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GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS-RAILWAYS (GSM-R) IN INDIA

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ABSTRACT:

This paper specifies Railway voice communication in comparison to the commercial mobile telephony. TheVoLTE architecture and call setup procedures are presented. The VoLTE performance is validated in simulations using extended scenarios.The primary characteristics of LTE – high speed, high security and high-bandwidth capacity – allow it to carry voice and data for train control, on-board video surveillance and infotainment services for passengers on a single IP network. LTE has latency as 10 milliseconds allowing for support of time-sensitive applications and providing quality of service management, according to Nokia. It can be deployed in many different frequency bands and has multiple features related to encryption and authentication for security purposes.

INTRODUCTION:

In railway, the data-based applications are continuously growing in terms of importance and popularity. The best examples are the modern command-control systems, such as ETCS and CBTC. They became fundamental elements that are necessary for safe, efficient, and high-speed railways.

Despite that, voice communication is still a crucial feature from the railway point of view. Voice calls are used in everyday operational procedures, such as ETCS mission start-up and shunting. Besides, voice communication shows its special importance in case of extraordinary and unplanned situations. For example, if a train stops in an unexpected location, ETCS can only inform the dispatcher that the train is not moving. Without a voice call from the driver, the dispatcher cannot know why the train stopped: due to a technical failure, due to an obstacle on the track, or due to an accident. Hence, voice communication does not become redundant with the introduction of ETCS. On the contrary, voice communication is a feature that complements even the most advanced railway signaling system.

Voice communication is used by almost the entire railway personnel. Besides drivers and dispatchers, it is also necessary for track-side, maintenance and other employees, who are often distributed over very large areas. For them, voice communication is an everyday work tool. Therefore, even if the role of voice communication may change over time, it is unlikely to diminish significantly.

Because of the above reasons, the future railway mobile network must satisfy specific railway needs related to voice communication. These include both feature and performance requirements. Therefore, regardless of the data-transmission performance, LTE must fulfil also railway voice requirements in order to be considered a viable alternative to GSM-R. This is a challenge, because LTE has been designed as a network for data-based applications. This is in contrast to GSM which has been designed and optimized for delivering telephony. The telecommunication industry has recognized the need for a VoLTE standard relatively late, i.e. only after the original LTE standard has been established. As a result, VoLTE, which is a Voice over IP

(VoIP) standard based on IP Multimedia Subsystem (IMS), gained a broad support of the telecommunication industry only recently.

RAILWAY VOICE COMMUNICATION REQUIREMENTS

Voice communication is an essential tool, which is necessary in the work of almost all railway personnel: train drivers, dispatchers, shunting staff, maintenance staff, on-board personnel, and others. They all communicate using a variety of terminals, which can be classified into three main types:

• *Cab-radios*, which are the voice terminals built into the train driver desks.
• *Fixed terminals*, which are used, e.g. by the dispatchers. These terminals are connected over a fixed network.
• *Handheld radios*, which are used for operational, shunting, and other purposes. These terminals are usually similar to mobile phones known from the commercial telephony.

Considering its core functionality, the voice communication for railways issimilar to the voice communication offered by the commercial mobile telephony.
For example, according to the UIC requirements [23, pp. 32–33], railway radios must support many features known from the commercial networks, such as:
• One-to-one calls,
• Caller identity display,
• Call forwarding,
• Call hold.
Due to these similarities in functional requirements, railways often can reuse the communication standards known from commercial telephony. The best example is GSM-R, which is almost entirely based on the commercially used GSM.
Despite these similarities, railway voice communication has its own specifics. Thus, the communication technology for railways may have to be enhanced with additional features and optimizations. Besides, railways impose specific performance requirements in terms of call setup time.

RAILWAY-SPECIFIC VOICE FEATURES

GROUP AND BROADCAST CALLS

One-to-one voice call (also called *point-to-point* call) is the basic call type that must be supported by the railway network. However, in their everyday operations, railways also use other call types, which are usually not offered in the commercial telephony. Therefore, the communication network must additionally support the following call types:
• *Broadcast calls*, including the REC, which are used to reach all terminals within a particular area. Usually, only the call initiator is allowed to speak.
• *Group calls*, which are used for communication within a predefined group of users, e.g. train drivers.
• *Multi-party calls*, which are similar to group calls, but the call parties are chosen ad hoc during call initiation.
REC is an especially important call type, because of its impact on railway safety. REC is a broadcast call that is used only in case of a dangerous situation. It can be initiated with a press of a dedicated button on any railway voice terminal. The call initiator is then automatically connected to the dispatcher responsible for the particular railway area. The conversation between the initiator and the dispatcher is broadcasted to all other terminals within the area. In this way, everyone is immediately informed about the danger. In order to ensure that REC is received by all terminals, this call type is given the highest priority by the network. REC pre-empts any other voice communication and, also, it can pre-empt any data communication, including ETCS traffic. Moreover, REC is automatically answered by the terminals without the need for any reaction from the user. Such a solution guarantees that all users listen to the ongoing REC.

CALL ADDRESSING

In order to simplify and speed up voice communication, railways introduced two features related to the call addressing:

• *Functional Addressing (FA)* provides automatic translation between a railway function (e.g. "dispatcher") and the corresponding phone number. This allows the caller to use the function instead of the phone number while placing a call.

For instance, in order to call a driver of a particular train, it is sufficient to enter the train running number. Thanks to this, the train driver can be easily reached regardless of who is the driver on that day or which train unit is used.

• *Location Dependent Addressing (LDA)* redirects the call depending on the current caller location. LDA is used most often when a train driver calls to a dispatcher.

Then, LDA automatically selects the particular dispatcher responsible for the area where the train is currently located.

CALL PRIORITIZATION

Railway communication network carries different call types. From the point of view of safety and train operations, they have different importance. Therefore, the network must provide a mechanism that assigns appropriate priority depending on the call type. The high-priority call should pre-empt the lower priority calls. For example, REC should pre-empt a one-to-one call.

PERFORMANCE REQUIREMENTS

Apart from the additional features, railways impose their own requirements on the call setup time. The maximum acceptable setup time is defined for each call type separately, as summarized in Table 4.1. The strictest requirement applies to REC, because it is a critical call used in the extraordinary and dangerous situations. A fast REC setup may prevent accidents.

Table: Railway call setup time requirements

Call type	Setup time
Railway Emergency Call (REC)	< 2 s
Group calls between drivers in the same area	< 5 s
Other operational mobile-to-fixed calls	< 5 s
Other operational fixed-to-mobile calls	< 7 s
Other operational mobile-to-mobile calls	< 10 s
All low priority calls	< 10 s

The required call setup times shall be achieved in 95% of cases. Call set-up times for 99% of cases shall not be more than 1.5 times the required call setup time.

Once a call is established, the network begins to transmit voice frames between the call parties. The performance of this transmission affects the quality of the received voice and, therefore, the usability of the voice communication. The voice transmission is affected by the transfer delay and the frame loss in the underlying network. However, railways do not impose any specific requirements on these measures or the resulting received voice quality. Therefore, in the work presented in this chapter, it was assumed that the railway mobile communication network must fulfill the same voice transmission requirements as any other network delivering VoIP services.

The total end-to-end delay, i.e. so-called “mouth-to-ear” delay, consists of the transfer delay and the coding/decoding delay (including all processing in the end user terminals). If the “mouth-to-ear” delay is below 150 ms, then the listeners do not notice distortions in the received voice. Moreover, even delays up to 200 ms do not cause annoying effects. For the purpose of the following analysis, it was assumed that the coding/decoding delay can be up to 50 ms, which is in accordance with an example published by Holma and Toskala. Hence, in order to have the total “mouth-to-ear” delay below 200 ms, the maximum acceptable transfer delay is 150 ms.The acceptable frame loss depends on the chosen codec. In this work, it was assumed that the network uses Adaptive Multi-Rate (AMR) codec fixed at 12.2 kbit/s.
In order for AMR to provide good voice quality, the maximum acceptable frame loss is approximately 1%.

VOICE OVER LTE (VOLTE)
LTE is the first fully packet-switched mobile communication network.On the other hand, it means that LTE does not include the circuit-switched network part, which was traditionally used for voice communication in the previous generations of the 3GPP mobile standards, e.g. GSM and UMTS.

CIRCUIT-SWITCHED FALL BACK (CSFB)
In order to overcome the lack of a standardized voice communication in LTE, 3GPP proposed the Circuit-Switched Fall Back (CSFB) as a temporary solution. CSFB is a procedure that forces an LTE terminal (UE) to switch to a GSM or an UMTS network in the event of an incoming or an outgoing voice call. This means that, in order to receive or make a voice call, an UE must turn off its LTE radio and handover all ongoing communication to one of the legacy networks.

VOLTE AS THE TELECOMMUNICATION INDUSTRY STANDARD
The CSFB shortcomings are also problematic for commercial operators and their customers, there was a need to develop a better voice communication solution for LTE. Multiple alternatives emerged, such as the IMS-based VoLTE, Voice over LTE via Generic Access (VoLGA), SimultaneousVoice and LTE (SV-LTE), and Over The Top (OTT) solutions.
Among these competing standards, the IMS-based VoLTEhave few important advantages, such as:
• It requires neither the legacy radio networks, nor the legacy circuit-switched core network.
• It does not interrupt data communication over LTE.
• It is based on well-defined open standards and provides an inter-operable solution.
• It offers call supplementary features, such as call waiting, forwarding, etc.
Due to its advantages, VoLTE gained support of the Global System for Mobile Association (GSMA) and was also backed by a significant number of mobile operators and equipment vendors. Therefore, VoLTE became the industry standard for voice communication in LTE. As a consequence, VoLTE should be also considered as a possible candidate for providing railway voice communication in LTE.
VoLTE is based on the IP Multimedia Subsystem (IMS) [81], which is a standardized IP-based architecture for the access-independent delivery of multimedia services. IMS is based on a set of well-defined open protocols. Another strength of IMS is that it provides a broad range of standardized functionalities for management of the IP-based services, such as: user roaming, inter-working with circuit-switched networks, and QoS negotiation. These advantages are inherited
by the VoLTE standard, which defines a subset of the IMS functionalities that are necessary for providing an inter-operable telephony service.

ARCHITECTURE

VoLTE architecture, as shown Fig, consist of three main parts: E-UTRAN, EPC and IMS. The first two parts are standard elements of the LTE architecture, as described. The third part, namely the IMS, is responsible for call setup and call management.

The central elements of IMS are the Call Session Control Functions (CSCFs),which provide user registration, session (call) establishment, signalling routing and session management. CSCFs functionality can be split into four separate logical elements:

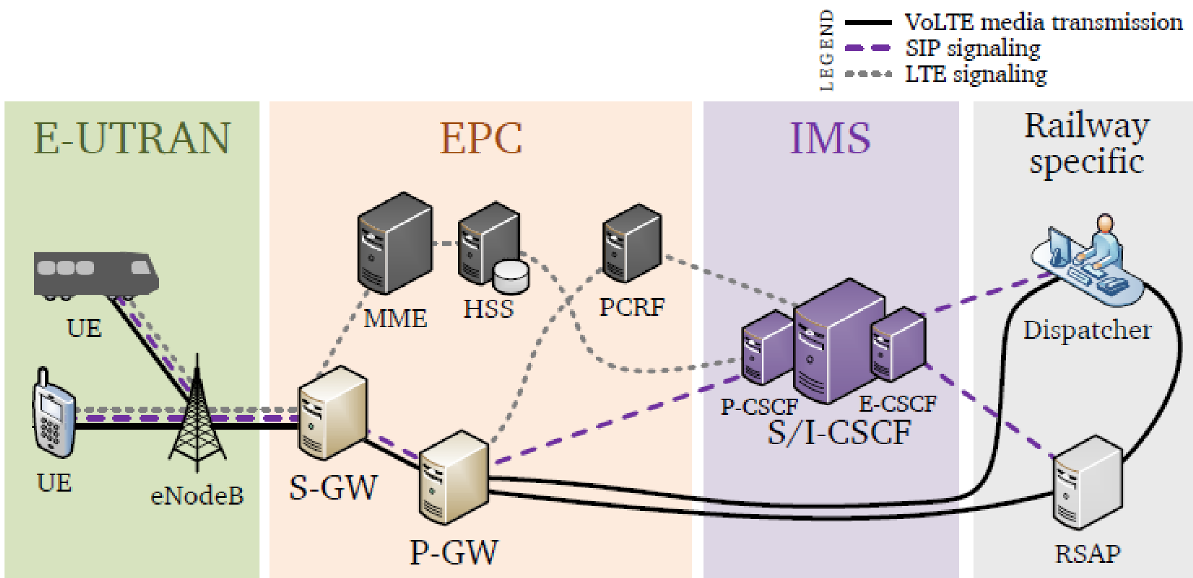

Figure 4.1: Simplified VoLTE architecture, which may be divided into the LTE radio part (E-UTRAN), the LTE backbone (EPC), and the IMS backbone. In the railway environment, two additional elements are added: the Dispatcher and the Railway Safety Answering Point (RSAP).

• *Proxy CSCF (P-CSCF)*, which is responsible for authorizing resources, detection of emergency sessions, signalling compression, and communication security.

• *Serving CSCF (S-CSCF)*, which is responsible for user registration, authorization, and call routing.

• *Interrogating CSCF (I-CSCF)*, which is used as the contact point for sessions incoming from external IMS domains?

• *Emergency CSCF (E-CSCF)*, which is responsible for routing emergency calls to the correct Public Safety Answering Point (PSAP).

Besides CSCFs, the full IMS architecture consists of other logical elements, many of which are responsible for supporting functions, e.g. inter-working with external networks and call charging. However, in this work, only those elements that are directly involved in the call setup procedures are of interest.

Finally, the last important element of the VoLTE architecture is the *Public Safety Answering Point (PSAP)*, which handles emergency calls. In this work, theconsidered network is dedicated for railways. Therefore, it is proposed to replacePSAP with the railway-optimized *Railway Safety Answering Point (RSAP)*. This newnode, besides the standard PSAP role, provides also functionality necessary for handling RECs.

In the two previously mentioned publication, it is explained how VoLTE can provide railway-specific voice features using a combination of various mechanisms and protocols, such as: LTE Localization Services, Push-to-talk over Cellular (PoC), Session Initiation Protocol (SIP) addressing, and EPS bearer-based QoS mechanism. Therefore, in this work, it was decided to focus on VoLTE performance in terms of call setup time and voice transmission. Two railway features, namely one-to-one call and REC, were chosen to be investigated due to the reasons explained in the following sections.

VOLTE ONE-TO-ONE CALL SETUP

The operational one-to-one call is the first call type that was chosen, in this research work, to be modelled as a VoLTE session. This is the call type that is the most often used in everyday railway operation.

From the railway point of view, the most important element are the call setup procedure and the time it takes to complete it. In VoLTE, calls are established using Session Initiation Protocol (SIP) and Session Description Protocol (SDP). SIP provides the means for session initiation, control, and termination. SDP is used for defining media transmission and its parameters, e.g. codecs and IP addresses.

VoLTE call setup procedure is illustrated with a SIP message flow shown Fig. There are three entities involved in the SIP message exchange: the call initiator, the called party, and the CSCF, which is routing the signalling messages between the two end points. In the presented example, only one integrated CSCFis assumed. This is because, due to a relatively small size of the railway network,the functionality of the four logical CSCFs can be placed in a single node.

Assuming that the call initiator (in this example an UE) is already registered in the LTE and the IMS networks, it can initiate the call with a *SIP INVITE* message (all the messages mentioned in this section are SIP). The message is sent from the initiator to the CSCF. It contains all information necessary for the call setup, such as: the called party identification, IMS network identification, and the call identification. Moreover, the *INVITE* includes also a description of the desired media flow in terms of codecs, IP addresses, and port numbers. This media description is written in SDP format.

The *INVITE* is sent to the CSCF, which replies to the call initiator with a

TRYING message. It informs that the *INVITE* was received and is being handled.

Then, CSCF resolves the IP address of the called party, i.e. it translates the called party identification (e.g. a phone number) to an IP address. This address resolution may involve contacting a Domain Name System (DNS) server. However, in the analysed case, both end points are in the same IMS domain, so DNS is not involved.

After resolving the address, the *INVITE* messages is forwarded to the called party, i.e. the call destination.

After receiving the *INVITE*, the called party replies with a *SESSION PROGRESS* message in order to notify the caller that the call invitation was received. Moreover, the *SESSION PROGRESS* message also carries an SDP reply with the information on which codecs are accepted by the called party.

When this initial message exchange is completed, the CSCF sends a resource reservation request to the PCRF. Resources, in the form of EPS bearers are established by the EPC and E-UTRAN nodes, i.e. P-GW, S-GW and eNodeB. The call end points exchange *PRACK* and *OK* messages in order to inform about the ongoing resource reservation process. When the EPS bearers are established, *UPDATE* and

OK messages are exchanged.

Once the resources are reserved, the called party terminal notifies the user about the incoming call. At the same time, a *RINGING* message inform the call initiator that the called party is waiting for the user answer. When the user answers the incoming call, the end points exchange *OK* and *ACK* messages. Then, the mediaflow begins.

CONCLUSION:

Voice communication is an essential application, which is used in everyday railway operations and, also, in case of emergency situations. From the railway point of view, its importance is comparable with the importance of ETCS. Therefore, the future railway communication network must provide voice communication thatfulfils the specific railway requirements.

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