OCORA

Open CCS On-board Reference Architecture

UVCC Bus Evaluation

Beta Release

Document ID: OCORA-40-003-Beta

Version: 1.01

Date: 01.07.2020

Status: Final

Revision history

Version	Change Description	Name (Initials)	Date of change
0.10	First Draft	SSt	2020-05-27
1.00	Review comments OCORA included	SSt	2020-06-22
1.01	Typographical Correction	CG	2020-07-01

Table of contents

Table of figures

Table of tables

References

The following references are used in this document:

[1] OCORA-10-001-Beta – Release Notes

[2] OCORA-10-002-Beta – Review Plan

[3] OCORA-10-003-Beta – Feedback Form

[4] OCORA-20-001-Beta – Program Slide Deck

[5] OCORA-20-002-Beta – Technical Slide Deck

[6] OCORA-20-003-Beta – Program Posters

[7] OCORA-20-004-Beta – Technical Posters

[8] OCORA-30-001-Beta – Introduction to OCORA

[9] OCORA-30-002-Beta – Problem Statements

[10] OCORA-30-003-Beta – Road Map

[11] OCORA-30-004-Beta – Business Objective and Economic Model

[12] OCORA-30-005-Beta – Alliances

[13] OCORA-40-001-Beta – Architecture

[14] OCORA-40-002-Beta – Architecture – Capella Model

[15] OCORA-40-004-Beta – Middleware Specification

[16] OCORA-40-005-Beta – CCS Vehicle Interface Specification

[17] OCORA-40-006-Beta – CCS Vehicle Interface Specification – SCADE Model

[18] OCORA-40-007-Beta – Functional Requirements

[19] OCORA-40-008-Beta – Non-Functional Requirements

[20] OCORA-40-009-Beta – Acceptance of Global Standards

[21] OCORA-90-001-Beta – Question and Answers

[22] OCORA-90-002-Beta – Glossary

[23] EN 50129:2018 – Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling

[24] EN 50159:2010 – Railway applications - Communication, signalling and processing systems - Safety-related communication in transmission systems

[25] CTA-T3.5-D-BTD-002-12_-_Drive-by-Data_Architecture_Specification

[26] CTA2-T3.4-T-SIE-019-03 – Safety Analysis SDTv4

[27] ERTMS/ETCS Subset-056: STM FFFIS Safe Time Layer, Version 3.0.0

[28] ERTMS/ETCS Subset-057: STM FFFIS Safe Link Layer, Version 3.1.0

[29] COAT-STI-BUS004 Evaluation UVCCB SBB V1.00

[30] NewTec GmbH: UVCCB Study BUS Technologies, Version A6-final

[31] Selectron Systems AG: UVCCB Technology Evaluation Report, Version 1.0.1

1 Management Summary

Today we have proprietary interfaces between CCS components on the vehicle. The proprietary interfaces do not allow to exchange or update CCS components from different suppliers. The OCORA architecture [13] aims for plug and play interchangeability within the CCS domain through the specification of a generic and open communication backbone, the Universal Vital Control and Command Bus (UVCCB). The UVCCB itself will be modifiable in accordance with future technological evolutions by means of strict separation of the different communication layers (OSI Layers).

This document establishes a list of requirements for the CCS bus and provides a summary of independent assessments of existing, open standard bus / network protocols for safe communication among the CCS components in the vehicle.

All the assessments of UVCCB bus technologies come to same result. The UVCCB should be a TSN Ethernet based network with the use of SDTv2 / SDTv4 as safety layer. In order to be able to integrate the UVCCB on the next generation of train communication network (NG-TCN) every safety related CCS device (e.g. CCU, BTM etc.) should have two TSN capable Ethernet ports whereas for non-safety related CCS devices a single TSN capable Ethernet port is sufficient.

On the OSI layers 3 to 6 at least IPv4, UDP, TCP and TRDP must be supported by the CCU(s) in order to be able to communicate directly to the TCMS. For communication between CCS devices only other protocols on session layer are possible (e.g. OPC-UA Pub/Sub or DDS-RTPS). These will be evaluated in future and published in subsequent releases of this document.

The protocol stack of UVCCB is listed in the following table. Standards to be used as mandatory in OCORA are listed in bold font. Protocols to be further investigated are listed in grey font.

Layer	Protocol	
Safety Layer	**SDTv2 / SDTv4**	
Session Layer	TRDP	e.g. OPC-UA Pub/Sub or DDS-RTPS
Transport Layer	UDP (for process and message data) TCP (for message data)	
Network Layer	IPv4	
Data Link Layer	**Time-Sensitive Networking (TSN) IEEE 802.1**	
Physical Layer	**100BASE-TX or 1000BASE-T**	

Table 1: Protocol Stack UVCCB

The technical integration of the UVCCB within the NG-TCN and the separation of responsibilities between the two domains must be clearly elaborated. The solution for retrofit vehicles, where there will be a UVCCB without a NG-TCN of TCMS, has also to be defined. Beside the TRDP it is beneficial to evaluate other data distribution protocols on session layer like OPC UA Pub/Sub or DDS-RTPS which can coexist with TRDP.

2 Introduction

2.1 Document context and purpose

This document is published as part of the OCORA Beta release, together with the documents listed in the release notes [1]. It is the first release of this document and it is still in a preliminary state.

The document was not released in the alpha release as it presents results obtained since then. This document focuses on the architecture, the content regarding the program can be found in documents [8] and [12]. Subsequent releases of this document (gamma, etc.) and topic specific documentation will be developed in a modular and iterative approach, evolving within the progress of the OCORA collaboration.

2.2 Why should I read this document?

This document is addressed to experts in the CCS domain and to any other person, interested in the OCORA technical concepts for on-board CCS. The reader will gain insights regarding the topics listed in chapter 2.1, will be able to provide feedback to the authors and can, therefore, engage in shaping OCORA.

Before reading this document, it is recommended to read the Release Notes [1], the Introduction to OCORA [8], and the Problem Statements [9]. The reader should also be aware of the Glossary [22].

The Capella Model [14], the Middleware [15], the CCS Vehicle Interface Specification [16], the SCADE Model [17], the Functional Requirements [18], and the Non-Functional Requirements [19] provide further technical details to this document.

2.3 Problem Description

Today we have proprietary interfaces between CCS components on the vehicle. The proprietary interfaces do not allow to exchange or update CCS components from different suppliers. The vendor locking created by proprietary interfaces leads to high costs. The existing proprietary interfaces do not allow to add new functions.

Moreover, these interfaces are implemented using heterogeneous bus technologies. This leads to increased complexity and extensive effort for the operator-maintainer to handle these heterogeneous systems.

2.4 Concept

The OCORA architecture [13] aims for plug and play interchangeability within the CCS domain through isolation of specific functions in combination with the specification of a generic and open communication backbone, the Universal Vital Control and Command Bus (UVCCB).

In the following figure the technical view of the OCORA architecture [13] is shown. The UVCCB connects all components of the future CCS system. The most important CCS components are:

- CCS computing units (CCUs)
- Driver Machine Interface (DMI)
- Vehicle Location System
- Balise Transmission Module (BTM)
- Loop Transmission Module (LTM)
- National Train Control System (NTC)
- Cab Voice

* Juridical Recording Unit (JRU)
* Input / Output Module (I/O)
* Gateway to Train Control Bus / Network and Passenger Information System Bus / Network
* Radio Communication to the trackside over GSM-R or FRMCS

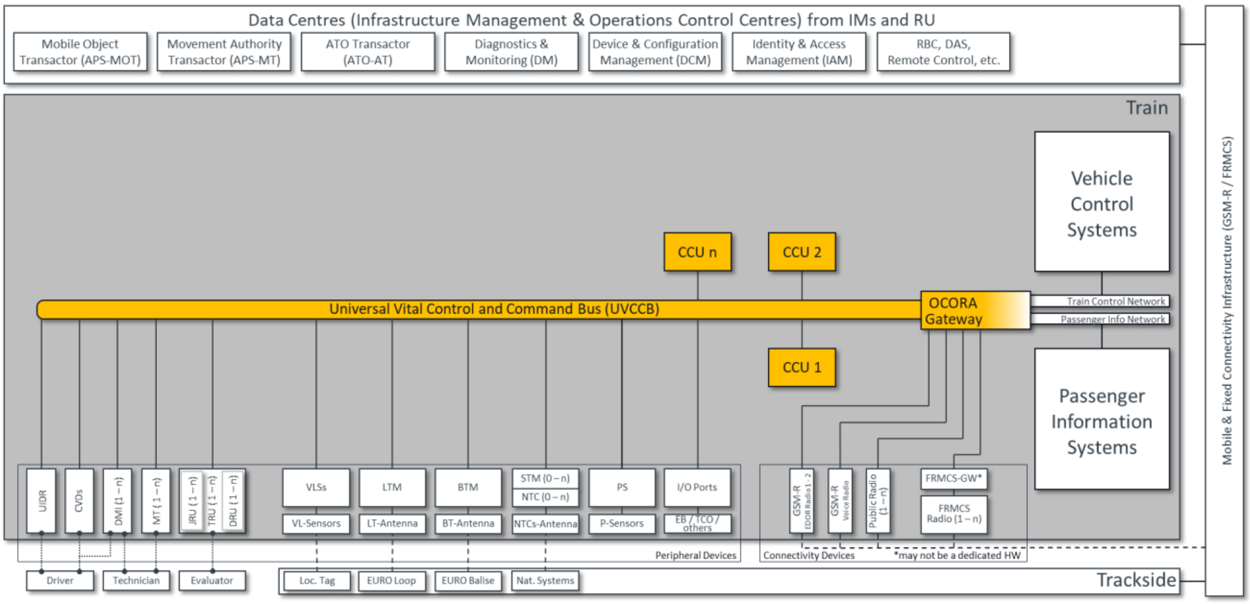

Figure 1: Technical architecture from [5]

An open standardized UVCCB (OSI-Layers 1 to 7 & Safety Layer) ensures a safe data connection between all CCS components. The bus topology allows simple upgrades of the CCS System by new functions or components. It also enables procurement on a component-based way which leads to more flexibility in the life cycle management and optimal components due to larger market size. The UVCCB itself will be modifiable in accordance with future technological evolutions by means of strict separation of the different communication layers (OSI Layers).

2.5 Goal

This document establishes a list of requirements for the CCS on-board bus and provides a summary of independent assessments of existing, open standard bus / network protocols for safe communication among the CCS components in the vehicle. The bus / network evaluation (UVCCB) considers OSI-Layers 1 to 4 & Safety Layer. Possibilities of existing bus or network protocols are collected and an evaluation regarding the requirements of the bus technology is performed. The goal was to decide for one specific stack of existing bus or network protocols fulfilling the requirements. This protocol stack is then defined as the chosen UVCCB technology within the OCORA initiative.

The following tasks have been performed:

1. Development of a list of requirements for the CCS bus with regard to application on the vehicle
2. Collection of existing, open standard bus / network protocols (OSI layers 1-4, as well as safety layers and possibly considering the other OSI layers 5 & 6).
3. Evaluation of the collected standard bus / network protocols including their topology regarding suitability for use as a CCS bus on the vehicle, verifying the protocols for compliance with the UVCCB requirements from point 1.

3 Requirements

3.1 Functional requirements for UVCCB

This chapter elaborates the functional requirements for the UVCCB (OSI-Layers 1-4 & Safety Layer).

UVCCB-01: Data transfer

- Requirement: The bus/network supports data exchange between different nodes (component of the CCS system).
- Type: must
- Remarks:

UVCCB-02: Safety

- Requirement: The bus/network supports safe data exchange for safety applications. It is possible to transmit data for safety applications with different safety integrity levels: from no safe data exchange to data exchange for safety applications with SIL2 and SIL4.
- Type: must
- Remarks: used for ETCS functions with SIL4 requirements.

UVCCB-03: Safety

- Requirement: The bus/network fulfils the requirements of EN 50159:2010 (Railway applications - Communication, signalling and processing systems - Safety-related communication in transmission systems) for safety applications.
- Type: must
- Remarks:

UVCCB-04: Safety

- Requirement: The safety targets of the safe data transmission are as follows (based on EN 50129 [23]):

Safety Integrity Level SIL	Tolerable Functional Failure Rate TFFR per hour and per function	Tolerable Function Failure Rate TFFR per hour and per part of function *
4	$10^{-9} \leq$ TFFR $< 10^{-8}$	$10^{-11} \leq$ TFFR $< 10^{-10}$
2	$10^{-7} \leq$ TFFR $< 10^{-6}$	$10^{-9} \leq$ TFFR $< 10^{-8}$

- * The transmission is only a part of a function. The safety target for the transmission part is estimated to be 1% of the safety target for the function.
- Type: must
- Remarks: Same failure rate allocation as in ERA Subset 057 v310.

UVCCB-05: Determinism, Predictability, differences in latency / cycle time

- Requirement: The bus/network shall be capable for real time applications. This means either cyclic slots for process data or a working prioritization methodology to guarantee a throughput of process data and avoidance of network capacity reduction in case of overload. It is important, that the methodology is transparent and accepted (authorized) in applications with real-time needs.
- Type: must
- Remarks:

UVCCB-06: Bandwidth

- Requirement: The physical layer of the bus/network supports a minimum gross data rate of 100 Mbit/s.
- Type: must
- Remarks:

UVCCB-07: Data type

- Requirement: The bus/network supports process data objects (cyclic) and message data objects (event based).
- Type: can
- Remarks:

UVCCB-08: Number of participating nodes

- Requirement: The bus/network supports a minimum of 62 nodes.
- Type: must
- Remarks:

UVCCB-09: Maximum physical distance

- Requirement: The maximum length of a wagon is 27 m. The bus/network system (with its topology) allows at least the physical distance between two nodes of 54m (two times the length of a wagon)
- Type: must
- Remarks:

UVCCB-10: Topology Flexibility

- Requirement: Bus/network shall be able to support different topologies i.e. Line, Star, Ring etc.
- Type: can
- Remarks:

UVCCB-11: Time synchronization

- Requirement: The bus/network provides a time synchronization of ± 1ms between several nodes.
- Type: can
- Remarks:

UVCCB-12: Independency of data streams for modularity, upgradability

- Requirement: In order to simplify the approval for updates, the bus/network provides a clear separation (independency) on physical layer of data streams between nodes/applications. If a data field of one stream changes, all other streams should not be affected.
- Type: must
- Remarks:

3.2 Non-functional requirements for UVCCB

This chapter elaborates the non-functional requirements for the UVCCB (OSI-Layers 1-4 & Safety Layer).

UVCCB-13: Openness

- Requirement: The bus/network technology is open and standardized. There is no restriction regarding intellectual property. This means that technical specifications is readily available for homologation purposes, obsolescence support, upgradability and 2nd source.
- Type: must
- Remarks:

UVCCB-14: Independence

- Requirement: The bus/network is based on a technology with components that either produced by different suppliers (independence) or if there is mainly a single supplier that there are many customers using these components.
- Type: must
- Remarks: This prevents a supplier lock-in where components price is mainly dictated by the supplier.

UVCCB-15: Availability

- Requirement: The bus/network is based on a technology with components that are commonly used on the market and produced on large quantities. In addition, it uses components that continue to be available on the market and that are not end of life within the next 5 years.
- Type: can
- Remarks: Large quantities ensure that prices are convenient. There is a commercially interesting market for the suppliers and obsolescence life cycle is handled directly by the suppliers.

UVCCB-16: Simplicity

- Requirement: The bus/network technology allows a simple design (architecture) from a network topology perspective (HW) as well as from the software integration perspective (simplicity).
- Type: must
- Remarks:

UVCCB-17: Portability

- Requirement: The same UVCCB can be used for different components, environments (subset of components) and vehicles without or with just a minimum of configuration work (portability).
- Type: must
- Remarks:

4 Evaluation Process

To have an assessment of the bus technologies that is as independent and neutral as possible, three separate assessments, one internal and two externals, were made based on the list of requirements from chapter 3. The results of the different assessments were considered in order to decide on the most suitable solution for the OCORA platform.

4.1 Internal assessment

In this chapter, the process for the internal assessment is described. The results are given in chapter 5.1. As it is impossible to compare all the existing standards and protocols that exist, a relevant subset of all standards and protocols was compared and evaluated for suitability with the OCORA system. The following set was chosen in order to give a comprehensive overview of available technologies.

- MVB according to IEC/EN 61375-3-1
- CANopen according to IEC/EN 61375-3-3
- Profibus FDL according to IEC 61158/IEC 61784 and Safe Time Layer and Safe Link Layer according [27] and [28].
- TRDP with SDTv2 according to IEC/EN 61375-2-3
- TRDP over TSN according to [25] with SDTv2 / SDTv4 according to [26]
- TTEthernet (time-triggered Ethernet) according to SAE AS6802
- EtherCAT with FSoE according to IEC 61158 and IEC 61784
- PROFINET with PROFIsafe according to IEC 61158 and IEC 61784

To compare the different technologies, each one was rated for a subset of the requirements deemed the most relevant. The technologies could then be compared. After comparison, the selected technology was checked for compliance with the complete set of requirements. The requirements of Table 2 were deemed most relevant and used for the comparison of technologies.

Number	Title	Requirement
UVCCB-02	Safety	The bus/network supports safe data exchange for safety applications. It is possible to transmit data for safety applications with different safety integrity levels: from no safe data exchange to data exchange for safety applications with SIL2 and SIL4.
UVCCB-05	Determinism	The bus/network shall be capable for real time applications. This means either cyclic slots for process data or a working prioritization methodology to guarantee a throughput of process data and avoidance of network capacity reduction in case of overload.
UVCCB-06	Bandwidth	The physical layer of the bus/network supports a minimum gross data rate of 100 Mbit/s.
UVCCB-08	Number of participating nodes	The bus/network supports a minimum of 62 nodes.
UVCCB-12	Independency of data streams	In order to simplify the approval for updates, the bus/network provides a clear separation (independency) on physical layer of data streams between nodes/applications. If a data field of one stream changes, all other streams should not be affected.
UVCCB-13	Openness	The bus/network technology is open and standardized. There is no restriction regarding intellectual property. This means that technical specifications are readily available for homologation purposes, obsolescence support, upgradability and 2nd source.

Number	Title	Requirement
UVCCB-15	Availability	The bus/network is based on a technology with components that are commonly used on the market and produced on large quantities.

Table 2: Requirements used to compare bus technologies.

4.2 External assessments

For the external assessments, the list of requirements from chapter 3 was given to two companies alongside a minimum list of bus technologies to be evaluated. The external assessments were made by *Selectron Systems AG* and *NewTec GmbH*. The companies had access to the alpha release of the OCORA initiative and used the descriptions of the OCORA initiative contained in that release to estimate the suitability of the technologies to the OCORA initiative. The results of the external assessments are given in chapters 5.2.1 and 5.2.2.

5 Evaluation Results

5.1 Internal assessment

The table below from [29] provides an overview of the assessment of the standard protocols regarding the most relevant requirements. The evaluation is based on the information for the protocols given in chapter 3 and its subchapters in [29].

Protocol Stack	Safety	Determinism	Bandwidth	Number of participating nodes	Independency of data streams	Openness	Availability
MVB	Safety Layer tbd	++	1.5 Mbit/s	≤ 4095	-	standardized	Hardware and software available but always rail specific since MVB is a rail specific standard.
CANopen	Safety Layer tbd	++	125 kbit/s - 1 Mbit/s	127	0	standardized	COTS hardware and software available. Widely used in automation industry and rail sector.
Safe Time Layer Safe Link Layer Profibus FDL	SIL 4	+	9.6 kbit/s – 12 Mbit/s	≤ 125	+	standardized	COTS hardware and software available. Widely used in automation industry and rail sector.
SDTv2 TRDP TCP/UDP IP Ethernet	SIL 2	--	100 Mbit/s	≤ 16382	0	Stack fully standardized Open source software for TRDP available (TCNopen)	COTS Ethernet hardware available Open source software for TRDP available (TCNopen)

Protocol Stack	Safety	Determinism	Bandwidth	Number of participating nodes	Independency of data streams	Openness	Availability
SDTv2 / SDTv4 TRDP TCP/UDP IP TSN	SIL 4	+	≥ 100 Mbit/s	≤ 16382 with addressing of TRDP	+	TRDP and TSN standardized. TRDP over TSN with new SDTv4 standardized in IEC 61375 in 2022. Open source software for TRDP available (TCN)	Prototypes of network devices available. Fully certified serial products expected in 2025. Open source software for TRDP available (TCNopen)
(SDTv2) (TRDP) TCP/UDP IP TTEthernet	Safety Layer tbd SIL 2, if SDTv2 is used	++	≥ 100 Mbit/s	≤ 16382 if addressing of TRDP is used	++	standardized	COTS hardware and software available. Used in automotive and avionics industry.
EtherCAT, FSoE	SIL 3	++	≥ 100 Mbit/s	≤ 65535	-	standardized	COTS hardware and software available. Widely used in automation industry.
PROFIsafe PROFINET	SIL 3	+	100 Mbit/s	≈4.2 Mrd. (IPv4 adress space)	++	standardized	COTS hardware and software available. Widely used in automation industry.

Table 3: Evaluation of Protocols regarding most relevant Requirements

The internal evaluation in [29] shows that only one of the evaluated protocol stacks fulfils every most relevant requirement in sufficient quality. Therefore, the proposal of the protocol stack to be used as UVCCB is TRDP over TSN with SDTv2 / SDTv4:

Layer	Protocol
Safety Layer	SDTv2 / SDTv4
Session Layer	TRDP
Transport Layer	UDP (for process and message data) TCP (for message data)
Network Layer	IPv4
Data Link Layer	Time-Sensitive Networking (TSN) IEEE 802.1
Physical Layer	100BASE-TX or 1000BASE-T

Table 4: Protocol Stack TRDP over TSN with SDTv2 / SDTv4

The Shift2Rail (S2R) projects CONNECTA and SAFE4Rail elaborated the Next-Generation Train Communication Network (NG-TCN) which is one of the main building blocks of S2R's next generation of TCMS architectures. The NG-TCN is based on today's TRDP protocol stack according to IEC/EN 61375-2-3. It introduces a new TRDP traffic class (TSN-PD) for scheduled data traffic based on Time-Sensitive Networking (TSN). This traffic class is intended to be used for safety critical and latency critical data. TSN is defined in IEEE 802.1 standards.

The proposed protocol stack fulfills the most and the less relevant requirements as shown in [29] and the following table:

Property	Characteristics
UVCCB-01 Data Transfer	TRDP over TSN with SDTv2 / SDTv4 is developed for data exchange between different onboard components of railway systems.
UVCCB-02 Safety	SDTv2 enables safe communication for functions of SIL 2. SDTv4 enables safe communication for functions of SIL 4.
UVCCB-03 Safety	The bus/network can fulfill the requirements of EN 50159:2010 [24]. The safety approval for the protocol stack will be done by CONNECTA.
UVCCB-04 Safety	The safety analysis for SDTv4 will be done by CONNECTA.
UVCCB-05 Availability	TSN IP core for railway application elaborated by TTTech. First prototypes of network devices elaborated by Westermo and Moxa in SAFE4Rail project. Network devices are used by Bombardier, CAF and SIEMENS in demonstrators of CONNECTA project. Fully certified serial products expected in 2025.
UVCCB-05 Determinism	TSN adds services on standard ethernet layer (layer 2) for deterministic networking with bounded latency and low jitter. TSN ensures a quite strong determinism for real-time applications. The following sub-standards of TSN describes mechanisms for stream specific bandwidth allocation and latency minimizing: • Stream Reservation Protocol (SRP) of TSN in IEEE 802.1Qat and 802.1Qcc • Per-Stream Filtering and Policing (PSFP) of TSN in IEEE 802.1Qci • Path Control and Reservation (PCR) in IEEE 802.1Qca In CONNECTA Drive-by-Data architecture specification a maximum end-to-end latency within consist network over 2 consist switches is estimated with 435 µs.
UVCCB-06 Bandwidth (Gross Data Rate)	≥ 100 Mbit/s
UVCCB-07 Data Type	TSN supports different traffic classes which can be understood as process data and message data. For time critical process data, a scheduled traffic can be used whereas for message data with low time criticality best effort ethernet traffic can be used.
UVCCB-08 Number of participating nodes (Address Space)	≤ 16382 with addressing of TRDP
UVCCB-09 Maximum physical distance	The maximum segment length of 100BASE-TX or 1000BASE-T physical layer is 100 m which fulfills the requirement of 54 m maximum physical distance.

UVCCB-10 Topology Flexibility	The UDP/IP over TSN stack is open to different network topologies. Nevertheless, if the UVCCB is integrated in the NG TCN of TCMS system, a common network topology of both domains has to be elaborated.
UVCCB-11 Time Synchronization	TSN allows precision time synchronization in the range of nanoseconds to microseconds which is lower than the required value of ±1 ms.
UVCCB-12 Independency of data streams	TSN ensures quite strong independency of data streams. The following sub-standards of TSN describes mechanisms for stream specific bandwidth allocation: • Stream Reservation Protocol (SRP) of TSN in IEEE 802.1Qat and 802.1Qcc • Per-Stream Filtering and Policing (PSFP) of TSN in IEEE 802.1Qci • Path Control and Reservation (PCR) in IEEE 802.1Qca
UVCCB-13 Openness	Standards for TRDP and SDTv2 (IEC/EN 61375-2-3 and others e.g. IEC/EN 61375-2-5) should be enhanced by TRDP over TSN and SDTv4 until 2022. TSN itself is specified as an open standard by IEEE 802.1 TSN group. Today's TRDP and safety layer SDTv2 is available as open source software (TCNopen)
UVCCB-14 Independence	The network hardware must be compatible with TSN standard. The rest of the protocol stack will be done in software. Since the TSN standard is open and not railway specific and will be used among different domains, it is expected to have different hardware suppliers. Already the first prototypes of network devices for railway use in CONNECTA/SAFE4Rail project are elaborated by two independent hardware suppliers (Westermo and Moxa).
UVCCB-16 Simplicity	The design of a TSN network in terms of hard and software integration of the end devices will be quite simple. However, the configuration of the network devices (switches/routers) will be challenging. But with establishment of the standard, it is assumed that different configuration tools will simplify the configuration process.
UVCCB-17 Portability	The portability can be ensured with an adequate configuration of the UVCCB within the hole TSN network.

Table 5: Properties TRDP over TSN with SDTv2 / SDTv4

5.2 External assessment

5.2.1 NewTec GmbH

This chapter contains the main parts of the executive summary of the evaluation report from NewTec GmbH [30].

The legacy bus protocols MVB, CANopen and Profibus cannot support major OCORA requirements in chapter 3. All state-of-the-art Ethernet based protocols meet most of OCORA requirements – and each has its pros and cons:

Protocol	TCMS compatible (UVCCB connecting to TCMS)	TCN integration (Extending UVCCB thru ECN)	Safety	Development Support
TRDP 2.0	✔	✔	With SDT (SIL4)	Medium / standard in progress
OPC UA	Gateway needed	With TSN	– (in preparation)	Good
Profinet	Gateway needed	With TSN	SIL 3	Medium
EtherCAT	Gateway needed	No, gateway needed	SIL 3	Good
CIP	Gateway needed	No, TSN in preparation	SIL 3	Good
FDF	✔	✔	SDT (SIL4)	Standard in progress

Table 6: High Level Comparison Chart

EtherCAT does not, and CIP does not yet support TSN – thus an UVCCB using those protocols and supporting real time traffic will be isolated. A hardware gateway to access the TCMS is needed.

Using OPC UA (TSN) or Profinet, the UVCCB can use a software gateway to access TCMS; via TSN remote CCS devices could be attached to the ECN and save additional wiring.

TRDP 2.0 with SDTv2 / SDTv4 can be used without any additional gateway but has no object modelling support – configuration is aimed for use with the TCMS.

Using the Functional Distribution Framework (FDF) could be a valuable solution, especially as it is not bound to TCMS use and is independently developed using two diverse Operating Systems / middleware. The FDF, which uses TRDP as communication protocol (the AUTOSAR AP version additionally provides OPC UA), seems currently the best option, although its development is still ongoing.

5.2.2 Selectron Systems AG

This chapter contains the main parts of the conclusion of the evaluation report from Selectron Systems AG [31].

The traditional fieldbuses are increasingly being replaced by Ethernet solutions. This trend can be observed in all relevant markets: Industrial automation, automotive, aerospace and railway. In addition, the technology assessment shows that especially the bandwidth requirement can only be fulfilled by an Ethernet solution. Such a solution can be divided into three layers: An Ethernet Layer, a Protocol Layer and a Safety Layer. For each layer, a different solution can be chosen according to detailed requirement of the OCORA system.

5.2.2.1 Ethernet Layer

An Ethernet network can consist of different types of architecture. In order to improve the failure tolerance against hardware faults, at least ring architecture should be chosen for the UVCCB. Such an architecture could easily be extended to ladder architecture which would provide even more redundancy and it would also support dual homing. Figure 2 shows an example architecture.

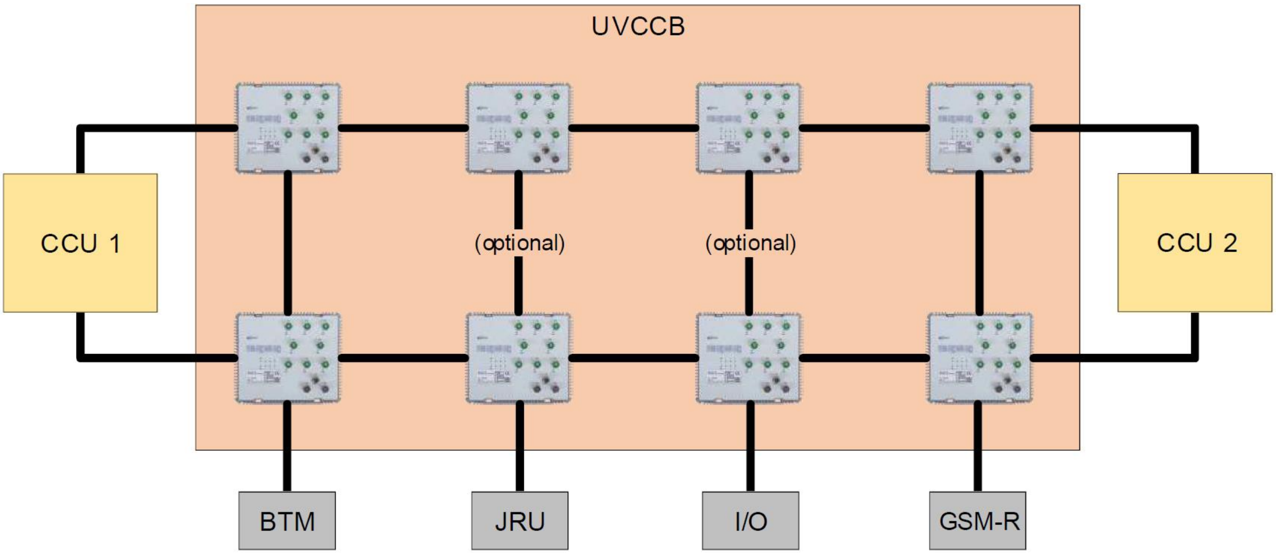

Figure 2: Possible UVCCB Architecture

In the future, it is recommended to use TSN Ethernet to manage the network. TSN Ethernet is seen as the future standard for most automation networks. However, not all TSN Ethernet standards are already released or only rarely implemented in serial products. Therefore, if the UVCCB should be implemented before these changes, a migration strategy could be defined. Such a migration strategy could look as follows:

1. Build up the system with available Ethernet components. For network management, a solution which fulfils the performance and redundancy requirements should be chosen:
   - RSTP
   - MRP

- LLAP
- PSP

2. Update the system with TSN Ethernet networking devices (switches). This step can be seen as a preparation for the next step.
3. Update the system with TSN Ethernet capable End Devices. This would be the final stage for the UVCCB, where all defined features (low jitter, high bandwidth, traffic with mixed criticalities) could be used.

In order to have the possibility to perform the migration strategy step by step, it is essential that the Ethernet layer contains no safety critical functionality.

5.2.2.2 Protocol Layer

Most of the protocols evaluated use a master / slave approach, where one (master) device configures and manages the slave devices.

From a configuration point of view, this provides the possibility to configure all devices from one single point. On the other hand, the master / slave approach complicates significantly a slave to slave resp. master to master communication.

Of all protocols examined, TRDP causes the least restrictions for such flexible communication structures. Therefore, it is recommended to use TRDP for the UVCCB, but it must also be mentioned that the use of TRDP will require a lot of standardization effort by the OCORA organization. This is because for TRDP resp. in the IEC 61375 standard series, nearly no application profiles for End Devices are defined which would be required in order to provide the possibility to exchange devices from different suppliers.

5.2.2.3 Safety Layer

The UVCCB requirements in chapter 3 require Safety layers for SIL 2 and SIL 4. For both SIL, at least a different safety code shall be used. The safety layers SDTv2 / SDTv4 defined in IEC 61375-2-3 and Subset 056 / 057 defined by UNIFE are the only safety layers investigated which fulfil these requirements. Unfortunately, both safety layers have considerable disadvantages:

- SDTv2 / SDTv4
  Limited latency monitoring which requires measures on application level or allow only a classification as Class 1 safety protocol according to EN 50159 [24].
- Subset 056 / 057
  The safety code (CRC) of subset 057 is 48 Bit and considers PROFIBUS as non-safe communication system. The Ethernet resp. protocol layer of the UVCCB would have to provide the same Bit error probability as PROFIBUS, which violates the black channel approach.

Because SDTv2 / SDTv4 provides more flexibility (quantity of payload data, number of communication partners), it is recommended to use SDTv2 /SDTv4.

5.2.2.4 Additional Remarks

The suggested solution with an Ethernet based UVCCB which uses TRDP and SDTv2 / SDTV4 is similar to the approach chosen by Connecta. The goal of this project is to define the next generation TCMS. According to the OCORA Architecture [13], TCMS shall be connected to the UVCCB directly or via a gateway. This can be a chance to standardize the technology used in railway industries even more. On the other hand, this can be a risk if the OCORA and Connecta efforts are not coordinated. Problems which can occur if the efforts are not coordinated could be for example:

- Ambiguous definition TRDP ComId
  The same TRDP ComId could be assigned to devices / functions of UVCCB and TCMS.
- Multiple use of SDT SMI
  The same SDT SMI could be assigned to VDPs in UVCCB and TCMS. Such an error could be difficult to find and prevent the homologation of a vehicle.

Therefore, it is recommended to coordinate the activities of OCORA and Connecta.

5.3 Summary and preliminary specification

All the internal and external assessments of UVCCB bus technologies come to the same result. The recommended UVCCB is a TSN Ethernet based network with the use of SDTv2 / SDTv4 as safety layer. In order to be able to integrate the UVCCB on the next generation of train communication network (NG-TCN) every safety related CCS on-board device (e.g. CCU, BTM etc.) shall have two TSN capable Ethernet ports whereas for non-safety related CCS devices a single TSN capable Ethernet port is sufficient.

On the OSI layers 3 to 6, at least IPv4, UDP, TCP and TRDP must be supported by the CCU(s) in order to be able to communicate directly to the TCMS. For communication between CCS on-board devices only other protocols on session layer are possible (e.g. OPC-UA Pub/Sub or DDS-RTPS) which can coexist with TRDP. These protocols will be further investigated.

The protocol stack of UVCCB is shown in the following table. Standards to be used as mandatory in OCORA are listed in bold font. Protocols to be further investigated are listed in grey font.

Layer	Protocol	
Safety Layer	**SDTv2 / SDTv4**	
Session Layer	TRDP	e.g. OPC-UA Pub/Sub or DDS-RTPS
Transport Layer	UDP (for process and message data) TCP (for message data)	
Network Layer	IPv4	
Data Link Layer	**Time-Sensitive Networking (TSN) IEEE 802.1**	
Physical Layer	**100BASE-TX or 1000BASE-T**	

Table 7: Protocol Stack UVCCB

6 Next Steps

The new UVCCB based the same network technology as it will be used for TCMS brings opportunities but also risks:

1. Opportunities
   a) One network for TCMS and CSS in the whole train or locomotive possible
   b) Same safety approval for network components and safety layer
2. Risks
   a) Currently no certified products available. There is a risk that fully certified products will be available later than expected (2025).

The technical integration of the UVCCB within the NG-TCN and the separation of responsibilities between the two domains must be clearly elaborated. One technical solution is the direct integration of the CCS devices into the ECN of the NG-TCN which is shown in Figure 3. With this solution it is still possible to separate the UVCCB from the NG-TCN with different VLANs connected by a software gateway. But the shared TSN network configuration of the UVCCB and NG-TCN will be a challenge. The solution for retrofit vehicles where there will be a UVCCB without a NG-TCN of TCMS has also to be defined. Beside the TRDP it is beneficial to evaluate other data distribution protocols on session layer like OPC UA Pub/Sub or DDS-RTPS which can coexist with TRDP.

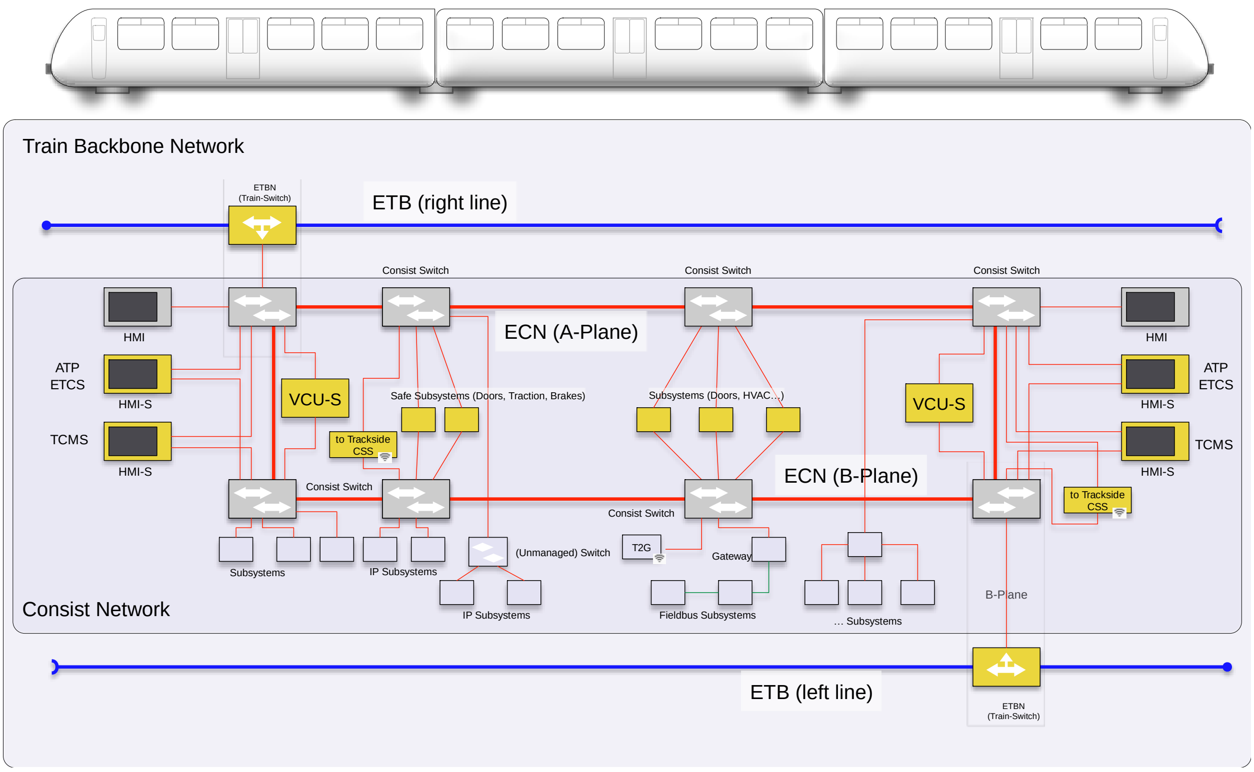

Figure 3: Next-Generation Train Communication Network with CCS devices integrated into ECN from [30]