Deliverable D3.3
Proposals for Virtual Coupling Communication Structures

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Executive Summary

This document is MOVINGRAIL Deliverable D3.3 ‘Proposals for Virtual Coupling Communication Structures’ in the framework of TD2.8 of IP2 according to the Shift2Rail Multi-Annual Action plan (MAAP).

Work Package 3 on Communication Technology for Virtual Coupling aims at assessing wayside/on-board communication structures already proposed by Shift2Rail projects (e.g. CONNECTA, X2Rail-1, Safe4Rail) so to propose analytically determined systems for safe and effective communication for Virtual Coupling. This third deliverable of Work Package 3 takes the communication technology identified in D3.1 Virtual Coupling Communication Solutions Analysis and proposes Virtual Coupling communications solutions, that could be exploited to implement virtual coupling on a real railway.

Some background is given identifying the key findings from D3.1 that shape the virtual coupling communications system proposal. The main factors impacting the architecture of the proposed solution for the virtual coupling communication system including train topology and the baseline control system are discussed. The proposed virtual communications solution is presented and explained. The factors affecting the roll out of the solution are also discussed and a roadmap presented.

It is concluded that the communications architecture for virtual coupling should be based around 5G principles with a cellular network connection for long distance communication and a Peer to Peer direct link similar to IEEE802.11 (Wi-Fi), but fully integrated into 5G, for short range communication.

It is recommended that further analysis and practical investigation is carried out to confirm the suitability of this communications proposal in achieving virtual coupling.

Abbreviations, Acronyms and Definitions

Abbreviation/Acronym /Definition	*Description*
5G	Fifth-Generation mobile communications (in accordance with standards set issued by 3GPP)
3GPP	Third-generation Partnership Project
ATO	Automatic Train Operation
ATP	Automatic Train Protection
CAMs	Co-operative Awareness Messages
CBTC	Communications Based Train Control
COTS	Commercial-Off-The-Shelf
E2E	End-to-end; relating to 5G network slicing allowing operators to slice one physical network into multiple, virtual, end-to-end (E2E) networks
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETN	Ethernet Train Network
FRMCS	Future Rail Mobile Communications System
GNSS	Global Navigation Satellite System
GSM-R	Global System for Mobiles – Railway
IEEE	Institute of Electrical and Electronic Engineers
ITS	Intelligent Transportation System
Latency	Latency is defined as the time it takes for a source to send a packet of data to a receiver.
LTE	Long Term Evolution
MA	Movement Authority
Moving block	Contrasts with fixed block. In a moving block the “block sections” are not tied to specific locations but can be adjusted continuously.
MOVINGRAIL	MOving block and VIrtual coupling New Generations of RAIL signalling.
NAD	Network Access Device
P2P	Peer to Peer
PARK	Park Signalling Limited
RBC	Radio Block Centre
SDT	Safe Data Transmission
S2R	Shift2Rail
STC	Streetcars
T2I	Train to Infrastructure
T2T	Train to Train
TBTC	Transmission-Based Train Control
TIMS	Train Integrity Monitoring System
TMS	Traffic Management System
UIC	International Union of Railways
V2V	Vehicle to Vehicle

VCTS	Virtually Coupled Train Set
VOBC	Vehicle On-Board Controller
WLCN	WireLess Consist Network
WLTB	WireLess Train Backbone

1. Objective

The objective of this deliverable is to propose Virtual Coupling communications solutions, that could be exploited to implement virtual coupling on a real railway.

1.1. S2R Context

This report forms Deliverable D3.3 of MOVINGRAIL, which contributes to Task 3 of the Virtual Coupling Technical Demonstrator TD2.8 – Feasibility Analysis of Virtual Coupling. This report follows an analysis of potential communication solutions (Deliverable D3.1) that considered the high-level requirements of Virtual Coupling communications and an assessment of the state-of-the-art in communications systems that are candidates for implementation in a final virtual coupling solution.

1.2. Aims

To propose and explain Virtual Coupling communications solutions, that could be exploited to implement virtual coupling on a real railway.

2. Background

MOVINGRAIL is a research project funded by the Shift2Rail Joint Undertaking (S2R JU) of the European Commission in response to the open call S2R-OC-IP2-01-2018.

This document is Deliverable 3.3 (D3.3) of MOVINGRAIL, and is part of Work Package 3 (WP3): Communication Technology for Virtual Coupling.

This section provides a brief background about the MOVINGRAIL project, and WP3.

2.1. MOVINGRAIL

Train-centric signalling systems represent the most promising technology for increasing railway capacity, and reducing railway life-cycle costs. These systems include moving block signalling, which enables trains running at absolute braking distance, and virtual coupling that aims at running at relative braking distance, with trains virtually coupled into a convoy.

MOVINGRAIL aims to support the further development of train-centric signalling systems by introducing and applying a multidimensional analysis framework to assess train-centric signalling from the operational, technological and business perspectives. This is applied to moving block and virtual coupling at different levels, highlighting the differences to traditional fixed block signalling.

Work Package 3, Communication Technology for Virtual Coupling, aims at assessing wayside/on-board communication structures already proposed by Shift2Rail projects (e.g. CONNECTA, X2Rail-1, Safe4Rail) so to propose, from the results of the analysis, systems for safe and effective communication for Virtual Coupling. An extensive review of these projects has been performed to collect specifications of proposed communication systems.

Work Package 3

- Identified appropriate Virtual Coupling technical communication solutions by reviewing previous studies and projects and analysing these against requirements for this work package, and recorded this in Deliverable D3.1, Virtual Coupling Communication Solutions Analysis [1].
- Identified proposals for Virtual Coupling technical communication solutions facilitating business analysis and exploitation road map.
- Investigated the application, solutions and dynamics of automated car driving and evaluate the applicability to the railway field, and recorded in Deliverable D3.2, Advances in Automated Vehicle Technology and Applicability to Railways [2].
- The current Work Package 3 activity takes this information to propose suitable Virtual Coupling communications structures.

2.2. Key Virtual Coupling requirements and findings from D3.1

The key requirements from D3.1 [1] for the virtual coupling communication system relating to the communications system architecture are to support low latency trusted data messages between the trains in a convoy over the distances involved in rail systems taking account of the differing application sectors.

Movingrail deliverable D3.1 ‘Virtual Coupling Communication Solutions Analysis’ [1] found:

- that evolution from GSM-R to 5G in accordance with the aims of the Future Rail Mobile Communications System project presents the best path forward for elaboration into a communications proposal for virtual coupling for the European rail network and that 5G is also appropriate, for consistency and economy, for the other sectors.
- the distances between trains that are about to virtually couple (e.g. in excess of 1km) are much larger than for automotive convoys. These distances are beyond the capability of direct link (T2T) and therefore require trackside infrastructure (multiple access points or broadcast cells).

2.3. Automotive Synergy

There is clearly a close synergy between automotive platooning and railway virtual coupling.

D3.2 [2] ‘Advances in Automated Vehicle Technology and Applicability to Railways’ suggested that Rail traffic can piggyback on developments in automated car driving while preserving its own characteristics and specific requirements. ‘Piggybacking’ is of interest given that automotive is a mass market, which brings pressure on costs.

D3.1 [1] looked at the areas where that the automotive sector can provide enabling technology for rail virtual coupling communications. The significant differences between these areas relating to poor braking and safety levels were highlighted.

3. Architectural considerations

In this section we discuss the factors that have impacted on the virtual coupling communication system architectural proposals. These include the impact of:

- train topology (particularly on the distances involved as these can exceed the reliable operational distance for certain types of communications);
- the key virtual coupling requirement of inter-consist communication;
- the need for intra-consist communication;
- the safety and security needs where it is vitally important that any communication can be trusted and acted upon in a timely manner;
- the implications of the baseline control system.

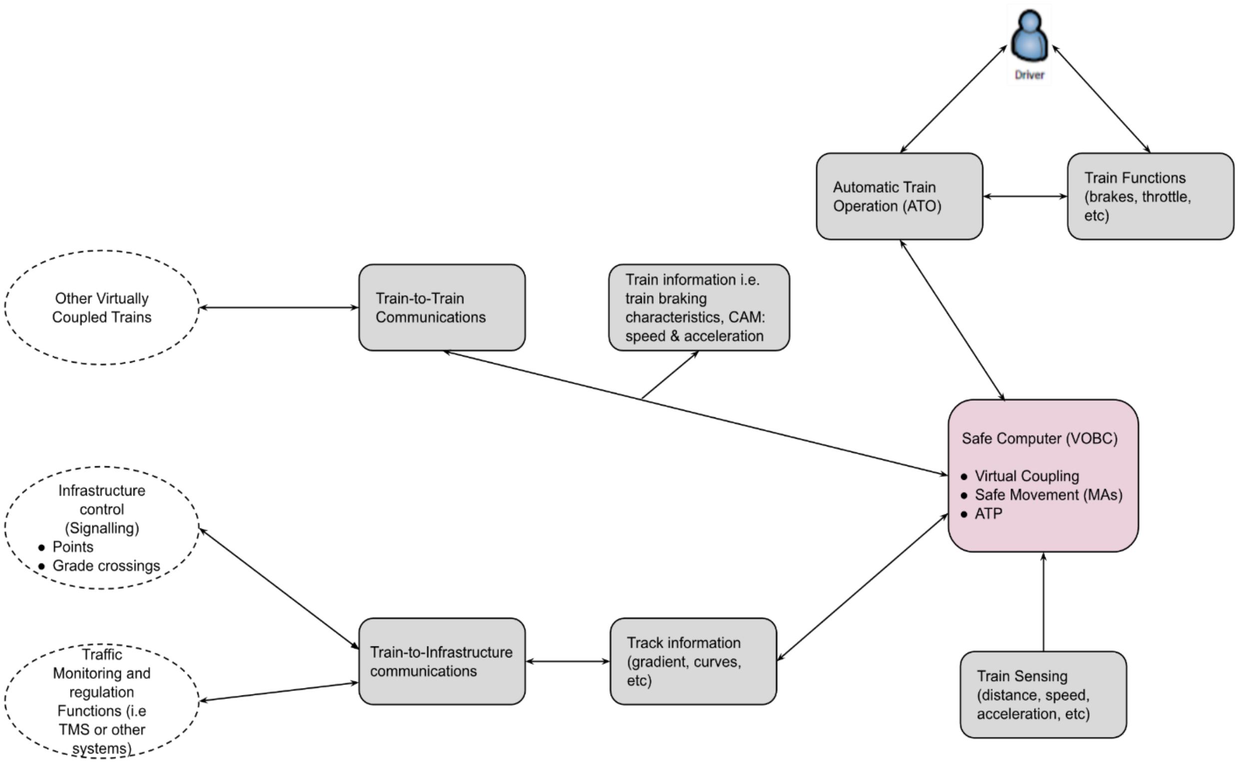


Figure 1 – Virtual Coupling Communications Context and Interfaces Diagram

The context in which the virtual coupling communications system exists is shown in Figure 1.

The virtual coupling communications system provides the communications path for messages between the virtual coupling control applications on the trains forming the convoy. (Train-to -Train communications). The virtual coupling communications system may also share or provide the communications to the infrastructure and the baseline control system/signalling (Train-to-Infrastructure communications).

3.1. Train topology

A clear function of the virtual coupling communications system is to provide train-to-train communication between trains/consists forming the convoy. This functionality has to support:

- Virtual coupling initiation (with train absolute braking distance, or more, apart);
- Virtually coupled convoy (relative braking distance + safety margin);

- Intentional or unintentional decoupling as all or part of the convoy is removed.

The distance achievable for short range direct communication is currently less than 500m [1]. The distances over which communication is required is defined by train topology and, in the initiation stage, will typically exceed the 500m envelope.

3.1.1. Long braking distances

Braking distances for trains are much larger than for automotive transport. For High Speed and mainline railways, the speeds involved and mass of these trains mean that absolute braking distances are large, e.g. 1250 m from 180 km/h [1].

3.1.2. Length of trains

The length of trains determines if a single transceiver is sufficient, as is the case for the automotive sector. Trains, particularly freight trains, can be of considerable length. The reference train unit of the UIC 556 which may be composed of up to 22 vehicles and have a maximum length of 850m [3].

3.1.3. Multiple units / locomotives

The formation of trains is also significant. The formation may be fixed or variable, e.g. multiple units can have a fixed formation but trains can be formed from multiples of these.

For example, it is not unusual for trains in the UK to consist of two or three multiple units formed as a single train. This can create a train of upwards of twelve cars. Eurostar typically run two eight-car units together.

So, for all but the shortest of trains, virtual coupling communication will require transceivers for the direct communication between trains at each end of the trains. It will be necessary for these transceivers to communicate with each other and the virtual coupling communications controller/manager.

3.2. Inter-consist communication

Key to the operation of virtual coupling is the transfer of information (particularly the highly dynamic information: current position, speed, acceleration and brake demand) between the consists in a train convoy.

It is envisaged that communication will not only be required between adjacent trains (preceding or in rear) but between all trains and the master. The proposed communications system provides this capability (noting this is likely to require network for all but adjacent trains), but the Virtual Coupling control system will define allocation.

A virtual coupling communication protocol/language will need to be developed. It is suggested that this should be as open as possible and should maximise compatibility with:

- Consist Network (ETN, WLCN) – messages
- European Train Control System (ETCS) – telegrams/data dictionary
- Intelligent Transportation System (ITS) – message standards/automotive

In particular the synergy between automotive Co-operative Awareness Messages defined by the Intelligent Transportation System (ITS) specifications and the information required for virtual coupling should be exploited.

Because of the deterministic nature of railways, the ad-hoc network capability that is necessary for the automotive sphere is not essential for virtual coupling. At the early stage of coupling discovery time will not be critical.

3.3. Intra-consist communication

Communication will be necessary between the virtual coupling communications elements (transceivers and the communications controller) within a train.

From the discussion on train topology it can be seen that there is a need for the virtual coupling communication transceivers at the ends of trains to communicate with each other and the virtual coupling communications controller/manager. Where this distance is short enough (< 500 m) this is achievable directly by wireless communication. For larger distances it is proposed that the trains communication network (Ethernet Train Network (ETN), WLCN) be used, and this could form the generic case.

There are a number of possible options available for achieving the intra-consist communication. The selection of the most appropriate solution is dependent upon the existing capability of the train to be fitted.

3.4. Safety and security considerations

D3.1 [1] identified that 'responsibility for the highest integrity control functions (authorisation, identity and key management) lies with the application layer and is implemented by the safe computer (e.g. European Vital Computer (EVC)) of the train control system rather than by the communications equipment.'

It is not intended that safety requirements are apportioned to the virtual coupling communications controller/manager or the virtual coupling transceivers. To do so would seriously impact the aim of maximising the use of Commercial-Off-The-Shelf (COTS) items.

However, by using SDTv2/SDTv4 {Safe Data Transmission} as a safe end-to-end communication protocol, it is possible to exchange safety related data over the wireless network [3]. This will enable the virtual coupling system to maintain safety under the communications system threats defined in 50159, the standard for railway safety related communications [4].

Loss of communication must result in the trains entering a safe state. Therefore, it is not necessary to have a redundant architecture to achieve safety for the virtual coupling communications. However, redundancy could be incorporated into the virtual coupling communication items to enhance availability and is not precluded by the proposed architectures.

There are significant advantages in achieving a trusted status for the communications networks from selecting 5G which brings native network slicing support, enabling the definition and operation of virtually separated end-to end (E2E) networks, which is especially relevant if critical rail operations may have to share the same spectrum and/or communications infrastructure with non-critical services.

3.5. Signalling control systems

The architecture for the communications system for virtual coupling cannot be consider in isolation from the train control framework in which it operates.

There are two philosophies under consideration; integrated and stand alone. Standalone has the greatest synergy with automotive.

Whilst it is likely that, for the majority of the virtual coupling applications, virtual coupling will be an add on sitting upon the existing baseline rail control systems, such as ETCS, CBTC, etc. there is also the possibility of virtual coupling becoming the primary control system organising traffic flows in a similar manner to automotive, e.g. using 'swarm' principles. The differences between these principles is likely to have significant impact upon the interfaces between the systems and roll out plan. Standardised interfaces should be used wherever possible.

A key issue is the extent to which the virtual coupling communication and control system are integrated with the conventional control systems or are standalone. The authors consider that a standalone approach is likely to only be viable for totally segregated systems, as found with some Metro systems.

When a train first becomes aware of a virtual coupling partner, it follows that both trains must be under the supervision of the baseline train control (signalling) system. The handover is likely to involve more than a simple on/off at the Automatic Train Protection (ATP) interface.

For the purposes of the virtual coupling communications system proposal, it is suggested that these interfaces are handled by the virtual coupling controller which could be different for the different sectors and philosophies, while maintain a standard interface to the communications system.

4. Virtual coupling communications architecture proposal

4.1. Sector differences relevant to Virtual Coupling communications

There are significant differences between the railway markets relevant to Virtual Coupling communications, mainline, metro and tram, that may be exploiters of virtual coupling. See [1].

For the European rail network, The European Railway Traffic Management System (ERTMS) is prescribed by legislation, with the aim of achieving interoperability, open market and market scale. The European rail network is large and non-homogenous. This sector incurs the very large distances which can only be viably addressed by cellular network communication.

Metro systems are usually self-contained and homogeneous. This makes this sector more open to specialised bespoke control solutions, and therefore potentially lead exploiters of the more advanced forms of virtual coupling.

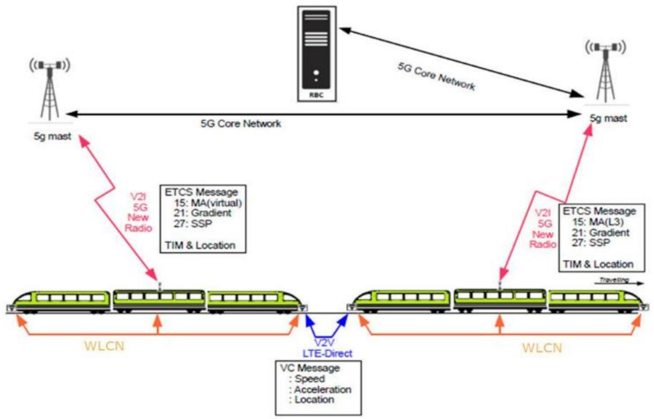
Urban tramways with line-of-sight operation are the rail sector closest to automotive and the sector where there is the most potential for benefit from the T2I (train to infrastructure) communication e.g. to road traffic lights, to other road vehicles. This sector does not incur the large distances of the other sectors and therefore communication via cellular network is less significant.

The Sectors:

European rail network High Speed/Mainline/Freight

Mixed Fleet, inter-running

Baseline control: ETCS

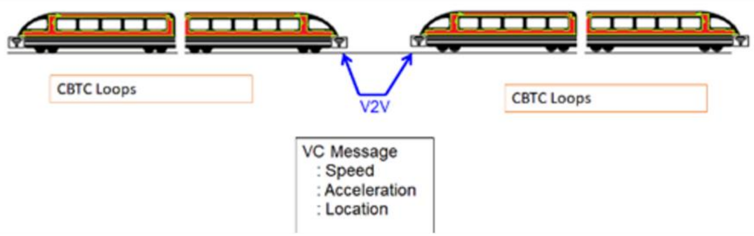


Urban Metro

Intensive service, high performance trains

Standalone system (homogeneous, no inter-running)

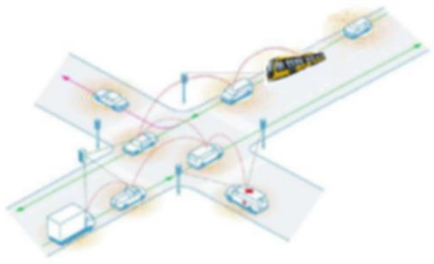
Baseline control: CBTC



Urban – Tram (STC)

Intermixed with other traffic

Baseline control: Line of Sight



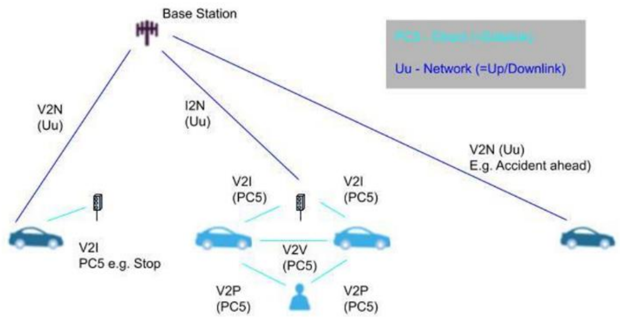


Figure 2 – Virtual Coupling -Sector Differences

These differences lead to potentially different virtual coupling communication architectures for the sectors. The proposed solution to the virtual coupling communications system allows for the differences between the sectors which can be addressed by differing options at implementation.

4.2. Elements/Equipment

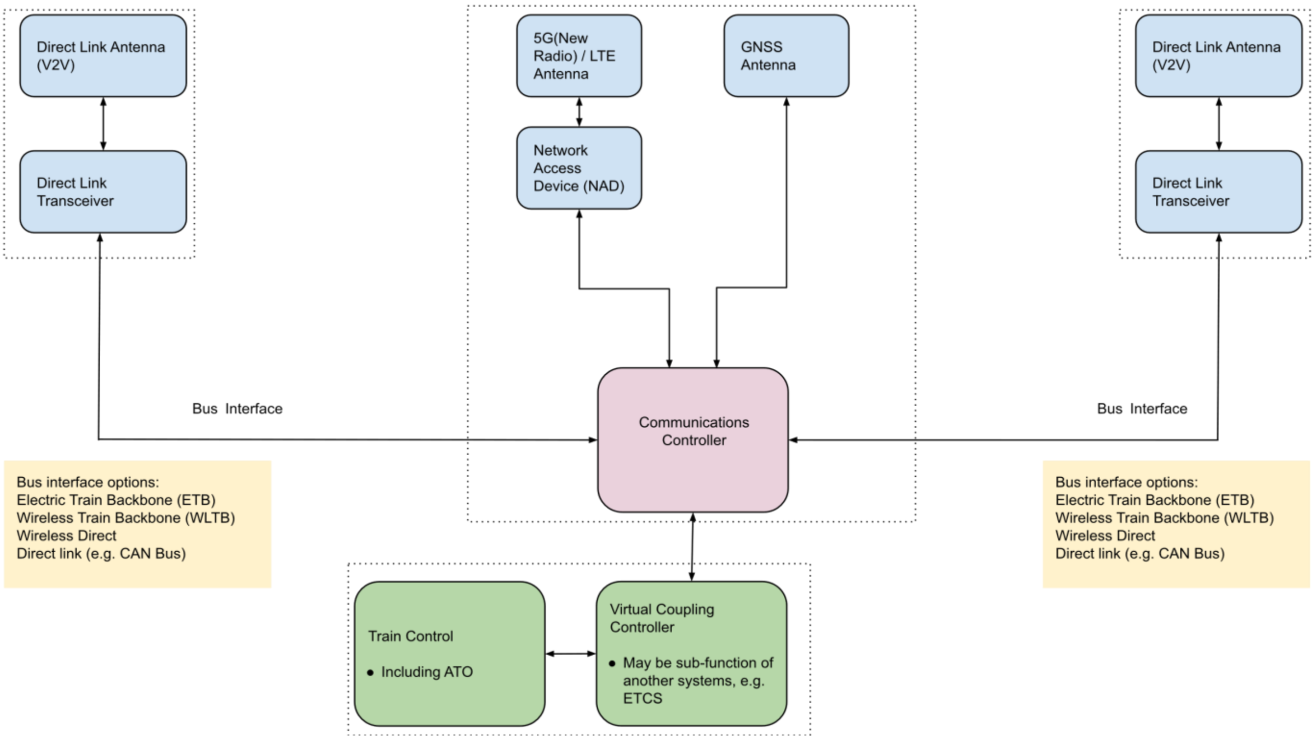


Figure 3 – Virtual Coupling Communications Equipment Architecture Diagram

It is proposed that the major elements that form the virtual coupling communications solution shown in Figure 3, are: the virtual coupling communications controller and the virtual coupling (direct link) transceivers.

The virtual coupling communications manager/controller. This unit has the primary responsibility for routing and holds the network map. One of these will be required per train and this will provide the interface to the virtual coupling controller. It is logical for this unit to incorporate the Network Access Device (NAD) and will be connected to antennae for the network and Global Navigation Satellite System (GNSS). Note that the standards for 5G incorporate the use of the GNSS for Positioning, Navigation, and Timing (PNT). Whilst this will be available, via incorporation in the protocols, to the virtual coupling controller, it's use here is primarily to support Vehicle-to-Everything communication.

P2P/T2T transceivers and associated antennas will be needed at the front and rear ends of trains. There is the possibility of ultimately combining this with the WLCN.

A Virtual coupling low latency cellular communications network is needed to provide P2P/T2T link over longer distances. It is possible that as network capability evolves it may ultimately be capable of supplanting the need for direct P2P. It is expected that this network will be shared

with the baseline control system e.g. to be part of Future Railway Mobile Communication System (FRMCS) supporting ETCS for the European network.

Protocols for the virtual coupling communications should be specified and it is expected that these will retain a close synergy with those for Intelligent Transport Systems (ITS) as used by the automotive sector, see Figure 4 – Intelligent Transportation System (ITS) Communications Domain and Figure 5 – Virtual Coupling Communications Domain.

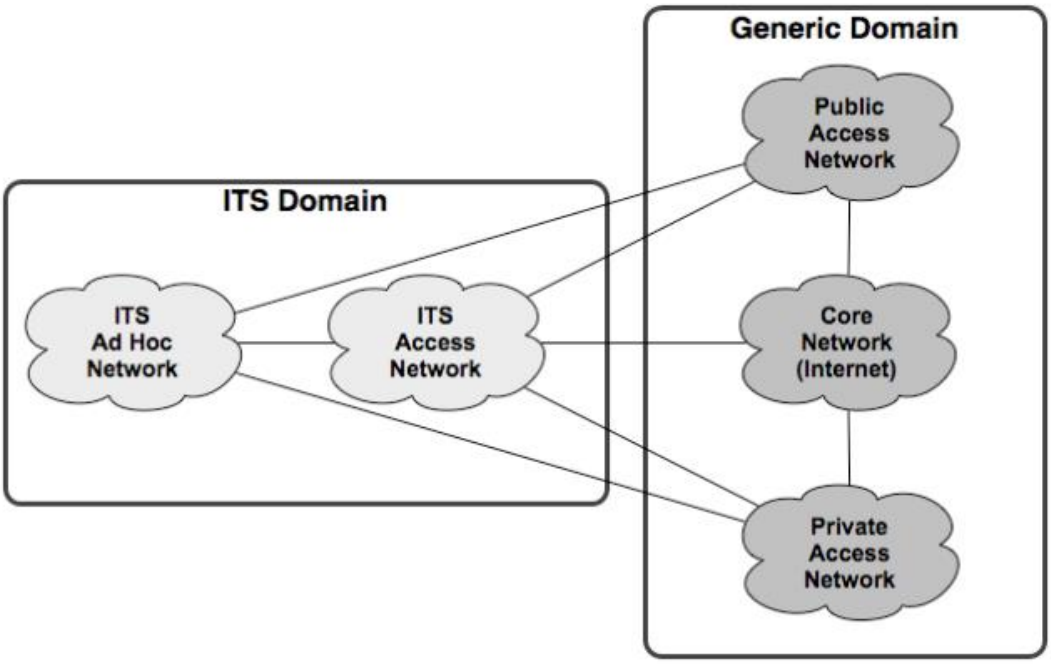


Figure 4 – Intelligent Transportation System (ITS) Communications Domain *[5]*

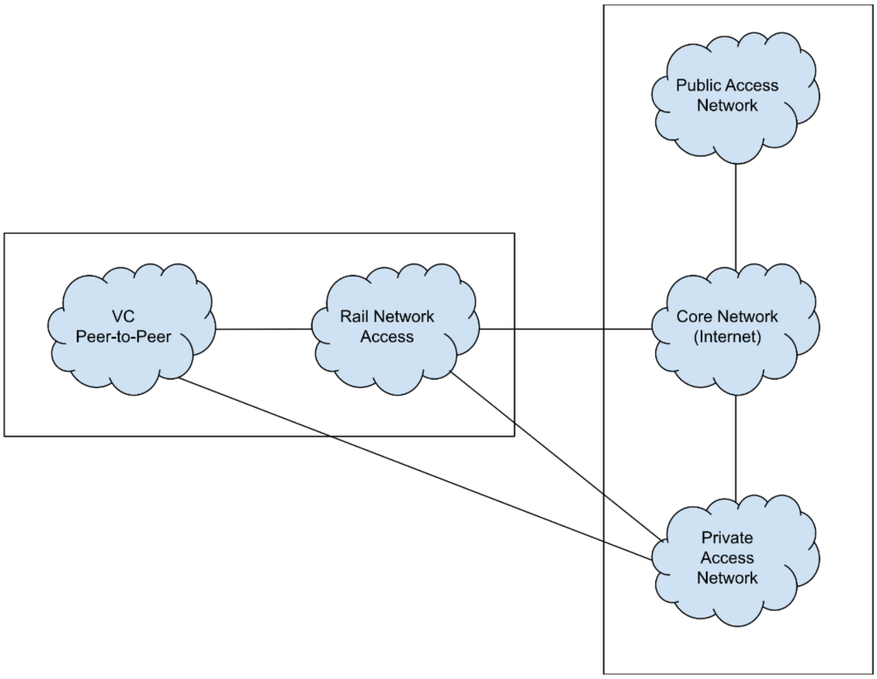


Figure 5 – Virtual Coupling Communications Domain

4.3. Virtual Coupling Communications Architecture Options

There are a number of different circumstances under which virtual coupling might be rolled out onto a rail network. The high level architecture that we propose for the communications solution to support virtual coupling gives rise to a number of implementation options depending on the existing state of the rail system where virtual coupling is to be employed and the view of the railway authority. The following sections examine these options.

4.3.1. Rollout onto an existing railway

The more common and therefore 'standard' virtual coupling rollout is onto an existing infrastructure and rolling stock. The basis for this is most likely to be an existing ETCS Level 2 or Level 3 platform. See Figure 6 & Figure 7.

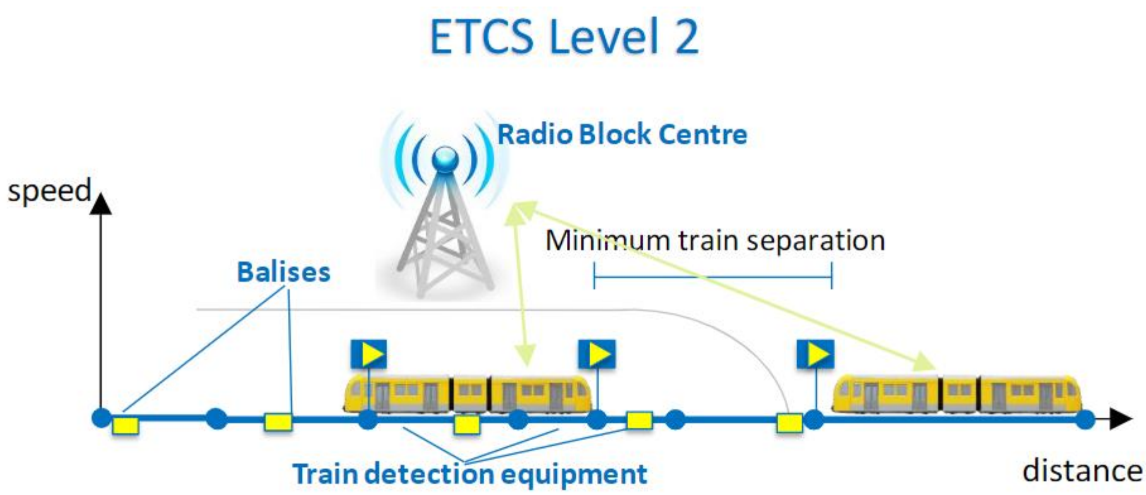


Figure 6 – Schematic layout of ETCS Level 2

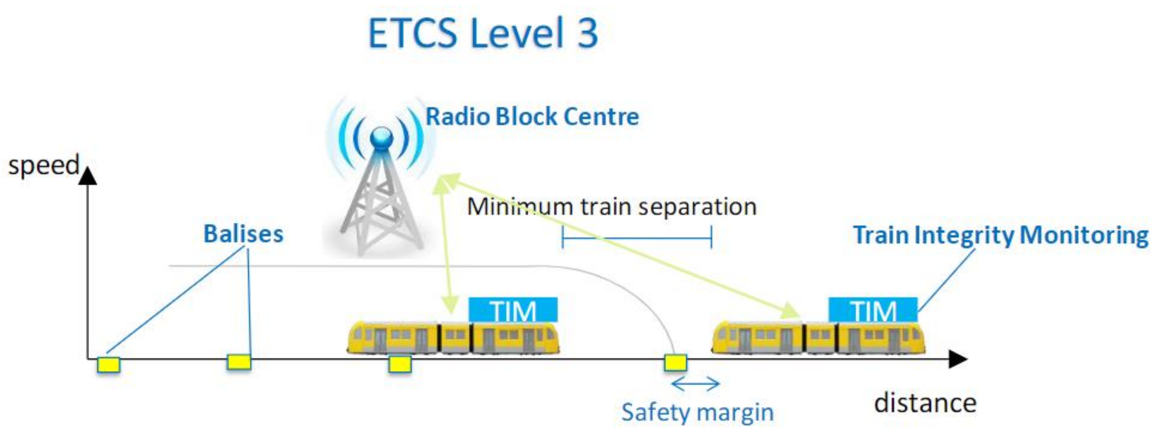


Figure 7 – Schematic layout of ETCS Level 3

The implication of this is that there will be an existing safe computer Vehicle On-Board Controller (VOBC) providing the option to integrate the virtual coupling control application. The communication infrastructure is likely to be GSM-R, or its successor FRMCS. Rolling stock will already have a consist network available.

4.3.2. Rollout onto a new railway

For new build railways, there is the possibility of a 'clean' rollout using both brand new rolling stock and new infrastructure. The recommended communication network is 5G, either in a bespoke or commercial form.

For a new railway, or when replacing an obsolete control system, it is plausible that the virtual coupling controller may be the only train control system to be employed. In this case the approach can use automotive experience as a starting point. This scenario is perhaps most likely on light rail or tram systems.

4.3.3. Architecture Options for Inter-consist communications

There are two communication paths proposed for inter-consist communications for virtual coupling. These are:

- Cellular Network communication. This is required for large rail distances and is most likely to be based upon 4G succeeded by 5G and FRMCS (which itself may be based on 5G). It is also possible that the performance of such a network will evolve over time to be adequate to eliminate the need for a direct link between the consists.
- Direct Link (T2T). This employs virtual coupling transceivers and is based upon the automotive model. There is the possibility of reuse of the consist network wireless end node which should be considered.

4.3.4. Architecture Options for Intra-consist communications

The Intra-consist communication options are needed to connect the virtual coupling communication system elements. This gives three potential options:

- Where virtual coupling is being applied 'standalone' there is the option to use a bespoke connection e.g. CAN bus or Ethernet combination;
- For 'short length consists' it would be possible to utilise the local Wi-Fi direct connection of the transceivers;
- For 'standard' roll out the most likely scenario is to reuse the existing network such as Ethernet Train Network (ETN) and WireLess Consist Network (WLCN) – see Figure 8.

Our virtual coupling communications proposal has adopted the 'standard' roll-out model (see section 4.3.1).

Figure 8, courtesy of CONNECTA-2 [3], taken as-is shows CONNECTA-2's thinking on the architecture for the Wireless TCMS.

The WTCMS is designed to complement wired NG-TCN network in order to reduce cabling costs and ease the insertion of the WTCMS in existing fleet where the installation of new wiring is difficult or even impossible. The WTCMS consists of two new wireless networks; the WLTB, which works within a train and the WLCN, which connects wireless end devices to the consist network.

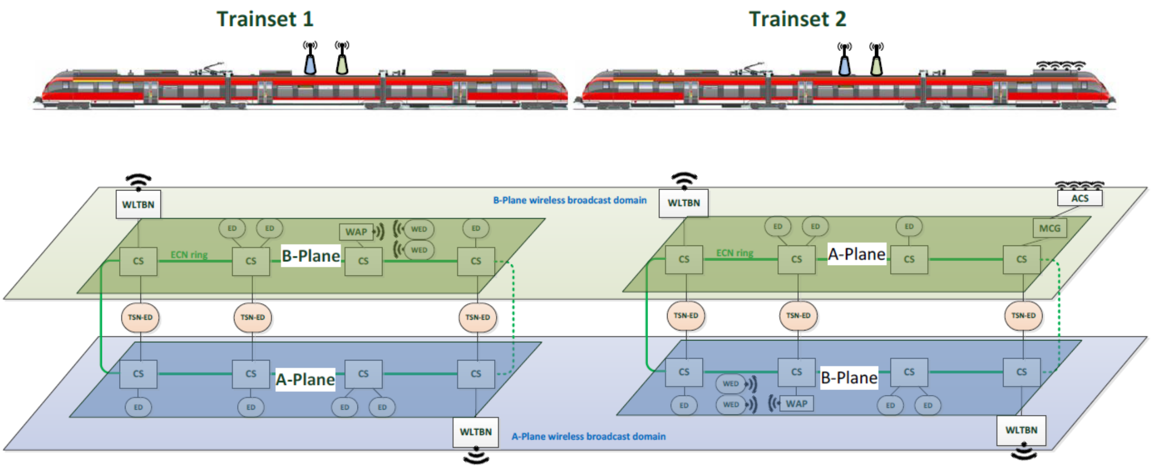


Figure 8 – General architecture of the Wireless TCMS (courtesy CONNECTA-2)

4.4. Communications Solution Proposed for Virtual Coupling

We propose an architecture for the communications system solution for virtual coupling that:

- Can meet the primary requirement for the trusted exchange of information between trains forming a convoy;
- Can operate with the large distances involved with rail;
- Can benefit from automotive developments;
- Can be integrated into and share resources with the baseline control systems.

We therefore, based on the technology identified in D3.1, the lessons from automotive in D3.2, and taking into account the rail specific issues impacting the architecture, propose that the communications architecture for virtual coupling should be based around 5G principles and be similar to the diagram below.

Referring to the diagram the trains will make use of a low latency (5G) cellular network for T2T communication, such as the long distances when first coupling, supported by a direct P2P link similar to IEEE802.11 (Wi-Fi), but fully integrated into 5G.

The proposed communication structure is that direct train communication is merged with longer distance network capability. The most suitable technology for this is from the evolving 3GPP standards, 5G. This also gives synergy, for the European rail network, with the intention to replace GSM-R with FRMCS, which is also favouring 5G. It's application for the European mainline network shown in Figure 9. For the urban sectors (metros, tramways) the importance of the network element is reduced, because of the generally smaller distances involved, giving a variation of architecture as shown in Figure 10, however the applicability of 5G remains.

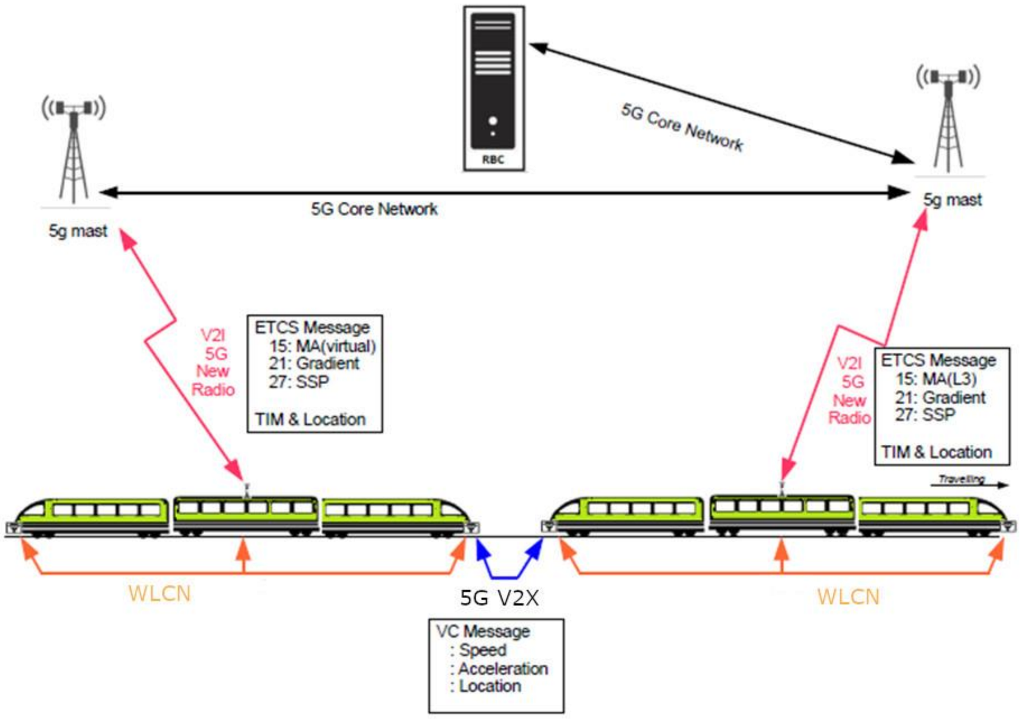


Figure 9 – Proposed Communications Architecture for mainline railways

Figure 9 shows the virtual coupling communications system applied to the European rail network where cellular link is shared with ERTMS and intra-consist communication shares the trains network.

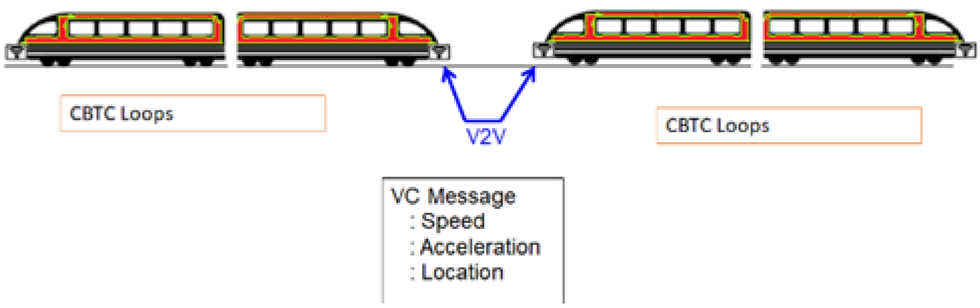


Figure 10 – Proposed Communications Architecture for metro systems

Figure 10 shows the virtual coupling communications system applied to a metro system.

The implementation of the virtual coupling communications proposal allows options to be varied to suit the details of specific applications while maintain the maximum commonality.

5. Roll-out options

Virtual coupling builds on the work of earlier Shift2Rail projects such as Roll2Rail. The environment under which this work is conducted is one in which the context is rapidly changing and evolving as new technologies continue to emerge. These technologies offer an increasingly rich communications environment for future exploitation.

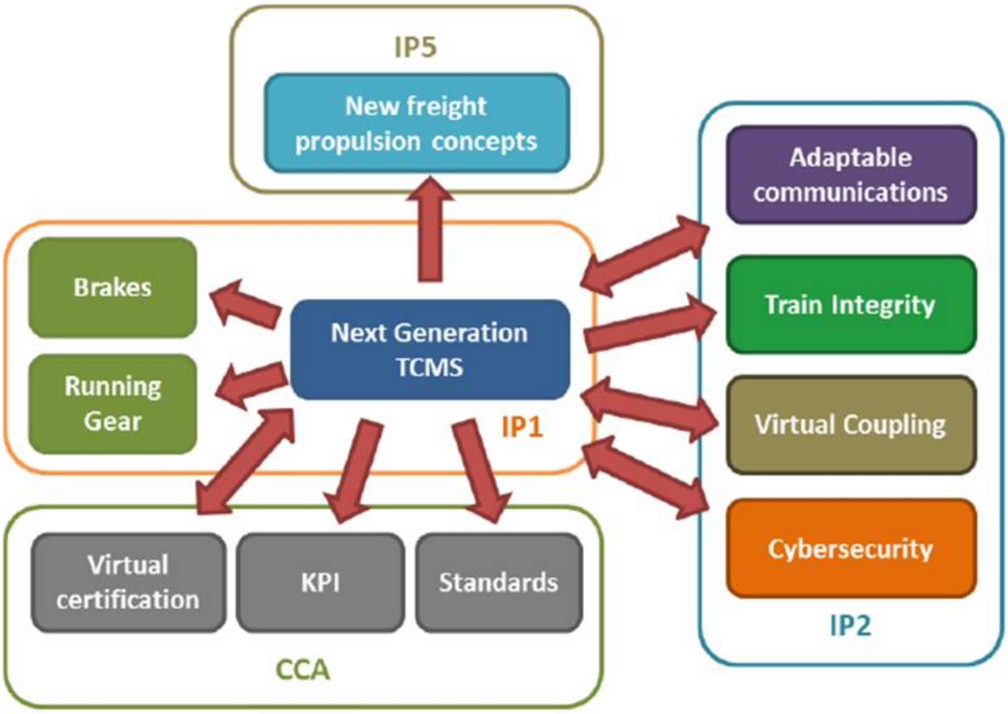


Figure 11 – Shift2Rail context

Virtual coupling will be taken forward by Shift2Rail complementary projects (CONNECTA-2, X2RAIL-3) via the technical demonstrators through the rail industry Technology Readiness Levels. This should result in a suitable set of standards and specifications to enable the rail industry to produce virtual coupling implementations.

MOVINGRAIL deliverable D3.1 [1] outlined the current leading communications technologies suitable for virtual coupling, of which 5G has emerged as the current front runner. This document proposes a suitable virtual coupling communications architecture.

The roll out of communications systems suitable to support virtual coupling is just one of the factors in the virtual coupling timeline, see MOVINGRAIL D4.3 – Application Roadmap for the Introduction of Virtual Coupling. Since communications in general have progressed to a point where supporting virtual coupling requirements is not exceptional, it is likely that achievement of safety acceptance and integration with baseline control systems will be the factors that dominate.

5.2 Equipment rollout

Equipment support for 5G is becoming available now and can be expected to be available soon for the automotive sector and public commercial domain.

Whilst there remain some significant differences between the automotive industry and the railways, there is the obvious potential for sharing of technology and solutions. The reuse of automotive hardware, where there is matching environmental and reliability requirements, should be investigated. In general, maximising the reuse of COTS equipment by exploiting the larger automotive market size should result in cost effective solutions to railway virtual coupling roll out.

In order to standardise, protocols for rail virtual coupling communications should be drafted and industry agreement obtained. As far as is possible this should be in line with and incorporated into railway standards dealing with communication. In order to maximise the potential reuse of automotive solutions, it is also recommended that as far as is possible, reuse of automotive constructs should be considered.

5.3 Interface of virtual coupling communications system and the train control system

It is assumed that for the majority of virtual coupling applications there will be significant integration with a baseline control system, such as ETCS L3 or CBTC. This will be necessary in order to achieve safe handover between the systems.

Since the baseline systems already have high integrity computational processing capability, it is suggested that this should be exploited as the host for the virtual coupling application. It is important to note however, there may also be instances where a standalone virtual coupling system is appropriate, e.g. for tramways.

To enable the design of the virtual coupling communications system and equipment it will be necessary for the interfaces with the baseline train control system to be defined and standardised.

5.4 Virtual Coupling communications roll-out roadmap

The roadmap for the roll out of virtual coupling is shown in Figure 12 – Virtual coupling communications roll out roadmap. As well as following a well-defined route to implementation, it is important to promote the definition and publication of the protocol standards to encourage a wider number of suppliers to engage in the provision of products to support virtual coupling.

The generic steps to rollout a virtual coupling solution are as follows:

- Define and agree protocol standard for virtual coupling communications;
- Define and agree interface standard for virtual coupling communications;
- Apportion functionality across the architecture;
- Select/design hardware taking into account availability of suitable elements from the automotive solution;
- Develop virtual coupling specific software;
- Develop a trial application;
- Incorporate virtual coupling into operational rules;
- Fit rolling stock and provide trackside infrastructure for first application of virtual coupling;

- Maximise equipment sharing;
- Generic application of virtual coupling available.

5.5 Factors affecting roll out

Current railway communication systems are not capable of meeting the requirements of virtual coupling. Suitable systems are emerging in the commercial cellular and automotive sectors. Plans are emerging for future rail communications systems, such as FRMCS, that will be able to support virtual coupling. To achieve a timely and cost-effective roll out of a communications system for virtual coupling the following factors should be considered in the implementation:

- What options can be incorporated to create sufficient flexibility to cope with future developments, such as the upgrading and maintaining of on-board equipment (for both hardware and software), and taking into account the economic and operational impact of upgrade activities? The use of over-the-air update should be considered where feasible, with due concern for integrity, reliability and safety.
- Maximise sharing and reuse of emerging systems e.g. FRMCS, WLCN, public cellular.
- Allow for the rapid changes in telecommunications by maintaining synergy with large equivalent sectors, such as automotive, and maximise standardised interfaces and open architectures.

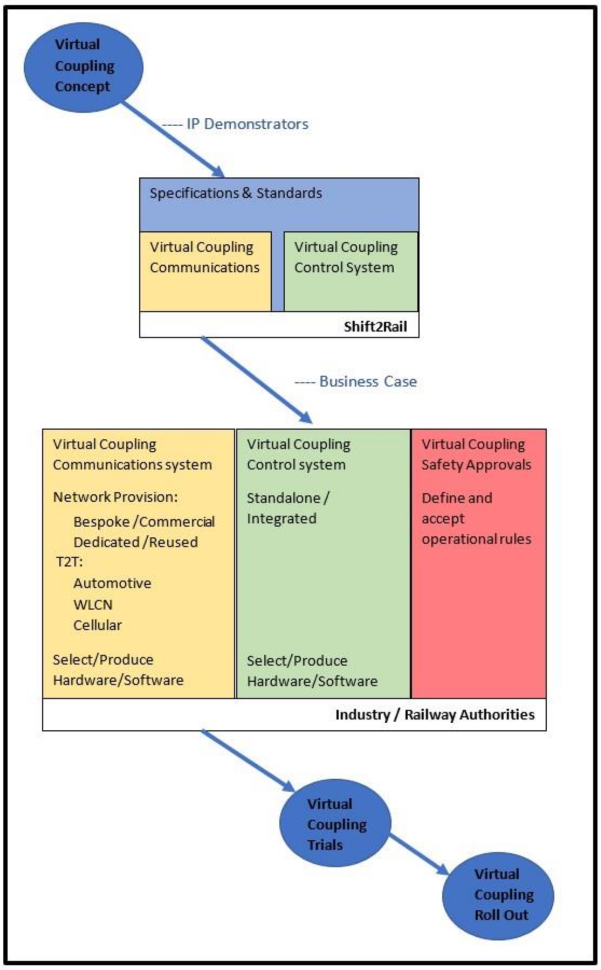


Figure 12 – Virtual coupling communications roll out roadmap

6. Further work / open points

The possible use of emerging automotive hardware, where there is matching environmental and reliability requirements, should be investigated.

Redundancy (duplication) is not required in the virtual coupling communications system for safety, but an open point is whether redundancy is required to achieve system availability. This may depend on the ease and consequence of falling back to the baseline control system.

It is clear that a solution to meeting the communications requirements for virtual coupling is viable and can be achieved with the proposals described using current and evolving technology. The challenge for virtual coupling remains in the safety and integration areas.

7. Conclusions

The primary difference in the communications requirements for virtual coupling over moving block is the envisaged need for low latency peer-to-peer communication. There is clear synergy with work carried out in the automotive field, where 5G evolved to incorporate peer-to-peer 'sidelink' communications which are already incorporated into the 3GPP standards for 5G, meeting the requirements for virtual coupling. This is confirmed by the high scoring from the SWOT analysis carried out in the Virtual Coupling Communication Solutions Analysis (see [1]).

It is an aim of the FRMCS project that suitable communications equipment will be available 'off the shelf'. In terms of equipment virtual coupling will require additional antenna and transmitter/receivers at each end of the train. This is a difference to the automotive field which does not have to deal with the significant length of trains (100s of metres). We propose that where available an existing train network (ETN, WLCN) be utilised to achieve this equipment interconnection, though this will require the virtual coupling application to provide the necessary protections for safety and security. The other major difference to automotive, the relatively large separation between trains, can be addressed seamlessly by 5G transitioning to network connection when required. We see that chip sets are already emerging from manufacturers, such as Qualcomm, with the appropriate capabilities.

We therefore propose that the communications architecture for virtual coupling should be based around 5G principles and is shown in Figure 9 – Proposed Communications Architecture for mainline railways

Referring to the diagram the trains maintain a cellular network connection for long distance communication and a Peer-to-Peer link similar to IEEE802.11 (Wi-Fi), but fully integrated into 5G, for short-range communication.

We recommend that further analysis and practical investigation is carried out to confirm the suitability of this communications proposal in achieving virtual coupling.

8. References

[1] MOVINGRAIL, "Deliverable D3.1, Virtual Coupling Communication Solutions Analysis," Shift2Rail, 2020.

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[5] ETSI, "Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 3: Network architecture; ETSI TS 102 636-3 V1.1.1," ETSI, (2010-03).