Impact of SIB Scheduling on the Standby Battery Life of Mobile Devices in UMTS

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Abstract—**The UMTS standard for third generation wireless communications specifies several parameters that play a role in the tradeoff between the performance and the battery life of mobile devices. There are also other, non-standardized, implementation-specific mechanisms that affect both the performance as well as the battery life. In this paper, we focus on the scheduling of System Information Blocks (SIB) broadcasts on the network side and the inter-SIB sleep management on the mobile device side. We analyze the impact of these mechanisms on the standby battery life of mobile devices in three commercial networks.**

Index Terms—**UMTS, wireless networks, battery life**

I. Introduction

With the steady rise in popularity of the third generation high-speed wireless data services and the multifunctional convergence mobile devices that enable them, it is expected that the daily usage time will continue to rise. As users become more accustomed to anytime-anywhere high-speed data network access, the battery life of mobile devices will be the major factor limiting the usage time. Consequently, the battery life will rise in importance as one of the major selling points. Recent market research study shows that consumers now fully realize that powerful, new applications require enhanced battery life and they are demanding these improvements as a priority [1].

There is a great deal of current research regarding battery life improvements. In addition to the battery technology [2], the research focuses around various aspects of the design of mobile devices affecting battery consumption, such as the size, display [3], [4] and processor [5].

In parallel to these research areas, there is additional room for battery life improvement by means of optimization of the mobile device sleep cycles. There are several factors that play a role in the dynamics of the sleep cycles of mobile devices in UMTS networks. Some of these factors have been standardized [6], while others depend on the particular implementations on network and a mobile device side. Ref. [7] contains a summary of all UMTS network parameters affecting battery life. In [8] and [9], the impact of the standard parameter settings on the standby battery life in CDMA2000 and UMTS networks is examined, respectively.

In addition to the standard parameters, there are several implementation-specific mechanisms that affect the sleep cycle and therefore the battery life of mobile devices. In this paper, we focus on the impact of the scheduling of the SIBs on the Broadcast Common Control Channel (BCCH) on the battery life of mobile devices. We analyze and compare the SIB scheduling schemes in three different commercial networks for different user mobility patterns and discuss the tradeoffs and implications. We point out the possible enhancements in the implementation of the SIB scheduling that could improve the battery life. The terms "mobile device" and "User Equipment (UE)" are used interchangeably throughout the paper; the same applies to the terms "battery life" and "battery time".

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II. System Description

In this section we define the UMTS concepts that are the basis of the discussion in the rest of the paper.

A. UE sleep cycle

In UMTS networks, one of the four possible modes that the UE can be in is idle mode [6], which is characterized by the absence of the signaling connection with the network. While in idle mode, the UE is either in the sleep state or in the wake-up state. In the sleep state, the UE shuts down its RF circuitry, and maintains no physical channels. The UE goes periodically into the wake-up state in order to demodulate the Paging Indicator Channel (PICH) and evaluate the signal quality of the camping cell and the neighboring cells. The UE goes into the wake-up state during its periodic paging occasions, whose timing depends on the UE identifier called IMSI (International Mobile Subscriber Identity). This method ensures equal spread of paging occasions in time. The frequency of paging occasions is determined by the network parameter, called DRX Cycle Coefficient [6], which is included in the system information broadcast on the BCCH to all devices in a given cell. Fig.1 illustrates these concepts. The sleep cycle is controlled by the physical layer functions in the UE, based on the IMSI and the DRX cycle coefficient received from the radio network and handed down to the physical layer by means of the radio resource control (RRC) layer [6].

B. Cell Reselection

The outcome of the process of evaluation of the quality of the camping and neighboring cells is either the decision to remain camping on that cell or the decision to reselect to a new cell. This evaluation process is standardized by means of standard cell reselection parameters. These parameters include the signal quality thresholds for initiating measurements of the neighboring cell signals, signal quality thresholds and histeresis offsets for triggering reselection to a new cell and the timers. These parameters are discussed in [7], [9] and [10]. If the UE decides to reselect to a new cell, it needs to read the necessary system information broadcasted on the BCCH of the target cell.

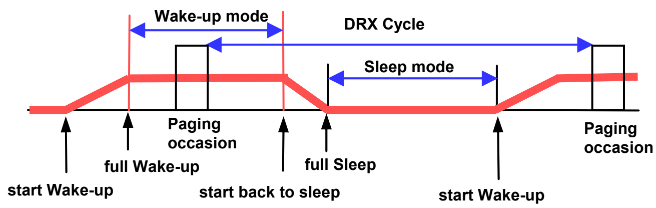

Fig.1 – UE sleep cycle in idle mode (not to scale)

C. *System Information Broadcast*

The system information broadcasted on BCCH is partitioned into SIBs. Each SIB carries particular type of system information, such as PLMN info, DRX cycle coefficient (SIB1), thresholds for cell reselection (SIB3), current uplink interference level (SIB7) and other. Each SIB can be segmented and transmitted over several BCCH frames and is repeated periodically with the fixed period, called repetition count, expressed in number of system frames. The duration of one system frame is 10 ms. The size of SIBs varies depending on the information they carry. For example, SIB11 carries the list of neighbors of the camping cell that the UE is supposed to measure for cell reselection purposes. Its size and number of segments will be affected by the number of neighbors of the camping cell.

The information about the scheduling of SIBs onto 20ms-long BCCH frames is contained in the master information block (MIB), which is broadcasted in the regular, pre-determined time intervals of 80 ms (i.e. every fourth BCCH frame). MIB contains the exact repetition count, number of segments, System Frame Number (SFN) of the first segment and SFN offset for the remaining segments (if any) for each of the SIBs. Sometimes, in addition to MIB there could be scheduling blocks (SB), which contain the information for the rest of the SIBs that have not been included in the MIB.

One example of the SIB scheduling in a commercial UMTS network, denoted as Network A, is given in Fig.2.

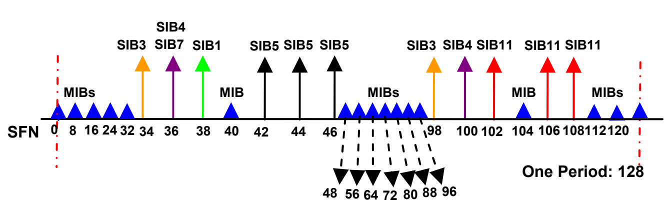

Fig.2 – SIB scheduling example in Network A

In this example, SIB3 and SIB4 consist of one segment each, with repetition count of 64; SIB5 and SIB11 consist of three segments each and have repetition count of 128; SIB7 consist of one segment with repetition count of 128.

Upon reselection to a new cell, the UE needs to collect the SIBs that carry the system information required for the operation in idle mode. Strictly speaking, these include SIBs 1, 3, 5, 7 and 11. The UE may decide to postpone reading other system information blocks until the content is needed.

Decoding and managing of the information broadcasted on the BCCH is the task of the Radio Resource Control (RRC) layer in the UE. The RRC will read the SIB scheduling info from MIBs, collect and reassemble SIB segments and decode the system information parameters contained therein.

III. SIB COLLECTION AND STANDBY BATTERY LIFE

A. *SIB scheduling and battery life*

There is a tradeoff between the standby battery life and the idle mode performance of mobile devices in wireless networks in general. For example, the longer the DRX cycle, the longer the average mobile-terminated call setup time, since the UE will wait longer to get out of the sleep state and respond to a page. Standard parameters affecting cell reselection, will also indirectly impact the battery life, since SIB collection is required upon cell reselection.

In order to see the impact of SIB scheduling on the battery life, observe again the SIB scheduling in Network A. The maximum repetition count across all SIBs is 128; therefore, it will take the UE about 1.28s in order to collect all the SIBs in the target cell. During this time, the UE will drain its battery at a faster rate. For the sake of example, let's assume that the ratio of the current drawn by the UE when awake to the current drawn when asleep is 25. This means that each SIB collection will in this case reduce the standby battery life of the UE by about 24 x 1.28 ≅ 30 seconds. Therefore, the maximum repetition count is an important non-standard parameter affecting battery life of mobile devices in UMTS.

B. *Inter-SIB sleep management*

It is possible to optimize the SIB collection by allowing the UE to take advantage of the opportunities to go to sleep state between reading SIBs. Looking at Fig. 2, assume that the UE starts demodulating the target cell's BCCH (denoted as N-BCCH, as opposed to the BCCH of the camping cell) at the time of SFN 48. This UE will first acquire the MIB scheduled at SFN 48 with scheduling information for all the SIBs. The next information broadcasted on the N-BCCH will be SIB3 at SFN 98. If the UE stays in the wake-up state during this time (500ms) it will drain its battery at a faster rate than in the sleep state. Hence, it would be advantageous in this case if the UE could go to sleep mode until the SIB3 broadcast starts. On the other hand, after the UE reads the first segment of SIB11 at SFN 102, there is only 40 ms until the broadcast of the second segment of SIB11 at SFN 106. This time gap might not be sufficient for the UE to complete the sleep cycle shown in Fig.1. The UE could detect the time gaps of sufficient length and use them as opportunities to go into sleep state without missing a SIB broadcast. Without this mechanism, that we can call inter-SIB sleep management algorithm, (ISMA), the UE could remain in the wake-up state longer than necessary. It should be noted that, as we shall demonstrate later, the SIB scheduling scheme will affect the battery life of mobile devices, with or without the ISMA. However, this feature will ensure that the UE maximizes its standby battery life for any given SIB scheduling scheme.

IV. Performance Evaluation

Since SIB scheduling schemes are not specified in the UMTS standard specifications, they vary significantly among commercial networks. Fig. 4 and Fig. 5 show two more examples of SIB scheduling in commercially deployed networks, denoted as Network B and Network C, respectively. All three networks use the maximum repetition count of 128 and the DRX cycle duration T_{DRX} of 1.28 s. In this section, we will first compute the SIB collection times without and with ISMA, respectively. We define the SIB collection time as the time required for the UE to spend in the wake-up state in order to collect the necessary SIBs on the target cell. We will then use these results to analyze the relationship between the SIB scheduling schemes and the standby battery time of mobile devices with and without ISMA for various user mobility patterns.

A. SIB collection times

1) Without ISMA

Consider the SIB scheduling of Network A on Fig.2 again. If the UE starts SIB collection at a time between SFN 0 and 32, it will be able to complete the collection of all SIBs at SFN 110. If, however, the start time is between SFN 96 and 128, the collection will be completed at SFN 128+110=238.

Based on Fig.2, the minimum and maximum SIB collection times without ISMA for Network A are:

$$T_{\min}^{A} = 1100\,ms - 320\,ms + \tau_1 + \tau_2 = 850\,ms \quad (1)$$

$$T_{\max}^{A} = 2380\,ms - 960\,ms + \tau_1 + \tau_2 = 1490\,ms \quad (2)$$

where τ_1 and τ_2 are the ramp-up and ramp-down times, assumed, for the sake of example, to be 40 ms and 30 ms, respectively. Since the SIB collection start time depends on the cell reselection time, it can be considered to have a uniform distribution. It is then straightforward to compute the average SIB collection time, by evaluating SIB collection times and averaging them over uniformly distributed start times. The derivation of the average SIB collection time for Network A is described in the Appendix. Table 1 shows the maximum, minimum and average SIB collection times without ISMA for Networks A, B and C. The numbers suggest that SIB scheduling schemes have significant impact on the time the UE spends collecting SIBs upon cell reselection. This is important for wireless operators using different infrastructure vendors in different areas; in such cases, the users might experience different standby battery times in different areas.

2) With ISMA

In the computation of the SIB collection times with ISMA, we need to take into consideration that the UE will go to sleep whenever the time until the next scheduled SIB is greater than or equal to the sum of the ramp-up time, ramp-down time and one system frame, i.e. $\tau_1 + \tau_2 + 10$ ms = 80ms. With this in mind, one can compute the SIB collection times for the SIB scheduling schemes in Networks A, B and C. The derivation is the straightforward extension of the derivation for the case without ISMA, described in the Appendix.

Clearly, the SIB collection times have improved significantly with respect to the scenario without ISMA. The average SIB collection times, as well as their ranges were reduced. ISMA also reduces the impact of SIB scheduling schemes on SIB collection times, since the difference between different network implementations has been reduced.

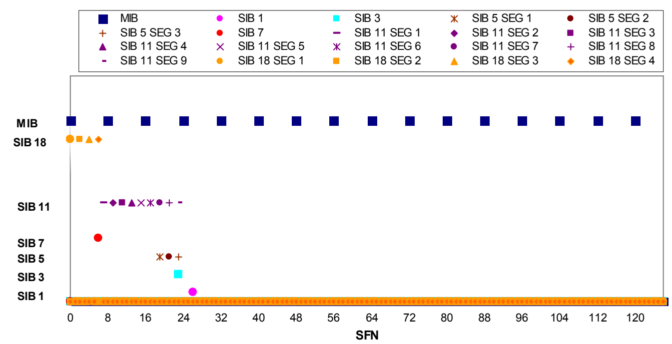

Fig.4 – SIB scheduling in Network B

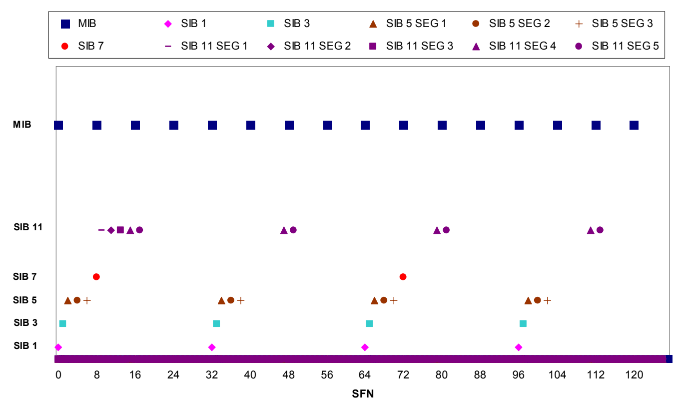

Fig.5 – SIB scheduling in Network C

TABLE I
SIB Collection Times without ISMA

Network	T_{min}	T_{max}	T_{avg}
A	850 ms	1490 ms	1175 ms
B	350 ms	1490 ms	953 ms
C	250 ms	1430 ms	781 ms

TABLE II
SIB Collection Times with ISMA

Network	T_{min}	T_{max}	T_{avg}
A	380 ms	530 ms	480 ms
B	350 ms	540 ms	367 ms
C	250 ms	410 ms	350 ms

B. SIB scheduling schemes and the standby battery life

A mobile device will need to collect all the SIBs upon the following events [6]:

1. When the UE is powered-up
2. When a MIB value tag changes
3. When the out-of-service condition occurs
4. When a cell reselection occurs

The frequency of occurrence of the first and the second event during typical battery time duration is sufficiently low that its impact on the battery life can be neglected. The third event will occur frequently only in bad coverage conditions. In that case, the optimization of the coverage would reduce the frequency of this event. In addition to this, the user experience in this case would probably be more affected by the lack of service than the battery life. Consequently, we will focus on the fourth event listed above, as it is the most frequent.

Each time the UE reselects to a target cell whose valid system information it does not have, the UE will need to collect all the SIBs of the target cell. During the SIB collection time, the UE will need to transition from the sleep state to the wake-up state. The longer the SIB collection time, the more time will the UE spend in the wake-up state, draining its battery at a faster rate.

Following the notations and definitions in [8] and [9], let B denote the battery capacity, let I_a and I_s denote the current drawn by the UE when awake and asleep, respectively, and let f_a denote the fraction of time the UE is awake. Then, the standby time of the UE can be expressed as:

$$ST = \frac{B}{f_a I_a + (1 - f_a) I_s} \tag{3}$$

For two implementations i and j, the standby time gain of i with respect to j is then:

$$\gamma_{i/j} = \frac{ST_i}{ST_j} - 1 = \frac{1 + f_{a,j}(\alpha - 1)}{1 + f_{a,i}(\alpha - 1)} - 1 \tag{4}$$

where $\alpha = I_a / I_s$. We can express the fraction of time the UE spends in the wake-up state as:

$$f_{a,i} = \frac{T^i_{awake}}{T_{DRX}} = \frac{(T_c + T^i_{avg} R_n)}{T_{DRX}} ms / DRX\ cycle \tag{5}$$

where T_c is the time UE spends for PICH decoding and cell quality measurements. T_{avg} is as defined in Tables 1 and 2. R_n is the net average reselection rate per DRX cycle duration. Alternatively, for a given network with fixed T_{DRX}, R_n can be expressed as the net average cell reselection rate per minute or per hour. R_n can be further factored as:

$$R_n = r \cdot R \tag{6}$$

R represents the average cell reselection rate, whereas r is the fraction of the reselections that require SIB collection, which is directly related to the UE capacity of storing the SIBs of the recently visited cells for certain time.

It is clear from (4) and (5) that $\gamma_{i/j}$ depends greatly on the net reselection rate R_n. It is interesting to note, however, that users with quite different patterns might have similar R_n. This is because r and R are independent parameters that can have wide range of combinations ending in the similar product. For example, a constantly mobile user (i.e. high R) who spends all his time within the areas of few cells (low r) could have a standby battery time similar to a user who moves rarely (low R) but within a larger geographic area (high r). Similarly, a user who is static half of the time and is mobile during the other half, experiencing cell reselections at the rate of one per minute, will experience similar battery life to the user who is constantly mobile and experiences cell reselections at the rate of one per two minutes, provided they move within the same area. Another important factor impacting R_n is the cell area size; for example, users in highly dense urban areas will have R_n higher than users in rural areas.

Fig. 6 shows the standby battery time gain for Networks B and C, with respect to Network A, for two different values of R_n (expressed in reselections per minute). T_c and α were set to typical values of 25 ms and 25, respectively. It outlines the impact of the SIB scheduling schemes on the standby battery time of the UE. The SIB scheduling scheme in Network A results in inferior standby battery time for mobile devices compared to networks B and C. This is true with or without ISMA, although ISMA clearly reduces the impact of the SIB scheduling schemes on the standby battery time. It is notable that higher R_n yields higher difference, in accord with the previous discussion. These results strongly suggest that the impact on the standby battery life should be one of the major considerations in the design of the SIB scheduling schemes by the network infrastructure vendors.

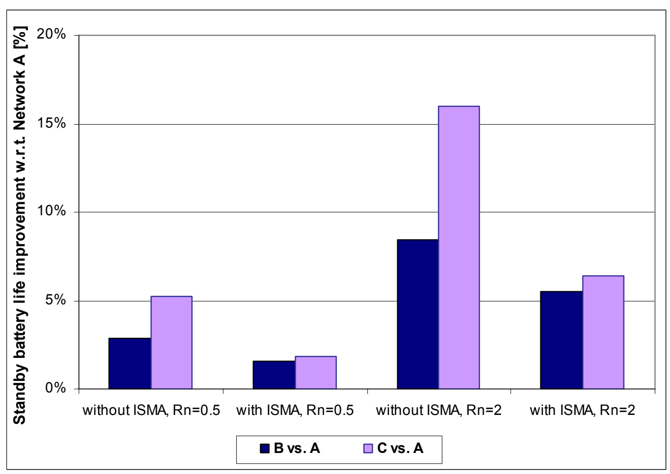

Fig.6 – Standby battery time gain vs. scheduling scheme

Fig.7 shows $\gamma_{i/j}$ for Networks A, B and C versus the net reselection rate R_n, where i and j denote the implementation scenarios with ISMA and without ISMA, respectively. The graphs indicate that for highly mobile users, UEs with ISMA could experience battery life gains of up to 50%. However, the improvement is substantial even for users with medium mobility, such as users who are highly mobile for a fraction of the battery life duration. This is in accord with our field tests of the standby battery time improvement of around 40%, using ISMA in Network A in highly urban areas and high mobility.

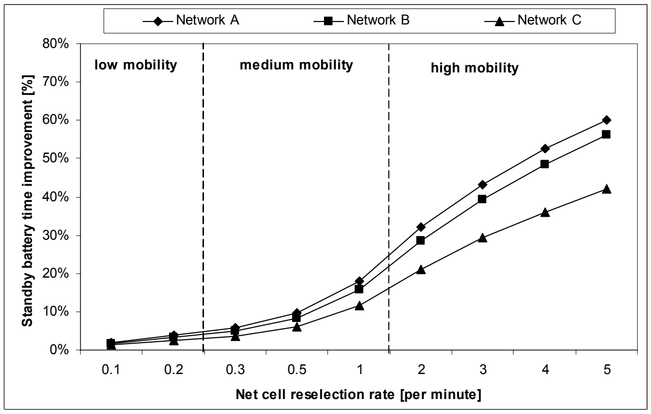

Fig.7 – Standby battery time improvement using ISMA

V. SIB SCHEDULING OPTIMIZATION ON THE NETWORK SIDE

From previous discussion, it is clear that the SIB scheduling scheme implemented on the network side greatly impacts the battery life of the UEs. This is true for the UEs that have inter-SIB sleep optimization implemented, as well as for the UE that don't have it. Therefore, it is important that the battery life of mobile devices is taken into account in the design of the SIB scheduling scheme on the network side. Scheduling SIBs on BCCH as often as possible would lead to the reduction of SIB collection times and therefore increase of the UE standby battery life. In order to achieve this, the smallest possible repetition count should be used for all SIBs. Also, keeping the number of segments for the SIBs as small as possible would have the same effect.

Frequent updating by the network of the SIBs on BCCH is beneficial from several aspects. For example, frequent broadcast of SIB7, which contains the current uplink interference level, helps to reduce the voice and data mobile-originated and mobile-terminated call setup times, registration delays and location updates. This is because the UE needs to get the current uplink interference information in order to determine the appropriate initial transmit power for the connection request messages. As we have shown here, the time required to acquire all necessary SIBs upon cell reselection is reduced if SIBs are broadcasted more often.

There seems to be no downside to more frequent scheduling of SIBs from the point of view of downlink interference, since the "no-segment" block is transmitted in BCCH frames that have no SIBs scheduled for transmission [6] and there is only one transport block size available for BCCH [11]. In other words, the activity factor for BCCH is 100% regardless of the SIB scheduling scheme. On the other hand, the information throughput of BCCH is limited to 12.2 kbps, which practically limits the frequency of SIB broadcasts.

VI. CONCLUSION

In this paper, we analyzed and quantified the impact of the SIB scheduling schemes on the network side and the inter-SIB sleep management schemes on the UE side on the standby battery life of the UE. The results indicate that these mechanisms can greatly impact the standby battery life. The impact grows in proportion with the user mobility, expressed in terms of the net cell reselection rate. This analysis should help increase the awareness towards the battery life design tradeoffs for the network infrastructure and the UE vendors. The design should maximize the quality of all the aspects of user experience with the services offered by a particular operator as well as with the UMTS technology in general.

APPENDIX

Here we derive the average SIB collection time, T_{avg}, without ISMA, for Network A. Let the random variable t represent the starting time of SIB processing for the N-BCCH. It is uniformly distributed over one combined SIB scheduling period. Assuming ramp-up and ramp-down time of 40 ms and 30 ms, respectively, we have:

$$0 < t <= 320 - 40 \text{ ms} \Rightarrow T = 1100 - t + 30 \Rightarrow T = 1130 - t$$

$$280 < t <= 400 - 40 \text{ ms} \Rightarrow T = 1680 - t + 30 \Rightarrow T = 1710 - t$$

$$360 < t <= 960 - 40 \text{ ms} \Rightarrow T = 1760 - t + 30 \Rightarrow T = 1790 - t$$

$$920 < t <= 1040 - 40 \text{ ms} \Rightarrow T = 2380 - t + 30 \Rightarrow T = 2410 - t$$

$$1000 < t < 1280 \text{ ms} \Rightarrow T = 2380 - t + 30 \Rightarrow T = 2410 - t$$

Based on the above equations, one may compute the minimum and maximum SIB collection time as T_{min}= 850 ms and T_{max} = 1490 ms. The average of T may be computed by taking the expected value of T given a uniformly distributed t over [0 , 1280). Therefore:

$$T_{avg} = \int_0^{1280} T(t)\,dt$$
$$= \frac{1}{1280}\left(\int_0^{280} (1130-t)\,dt + \int_{280}^{360} (1710-t)\,dt + \int_{360}^{920} (1790-t)\,dt + \int_{920}^{1280} (2410-t)\,dt \right)$$
$$= 1175 \ ms$$

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