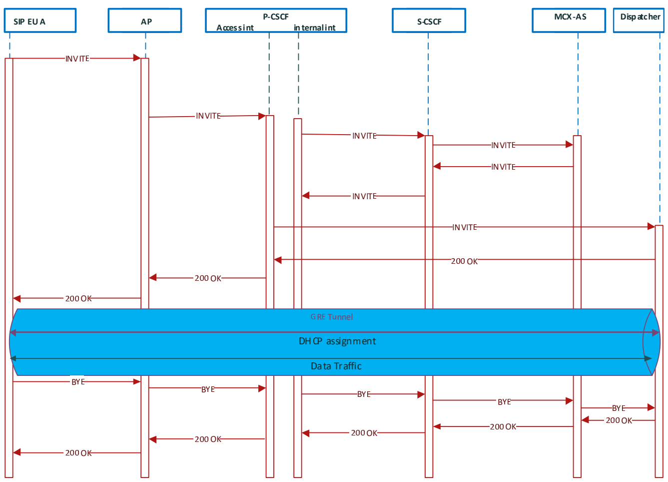

Fig. 8: Call flow of an IPconn connection

in the Digital Rail testbed in Erzgebirge. The following results can be highlighted:

- System verification via different call scenarios in stationery and mobility mode (e.g., MCPTT point-to-point/group calls/emergency calls, MCData IPConn);
- First studies on how to assess and analyze quality parameters on different layers;
- Testing the different MC Services with different test setups and user devices gave important insights about implementation and addressing issues for successful end-to-end call setups.

Further focus will be set on the modularization of the Onboard setup to get more applications attached to one modem via an onboard gateway. Traffic steering towards a centralized control plane and decentralized media plane. Location based services will also be an upcoming topic. The test methodology for the end-to-end setup, analyzing the QoS parameters at different layers and the dependencies between them is another topic of interest.

Advanced FRMCS trials in the testbed will take place within the Horizon 2020 project 5GRail [14] and the French-German 5G RACOM project, which will focus on hybrid FRMCS networks, combining public and private 5G networks [15]. Different innovative railway applications as an ETCS L3 moving block demonstrator and trials with advanced level of automation are planned in the Digital Rail testbed within the Europe's Rail Joint undertaking project. Their connectivity will be based on the FRMCS deployment.

Acknowledgement: The authors would like to thank Nokia for providing the underlying 5G-SA network.

References

[1] P. Marsch, R. Fritzsche, B. Holfeld, and F.-C. Kuo, "5G for the digital rail system of the future - the prospects for FRMCS," in *SIGNAL+DRAHT*, Mar. 2022, pp. 11–17.

[2] B. Holfeld, M. Lossow, M. Tyrskyy, S. Mehira, L. Garcia, S. Biemond, and C. Bach, "Field study on multi-antenna radio technologies for future railway communications at 1.9 ghz," in *IEEE VTC-Spring*, 2022.

[3] EU, "Commission Implementing Decision (EU) 2021/1730 of 28 September 2021 on the harmonised use of the paired frequency bands 874,4-880,0 MHz and 919,4-925,0 MHz and of the unpaired frequency band 1900-1910 MHz for Railway Mobile Radio," Sep. 2021.

[4] "Mission Critical Services in 3GPP," accessed on Feb. 22, 2023. [Online]. Available: https://www.3gpp.org/news-events/1875-mc_services

[5] DB Netz AG, Kontron Transportation, "Design and Evaluation of an FRMCS E2E System using Mission Critical Services for Future Rail Operation for Future Rail Operation (Study Report)," Feb. 2021.

[6] 3GPP TS 24.379, "Mission Critical Push To Talk (MCPTT) call control."

[7] 3GPP TS 24.380, "MCPTT media plane control."

[8] 3GPP TS 24.282, "MCData signalling protocol."

[9] 3GPP TS 24.582, "MCData media plane control."

[10] 3GPP TS 24.281, "MCVideo signalling protocol."

[11] 3GPP TS 24.581, "MCVideo media plane control."

[12] ETSI TR 103 459 V1.2.1, "Rail Telecommunications (RT); Future Rail Mobile Communication System (FRMCS); Study on system architecture."

[13] 3GPP TS 23.280, "Technical Specification Group Services and System Aspects; Common functional architecture to support mission critical services."

[14] "5GRail project," accessed on Apr. 27, 2023. [Online]. Available: https://5grail.eu

[15] "5G Racom project," accessed on Apr. 27, 2023. [Online]. Available: https://franco-german-5g-ecosystem.eu/5g-racom