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A Feasibility Study on TETRA System Application for Train Control Systems

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ABSTRACT

TETRA communication system is very versatile system which can transmit voice + data and packet data optimized. Direct mode operation permits to connect between mobiles when mobile stain is out of coverage of networks. It can be more secure communication channel for railway signaling systems. Railway signaling systems use many of wayside signal equipment, which require many maintenance efforts and budget. Many railway authorities want to reduce and replace the wayside equipment. Radio based signaling systems are one of candidate for replacing the conventional signaling systems. The radio based signaling systems can replace track circuit and wayside signal. The radio systems permit to connect between control centers and trains. The radio systems have to ensure high quality of the connectivity more or equal to the existed track circuits. We studied the application of TETRA systems for railway radio systems for bridging between train control centers and trains. We provide an operation scenario for radio based train control system to ensure the safety require to the existed trains control system and satisfied the existed operational availability. We showed the data transmission speed, maximum bit error rate, and data coding for the radio-based signal system using TETRA systems.

Keywords: *Train control system, radio-based, TETRA, safety, requirement*

1. Introduction

Train speed control systems have used block systems which consist of track circuits and speed calculation devices. The track circuits detect train position and can transmit allowed train speed. The track circuits are installed in track, is required a lot of maintenance cost. The train detection accuracy depends on length of block sections which are several hundred meters or kilometers. Train position accuracy would be increased when train itself calculate the position, for example, through tachometers and beacons. Communication-based train control is a mean that trains itself can detect the position and the block systems inform permitted train speed to trains.

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Communications-based train control (CBTC) is a railway signaling system that makes use of the radio communications between the train and ground equipment for the train controlling. The exact position of a train, courtesy of the CBTC systems, results in a more efficient and safe way to manage the railway traffic. Railways are able to improve headways while maintaining or even improving safety.

One of CBTC core systems is telecommunication systems which make bidirectional train-to-wayside data communications. The other parts except telecommunication systems are normally linked with hardwires which allow of transmitting data between ground to ground or trainborne to trainborne1. As a CBTC system is required to have high availability more or equal to track circuit based system, and particularly, it might be provided to ensure some level of non-degraded service upon partial or complete CBTC unavailability. The primary risk of a CBTC system can be disrupted by a lot of causes. If the telecommunications link between systems is disordered then all or part of the system might have to enter a failsafe state until the problem is solved. Depending on the severity of the communication loss, this state can range from vehicles temporarily reducing speed, coming to a halt or operating in a degraded mode until communications are re-established.

The radio systems play key role in CBTC systems. We need to study the radio systems to implement in CBTC systems to choose a robust radio connection between the systems. In this paper we studied on radio systems for CBTC systems.

2. Wireless Communications

2.1 State of art in wireless communication

In the last decade, wireless communication technologies have been developed on the basis of digital data communication using PSK or FSK. To increase data transmission capability, several methods are proposed such as M-ary phase shift keying and increasing channels such as TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access) and CDMA (Code Division Multiple Access). Voice centric 2G systems to 4G broadband multiservice systems (LTE) offer several 10s of Mbps to the end-users. And, the broadband capability of 4G is actually fostering the creation of new services and applications for mass consumers to improve the way they communicate, keep informed and are entertained.

Only solution for connecting between train and ground is wireless communication. Digital communication systems provide us versatile means to transmit voice and data simultaneously. The digital communication systems have been developed on basis of some standards such as GSM TDMA cellular system Europe Digital, CDMA specification Qualcom Digital, Wideband 3G CDMA ITU Standards Digital, 2000 IMT 2000/UMTS International Digital, Smartphone (PDA) Blackberry, and WiMAX ITU Standard Digital.

In short range radio communication, that are able to replace wired installations. Standards including Bluetooth, Wi-Fi or IEEE 802.11, Ultra Wide Band, Zigbee and many more all fall into this category.

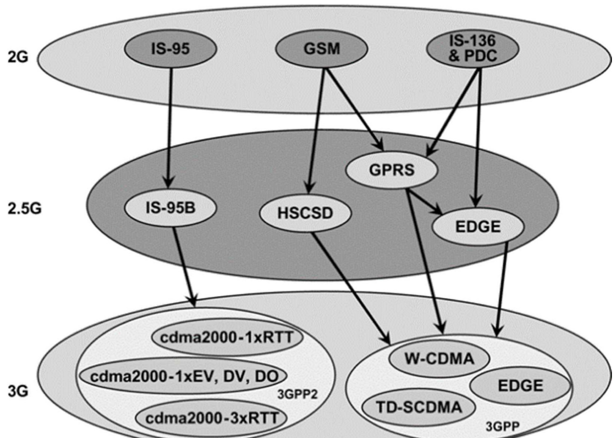

Fig. 1. Various upgrade paths for 2G technologies[1]

2.2 System requirements

Vital application

Vital Applications are related to signaling and control/command of safety-related equipment such as level crossing. The vital applications require generally a low bandwidth with some 10 to 100 kbps but a very high degree of availability at least 99.99%, robustness and liability with typically a bit error rate of 10^{-6}. The performance requirements have to be fulfilled under high speed mobility (600km/h) in which frequent handover arises for AP point changing [1].

Non-vital application

Non-vital applications are related to Passenger Information, remote maintenance, on-board video surveillance, CCTV for track or platform monitoring, internet access, etc. Such non-vital applications generally require much

Table 1. Second Generation Digital Cellar Systems[1]

Region	USA	Europe	Japan	USA
Parameter	IS-54	GSM	PDC	IS-95
Multiple Access	TDMA/FDD	TDMA/FDD	TDMA/FDD	CDMA/FDD
Modulation	π/4 DQPSK	GMSK	π/4 DQPSK	QPSK/OQPSK
Forward Channel	869-894MHz	935-960MHz	810-826MHz	869-894MHz
Reverse Channel	824-849MHz	890-915MHz	940-956MHz	824-849MHz
Channel Spacing	30KHz	200kHZ	25kHz	1,250kHZ
Data/Chip Rate	48.6kbps	270.833kbps	42kbps	1.2288Mcps
Speed Codec Rate	7.95kbps	13.4kbps	6.7kbps	1.2/2.4/4.8/9.6 kbps

higher bandwidth (several 10s of Mbps in both direction train-to-ground and ground-to-train), together with lesser robustness constraints (a packet error rate of 10^{-2} for an approximately 1Mbyte packet length).

2.3 Wireless communication for railways

Rail operators have implemented radio systems to their operational needs. There is no standard for railway radio communication systems.

EU have been implementing TEN-T (Trans-European Transport Networks) for next generation and developing GSM-R for employing ERTMS with 800 MHz. China also employ GSM-R system for CTCS(Chinese Train Control System) with 900 MHz. Taiwan is only country to have implemented TETRA system for railway communication, which is called THSR(Taiwan). THSR adopts 380~400 MHz frequency range used for wireless communication, and trainborne subsystems. USA railways are compulsively forced to adopt PTC(Positive Train Control) in 2008, the act antecedently, ATCS (Advanced Train Control System) was developed which use 6 different FM channels with 9.6Kbps in the range of 900 MHz .

2.4 Wireless technology comparison

The selection of an optimal wireless communication system for railways and metros need to consider many performance parameters and service attributes such as voice support, vital traffic, priority, availability, frequency band, commercial

Wireless train control systems have to be fulfilled fundamental requirements. The fundamental requirements are classified into core operational requirements, core functional safety requirements and essential support safety requirements. The operational requirements charge the systems to be safe, reliable and efficient for operating the systems. The Safety requirements oblige the systems to provide protection functions not arrive accidents caused from the systems. The essential support safety requirements adjure the system to meet specified safe targets [3].

Wireless train control systems are addressed to replace train space controls accomplished by track circuits in which train detection and speed codes transmission arises. The safety requirement for the functional safety requirements of track circuits is SIL 4. Wireless train spacing control systems must be satisfied to SIL 4.

3.2 Core functions for train spacing control

The core functions of the wireless train space control systems are to calculate train position and transmit moving authorities. The train positioning can be realized either onboard or ground. If the train positioning carry out on onboard, the position information has to be transmitted to ground for calculating permitted train speed, vice versa. Normally all train positions are gathered in ground because the speed calculation has to consider a precedent train in running direction.

The wireless communication systems have high reliability for exchanging vital information for calculating train

Technology comparison[2]

	GSM-R	TETRA	P25	WiFi	LTE
Operational voice support	+	+	+	VoIP	VoIP
Broadband data support	< 10kb/s	< 10kb/s	< 100kb/s	> 10Mb/s	> 10Mb/s
All IP (native)	.	.	.	+	+
Vital traffic support	+	+	+	.	+
P2T /call set up time	1 to 5 s	250 ms	800 ms	100 ms	100 ms
Handover mechanisms	Standard	Standard	Standard	Proprietary	Standard
Priority / Pre-emption	+	+	+	3 levels /no	9 level / yes
Choice for operating frequency	900 MHz UIC	400 MHz PMR	700 MHz + VHF	2.4/5.x GHz	400 MHz to 3.5 GHz
Market support(vendors)	3 vendors	+	Limited (US specific)	+	+
Maturity	End of Life 2025	Mature	Mature	Widely adapted	Emerging

3. Wireless Train Control System

3.1 Train control system requirements

speeds. The bit error rate of the wireless communication is below 10^{-6} and the system availability is $10^{-4}/h$. The communication period can be decided on the basis of conventional train detection systems. The cyclic communication time is dependent on train speed and moving authority distance. Theoretically, the communication has to finish before arriving moving authority. The more short communication, the better it is.

3.3 Wireless train control system architecture

Architectures of the wireless train control systems simply represent radio block systems, onboard systems control center systems. The control systems play roles which integrate block systems and interlocking systems. The control center systems gather train positions, calculate allowed train speeds and control train routes. The centers distribute the processed results to radio block. The radio block systems identify all related train ID and its positions. In case of distance-to-go systems, the radio block systems send a precedent train position to a following train, for example, layer 3 protocol of OSI. The radio block systems know the train ID and send train position to correspondent trains. The onboard systems have its ID and exchange the vital information with the radio block systems.

4. TETRA system for Train Control System

4.1 TETRA systems technical characteristics

TETRA provides a number of services which are characterized as bearer service and teleservices. The bearer services are the same as general networks, the teleservices is similar to mobile communication included the bearer services. TETRA provides encrypted data communication in each of the following

- Individual call (point to point)
- Group call (point to multipoint)
- Acknowledged group call
- Broadcast call

Table 2. TETRA technical characteristics [4]

Parameter	Value
Carrier spacing	25kHz
Modulation	π/4-DQPSK
Carrier data rate	36kb/s
Voice coder rate	ACELP(4.56kb/s net, 7.2kb/s gross)
Access method	TDMA with 4 time slot/carrier
User data rate	7.2kb/s per time slot
Maximum data rate	28.8 kb/s
Protected data rate	Up to 19.2 kb/s

TETRA system has main parameters shown in Table

We can use TETRA for data communication with data rate (< 10 kb/s) such as GSM-R. The vital information which would be specially the precedent train position or speed limit conditions in the wireless train control systems depends on several factors which are control methods, data format and encryption methods and so on. TETRA only has data rate which is inferior to 10kb/s, theoretically, the data rate of the wireless train control systems should be lower than 10 kb/s.

4.2 TETRA systems carrier frequencies

TETRA provides a number of services which are characterized as bearer service and teleservices. The bearer services are the same as general networks, the teleservices is similar to mobile communication included the bearer services. The teleservice provides the complete capability for wireless communication between base stations and mobile terminal and includes attributes of the higher layers (4 to 7) of OSI stack [5].

The teleservice uses multiple carrier frequency such as different offsets from multiple 25kHz which space between carriers. The main carrier frequency is defined as

- Downlink main carrier frequency = base frequency + (carrier number × 25 kHz) + offset kHz

We can extend the communication capacity by providing multiple carrier frequencies.

The carrier signal loss can be represented Equation ** known as Friis transmission equation.

- $L = 20log_{10}(4\pi d) + 20log_{10}(f)$ where L(m) : is the path length, f(Hz): carrier wave frequency

Table 3. Frequency range by country[6]

Country	Allocation	Frequency pairs(MHz)
France	Civilian / private	410 – 430
France	Emergency services	380 – 400
Germany	Emergency services	380 – 385, 390 – 395
Ireland	Civilian / private	385 -389.9, 395 – 399.9
Ireland	Emergency services	380 – 385, 390 – 395
Italy	Emergency services/ armed forces	380-390
Italy	Civilian / private	462
Norway	Emergency services	380-385, 390-395, 406.1-426, 870-876
UK	Airwave	390.0125 - 394.9875, 380.0125 - 384.9875
	AirRadio	454, 464 or 460

5. Conclusion

We considered TETRA as a candidate for wireless trains control systems. TETRA is a kind of versatile system to construct private communication system, which contains bearer service and teleservice. It means that national wide communication system can be constructed by TETRA. We considered two factors for applying TETRA to wireless train control system. The first is whether TETRA can be applied to national wide communication system or not. The second is data rate in wireless communication to be fulfilled for train control systems. TETRA can construct national wide communication systems using its system configuration. The data rate constraints are dependent on control contents, data format, encryption and so on… Further research to use TETRA as a train control system would be required for bit error rate to decide radio emission power, fixing control contents and so on .

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