Reconfigurable QoS Monitoring for Professionalized Messaging in Mobile Networks

Andreas Waadt, Michael Kowalzik, Thorsten Trapp, Christoph Begall, Guido H. Bruck and Peter Jung

Abstract—**In mobile environments, packet transmission services suffer from packet losses due to e.g. inadequate received signal quality, which is caused by the time and frequency selectivity of the mobile radio channel and by imperfections of mobile terminals, but also due to time-outs and entailed packet deletions, forced by protocols in the signaling domain of the infrastructure of a mobile communications network. To reduce the occurrence of packet losses and, hence, to improve the quality of packet transmission services, such as e.g. the Short Message Service (SMS) deployed in GSM (Global System for Mobile Communications) and in GPRS (General Packet Radio Service) based mobile communications networks, a quantitative analysis of the Quality of Service (QoS) in the signaling domain is mandatory. For this reason, appropriate additional QoS parameters, which complement the presently existing set of QoS parameters defined by e.g. ETSI, are needed. In this communication, the authors propose such QoS parameters and apply them to the SMS in GSM networks. Furthermore, a system framework for QoS monitoring, alerting and reconfiguring an SMS Center is presented. The system framework operates near real-time and, therefore, facilitates the reduction of the turn-around time needed for necessary reconfigurations at the SMS Center to maintain a high QoS level. Also, selected monitoring results gathered during real world network operation are presented and discussed.**

Index Terms—**Quality of Service (QoS), Mobile Communications, Packet Transmission, Short Message Service (SMS) in GSM (Global System for Mobile Communications)**

I. Introduction

PACKET transmission services have continuously gained importance in mobile communications. Such services include e.g. the SMS (Short Message Service), first introduced in GSM (Global System for Mobile Communications) [1],[2], and TCP/IP services. In mobile communications, the SMS used in GSM and in GPRS (General Packet Radio Service) [3] mobile communications networks has become the most important economical success during the past decade. Sect. II presents a brief introduction to the SMS.

To enable the deployment of packet services like SMS in professional environments, complying with sustained high Quality of Service (QoS) levels is mandatory [4]. QoS levels are measured by evaluating QoS parameters, like a pre-determined level of reliability and well defined attributes for precedence and delay of the service.

Unfortunately, sustained high QoS levels can usually not be guaranteed for the SMS, and SMS Centers therefore cannot provide a high service quality in all cases, today. In particular, SMS suffers from packet losses due to e.g. inadequate received signal quality, which is caused by the time and frequency selectivity of the mobile radio channel and by imperfections of mobile terminals. However, packet losses are also produced by time-outs, entailing forced packet deletions. These forced packet deletions are the consequences of protocols in the signaling domain of the infrastructure of a mobile communications network, including the Base Station System Application Part + (BSSAP+) and the Mobile Application Part (MAP) protocols [4].

The mentioned time-outs occur for various reasons. For instance, when a mobile terminal, which shall be contacted by means of SMS, stays outside the coverage area or has been switched off for a certain period of time, the allocated Mobile Switching Center (MSC) will detect an absent subscriber and may force the deletion of packets. Another cause for defying the delivery of packets, which comes into the play when the origin and the destination terminals are subscribed to different network operators, lies in the absence of roaming agreements between these network operators.

When SMS is used for non-professional, i.e. private, communication from one subscriber to another, the lack of sustained high QoS levels may be acceptable. However, this is no longer the case for the deployment of SMS in professional scenarios.

To reduce the effect of packet losses and, hence, to improve the quality of the packet transmission service, a quantitative analysis of the QoS in the aforementioned signaling domain is a must. However, only few QoS parameters were defined by e.g. ETSI [5],[6] to monitor the transmission quality, only, covering mobile originated and mobile terminated SMS. These definitions are tailored for the end-to-end transmissions [5],[6], including *Delivery Time* and *Completion Rate* as QoS parameters. After modification, they can be used to observe the quality from the SMS Center's point of view, cf. Sect. II.

The corresponding QoS aspects have also been treated in previous research publications, which usually set out from the statistical modeling of the packet traffic and present results on the related efficiency parameters [7],[8]. The forced packet deletions mentioned above have not been taken into consideration, yet. Also, the defined QoS parameters [5],[6] do not completely fulfill the needs arising from a professional SMS. Therefore, additional QoS parameters, which complement the presently existing set of QoS parameters

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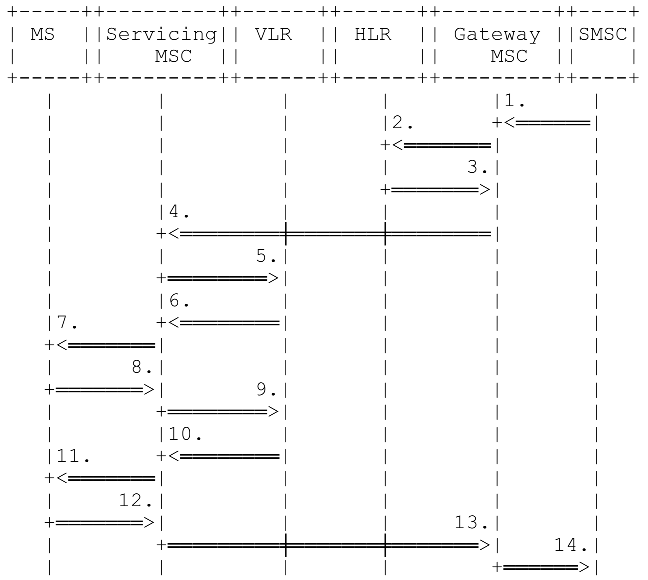
defined by e.g. ETSI [5],[6], are required.

In Sect. III, the authors propose such additional QoS parameters. These QoS parameters are termed

- *Success Ratio SMS (SR SMS)*, i.e. the ratio of the number of MAP commands associated with error code 0, cf. TABLE I, and the total number of MAP commands,
- *Error # Ratios SMS (E#R SMS)*, i.e. the ratio of the number of a specific error code number # of the SS7 protocol, cf. TABLE I, and the total number of MAP commands, and
- *Effort SMS (E SMS)*, i.e. the average number of protocol commands to transmit a short message.

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1.     Short Message
2.     MAP_SEND_ROUTING_INFO_FOR_SM (srism)
3.     MAP_SEND_ROUTING_INFO_FOR_SM_ACK
4.     MAP_FORWARD_SHORT_MESSAGE (fwsm)
5.     MAP_SEND_INFO_FOR_MT_SMS
6.     MAP_PAGE/MAP_SEARCH_FOR_MOBILE_SUBSCRIBER
7.     Page
8.     Page response
9.     MAP_PROCESS_ACCESS_REQUEST_ACK and
       MAP_SEARCH_FOR_MOBILE_SUBSCRIBER_ACK
10.    MAP_SEND_INFO_FOR_MT_SMS_ACK
11.    Short Message
12.    Short Message Acknowledgement
13.    MAP_FORWARD_SHORT_MESSAGE_ACK
14.    Short Message Acknowledgement

MS     Mobile Station
MSC    Mobile Switching Center
VLR    Visitor Location Register
HLR    Home Location Register
SMSC   SMS Center
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Fig. 1. SMS transmission procedure, assuming successful SMS delivery from the SMS Center (SMSC, top right) to the Mobile Station (MS, top left); the Mobile Application Part (MAP) commands of the SS7 protocol [5] are applied.

Since SMS Centers communicate with service providers' infrastructures by using the SS7 (Signaling System 7) protocol [5], the additional QoS parameters consider the signaling domain explicitly. The additional QoS parameters have been applied to SMS in real GSM networks. To quantify the corresponding QoS levels, the signals and error acknowledgements, made available through the SS7 protocol, have been evaluated. These signals and error acknowledgements also cover SMS related services, which use signals from the MAP layer of the SS7 protocol.

In Sect. IV, the authors will present a system framework for QoS monitoring, alerting and reconfiguring an SMS Center. The system framework, which makes use of the additional QoS parameters, has been implemented at the SMS Center of TynTec Ltd. The system framework is based on programs and data bases. The programs have been developed in Java to ensure an open platform system.

TABLE I
ERROR CODES FOR MAP COMMANDS IN SMS CENTER OF TYNTEC

Error code	Verbose description
0	Successful SMS Without Errors
1	TC-INVOKE Timeout
2	Unknown MSISDN
3	Absent Subscriber Short Message
4	Short Message Delivery Failure: SIM (Subscriber Identity Module)/Mobile Terminal Memory Exceeded

The system framework operates near real-time. Therefore, it facilitates the reduction of the turn-around time for necessary reconfigurations at the SMS Center, which shall sustain high QoS levels. In case the value of a certain QoS parameter drops below or exceeds a preset threshold, the system framework generates an alerting message which can be exploited for the aforementioned reconfigurations.

The information gained by applying the system framework reflects the type of traffic. Therefore, this information can be used for traffic shaping and tailoring billing strategies. Selected information gathered by monitoring the operation of the aforementioned SMS Center will be presented and discussed, in what follows.

Finally, selected monitoring results gathered during real world network operation are presented and discussed in this manuscript. Sect. V deals with results obtained when evaluating the QoS parameters defined by ETSI [5],[6] and Sect. VI complements the evaluation done by the authors by considering the additional QoS parameters proposed in Sect. III. Sect. VII concludes the manuscript.

II. PACKET TRANSMISSION IN AN SMS CENTER

A. *Short Message Services*

Fig. 1 shows the successful transmission of a packet, containing a short message, from the SMS Center to the Mobile Station. Several commands and processes are used as described in Fig. 1.

From the point of view of the SMS Center only three commands out of the MAP of the SS7 protocol are used, namely:

1) MAP-SEND-ROUTING-INFO-FOR-SM (srism)

This command is used between the gateway MSC (Mobile Switching Center) and the HLR (Home Location Register) to retrieve the routing information needed for routing the short message to the servicing MSC, where the subscriber roams. This request for routing information from the SMS Gateway MSC contains the MSISDN (Mobile Subscriber ISDN) of the subscriber, while the result contains the ISDN number (routing address) of the Servicing MSC. This address is used to forward the short message in a forward SM process.

2) MAP-FORWARD-SHORT-MESSAGE (fwsm)

This command is used to forward mobile originated or mobile terminated short messages between the SMS Gateway MSC, which has a connection to the SMS Center, and the Servicing MSC, where the subscriber roams.

3) MAP-REPORT-SM-DELIVERY-STATUS (rsds)

This command is used between the Gateway MSC and the HLR. When the transmission of a short message from the SMS Service Center to the MS is unsuccessful, e.g. because the subscriber was absent, the MSC returns a negative response to the Gateway MSC and the Gateway MSC sends a ReportSM-DeliveryStatus to the HLR to allow for a delayed delivery of the short message. MAP-REPORT-SM-DELIVERY-STATUS is used to set the Message Waiting Data

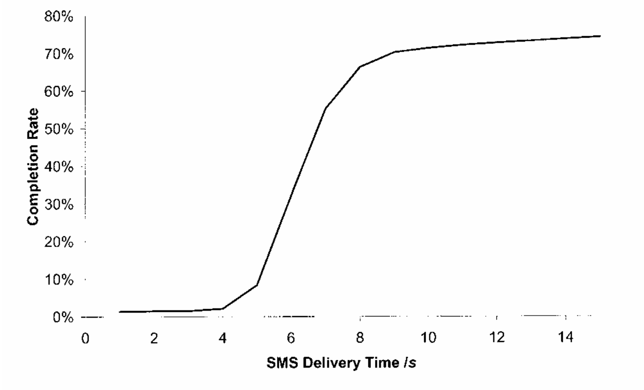

Fig. 2. Typical completion rate depending on the delivery time for the Short message Service Center, averaged over one month in 2004.

flag into the HLR or to inform the HLR of successful SM transfer after polling.

Every command delivers a status report. The interpretation of these status reports at the SMS Center facilitates the generation of various error codes, including the acknowledgement of the successful delivery of the SMS. The mapping of error codes to their verbose description has not been standardized. TABLE I shows a conceivable mapping of error code numbers to verbose descriptions as they are used in the SMS Center of TynTec. Since the error code descriptions are not standardized, yet, other error codes descriptions are conceivable, as well.

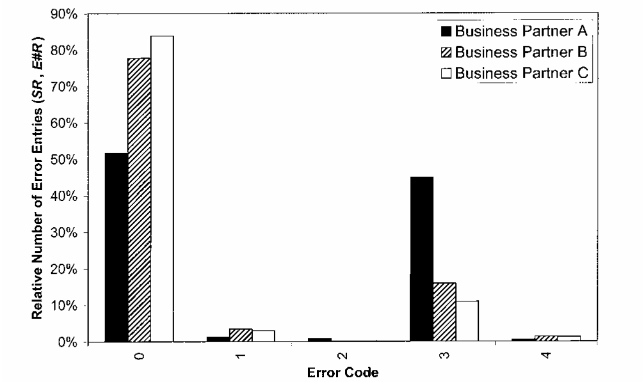

Fig. 3. Success Ratio SR SMS and Error Ratios E#R SMS for three Business Partners averaged over one month in 2004.

B. Supplementary Services

Supplementary services, like location queries, requesting the address of the Servicing MSC, or presence queries, requesting the availability of a particular mobile station from e.g. the Servicing MSC or the HLR of the Gateway MSC, are also based on the use of the MAP commands for short messages. For instance, the MAP-SEND-ROUTING-INFO-FOR-SM command already provides information about the location of a mobile station. This information can be analyzed to provide the demanded information.

C. Business Partners

Different service providers use the SMS Center of TynTec to transmit SMS of their customers. They are called "Business Partner" to distinguish them from their customers, normally the senders and receivers of the SMS.

The characteristics of the SMS traffic specific are specific for each business partners. For instance, several business partners only offer SMS traffic related to individual users, termed individual SMS traffic in what follows, whereas other business partners send bulk SMS to their individual customers, termed bulky SMS traffic in the sequel. There is ongoing research to identify unsolicited short messages from their signalling characteristics. In few cases, even spam SMS can be observed. The bulky SMS traffic is more difficult to handle than the individual SMS traffic because the chance of congestion is greater due to the large number of short messages which have to be handled by the SMS Center almost simultaneously.

D. Routing

As already mentioned, the fwsm command is used to deliver a particular short message to a customer, i.e. the owner of a SIM inside a mobile station, via its Servicing MSC. In order to locate the mentioned customer, the ISDN number of the Servicing MSC must be known. This ISDN number is considered as the routing address, which is obtained by evaluating the report associated with a srism command.

When the network operator owning the Servicing MSC and the network operator owning the Gateway MSC do not have any roaming agreement for the SMS, a subscriber will not be reachable for the delivery of a short message. In this case, the provision of the SMS may be possible through a different network operator who also provides service at the temporary location of the aforementioned subscriber.

E. Standardized QoS Parameters

There exist several standardized QoS parameters for the SMS [6], namely

1) Service Accessibility SMS MO,
2) Access Delay SMS MO,
3) End-to-end Delivery Time SMS and
4) Completion Rate SMS Circuit Switched.

The first two QoS parameters, i.e. Service Accessibility SMS MO and Access Delay SMS MO, are not applicable to the QoS evaluation in an SMS Center because they are tailored to the mobile originated SMS.

The other two QoS parameters are applicable, however, after modifications. This shall be explained in what follows. With t_{receive} denoting the point of time the mobile equipment 2 receives the Short Message from mobile equipment 1 and with $t_{\text{send SMS}}$ being the point of time the customer sends his short message to the SMS Center, the End-to-end Delivery Time SMS is defined as [6]

$$t_{\text{End-to-End Delivery Time SMS}} = t_{\text{receive}} - t_{\text{send SMS}} . \tag{1}$$

Both points of time, $t_{\text{send SMS}}$ and t_{receive}, are unknown to the SMS Center. In order to be able to deploy the QoS parameter End-to-end Delivery Time SMS, the authors modified it in the following way: Setting out from (1), with t_{fwsm} being the point of time associated with a successful fwsm command for a particular short message and with t_{srism} denoting the point of time of the first srism command associated with the same short message, we define the new QoS parameter Delivery Time SMS (DT SMS) as follows:

$$t_{\text{DT SMS}} = t_{\text{fwsm}} - t_{\text{srism}} . \tag{2}$$

With N_{SUC} denoting the number of successfully received short messages, with N_{DUP} being the number of duplicate received short messages, with N_{COR} denoting the number of corrupted short messages and with N_{all} being the total number of sent short messages, respectively, the QoS parameter Completion Rate SMS Circuit Switched is defined according to [6]

$$CR\ SMS\ CS = \frac{N_{\text{SUC}} - N_{\text{DUP}} - N_{\text{COR}}}{N_{\text{all}}} . \tag{3}$$

Unfortunately, N_{DUP} and N_{COR} cannot be obtained at the SMS Center. Also, N_{SUC} is not known, since the end-to-end reporting is not available at the SMS Center. To be able to use the QoS parameter

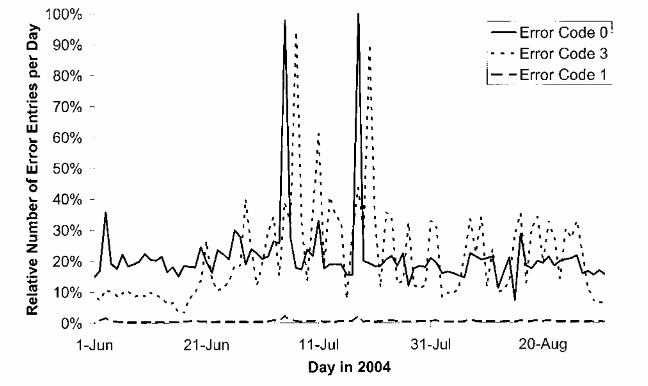

Fig. 4. Relative number of error entries per day for Business Partner A per day.

Completion Rate SMS Circuit Switched, the authors modified it in the following way:

Setting out from (3), with $N_{\text{fwsm,SUC}}$ being the number of successful fwsm commands and with $N_{\text{fwsm,ALL}}$ denoting the total number of all fwsm commands, having mutually different message IDs, we define the new QoS parameter Completion Rate SMS (CR SMS) in the following way:

$$\eta_{\text{CR SMS}} = \frac{N_{\text{fwsm,SUC}}}{N_{\text{fwsm,ALL}}} . \quad (4)$$

Measurement results for the new QoS parameters DT SMS $t_{\text{DT SMS}}$ and CR SMS $\eta_{\text{CR SMS}}$ are presented in Sect. V.

III. NEW ADDITIONAL QOS PARAMETERS

To improve the QoS level and to simplify the measuring process of the QoS parameters, the error codes, cf. TABLE I, resulting from the interpretation of status reports are analyzed. As already mentioned in Sect. II.A, these error codes can be measured and the ratio to the total number of error codes can be calculated. With reference to Sect. I and TABLE I, the related QoS parameters are SR SMS and E#R SMS. With $N_{\text{MAP-SUC}}$ being the number of successful MAP commands and with $N_{\text{MAP-ALL}}$ denoting the number of all MAP commands, the SR SMS is defined as

$$\eta_{\text{SR SMS}} = \frac{N_{\text{MAP-SUC}}}{N_{\text{MAP-ALL}}} . \quad (5)$$

With $N_{\text{MAP-ERROR\#}}$ and with $N_{\text{MAP-ALL}}$ denoting the number of all MAP commands, the E#R SMS is defined as

$$\eta_{\text{E\#R SMS}} = \frac{N_{\text{MAP-ERROR\#}}}{N_{\text{MAP-ALL}}} . \quad (6)$$

A further QoS parameter is called E SMS, cf. Sect. I and TABLE I. Under ideal circumstances, only two MAP commands are needed for a successful delivery of a new short message: First a srism command is sent which is followed by an fwsm command. When an error code other than 0 occurs, more MAP commands are required for the service completion. In the case of e.g. concatenated short message packets, only one command is minimally required for those packets succeeding the first packet. Obviously, the delivery of short messages requires various sequences of MAP commands. For illustration, TABLE II shows the most probable sequences of MAP commands which were measured at the SMS Center of TynTec, averaged over one month in 2004.

Now, let n_{SEQ}, $n_{\text{SEQ}} \in \mathbb{N}$, be the number of a particular sequence of MAP commands, which are required for the delivery of short messages. With $p_{n_{\text{SEQ}}}$, $n_{\text{SEQ}} \in \mathbb{N}$, being the probability of sequence n_{SEQ} of MAP commands, with $N_{n_{\text{SEQ}}}$ denoting the number of MAP commands in the said sequence and with K_{SEQ}, $K_{\text{SEQ}} \in \mathbb{N}$, representing the total number of different sequences of MAP commands, the QoS parameter E SMS is defined as

$$E = \sum_{n_{\text{SEQ}}=1}^{K_{\text{SEQ}}} N_{n_{\text{SEQ}}} \cdot p_{n_{\text{SEQ}}} . \quad (7)$$

Thus, E is the average number of MAP commands needed to transmit the short messages.

It is worth to mention that the measurement of the new additional QoS parameters can be done under special conditions, e.g. for selected business partners and for pre-selected special time intervals. Measurement results for the new additional QoS parameters are presented in Sect. VI.

IV. SYSTEM FRAMEWORK FOR QOS MONITORING, ALERTING AND RECONFIGURING AN SMS CENTER

In this section, we consider the concept of the system framework for QoS monitoring, alerting and reconfiguring an SMS Center. The SMS Center stores all commands on the SS7 interface and their status reports in the SS7 log database. This SS7 log database is the information source for the QoS monitoring system, which is connected to the SMS Center via a virtual private network. The QoS monitoring system contains Java programs and a graphical analysis tool to visualize the behaviour of different QoS parameters, which vary depending on e.g. the traffic characteristics, the business partners or the Servicing MSC.

Value ranges for the QoS parameter values are set in the Parameter Supervision block depending on the traffic, which is expected from e.g. the various business partners, or on the error behaviour of the Servicing MSC. The values of the QoS parameters are then measured and compared to the value ranges in the Parameter Supervision block. In the case of a QoS parameter value being out of range, an alerting message is sent to the operators of the SMS Center. This alerting message can be sent via e-mail or via SMS.

If an adaptation of the system framework at the SMS center leads to an improvement of the QoS level, an automatic reconfiguration can be initiated from the Reconfiguration block. This reconfiguration may be e.g. a modification of the scheduling of the retry cycles in the short message transmission system or a change of the Servicing MSC if the mobile station is reachable via a different Servicing MSC than the already attempted.

V. RESULTS FOR STANDARDIZED QOS PARAMETERS

The parameter $t_{\text{DT SMS}}$ defined in (2) depends on the rate of the successfully delivered short messages. It depends on the time interval, which is allowed for the delivery of the short messages. Fig. 2 shows the completion rate for the time interval between 0 and 15 seconds. Higher values than 70% are hard to reach because of many destination mobiles that are not reachable, because they switched off their mobile, are outside of the coverage area or do not have valid contracts to service providers anymore.

VI. RESULTS FOR NEW SPECIFIC QOS PARAMETERS IN SIGNALLING DOMAIN

Fig. 3 shows the Success Ratio $\eta_{\text{SR SMS}}$ and several Error Ratios $\eta_{\text{E\#R SMS}}$ for three business partners of the SMS Center. For business partner A the E3R SMS $\eta_{\text{E3R SMS}}$, representing "Absent Subscriber", has nearly the same value as the Success Ratio $\eta_{\text{SR SMS}}$. The traffic caused by business partner A was directed to many mobile stations, which were not available at the time the short messages were sent. On the other hand, business partner C caused traffic, which had a large Success Ratio $\eta_{\text{SR SMS}}$ and a very low E3R SMS $\eta_{\text{E3R SMS}}$. The values corresponding to business partner B are in between the values of the business partners A and C.

The relative number of several error entries per day for business partner A can be seen in Fig. 4. Large values of entries with error

TABLE II

PROBABILITIES FOR SEQUENCES OF SIGNALS

Probability	Sequence Length	Sequence s: srism, f: fwsm, r: rsds 0, 1, 2, 3 etc.: Error Codes
63,21%	2	s 0 f 0
8,43%	1	s 0
7,30%	1	s 1
1,92%	1	s 2
1,31%	1	s 3
1,23%	1	f 0
0,83%	6	s 0 f 3 r 0 r 0 s 0 f 0
0,77%	7	s 0 f 3 r 0 r 0 s 3 s 0 f 0
0,53%	4	s 0 f 6 s 0 f 0
0,51%	8	s 0 f 3 r 0 r 0 s 3 s 3 s 0 f 0
0,43%	4	s 0 f 1 s 0 f 0
0,41%	9	s 0 f 3 r 0 r 0 s 3 s 3 s 3 s 0 f 0
0,35%	5	s 3 r 0 r 0 s 0 f 0
0,30%	10	s 3 r 0 r 0 s 3 s 3 s 3 s 3 s 3 r 0
0,25%	4	s 3 s 3 s 0 f 0
0,25%	2	s 0 f 5
0,24%	6	s 1 s 1 s 1 s 1 s 1 s 1
0,23%	6	s 3 r 0 r 0 s 3 s 0 f 0

code 0, cf. TABLE I, and large values of entries with error code 3 are concentrated on 2 days and 3 days respectively. The corresponding Success Ratio $\eta_{SR\,SMS}$ and the Error Ratios E3R SMS $\eta_{E3R\,SMS}$ and E1R SMS $\eta_{E1R\,SMS}$ can be seen in Fig. 6 per day. The E3R SMS $\eta_{E3R\,SMS}$ reaches large values of over 70% on three days. If these values of the QoS parameters $\eta_{E\#R\,SMS}$ are detected, a reconfiguration of the transmission system at the SMS Center, e.g. a change in the scheduling of the retry cycles can reduce the number of MAP commands with the outcome of error code 3. Fig. 5 on the other hand shows the Success Ratio $\eta_{SR\,SMS}$ and two Error Ratios E#R SMS $\eta_{E\#R\,SMS}$ for business partner C. The Success Ratio $\eta_{SR\,SMS}$ is larger than 80% nearly over the whole time interval. The Error Ratio E3R SMS $\eta_{E3R\,SMS}$ Ratio is at about 10%, other Error Ratios are negligible. The values for business partner B are in between the values of the business partners A and C.

TABLE II shows the most probable sequences of MAP commands averaged over one month in 2004. The sequences in TABLE II represent 88% of all messages and 59% of all signals in that month.

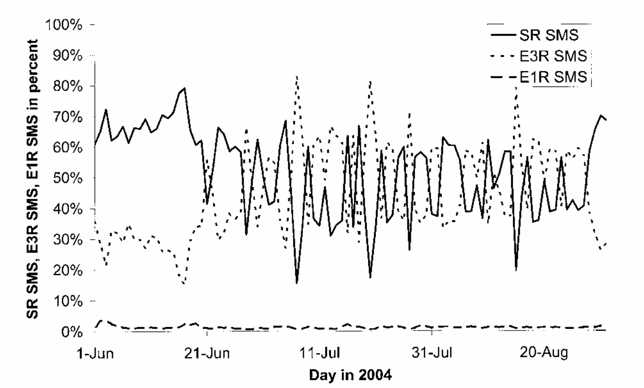

Fig. 6. Success Ratio and Error Ratios Relative for Business Partner A per day.

The calculation of the Effort E SMS defined in (7) for the said month leads to a value of the Effort E of 3. If the Effort E increases, the reconfiguration can change the retry schedule at the SMS Center in order to reduce the number of MAP commands which are needed to transmit the short messages. This reduces efforts and cost at the SMS Center.

VII. CONCLUSION

The observation of properly chosen QoS parameters together with a reconfiguration of the transmission systems will improve the QoS level and, at the same time, reduce the efforts of the SMS Center. The improved QoS level is mandatory if business applications shall use SMS. The authors presented a system framework for the QoS monitoring, alerting and reconfiguring an SMS Center and presented measurement results for a variety of business partners and situations. This system framework makes use of the appropriate implementation of standardized, however modified QoS parameters as well as of newly proposed additional QoS parameters. It was illustrated that the chosen QoS parameters are a viable means for the near-real time characteristics of SMS provision. To the knowledge of the authors such an evaluation has not been published before.

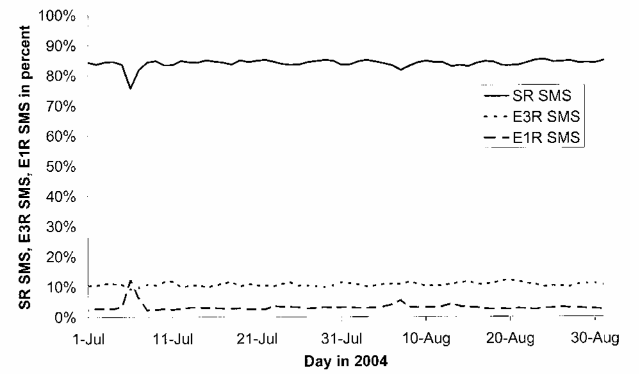

Fig. 5. Success Ratio and Error Ratios Relative for Business Partner C per day.

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