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TECHNICAL PROBLEMS OF WIRELESS COMMUNICATION SYSTEMS USED BY RAILWAY COMPANIES AND PASSENGERS

Railway telecommunication systems are the main tool in communication between driver and dispatcher and traffic control equipment. Assurance of round-the-clock safe railway communication is a guarantee of safe travel. In this work several technical issues concerning wireless communication, including present and future needs and requirements for railroad system have been discussed.

TECHNICZNE PROBLEMY BEZPRZEWODOWYCH SYSTEMÓW KOMUNIKACYJNYCH UŻYTKOWANYCH PRZEZ PRZEDSIĘBIORSTWA KOLEJOWE I PASAŻERÓW

Analogowa łączność kolejowa nie spełnia przyszłościowych potrzeb i wymagań służb kolei. Zakłócenia łączności w relacjach: maszynista-dyspozytor-urządzenia przytorowe wpływają negatywnie na bezpieczeństwo ruchu. Duża część polskiego rynku telekomunikacyjnego znajduje się w zasięgu pokrycia sieciowego polskich kolei. Zapewniona jest mobilność pasażerów dzięki stacjom bazowym usytuowanym przez operatorów sieci komórkowych GSM w pobliżu linii kolejowych. Każdy system łączności radiowej jest źródłem szkodliwego promieniowania elektromagnetycznego. Zapewnienie właściwej ochrony przed nim, to zadanie dla projektantów radiowych systemów łączności. Możliwość świadczenia usług transmisji mowy i danych oraz usług dodatkowych dają systemowi GSM - R szansę na zaistnienie w kolejowej służbie łączności.

1. INTRODUCTION

Telecommunication and transportation are both strategically important branches of economy and state defense system. Technically efficient and up-to-date communication network utilized in railway transport creates the base Polish State Railways (PKP) company is based upon. 73% share of Poland's telecommunication market is within reach of PKP's network. PKP's own communication network is completely remote controlled and covers all Poland's area. Telecommunication copper and fiber optics cables network are dug alongside railway lines, what reduces TCO, but also causes main technical problems (stray currents, micro-cracks of fiber optics cables alongside railway lines). Technology progress in wireless telecommunication, electronics, IT and transport automatization as well as passengers' requirements make it necessary for railroad network operator to introduce a uniform wireless digital communication system.

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2. ANALOG RAILWAY TELECOMMUNICATION

Inter-train communication system designed for train driver to communicate with dispatchers and other drivers. Presently used analog radiophones working within 150MHz and 450MHz frequency range do not comply to technical requirements or quality and data transfer speed when used to communicate between fast moving objects. Variety of equipment types working within different frequency range increases TOC of the whole network.

Here are the main disadvantages of analog wireless railway communication systems:

- lacking data transmission (only voice communication allowed),
- only simplex mode of operation allowed (duplex is required today),
- cannot localize answering drivers,
- 450 MHz systems cannot be upgraded (too small amount of voice channels within 450 MHz frequency range).

Analog railway wireless communication systems do not comply with future requirements. Increase in train speed up to 300km/h and dynamically growing traffic generated by passengers using GSM network create a baseline to introduce this digital wireless railway communication technology.

3. REVIEW OF PUBLIC DIGITAL WIRELESS TELECOMMUNICATION SYSTEMS

Each wireless access system is designed and based upon specific physical methods of operation and modes of usage. GSM standard *(Global System Mobile)* is based on fixed allocation of radio channels to specific network cells.

In DECT system a method of dynamical allocation of the best possible channel CDCS *(Continuous Dynamic Channel Selection)* is employed. Each time one of 120 physical channels is chosen, i.e. the most reliable of 10 carriers and the most reliable of 12 timeslots are allocated.

In TETRA *(TransEuropean Trunked Radio)* system a bandwidth allocated for particular system is divided into physical radio channels of 25kHz each. Each time multiplexed channel is divided into 4 timeslots. It makes duplex communication possible (due to tie shifting of transmit and receive timeslots transmitted in different frequencies), simultaneous voice and data transfer (due to usage several timeslots at the same time) and „bandwidth on demand" (flexible change in data speed within 2,4 to 28.8kbps according to number of timeslots allocated and data security level required). Such systems allow the following types of operation: terminal-to-terminal, group-to-group, priority calls, alarm calls.

In UMTS *(Universal Mobile Telecommunication System)* system two data transfer methods will be employed:: TDD *(Time Division Duplex)* for micro- and pico-cells and FDD *(Frequency Division Duplex)* for micro- and macro-cells. At present detailed technical specifications of this system cannot be presented, as there are no operators in Poland employing it.

Table 1

Basic wireless communication systems specifications

Wireless system	Units	TETRA	GSM	DCS	DECT	UMTS
Frequency range	MHz	400	900	1800	1900	
Modulation		PI/4 DQPSK	GMSK BT=0.3		GFSK (GMSK BT=0.5)	QPSK
Rmin cell	m		500	300	50	<100
Rmax. cell	km	60	35	10	0,5	20
Bandwidth base station - terminal	MHz	395-400	935-960	1805-1880	1880-1882	1970-1980 1900-1920
Bandwidth: terminal – base station	MHZ	380-385	890-915	1710-1785	1896-1898	2110-2170 2010-2025
Max. Speed of mobile terminal	km/h		250		6	500
Voice signal delay	ms		90		28	
Average transmitter power - terminal	mW		100-600		5-10	
Transmission speed	Kbps	2.4- 28.8	9,6 (GPRS up to 40.2)		32	384

Author's own description based on [2],[7],[10],[13]

4. TECHNICAL ISSUES CONCERNING WIRELESS RAILWAY TELECOMMUNICATION

With increasing speed of trains specific negative issues are appearing which have unfavorable effect on communication quality:

1. Source of EMI interferences is current-collector – trolley wire unit.
2. Doppler effect – frequency shift of a signal received by fast-moving receiver.

Frequency shift f_d is calculated as follows:

$$f_d = v * f_d / c \ [Hz],$$

where:
f_d - receiver rated frequency,
v - receiver speed,
c - speed of light, c = 300,000 km/h.

When receiver is moving faster and faster, it receives frequency signal that is offset from carrier. Therefore receiver unit should compensate for time-dependant radio channel characteristics.

3. As the train is a fast-moving object, assess time of terminal to transmitting-receiving base stations are becoming shorter and shorter. A driver using analog wireless communication equipment must manually set frequency channels along railway line.
4. Radio-waves propagation

- attenuation and reflection of radio-waves on terrain obstacles (houses, woods),
- weather condition,
- interferences with signals received from the other transmitting terminals.

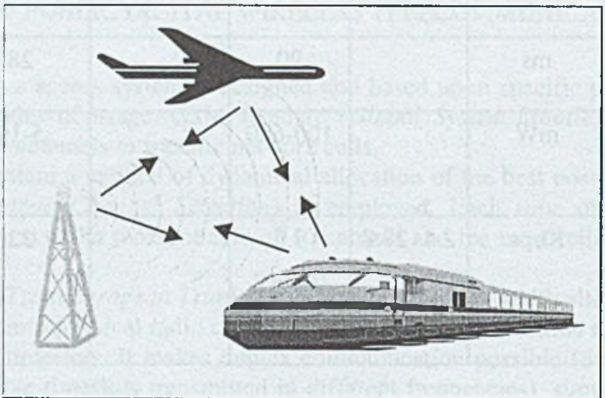

Fig.1. Sources of radio interferences [own calculations]

Passenger-oriented services were introduced as early as 1994 when in EC Berolina express train a telephone booth on tokens was installed. The telephone was connected to mobile terminal working in NMT Centertel 450MHz network. During test period microchip cards sold by train onboard staff replaced tokens. Introducing GSM 900MHz mobile telephony in Poland in 1996 contributed to dynamic development of said technology.

Train passengers with GSM mobile phones, when on board, access data services made available by different operators (stock exchange quotations, train timetables). Businessmen use mobile communication to safely exchange data with companies and banks. Mobiles are also employed in emergency to call for assistance in case of fire, burglary or sudden illness of passenger. Wireless communication for passengers is not efficiently utilized due to the following reasons:

- businessmen do not use notebooks connected to GSM mobile phones when on board due to insufficient safety measures and possible theft,
- transmission interferences due to insufficient coverage by base stations in specific areas alongside railroad lines,
- decreasing number of passengers resulting from high unemployment.

When on board, passengers rest, stroll in corridor, read papers or books, smoke cigarettes and have snacks. Travel is a period when their thoughts are diverted from sad reality. Introducing wireless access to Internet makes sense only in Inter City and Euro City trains. In fast and slow trains, where compartment comfort and fear for robbers do not allow passengers to concentrate on tele-working, it's no use installing wireless communication units. Investment cost will not repay due to possible lost of mobile terminals and usage fraud.

Another issue is how harmful EMI interferences might influence passengers or train drive and control system.

To properly design a GSM system a thorough knowledge of radio-waves propagation theory and communication traffic distribution. Results of computer simulation show that within 900MHz bandwidth an operator's head absorb from approx. 40% to 50% of total power radiated by hand-held mobile terminal. High-frequency electro-magnetic radiation causes so called thermal effect (tissues overheating) and non-thermal effect (changes in blood picture, interferences in ion transportation within cell membrane, nervous disorder). Each mobile terminal is a source of electro-magnetic radiation. Using them is prohibited in hospitals, banks, and airplanes as they may interfere with other equipment. It makes sense to ask whether GSM mobile phones will not interfere with train control system?

Properly designed base station that has been installed according to safety rules should not interfere with other base stations. Antennas of base stations must cover a cell area and therefore they are mounted on steel poles, roofs of high buildings, chimneys. To decrease directional radiation toward cells utilizing the same frequency channels, selective antennas are used which are inclined at a certain angle to the ground level. In Poland 20W (43dBm) transmitters are generally used for GSM wireless system. Safe distance from base station's antenna is, according to local rules, as follows: 40m alongside main lobe axis and 7m alongside side lobes. To install several antennas for different wireless communication operators requires computer-aided calculations and pre-tests on site. Whenever interferences are observed transmitter power should be decreased or channel frequency changed or antennas mounted in different place or, at the last resort, different location should be chosen.

5. ADVANTAGES OF DIGITAL GSM TELEPHONY

Digital GSM telephony has the following advantages:

- good voice quality,
- possibility of exchanging SMS *(Short Message Service)* messages
- possibility of data transmission,
- possibility of fax transmission,
- co-operation with mobile and stationary users,
- noise immunity,
- effective utilization of frequency bandwidth.

GSM telephony allows offering additional services (well-known from digital ISDN telephony), e.g.:

- CLIP – Calling Line Identyfication Presentation,
- CLIR – Calling Line Identyfication Restriction,
- COLP – Connected Line Identyfication Presentation,
- COLR – Connected Line Identyfication Restriction,
- CW – Call Waiting,
- HOLD – Call Holding,
- AOCI – Advice of Charge Information,
- MPTY – Multiparty Call,
- Barring of Outgoing Calls,
- Baring of Incoming Calls,
- Call Forwarding,
- international roaming,
- Centrex – private workgroup.

Although data transmission is as slow as 9.6 kbps, user mobility is a benefit.

6. GSM-R (GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS -RAILWAYS) SYSTEM

Whenever a train is going very fast, say over 160km/h, traditional railroad signaling (semaphores) does not guarantee safety. Drivers of fast moving train are unable to spot and read light signals and react fast enough. GSM-R system is a standard, public GSM system upgraded with additional services for railway wireless communication. Newly introduced EIRENE *(European Integrated Railways Radio Enhanced Network)*, based on standard GSM system is intended mainly for:

- Railway wireless communication (voice transmission between drivers and dispatchers),
- Passenger communication (phone, fax, duplex data transmission, i.e. Internet),
- Internal train communication network (accessed by drivers, guards),
- Alarm signaling (accessed by drivers, dispatchers, railroad workers at specific railroad section),
- Communication for local railroad workers,
- Communication at the railway station (accessed by station staff).

GSM-R network is designed typically for on-duty, private communication only. Railway companies require voice transmission and data transmission in separate channels. GSM-R system should provide for exchange of data and control instructions between ERTMS *(European Rail Traffic Management System)* units installed along the line and on-board ERTMS units installed at the railway stations. Network cells covering railway line must be longitudinal shaped, those covering stations must be round. Real shape of cells may differ from theory, as field distribution around base stations in not uniform due to terrain conditions. Number of base stations should be calculated according to radio-wave propagation scheme. Interferences resulting from neighboring base stations as well as telecommunication traffic must be accounted for. For railroad transport the following frequency ranges have been provided: „up" channel (from base station to user terminal): 921-925MHz; and „down" channel (from user terminal to base station): 876-880MHz.

According to unit localization the following types of radiophones shall be used: for maneuvers, hand-held, train-mounted and vehicle-mounted. All units should work properly in unfavorable weather conditions, at limited light and should be shock-resistant

Advantages of GSM-R over GSM:

- Sophisticated system of workgroup calls (unilateral information broadcasting to many users),
- High-priority calls (connections of lower priority are disconnected immediately),
- General calls,
- Function-dependent and localization-dependent addressing (calling railway engine either by entering ID code or entering train No according to time-table),
- Preset short messages SMS (slower, faster);
- Maneuvering mode,
- Inter-driver communication in multi-traction mode,
- Possibility of proper work at speeds up to 500km/h,
- Emergency call switching 1s.

Advantages of digital communication in railway transportation industry:

- Safer travel,
- Increased speed of travel,
- Passengers can use wireless communication,
- Lower maintenance and service cost due to central management and maintenance,
- Effective utilization of 900MHz frequency range,
- Integration within single system all services available in railway wireless communication network.

In order to maintain collision-free train travel adequate traffic control units and communication systems are a must. Strongpoints of Polish State Railways are its own data transmission, switched fiber optics network. Wireless access systems utilize fiber optics network. GSM-R units and railroad side-mounted units are interconnected within a fiber optics ring what makes it possible to transfer data bilaterally with minimum BER. Making use of design and operation expertise of mobile network operators, Polish Railways may offer GSM-R system as a complete and final solution for wireless communication. GSM technology has been utilized in Poland for a couple of years and it has gained recognition as a reliable solution. Equipping all railway company staff with GSM-R mobile terminals would give them complete independence from other mobile telephony operators. Starting phone calls and transmitting voice and data in a private communication network mean both economical and strategic independence from other operators and eliminates possible overhearing. Will Polish State Railways, facing privatization, find funs for this prospectuous investment?

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