Performance Evaluation of GSM Signaling Protocols on USSD

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Abstract

Today the GSM network operators are trying to distinguish themselves from the competition by offering new operator specific services. Some of these services shall be realized by the dialogue oriented *Unstructured Supplementary Service Data* (USSD) mechanism.
In this work the impact of the introduction of a USSD based operator specific service, i.e., the interactive *Unified Mail Service* (UMS), on the existing GSM basic services, e.g., speech or circuit switched data, with the focus on the air interface between mobile stations and base station is investigated. In case new services are introduced, which occupy the signaling channels for a long time, there can occur so much shortage of the base station's resources that the provision of other services (on traffic channels) may be affected. The simulation based approach chosen in this work, allows the examination on how disturbance on the air interface affects the setup and dialogue times, as well as the channel holding times of the dedicated channels.

1 The GSM Supplementary Service USSD

USSD stands for *Unstructured Supplementary Service Data* [1][2][3]. In order to provide its services, USSD utilizes the services provided by the *Supplementary Service* (SS) and *Connection Management* (CM) sub-layers of the GSM layer 3 protocol stack. USSD enables a dialogue-oriented communication between a mobile station and network-side applications. The so-called USSD applications may reside in *Mobile Switching Center* (MSC), *Visitor Location Register* (VLR), *Home Location Register* (HLR), or in an *External Service Node* (ESN) within the core network. In case that the application – residing in a specific network node – is not addressed by the USSD user, the USSD message is forwarded by the corresponding USSD handler transparently to the next nodes, until it reaches HLR or ESN, as shown in **Figure 1**.

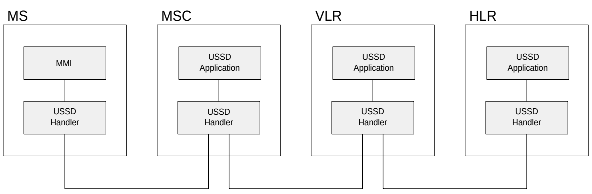

Figure 1 USSD handling in GSM

Similar to *Short Message Service* (SMS), two types of USSD services are defined: the *mobile initiated* and the *network initiated* USSD. Depending on its purpose, USSD services can be offered during an established call connection (*call related*) or outside the call (*call independent*). Call related USSD allocates the *Fast Associated Control Channel* (FACCH), while call independent USSD allocates the *Standalone Dedicated Control Channel* (SDCCH) to transport the messages across the air interface U_m.
Typical operator specific services, which can be offered using USSD mechanism, are:

- Support of Private Numbering Plan (SPNP)
- Prepaid Calling Card Service (PCCS)
- Unified Mail Service (UMS)
- Location Dependent Service (LDS)

This work focuses on the introduction of UMS as a call independent USSD service.

2 Unified Mail Service (UMS)

UMS is a dialogue-oriented service, which enables the mobile user to request, process and forward his e-mails, voice mails or fax messages from an application at an external service node (ESN). In the present service implementation the user has to establish a connection using a traffic channel. The communication between the network-side application and the user is carried out by means of synthesized speech and *Dial Tone Multiple Frequency* (DTMF) signals. This approach has some drawbacks, since the bandwidth of a traffic channel could be wasted, and the mobile is busy during the dialogue, e.g., incoming calls can not be accepted.

The use of USSD mechanism can solve the problem. Since UMS is a call independent service, a narrow-band control channel (SDCCH) can be used as the transport medium. The user activates the USSD service by sending a USSD request message in form of a special character sequence, which is then forwarded by the network to the application at ESN. The application replies with a USSD string, which is then displayed – typically as a menu – on the mobile. The user selects an option, which is then processed by the application at ESN correspondingly.

3 Simulation Environment

3.1 Overview

A simulation based approach is chosen to evaluate the performance of GSM signaling protocols on the provisioning of USSD based operator specific services. The simulator program was developed using *Specification and Description Language* (SDL) and C++. As shown in **Figure 2**, each of the GSM signaling layers is implemented as blocks within an SDL system. Altogether the simulator consists of three SDL systems, i.e., *Mobiles*, *Network* and *Load Generator*, which are interconnected via an *SDL Process Environment*. The implementation of the air interface U_m is carried out by means of bit error pattern files.

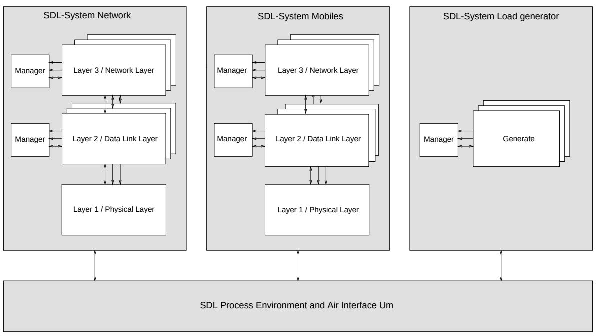

Figure 2 Simulation system overview

3.2 Physical Layer

The SDL block representing the physical layer (*L1Block*) only consists of one SDL process *L1Manager*, which is responsible to distribute the protocol data units to the addressed layer 2 protocol instances. Due to the implementation aspects, some layer 1 related processes are implemented within the layer 2 block (*L2Block*).

3.3 Data Link Layer

As already mentioned, the data link layer protocols [4] are implemented in the SDL block *L2Block*. **Figure 3** shows the interaction between the related SDL processes within the block:

- **L2Manager**: This process manages the interaction between layer 2 processes. There exists only one single instance of this process at a time. Since the *Process Identification* (PID) of other processes are known to *L2Manager*, signals coming from the upper and lower layers can be routed to the addressed process within the block.
- **LAPDm**: Almost all of the $LAPD_m$ protocol functionality are implemented in this process, which is the main process within *L2Block*.
- **Receiver**: In this process, the *PH_DATAind* primitive of the physical layer is decoded into the corresponding $\mathrm{LAPD_m}$ frame types (*I*, *RR*, *RNR*, *REJ*, *SABM*, *DM*, *UI*, *DISC* and *UA*). The results are forwarded to the *LAPDm* process.
- **Sendout**: This process is responsible to determine the correct points of time to send the data blocks of the logical channels *RACH*, *SDCCH*, *SACCH/S*, *FACCH/F*, *FACCH/H* and *SACCH/T*. The block recurring times and the time synchronization between base station and mobile are modeled for each type of channel.
- **SenderC_BS**: This process is implemented only for the base station (*Network* system). Its responsibility is similar to that of *Sendout*, with a small difference that the shared control channels *AGCH*, *BCCH* and *PCH* are considered.

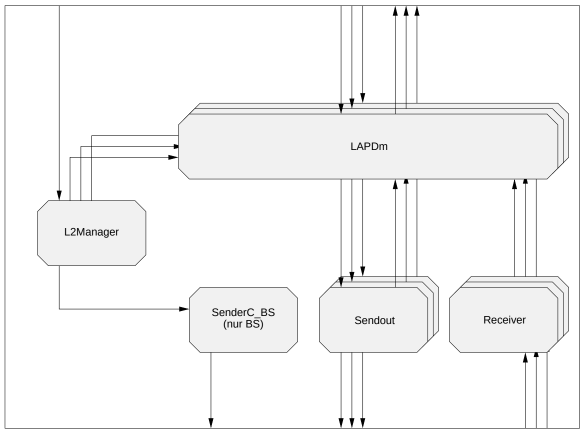

Figure 3 Implementation of the data link layer

3.4 Network Layer

The structure of the network layer conforming to the standard [5] is adopted in the simulator (**Figure 4**). The network layer block (*L3Block*) consists of the following processes:

- **Interface_L3**: This process provides an interface to an upper layer, which – in our case – is represented by a load generator.
- **L3Manager**: Similar to *L2Manager*, this process takes the control over the other layer 3 processes, i.e., routing incoming signals to the target processes, or starting and stopping the processes.
- **CC, SS, MM and RR**: The functionality of the GSM sub-layers *Call Control*, *Supplementary Services*, *Mobility Management* and *Radio Resource Management*, are implemented in these processes.

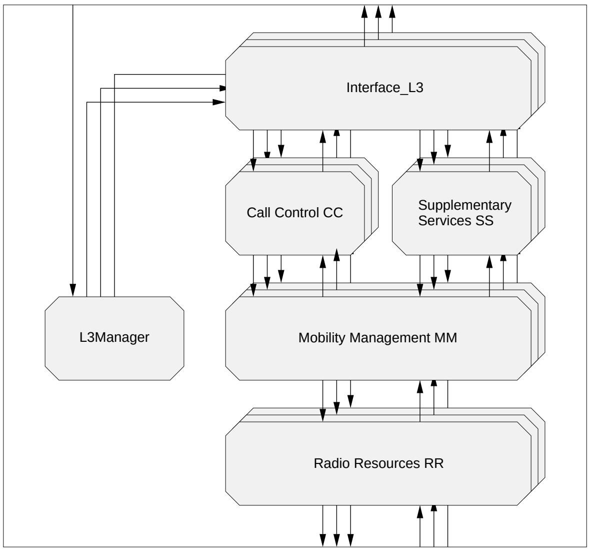

Figure 4 Implementation of the network layer

3.5 Load Generator

The load generator is implemented in two processes:

- **LGManager**: This process routes the signals coming from the *SDL Process Environment* to the process *Generate*.
- **Generate**: The *Generate* processes are independent load generators for each mobile station. Poisson-distributed traffic load is generated for the following events:
  - Location Updating
  - IMSI Detach
  - Mobile Originated (MO) Call
  - Mobile Terminated (MT) Call
  - Mobile Originated USSD (call independent)
  - Mobile Terminated USSD
  - Mobile Originated Call Release
  - Mobile Terminated Call Release

4 Performance Evaluation

In the following the simulation results regarding the performance of GSM signaling protocols on the provisioning of the USSD based UMS service concerning the timing behavior and network load are presented.

4.1 Connection Setup Time

First the simulator is used to determine the time needed to establish a single mobile originated call connection at different channel quality, which is expressed in dB (*Carrier to Interference Ratio, CIR*). The connection setup time is ascertained between the transfer of *MS_CONNECT_req* primitive by the mobile and the receipt of *MNCC_SETUP_COMPLind* primitive by the base station. The results are shown in **Figure 5**.

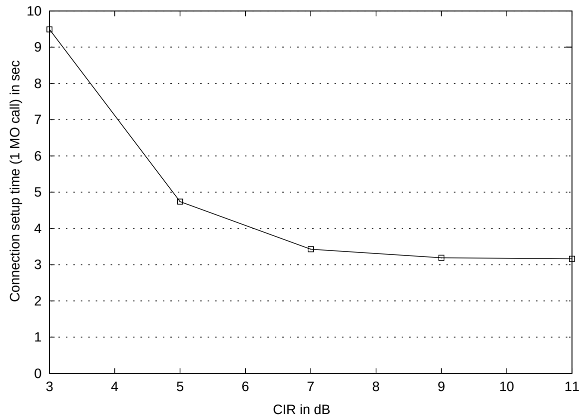

Figure 5 Connection setup time (MO call)

4.2 Service Description and Timing Behavior

For the evaluation purpose, the USSD based UMS service is modeled as follows:

- A fixed processing time of 0.2 seconds at the external service node is assumed as the only one delay, which occurs at the network side.
- Totally three messages of each 90 bytes long are transmitted from the network (ESN). The user needs about 10 seconds to read each message in average.

- Each request directed to the application at ESN requires a USSD string of 1 byte long to be transmitted.

The times needed to reply to the first USSD request with a message (USSD string) of various length, including the setup time for a new MM connection with SDCCH allocation and initialization, are shown in **Figure 6**. The reply times are ascertained for different CIR-values. **Figure 7** shows the ascertained reply times in case the dialogue (i.e. MM connection) is already established.

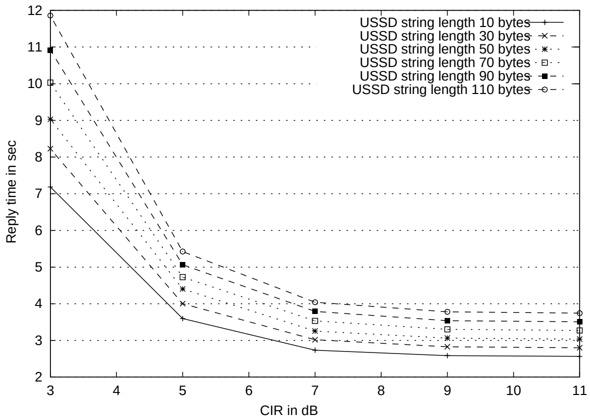

Figure 6 Reply times to the first USSD request

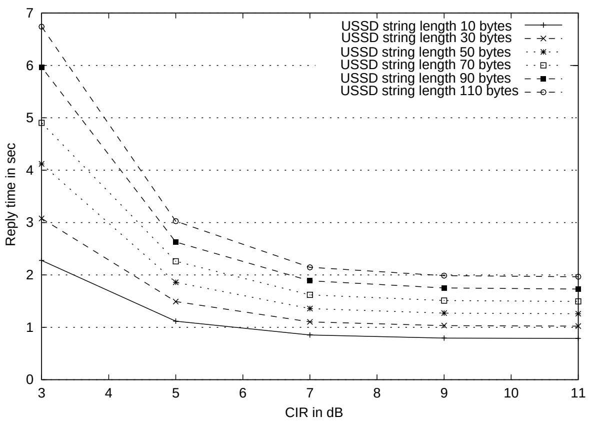

Figure 7 Reply times to a USSD request on an established dialogue

The total dialogue time for a UMS session as modeled before is shown in **Figure 8**. The dialogue time is a little shorter than the actual SDCCH holding time, since the times needed to release the SDCCH and the layer 2 connection are not included.

4.3 Network Model and Channel Load

The various services and mobility management tasks cause different traffic loads in a GSM network. In order to investigate the impact, i.e., additional load, of the new UMS service on the existing network, the GSM network and its load situation during the busy hour is modeled using the parameters listed in **Table 1**, which corresponds to a German GSM network in mid 1997 [6].

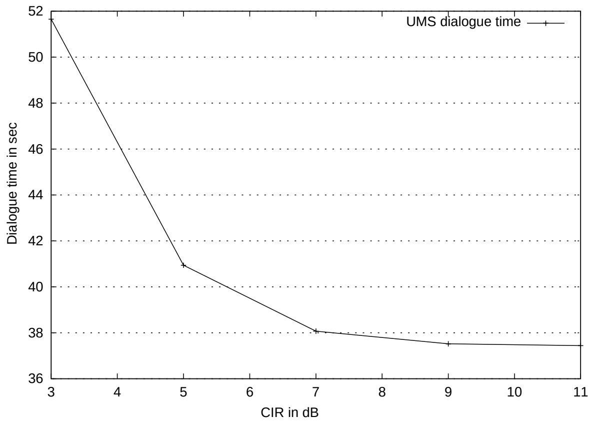

Figure 8 Dialogue time for a UMS session

Parameter	Value
No. of subscribers (MS)	3,000,000
No. of MSCs	30
No. of BSCs per MSC	2
No. of BTSs per BSC	120
Average no. of calls per MS and hour	0.8
Average no. of MO calls per MS and hour	0.47
Average no. of intra MSC calls per MS and hour	0.05
Average no. of MT calls per MS and hour	0.23
Average no. of location updates and registrations per MS and hour	0.63
Average no. of de-registrations and periodic registrations per MS and hour	0.38
Fraction of active MS during a busy hour	40 %

Table 1 Network parameters, loads during a busy hour

According to **Table 1** totally 1,200,000 subscribers are active and in average, each of them makes 2 calls per hour during the busy hour. There are totally 7,200 base stations located within the network and thus 167 active subscribers serviced by each base station in average. In the simulations, a middle-size cell with 8 SDCCH and 14 TCH available is considered. **Figure 9** depicts the simulation results for the load on the traffic channels, expressed in the number of occupied channel (of one base station) ascertained during the simulated time. It shows that in 2.7 % of the time the base station's capacity is fully used, i.e., all 14 traffic channels are occupied. On the contrary, it is not the case for the signaling channels (SDCCH), as shown in **Figure 10**. The probability, that there is no signaling channel available to allocate, is zero. As expected, the bottleneck on the air interface U_m at high traffic load is thus caused by the limited number of traffic channels. The available signaling channels do not pose any problem (supplementary services are not considered yet).

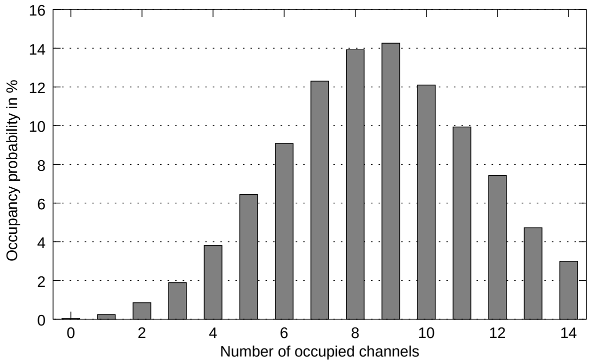

Figure 9 Utilization of the traffic channels at high network load (ideal channel)

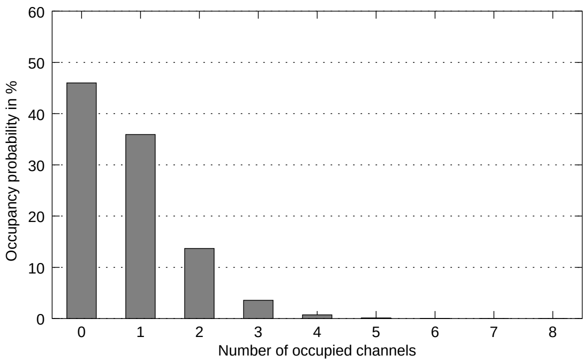

Figure 10 Utilization of the signaling channels (SDCCH) at high network load (ideal channel)

4.4 Blocking Probability

The simulation results for the blocking probability of new MO and MT calls for different USSD (UMS) traffic loads at CIR > 11dB (ideal channel) are depicted in **Figure 11**. Totally up to 15,000 successful channel setups (for calls and USSD) were simulated.

The ascertained blocking probability for the UMS usage itself is depicted in **Figure 12**. Since USSD allocates the control channel SDCCH for the message transport, its blocking probability is lower than for calls (using traffic channels).

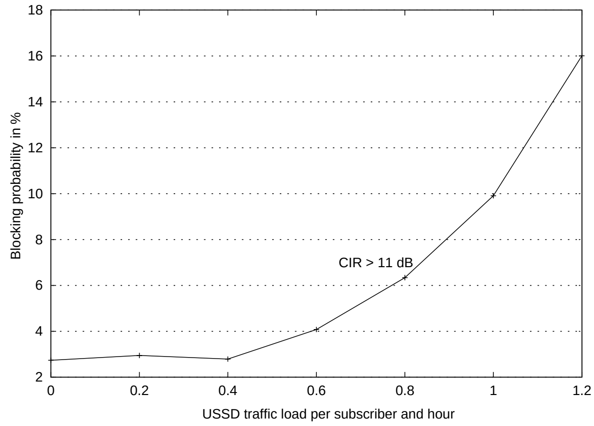

Figure 11 Blocking probability for new call setups

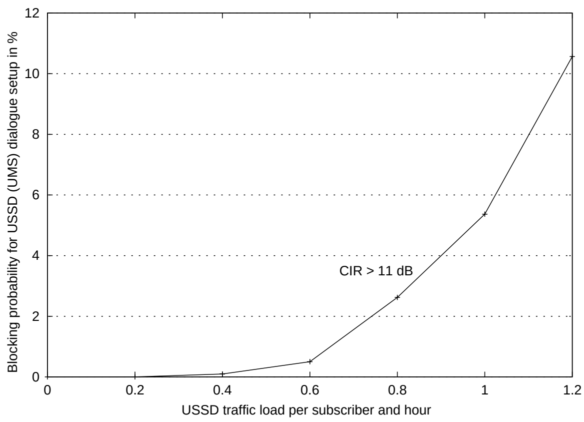

Figure 12 Blocking probability for USSD dialogue setups

5 Conclusion

A simulation based approach for the performance evaluation of GSM signaling protocols on the provisioning of USSD based operator specific services is introduced. The characteristics of an interactive message service UMS are used to investigate the timing and load behavior of an existing GSM network with specific parameters.

Under the assumptions made in the simulation, the results show that the bottleneck is not on the signaling channels SDCCH, but on the traffic channels TCH, even when new call independent USSD services are introduced. This might be caused by the present implementation of *Non Off Air Call SetUp (Non-OACSU)* approach in the simulator, whereby a traffic channel is earlier assigned as in case of *OACSU* approach. The implementation of *OACSU Late Assignment* may lead to higher loads on SDCCH. Due to the traffic channel demands the GSM network operators may also apply *call queuing* mechanism to reduce the call loss probability, while also causing higher loads on SDCCH.

6 References

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Author's Biography

Ian Herwono received his diploma in Electrical Engineering from the Aachen University of Technology (RWTH Aachen), Germany, in July 1996. In October 1996 he joined the Chair of Communication Networks at RWTH Aachen. His research interests are in the areas of development and performance evaluation of mobile commerce services, network security and tele-teaching.