Multi Service Radio Communication for MAGLEV and Train Systems

P. Egner, L. Brühl, J. Dangelmeyr & M. Schienbein

TELEFUNKEN Radio Communication Systems GmbH & Co. KG

ABSTRACT: Evolution of system concepts is mostly driven by new requirements. Particularly in public transportation systems increasing demand for passenger communication as well as for safety/security purposes is characteristic. Broadband radio communication can provide the services for these requirements. The RBS network of the evolutionary TELEFUNKEN maglev radio system is IP-based. A fast and seamless RBS handover for instant routing of the radio link to a vehicle is implemented there. The system uses a digital modem with the possibility of instantaneous adaptation of the modulation scheme to propagation conditions. To handle rapid changing conditions in train communications, fast signalization with minimum protocol overhead is crucial for throughput optimization. By using decision criteria depending on the required quality of service, a high reliability is maintained.

1 SERVICE REQUIREMENTS

This chapter primarily describes requirements and services for MAGLEV train communication scenarios.

1.1 Requirements

The evolution of traditional or existing system concepts is often - at least - influenced and sometimes even forced by new technology innovations, due to science and research discoveries. Everybody knows, these important historical examples such as the first steam machine, the first electric light bulb or the first semiconductor and their effects for future life. But more often, the evolution of products and systems is driven by a change of the requirements or by modified customer expectations resulting in new customer requirements. Especially in public transportation systems two main sectors for new requirements can be identified.

One of these sectors is the public area, with the fast growing demand for passenger communication and information possibilities. The other main sector is the non-public area of safety and security applications used for operation purposes. Both are surely not only limited to public transportation systems. But a public transportation system on one hand offers a good “platform” and occasion for passengers to communicate, but on the other hand is also a potential center for criminal threats and acts.

At first glance, it seems that both sectors are completely different and independent from each other. But both sectors are dealing with different information or data to be exchanged with moving public transportation vehicles, simply summarized by the term mobile communication.

Whereas the passenger communication sector was negligible for a long time - traveling was more an event or a time for relaxing without any disturbance. Simple communication solutions like telephones and fax machines installed in trains and aircrafts were installed at a later time. Today, terrestrial mobile telephones in trains, as well as satellite telephones in aircrafts are standard communication means.

With the rise of personal computers, small mobile cellular phones and internet access the global mobility and connectivity has reached new dimensions. Everybody wants to communicate with everyone else, anytime and everywhere. Thus, also internet access in aircrafts as well as in high speed train systems becomes more and more popular. Public transportation systems will no longer “isolate” its users during the travel. Depending on the kind of public transportation system and the duration of the travel, there are different requests by passengers and system operators which have to be considered.

1.2 Szenarios

On short distances and mass transit operations the focus is more on quick and simple communication as there is less time for intensive work. Besides voice communication passenger could quickly check for new text messages using small computer devices (Palm, PDA). But also in some new advertisement concepts, the usage of broadband connections to public transportation systems is groundbreaking. With promotions via video screens, consumers are faced with a new way of direct marketing for products together with up-to-date news. So, advertisement can be used for re-financing of the communication investments. Combined with wireless LAN distribution on board, tourists can also use this connection for downloading updates of site information, maps or easily modify their sightseeing and travel arrangements. Regardless of all these aspects, the operator of such a transportation system will use it primarily for passenger information and his security obligations.

Quite different on long distance travel, people can take advantage of existing infrastructure and workspace within the transportation system. Regardless of usual passenger information systems with new additional features such as online reservation or updated individual travel information for example, an access to all internet services is desired. With this internet access both amusement and work can be provided. Other passengers can enjoy themselves by chatting, surfing and VoIP communication, while business people can connect via a virtual private network (VPN) to their office servers for working in an office-like environment. Downloading files and reworking presentations, checking mail accounts and answering correspondence, instead of wasting precious working time during a trip.

Meanwhile many travelers are very sensitive in missing adequate communication possibilities regardless whether they use it just for fun or for business purposes.

The other important sector of new requirements in public transportation system has a very serious reason. The dramatic situation on September 11th has not been the initial signal of vulnerability for our daily life, but it has been a very significant one. Already before and for sure after this situation there have been attacks against exposed targets in our society, with a criminal, religious or terrorist background. From toxic gas attacks in Japanese subway system, and the bombing in the London underground trains until bombing of Spanish commuter trains, public transportation has been identified as the target number one for such terrorist activities. Combined with conventional installations of sensors for fire and smoke, permanent video surveillance is seen to be one of the best solution to detect potential risks, protect people and avoid disasters.

Beside these rather dramatic sceneries video surveillance has proven its potential also against normal crime and vandalism in city areas as well as in public transportation systems. Available 24 hours a day, with automatic recognition and detection of potential problems it is an effective and economic solution to prevent all kind of terrorist and criminal problems in and outside of public transportation systems. Most of this surveillance is focused on stationary objects like train stations, platforms, escalators, whereas only a limited capability is available inside moving objects such as train vehicles. Fixed installation of cameras are surely the easiest way to achieve a good surveillance coverage of large sensitive areas, but moving trains must not stay a critical white spot due to limited video data transfer capabilities.

1.3 Services

Special communication equipment can provide high upload capabilities for all kind of data to transmit data to a central control and monitoring station.

To ensure a reliable and optimized data transmission for all services, the data shall be handled corresponding to their individual priority and quality of service (QoS). For this reason the TELEFUNKEN radio system provides different QoS values, which are handled internally on different levels. Table 1 gives an overview of this quality levels.

Table 1: Quality of service for TRainCom MAGLEV

Quality of service description				
ID	Char	Name	Service	Properties
1	RT	real time	propulsion	as fast as possible
2	HQ	high quality	operation control	as reliable as possible
4	HDR	high data rate	video, internet	as much as possible
8	TFK	TELEFUNKEN	---	special for train com

All these described communication services for passenger communication, as well as for security purposes require different data volumes, both, in upload and download direction. Sometimes there are concurrent transfer demands in a specific direction, but most of them are complementary. Today's mobile data communication standards are dedicated to very asymmetrical conditions with a high download and a limited upload capability. Together with technical constraints towards higher velocity and high service availability, these standard systems can hardly fulfill all customer expectations and operator requirements of the near future.

Dedicated communication systems which provide the required technical solution, but considering economical conditions and health regulations at the same time, are necessary for continued successful operation of public transportation systems.

TELEFUNKEN Racoms microwave link technology can provide suitable solutions for high speed train operations as well as for mass transit applications with a very high data transmission capability in uplink and downlink. This way, a broad variety of passenger und safety/security applications are enabled simultaneously. Combined with it's other outstanding features only one efficient and economic system is required as an integrated solution.

2 RADIO SYSTEM BACKBONE

This chapter primarily describes the backbone and the near trackside components of the System.

2.1 Architecture

Usually the radio system base station network is a double channel system consisting of radio channel A and B. Double radio channel systems are required for safety critical train applications where train control data and other operation relevant data have to be transferred to guarantee a faultless and reliable train operation.

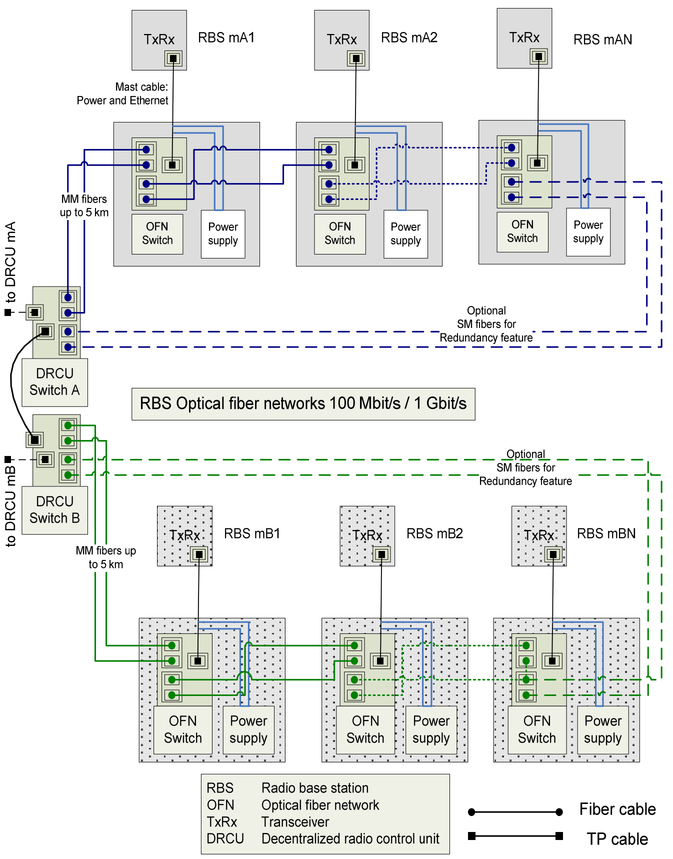

Figure 1: Architecture of the radio base station network.

Normally the radio base stations are alternately located along the railway track as shown in figure 1. An A-base station for example has two B-base stations as neighbors.

Each sub network is controlled by a DRCU (Decentralized Radio Control Unit). Because of the double channel principle also the DRCU is splitted into two parts, the DRCU plug-in A and B, which are the gateways and control centers for the correspondent optical fiber ring.

The radio base station as shown in figure 2 consists of the following parts:

1 Radio base station mast

2 Radio base station antenna

3 Radio base station transceiver with mast cable to connection box

4 Radio base station connection box with:

- Splice box for fiber cables
- Redundant power supply
- Base station switch

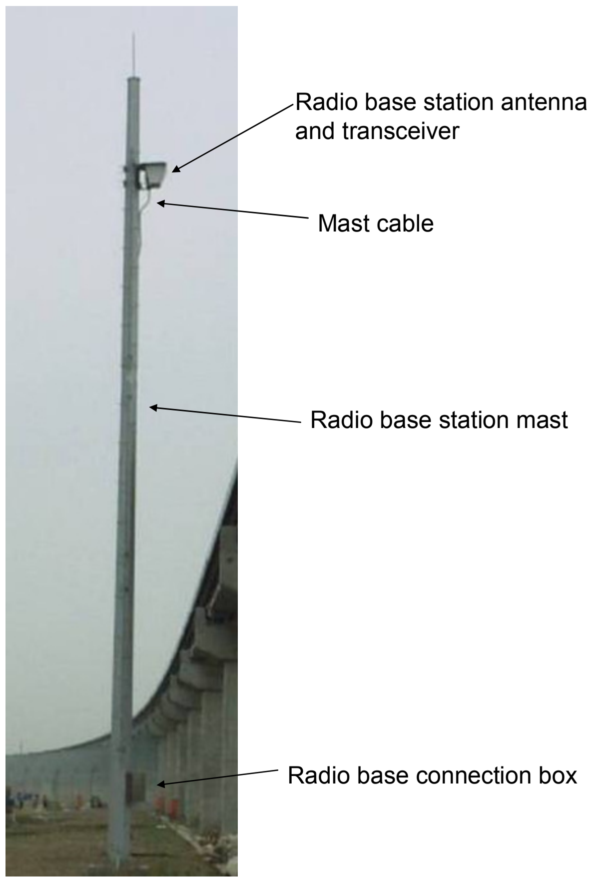

Figure 2: Architecture of the radio base station network.

2.2 Technology

The radio base station network is an IP-based switched optical fiber network with 100 Mbit/s or 1 Gbit/s. The technology represents state of the art technology concerning the applied hardware. The optical fibers could be mono mode or single mode fibers due to the fact that the distances between two radio base stations are usually less than two kilometers. The relative short distances result in the fact that radio systems with a high availability require a good radio coverage.

For functional purpose the routing and forwarding mechanisms of the data packets must be seamless and of course lossless as well. Therefore special routing mechanisms have to be developed in order to guarantee radio base station handovers at speeds of 500 km/h. The intelligence behind is located in the network itself but is not based in the firmware or software of the base station switches.

A similar challenge is the priority handling of data packets. Some safety critical data services must have the opportunity to be handled prior compared to others for example passenger information data. For handover mechanisms there is no need to change the commercial of the shelf firmware or software of switches. The firmware and software of radio specific components such as transceiver and DRCU are offering methods to realize these features without changing any of the IP-packets.

As a result of this for linked subsystems and data services the interface to the radio system is a real IP-interface which everybody knows from his/her DSL-modem at home.

2.3 Redundancy

Redundancy is used to increase the system reliability and availability. One possibility is to work with redundant power supplies and USV. If one power supply fails an automatic switch to the redundant power supply will be done.

To guarantee that the optical fiber network in whole is working when one radio base station breaks down redundancy switching mechanisms have to be considered. In each case of a single failure the breakdown of the complete network should be prevented. Specified, tolerated timeouts of the radio link lead to the requirement for the network reconfiguration. With the spanning tree algorism it is not possible to guarantee the allowed timeouts. On the other hand supplier specific reconfiguration protocols are available but they are not open standard based.

Industrial solutions offer reconfiguration times of 500 ms. This value can be reached for a maximum number of switches in the network of 50. For larger networks the network must be split into sub networks.

For the hardware a ring structure is required. This will not cause more hardware costs since fibers of the other radio channel could be used. Single long haul fiber cables could therefore be prevented.

2.4 Maintenance aspects

Due to the standard network technology also standard diagnosis methods could be used. The first choice in this matter is SNMP (Simple network management program). Diagnosis information of the radio base station transceiver and switch are realized by SNMP-agents. At the control center those information will be collected by the CRCU (Centralized radio control unit), stored in a database and displayed by a HMI (human machine interface). Due to this open standard radio system diagnosis information could also be integrated in other subsystems or in master system of the whole train system.

3 MODEM

This chapter primarily describes the features of the modem within the transceiver.

3.1 Introduction and Outline

Because of the unique radio propagation environment and quality of service requirements, existing mobile communication systems are not optimal, mostly not even applicable for MAGLEV and train applications. The physical layer (PHY) has to provide broadband communications with a high reliability over a rapidly varying radio channel. The TELEFUNKEN RACOMS maglev radio system, deployed in Shanghai, guarantees the required reliability with a raw data rate of 4 Mbit/s by using robust incoherent modulation in conjunction with space, location and time diversity. The system also uses two frequency bands at the same time.

In order to extend the support of additional services, the data rate has to be increased. Due to robust transmission a low spectral efficiency is always implicated. In mobile communications the adaptation of modulation to the momentary capabilities of the transmission channel is a common approach to increase efficiency and thus throughput.

After a brief introduction on the propagation environment and the PHY deployed in Shanghai, the application of link adaptation in the specific scenario of wireless train communications is discussed within this paper. Without equalization, bandwidth is always limited by delay spread due to multi-path propagation. Therefore orthogonal frequency division multiplexing (OFDM) using incoherent modulation is finally proposed for future broadband communications in the considered scenario.

3.2 Propagation Characteristics

For MAGLEV and conventional train applications radio coverage is bound to track topology. Directional antennas in base stations as well as on vehicles, increase range and decrease Doppler spread by limiting the propagation field parallel to the moving direction. While line of sight (or guided propagation in tunnels) can usually be assumed, multi-path propagation due to reflections on ground, track, buildings and terrain still causes significant amounts of Doppler and delay spread as shown in figure 3.

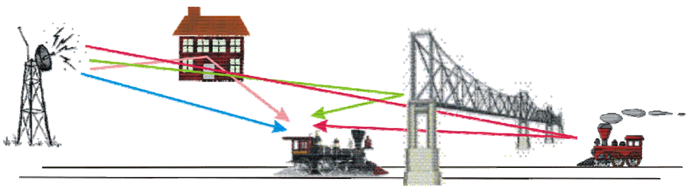

Figure 3: Radio propagation in MAGLEV and train scenarios using directional antennas. Multi-path propagation introduces limiting factors of Doppler and delay spread.

3.3 Diversity principle

The TELEFUNKEN RACOMS MAGLEV radio system deployed in Shanghai uses continuous phase frequency shift keying (CPFSK) as a robust, incoherently detected modulation scheme. With a symbol rate of 4 MHz the symbol duration is kept well below typical delay spread in order to avoid inter symbol interference. The remaining flat fading is compensated by the extensive use of diversity in space, location and time domain. Figure 4 shows the multiple link configuration for the space and location diversity used by downlink (a) and uplink (b).

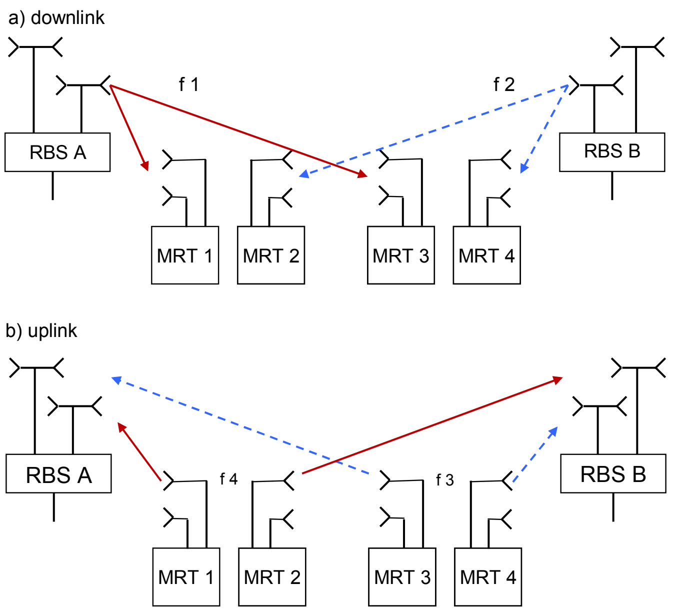

Figure 4: Combination of space and location diversity deployed in the Shanghai MAGLEV radio system to meet reliability and availability requirements.

By using two frequency bands simultaneously, location transmit diversity is utilized. Even for a high carrier frequency of 38 GHz and velocities of about 500 km/h, Doppler spread and shift still remain small compared to the bandwidth und thus can be neglected for frequency shift keying (FSK) modulation. The continuous phase property further allows for high transmission power by an efficient use of power amplifiers. In order to fulfill the high reliability and availability requirements of propulsion systems and operating control systems the TELEFUNKEN radio system was designed to offer a constant raw bit rate of 4 Mbit/s even in worst case propagation environments.

By improving system concept, modem and microwave transceivers the raw data rate is pushed up to 8 Mbit/s. Link adaptation now will be the next step to further increase data rate whenever the propagation environment is better than worst case.

3.4 Link Adaptation Potential

Cell planning has to ensure sufficient receive power at cell borders while considering system reserve and rain attenuation. Without rain and approaching the base stations, a significant excess of receive power can thus be expected. Furthermore, on straight track in open field propagation conditions approach ideal point-to-point propagation, without significant limiting effects of Doppler and delay spread. Under these conditions robustness can be traded in for higher throughput by increasing symbol rate or using higher order modulation schemes.

3.5 Adaptation Process

While mean receive power, determined by distance and weather, will drift relative slowly, with velocities of about 500 km/h fast fading varies in the order of micro seconds. The occurrence of new reflection points can change Doppler and Delay spread limitations in the same order of time. These properties conclude to the following basic adaptation approaches:

- 'slow link adaptation', which adapts to mean receive power, being always robust against worst case Doppler and delay spread
- 'fast link adaptation', which adapts to momentary receive power, Doppler and delay spread, being fast enough to follow fast fading

Due to the strong limitations by Doppler and delay spread, the potential of slow link adaptation is quite low for MAGLEV applications. Worst case Doppler makes coherent detection with adaptive equalization infeasible. With incoherent modulation, like CPFSK or differential phase shift keying

(DPSK), inter symbol interference will always limit the product of symbol rate and modulation order, regardless of the available receive power.

With a fast link adaptation symbol rate and modulation order could be freely adapted, even a coherent detection with equalization could be used whenever Doppler spread is low.

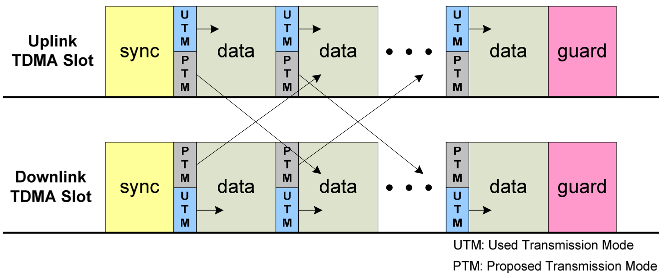

Figure 5: Slot structure for fast link adaptation using direct feedback of transmission mode proposals in FDD systems with symmetrical uplink/downlink scheduling

Preconditions for this are a configurable digital modem as well as a fast adaptation process. An adaptation within the order of micro seconds is achievable only with the frequency division duplex (FDD) and symmetrical uplink and downlink scheduling for multiple access. Such a real bidirectional link allows for a fast link adaptation within the PHY with direct feedback during transmission as depicted in figure 5. Based on the measured link characteristics a decision algorithm in the receiver proposes a transmission mode to the opposite transmitter. The proposal, 'proposed transmission mode' (PTM) together with the actual - used transmission mode - (UTM) are repeatedly signaled by the transmitters in a predefined time with a predefined and robust transmission mode.

3.6 *Quality of Service*

Compared to the original approach of always assuming worst case conditions, a fast link adaptation will implicate a loss of reliability. Data crucial for safeguarding and MAGLEV propulsion should therefore still be transmitted in the most robust transmission mode. This non-adapted high priority class data can be seen as ground load with guaranteed data rate and quality of service. In the remaining transmission time spectral efficiency can be increased by link adaptation, offering a variable data rate for additional services with different QoS requirements.

3.7 *Feedback*

With two dominant propagation paths of line of sight and ground reflection fading is likely to extend over many wavelengths. Spatial macro diversity is therefore crucial in order to achieve the required reliability and availability. For throughput optimization link adaptation should always adapt to the diversity branch with the best link quality. The above proposed fast link adaptation requires direct feedback from all receivers. With only one active transmitter feedback has to be timely gathered from spatially wide apart receivers, which is rather difficult to implement. With TELEFUNKEN RACOMS' patented comb structure under dual frequency approach, feedback can be given directly from each transceiver using a distinct frequency band.

3.8 *Incoherently detected OFDM*

OFDM is a promising candidate to break the bandwidth limitation of incoherent single carrier modulation due to inter symbol interference. For MAGLEV propagation conditions OFDM can be designed to be robust against both, Doppler and delay spread. Longer symbol duration in OFDM results in even stronger channel variations from symbol to symbol and therefore demands incoherent modulation.

Table 2: Operating range of modulation schemes for OFDM in dependence of Doppler and delay spread

selection table		doppler spread (normalized to sub-carrier spacing)		
		low (0-2%)	medium (2%-5%)	high (5%-20%)
delay spread (normalized to symbol duration)	low (0-5%)	QAM (coherent detection with channel tracking)	DPSK (time)	DPSK (frequency)
	high (5-20%)			4-FSK

As shown in table 2 DPSK is applicable in time domain (from symbol to symbol) for low to medium Doppler spread and in frequency domain (from sub-carrier to sub-carrier) for low delay spread. Under worst case conditions of Doppler and delay spread only OFDM-FSK offers sufficient robustness at the cost of spectral efficiency (0.2 bit/s/Hz including channel coding). Because of this low spectral efficiency for robust transmission, in the regarded scenario OFDM is efficiently applicable only in conjunction with link adaptation.

In scope of the government funded research project WIGWAM (wireless gigabit with multimedia support) the TELEFUNKEN RACOMS currently builds an OFDM demonstrator with 50 MHz bandwidth, offering a scalable netto data rate on PHY level of up to 90 Mbit/s.