A Statistical Traffic Analysis of Group Speech Communications in the German TETRA Trial Aachen

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Abstract

In this paper we present a novel model for group speech communications. This model includes timing parameters as well as parameters for spatial distribution and communication topology. Parameter values for this model are derived from the German Terrestrial Trunked Radio *(TETRA) trial Aachen. In order to derive generalized parameter values, we study statistical relationships between model parameters and other measured values. Finally, we apply the new traffic model to a queuing model of a TETRA system and study* Quality of Service *(QoS) aspects.*

1 Introduction

In all European countries, the nation-wide set-up of digital trunked radio networks for public safety forces is under discussion or in progress. The German Ministries of Interior are operating a TETRA network in the area of Aachen to test the system in daily use and to derive input parameters for the planning of a nation-wide network. The TETRA pilot network is in operational use since July, 2001.

The planned coverage area includes the city and district of Aachen with 715 km^2. Mountain ranges up to 600 m and lowlands are within this area. Twelve base stations provide an availability of nearly 95 %.

Our activities in this area cover performance engineering tasks, i. e., the optimization of the existing infrastructure as well as performance analysis, i. e., the provision of technical dimensioning rules regarding traffic capacity and radio coverage for a nation-wide network.

The optimization of the pilot trial's infrastructure includes the development of tools to analyze the system's performance. We use tools to

- to analyze the speech service usage and utilization of radio resources, e. g., traffic channels.
- to monitor technical parameters (like bit error ratio, received signal strength indicator, service availability) as close to the radio user as possible without affecting users or network operation.

Traffic measurement and its modelling contribute to the number of required traffic channels at base station sites. The traffic modelling of group communications is an important factor because of the correlation of user activities and their spatial distribution over one or more radio cells and the scope of this paper.

Simulation is a method used to evaluate the performance of a multi-cellular TETRA network for scenarios, that differ from daily use in Aachen. The system performance can be examined before new data applications are introduced. Therefore traffic models are required to generate typical traffic loads.

TETRA offers circuit-switched speech services and connectionless or connection-oriented data transmission. Group communication is supported in a flexible and comprehensive way. Besides others, the possibility to use line connected terminals with prioritized access for dispatchers is another important feature, which makes TETRA interesting for public safety forces.

In this paper we present an extensive statistical analysis of speech activities in group communications. In Section 2 we describe our traffic model. Traffic measurement results from the TETRA trial Aachen are discussed in Section 3. Distributions are obtained for interarrival times and call durations. Particular emphasizes is placed on correlations, see Section 4. In Section 5 we consider some QoS aspects. Finally, we give conclusions in Section 6.

2 Traffic Model Description

Traffic models are employed as part of an analytical model or as part of a discrete-event simulation [3]. The context, in which traffic models are used here, is queuing, where traffic is applied to a network of queues to determine various performance measures.

In order to determine performance measures of the TETRA radio access network, a prototypic implementation of the protocol stack of the TETRA air interface [12, 2] has been integrated into our *SDL Performance Evaluation Tools* (SPEET) simulation framework [7, 8, 9]. Thus, the behavior of the air interface protocols is emulated during simulations. To derive performance measures, traffic load is imposed to the protocols using a traffic model.

2.1 Traffic Load Definition

To model group activity in group communications, different time scales and levels can be distinguished. Figure 1 depicts examples for different activity levels. On the access session level the user activity could be modelled by a user model that describes the access session lengths and their arrival rate. On the application level applications are active during sessions. An application session may consist of one or more connections. During connections transmissions can be continuous in time or for example packet based.

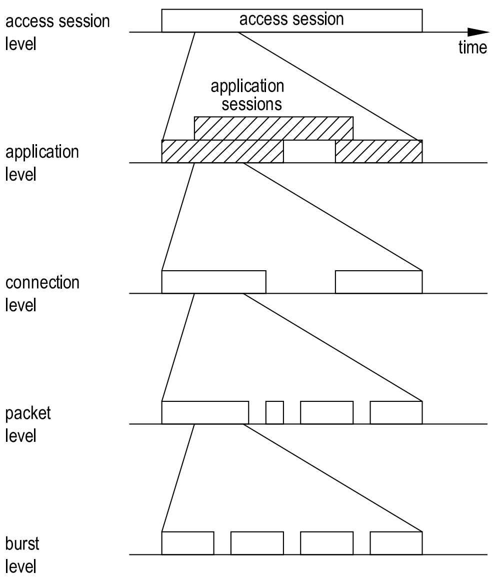

Figure 1: Different activity levels.

While the model of the TETRA radio air interface covers the *Open System Interconnection* (OSI) layers 1–3, a traffic model is used to describe the group behavior during speech group communications (group model). Users are *always on* in TETRA networks nearly all the time, i. e., their terminals are registered and authentication has been performed. The traffic load, that has to be served by the TETRA network, is generated on the application level.

2.2 Timing Analysis

Single arrivals of discrete traffic entities, so called *talkspurts*, can equivalently be described as a point process, counting process or interarrival time process. The latter one is straightforward for discrete-event simulations and is a non-negative random sequence $\{A_n\}_{n=1}^{\infty}$. $A_n = T_{n+1} - T_n$ is the length of the time interval between the nth arrival and the next one. As we focus the application level, arrivals directly correspond to the pressing of the *Push-to-talk* (PTT) buttons. Releasing the PTT button marks the end of a talkspurt. In the following we use the term *group call* as a synomym for talkspurt. We assume that $\{A_n\}$ is a stationary sequence and the common variance of the random variable A is finite.

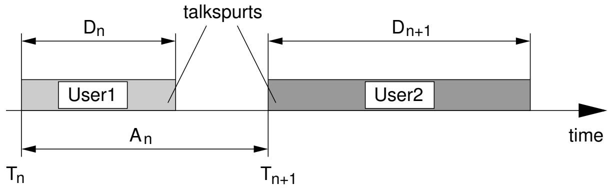

Figure 2: Sequence of talkspurts of one or more group members.

In addition to interarrival times it is essential to describe the duration of the nth talkspurt $\{D_n\}$, cp. Figure 2. Trunked radio systems manage radio resources in such a way that there is always only one talkspurt within a group. Hence, A_n and D_n satisfy $A_n \geq D_n \forall n$.

2.3 Spatial Analysis

As a group may consist of members that are widely spread over the coverage area of a cellular TETRA radio network, another aspect of the group's activity becomes important. Besides the temporal behaviour of the group members, their location area has to be modelled as well. Therefore $p_i(n)$ describes the probability, that at least one group member is located in radio cell i during the nth talkspurt, with $p_i(n) \in \{0, 1\}$. If the TETRA network consists of N_C radio cells, the actual number of radio cells involved into a group call is $N_{TCH}(n) = \sum_{i=1}^{N_C} p_i(n)$. Thus, a *Traffic Channel* (TCH) is reserved in $N_{TCH}(n)$ radio cells during the nth talkspurt. On the other hand, the mean number of TCH reserved for a certain group in a certain radio cell i is $p_{TCH} = \sum_{n=1}^{\infty} p_i(n)$, where $p_{TCH} \in [0, 1]$.

In TETRA systems $p_i(n)$ can be used to determine the following two types of group activity areas

fixed group area: a predefined set of radio cells, where a group call is broadcast, regardless whether group members reside within this cells or not.

shifting group area: an additional set of radio cells, where group members are located. Here, a group call is broadcast as well.

2.4 Topology Analysis

The procedure of group communication within German public safety forces is influenced by special regulations. Some public safety forces, e. g., medical services, normally do not allow direct communication between individual group members. In these groups communication is only permitted between a group member and the dispatcher of the group. This restriction can be described by a star topology, cp. Figure 3. The nodes symbolize group members and the edges define possible communication relationships.

Thus, the group topology is another aspect of traffic in group communications.

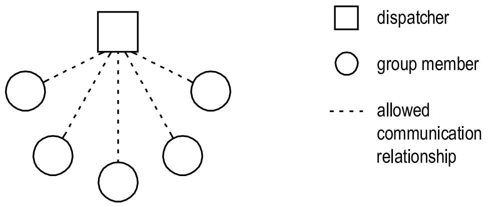

Figure 3: Star topology within a group

The inverse case, where direct communication is allowed between all individual group members without restrictions, can be described by a fully mashed topology as depicted in Figure 4.

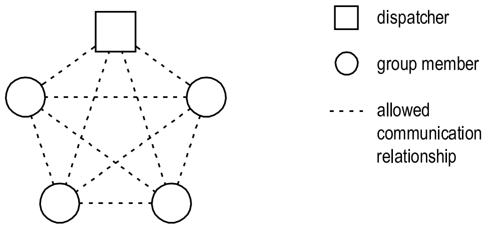

Figure 4: Fully mashed topology within a group

The Police force is a typical group, where direct speech communication between individuals is used.

3 Traffic Measurements

In [5] ITU-T has defined traffic intensity measurement principles, which we have chosen as the basis of our own traffic measurements.

Control messages of the TETRA system regarding

speech activity: call set-up and release requests

radio resource utilization: information on the allocation of traffic channels

mobility: terminal registration and deregistration

have been evaluated for a period of 9 months (from April till December, 2002), where holes in the trace data have been excluded. From these evaluations measurement results with a resolution of 1 s and busy hours have been derived. These passive measurements do not affect the values to be measured. According to our traffic model results from the timing analysis are presented in Section 3.1. Results of the spatial analysis can be found in Section 3.2 and the effect of different topologies is discussed in Section 3.3.

3.1 Timing Measurements

The network is most active on weekdays, which has also been discovered in other wireless networks [10]. This pattern holds regardless of the type of control messages (speech activity, radio resource utilization, mobility). Due to the temporal resolution of 1 s, the samples of interarrival time and call duration are value-discrete.

The empirical complementary *Cumulative Distribution Function* (CDF) of the interarrival time A between group calls within one group is depicted in Figure 5. The mean interarrival time $E[A]$ equals 11.6 s and the standard deviation is $\sigma_A = 27.5$ s. This results in a coefficient of variance of $C_A = \frac{\sigma_A}{E[A]} = 2.4 > 1$. Thus, the variability is more than that of the exponential distribution.

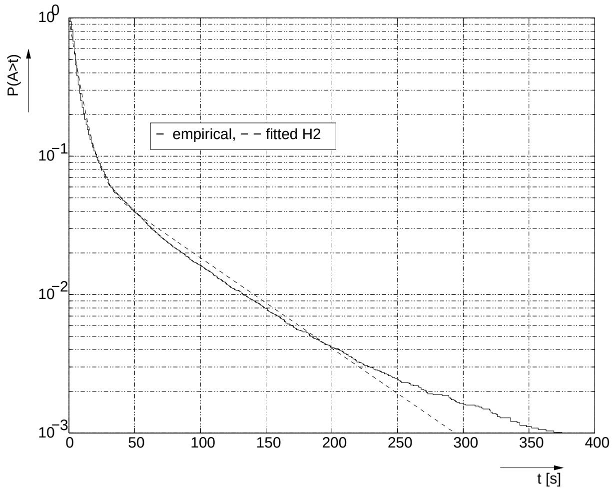

Figure 5: Complementary CDF of the interarrival time A between group calls within one group during busy hours

In comparison to an exponential distribution with the same first moment, with the empirical distribution smaller as well as very large interarrival times are more likely. This property results from the fact that group speech communication is characterized by a sequence of talkspurts with short interarrival times followed by a larger communication pause.

In order to get a flexible model for stochastic simulations, we look for a suitable approximation. The hyperexponential distribution with two phases (H_2) $P(A > t) = 0.0825 \cdot exp(-0.0151 \cdot t) + 0.9175 \cdot exp(-0.1493 \cdot t)$ turned out to be a sufficient continuous approximation of the discrete empirical distribution, cp. Figure 5. This approximation only fits good for $A \leq 200$ s. More phases would be necessary to fit the slow decay of $P(A > t)$ for $t > 200$ s, but it is sufficient to be used in simulations.

We used the *Expectation Maximization* (EM) algorithm to find the fitting parameters [1]. The EM algorithm is a statistical method which performs an iterative optimization over the parameter space to minimize the information divergence (the Kullback-Leibler information) [6].

Figure 6 shows the empirical complementary CDF of the group call duration D. The mean call duration $E[D] = 5.0$ s is much smaller than the mean call duration that can be found in point-to-point calls and very much smaller than the mean call duration in public radio of fixed networks. The standard deviation of the call duration has been calculated to $\sigma_D = 4.5$ s. Hence, the coefficient of variance is $C_D = \frac{\sigma_D}{E[D]} = 0.9$ and the variability of the call duration is slightly less than that of the exponential distribution. Due to the timely resolution of 1 s the minimal group call duration is $D_{min} = 1$ s.

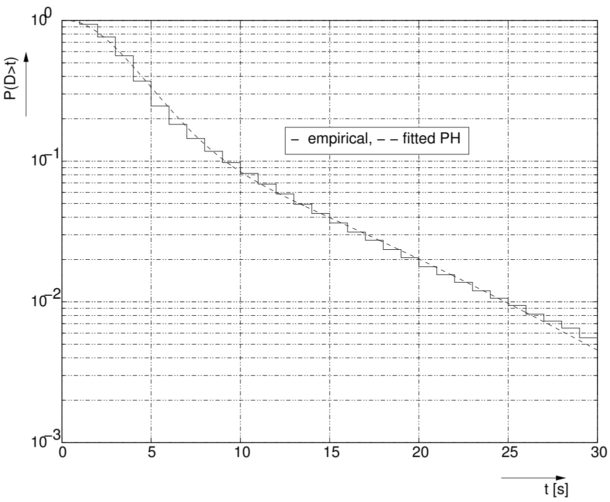

Figure 6: Complementary CDF of the group call duration D during busy hours

A suitable approximation can be found by fitting a phase-type (PH) distribution:

$$P(D > t) = \mathbf{\Pi} exp(\mathbf{T}t)\mathbf{e}$$

with

$$\mathbf{T} = \begin{pmatrix} -0.76 & 0.76 & 0.00 & 0.00 & 0.00 \\ 0.00 & -0.76 & 0.76 & 0.00 & 0.00 \\ 0.00 & 0.00 & -0.76 & 0.07 & 0.00 \\ 0.00 & 0.00 & 0.00 & -0.18 & 0.18 \\ 0.00 & 0.00 & 0.00 & 0.00 & -0.18 \end{pmatrix}$$

and $\mathbf{\Pi} = (1, 0, 0, 0, 0)'$, $\mathbf{e} = (1, 1, 1, 1, 1)$.

3.2 Spatial Measurements

Within the coverage area of the TETRA Trial Aachen, four Police stations are located. The groups of each Police station cover a certain area, in such a way that the overlapping between the activity areas of different Police stations is minimal. Additional values for a global Police group are given, which is used by all Police stations. Table 1 lists the mean probabilities p_i to find atleast one group member within the radio cells of the network at the time a group call is set-up.

These probabilities describe the activity areas of the individual groups and give input to the traffic optimization of the network (see Section 2.3).

Radio cells 1 to 6 cover urban areas, were higher activities and higher residence probabilities than in rural areas (cells 7 to 12) can be measured. While activities in the global Police group are uniformly distributed over all cells, activities in local Police groups are limited to certain cells. This information can directly be used to define fixed group areas.

Table 1: Results from the spatial analysis during busy hours

	global	**Police Station**			
Cell	**Police**	**1**	**2**	**3**	**4**
1	9.8%	2.8%	12.6%	3.3%	0.3%
2	18.6%	74.6%	44.5%	7.9%	28.6%
3	15.5%	1.3%	1.0%	27.2%	12.1%
4	18.7%	5.4%	3.3%	16.1%	53.9%
5	18.0%	1.9%	5.8%	29.5%	2.9%
6	18.4%	14.0%	32.3%	1.8%	2.2%
7	0.1%	0.0%	0.0%	2.3%	0.0%
8	0.2%	0.0%	0.0%	2.2%	0.0%
9	0.0%	0.0%	0.0%	0.7%	0.0%
10	0.1%	0.0%	0.0%	1.5%	0.0%
11	0.1%	0.0%	0.1%	1.7%	0.0%
12	0.5%	0.0%	0.4%	5.8%	0.0%

3.3 Topology Measurements

Table 2 lists the results regarding the relative activity of members of two certain groups. The first group is the global Police group. Although direct communication is allowed within the Police group (fully mashed communication topology), the dispatcher is the most active group member, but the other group members produce a remarkable fraction of 41.9% on the total activity. The relative activity of the five most active group members are 2–3% each. This is an interesting result because only less than half of the group call set-up requests are initiated from mobile terminals. Most set-up requests are initiated by line connected terminals (dispatch positions) and can be transmitted fast over dedicated lines without the limitations of the radio transmission.

Table 2: Results from the topology analysis during busy hours

User	**global Police**	**Medical Service**
`Dispatcher`	58.1%	95.7%
`User 1`	3.0%	2.3%
`User 2`	2.9%	0.8%
`User 3`	2.8%	0.5%
`User 4`	2.6%	0.4%
`User 5`	2.0%	0.2%
others	28.6%	0.1%

In comparison to the Police group, Table 2 also lists the results regarding the relative activity of members of a Medical Service group. Within the Medial Service group only communication relationships as described by a star topology are allowed. Hence, the dispatcher is involved into each group call. His relative activity is about 95.7%, i. e., the activity of mobile group members is only about 4.3%. Nearly all set-up requests are initiated via line connected terminals.

4 Correlations

In Section 3 measurements regarding the characteristic values of the group communication model (see Section 2) have been presented. For other public safety groups different parameter values may apply. So, we study statistical relationships between the call duration and other random variables like group size.

Let

$$\sigma_X^2 = Var(X), \quad \sigma_Y^2 = Var(Y),$$
$$Cov(X,Y) = E[X \cdot Y] - E[X] \cdot E[Y]$$
$$R = \frac{Cov(X,Y)}{\sigma_X \cdot \sigma_Y}, \quad -1 \leq R \leq 1.$$

If the coefficient of correlation $R = \pm 1$, X and Y are completely correlated; if $R = 0$, X and Y are statistically independent.

Figure 7 shows the dependence between group size and interarrival time for the global Police group. Here, $R = -0.18$ indicates that there is a small statistical dependency between group size and interarrival time. This means that more groups calls within a given period of time are generated if the group size increases.

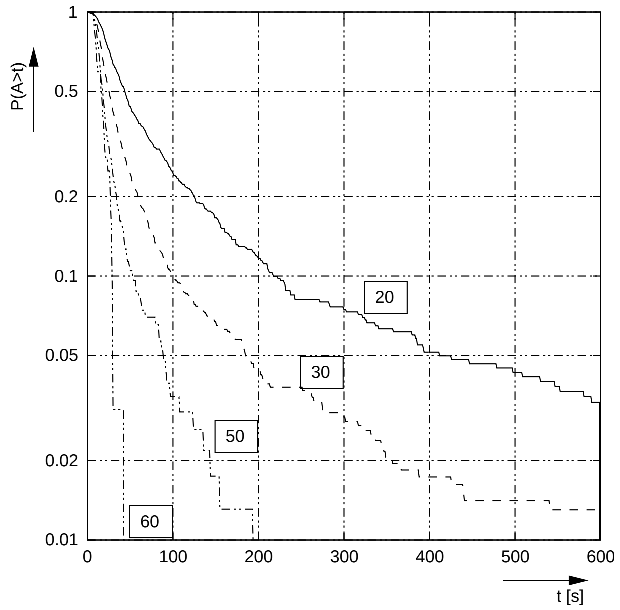

Figure 7: Complementary CDF of the interarrival time A for group sizes 20, 30, 50, and 60

Figure 8 shows a scatter plot for group size and group call duration. In this particular case $R = 0.01$ indicates that group size and group call duration are far from being dependent.

Another interesting question might be, whether the random sequences $\{A_n\}$ and $\{D_n\}$ are statistical dependent. Figure 9 depicts the scatter plot for pairs of measurements of group call duration and interarrival time. The coefficient of correlation R equals 0.101. So, group call duration and interarrival time seem to be slightly dependent. In Section 2.2 we have already seen that there is the dependency $A_n \geq D_n$.

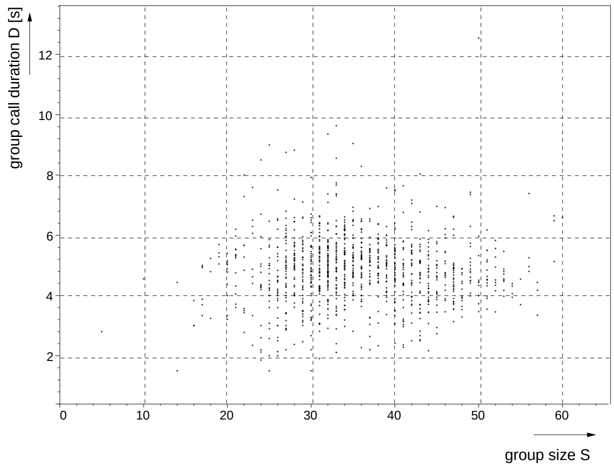

Figure 8: Scatter diagram showing no specific dependence between group size and group call duration D

In Figure 9 can be seen that all pairs of measurments of group call duration and interarrival time are located above the line $A = D$.

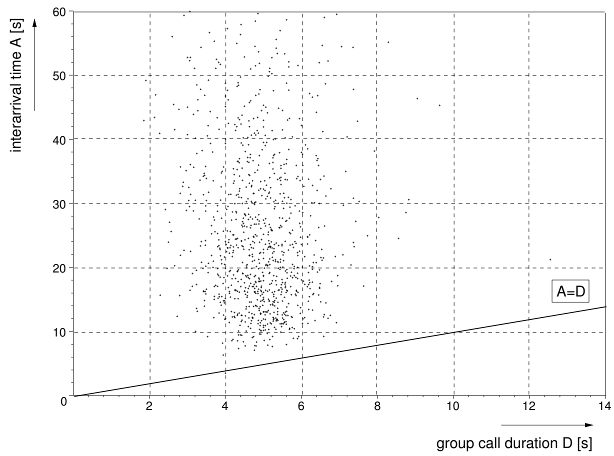

Figure 9: Scatter diagram showing no specific dependence between group call duration D and interarrival time A

5 Quality of Service Aspects

So far a new traffic model for group speech communications has been introduced and parameter values have been derived from measurments in the German TETRA trial. In this section we apply this model to a simple queuing station in order to compare the achiveable QoS with results derived from classical approaches.

When dimensioning circuit-switched radio networks for speech communications often Markovian arrival and service processes are used. We have shown in this paper that the arrival process (interarrival time process) and the service process (duration process) both are not Markovian. If we assume that the TETRA radio resource management handles group call requests under *First Come First*

Serve (FCFS) strategy, we can model a single radio cell as an $H_2/PH/n-\infty$ or $M/M/7-\infty$ queuing system. A typical TETRA radio cell might have $n = 7$ TCH.

The QoS parameter we have chosen to study is the mean waiting time W^- for a free traffic channel of queued call set-up requests normalized by the mean group call duration D. Figure 10 depicts this QoS parameter for different traffic channel utilizations ρ for an $H_2/PH/7-\infty$ queuing system in comparison to the classical $M/M/7-\infty$ queuing system.

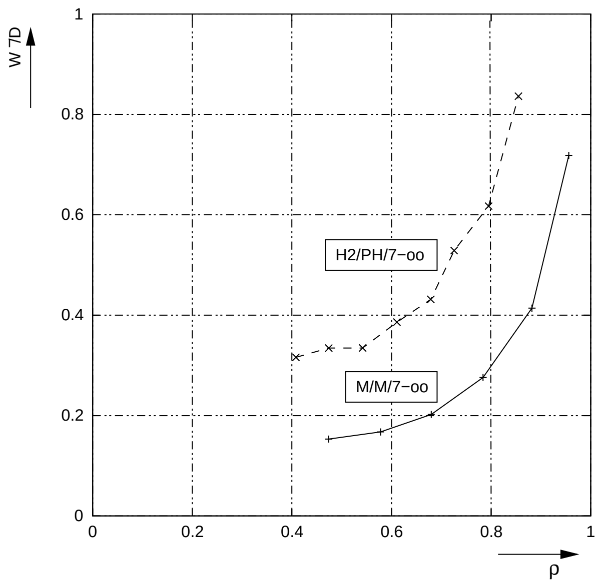

Figure 10: Mean waiting time W^- of queued call set-up requests normalized by the mean group call duration D for different traffic channel utilizations ρ

The simulation results clearly show that an $M/M/7-\infty$ can not be used to reliably predict the mean waiting time for a free traffic channel if group speech communications in TETRA trunked radion networks are investigated, but the new traffic model provides more realistic results.

6 Conclusions and Outlook

We have presented a model for group speech communications including different dimensions (time, space and topology) that can be used for stochastic simulations of a TETRA network. Parameter values for this novel model have been derived from measurements in the German TETRA Trial Aachen. The arrival process as well as service time process can not be modelled as Markovian processes.

A correlation analysis has shown that in contrast to the interarrival time the group call duration is not dependent on the total group size. Further correlation analysis will help to better understand group speech communications.

The novel traffic model for group speech communications in circuit-switched radio networks helps to reliably predict system performance.

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