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# Deliverable D 3.4

# Integration of Radio Modules

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# 1 Definition of the system

## 1.1 Context

To achieve the objectives of the European Commission white paper on Transport 2011, aiming at a 30% shift to rail of road freight transportation over 300km by 2030, the rail freight transport market share has to increase strongly. As part of the Shift2Rail projects (FFL4E closed and FR8RAIL II currently on going), a Distributed Power System (DPS) has been developed by Bombardier, Faiveley and Funkwerk (partner of M2O project collaborating with FR8RAIL II) for increasing the capacity of goods trains and installed on locomotives of the BR 187 and BR 188 series. This DPS train allows implementing multiple traction through radio communication, being driven by one driver at the first Traction unit. The previous FP7 MARATHON project [1] have shown the feasibility of 1500m long coupled heavy trains with distributed power of two Traction Units (TU) running safely on the French network. Within this context, the Shift2Rail M2O project intends to extend the possibilities to multiple Traction units as Distributed Power System (DPS), in collaboration with FR8RAIL II project.

## 1.2 Purpose and scope

The present deliverable of the M2O project contributes to the show the integration of new radio components RCDPS in DPS train. Precisely, it refers to the specific application of DPS train concept for the execution of the experimental test campaign, planned and managed by the FR8RAIL II project partners.

The main objectives of this deliverable are:

- to describe the communication concept details
- to describe the strategy of integration testing
- to describe the preparation of test campaign of FR8RAIL II project;

Because of the scope of the M2O and FR8RAIL II projects, the test campaign is managed by FR8RAIL II project partners.

## 1.3 Structure of the document

The present chapter gives an overview to the context of long freight train as integrated system and the long train itself.

Chapter 2 focuses on the communication concept, architecture and design including the on train communication and the communication architecture of the integrated system – in particular the track side components.

Integration and testing are the objective of the third chapter with consideration of the points test equipment and test execution.

Chapter 4 reflects the preliminary performance tests and the evaluation of the test track planned for the train test campaign.

Conclusions to the topics are summarized in the last chapter.

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## 1.4 Subsystem Overview

Figure 1 (taken from D2.3 [3]) provides a graphical representation of the general context.

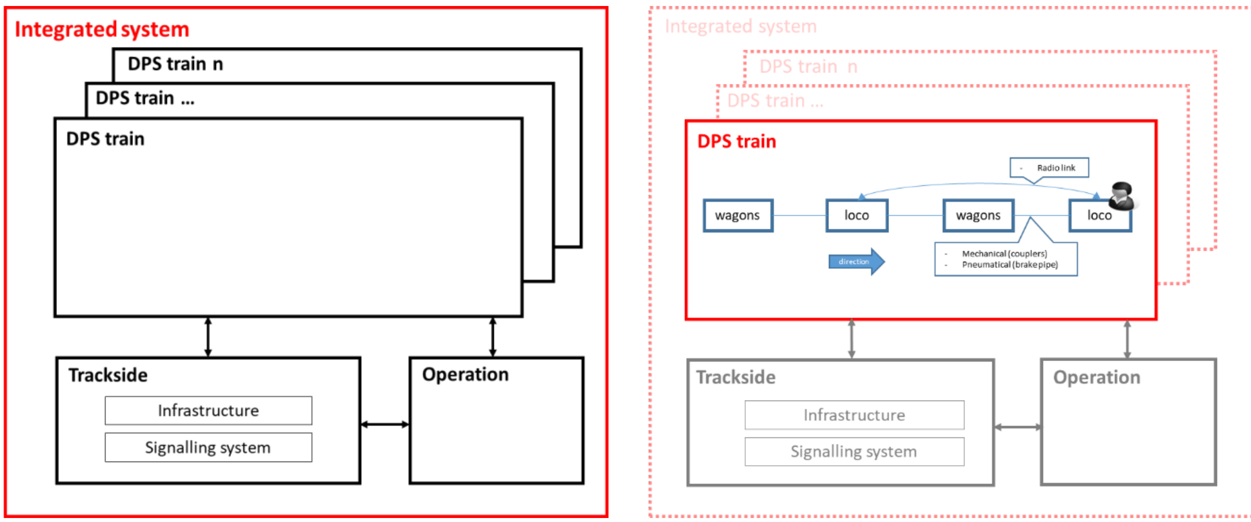


Figure 1 - General context, and "Long freight train" Integrated system (left) and DPS train (right)

The picture on the left side represents the whole "Integrated railway system", including different "long freight trains" equipped by Radio communication and Distributed Power System (DPS trains) and trackside elements. The picture on the right side focuses on a single DPS train, with its external interfaces.

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# 2 Communication concept and architecture

## 2.1 Boundary constraints and assumptions

The outcome of Shift2Rail predecessor project FFL4E "Future Freight Loco for Europe" was a GSM-R based demonstrator long train setup with 2 TU's. When the concept was expanded from two to four vehicles, the limitations of the GSM-R based concept became obvious (see also D2.1 [2]).

Both the vehicle equipment and the use of up to six CSD channels make this concept appear unfeasible.

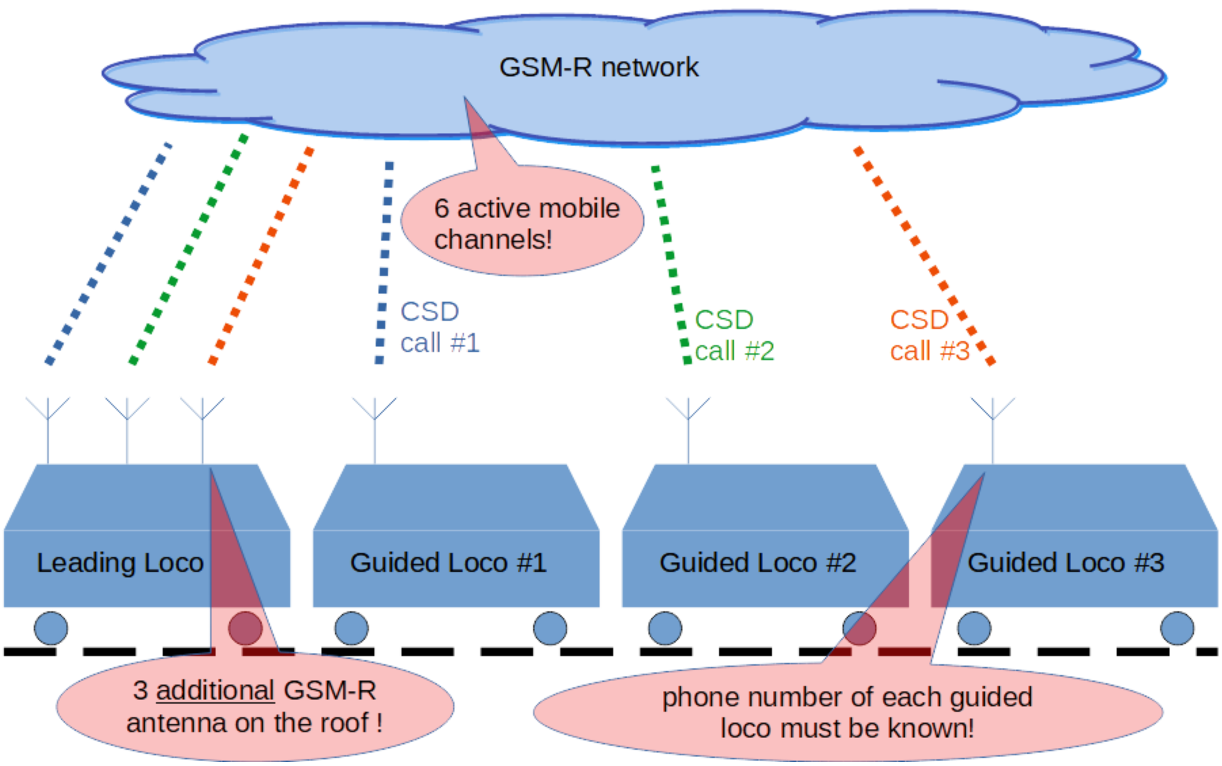


Figure 2 - GSM-R based solution

Figure 2 shows the usage of GSM-R resources – the leading Loco / TU must also be equipped with three RCDPS devices. This means that the leading TU must have additional equipment compared to the guided TUs - the TUs are no longer interchangeable.

In addition, the poor performance of CSD data call communication leads to large latencies and runtime fluctuations during transmission.

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The problem of train composition was not considered or solved in the previous project. In the early phase of the project, a concept was developed to overcome these limitations and prepare a product-ready solution. The FRMCS specification, which was progressing in parallel, was to be taken into account.

## 2.2 Communication Concept

The following requirements were identified for the Long Trains communications concept:

1. Up to four TU's need to communicate with each other
2. Communication in one direction should not exceed 500 ms (mean value)
3. Train composition (build the consist and interconnect the TU's) shall be possible without "magic" information[1]
4. Cyber security goals are to be supported

And optional:

5. Compatibility between different TU types and TU manufacturers to be facilitated

To meet these requirements, the concept was based on IP-based communication and examined the extent to which established mobile radio technologies can be used.

Because of the good real-time characteristics and the availability in the field[2], 4G mobile communication was chosen. The outlook that FRMCS is planning to equip the railroad lines with 5G mobile communications makes this decision seeming right. The transition from 4G to 5G is possible with the developed concept with little effort. The project deliverable D2.1 [2] explains this decision based on various aspects.

[1] Information like IP address or other not published data

[2] Public mobile network

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## 2.3 Communication architecture of the integrated system

Following the concepts of FRMCS, the communication architecture was designed (see Figure 3).

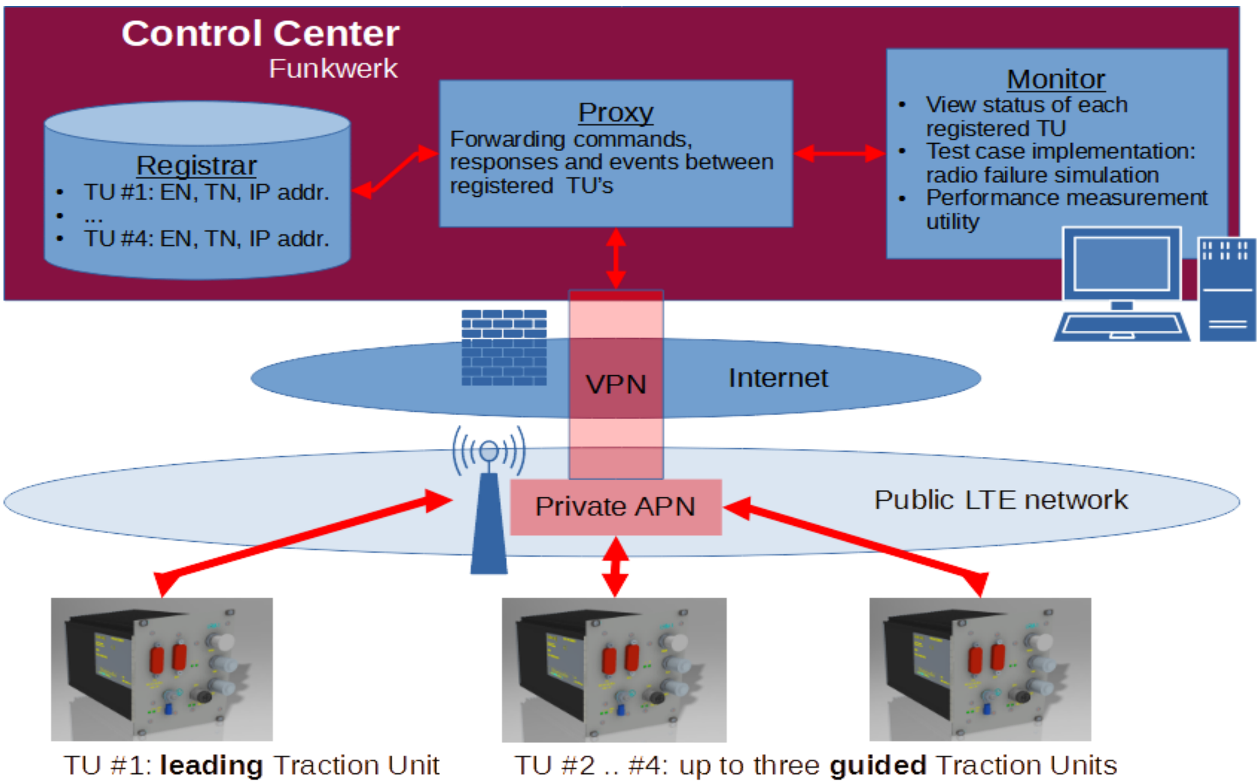


Figure 3 - Communication architecture of the integrated system

The communication architecture is based on the following components and interfaces:

1. On-board interface: real time protocol IPTCom
2. On-board communication equipment: RCDPS 4G/LTE unit
3. Radio interface: 4G/LTE with fall back to 3G/UMTS or 2G/GSM
4. Over the air communication: private APN with IPv4 traffic
5. Communication on the land side: VPN between APN/mobile gateway and Long Trains land side equipment
6. Land side equipment: control center with subcomponents (registrar, proxy and monitor)

The following section 2.4 explains the on-board part of DPS communication and the on-train communication layers.

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## 2.4 Communication architecture on-train

On-train the communication is built from two layers:

1. The security layer which is implemented by RCDPS and the radio and landsite network nodes. This layer is abstracted from the RCDPS and hidden from on-board communication. This is also true for the radio technology used.
2. The safety layer is implemented by CCU devices and is treated only as payload by RCDPS. CCU implements SDTv2 based protocol elements as part of IPTCom dataset.

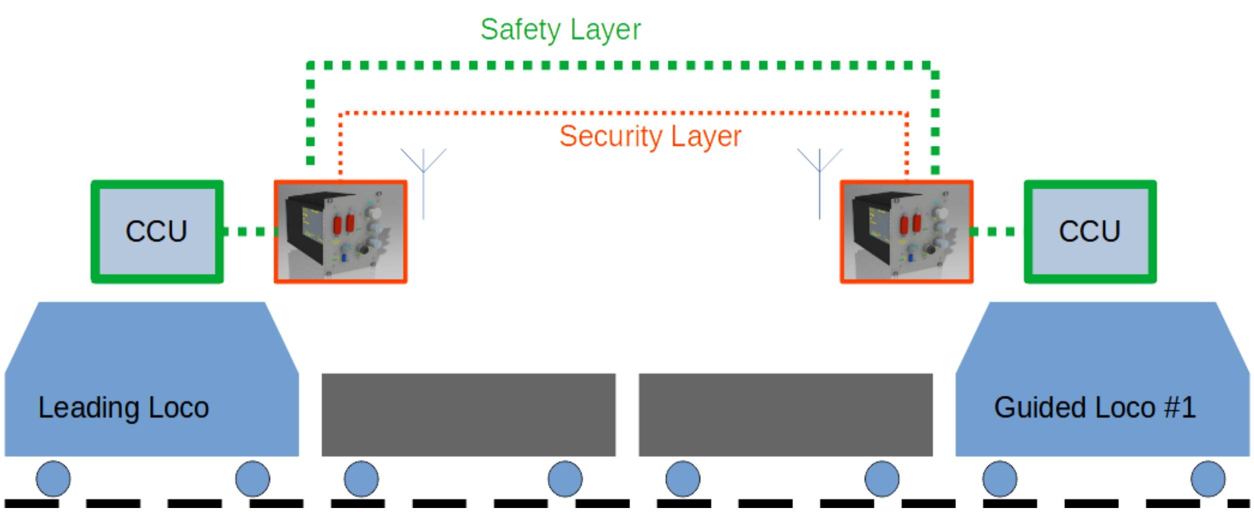


Figure 4- Communication architecture on train

In addition a command and control dataset was defined as part of IPTCom on-board communication. This is explained in M2O D2.1 [2], section 6.4.2. This dataset is not part of radio transmission payload.

The Figure 4 shows a highly simplified view: the radio infrastructure of the mobile network is not included. Neither is the Control Center shown.

## 2.5 Radio communication

The radio communication is controlled by CCU: CCU triggers the radio to an active or inactive state as shown in M2O D2.1. As part of command and control dataset the own engine number and the train running number is published by CCU to RCDPS device.

The command and control dataset is designed to support up to four TU's per train consist. RCDPS recognize them remote TU's and stores the paired TU engine number in the local command and control dataset.

In case of M2O prototype a direct communication between the TU's is avoided. The reason is that:

a) From a cyber security perspective a kind of broadcast or multicast is difficult to manage.
b) Future TU's must have identical equipment with regard to encryption and other properties of the transport layer (restriction for interoperability).
c) The network infrastructure needs to support it.

To overcome these points, a Point-to-Point communication was designed and implemented: each TU communicates exclusively with the Control Center. In this way, the position of trust can be established independently between a TU and the control center. This will enable the implementation of additional security measures in the future.

As introduced in M2O D2.1 [2], section 6.5 the payload of DPS process data is inserted in a frame which is generated by RCDPS. Based on the data contained in this frame, the control center manages the registration of TU's automatically.

## 2.6 Interface Implementation in RCDPS device

RCDPS is designed as an abstraction layer following the FRMCS architecture. The on-board communication is replaceable – another real time protocol like CIP, Profinet or TRDP is suitable instead of IPTCom used by the M2O prototype.

The radio communication is based on IP / UDP. Thanks to the framing that RCDPS implements, different telegram formats can be used in the future. The important point is that the DPS payload and the safety layer would be standardized – independently from the TU manufacturer.

The radio hardware is based on a 4G / LTE modem. The hard- and software design of RCDPS allows to switch to a 5G enabled radio module. The communication protocol can still be used.

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# 3 Integration Testing

## 3.1 Laboratory tests at Funkwerk site

### 3.1.1 Test set #1 – Funkwerk Laboratory

A customized rack was engineered and provided by Funkwerk containing three LTE26 components and a 24 V power supply. Each LTE26 component can be treated as a traction unit radio module (substituting the on-board unit RCDPS).


Figure 5 – Test set #1 - Funkwerk Laboratory

The software stack is compatible for using in RCDPS.

Each LTE26 ETH interface will be connected to a dedicated CCUS/CCUO (or simulation) by IPTCom protocol. The vehicle interconnection is provided by the LTE radio path.

### 3.1.2 Mobile Radio Network with private APN

The partner project FR8Rail II has fixed the test campaign track: "Frankenwaldrampe". After analysing the 4G / LTE network coverage along this track the Vodafone network was selected as the test campaign mobile network.

To prevent DPS process data to reach internet nodes and to avoid influence coming from other internet nodes or mobile subscriber a private APN was used during Funkwerk site integration testing. As the private APN provider MDEX was chosen because of proven in use experience over the last five years.

Each RCDPS uses a dedicated account to access the APN. In addition a control center VPN is provided by MDEX. The DPS Control Center application uses this VPN to interconnect with the RCDPS devices.

MDEX provides in addition a management portal. The management portal allows analyzing the session of all APN / VPN parties including online sessions and traffic volume.

During integration testing on Funkwerk site, information of MDEX management portal was used to analyze the network compound.

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### 3.1.3 Control Center / Monitor

The Control Center Software implements beside the registrar functionality – to build up train consists automatically – two main additional functions:

1. A logging facility
2. A monitor GUI to show the current state of all registered train consists with the associated TU's

To support the test campaign of FR8Rail II partner project a third additional function is provided:

3. A simulation for location-based radio interruptions

The logging facility was widely used to support performance measurements. The prototype implementation is based on a Java Application and is available on Linux and Windows PC's. The FRMCS architecture identifies such a node as an FRMCS Service Server.

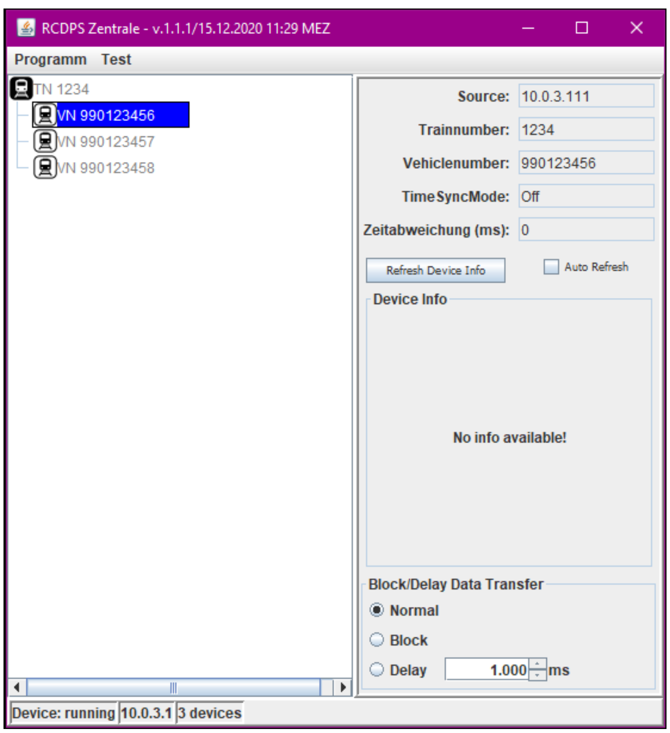


Figure 6 - Control Center – RCDPS and Train Monitor

Figure 6 shows the train and RCDPS monitor. Multiple trains can be managed. If an RCDPS device announces itself with a train number and vehicle/engine number, either a new train is created for the train number, or the RCDPS device is assigned to an existing train with the same train number - this is the automatic inauguration function of RCDPS Monitor. The figure shows a train with train number TN "1234" and three already registered TU's.

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### 3.1.4 Integration test setup

Integration testing in Funkwerk laboratory focuses on the following points:

- Syntax correctness
- Initialization / de-initialization
- Performance measurement

Figure 7 shows the test setup in the laboratory and the communication path which was used for performance measurement:

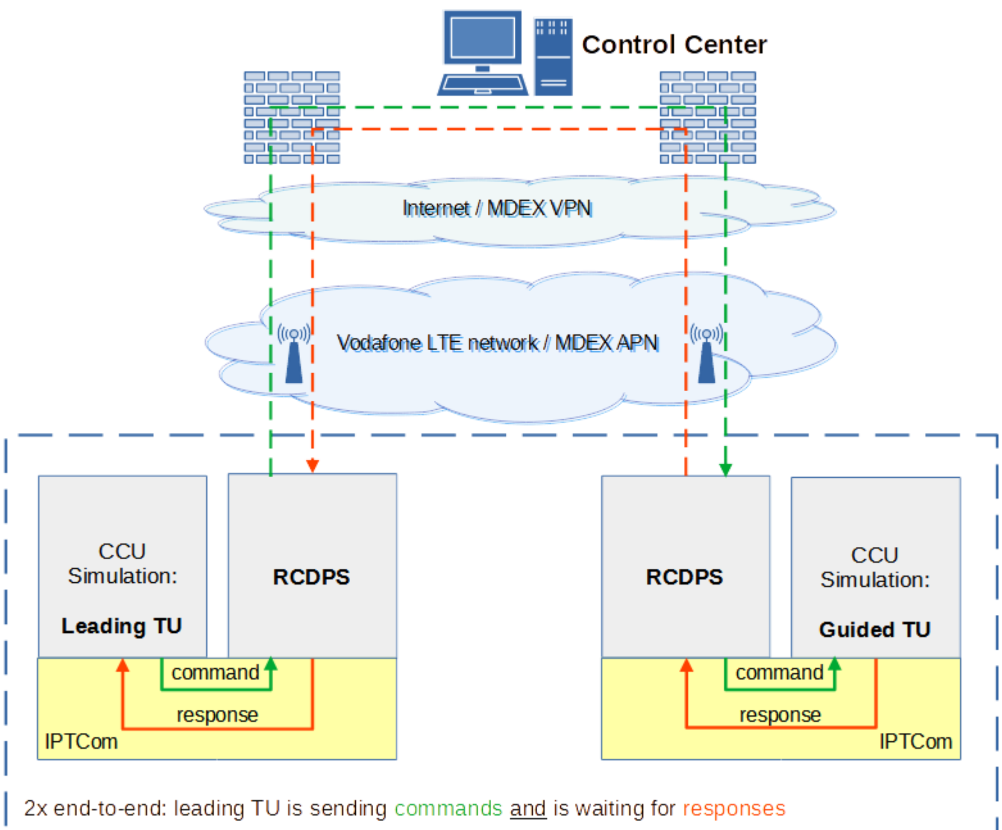


Figure 7 - Integration test setup in Funkwerk laboratory

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The used private APN is provided by MDEX Corporation within a "fixed.IP" contract. The APN has a monitoring instrumentation which can used to check connection state, transferred data volume and other parameters. The RDCPS devices are registered as shown in Figure 8.

| Zugang | web.direct | Device-Username | IP Adresse |
|---|---|---|---|
| RCDPS01 | | m[redacted]75@mdex.de | 172.20.1.71 |
| RCDPS02 | | m[redacted]76@mdex.de | 172.20.1.72 |
| RCDPS03 | | m[redacted]77@mdex.de | 172.20.1.73 |

Figure 8 - APN Monitor with three registered RCDPS devices (MDEX fixed.IP contract)

The components under test are:

- RCDPS
- IPTCom local communication
- 4G / LTE network

Instead of Bombardier CCU devices a simulation was implemented to provide the IPTCom communication path for end-to-end measurement.

### 3.1.5 Integration test results

The integration test was used to verify the correctness of protocol implementation. Any deviations of RCDPS implementation detected were corrected and the function was retested with the established test setup.

Syntax correctness and initialization / de-initialization were successfully tested including the over air communication.

Based on the communication model documented in M2O deliverable D2.1 [2], chapter 6.4.3, assumptions were made for particular latencies in the communication path (one way):

$$T_{\mathrm{end-to-end}} = 2*T_{\mathrm{CCUproc}} + 2*T_{\mathrm{RCDPSproc}} + 2*T_{\mathrm{cyle}} + 2*T_{\mathrm{poll}} + T_{\mathrm{LTE}}$$

With estimated values this give us a result for one way communication:

$$T_{\mathrm{end-to-end}} = 2*128\ \mathrm{ms} + 2*50\ \mathrm{ms} + 2*64\ \mathrm{ms} + 2*25\ \mathrm{ms} + 60\ \mathrm{ms} = 594\ \mathrm{ms}$$

And two way end-to-end (conservative)

$$T_{\mathrm{2way-end-to-end}} = 2*594\ \mathrm{ms} = 1188\ \mathrm{ms}$$

The test setup shown in Figure 7 can be uses to substitute most of the estimated values by a measured value. During a preliminary integration test the setup was used to measure the round trip time between the Control Center Monitor and each single RCDPS. This measurement was used to better understand the performance of 4G / LTE network and modem hardware which is integrated in RCDPS devices.

The data were recorded by the monitor software. The measured time is the duration between a request sent from monitor to a dedicated RCDPS and the answer received (two times radio link transmission). Included is the processing time on RCDPS.

The worst performance is shown in the second row (RCDPS with IP address 172.20.1.72) in Figure 9 with:

- Average time = 102 ms
- Standard deviation = 19 ms

As shown in M2O deliverable D2.1 [2], chapter 6.4.3, this value can be used to substitute the two estimated values $T_{RCDPSproc}$ and $T_{LTE}$:

> $T_{RCDPSproc} + T_{LTE}$ = 50 ms + 60 ms = 110 ms can be substituted by the measured value (average time + standard deviation) = 121 ms

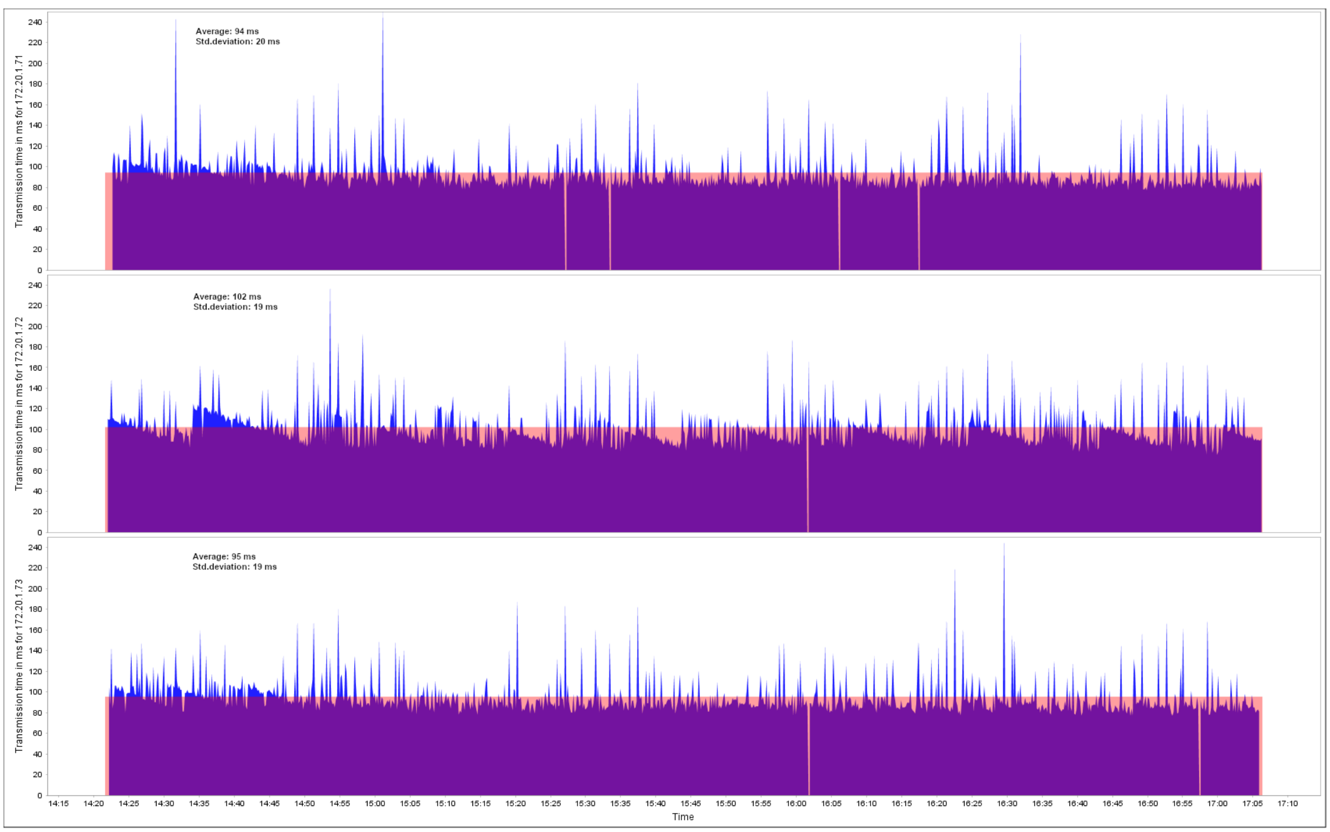


Figure 9 - Laboratory test to show the communication performance of 4G / LTE network

To verify more assumptions further estimated values were substituted by measured values.

The integration test (Figure 7) was used again but the measurement was modified with help of an additional instrumentation of CCU simulation: instead of Control Center Monitor the communication was triggered by the

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CCU simulation instance which was enabled to record the timestamp of sending commands and receive their response. This measurement method is close to the future use case of the DPS system communication.

Description / steps:

- RCDPS #1 is registered (leading TU) on the Control Center Monitor with arbitrary train number
- RCDPS #2 is registered (guided TU) on the Monitor with the same train number
- RCDPS #1 sends with a cycle time of 64 ms commands to the guided TU RCDPS
- RCDPS #2 answers with a response on each command
- The round trip time of command/response is measured and recorded by RCDPS #1
- The measurement can be done over hours to get statistically relevant data

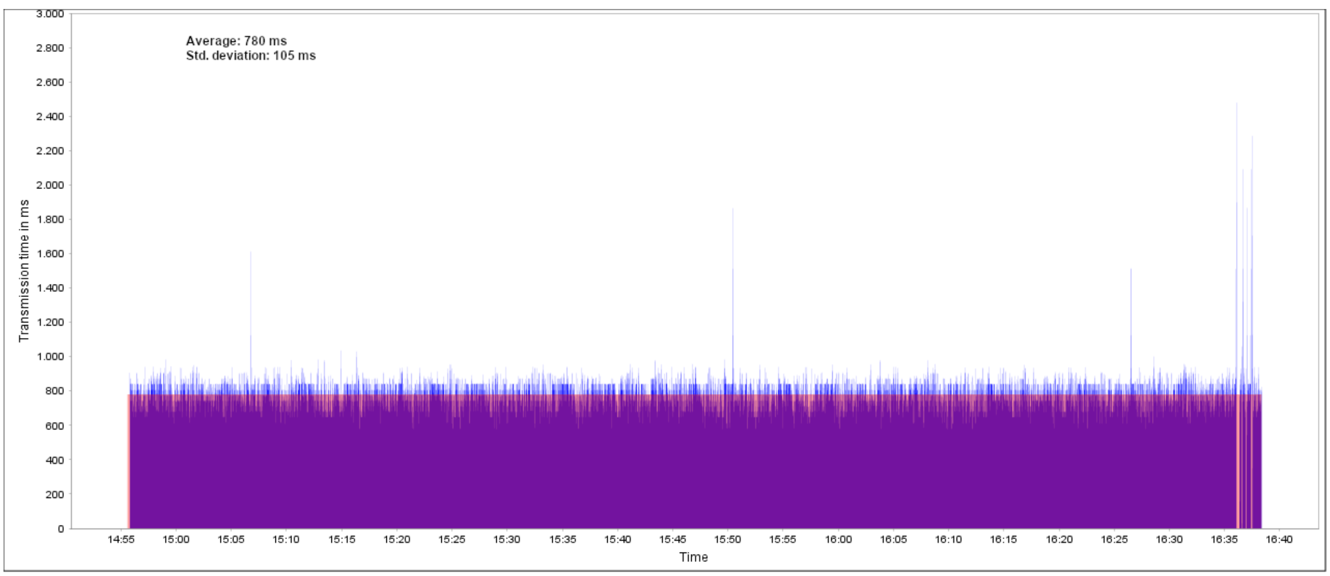


Figure 10 - Laboratory test 2-way end-to-end with 4G / LTE network – 100 min recording

Result of **2-way end-to-end** test:

- Average time = 780 ms
- Standard deviation = 105 ms

As explained before the expected value for 2-way end-to-end is 1188 ms. This expected value is based on worst case assumptions for local communication – every time a full IPTCom cycle has to be wait before data can be send. With 780 ms + 105 ms ≈ 900 ms the measured value is about 300 ms better as the worst case value. To prove the communication model instead of worst case values an average latency is expected within average time values (estimated as the half value) for the particular local transmission steps and processing delay times:

$$T_{\mathrm{end-to-end}} = 128\ \mathrm{ms} + 50\ \mathrm{ms} + 64\ \mathrm{ms} + 25\ \mathrm{ms} + 60\ \mathrm{ms}$$

this results in

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$$T_{\text{end-to-end}} = 327 \text{ ms}$$

and

$$\boldsymbol{T_{\text{2way end-to-end}}} = 654 \textbf{ ms}$$

Conclusion: the communication model over-estimates the latency for on-board local communication. The half value assumed as an average latency time for processing and IPTCom transfer time leads to under-estimation of about 250 ms. The forecast of the communication model could be verified by the measurement – the deviation is in good range.

## 3.2 Laboratory tests at Bombardier site

### 3.2.1 Test set #2

A customized rack was engineered and provided by Funkwerk containing three SWI26 components and a 24 V power supply. Each SWI26 component can be treated as a traction unit (vehicle) radio module (substituting the on-board unit LRM-1).


Figure 11 – Test set #2 - Bombardier Laboratory

The software stack is compatible for using in LRM-1 – excepting the radio module control function.

Each SWI26 IFE3 interface can be connected to a dedicated CCUS/CCUO (or simulation) by IPTCom protocol. The vehicle interconnection is provided by the Ethernet path (IFE1 and/or IFE2).

### 3.2.2 Integration testing

With Test set #2 Bombardier was enabled to perform integration tests without using mobile network equipment. To avoid an overlay of mobile network problems with problems of local communication during the early phase of the development, the mobile network management and communication was substituted completely by a simple LAN based solution. To simulate the mobile network behavior the RCDPS software implements an additional latency.

The goal of integration testing by Bombardier was to investigate the compatibility between CCU and RCDPS protocol implementation (syntax and state switching regarding mobile network management – state changes are simulated) and end-to-end testing of the safety layer.

The integration testing on Bombardier laboratory was finished successfully during third quarter of 2020.

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## 3.3 On-train Test

### 3.3.1 RCDPS Hardware - LTE on-board Units

In the scope of this project a RCDPS prototype was derived from a Funkwerk standard product LRM-1 with a modified housing and a new software stack.


Figure 12 - RCDPS Prototype (case for installation in rack of Bombardier TU's)

### 3.3.2 Integration Test on-train

In December 2020, integration tests began on the Bombardier locomotives. The integration test was planned with three phases:

1. Integration test with all DPS equipment including the modified braking system, the DPS software for train controller and RCDPS to verify communication and state changes
2. Stationary function tests with the new integrated DPS equipment
3. Synchronization of all three locomotives and execution of commands simultaneously

All phases were successfully finished.

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# 4 Performance measurement

## 4.1 Preliminary Tests

During integration testing (see chapter 3.1.5) performance measurement take place. The determined results were taken into account for train forces simulation and the safety evaluation. This preliminary test were executed with the same 4G/LTE public mobile network (Vodafone), the fixed infrastructure (MDEX private APN gateway and VPN Control Center access) and Funkwerk Control Center Software as foreseen for the test campaign of FR8RAIL II in February 2021 – but: the RCDPS devices were installed in the Funkwerk laboratory and registered stationary in one mobile network cell.

To get more data to prepare the test runs planned for the test campaign, dynamic data from the test campaign track were necessary to determine.

## 4.2 Evaluation of test campaign track

### 4.2.1 Test setup

In cooperation with FR8RAIL II partner DB Cargo AG a test run was prepared and executed and took place on 04.11.2020. A regular scheduled cargo train ride was used to make the test run on the track starting in Halle/Saale. The standing time in Halle/Saale was used to prepare a Bombardier TU type BR187 by installing two RCDPS devices – one with a fixed antenna on the roof (antenna from maintenance monitoring device) and one with a cable antenna fixed outside the car.

The network and device setup used during the test run is like described in chapter 3.1.2 "Mobile Radio Network with private APN" and chapter 3.1.4 "Integration test setup" and used before during performance and integration testing. All data transferred between RCDPS #1 and RCDPS #2 (installed in TU) are routed over the Control Center Monitor explained in chapter 3.1.3 "Control Center / Monitor" and is placed on Funkwerk site.

The functional overview is as follows:

- RCDPS#1 and RCDPS#2 installed on TU
- RCDPS#3 fixed installed on Funkwerk site
- all three RCDPS devices are registered in Vodafone LTE network and are connected with MDEX private APN
- the Control Center Monitor is connected via a cable internet connection over VPN-access to the MDEX private APN gateway
- RCDPS#1 is running as test master (guiding TU) with a recording function
- RCDPS#2 is running as active slave (guided TU)
- RCDPS#3 is running as passive slave (not responding to commands but involved as communication partner to introduce typical workload to the communication path)
- Control Center Monitor is the switching point of data packets from each device to all other devices

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- Further functions of the Control Center are time synchronization of all mobile devices and recording of all data packets.
- A CCU simulator specially developed for RCDPS testing is connected to each of the three RCDPS devices, with which communication takes place via IPTCom

### 4.2.2 Test track infrastructure

During the test run GPS data were recorded. The recorded height profile is shown in Figure 13

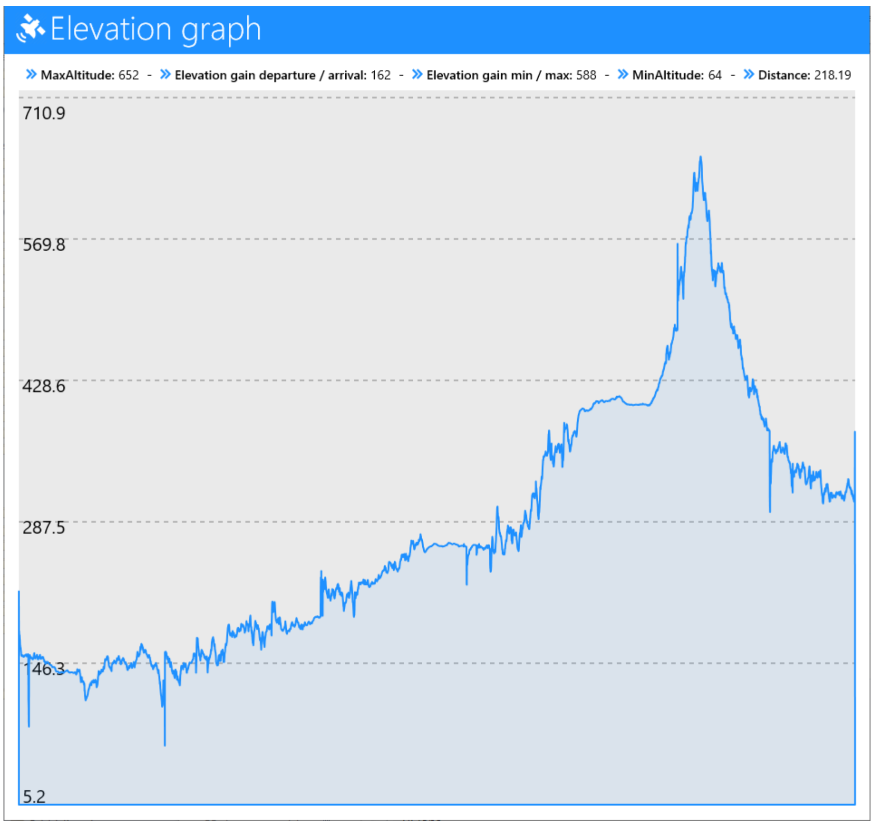


Figure 13 - Height profile of track during test run

The track route starting in Halle/Saale ends in Lichtenfels. The route is shown in Figure 14. During the planned test campaign in February 2021, a shorter part of this route will be used.

The evaluation test run aims to measure LTE network coverage and collect statistical data of communication behavior to support performance analysis.

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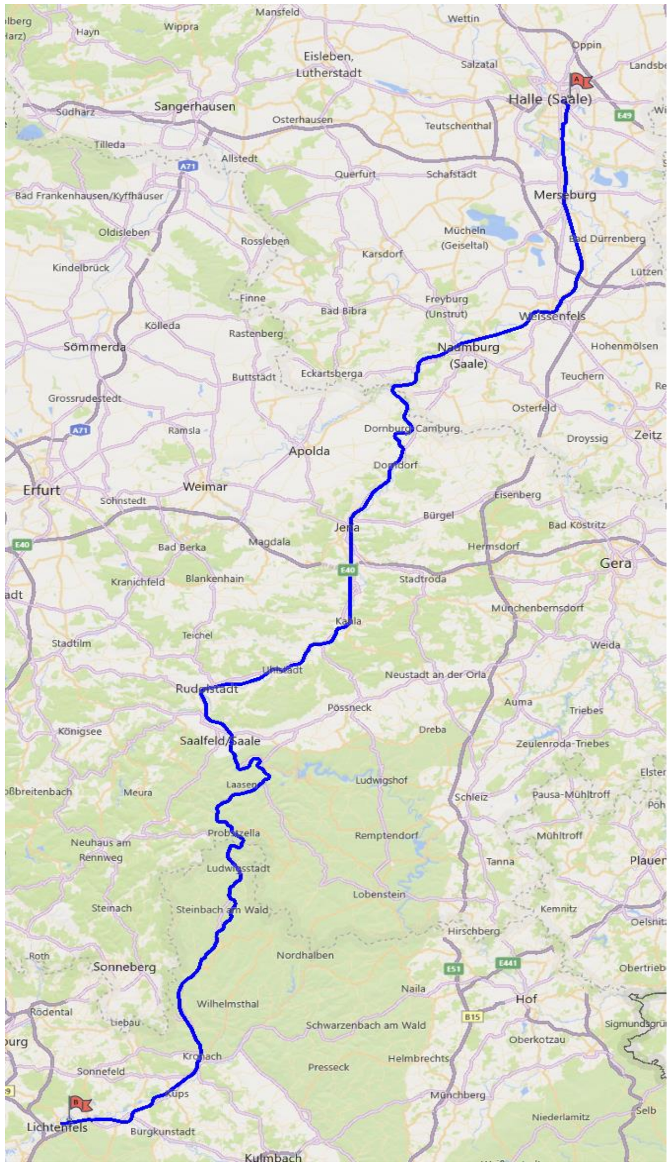


Figure 14 - Test track route

An intermediate stop causes an anomaly regarding the radio link. The stop occurred at station Probst-Zella (Figure 15). The traction unit stopped next to another train, causing shadowing of the cable antenna and interruption of radio communication for RCDPS #2. RCDPS #1 connected with the roof antenna was less affected.

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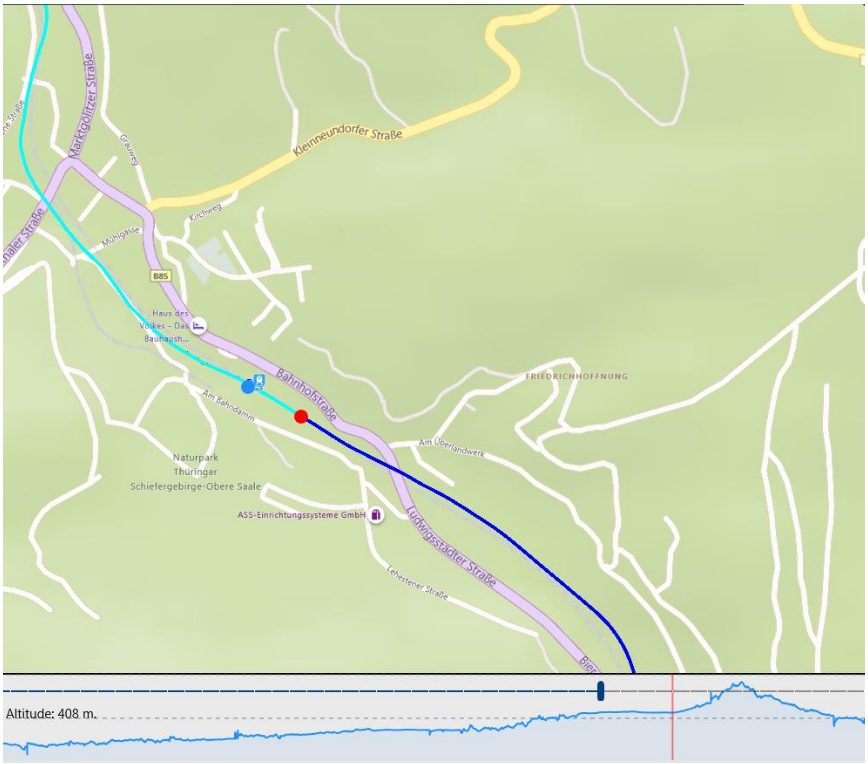


Figure 15 – Station Probst-Zella (between 14:32-14:50)

### 4.2.3 Evaluation Results

The testing and recording activities were done automatically as described in section 4.2.1. The statistical analysis gives:

- Count of measured values: 16.171
- Duration: 3:48 h
- Mean value (2-way end-to-end): 752 ms
- Standard deviation (2-way end-to-end): 154 ms

Figure 16 shows the measured latency values over time. The latencies are the 2-way end-to-end values measured by CCU-simulation of guiding TU: from command send request over IPTCom until reception of response over IPTCom.

The laboratory performance measurement result (see section 3.1.5 "Integration test results") gave us a mean / average value of 780 ms and a standard deviation of 105 ms – what is a good match.

With exception of station Probst-Zella the network coverage was very good. Both RCDPS could communicate on LTE network without fallback to 3G or 2G network.

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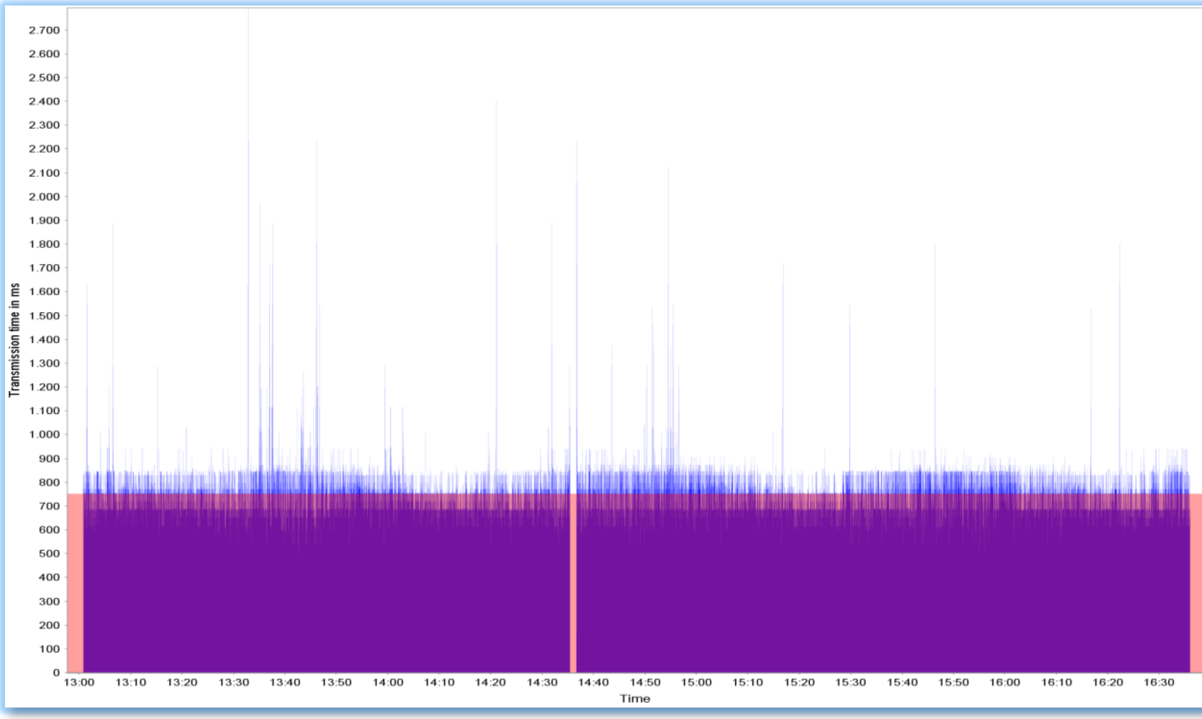


Figure 16 – Recorded latency times during evaluation test run

The figure above shows the 16.171 measured values. Remarkable is, that a maximum value of 2.700 ms is not exceeded. Between 14:30 and 14:40 the communication is disturbed caused by the radio link breakdown at station Probst-Zella.

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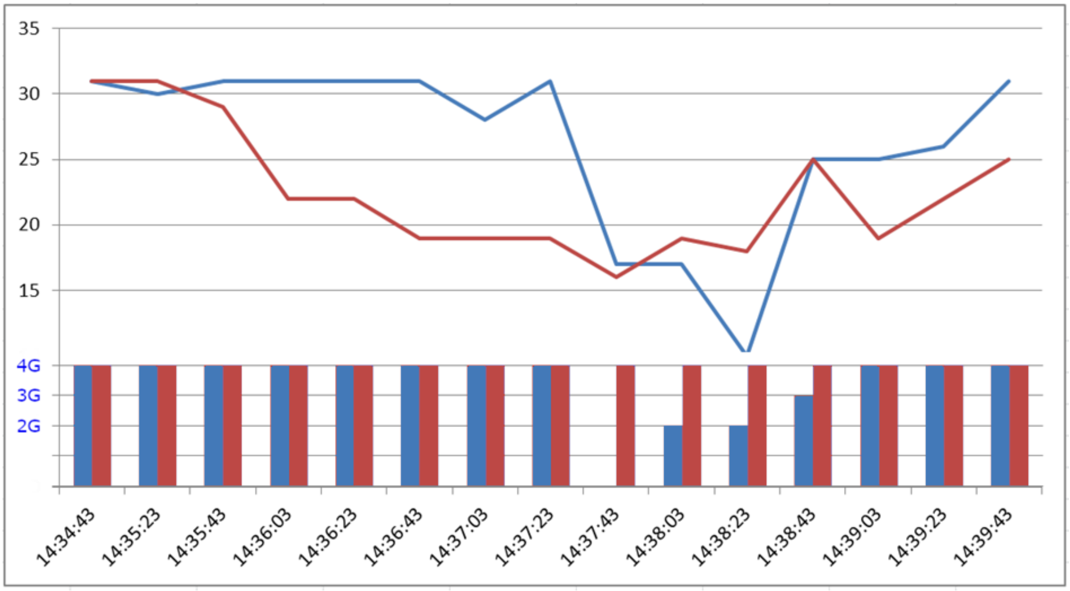


Figure 17 - Network coverage – red=RCDPS #1; blue=RCDPS #2

In Figure 17 RCDPS #2 (guided TU simulation) is blue colored. At timestamp 14:37:43 the radio link is lost. Beginning with timestamp 14:38:03 the RCDPS #2 is again registered with 2G and switches over 3G until 4G network link is established.

Special cases in the measurement data are defined as: more than the double of the mean value. The following table shows all this special cases. The maximum value is orange marked.

| Timestamp | Latency | RCDPS #1 Network / SQ | RCDPS #2 Network / SQ |
|---|---|---|---|
| 13:01:25 | 1870 | 4G / 31 | 4G / 31 |
| 13:06:25 | 1690 | 4G / 30 | 4G / 31 |
| 13:32:45 | 2610 | 4G / 31 | 4G / 31 |
| 13:35:00 | 1795 | 4G / 31 | 4G / 27 |
| 13:36:55 | 1838 | 4G / 25 | 4G / 24 |
| 13:37:35 | 1938 | 4G / 28 | 4G / 24 |
| 13:46:08 | 2160 | 4G / 29 | 4G / 29 |
| 13:46:35 | 1555 | 4G / 29 | 4G / 29 |

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| | | | |
|---|---|---|---|
| 14:21:03 | 2336 | 4G / 31 | 4G / 31 |
| 14:31:50 | 1876 | 4G / 31 | 4G / 31 |
| 14:36:38 | 2525 | 4G / 31 | 4G / 22 |
| 14:51:24 | 1552 | 4G / 31 | 4G / 31 |
| 14:54:27 | 1856 | 4G / 31 | 4G / 31 |
| 14:55:25 | 1564 | 4G / 26 | 4G / 23 |
| 15:16:48 | 1880 | 4G / 31 | 4G / 31 |
| 15:29:47 | 1590 | 4G / 27 | 4G / 23 |
| 15:46:25 | 1740 | 4G / 27 | 4G / 31 |
| 16:16:44 | 1552 | 4G / 26 | 4G / 22 |
| 16:22:17 | 2010 | 4G / 31 | 4G / 31 |

Table 1 - Special cases

The table shows, that the network coverage is always in a good range. The minimum value of signal quality SQ is marked with yellow color. RCDPS #1 has measured a minimum value of 25 and RCDPS #2 of 22.

The integrated system consisting of three RCDPS and the Control Center ran stably for over 3.5 hours.

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# 5 Conclusion

## 5.1 Suitability of 4G/LTE for DPS based Long Trains

The present deliverable of the M2O project contributes to evaluation of 4G/LTE mobile network as a communication solution for Distributed Power System DPS used for running long trains. The evaluation has covered two aspects: performance measurement and analyzing and measurement of network coverage of 4G/LTE mobile network along a typical cargo train track.

Both aspects were positive assessed. The performance and scalability of IP based network communication over 4G/LTE mobile networks is better than the GSM-R based communication. The 4G/LTE Radio Controller for DPS RCDPS could be integrated in the same way like the GSM-R based RCDPS into the traction unit. Integration testing performed shows the achieved functionality and suitability for DPS function.

The evaluation of 4G/LTE network coverage shows the suitability of the public Vodafone mobile network for the planned test campaign in February 2021.

As the predecessor of the upcoming 5G network with improved real time capabilities the 4G/LTE mobile network seems to be a good bridge solution.

## 5.2 FRMCS Compatibility

The Future Railway Mobile Communication System FRMCS will be based on 5G mobile network. The communication architecture of DPS was developed under consideration of FRMCS design goals.

The FRMCS high level logical architecture is shown in the following figure:

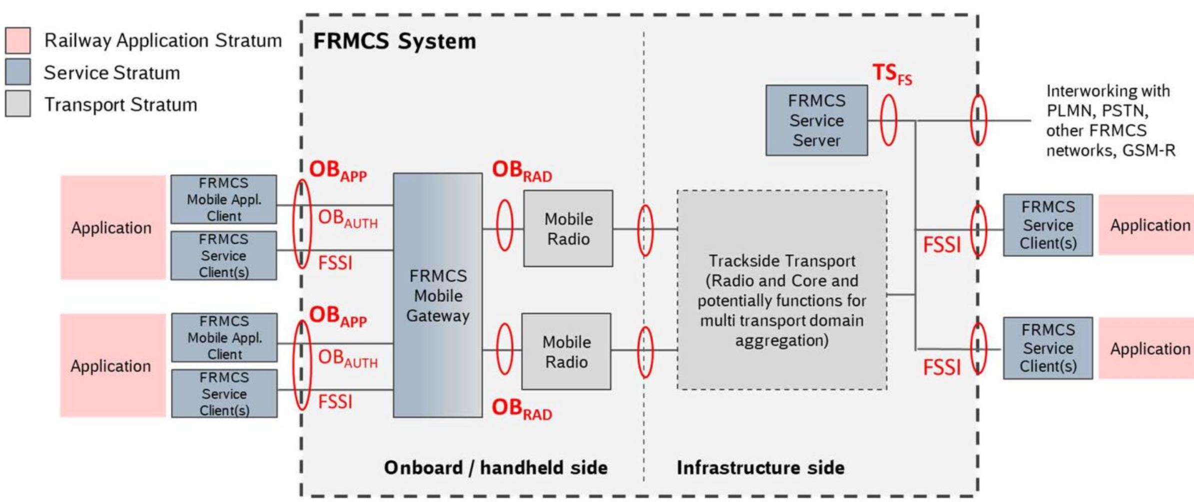


Figure 18 - FRMCS high-level architecture (taken from Future Rail Mobile Communication System; Study on system architecture [4])

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In the Long Train DPS Concept the FRMCS items can be interpreted as follows:

- The Application Stratum can be identified as the CCUO with his traction unit control data transfer.
- The interface $OB_{APP}$ is implemented as a control set of commands and status responses (see M2O deliverable D2.1 [2]) as part of the IP based real time protocol IPTCom (extended dataset)
- The FRMCS Client (Mobile Application and Service Client) is implemented by CCUO as control logic to handle the communication state between the traction units and the start and shutdown of the radio link.
- The FRMCS Mobile Gateway part is implemented by RCDPS. The RCDPS controls the contained LTE radio and is an aggregation of Mobile Gateway and Radio

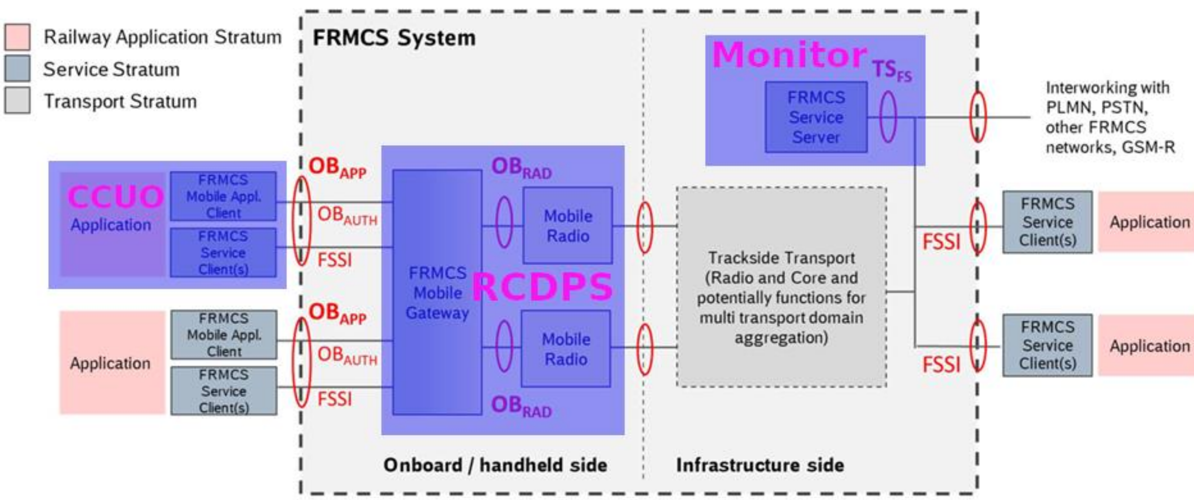


Figure 19 – FRMC high-level architecture adapted to Long Train Concept

The FRMCS Service Server is implemented by Funkwerk DPS Monitor Software (Control Center) which contains a train consist registrar, a communication hub and a logging facility.

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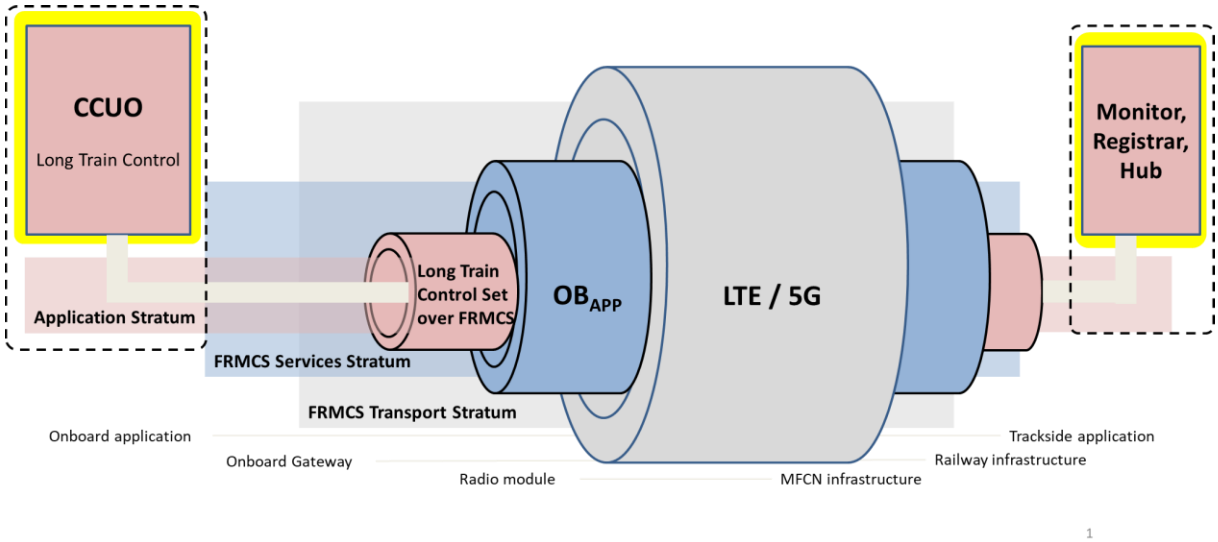


Figure 20 - Long Train Concept mapped to FRMCS Stratum Model

Figure 20 shows the mapping from Long Train DPS Concept to the FRMCS stratum model. The IPTCom data communication between CCUO and RCDPS implements both – the Application Stratum and the Service Stratum. The Application Stratum data is identified by the Long Train Control Set (safety layer) – which are transferred between the traction units (over the Long Train Hub / Control Center).

The following sections define CCUO as FRMCS Client and RCDPS as FRMCS Mobile Gateway + Radio. The point of view is the Long Train concept.

### 5.2.1 Similarities to FRMCS

1. The Application Stratum does not know anything about radio network specifics.
2. The FRMCS Client requests a communication channel over the wireless/radio network.
3. The Mobile Gateway abstracts the use of radio channels and radio devices.
4. The FRMCS Client does not know IP addresses of other mobile communication partners.

### 5.2.2 Differences to FRMCS

1. Neither the FRMCS Client nor the Mobile Gateway implements authentication ($OB_{AUTH}$) or a dedicated service session interface ($OB_{FSSI}$). The $OB_{APP}$ interface is implemented by proven in operation real time protocol.
2. A real time protocol (IPTCom) is used to transfer process and control data
3. The Mobile Gateway does not work as an IP router but as a proxy (extracted process data are transmitted).
4. The Mobile Gateway communicates only with one fixed base station device which forwards all the traffic inside a train consist as unicast traffic.

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### 5.2.3 Compatibility to FRMCS

The 4G/LTE based Long Train DPS Concept developed by Funkwerk is FRMCS ready. Future adaption to final specification of FRMCS interfaces and device roles can be made. The FRMCS Client can be interpreted as an IPTCom Software plugin running on RCDPS which implements the requirements of $OB_{APP}$ ($OB_{AUTH}$ und $OB_{FSS}$) interface without changing the CCUO software stack.

The used $OB_{APP}$ interface implementation can be substituted by any well-known IP based industrial protocols like CIP (Alstom), Profinet (Siemens), TRDP (Bombardier, Hyundai Rotem, Talgo, …) → the final specification for $OB_{APP}$ ($OB_{AUTH}$ and $OB_{FSS}$) interface in some years is not a blocking point – the Long Train DPS concept is FRMCS ready.

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# 6 Acronyms

| | |
|---|---|
| APN | Access Point Name (mobile network gateway) |
| ATP | Automatic Train Protection |
| ABC | Actuator Brake Control (existing brake handle) |
| BP | Brake Pipe |
| CCU or CCUO | Vehicle control computer |
| DF | Down/Flat |
| DPS | Distributed Power System |
| ED | ElectroDynamic |
| GUI | Graphical User Interface |
| HA | Hazard Analysis |
| IHA | Interface Hazard Analysis |
| IPTCom | Internet Protocol Based Communication for Trains |
| LCF | Longitudinal Compressive Forces |
| LTD | Long Train Dynamics |
| LTF | Longitudinal Tensile Forces |
| LTE | Long Term Evolution (4G-Wireless Network) |
| MIT | MITigation |
| MVB | Multifunction Vehicle Bus |
| PHA | Preliminary Hazard Analysis |
| RCDPS | Radio Controller for Distributed power system |
| SIL | Safety Integrity Level |
| SDTv2 | Safe Data Transmission version 2 (defined in IEC61375-2-3) |
| TCMS | Train Control and Management System |
| TRL | Technology Readiness Level |
| TU | Traction Unit |
| TSI | Technical Specifications for Interoperability |
| UD | Up/Down |
| VPN | Virtual Private Network |

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# 7 References

[1] MARATHON (Make Rail The Hope for protecting Nature), project ended on 30 September 2014, URL: https://cordis.europa.eu/project/rcn/98327/reporting/en

[2] M2O project, Deliverable D2.1 - GSM-R or LTE design solution.

[3] M2O project, Deliverable D3.2 – First and Second Demonstrator(s), Specific application Safety case

[4] Rail Telecommunications (RT); Future Rail Mobile Communication System (FRMCS); Study on system architecture – ETSI TR 103 459 V1.2.1 (2020-08)