GSM/GPRS Bearers Efficiency Analysis for Machine Type Communications

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Abstract—**Short Message Service (SMS) over circuit switched (CS), Unstructured Supplementary Service Data (USSD) and GPRS are the main bearers to support different Machine Type Communications (MTC) over a 2G network. Communications of a large amount of Machine to Machine (M2M) terminals may have a significant impact on worldwide deployed 2G networks. This paper compares the efficiency for each of the 2G bearers when M2M terminals perform mobile originated (MO) data calls under a predefined M2M application. The efficiency of each bearer is evaluated at Layers 2 (L2) and 3 (L3) by the ratio of user data payload to the total L3 messages and by the amount of M2M terminals the radio interface can support within one hour. Results show that USSD is the most efficient bearer in L3. When considering L2 messages in radio interface, GPRS proves to be the most efficient bearer.**

Keywords-component; GPRS, SMS, USSD, Bearer Efficiency, Machine-to-Machine, M2M, MTC

I. INTRODUCTION

M2M enables the flow of data between machines and machines and ultimately machines and people. Regardless of the type of machine or data, information usually flows in the same general way -- from a machine over a network, and then through a gateway to a system where it can be reviewed and acted on.

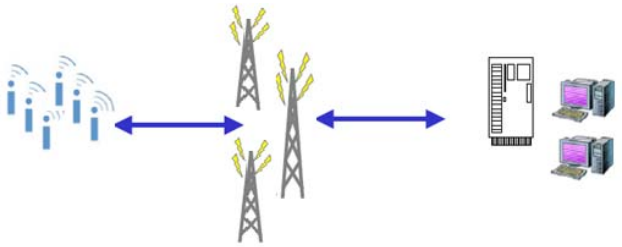

Figure 1. M2M over cellular.

M2M technology can be used for a huge range of applications including data collection, remote control, offsite diagnostics and maintenance, remote monitoring, status tracking, fleet management, road traffic control and security systems.

M2M information can be carried through a variety of different communication systems. Among these, cellular communications are considered to be the most attractive way (commercially viable) to send this M2M data. Although 2G networks are throughput limited (compared to more advanced cellular networks: 3G and 4G), the radio technology presents many practical (e.g. global coverage, reliability, roaming, well planned etc.) and commercial (e.g. scale, low unit cost, mature operating experience etc.) upsides that are suitable for many M2M applications. While the trend is that many data applications are demanding more and more throughput capabilities, many M2M applications (that only require low throughput) can be sufficiently served by 2G networks.

This paper covers a complete analysis of the three main GSM/GPRS bearers (GPRS, SMS and USSD) for a typical Machine Type Communications (MTC) scenario and is organized as follows: Section II introduces the GSM/GPRS and the signaling characteristics of the bearers (showing the signaling flows and headers fields), together with the conditions assumed for a M2M scenario. Sections III and IV present the studies and results of L2 and L3 respectively, with a conclusion on the efficiency of each bearer and finally, section V summarizes the conclusion of the detailed analysis showing how USSD and, in particular, GPRS type II are the most efficient bearers for sending M2M data.

II. BACKGROUND

A. GSM/GPRS Introduction and M2M scenario conditions

The standard specifications for GSM/GPRS system are maintained by the 3GPP (Third Generation Partnership Project). GSM/GPRS is the term given to the second-generation (2G) digital cellular radio access technology, including its evolution in the form of EDGE (Enhanced Data rates for Global Evolution).

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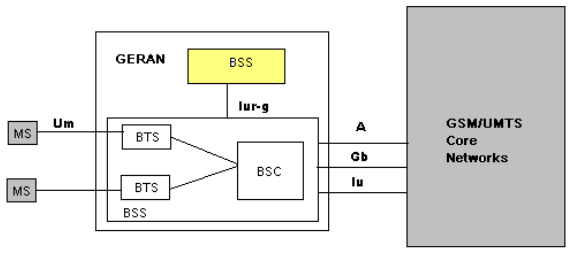

Figure 2. GERAN Architecture

In 2G network, data for M2M communication can be carried by SMS or USSD in CS domain or by GPRS/EDGE in PS domain. SMS provides a means of sending messages of limited size to and from GSM mobiles. Mobile originated/terminated messages shall be transported between a device and a Service Centre [5]. USSD mechanism allows the Mobile Station (MS) user and a PLMN operator defined application to communicate in a way which is transparent to the MS and to intermediate network entities. USSD allows development of PLMN specific supplementary services [6]. GPRS/EDGE supports to dynamically multiplex timeslots (in time division or in parallel) between different users and these timeslots are used only when data packets and RLC/MAC control signaling are actually transmitted [7].

In [8], a probability model is used to analyze the reliability, cost and delay performance of SMS delivery methods. In [9], a simulation based approach is supplied to analyze the impact to the GSM performance after introducing USSD service. In [10], the performance of GPRS is researched in the scenario where GSM circuit switched services and GPRS share the same resource system. In [11], a analytical model is provide to estimate the E-GPRS link adaptation performance. To our knowledge, there are still no documents discussing and comparing the performance of SMS/USSD/GPRS as data bearers for small data packet which is a common feature of many M2M applications.

As a constraint and assumption for the research presented here, the size of the M2M user data transferred was set in the range of [10 - 1000] bytes as required by one carrier group. The M2M scenario considered models a single static user performing mobile originated (MO) data sending. Most currently deployed GPRS networks support CS-1 ~ CS-4 coding scheme and CS-2 is chosen for this analysis because CS-2 is reliable (approximately 2/3coding rate) and has sufficient transmission rate (13.4 Kbit/s per GSM timeslot). When calculating the efficiency of the bearer, the payload is the user data and the cost is the sum of the additional L3 messages caused by sending the M2M user data.

B. Signalling call flows and headers

The first step in the study of the three main GSM bearers used for M2M (GPRS [4], SMS [1], USSD [2]) is to define the call flows and headers sizes for each M2M user data packet. For the following signaling flows graphs, messages used for signaling transmission are marked by black solid lines. The number of the radio blocks occupied by these signaling messages is fixed. The messages used for user data transmission are marked by red solid lines with italic names. Red dotted lines with italic names are used when more than one user data message is required to transport all the user information.

1) For GPRS, Figure 3 shows the signaling flow (with the three main procedures: Attach, Data Transmission and Detach) and Figures 4 shows the structure of the data and logical link control (LLC) Packet Data Units (PDUs) information and Figure 5gives the header consumptions of these two PDUs.

From the following figures, one GPRS LLC PDU header size is 10 bytes. IP packet is packed inside the SN-DATA PDU. Note that IP header compression is used and minimum IP header is about 1~4 bytes long after compression [12] and is ignored for this evaluation.

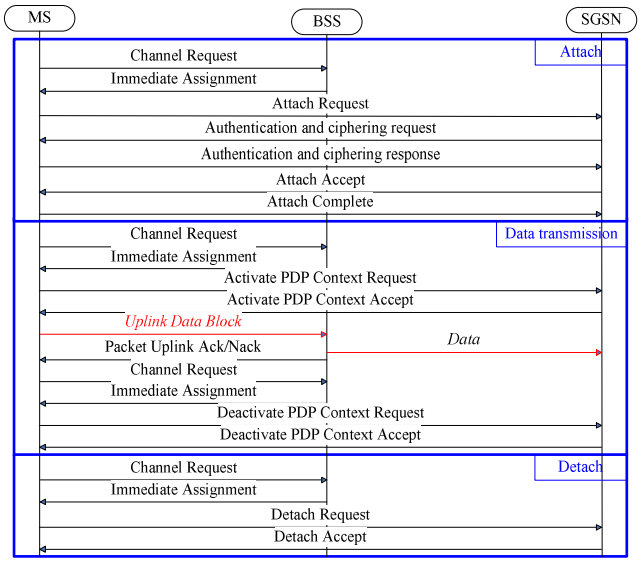

Figure 3. GPRS Signalling Flow

Bit	8	7	6	5	4	3	2	1
Oct 1	X	F	T	M	NSAPI			
2	DCOMP				PCOMP			
3	Segment number				N-PDU number - unacknowledged mode			
4	N-PDU number - unacknowledged mode (continued)							
…	Data segment							
N	…							

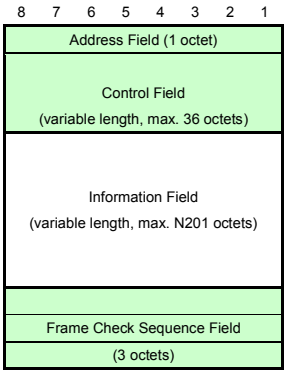

Figure 4. Structure of SN-DATA PDU (left) and LLC PDU (right)

SN-DATA PDU is packed inside of LLC PDU, M2M user data is carried within data segment part in SN-DATA PDU. The total size of control parameters in both PDU is 10 Bytes if the control filed in LLC PDU is assumed to be 2 Bytes.

2) For SMS, Figure 5 shows the signaling flow (with the three main procedures: Attach, Data Transmission and Detach) and Figure 6 shows the data PDU information.

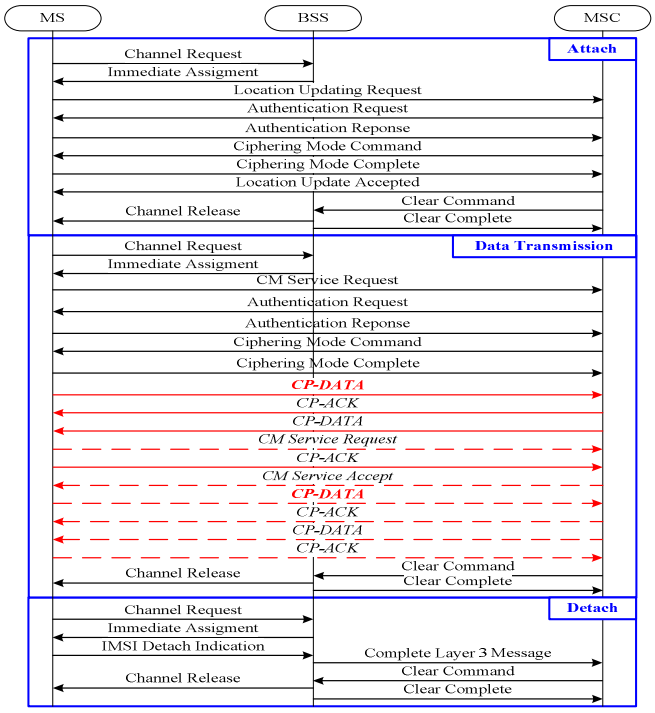

Figure 5. SMS Signalling Flow

CP-DATA message format	Length （Byte）	Note
CP-DATA non-data information	30	111 Bytes is the longest length which is not applicable for real configuration, now 30 Bytes are used according to the live network configuration.
CP-DATA data information	1~140	M2M user data packed inside with range of [10~1000] Bytes. The longest length of CP-DATA is 170 Bytes

Figure 6. SMS PDU structure

3) Finally, USSD is presented in Figures 7 and 8. Figure 7 shows the USSD signaling call flow and Figure 8 the data PDU structure. Most part of the signaling call flow is same as SMS in Figure 5. The only difference is shown in Figure 7, i.e. the flows between ciphering mode complete and clear command messages in data transmission part.

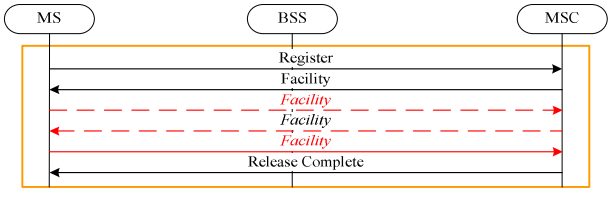

Figure 7. USSD Signalling Flow

FACILITY message format	Length （Byte）	Note
FACILITY non-data information	20	91 Bytes is the longest length which is not applicable for real configuration, now 15 Bytes are used according to the simplest configuration.
FACILITY data information	1~160	M2M user data packed inside with range of [10~1000] Bytes. The longest length of FACILITY is 180 Bytes

Figure 8. USSD PDU structure

III. THE LAYER 3 MESSAGE COST ANALYSIS

Based on the signaling call flows and headers presented in previous section and packet sizes at L3, the total cost and efficiency are calculated and analyzed focusing on the efficiency of the three bearers: GPRS with CS2 coding scheme (GPRS-CS2), SMS (SMS over CS) and USSD [3]. Figure 9 below shows the results of the analysis.

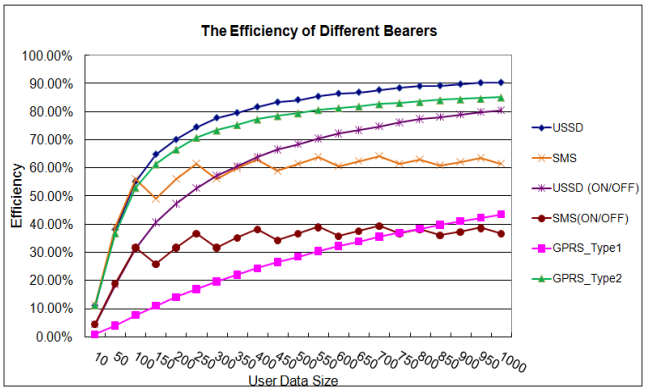

Figure 9. Bearers efficiency results

Firstly, the definition of "user data transmission transaction" should be clarified. One user data transmission transaction means that for this interaction between MS and network, the expected user data have been sent out and acknowledged by the network. For example, according to a certain requirement, the MS should send out 900 bytes data to the network to report something. Once the MS sends out the total 900 bytes and gets the acknowledgement from the network, this user data transmission transaction has been finished. As having stated above, the "cost" of one bearer is the L3 message sent by the user when the bearer is selected to transfer user data.

For GPRS two types of situations are considered, named Type 1 and Type 2. The former refers to the case where for every user data transmission transaction, the MS should perform the whole PS attach – PDP context activation – One transaction – PDP context deactivation – PS detach procedure. The latter, type 2, refers to the situation where a MS would perform several transactions within the same PDP context: PS attach – PDP context activation – Several transactions – PDP

context deactivation – PS detach. GPRS type 1 refers to a scenario where the MS seldom sends out data to the network. For example, a power meter sends out data to the network weekly. Whereas GPRS type 2 refers to a scenario where a MS has to frequently interact with the network in a short period. For example, the power meter sends out data to the network every minute during the day.

For USSD and SMS, also two kinds of situations are studied. One is that the RF module in the MS keeps on until it is powered off, which means only one attach and detach procedure are considered even for many transactions of M2M user data. The other one is that the RF module in the MS will be switched on and off for every transaction which means each transaction of M2M user data will cause an attach and detach procedure. The first case is called USSD/SMS, and the second one is called USSD (ON/OFF)/SMS (ON/OFF).

This L3 efficiency analysis draws the conclusion that when taking L3 message as the extra cost, USSD is the most efficient bearer to transfer M2M data. At the same time, GPRS_Type2 is also a very efficient bearer compared with SMS or GPRS_Type1. Besides, because SDCCH has better link performance (more robust codification) than PDTCH-CS2, USSD/SMS is more reliable than GPRS-CS2 in poor radio conditions. However, GPRS-CS2 is much faster than SMS/USSD in transmission speed.

IV. THE LAYER 2 EFFICIENCY ANALYSIS

In this section L2 efficiency is assessed in terms of total TDMA frames used and maximum number of users supported within a specific time period. Only one timeslot in a cell is considered in this evaluation and two types for each bearer (total of 6 bearers) are evaluated:

- GPRS_Type A: same as GPRS Type 1 in L3 analysis
- GPRS_Type B: different from GPRS type 2 in layer 3 analysis, each transaction accompanied with a PDP context activation/deactivation procedure.
- SMS A/B: same as SMS(ON/OFF)/SMS respectively in L3 analysis
- USSD A/B: same as USSD(ON/OFF)/USSD respectively in L3 analysis

For Type A attach and detach procedures are considered. For type B attach and detach procedures are not considered. Because GPRS PDP context activation/deactivation does not belong to attach/detach procedure, PDP context activation/deactivation should be considered when attach/detach procedures are not considered. When comparing the CS and PS bearers, it is better to compare them within the same type. That is when attach/detach procedures are considered for CS, and attach/detach procedures should also be considered for PS.

A. *Total TDMA Frames*

As TDMA frames is one of the main resources in GSM technology, in this section we study the number of TDMA frames that are used for transmitting the M2M data and signaling, both in UL and DL, for the three bearers. The objective is to identify which bearer is the most efficient using less TDMA frames for the same data transmission.

TABLE I. NUMBER OF TDMA FRAMES USED FOR USER DATA TRANSMISSION AND SIGNALING BOTH IN UL AND DL

Transmission		GPRS A W=1	SMS A W=2	USSD A W=2	GPRS B W=1	SMS B W=2	USSD B W=2
		Number of used TDMA frames					
Signaling part		208	135	159	86	53	77
Data part (Byte)	10	4	40	16	4	40	16
	100	16	80	48	16	80	48
	200	28	176	104	28	176	104
	300	44	272	144	44	272	144
	400	56	312	200	56	312	200
	500	68	408	256	68	408	256
	600	84	504	296	84	504	296
	700	96	544	352	96	544	352
	800	108	640	392	108	640	392
	900	124	736	448	124	736	448
	1000	136	832	504	136	832	504

Weight (W) = 1 refers to the case where a DL/UL message only occupies the TDMA frame in DL/UL respectively. While W = 2 refers to the situation where a DL/UL message requires both DL and UL TDMA frames. The sum of TDMA frames used for signaling and data transmission shows the bearer efficiency as shown in Figure 10.

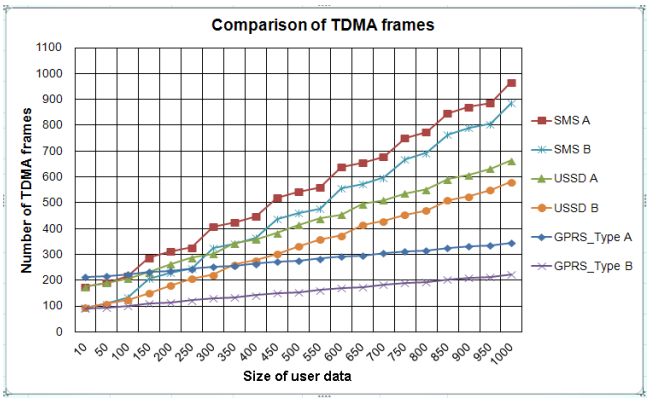

Figure 10. L2 Efficiency in terms of TDMA frames used

From the information presented, it can be seen that GPRS B is the most efficient bearer since GPRS B consumes the least TDMA frames when transmitting the same amount of user data. For GPRS, USSD and SMS within the same type, GPRS always shows better data handling efficiency, except for very small data transmission (user data size < 100bytes) since these three bearers have similar efficiency.

B. *Number of supported users*

To have a complete view of L2 efficiency, an additional analysis of the maximum number of users supported in UL has been performed. For TDMA frames used on PDTCH/UL and PACCH/UL channel are considered for GPRS, while TDMA frames used on both SDCCH/UL and SDCCH/DL channel are considered since weight=2 is used for SMS and USSD. Following table and figure show the results.

TABLE II. THE NUMBER OF USERS SUPPORTED BY GPRS/SMS/USSD

Transmission		GPRS A	SMS A	USSD A	GPRS B	SMS B	USSD B
		Number of used TDMA frames					
Signaling part		92	60	72	36	24	36
Data part (Byte)	10	4	20	8	4	20	8
	100	16	40	24	16	40	24
	200	28	88	52	28	88	52
	300	44	136	72	44	136	72
	400	56	156	100	56	156	100
	500	68	204	128	68	204	128
	600	84	252	148	84	252	148
	700	96	272	176	96	272	176
	800	108	320	196	108	320	196
	900	124	368	224	124	368	224
	1000	136	416	252	136	416	252

Within one hour, the total available TDMA frames in the uplink are 720000 frames for GPRS and 489412 frames under SDCCH/8 configuration for SMS and USSD. Figure 11 shows the comparison on the number of users in UL which is the total available TDMA frames within one hour divided by the sum of used TDMA frames for both signaling and data transmission .

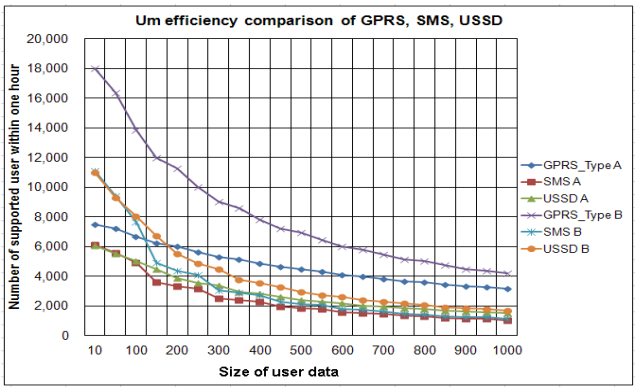

Figure 11. L2 Efficiency in terms of number of UL users supported

From the information shown it can be seen that GPRS B is the most efficient bearer. For all samples of different length data (10-1000 bytes), the maximum number of users supported by GPRS is always the largest within the same type.

C. *Layer 2 Analysis Results*

In addition to the conclusions presented for L2 in the section above, other factors are considered and how they could impact the results.

Firstly, additional factors may further decrease GPRS efficiency:

- Considering packet ACK/NACK messages and error RLC data retransmissions, more radio blocks will be occupied which will decrease the efficiency of GPRS bearer in some degree.
- Maximum value of USF is 8 which may limit user capacity multiplexed on the same PDCH.
- Uplink scheduling implementation in real operation cannot guarantee no uplink radio blocks will be wasted.

Secondly, one direction transmission occupies the channel resource in both directions for CS bearers (weight = 2) which decreases the efficiency for SMS A/B and USSD A/B.

V. CONCLUSIONS

In this paper the efficiency of the three main GSM/GPRS bearers used for Machine Type communications (GPRS, SMS, USSD) has been studied. After presented the signaling call flows and headers used in the analysis, the results for both L2 and L3 have been shown.

For L3, the results of the analysis show that USSD is the most efficient bearer to transfer M2M data. Also, GPRS_Type 2 is also a very efficient bearer compared with SMS or GPRS_Type 1. Since SDCCH has better link performance than PDTCH-CS2, USSD/SMS is more reliable than GPRS-CS2 in poor radio environment. Another consideration is that GPRS-CS2 is much faster than SMS/USSD in transmission speed.

The analysis of L2 has been performed in terms of number of used TDMA frames and also maximum number of users supported within one hour. The results obtained show that for TDMA usage perspective GPRS_Type B is the most efficient bearer. When the number of supported users for UL is studied, it can be seen that GPRS_Type B is also the most efficient.

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