On the Suitability of the Short Message Service for Emergency Warning Systems

Rastin Pries, Tobias Hoßfeld, and Phuoc Tran-Gia
Department of Distributed Systems, University of Würzburg, Germany.
Email: {pries,hossfeld,trangia}@informatik.uni-wuerzburg.de

***Abstract*— The Global System for Mobile Communications (GSM) is the most popular standard for mobile phones in the world with about 1.57 billion customers. The Short Message Service (SMS) in GSM allows amongst others the transmission of short text messages to mobile phones. In case of an emergency, the SMS can be used to warn a large number of individuals. However, the short message delivery is performed on best-effort basis and no quality of service (QoS) agreement is given, i.e., there is no guarantee how long it takes a message to reach the recipient or that the message will be successfully delivered. In this paper, we investigate the message loss probability and the transmission time by performing measurements with different scenarios in a public GSM network. Then, we identify problems according to the requirements for an emergency warning system. We present a solution based on the cell broadcast in GSM and show numerical results regarding the delay and the capacity of the SMS.**

***Index Terms*— SMS, GSM, transmission delay measurements, emergency warning system**

I. Introduction

Different disasters like the tsunami in December 2004 and the terrorist attacks in September 2001 have shown that an alert and warning system capable of disseminating adequate and timely warning to the public is absolutely necessary. The increasing number of mobile phone subscriptions, more than 80 out of 100 inhabitants in Europe, show that a large number of persons can be reached via a mobile phone service like the short message service (SMS).

In case of an emergency, where for example a sensor gives an alarm, the short messages, which can contain up to 160 characters, will automatically be created and transmitted to all affected users. However, the SMS is not a reliable service that guarantees QoS levels, but only offers a store-and-forward mechanism. The transmission of a short message (SM) is always relayed by a short message service center (SMSC). Because SMS uses the control channel (rather than the voice channel), a unique feature of SMS is that the user can receive a SM whether or not a call is in progress - the phone only needs to be switched on or else, the SMSC stores the message until the phone is turned on. The common channel signaling system 7 (SS7) is used to transmit SMs in the network subsystem of GSM and dedicated control channels (DCCH) are used for the radio transmission over the air interface. The transmission delay is determined by the signaling path and mainly by the radio interface.

In this paper, we take a closer look at the short message service to see if it can meet the high performance demands for an emergency warning system. Therefore, we measured the message delay and packet loss in the public German GSM network in order to identify problems according to the requirements for an emergency warning system.

The rest of this paper is organized as follows. In Section II, the related work focusing on the SMS is presented. A basic description how the SMS is implemented in GSM is given in Section III. The measurement setup and the obtained numerical results for the different measurement scenarios are provided in Section IV. Section V introduces the idea of improving the emergency warning system by using cell broadcast and shows some numerical results regarding the delay and the capacity of the SMS. Finally, the paper is concluded in Section VI.

II. Related work

The American initiative E911 [1] and the European initiative E112 [2] facilitate a seamless communications infrastructure for emergency services. Both initiatives focus on standardizing and improving emergency service calls for telephone subscribers in the United States and the European Union. The E911 and the E112 investigate additional functionalities like providing a precise location information of the calling mobile station in emergency cases. In this work, however, we consider the opposite direction, a emergency warning system based on the SMS which informs the mass of people about an emergency and a special group of subscribers, like firemen, to react to it.

In GSM, there are two types of SMS available: cell broadcast (SMS-CB) and point-to-point (SMS-PP). The technical realization of the SMS-PP and the SMS-CB is defined by the ETSI in [3] and [4], respectively. An overview of the SMS in GSM is presented in [5] and a detailed description of the physical layer, the channel structure, and the involved protocols is provided in [6].

In [7] from the Canadian government, communications like SMS are discussed in recovery and crisis management following a disaster. It is claimed that the short message service worked well just after the terrorist attack in September 2001 but it was impossible to make any voice calls. A very rough analysis of the SMS load and the network capacity for the use of the SMS in emergency cases is derived in [8]. The reliability of the SMS with respect to security attacks and the bottlenecks of the SMS in cellular networks are discussed in [9].

The study in [10] analyzes the capacity of the GSM short message service. The paper focuses on the blocking probability of SMs considering standalone DCCH (SDCCH) and applies the Erlang B formula for loss systems. [11] also computes the capacity of the SDCCH signaling channel by using the Erlang B formula. However, in both papers, the message delay which is crucial for emergency warning systems is not considered. A network model is proposed in [12] which considers the different signaling channels including DCCH for transmitting SMs. A simple optimization problem is developed with a very basic cost function to minimize, among others, the probability of delay for the SMs. However, the SM delay is not discussed and derived.

To the best knowledge of the authors no emergency warning system based on SMS has been investigated which evaluates the message loss probability and the message delay times by means of measurements in public GSM networks or other performance evaluation methods.

III. Short Message Service in GSM

In order for the sensor, indicating the emergency, to communicate with a number of mobile stations, several protocols are needed. The basic architecture for such a system is shown in Figure 1. The sensor network is connected to the SMSC. The SMSC forwards the messages to the recipient. However, if the user is not reachable, the SMSC stores the message temporarily. It is possible to specify the period of time, the so-called validity period, after which the message will be deleted from the SMSC and hence will not be forwarded to the recipient. For an emergency system, a validity period of about one hour might be sufficient to inform about a crisis. If the user gets reachable again, the protocol between MSC, HLR, and SMS-GMSC enables the alerting of the SMSC to forward the message. For this purpose, a protocol between the SMS-GMSC and the SMSC has to be defined by the operator, as it is not specified in GSM.

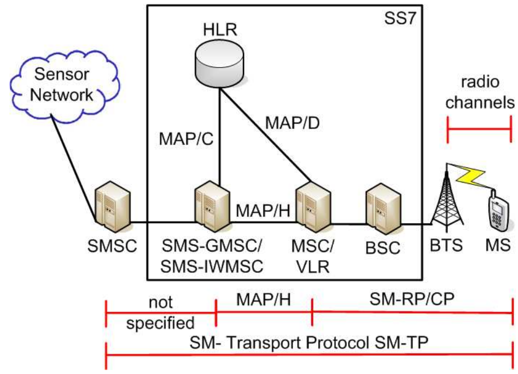

Fig. 1. Protocols for the short message transfer

The forwarding of a message from the SMSC to the mobile station[1] uses the short message transport protocol (SM-TP). If the SMSC now receives a short message, it will create a SM-TP SMS-Deliver message with the needed information for the MS. Due to the fact that the SMSC is outside the GSM network, it first forwards the message to the SMS-Gateway MSC (SMS-GMSC). The SMS-GMSC has to get some routing information from the HLR and retrieves them using the interrogation function of MAP/C. The routing information contains a SS7 address with the MSC/VLR where the mobile station is actually located. The SMS-GMSC makes use of the SS7 address and forwards the short message to the relevant MSC using the MAP/H protocol. The MSC is now responsible for delivering the SM to the MS. It therefore uses the SM Relay Protocol (SM-RP) as seen in Figure 1.

The actual information exchange on the radio channels for a point-to-point message is shown in Figure 2. First, a paging request is transmitted over the paging channel (PCH) notifying the mobile station about an incoming short message. The MS replies to the request using the random access channel (RACH) of the closest cell site. Once this paging traffic is exchanged, the BSC establishes a connection and transmits the short message over the standalone dedicated channel (SDCCH). According to the GSM channel coding scheme, the SDCCH is organized into a structure with 51 frames, the so-called multiframe, and a user is assigned one SDCCH for receiving the SM. A sector of a cell has between four and twelve SDCCHs depending on the population density of the area.

If we use the cell broadcast service SMS-CB instead, the short message is delivered on the cell

[1] denoted as mobile terminating short messages (SMS-MT) in the specifications of the GSM

broadcast channel (CBCH) to all mobile users in a specified geographical area. The geographical area is described in terms of cell identifiers which the BSC uses to route the message content to BTSs and the corresponding cells. Messages are broadcast for a user defined number of broadcasts with a user specified broadcast repetition rate. On the CBCH it is only possible to transmit 82 Bytes which holds up to 93 7-bit characters. In contrast to the SMS, a cell broadcast center (CBC) outside of the GSM network is installed instead of the SMSC. The CBC initiates the broadcast message containing the list of cells where the message should be destined for.

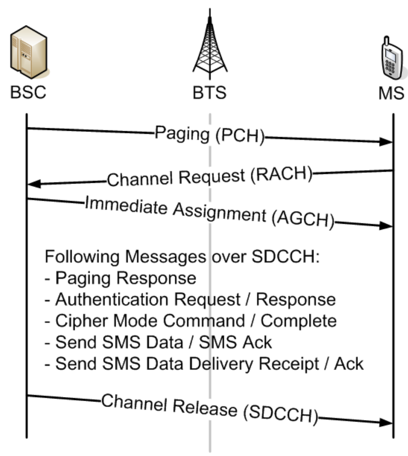

Fig. 2. Air interface channels used for SMS-MT

IV. Measurements

Our measurement scenario is shown in Figure 3. We use two Siemens S45 mobile phones with independent SIM cards, connected to one laptop. We implemented a small program in C which generates short messages at the laptop. Each of these messages contains an identifier and the timestamp when it was created. The SM is sent by the transmitting mobile phone using standard AT commands. The receiving station measures the delay of the SM and looks for lost packets at the message identifiers. We force the receiving mobile phone to notify the attached laptop about an incoming SM using the AT command (AT+CNMI = 1,1,2,2,1). Otherwise, the laptop would have to periodically request the mobile phone if it received any messages; this would lead to unexact results. The measurements are carried out within the GSM network of a major German operator (”operator a”). Additional measurements were performed in the network of another German operator (”operator b”) in order to check provider specific differences in the measurement results.

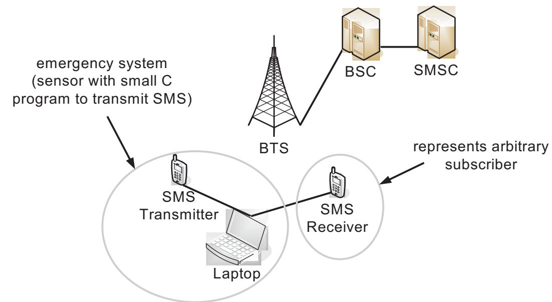

Fig. 3. Measurement scenario

In the first scenario, 400 short messages are transmitted with an inter-transmission time of one minute. The histogram of the delay can be seen in Figure 4. The figure shows that the delay of the short messages is between 8.9 s and 11.1 s.

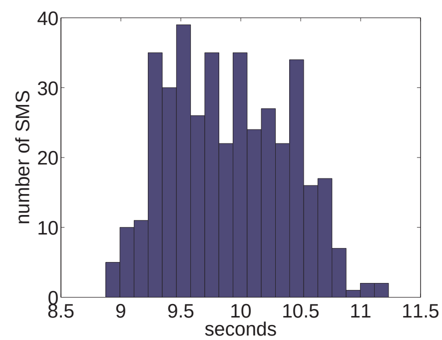

Fig. 4. Histogram of SMS delay

Figure 5 illustrates the detailed results. Every measured delay is plotted and the dashed line shows the mean SM delay of 9.95 seconds. 99 % of the short messages are received in less than 11 seconds and the figure shows that we received all 400 short messages, so no message loss occured in this measurement. The solid line illustrates that the SM is received in less than 10 seconds on

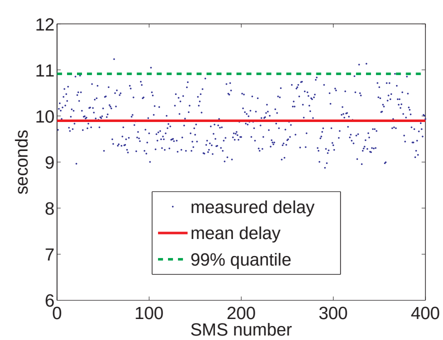

Fig. 5. Measured and mean delay and 99 % quantile

average. These first measurements show that the short message service is a reliable service with reasonable delay times for emergency cases.

In order to compare the SMS performance of two operators, we performed measurements during the busy hours with two operators. The results of these measurement are shown in Table I. It can be easily seen that the average message delay of operator b is well below the average delay of operator a. This value might depend on the actual network load during the measurements and the number of SDCCHs at the used cell. However, the observed traffic pattern is the same, no messages get lost and the maximal delay is about 12 seconds.

TABLE I
SMS DELAY DURING BUSY HOURS

	operator a	operator b
samples	200	200
min	8.663s	6.384s
mean	9.953s	7.555s
max	11.664s	12.384s

In our next scenario the receiving mobile phone is switched off when the message is sent. The user to which the message is addressed realizes that something has happened and switches his mobile phone on. We measured the delay between the activation of the phone and the SM arrival. Like in our previous scenario, we haven't seen any message loss and the messages are received in less than 45 s as seen in Table II. This rather long delay depends on the fact that, first, the mobile has to find a cell, connect to it, and has to be registered at the VLR. The VLR has to inform the HLR about the new location. Finally, the SMSC has to notice the availability of the mobile station and transmits the message.

TABLE II
SMS DELAY IN SECONDS

	standard scenario	on/off scenario
min	8.663s	37s
mean	9.953s	38.3s
max	11.664s	41s

During our next scenario, we transmit six times 20 short messages in a bulk, resulting in a total number of 120. Figure 6 illustrates the cumulative distribution function of the delay for bulk transmissions. In this scenario, all messages arrived in the correct order.

Furthermore, it can be seen that 48 percent of the short messages arrive no later than 10 seconds after their transmission, but for some messages it takes more than 40 seconds before they are received. So we take a closer look at one bulk scenarios with

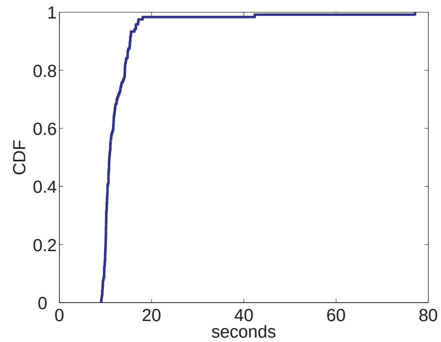

Fig. 6. CDF of bulk SMS delay

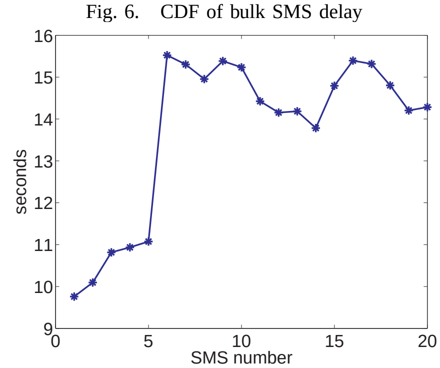

Fig. 7. Delay of a single bulk measurement

large delays, which is shown in Figure 7. The plot illustrates that if one SMS is delayed all following messages will also be delayed. This delay might be caused by failed channel requests due to other services or mobile stations utilizing the radio link capacity.

In our measurement scenarios, we have created a maximum of 20 short messages in a bulk. Even with this small number of messages the average delay and variance has increased compared to the standard scenario. However, in case of an emergency, between 100 and several thousand messages have to be created. Therefore, we suggest improvements with respect to emergency cases in the following section.

V. Improvement for Emergency Systems

The emergency system consists of two functions. First, all people within a concerned geographic area have to be informed or forewarned about an emergency. As we have seen in our measurements, only a few messages in a bulk let the delay increase significantly when transmitting each SM individually via the SDCCH. If the number of messages in a bulk further increases, the delay might become unacceptable. As stated in [8], the average number of subscribers per cell sector is 3,600 and 18,000 for Washington D.C., and Manhattan, New York, respectively. The maximal number of channels for the SMS per sector is 12 SDCCH. Neglecting the additional delay for bulk measurements, within one minute on each SDCCH $\lfloor 60/2.82 \rfloor = 21$ messages can be delivered (see below for the computation of the radio transmission time of a SM), in total 252 messages for the entire cell sector. The SMS-MT would require about 14 min and 71 min to warn all subscribers in a cell sector of Washington D.C. and Manhattan, respectively. This requires the usage of the cell broadcast which decreases the number of messages per cell to one. The second functionality of the emergency system is to inform a group of special people, like firemen, by sending extra messages, e.g. in order to instruct them how to react to the emergency. These messages have to be sent via SMS-MT to guarantee that the SMSC tries to forward the SM to them within a fixed period of time.

In the following, we approximate the message transmission time using SMS-CB by mapping the measurement results on the CBCH. A single SM contains 160 7-bit character, i.e. 140 Byte, which are transmitted in SDCCH bursts of 23 Bytes. Each burst appears in one multiframe consisting of 51 frames which consist of eight bursts of length $\frac{15}{26}$ ms. Hence, the length of a multiframe is $51 \cdot 8 \cdot \frac{15}{26}$ ms≈ 235.38 ms. The resulting transmission time of the content of the SM over the air interface follows as 1.88 s. The minimal time for setting up the SM transmission requires four multiframes for paging, channel requesting, authentication, and the encryption. In total, the transmission of a single SM from the BSC to the MS needs 2.82 s. In our measurements, the air interface was traversed twice due to the mobile-originating SM and then the mobile-terminating SM. In the measurements, the minimal observed SM transmission delay was about 6.38 s. We can therefore assume for the delay from the SMSC to the BSC a time period of $\frac{1}{2}(6.38\,\mathrm{s} - 2 \cdot 2.82\,\mathrm{s}) \approx 0.37\,\mathrm{s}$. Therefore, the delay for transmitting 93 7-bit character, i.e. 82 Byte, from the CBC to the MS via the CBCH is about 1.31 s.

VI. CONCLUSION

The measurement results have shown that the short message service SMS is usable in emergency cases, because we haven't seen any message loss and almost every message is received within a short time. However, a high capacity is needed if we transmit the short messages to every user individually. This requires the usage of the cell broadcast which decreases the load in terms of messages per second in the system. Therefore, we investigated the delay when using the cell broadcast service by mapping the measurement results on the cell broadcast SMS.

Future work will have to take a closer look on provider independent measurements and at the SMS broadcast service.

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