Traffic Measurement and Statistical Analysis in a Disaster Area Scenario

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Abstract

Disaster areas are a typical usage scenario for mobile wireless communication systems (e.g. ad-hoc networks). Performance evaluation in mobile wireless communication systems is mainly done using simulation. Simulation results strongly depend on the traffic models used. Today, the traffic mainly used in disaster areas is voice traffic. In this paper, we present measurements of voice traffic done in a disaster area maneuver. Based on these measurements, we perform a statistical analysis of channel holding and interarrival times. We show that the traffic in disaster area scenarios has characteristics different from public mobile telephony systems. Thus, when simulating disaster area networks, different traffic characteristics should be assumed. With the results presented in this paper, it is possible to reach a realistic traffic for disaster area scenarios.

I. Introduction

Mobile wireless ad hoc networks (MANETs) are an area of intensive research. Performance analysis in this area is usually based on simulation. The choice of the traffic and its parameters has significant impact on the results of the simulations. In literature (e.g. [1]), traffic is often chosen uniformly or exponentially distributed. Some approaches (e.g. [2]) simulate voice traffic based on studies in telecommunication or cellular systems. The channel holding time in a cellular telephony system is for example analyzed in [3].

One of the most interesting scenarios for MANETs is the disaster area scenario (cf. [4]). "Wireless peer networks that involve ad hoc wireless routing networks [..] offer a promising solution to the many challenges of information sharing in OOH [Out-of-Hospital] disaster response."([5]) Public safety units need reliable communication independent of any infrastructure, because this infrastructure may be destroyed. Nowadays, the traffic in disaster areas is voice traffic. Thus, when simulating disaster area MANETs the traffic should be modelled as voice traffic. The question is whether the assumptions (channel holding times and interarrival times) in public safety scenarios are similar to a cellular telephony system.

To answer this question, we performed field studies and measured channel holding times and interarrival times in several German public safety maneuvers. In this paper, we present the results of one characteristic maneuver. Furthermore, we performed statistical analysis and compared the results to the study [3] of the cellular telephony system.

The remaining part of the paper is structured as follows. Section II describes the communication system in which the measurements were performed, as well as our measuring system. The scenario measured and the measurements are described in section III. In section IV, the analysis is described and results are presented. Finally, conclusion and future work are discussed in section V.

II. Measuring System

The measurements were performed in the analog German national radio system, called BOS-system, that is used by public services. Several frequencies are reserved, e.g. 68-87.5 MHz (4m

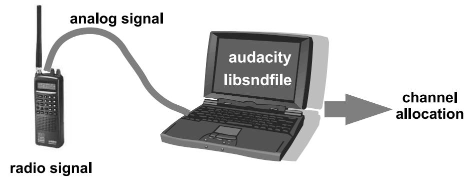

Fig. 1. Measuring system

channels) and 146-174 MHz (2m channels) are reserved for the BOS system. We measured in a maneuver of civil protection units using the BOS frequencies.

Each measuring system can measure one channel. As shown in figure 1, it consists of a radio scanner and a notebook. As radio scanner we used a Uniden Bearcat UBC60XLT-2. As notebooks we used Dell Inspiron 8100 with 1GHz processors and 256MB RAM. We recorded the audio-stream with audacity [6] and analyzed the recorded wav-files by using a little C-program, which is based on libsndfile [7]. If several samples of the wav-file exceed/fall below a threshold, the channel is regarded as used/not used. The threshold depends on the quality of the recorded signal. The more background noise there is, the higher the threshold has to be chosen. Due to background noise in the analog system, a fully automatic analysis is not possible and the threshold has to be carefully adapted for each measurement. The recordings on which this paper is based, have a quite low quality (a lot of background noise) so that the threshold was chosen appropriately.

The output of our analysis is the start and end time of each call. A call, which has a length smaller than two seconds was regarded as failure and ignored. The following two definitions specify the terms call and conservation as used within this document.

Definition 1 *A call is done by one sender that starts speaking and stops after a certain time. Note, there is only a simplex connection - unlike a telephone call.*

Definition 2 *A conversation consists of an arbitrary number of calls between two senders. Typically, the senders alternate in calling each other.*

To analyze the conversations, we considered a gap between two consecutive calls that is larger than three seconds as a separation between two conversations. This value was evaluated by checking the recorded signal semantically. We analyzed channel holding times and interarrival times for both calls and conversations. The reason for analyzing conversations was to be able to compare our results to those of [3]. In reality, the traffic in disaster area is broadcast traffic. It is unusual to simulate broadcast traffic with permanent up- and down-streams. Thus, modelling traffic by using calls is more realistic.

III. Measurements

The measurements were performed during a disaster area maneuver in Cologne. The public safety forces of the cities Cologne, Bonn, and the Rhein-Sieg-County were involved. The scenario was a train-derailing of the German high speed train ICE in a tunnel. The train had an assumed passenger number of 300. Furthermore, there was smoke emission in the engine of the train. The aim of this maneuver was to control administrative and organizational methods as well as the interoperability between the different forces.

In the maneuver there were about 1000 units (firefighters, paramedics, etc.) involved. These units shared eight different radio channels. The channels are separated due to tactical issues based on German disaster area manuals ([8], [9]). On five of these eight channels measurements could be performed. The other channels could not be included due to hardware restrictions. For two of the five channels the start- and end-times of the conversations were provided by the Cologne fire department.

The results of the measurements are shown in figures 2 and 3. Figure 2 shows the calls depicted over the time of the three channels measured with our system. Altogether, 1086 calls were

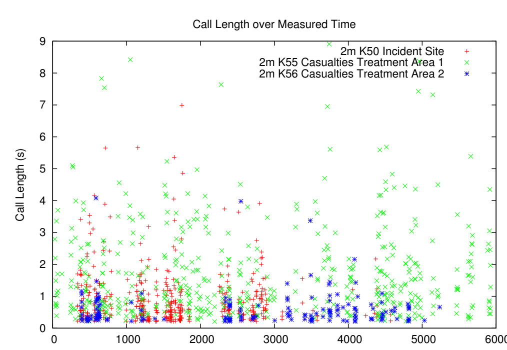

Fig. 2. Calls over measured time

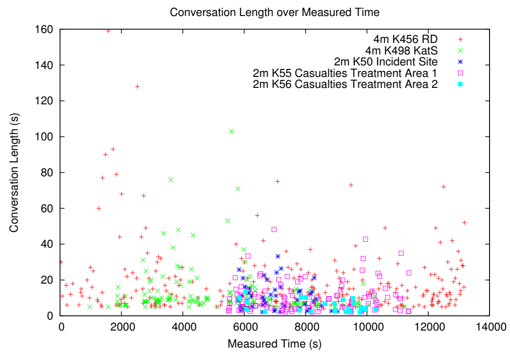

Fig. 3. Conversations over measured time

gathered. The conversation data provided by the fire department could not be split into calls.

Figure 3 shows the conversations over the time. Altogether, 600 conversations were collected. The measurements provided by the fire department started earlier at the beginning of the maneuver, while the measurements with our system had to be started later due to organizational problems.

Both figures give a general impression. Channel holding time and inter arrival time seem to be uniformly distributed over the time. In the next chapter a detailed statistical analysis is presented.

IV. Statistical Analysis

Before we show the results of the statistical analysis, the mathematical fundamentals and principles that were used during the analysis are explained.

A. Mathematical fundamentals

For the statistical analysis we took the empirical data and calculated channel holding times as well as interarrival times for each channel. In general, the statistical analysis was done as in [3], but in contrast to them we only used standard distributions.

The definition of interarrival time is as follows:

Definition 3 *Let $s_1, s_2, .., s_n$ ($n \in \mathbf{N}$) be a sequence of starting times, $s_i < s_{i+1} (i \in \mathbf{N} \wedge 1 \leq i \leq n)$. The interarrival time is the time between s_i and s_{i+1}.*

$$iat := s_{i+1} - s_i$$

Having measured interarrival times on different channels the calculation can be performed in two different ways, local and global.

- local
  Make a sequence for each channel and calculate the interarrival times according to definition 3 for each channel separately. The statistical analysis can be performed for each channel separately, as separated data sets. Additionally, the combined calculated interarrival times of all channels can be analyzed as one single empirical data set.
- global
  Take all the measured data into one sequence. Calculate the interarrival times according to definition 3. The calculated interarrival times will be smaller compared to the local calculation.

In our opinion, the global calculation makes sense for global scenarios with a raw model. Modeling more accurately, it makes sense to use the local calculation. In reality there are different groups that use different channels. If this is modelled via different broadcast channels or multicast groups, it will make sense to model the traffic separately for each channel or group, respectively. As mentioned above, modelling using calls instead of conversations is more realistic. Thus, the local calculation was used for the call inter arrival times. It was not possible to perform separate statistical analysis for each channel, because the amount of data was too small. Thus, the interarrival times calculated separately for each channel were taken as one empirical data set for the statistical analysis. The interarrival times of the conversations were calculated the global way. When modelling conversations a raw model will probably be used anyway, may be for complexity reasons.

After having identified the empirical distributions, the next step is to find theoretical probability distributions that fit. At first a set of theoretical distributions has to be chosen. The distribution should be chosen based on a hypothesis. The coefficient of variation of the empirical data is larger than one. Thus, only distributions that meet this requirement are considered. We decided to test the following distributions (density functions shown):

- Exponential Distribution

$$f(t) = \frac{1}{\beta} e^{-\frac{t}{\beta}}, t \geq 0$$

- Lognormal Distribution

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} e^{(-\frac{(log(t)-\mu)^2}{2\sigma^2})}, t > 0$$

- Gamma Distribution

$$\Gamma(\alpha) = \int_0^\infty e^{-x} x^{\alpha-1} dx, \alpha > 0$$

$$f(t) = \frac{\lambda^\alpha t^{\alpha-1} e^{-\lambda t}}{\Gamma(\alpha)}, t \geq 0$$

- Weibull Distribution

$$f(t) = \frac{\alpha}{\beta}(\frac{t}{\beta})^{\alpha-1} e^{-(\frac{t}{\beta})^\alpha}, t \geq 0$$

For each distribution the optimal parameters for the empirical distribution have to be found. Therefore, we used the Maximum-Likelihood-Method.

Having found the optimal parameters for each theoretical distribution, the quality of fitting to the empirical data has to be evaluated. For this there are several tests possible, e.g. the χ^2 (chi-squared) test and the Kolmogorov-Smirnov (K-S) test. The χ^2 test is designed for large samples and discrete distributions. In contrast the K-S test is specifically designed for small samples and continuous distributions [10]. Our data is continuous and the amount of measured data is quite small. Thus, we decided to use the K-S test. With the K-S test the distance between the theoretical distribution F_{theo} and the empirical distribution F_{emp} is represented in a value D.

$$D := \max_x |F_{theo} - F_{emp}|$$

The lower the value D is, the better the theoretical distribution fits to the empirical distribution. In the rest of this section we perform the statistical analysis for calls and for conversations. The analysis has been performed with the statistical computing tool R [11]. The MASS (Modern Applied Statistics with S) package supports the Maximum-Likelihood-Method via the *fitdistr* command and the KS-test by using *ks.test*.

B. Call analysis

In this section, the results of the call analysis are presented. These results are useful for generating realistic Broadcast or Multicast traffic.

Distribution	Parameters	KS-test distance
exponential	β = 0.79492188	D = 0.15
lognormal	μ = -0.13673588 σ = 0.83741900	D = 0.1125
gamma	α = 1.51011607 λ = 1.20034137	D = 0.125
weibull	α = 1.17570781 β = 1.34044805	D = 0.1375

TABLE I. Results of Maximum-Likelihood-Method and KS-test for call channel holding times

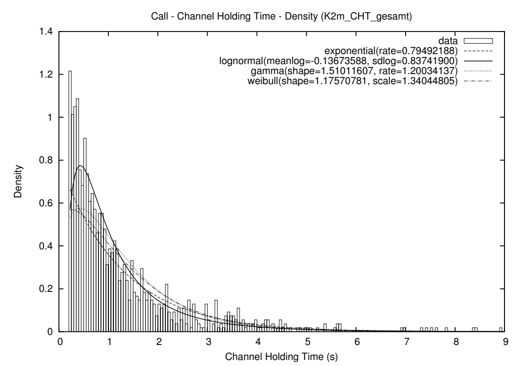

Fig. 4. Call channel holding time distributions

As mentioned above, 1086 calls were collected. Based on these, the call analysis was performed. At first, the channel holding time was analyzed. The results determined by the Maximum-Likelihood-Method can be seen in table I. The different distributions with the parameters determined are plotted against the empirical channel holding time distribution (figure 4). The figure gives an impression on the fitting of the different theoretical distributions. The results of the KS-test (distance D) can be seen in table I. The analysis shows that the lognormal distribution has the lowest distance for the call channel holding time. However, there is only a small difference between the KS-distance of the different theoretical distributions.

Additionally, the interarrival times between the calls were analyzed. As explained above, we analyzed it separately for each channel, but used one data set for the statistical analysis. The Maximum-Likelihood-Method produces the parameters shown in table II. Figure 5 gives an impression on how the distributions fit. Furthermore, the results of the KS-test can be seen in table II. Again the lognormal distribution shows

Distribution	Parameters	KS-test distance
exponential	β = 0.087402344	D = 0.5
lognormal	μ = 1.02846133 σ = 1.44560895	D = 0.33
gamma	α = 0.457331525 λ = 0.039994004	D = 0.4667
weibull	α = 0.59630008 β = 6.01821968	D = 0.3667

TABLE II. Results of Maximum-Likelihood-Method and KS-test for call interarrival times

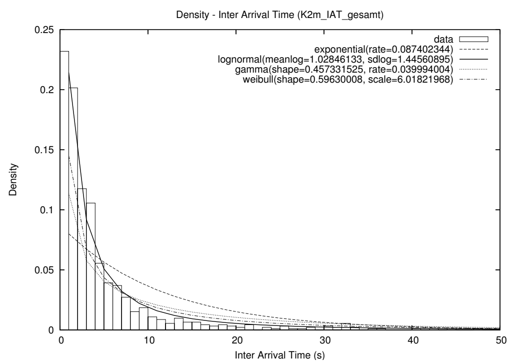

Fig. 5. Call interarrival time distributions

the best fit to the empirical distribution.

C. Conversation analysis

The results of the conversation analysis are presented in this section and compared to the results in cellular telephony systems. As mentioned above, 600 conversations were analyzed. Table III shows the results of the Maximum-Likelihood-Method. They are visualized in figure 6 and the KS-distance is shown in the right column of table III. Again, the lognormal distribution suits best.

After having shown the results of our statistical analysis, we want to compare the results with the ones in a cellular telephony system [3]. In this paper, the lognormal distribution is recommended for simplicity and accuracy reasons. The recommended parameters are shown in table IV together with the best fit of our analysis. The KS-distance of the recommended distribution to our empirical distribution was calculated and is shown as well. Furthermore, figure 7 visualizes the results. Finally, it can be said, that the traffic distribution of cellular telephony system is not transferable to disaster area networks.

Distribution	Parameters	KS-test distance
exponential	β = 0.068945312	D = 0.26
lognormal	μ = 2.35138258 σ = 0.75882683	D = 0.14
gamma	α = 1.696404859 λ = 0.116937031	D = 0.18
weibull	α = 1.19632954 β = 15.57954856	D = 0.22

TABLE III. Results of Maximum-Likelihood-Method and KS-test for conversation interarrival times

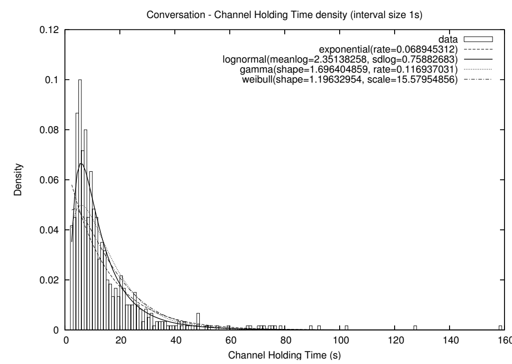

Fig. 6. Conversation channel holding time distributions

Distribution	Parameters	KS-test distance
lognormal ([3])	μ = 3.287 σ = 0.891	D = 0.54
lognormal	μ = 2.35138258 σ = 0.75882683	D = 0.14

TABLE IV. Comparison between results of cellular telephony system and disaster area communication

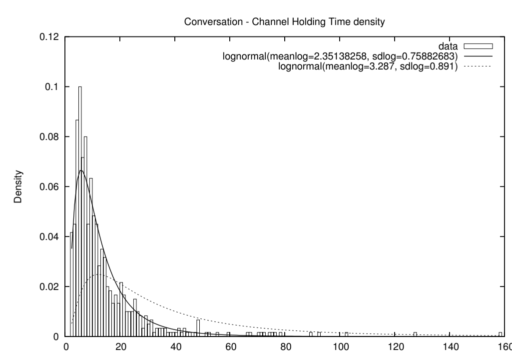

Fig. 7. Comparison between results of cellular telephony system and disaster area communication

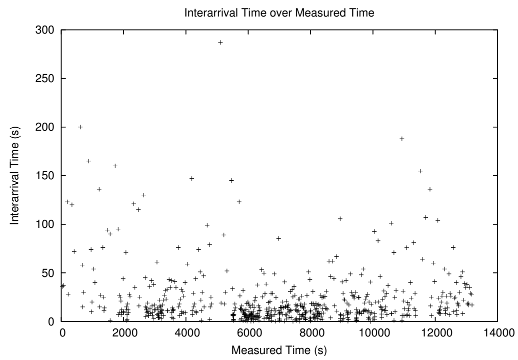

Fig. 8. Conversations interarrival time over measured time

For the sake of completeness, the statistical analysis of the global interarrival times for conversations should be performed. Figure 8 shows the conversations interarrival times displayed over the measured time. It makes no sense to perform a statistical analysis for a global calculation, because the later start of some of the measurements (from about 5600s on) can even be seen in figure 8. The values decreases, when a measurement on a further channel starts. Thus, the results of such an analysis would not be representative. A local analysis may be performed, but for this the number of conversations is too small to achieve reliable results. Thus, we decided to omit the analysis for the conversation interarrival times from this measurement.

V. Conclusion and Future Work

Measurements in public safety maneuvers and their statistical analysis help in characterizing realistic traffic for disaster area scenarios. As pointed out, results differ from the results obtained in cellular telephony systems. A reason for this is the different kind of situation (stress) and conversation (broadcast) in disaster areas.

In the future, we plan to perform additional measurements in order to get more data on which we can base our analysis. Different scenarios may show different characteristics. Furthermore, we plan to perform simulations to evaluate the results of the statistical analysis. The measured traffic (channel holding times and inter arrival times) should be simulated and compared to the generated ones. The general results of the simulation should be the same. Furthermore, we plan to perform performance analysis e.g. of routing protocols in disaster area scenarios.

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