Paper submitted to

European Wireless 2005

Name:	Dirk Kuypers, Marc Schinnenburg
Contact:	Dirk Kuypers
Affiliation:	Communication Networks Aachen University of Technology
Address:	Kopernikusstr. 16 D–52074 Aachen, Germany
Phone:	+49 241 879 3779
Fax.:	+49 241 889 0371
Email:	dk@comnets.rwth-aachen.de
Paper Title:	Traffic Performance Evaluation of Data Links in TETRA and TETRAPOL
WWW:	http://www.comnets.rwth-aachen.de

Traffic Performance Evaluation of Data Links in TETRA and TETRAPOL

Dirk Kuypers, Marc Schinnenburg

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

Abstract

TETRA and TETRAPOL are competitors in the market of *Professional Mobile Radio* (PMR). In a previous study [1] we compared the trunked mobile radio systems TETRA V+D and TETRAPOL by evaluating random access performance. Here we present a comparison of the TETRA and TETRAPOL error correction schemes involved to secure LLC data links. The traffic performance of both systems was compared for ETSI scenario 8 [7]. Realistic models for the effects of propagation circumstances and co-channel interference are taken into account. The results of the traffic performance measurements exhibit differences in connection set-up times and transmission delays for data links in TETRA and TETRAPOL systems in favour of the TETRA system and reveal a strong dependency on random access delays.

1 Introduction

TETRA and TETRAPOL are competitors in the market of *Professional Mobile Radio* (PMR). 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 new trunked digital mobile radio systems are implemented in all European countries it is essential to compare the performance of both systems.

Currently, the German Ministry of Interior is preparing an invitation of tenders where both standards are expected to compete and to fulfill the requirements differently.

This study compares the traffic performance of TETRA and TETRAPOL by means of stochastic simulation using a prototypic implementation of the air interface protocol stacks. To achieve realistic results propagation effects and interference are modelled in great detail.

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 performed measurement scenarios. Finally, the results of these measures are discussed in Section 5 and conclusions are drawn in Section 6.

2 TETRA and TETRAPOL

The trunked radio systems TETRA and TETRAPOL can be used as local or multicellular networks. TETRA is operated in the frequency bands between 380 MHz and 470 MHz and between 870 MHz and 933 MHz whereas TETRAPOL is operated between 70 MHz and 520 MHz.

Following, a short outline of the TETRA and TETRAPOL systems and their protocol stacks at the air interface is given.

2.1 TETRA Technical Data

The TETRA air interface between radio terminal and radio base station is denoted as reference point U_M. A typical TETRA *Base Station* (BS) can handle up to 8 carrier frequencies with a total of 31 traffic channels (TCHs).

The TETRA system uses $\pi/4$-*Differential Quaternary Phase Shift Keying* (DQPSK) modulation and provides a gross bit rate of 36 kbit/s (28.8 kbits/s net) in a single 25 kHz frequency channel. Four time slots establish four voice or data channels per carrier (*Time Division Multiple Access*, TDMA) [2, 3]. A time slot lasts 14.17 ms or 510 bit. 4 time slots build a frame, 18 frames form the multiframe and 60 multiframes set up a hyperframe. The hyperframe represents the largest time unit in the TETRA system and takes approximately one minute. Each TCH provides data rates of 7.2 kbit/s (no channel-coding), 4.8 kbit/s (medium channel-coding) and 2.4 kbit/s (strongest channel-coding) for data transmission. Our simulations use TCHs with 4.8 kbit/s net bit rate.

2.2 TETRAPOL Technical Data

The TETRAPOL air interface between radio terminal and radio base station is denoted as reference point R_3. A TETRAPOL BS can handle up to 24 radio channels. 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. The net bit rate for data transmission is 4.6 kbit/s (low protected data) and 3.6 kbit/s (high protected data), the latter was used for simulations.

A TETRAPOL radio channel provides a 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 [4].

The temporal structure of a physical radio channel is described by the subsequent repetition of so-called superframes. A superframe lasts 4 s and consist of two-hundred 160-bit frames with a duration of 20 ms each. A logical channel uses regular recurrent parts of the superframe structure.

2.3 Protocol Stack Architectures

As depicted in Figure 1, the protocol stacks at the reference points U_m resp. R_3 exhibit a similar architecture comprising three layers:

- the *Physical Layer* (PL), which is divided into demodulator, deinterleaver and decoder;
- the *Data Link Layer* (DLC), which is divided into *Medium Access Control* (MAC) and *Logical Link Control* (LLC), see Section 2.4;
- the *Network Layer* (N), which is divided into several sublayers and offers management services to base and mobile stations. In the TETRA system this layer is called *Mobile Link Entity*, in TETRAPOL systems it is called *Transport Layer* (TL).

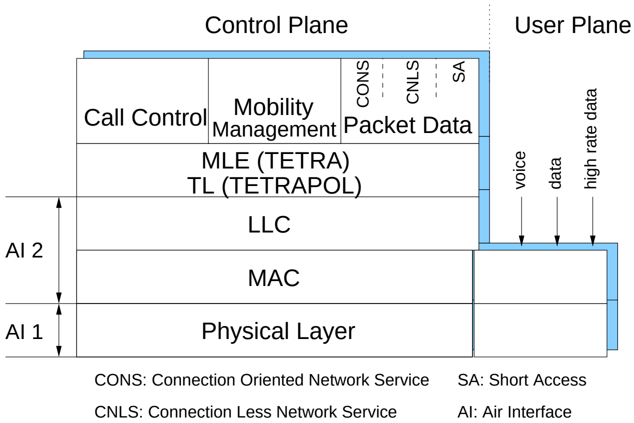

Figure 1: TETRA and TETRAPOL protocol suite

The MAC layer is based on two protocol stacks: the *user plane* responsible for information transport and the *control plane* responsible for signalling.

2.4 The LLC Sublayer

A rough overlook on the protocol architecture of the LLC layers of TETRA and TETRAPOL reveals only slight differences in the general arrangement of corresponding functions. However, major differences exist in the way data links are handled by the link entities of both systems. In contrast to TETRAPOL, TETRA differentiates between short and medium data. Short data is only fragmented in the MAC layer while medium data is segmented in the LLC layer and secured by a Selective Reject ARQ (SR-ARQ) scheme. TETRAPOL secures segmented data from the transport layer with the HDLC protocol in the LLC which provides a simple Go-Back-N ARQ mechanism before the segments are fragmented in the MAC layer.

Due to the different segmentation and fragmentation schemes in both systems, a direct comparison of the LLC layers is not appropriate.

2.5 System Characteristics Summary

A closer look at both protocol stacks reveals two completely different schemes for data transmission:

TETRA is fast by modulation, yielding high gross bit rates, although sensitive to bad radio channel conditions. To overcome its suceptibility to disturbance TETRA provides an efficient error detection and a fast retransmission scheme.

TETRAPOL uses a robust binary modulation with a smaller bandwidth leading to less transmission errors with the same radio conditions compared to TETRA. TETRAPOL provides only low gross bit rates and a weak retransmission mechanism.

In general, the robustness of the TETRAPOL radio transmission results in larger cells with small cluster

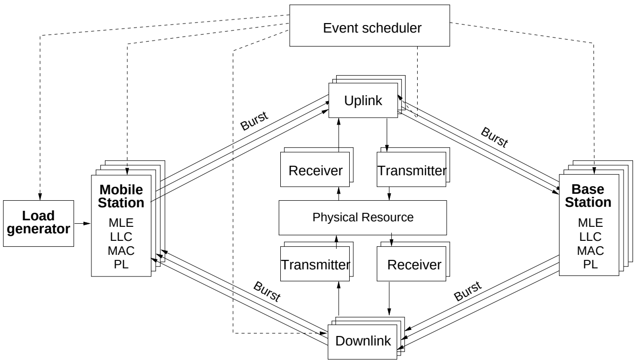

Figure 2: Structure of the simulation environment

size. In real world radio network planning there, are more parameters with great influence on cell planning, e.g., traffic capacity, performance and the overall spectral efficiency.

To compare the performance of both systems and cover all effects described, we used the detailed transmission of *Transport Layer/Mobile Link Entity Protocol Data Units* (TL/MLE-PDUs) via the lower protocol layers together with a detailed physical layer model. Therfore, the performance evaluation was done from an end user's point of view.

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) and R_3 (TETRAPOL) were implemented in the simulator TETRIS (Figure 2). The protocol stacks of the trunked radio systems were specified using *Specification and Description Language* (SDL) as widely used *Formal Description Technique* (FDT) in the area of telecommunications [5]. With the help of the C++ code generator SDL2SPEETCL [6] that converts SDL phrase representation into C++ source code, the mobile and base station protocol stacks were embedded in the C++ simulation environment.

The simulation control is the core of the simulator creating mobile and base stations and assigning the traffic generators to create specific traffic loads to the individual mobile stations. Depending on the scenario, the traffic generators provide a certain traffic load. Traffic load is defined by inter-arrival times of a negative exponential distribution and the size of the data units.

The information bursts of MS and BS are transmitted via up- and downlink. All receivers are attached to a physical resource that is charecterized by its frequency and bandwidth. The attached receivers are notified, if a transmission is started or ended on their specific physical resource. The physical resource holds a detailed model of the physical layer containing pathloss and interference. With the help of the physical resource, every receiver calculates the average *Carrier to Interference Ratio* (CIR) for the received bursts. The CIR is provided as input to the demodulator of the receiver to calculate a raw *Bit Error Ratio* (BER) mapped to a residual BER by the decoder. With the number of transmitted bits per frame the *Frame Error Ratio* (FER) is finally obtained.

Table 1: Scenario 8: General Parameters

Parameter	Value
Type of area	Bad Urban (BU)
Covered area	500 km^2
Subscriber density	$2\,\frac{1}{km^2}$
Subscriber distribution	uniformly
Class of terminals	80% portable, 20% vehicle
Velocity	3–80 km/h
Grade of Service	5%
Speech activity	$A_s = 12\,\text{mE}$
Call duration	$\bar{\beta}_s = 20\,\text{s}$
Speech arrival rate	$\lambda_s = 2.16\,\text{h}^{-1}$
Mean waiting time	$\bar{\tau}_w = 4\,\text{s}$
Short data (100 byte) arrival rate	$\lambda_{sd} = 10\,\text{h}^{-1}$
Middle data (2 kbyte) arrival rate	$\lambda_{md} = 1\,\text{h}^{-1}$

4 Scenarios

The TETRA designer's guide [7] describes ten scenarios as a base to evaluate TETRA systems. Each scenario specifies speech activity and data traffic supplied by 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 are defined.

ETSI scenario 8 describes the parameters of a private network for civil service forces concerned with safety issues, for example police forces and fire brigades. It focusses on 'hot spots' with high occurence of accidents or events. Currently, the German Ministry of Interior examines *Private Mobile Radio* (PMR) networks on their fulfillment of their tactical and operational requirements. Therefore, we chose this scenario as a basis for our study and the general parameters defined are depicted in Table 1.

For urban areas the TETRA field trial in Aachen showed that 7 *Traffic Channels* (TCH) per cell are sufficient. It is also expected that the upcoming invitation of tenders in Germany for a nation-wide PMR network will request 7 TCHs + 1 CCH for urban areas. Hence, we chose 2 frequencies for TETRA and 8 frequencies for TETRAPOL per cell.

The scenario was set-up in the classic 7-cell cluster (Figure 3). The transmissions in the innermost cell is distorted by six interfering surrounding cells. The cluster size C can be expressed in terms of the cell

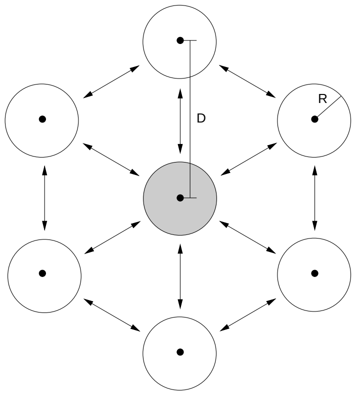

Figure 3: Scenario

radius R and the re-use distance D:

$$C = \frac{1}{3}\left(\frac{D}{R}\right)^2 \quad \text{or} \quad \frac{D}{R} = \sqrt{3C} \tag{1}$$

If the system to be planned is limited by interference, C has to rise to increase pathloss for the interfering signals; if the system is limited by the required signal strength, R can be shrunk to decrease the pathloss for the carrier field strength.

In the simulations the cluster sizes were varied from the minimum cluster sizes of $C = 13$ for TETRA and $C = 7$ for TETRAPOL [8]. The cell radius was diversified from 1–1.75 km for TETRA and 1.5–3 km for TETRAPOL. The larger cell size chosen for TETRAPOL compared to TETRA reflects the robust radio transmission of TETRAPOL with GMSK and the smaller bandwidth of 12.5 kHz.

We used an Okumura-Hata pathloss model for urban areas (f is the frequency of the carrier, h_B the height of the BS and R the radius of the cell):

$$\begin{aligned}\frac{L_{UA}}{\text{dB}} =& 69.55 + 26.16 \log \frac{f}{\text{MHz}} - 13.82 \log \frac{h_B}{\text{m}} \\ &+ (1.56 \log \frac{f}{\text{MHz}} - 0.8) \\ &+ (44.9 - 6.55 \log \frac{h_B}{\text{m}}) \cdot \log \frac{R}{\text{km}}\end{aligned} \tag{2}$$

The traffic activity defined by the ETSI scenario defines speech and data activity (Table 1). To focus on data transmissions without speech effects, we limited the traffic to data only. 400 mobiles were placed in each cell because both systems can easily carry the traffic load suggested by the scenario when cell area and user density are taken into account. Our simulations can be regarded as a catastrophe scenario where many public safety forces are concentrated on a small area.

The mobiles were placed randomly in the cells and moved by a Brownian mobility model parameterized according to Table 1. The transmitting power of pedestrian mobiles was set to 30 dBm and vehicular mobiles to 40 dBm.

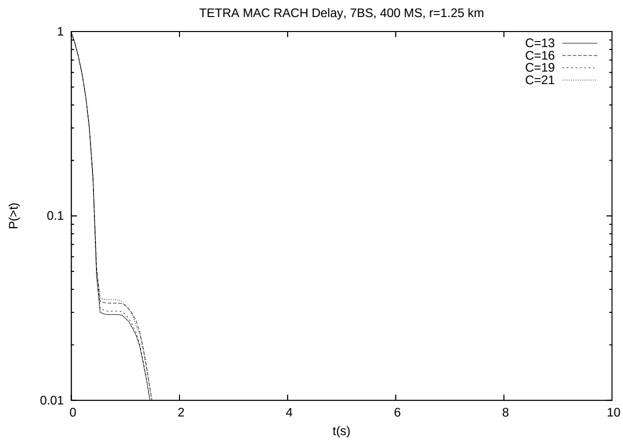

Figure 4: MAC RACH times TETRA for different cluster sizes

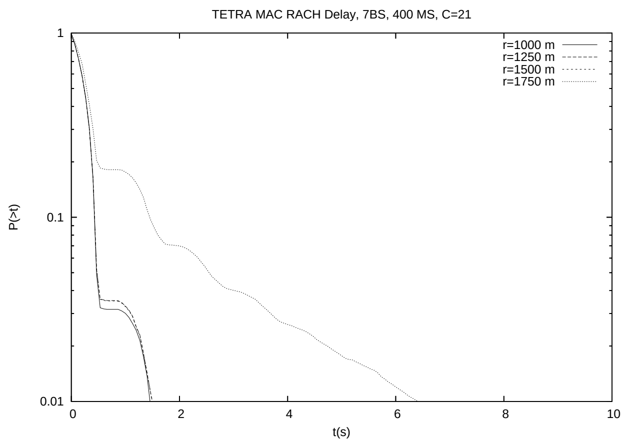

Figure 5: MAC RACH times TETRA for varied cell radius

5 Performance Measurements

This section presents our results of the traffic performance analysis as *Complementary Distribution Functions* (CDF). We used a scenario of 400 MS per cell with the data rates defined in ETSI scenario 8. Both systems were simulated at different cluster sizes and cell radii.

5.1 Random Access Times

Figure 4 and 5 present the MAC RACH Delay for TETRA, Figure 6 and Figure 7 for TETRAPOL. The MAC RACH Delay is defined as the time beginning with the first access of a mobile on the RACH until the mobile receives the positive acknowledge by the base station of successful access.

With 400 MS TETRA random access was not much susceptible to clustering. Even with cluster size $C = 13$, more than 90 % of all random accesses succeeded in less than 500 ms. The simulations for varied radii showed that for the used static pathloss model a cell

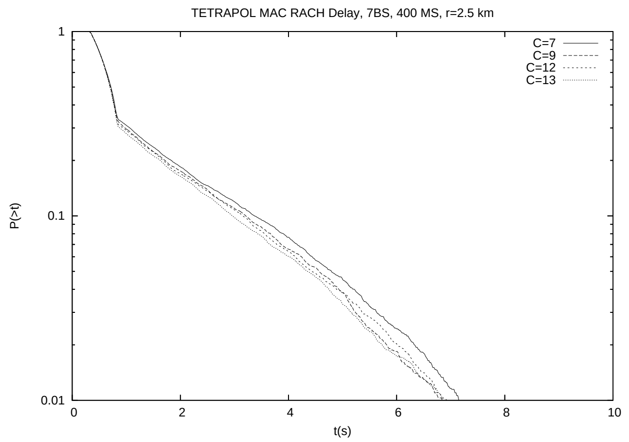

Figure 6: MAC RACH times TETRAPOL for different cluster sizes

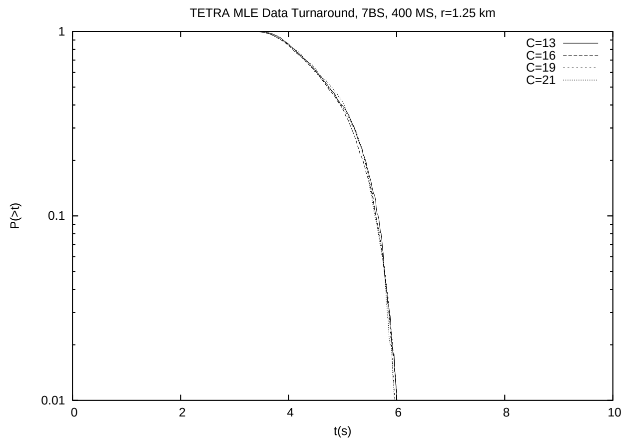

Figure 8: MLE data turnaround times TETRA for different cluster sizes

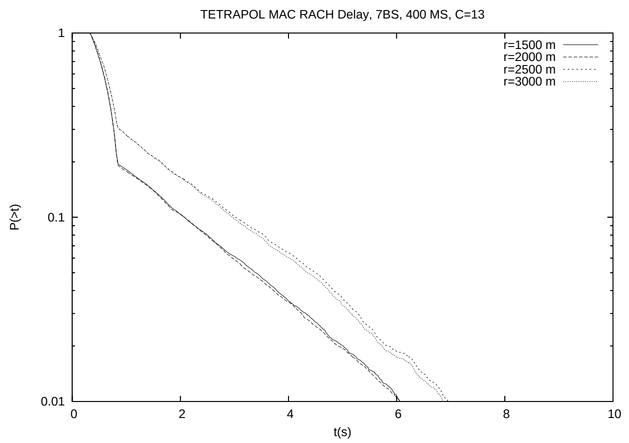

Figure 7: MAC RACH times TETRAPOL for varied cell radius

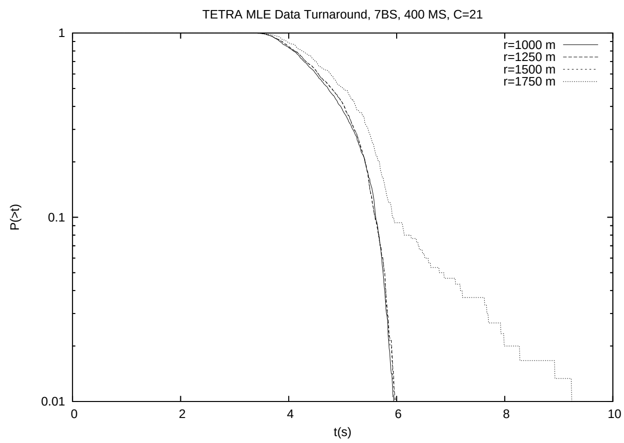

Figure 9: MLE data turnaround times TETRA for varied cell radius

radius of more than 1250 m leads to more and more stations outside base station radio coverage. The stairs in Figure 4 and 5 reflect the TETRA collision resolution algorithm.

With 400 MS TETRAPOL showed saturation effects for random access. Even under good radio conditions more than 20 % of all stations exceeded random access times of 1 s. For varied cluster sizes the RACH delay deteriorated slightly *(The simulations should be repeated for a cell radius of 2000 m)*. With increasing cell radius of more than 2000 m the TETRAPOL random access degraded, for 3000 m random access times grew about 2 s compared to 2000 m.

5.2 Data Transfer Times

Figure 8 and 9 present the Data Transfer Time for TETRA, Figure 10 and Figure 11 for TETRAPOL. The Data Tranfer Time is defined as the time from beginning to the end of the data transaction from a user's point of view.

TETRA's MLE data transfer times were only measured for long data packets. In average, for long data packets the transmission time took about 4–6 s. *The measurements for the short data packets have been omitted due to a simulator misconfiguration and will be presented in the final paper.* TETRA MLE data transfer times were not susceptible to clustering, all curves for the varied cluster sizes are very similar. With varied cell radius the same effect as in section 5.1 was observed: With cell radii less than 1250 m, all PDUs were transmitted successfully. With increasing radii more and more PDUs were lost, retransmissions are necessary and transmission times increase.

The data transfer times for TETRAPOL in this scenario showed a two-stage run of the curve reflecting the traffic load with 90 % short and 10 % long data. Short data needed about 1.5–5 s for complete transmission, long data with a length of 2 kByte about 6–10 s. The random access times on the MAC level had a great influence on overall transfer time. The cluster size revealed only a small influence on data transfer times in TETRAPOL. Retransmissions of data packets due to a higher interference level were rare. With growing cell

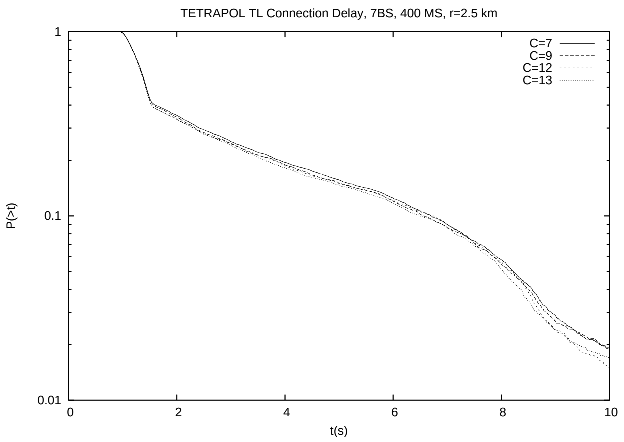

Figure 10: TL data turnaround times TETRAPOL for different cluster sizes

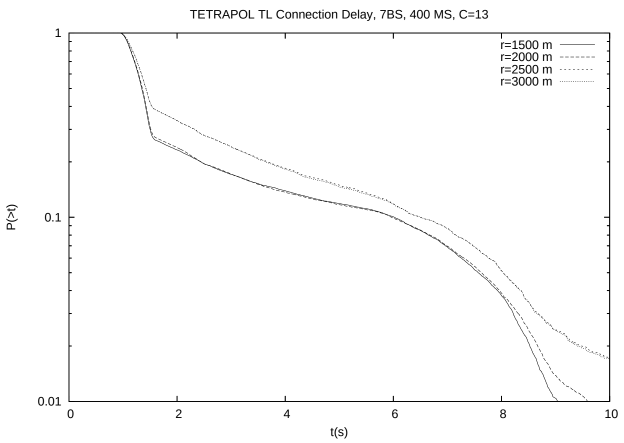

Figure 11: TL data turnaround times TETRAPOL for varied cell radius

radius the data transfer time increased, particularly for radii above 2000 m.

6 Conclusions

In this study we present a comparison of TETRA and TETRAPOL systems. Our concept for the traffic performance evaluation of trunked mobile radio systems has been described. The traffic load assumptions are based on scenario No. 8 as described by the ETSI.

Considering random access times and data transmission delays, the performance evaluation suggestss TETRA as the superior system. The results of the performance evaluation by means of stochastic simulation show that data transmission delays in TETRAPOL systems mainly depend on the random access delay. Due to these high delays, TETRAPOL systems offer a much lower grade of service in comparison to TETRA systems. The TETRAPOL random access delays data transfer delays may be reduced by using more control channels. Thus, the number of mobile terminals per control channel would be reduced and the collision probability is decreased.

It has to be noted that the comparison is based on radio cells with equal number of channels. Following studies have to take large-scale network plannings and group communication effects into account. The TETRA networks have to deal with higher traffic loads offered because a group activity area involves more radio cells than in a TETRAPOL system. Realistic scenarios should also consider fading and shadowing effects.

Further research is necessary to evaluate the performance of the TETRA and TETRAPOL systems under different traffic load situations with regard to voice traffic and group communication profiles based on traffic measurements in real public safety radio networks.

References

[1] D. Kuypers, P. Sievering, and M. Steppler, “Traffic Performance Evaluation of TETRA and TETRAPOL,” in *10th Aachen Symposium on Signal Theorie*, (VDE-Verlag, Berlin), pp. 183–188, September 2001. ISBN: 3-8007-2610-6.

[2] B. Walke, *Mobile Radio Networks, 2nd Edition.* West Sussex, England: John Wiley & Sons Ltd., 2001. ISBN 0-471-97595-4.

[3] ETSI, “TETRA Voice plus Data (V+D); Part 2: Air Interface (AI),” ETS 300 392-2, European Telecommunications Standards Institute, Mar. 1996.

[4] TETRAPOL Forum, “TETRAPOL Specification: Radio Air Interface,” Public Available Specification PAS 0001-2, TETRAPOL Forum, Bois d’Arcy, France, July 1998.

[5] ITU-T, “Specification and Description Language (SDL),” ITU-T Recommendation Z.100, International Telecommunication Union, Mar. 1993.

[6] M. Steppler and D. Bernhardt, “Formal specification, performance evaluation and visualization of communication systems,” in *Tools of Aachen 2001 International Multiconference on Measurement, Modelling and Evaluation of Computer-Communication Systems* (P. Kemper, ed.), vol. 760, pp. 47–49, Dekanat Informatik, Universität Dortmund, 2001. ISSN: 0933-6192.

[7] RES06, “Scenarios for Comparison of Technical Proposals for MDTRS,” Working Document (91) 23, European Telecommunications Standards Institute, June 1991.

[8] H.-P. A. Ketterlin, *Digital Professional Mobile Radio.* Mobile Communication Series, Norwood, MA: Artech House Publishers, 1 ed., 2004.