Wireless Computer Networks WCN, Sept 1994
IEEE/ICCC Conference, THE HAGUE, NL, pp. 799-802

MOBILE DATA COMMUNICATIONS IN GERMANY - A SURVEY

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Abstract: Mobile radio systems for data communications in Germany and their state of introduction are desribed. Some application-areas and related systems are addressed e.g. the cellular Global System for Mobile Communication (GSM), trunked cellular packet radio by Modacom and ETSI-TETRA, radio paging ERMES, cordless telecommunication according to ETSI/DECT, mobile satellite radio, and wireless LANs.

1. INTRODUCTION

For about eight years, cellular mobile radio networks have raised broader public interest in Germany and have proven since then able to adapt to the specific demands of their subscribers, Fig. 1. Mobile radio networks, which extend the telephony-service of fixed networks to mobile subscribers, have gained the largest economic relevance with, currently, about 1.9 million subscribers. Originally, radio paging-networks have had a comparable relevance, but now serve a significantly smaller number of approx. 430.000 users. Government and private company owned trunked mobile radio networks attract about 1 million subscribers. Further, about 2 million cordless telephony systems, mainly, for residential applications are in use. Wireless LANs according to draft ETSI standard HIPERLAN are being introduced already, enabling workstations to be moveable as needed. In the European Union's (EU) research programme RACE II, the system architectures and air-interfaces are being specified of both, the

- service-integrating 3rd generation universal mobile telecommunications system (UMTS),
- Mobile Broadband System (MBS), to extend the services of B-ISDN to the mobile user.

Increasing use of fixed telecommunication networks for PC to host data exchange motivated a service supporting mobile computing based on packet radio (Modacom) operated by the Deutsche Bundespost TELEKOM. In addition, a satellite-based mobile data service is available.

Worth mentioning is the GSM-R (railway) initiative of the European Railway Association to substitute their current analogue mobile radio network for train control by a GSM based packet radio network. Another traffic related area will soon face a new type of mobile data radio networks, digital short range radio (DSRR), namely for road transport support. The most promising applications there are electronic fee collection on motorways and multistorey car-parkings. The resp. standards from CEN TC 278 are expected by the end 1994 [1]; country wide introduction will start by 1995. DSSR networks typically rely on a link with some 100 kbit/s capacity and have an application-specific cell-radius of 15 to some hundred metres. Infrared radiance and radio at 5.8 and 62 GHz are assigned by ETSI as media. DSSR is expected to serve a variety of traffic- and journey-related services, e.g. automatic route-guidance, reservation services for car parking, hotels, event access tickets. A one year field trial with 10 manufacturers of DSSR equipment participating is currently performed at the A555 motorway between Cologne and Bonn. These services will be offered via a 9.6 kbit/s GSM link, too; related studies are performed in the EU's programme DRIVE II Sokrates projects.

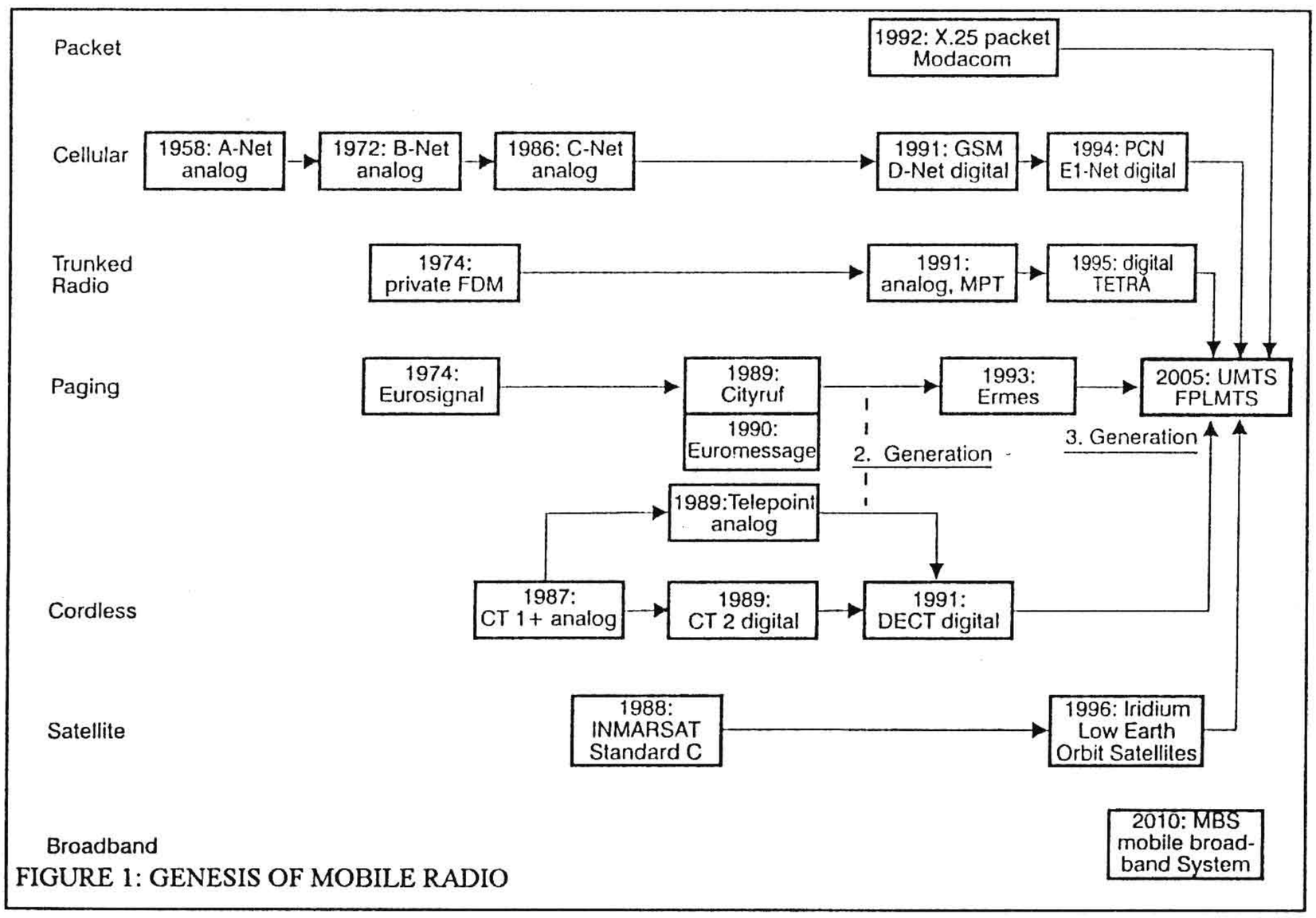


FIGURE 1: GENESIS OF MOBILE RADIO

2. DEVELOPMENT OF CELLULAR RADIO

The analogue, single channel per carrier, cellular radio network C operates since 1986 and is still in country-wide usage. Besides telephony, it offers data services like MobileFax and MobileBox and service interworking with Datex-J and Telebox 400 based on the Datex-P (X.25) network. Operation of network C terminals is limited to Germany and a few neighboured countries. From initial it supported handover and country-wide roaming.

2.1 Cellular Radio according to standard ETSI/GSM

In June 1992 the GSM-based cellular networks D1 (DeTeMobil) and D2 (Mannesmann Mobilfunk) have been opened for public use. They extend the services offered by the ISDN, opened in 1990, to mobile users. GSM, different from any other existing mobile radio networks, is designed to a high ISDN-compatibility. GSM network subscribers will be able to roam all over Europe, due to the system's broad acceptance. Services provided in Germany comprise telephony, a short-message service, the transparent mode of G.3 telefax service, MobilBox, (non-) transparent data transmission and signalling oriented services like call redirection and automatic call-back. Network-interworking is possible with the networks ISDN, Datex-P, Datex-L and Datex-J.

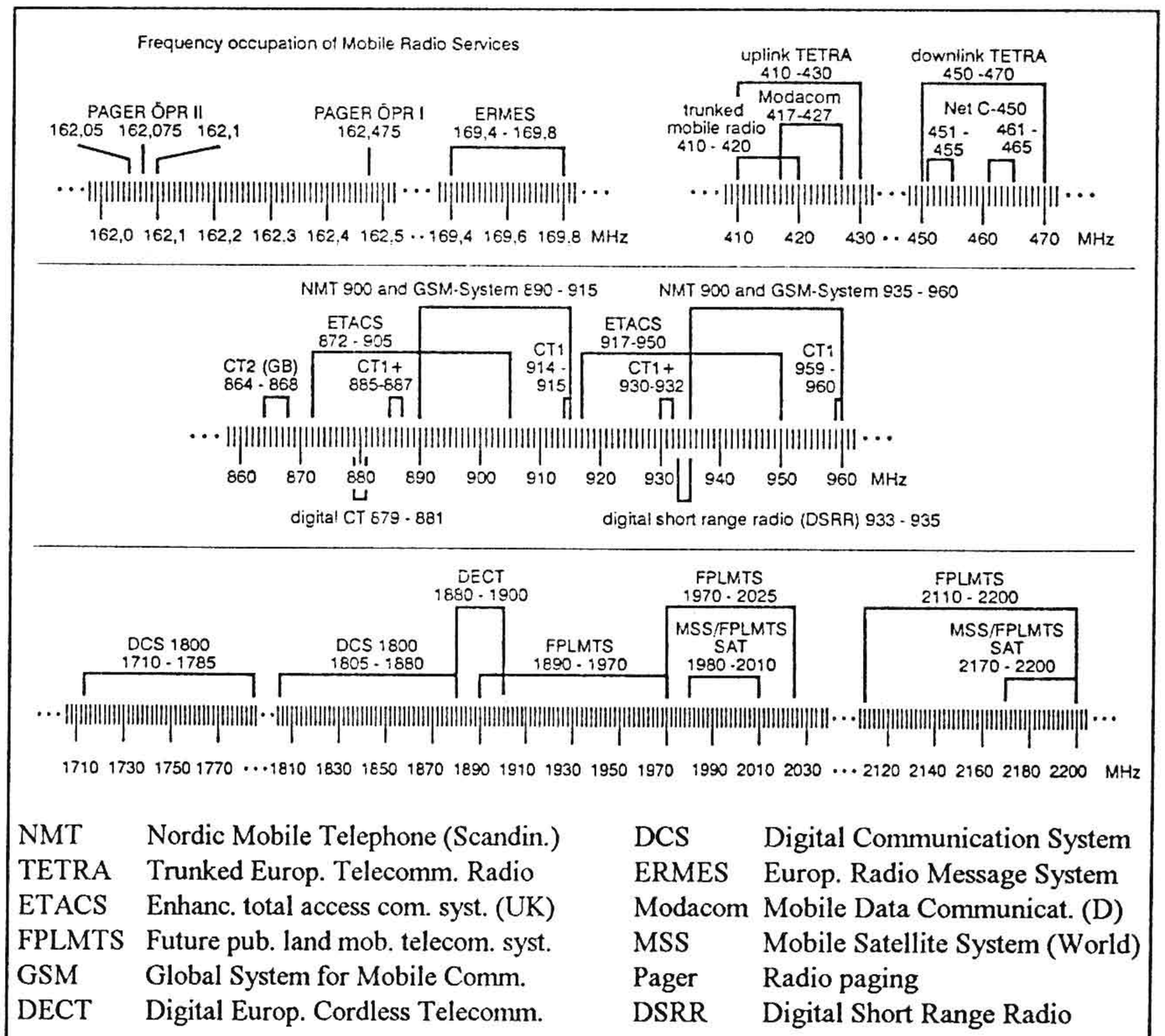
Since May 1994 a third network-operator (E-PLUS Mobilfunk) opened operation for cellular radio in Germany with three islands of the network E1 according to standard ETSI/DCS 1800, to be extended country-wide. Due to the frequency band used and smaller radio ranges per base station defined in the standard, all three networks D1, D2, and E1 follow the GSM standard, see [2] for details. DCS 1800 is better suited to serve heavily populated areas and GSM 900 to serve wide areas. Dual-mode mobile radio transceivers could roam between D- and E-networks, depending on the networks service availability, but this mode of operation might collide with the interests of the operators [3]. Further, it is expected that a fourth license for a second operator at 1800 GHz (E2-network) will be granted in the future. What can be expected for shure is a licence for a public DECT service at 1.9 GHz.

The concept of service providers is quite new for Germany, who progressively market mobile radio services through their easy access to some segments of the market like automobile club members, clients to a car manufacturer, etc. Besides telephony, a wide range of services, e.g. hotel reservation, flight-/journey-information etc. is offered by them. According to their quite complex tariff structures, it was proven that usage of a services might differ in cost by a factor of two, dependent on the service provider [4].

Table 1 shows the frequency-bands used in Europe. 2. generation cellular networks will be followed by a 3. generation to offer by the European UMTS in an integrated system all the services of mobile radio networks which are existing in parallel to date [5], Fig. 1. A Memorandum of Understanding (MoU) to develop UMTS in Germany has been signed already. Worldwide, comparable development work is being done towards a Future Public Land Mobile Telecommunication System [6, 7]. 230 MHz frequency band at 2 GHz have been reserved for those. Before this will happen, GSM will be developed in ETSI to GSM+ to further improve its current efficiency and to cover also those services expected promising in the future.

2.1.1. Data Services in the GSM

Since the GSM voice codec relies on the characteristics of human speech for compression, data transmission cannot be added to a voice terminal but requires a separate encoding device, or a terminal adaptor to interface to a PSTN modem. Interworking functions in the mobile switching centre have been defined to enable compatibility between data terminals linked to the mobile radio and fixed networks, and for telefax-devices connected via modem to the analogue telephone network.



NMT	Nordic Mobile Telephone (Scandin.)	DCS	Digital Communication System
TETRA	Trunked Europ. Telecomm. Radio	ERMES	Europ. Radio Message System
ETACS	Enhanc. total access com. syst. (UK)	Modacom	Mobile Data Communicat. (D)
FPLMTS	Future pub. land mob. telecom. syst.	MSS	Mobile Satellite System (World)
GSM	Global System for Mobile Comm.	Pager	Radio paging
DECT	Digital Europ. Cordless Telecomm.	DSRR	Digital Short Range Radio

TABLE 1: FREQUENCY BANDS ASSIGNED TO MOBILE RADIO

GSM Radio-Interface

The traffic channel (TCH) at the air interface offers the subscriber a TDM channel, either full-rate 22,8 kbit/s, or half-rate 11,4 kbit/s. During silence periods of a terminal the channel cannot be used by other terminals; the user is therefore charged with the total connection-time.

Forward *Error-Correction (FEC)*

The received signal strength of a mobile terminal varies by +/- 30dB and more around the average. At times of signal fades the receive-quality decreases drastically, due to high bit error rates. To reduce influenc of Doppler-shift, multi-path propagation and shadowing, several measures are provided with GSM:

- data are convolutional FEC encoded and interleaved,
- frequency-hopping is applied,
- a 24 bit cyclic redundancy check (CRC) code is used, if a high residual bit error-rate is requested.

Bearer-services for data transmission in GSM

Two different bearer-services are available: The transparent service, based on FEC, does not apply CRC and transmits data with constant throughput and delay. The service quality depends on that of the radio link. Dependent on the FEC method selected, possible user data rates are at full-rate channel: 9,6/4,8/2,4 kbit/s; and at half-rate channel; 4,8/2,4 kbit/s.

The non-transparent bearer-service uses on top of the transparent service the Radio Link Protocol (RLP), an ARQ-protocol based on CRC evaluation. Besides reject and repetition, starting from a certain block-number, selective reject of single blocks is available. Supervising commands are part of a frame. A maximum window-size of 62 is chosen to take the interleaving depth of 19 for RLP frames into account. Thereby, an residual bit-error-rateof $<10^{-7}$achieved, but throughput and delay of frames vary dependent on the receive quality.

Short messages in the GSM

The short-message service (SMS) is a packet based service carried by the GSM signalling channels. It enables mobile to receive (and transmit) messages with maximum length of 160 byte. As short messages may be transmitted with delay (up to some seconds), this service contributes to a higher utilisation of the signalling channels. Longer messages may be splitted into short messages of 160 byte legth each; the transmit sequence is not guaranteed, then.

Telefax-services

The transparent telefax-service has been recommended recently by ETSI to be introduced, preferently. Encoded data and related signalling messages are transmitted via a transparent bearer-service. During signalling (with a rate of 300 bit/s), by repetition of the information, redundant transport of commands is gained. Dependent on the receive quality, during data transmission, errors of document lines may occur as usual with the fixed network. If signalling is neglected, a telefax-transmission takes the same time as in the fixed network.

The non-transparent telefax-service requires adaptation of the terminal equipment to the bearer-service, which is supplied by the GSM. The related adaptor has modem-funtionality seen from the connected telefax-terminal and supervises and manipulates the telefax-protocol by the storing of data, transcoding and adaption of the telefax-rate to the radio channel quality. Outbalancing by short-buffering of the document in the sending and receiving telefax-adaptors is mandatory to be able to cope with a variable bit rate from the radio link. Due to time-out supervision at the receiving telefax-terminal, anyway, such situation may result in a premature termination of a connection. Simulation studies have shown that such terminations will not happen, since under critical received signal quality (5dB<CIR<7dB) a handover will be initiated, usually, and the problem resolved thereby. The non-transparent telefax-service thus is a promising alternative with a higher service quality than reachable with the transparent telefax-service [8].

Packet Data Services

SMG4 has recommended to introduce an X.25 based mobile packet radio data service, based on one virtual connection per GSM traffic channel. Work is under way to prepare for multiplex many virtual connections to one traffic channel [9]. Further, a packet based service for group communication is under study [10].

3. FURTHER COUNTRYWIDE RADIO SYSTEMS

Besides cellular, other radio services exist or are being introduced, adapted to specific applications

3.1. Cordless Telephony

Cordless Telephony (CT) is a service typically used in the range of the subscriber's fixed network termination to connect the telephone unit and the phone by radio over a max. distance of 300m/50m (out-/indoors), instead of using a wired connection. The telephone unit as the base station (connected to the fixed network) and the phone as the mobile unit are each supplied with transmit/receive equipment. The air interface is based on FDM with analog modulation (digital modulation with the CT2-system, Fig. 1). Via the mobile unit and the base station, the subscriber may generate calls and receive incoming calls.

The ETSI/DECT (Digital European Cordless Telecommunications) standard 1991 introduced a digital CT system for voice and data with 12 duplex TDMA channels per carrier (each 32 kbit/s) and 10 carriers at 1.89 GHz for high user densities with a transmit power of $\leq$ 250 mW [11]. One application is to extend private automatic

branch exchanges to mobile users. Large areas can be covered by multiple-cell systems, e.g. one ore more buildings of e.g. the private company ground. As usual with CT, any base station might provide any carrier.

DECT is considered a candidate for real personal communication systems (PCS) for public use in-/outdoors and in the local loop. The mobility-management defined enables both, calls originating from and terminating at the subscriber in different DECT environments. Use of a DECT system as a base station subsystem inside the GSM, presuming dual-mode mobile handhelds, have been proposed [12, 13].

Data transmission may use multiple channels (even at different carriers) in order to obtain n*32 kbit/s data rate per connection. In half-duplex transmission mode up to 704 kbit/s per link can be reached on one carrier. Data communication protocols, e.g. LAPC, are defined comparable to the RLP of GSM [11]. The bit rate of a connection can be continuously changed according to the current needs. On top of a (set of) channel(s) serving one connection, a packet service might be established. The DECT-system cannot fully compete with a radio LAN, since it is preferentially designed for voice transmission; the total system capacity of 7.68 Mbit/s (from ten carriers) might be sufficient for many local data applications.

3.2 Radio Paging Systems

Radio paging services like Eurosignal, Cityruf, Euromessage (as part of Cityruf) and ERMES are in use, which transmit narrow-band data signals in order to alert small mobile receive-only terminals. Besides a beep-signal, to which the subscriber may react with a call to a predefined telephone-number, also several phone numbers and short character-sequences can be displayed at the receiver in order to present a phone-number or a short message.

The standard ETSI/ERMES (European Radio Message system) has been finished in early 1992. [14]. International roaming is the most important improvement compared to earlier systems. The data rate has been increased by one order of magnitude to 6.25 kbit/s at 169 MHz on 16 FDM channels with a channel-width of 25 kHz. Besides tone-call (8 different tones), number-call (≤20 digits), alpha-numeric call (≤400 characters), also transparent data for process control, telemetry and alarm is offered.

18 countries and 28 network-operators have signed a MoU for the introduction of ERMES. By use of the standardized UPC-protocol, radio paging texts can be input into the system via all usual data networks. In addition, the service can be reached via service-providers.

3.3 Trunked Mobile Radio

Private trunked mobile radio systems have been operated many years by offices and organisations related to security tasks, airports, the major industry, energy-suppliers, public personal transport operators and taxi-offices. In a local range defined by the base station, voice and data radio is offered on half-duplex channels between one or many mobile users and a central dispatcher. Local systems with one base station only and (cellular) systems covering larger areas are in use. Base stations often are equipped also to connect to the fixed network.

Since 1990 a public trunked mobile radio service (Chekker) is operated in 18 German economic centres ("A-Regions") by the Deutsche Bundespost TELEKOM. In addition, private operators have been licensed to operate competing networks there. These networks are based on analog signal transmission and operate at 410 MHz with a channel-spacing of 12,5 or 25kHz, cf. Table 1. The user data rate is 2,4 kbit/s. The network follows a non-state-of-the-art standard [15, 16].

To date, Chekker has about 35.000, all private operators together serve about 25.000 subscribers. Licenses for B-Regions (with expected lower traffic demand) will be granted soon. These radio networks cover locally restricted areas, typically, conurbational city-areas with a maximum diameter of 50 km and a few cells each of 10-25 km diameter). Through suitable address assignment closed user-groups, virtually private radio networks dedicated e.g. to a company, are possible. All mobile stations of a user-group can be called and connected directly within a region. Chekker permits a maximum call-length of 60 sec. Multicast, identification of caller, re-direction of calls and short data transmission up to 23 characters are offered optionally. Trunked radio is typically used point-to-multipoint and thereby differs from cellular or cordless, where users communicate point-to-point. Connection establishment is by push-button (push-to-talk).

3.3.1 Mobile Data Communication (Modacom)

Mobile radio networks to connect X.25 data terminals to its host are, e.g. Mobitex (Sweden/United Kingdom), Cognito (UK), Ardis (United States). The German Telekom operates the Modacom system based on proprietary protocols since 1992 [17] , Table 2. A second license to operate a packet data network has been granted to RWE/Eurokom this year. The networks are similar in structure to the Chekker networks.

Base station controllers of the Modacom system are connected to area communications controllers (ACC), and ACCs to each other, via 9.6 kbit/s direct data connections leased from the DBP TELEKOM Datex-P network. One or more radio cells and the corresponding ACC units build a radio domain. Mobile terminals (MT) may pass domain borders and are handed over between ACCs. Some gateway ACCs interface to the X.25 network.

The radio data link access procedure (RD-LAP) enables synchronous switched connections for both connec

frequency band	417-427 MHz (10 MHz dupl. distance)
channel-width	12.5 kHz
modulation	4-level FSK
bit rate	9.6 kbit/s netto
message length	≤ 2048 byte = 4 packets of ≤ 512 byte
channel per carrier	one data channel per carrier
MAC protocol	DSMA (data sense multiple access)
FEC	Trellis-coding with interleaving
error-detection	CRC-checksum
radiated power	6 W emitted radiated power
bit error rate	better than 10^{-6}, typically 10^{-8}

TABLE 2: MODACOM PACKET RADIO NETWORK

tion-oriented and -less communication in half-duplex mode between MT and its host. At the radio interface the Motorola p-persistent protocol DSMA (data sense multiple access) is used with a packet length ≤ 512 byte.

3.3.3.1 Connections in the Modacom Radio Data Network

Type 1 connections offer multiple usage of a switched virtual connection (SVC) but can only be established from interactive mobile terminals point-to-point to be used for access to a Mailbox-service or others. *Tpye 2* point-to-point connections are exclusively used SVCs which can only be established by the host. *Type 3* (fleet)-connections enable message flow between many (e.g. >100 mobile terminals) via a SVC or a PVC (P=permanent) and one host. None of the above connection types achieves the performance of the X.25-protocol with respect to a transparent teleservice; type 2 still suits best.

3.3.2 Trunked European Telecommunications Radio Air interface, TETRA

Since 1988 ETSI RES 06 is working for the TETRA standard to be finished in 1994 [18]. Aims are the European harmonization of frequency-allocation and standardization of

- the radio interface (air-interface),
- the basic elements of a man-machine-dialogue,
- some network-internal interfaces,
- interfaces in mobile stations.

Two standards are prepared in parallel: Voice and data (V+D) and packet radio (data optimized, DO). The TETRA V+D standard aims at a succesion of existing trunked mobile radio systems, while the DO-standard defines an optimized packet radio system. Both TETRA-systems will use the same bit transmission rate. It is not clear yet, if the same transmit/receive-equipment will be used. Table 3 shows the technical features. Table 4 shows the carrier- and tele-services available.

3.4 Mobile Satellite Radio

The Inmarsat-2 (International Maritime Satellite) network is based on geostationary satellites and enables

frequencies	2*5 MHz, later 410-430 & 450-470
chann. spacing	25 kHz
modulation	π DQPSK
bit rate	36kbit/s gross/19.2kbit/s net per channel
chann./carrier	V+D: 4, each 25 kHz, time divis. duplex
	DO: one channel
voice-coding	not defined, 4.8 kbit/s
access protoc.	V+D: S-Aloha multiple-access
	DO: S-Aloha w. reservation, resp. DSMA depending on the traffic
frame structure	V+D: 14,7ms/slot; 4slot/frame; 18 frame/multiframe; 1 slow control frame
	DO: downlink: 128 bit blocks, uplink: ≤ 256 bit blocks; FEC- protected, (dis)continuous data on (up)/downlink
co-channel	-60 dB
conn. establish.	<300 ms
transit-delay	V+D: <500 ms connection-oriented service
	DO: <100 ms with a 128 byte message

TABLE 3: CHARACTERISTICS OF TETRA

A)V+D:	
Bearer-services:	a) 7.2 kbit/s TDM unprotected voice
	b) ≤ 19.2 kbit/s TDM data
	c) ≤ 28.2 kbit/s TDM unprotected data
	d) conn.-oriented packet-transmission
	e) connection-less packet.
Tele-services	f) 4.8 kbit/s voice
	g) coded voice
B) DO:	Only the packet-services d)-e) do exist

TABLE 4: CARRIER AND TELESERVICES WITH TETRA

worldwide the communication between mobile (Inmarsat) stations and connections with terrestrial networks. The services provided comprise, amongst telex and data transmission (64 kbit/s), all services available in the telephone network (so-called Inmarsat Standard A Service) and data transmission with up to 600 bit/s duplex in the Inmarsat Standard C Service. Currently approximately 5.000 Inmarsat mobile radio stations (of some kilos weight) are installed on ships, land- and aircrafts. The combination of Inmarsat Standard C terminals and navigation-receivers (based on the Global Positioning System, GPS) is at the moment regarded as more and more important for the use in the management of large vehicle-fleets having a working radius all across Europe. Up to now there are worlwide about 20.000 Inmarsat-subscribers. To become independent of the GPS service, Inmarsat currently plans To introduce a synchronisation and positioning service based on its own satellites.

In order to open up rural areas for voice and data applications, Inmarsat plans to set up a personal satellite service (Inmarsat P) with hand-held mobile devices [19]. The following Inmarsat-services are already available respectively will be available soon:

- -C for portable mobile data radio (since 1991)
- -M, portable telephone (since '92) for 4.8 kbit/s voice and 2.4 kbit/s Telefax and data transmission
- radio paging to pocket receivers by 1994

3.6 Wireless Local Networks, ETSI/HIPERLAN

Wireless LANs is a new development for local use. Radio waves are used instead of a cable as a transmission medium to connect stations. Either, the radio transceiver is mounted to the movable station as an add-on and no base station has to be installed separately, or a base station is needed in addition per room. The stations may be moved during operation-pauses or even become mobile. The standard ETSI/HIPERLAN will be developed until end of 1994. Frequencies in the range around 5.2 and 17.1 GHz have been reserved for that, cf. Table 5.

The max. data rate for the user depends on the distance of the communicating stations. With short distances (≤ 50 m) and asynchronous transmission a data rate of 20 Mbit/s is achieved, with up to 800 m distance a data rate of 1 Mbit/s shall be provided. For connection-oriented services, e.g. video-telephony, at least 64 kbit/s are offered.

The access-protocols for wired LANS are standardized in IEEE 802. Project 802.11 works to enable the further usage of the IEEE 802.2 Logical Link Control (LLC) protocol with wireless LANs. Several EU research projects work towards the development of 3rd generation mobile radio systems which, besides others, will offer the wireless LAN services. E.g. the MBS-project R2067 develops an ATM based cellular radio system useful for indoor communication. Data rates of up to 80 Mbit/s will be available at the radio interface[20].

RadioLAN	ETSI	Group	
WLAN*	59..62GHz (at first)	IEEE	802.11
	61..61.5GHz (500MHz)		
HIPERLAN	5,15..5,35GHz or	ETSI TC RES 10	
	5,47..5,65GHz (150MHz)		
and	17,1..17,3GHz (200MHz)		
Wide band data transmission systems	2,4..2,5GHz (100MHz)	ETSI TC RES 2	

* Wireless local area network

TABLE 5: FREQUENCIES AND STANDARDIZATION GROUPS

ACKNOWLEDGEMENT:

This work has been partly funded by RACE project MBS R2067

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