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Name:	Dirk Kuypers, Peter Sievering, Martin Steppler
Affiliation:	Communication Networks Aachen University of Technology
Address:	Kopernikusstr. 16 D–52074 Aachen, Germany
Phone:	+49 241 879 3779
Fax.:	+49 241 889 0374
Email:	{dk,psi,steppler}@comnets.rwth-aachen.de

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Traffic Performance Evaluation of TETRA and TETRAPOL

Dirk Kuypers, Peter Sievering, Martin Steppler

Communication Networks
Aachen University of Technology
Kopernikusstr. 16, D–52074 Aachen, Germany
Email: {dk,psi,steppler}@comnets.rwth-aachen.de

Abstract

In this paper we present a novel approach regarding the comparison of trunked mobile radio systems. Based on this concept, the TETRA V+D and TETRAPOL standards are compared for a defined scenario, which is also presented. The results of the traffic performance measurements for ETSI scenario 10 show differences in connection set-up times in TETRA and TETRAPOL systems. The probability for a connection set-up time exceeding 300 ms in TETRA is about 7–30 %, whereas in TETRAPOL it is about 90 %.

1 Introduction

New trunked mobile radio systems are about to be implemented in European countries. Both standards, *Terrestrial Trunked Radio* (TETRA) developed by the *European Telecommunications Standards Institute* (ETSI) and TETRAPOL developed by Matra Nortel Communications, provide pure digital information technology for the transmission of speech and data and have been chosen as platforms for the operation of nation-wide trunked radio networks in Europe. As TETRA and TETRAPOL are competitors in the market of *Professional Mobile Radio* (PMR), it is essential to compare the performance of both system types.

Currently, the German public safety forces (police, fire brigades, customs etc.) examine, whether TETRA Voice+Data (V+D) meets their tactical and operational requirements. Both standards are expected to fulfill the requirements differently.

Our approach is the traffic performance evaluation of TETRA and TETRAPOL by means of stochastic simulation using a prototypic implementation.

Starting with an outline of the TETRA and the TETRAPOL systems in Section 2, we then present our simulation concept in Section 3. In Section 4 we describe the scenarios, our performance measures are based on. Finally, the results of these measures are discussed in Section 5.

2 The TETRA and TETRAPOL standards

The trunked radio systems TETRA and TETRAPOL can be used as a local or a multicellular network. They can be operated in the frequency bands between 380 MHz and 470 MHz and between 870 MHz and 933 MHz (TETRA) and between 70 MHz and 520 MHz (TETRAPOL) resp.

In this section we give a short outline of the TETRA and TETRAPOL systems and their protocol stacks at the air interface.

2.1 Technical data of the TETRA standard

The TETRA system uses $\pi/4$-*Differential Quaternary Phase Shift Keying* (DQPSK) modulation and offers a gross bit rate of 36 kbit/s in a single 25 kHz channel. With V+D, four *Time Division Multiple Access* (TDMA) voice or data channels are available per carrier [1, 2]. A typical TETRA *Base Station* (BS) can handle up to 8 carrier frequencies with 31 traffic channels, but there is no restriction imposed by the standard.

The frame structure consists of four 510-bit time slots per frame, 18 frames per multiframe and 60 multiframes per hyperframe, the latter representing the largest time unit and taking approximately one minute.

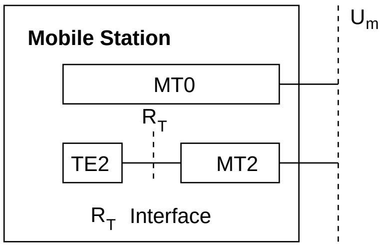

Figure 1: Reference point U_m

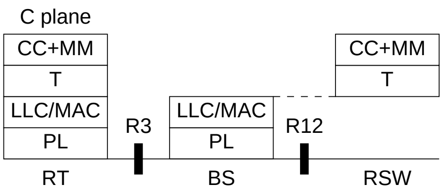

Figure 2: Reference point R_3

The reference point between radio terminal and radio base station is denoted as U_M, see Figure 1.

2.2 Technical data of the TETRAPOL standard

The TETRAPOL channel access is based on *Frequency Division Multiple Access* (FDMA) with a channel spacing of 12.5 kHz. The gross modulation bit rate is 8 kbit/s using binary *Gaussian Minimum Shift Keying* (GMSK) modulation. Each radio channel provides one bi-directional control or traffic channel and carries a set of logical channels. At least one *Control Channel* (CCH), which is called *Master Control Channel* (MCCH), is known to all *Mobile Stations* (MS) in a radio cell. Multiple *Extended Control Channels* (ECCH) can be defined in a radio cell to extend the signalling capacity. A traffic channel can either be used to transmit circuit-switched data or speech frames [3]. A TETRAPOL BS can handle up to 24 radio channels.

A radio channel's structure in time is described by the subsequent repetition of so-called superframes, which last 4 s and consist of two-hundred 160-bit frames, numbered from 0 to 199. Each logical channel uses a part of the superframe structure. The length of a single frame is 20 ms.

The reference point between radio terminal and radio base station is denoted as R_3, see Figure 2.

2.3 Architecture of TETRA and TETRAPOL protocol stacks

The protocol stacks at the reference points U_m resp. R_3 are characterized by a very similar architecture and comprise three layers: the *Physical Layer* (PL); the data link layer, which is divided into *Medium Access Control* (MAC) and *Logical Link Control* (LLC); and Network Layer (N) in TETRA systems, which is divided into several sublayers and offers management services to base and mobile stations, the Transport Layer (TL) in TETRAPOL systems resp. The MAC layer is based on two protocol stacks: the *user plane*, which is responsible for information transport, and the *control plane* for signalling, see also Figure 3.

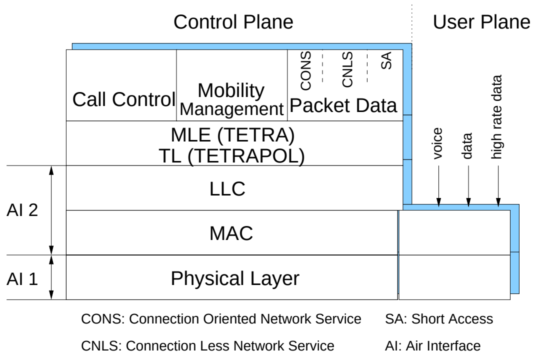

Figure 3: TETRA and TETRAPOL protocol suite

3 Simulation concept

For the traffic performance evaluation of the TETRA and TETRAPOL protocol stacks, the protocols of the air interface at reference point U_M (TETRA) resp. R_3 (TETRAPOL) have been implemented.

The structure of the simulator TETRIS is depicted in Figure 4. The protocol stacks of the trunked radio systems have been specified with the help of *Formal Description Techniques* (FDT) to guarantee not only syntactically and semantically unambiguous formal descriptions of the communication protocols but also interoperable and compatible implementations of these protocols independent of their implementors [4]. The *Specification and Description Language* (SDL) is the most widely used FDT in the area of telecommunications [5, 6, 7, 8]. With the help of the C++ code generator SDL2SPEETCL [9], which converts SDL phrase representation to C++ source code, the mobile and base station protocol stacks have been embedded in the C++ simulation environment. The C++ implementations are based on the *SDL Performance Evaluation Tool Class Library* (SPEETCL) [9]. The SPEETCL provides generic C++ classes as well as a simulation library with strengths in random number generation, statistics evaluation, and event-driven simulation control.

The core of the simulator is the simulation control, which creates mobile and base stations and assigns the traffic generators to create specific traffic loads to the individual mobile stations. Depending on the scenario, the traffic generators are controlled to offer a certain traffic load. Traffic load is defined by

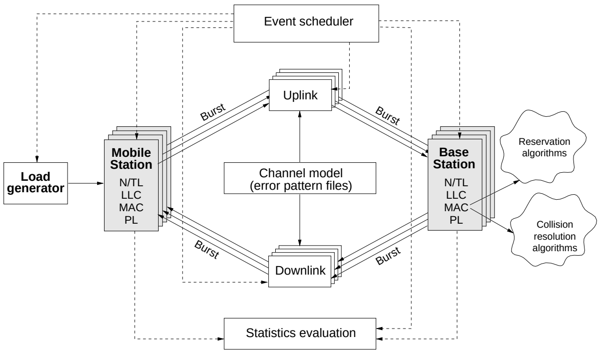

Figure 4: Structure of the simulation environment

inter-arrival times and the size of the data units. The SPEETCL contains traffic load generators for applications like speech [10], video [11], *Hypertext Transfer Protocol* (HTTP) [12], telnet [13], *File Transfer Protocol* (FTP) [13], *Simple Mail Transfer Protocol* (SMTP) [14], *Wireless Application Protocol* (WAP), and load-patterns with use-cases in *Message Sequence Charts* (MSC) [15].

Mobile and base stations communicate via uplink and downlink channels, created by the simulation control, by exchanging bursts. With the help of error pattern files, transmission errors can be introduced on the uplink or downlink dependent on the actual *Carrier to Interference Ratio* (CIR) value at the respective receiver. The error pattern files have been generated taking into account a channel propagation model, the characteristics of the physical layers.

4 Scenarios

In [16] ten different scenarios are defined for the comparison of TETRA systems. For each scenario, detailed specifications have been laid down concerning speech activity and offered data traffic of the mobile end user. Furthermore, the channel model to be used, the size of the scenario area, the number and type of the mobile stations, mobile or hand radio terminal, and their maximum velocity have been defined. Due to the fact, that scenario 10 defines the highest amount of offered load per terminal, this scenario has been chosen for our performance analysis. Scenario 10 describes the parameters of a public or private network for airlines ground services, airport security, fire brigades and so on. Table 1 depicts the general parameters defined by scenario 10.

As can be seen from Table 2, the total traffic load per mobile terminal is:

$$\lambda = \lambda_s + \lambda_{sd} + \lambda_{md} = 24.1\,\mathrm{h}^{-1} \qquad (1)$$

The speech arrival rate λ_s has been calculated using $\lambda_s = A_s/\bar{\beta}_s$. The mean waiting time is defined as the duration between the dialing of a subscriber or group

Table 1: Scenario 10 – General Parameters

Parameter	Value
Type of area	Bad Urban (BU)
Covered area	50 km^2
Subscriber density	50 $\frac{1}{km^2}$
Subscriber distribution	Gaussian
Class of terminals	80% portable, 20% vehicle
Velocity	3–50 km/h
Grade of Service	5%

Table 2: Scenario 10 – Traffic per radio user

Parameter	Value
Speech activity	$A_s = 20\,\mathrm{mE}$
Call duration	$\bar{\beta}_s = 20\,\mathrm{s}$
Mean waiting time	$\bar{\tau}_w = 4\,\mathrm{s}$
Speech arrival rate	$\lambda_s = 3.6\,\mathrm{h}^{-1}$
Mobile Station to Fixed Network Call	20%
Mobile Station to Mobile Station Call	20%
Acknowledged Group Call	50%
Open Channel Call	10%
Short data (100 byte) arrival rate	$\lambda_{sd} = 20\,\mathrm{h}^{-1}$
Middle data (2 kbyte) arrival rate	$\lambda_{md} = 0.5\,\mathrm{h}^{-1}$

number and the successful completion of the call set-up.

60 % of the voice calls are assumed to be group calls, the mean group size is 20 mobile terminals. We assume that the 2500 radio users are distributed over four radio cells. Configurations with 400, 500, 600, 700, and 800 users per radio cell are evaluated, taking into account a non-uniform distribution of the radio users over the four cells.

TETRA and TETRAPOL systems allow queueing of set-up calls and the Erlang C formula [1] is applicable for trunking capacity estimation under the call queuing strategy. Due to the mean number of 625 radio users per cell the total mean offered speech traffic is $A = 12.5\,\mathrm{E}$. To reach a call blocking probability of 5 % at least 20 traffic channels and one control channel are required. Therefore, in a TETRA system at least six carrier frequencies with four time slots, accordingly 150 kHz spectrum per radio cell, are required. For a fair comparison of TETRA and TETRAPOL with regard to the available number of traffic channels, the TETRAPOL system is provided with 24 carrier frequencies, consuming 300 kHz spectrum.

5 Performance Measurements

In this section the results of the traffic performance analysis are presented. At first, the TETRA system is examined. Then, the performance of a TETRAPOL system is evaluated in detail. Conclusion regarding the comparison between the two system types are drawn in the following section.

Due to the limited signalling capacity on the TETRAPOL *Random Access Channel* (RACH), a configuration with 2 signalling and 22 traffic channels has been chosen for the performance analysis.

5.1 TETRA

Figure 5 shows the complementary distribution function of the *Random Access Channel* (RACH) access delay in a TETRA system for the traffic load parameters of scenario ten. The RACH is used to activate point-to-point connections as well as group communications. The complementary distribution function describes the probability that the delay is lower than a given level.

The access delay is defined as the duration between the creation of a connection set-up request and the reception of the acknowledgment of a successful connection set-up sent by the BS. The access delay is influenced by the structure of the logical channels and the collision resolution algorithm.

If the TETRA BS can not assign capacity to an MS within a preset time after a successful access on the RACH, the MS accesses the RACH again to repeat the capacity request. In the simulation results presented, this time-out is set to 18 TDMA frames. Thus, the access delay, as shown in Figure 5, also takes into account the retransmission on the RACH due to these time-outs.

With a higher traffic load offered, the probability for a repetition of the capacity request is increased because of the limited number of traffic channels. In case of 400 MSs this probability is about 8 % and with 800 MSs it becomes more than 20 %.

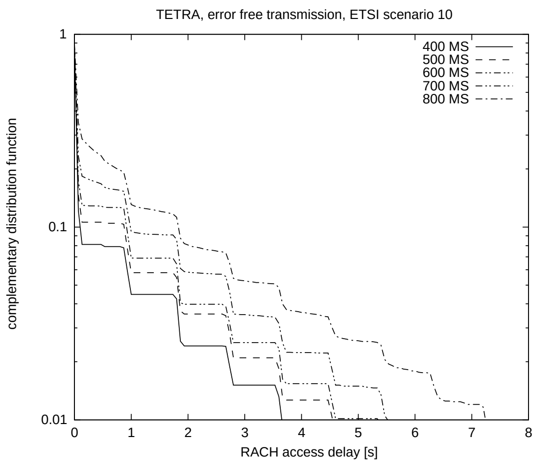

Figure 5: TETRA RACH access delay

The connection set-up time, as shown in Figure 6, includes both, the access delay and the waiting time for the assignment of a traffic channel. The measurements include point-to-point as well as group communications.

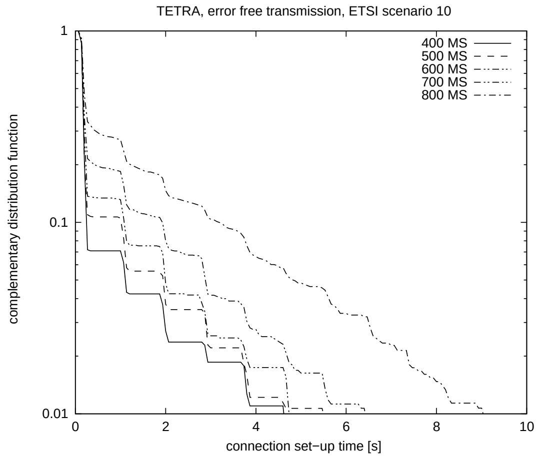

Figure 6: TETRA connection set-up time

Because of the low collision probability, the RACH access delay for the first access is small and the connection set-up time is mainly influenced by the waiting time for a free traffic channel. In all the traffic load settings studied, the blocking probability is smaller than 5 %.

5.2 TETRAPOL

In TETRAPOL, the logical *Random Access Channel* (RACH) is used to set-up or reestablish a transaction between mobile station and base station. Again, the RACH access delay is defined as the duration between the creation of a connection set-up request and the reception of the acknowledgment of a successful RACH access. Figure 7 depicts the complementary distribution function. The minimum access delay is 280 ms, which is the constant time difference in a superframe between the RACH and the *Random Access Answer Channel* (RCH). A TETRAPOL base station acknowledges the successful reception on the RACH by broadcasting on the RCH.

The number of active mobile stations has a huge impact on the probability, that two or more mobile stations disturb their transmission on the RACH. With 400 MSs this collision probability is 15 % and it rises up to 50 % if 800 MSs are assumed. The mobile stations retransmission algorithm determines whether a collided terminal accesses the following RACH frame again or switches to a wait state without accessing the RACH [17].

The *Dynamic Access Channel* (DACH) is used by the terminals to spontaneously transmit short information messages. For example, a group communication activation request is transmitted on the DACH. As can be seen from Figure 8, the DACH access delay is relatively short because the number of DACH frames per superframe is high in comparison to the number of RACH frames per superframe.

In addition to the RACH and DACH access delays,

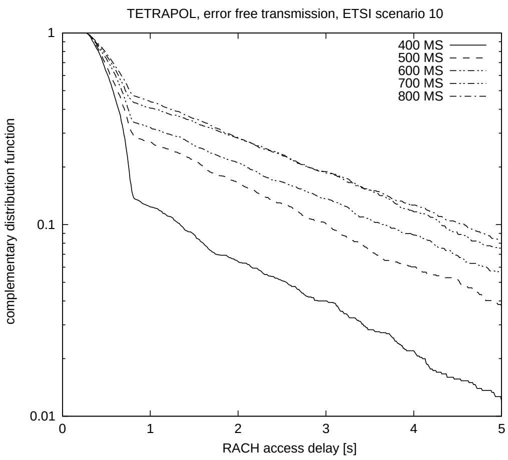

Figure 7: TETRAPOL RACH access delay

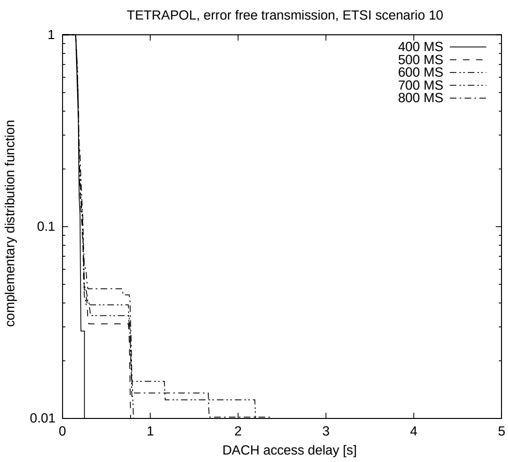

Figure 8: TETRAPOL DACH access delay

the connection set-up time also includes the waiting time for a free traffic channel. Figure 9 shows, that the connection set-up is mainly determined by the RACH access delay.

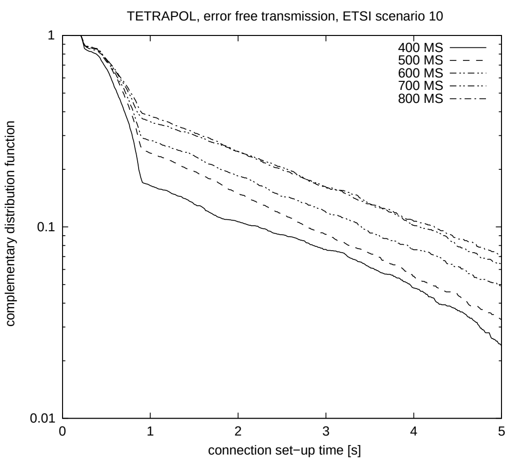

Figure 9: TETRAPOL connection set-up time

As the RACH access delay in case of 800 MSs is relatively high, the connection set-up time could be reduced by using three or four instead of two control channels. The resulting RACH access delays can be seen from the data sets “400 MS“ and “600 MS“ in Figure 7.

6 Conclusions

A novel approach for the comparison of TETRA and TETRAPOL systems has been presented. The concept for the traffic performance evaluation of trunked mobile radio systems has been laid down. The traffic load assumptions are based on scenarios described by the ETSI. The results of the traffic performance measurements for ETSI scenario 10 show differences in connection set-up times in TETRA and TETRAPOL systems. The probability for a connection set-up time exceeding 300 ms in TETRA is about 7–30 %, depending on the traffic load offered, whereas in TETRAPOL it is about 90 %.

The TETRAPOL connection set-up time is mainly determined by the RACH access delay, which can be reduced by assigning more control channels. In both systems, the mean connection set-up time is lower than 4 s as required in the ETSI scenario.

Further research is necessary to evaluate the performance of the TETRA and TETRAPOL systems under different traffic load situations as well as with the inclusion of transmission errors, e.g. due to fading and co-channel interference.

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Biographies

Dirk Kuypers (`dk@comnets.rwth-aachen.de`) received his diploma in Electrical Engineering in 1998 from Aachen University of Technology. His diploma thesis was about collision resolution algorithms and reservation strategies for the random access of TETRA PDO. In 1999 he joined the Chair for Communication Networks as a research assistant, where he is working towards his Ph.D. degree. He participated in the evaluation of the invitation of tenders for a field trial for a new digital trunked radio system for the German security forces to be performed in Aachen. At the moment he is concentrating on the Extension of the SPEET methodology to support hardware software co-verification.

Peter Sievering (`psi@comnets.rwth-aachen.de`) received his diploma in Electrical Engineering in 1999 from Aachen University of Technology. His diploma thesis was about automatic repeat request protocols in HIPERLAN/2 systems. In 1999 he joined the Chair of Communication Networks as a research assistant, where he is working towards his Ph.D. degree. At the moment he is concentrating on the performance evaluation of the TETRAPOL air interface protocol stack in comparison to the TETRA system.

Martin Steppler (`steppler@comnets.rwth-aachen.de`) received his diploma in Electrical Engineering in 1994 from Aachen University of Technology. His diploma thesis was about the performance evaluation of the TETRA multiple access protocol. Between 1995 and 2000 he served at the Chair of Communication Networks as a research assistant. Since 2000 he is the Managing Director of AixCom GmbH [9]. Currently he is working towards his Ph.D., which is about the performance evaluation of TETRA and software development methods for software implementation.