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Standby Time Analysis for Mobile Devices in Multi-carrier WCDMA Networks

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Standby Time Analysis for Mobile Devices in Multi-carrier WCDMA Networks

Abstract—This paper analyses and quantifies the tradeoff between the standby time of mobile devices and the received signal quality in multi-carrier WCDMA systems. The analysis is based on measurements collected in commercial multi-carrier UMTS networks. Results are presented for several parameter setting scenarios typically found in multi-carrier UMTS network deployments.

1. Introduction

With the steady rise in popularity of third generation high-speed wireless data services and the multifunctional mobile devices that enable them, the daily usage of mobile phones is expected to grow. 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 usage time. A recent market research study shows that consumers now fully realize powerful, new applications require enhanced battery life, and they are demanding improvements as a priority [1].

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

There are also ways of improving battery life by optimizing the radio network configuration. Some aspects of network configuration have been standardized through Radio Resource Management (RRM) parameters [6], while others depend on the particular implementations in the network and in the mobile device (UE) [7]. Reference [8] contains a summary of UMTS RRM parameters potentially affecting battery life. References [9] and [10] examine the impact of standardized RRM parameter settings on the standby time in single-carrier CDMA2000 and UMTS networks.

Recently, due to increased traffic, UMTS network operators have started deploying multiple 5-MHz frequency carriers to provide sufficient traffic capacity to meet the demand. While significant effort has been made to understand the capacity gains, load sharing, deployment scenarios and network optimization challenges [8] related to inter-system [11] and multi-carrier deployments [12], [13], very little work has been done to understand how such systems impact UE battery life.

The objective of this paper is to shed some light onto this topic and provide basic quantitative guidelines with respect to the impact of RRM parameter settings on the UE battery life in multi-carrier UMTS deployments. In particular, this paper focuses on the parameters that affect intra-frequency and inter-frequency cell reselection.

The study performed in this paper is based on measurements collected in commercial networks. The measurements are input into a simulator platform that mimics the behavior of a UE in idle mode, subjected to different cell reselection parameter settings.

2. System Description

In this section, we define the concepts that are the basis of the discussion in the rest of the paper. This paper considers a network and UE that are compliant to the 3GPP specifications for UMTS Radio Access (UTRA). The UTRA mode is Frequency Division Duplexed (FDD) without Hierarchical Cell Structures (HCS) and with two carriers deployed.

2.1. UE Measurements in Idle Mode

The purpose of the UE measurements in idle mode is the identification and ranking of the serving cell and neighboring cells so that the UE can find and camp on a high quality cell. Figure 1 illustrates the UE sleep cycle in idle mode, which is controlled by the physical layer functions in the UE, based on system parameters received from the radio network and handed down to the physical layer by means of the Radio Resource Control (RRC) protocol layer [6].

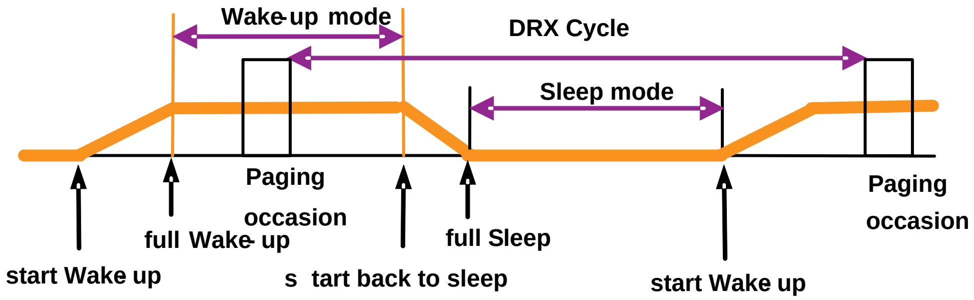

Figure 1: UE Sleep Cycle In Idle Mode (Not To Scale).

During the periodic wake-up times, a UE in idle mode is required to monitor the Paging Indicator Channel (PICH) time-aligned with paging occasions, and to measure intra-frequency and inter-frequency neighbors based on the following measurement rules [14]:

- If $S_{qual} > S_{intrasearch}$, UE does not need to perform intra-frequency measurements;
- If $S_{qual} <= S_{intrasearch}$ or if $S_{intrasearch}$ is not sent for serving cell, UE shall perform intra-frequency measurements;
- If $S_{qual} > S_{intersearch}$, UE does not need to perform inter-frequency measurements;
- If $S_{qual} <= S_{intersearch}$ or if $S_{intersearch}$ is not sent for serving cell, UE shall perform inter-frequency measurements;

where $S_{qual} = Q_{qualmeas} - Q_{qualmin}$; $Q_{qualmeas}$ is the Ec/No (dB) level of the Common Pilot Channel (CPICH) of the serving cell measured by the UE; $Q_{qualmin}$ is a cell-specific parameter broadcast by the network; $S_{intrasearch}$ and $S_{intersearch}$ are the thresholds for intra-frequency and inter-frequency measurement triggering in idle mode, respectively, broadcast by the network [8].

Once the UE starts measuring neighboring cells, the frequency of the UE measurements depends on the DRX cycle length (for a two-carrier scenario and a DRX cycle >= 1.28 sec, the UE will perform intra-frequency and inter-frequency neighbor measurements every DRX cycle [14]).

2.2. Cell Reselection Criteria

The UE will perform cell reselection to the new best ranked cell if the following conditions apply [14]:

- the new cell satisfies a minimum radio suitability criteria,
- the new cell is better ranked than the serving cell during a time interval $T_{reselection}$ (broadcast parameter),
- more than one second has elapsed since the UE camped on the current serving cell.

Cell ranking is computed as follows:

$$R_s = Q_{meas,s} + Q_{hyst,s}$$
$$R_n = Q_{meas,n} - Q_{offset,s,n} \qquad (1)$$

where R_s and R_n represent the computed rank of the serving cell and the neighboring cell, respectively; $Q_{meas,s}$ and $Q_{meas,n}$ is the measured CPICH quality of the serving cell and the neighboring cell, respectively; $Q_{hyst,s}$ is the hysteresis (dB) to be applied to the serving cell; $Q_{offset,s,n}$ is the offset (dB) to be applied to the n-th neighbor cell, broadcast by the serving cell.

When the above conditions are satisfied, the UE will reselect to the cell with the highest ranking. The best ranked cell can be either on the same frequency carrier as the last serving cell (intra-frequency reselection) or on a different carrier (inter-frequency cell reselection).

$Q_{meas,s}$, $Q_{meas,n}$, $Q_{hyst,s}$, and $Q_{offset,s,n}$ will refer to either the CPICH Ec/No or the CPICH Received Signal Code Power (RSCP) depending on the parameter *Quality Measure* broadcasted by the network. In this paper we will use Ec/No as the quality measure, corresponding to most of the practical cases.

2.3. Battery Life Model

The impact of intra- and inter-frequency reselection parameters, described in Section II, on the UE battery consumption will be reflected through the number of intra-/inter-frequency measurements and reselections.

In the first approximation [9] and [10], idle mode UE battery consumption due to a specific parameter setting scenario can be represented as follows:

$$B_{tot} = B_{base} + B_{add} \quad (2)$$

where

$$B_{base} = T_{tot} \cdot I_{idle} \quad (3)$$

$$B_{add} = T_{add} \cdot I_{active} = [t_{meas\_IntraF} \cdot R_{meas\_IntraF} + \\ + t_{meas\_InterF} \cdot R_{meas\_InterF} + t_{CR} \cdot (R_{CR\_IntraF} + R_{CR\_InterF})] \cdot I_{active}$$

where

- I_{idle} is the average current drawn by the UE while performing basic idle mode operations (mostly for serving cell quality monitoring and PICH decoding); I_{active} is the average current drawn by the UE while performing idle mode neighbor cells' measurements and reselections in wake-up mode (see Figure 1); T_{tot} is the overall time the UE is in idle mode and T_{add} is the wake-up time due to neighbor cells' measurements and reselections.
- t_{meas_IntraF} , t_{meas_InterF}, and t_{CR} represent the time UE stays in wake-up mode in order to perform intra-frequency measurements, inter-frequency measurements and cell reselections, respectively.
- R_{meas_IntraF} and R_{meas_InterF} are the rates at which the UE performs intra-frequency and inter-frequency measurements, respectively; R_{CR_IntraF} and R_{CR_InterF} are the rates at which the UE performs intra-frequency and inter-frequency cell reselections, respectively.

Furthermore,

$$t_{meas\_InterF} = t_{PSC} \cdot N_{NL\_InterF} + t_{tune} \quad (4)$$

where t_{PSC} represents time required to search for and measure the strength of one neighboring primary scrambling code; N_{NL_InterF} represents the size of the inter-frequency neighbor list; t_{tune} represents the time required to tune from one frequency carrier to another. Similarly:

$$t_{meas\_IntraF} = t_{PSC} \cdot N_{NL\_IntraF} \quad (5)$$

3. Measurements and Simulation Setup

As indicated in Section II, the frequency of measurements for a certain DRX cycle length is mainly determined by the parameters $S_{intrasearch}$ (for measuring cells on the same frequency carrier) and $S_{intersearch}$ (for measuring cells on another frequency carrier). Higher value of these parameters allows the UE to measure the corresponding cells more frequently, and has more up-to-date information to decide whether to reselect to a new, better cell or not, using rules described in Section 2.2.

As a general principle, there is no particular reason to measure cells on another carrier more often than cells on the same carrier so $S_{intersearch} < S_{intrasearch}$ is assumed, as typically configured in real systems.

The Qualcomm-developed system level simulator [10] and [11], is used to analyze the impact of different parameter settings on battery consumption. The simulator imports radio channel information from measurements collected in a dual-carrier urban commercial deployment (one-to-one 2x2.1 GHz carrier overlay, mixed stationary and low-speed mobility conditions) and emulates UE behavior in terms of intra-frequency and inter-frequency measurements and cell reselections for different parameter setting scenarios.

Figure 2 describes the setup of the simulator.

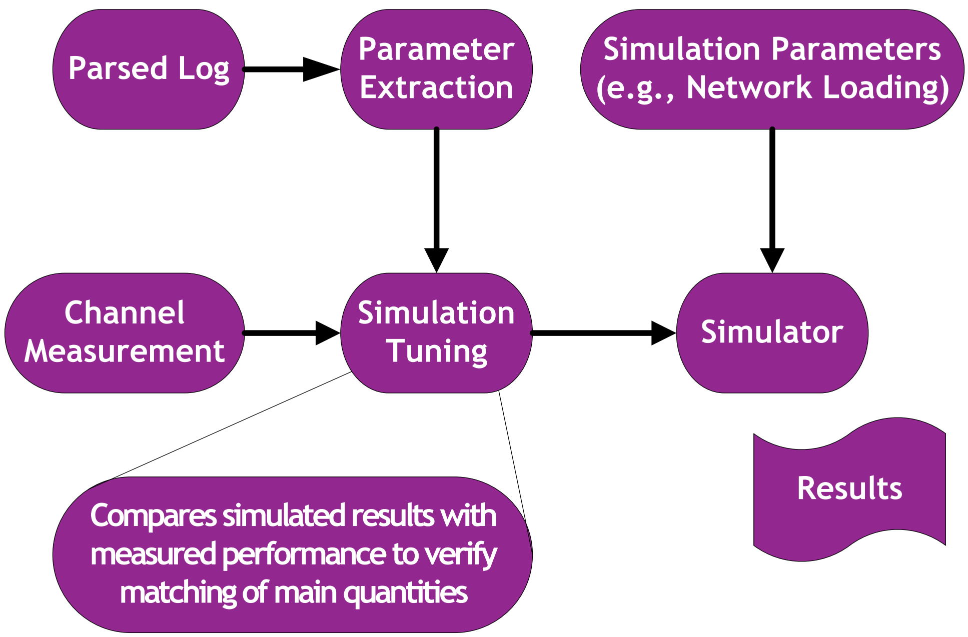

Figure 2: Simulation Setup

Table 1 and Table 2 show the parameter setting scenarios emulated by the simulator and considered in the analysis.

Thirty two different combinations of $S_{intrasearch}$, $S_{intersearch}$, and inter-freq $Q_{offset s,n}$ shown in Table 2 were analyzed, while other parameters were kept constant.

The following additional assumptions were made:

t_{CR} = 400 milliseconds on average [7]

t_{tune} = 5 milliseconds

t_{PSC} = 0.3 milliseconds [15]

$I_{active} / I_{idle} = 100$ [9]

$N_{NL\_IntraF} = N_{NL\_InterF} = 15$

Table 1: Parameter Setting Scenarios

Scenario #	$S_{intrasearch}$ [dB]	$S_{intersearch}$ [dB]	$Q_{offset,s,n}$ [dB] (n∈ other carrier)
1, 2,3 ,4	16	10, 8, 6, 4	0
5, 6, 7, 8	14	10, 8, 6, 4	0
9, 10, 11, 12	12	10, 8, 6, 4	0
13, 14, 15, 16	10	10, 8, 6, 4	0
17, 18, 19, 20	16	10, 8, 6, 4	3
21, 22, 23, 24	14	10, 8, 6, 4	3
25, 26, 27, 28	12	10, 8, 6, 4	3
29, 30, 31, 32	10	10, 8, 6, 4	3

Table 2: Fixed Parameters

Parameter	Setting
$Q_{rxlevmin}$	-115 [dBm]
$Q_{qualmin}$	-18 [dB]
Q_{hyst2}	2 [dB]
$Q_{offset,s,n}$ (n∈ same carrier)	0 [dB]
DRX_cycle	1.28 [s]
$T_{reselection}$	1 [s]
SsearchRAT	2 [dB]
Ssearch_HCS = SHCS_RAT	0 [dB]

4. Results and Analysis

For the scenarios described in Table 1, two metrics—battery life and the quality of the camping cell—were thoroughly investigated. Both metrics are related to the frequency of UE measurements and cell reselections: the more often the UE measures its neighbors and reselects a better cell, the better coverage quality the UE will experience, but at the expense of a reduced battery life.

4.1. Battery Life Impact

The battery consumption results shown in this section are expressed in terms of relative battery consumption increase:

$$\frac{Btot_2}{Btot_1}-1=\frac{(Bbase+Badd_2)}{(Bbase+Badd_1)}-1=\frac{1+\frac{Tadd_2}{Ttot}\cdot\frac{Iactive}{Iidle}}{1+\frac{Tadd_1}{Ttot}\cdot\frac{Iactive}{Iidle}}-1 \tag{6}$$

assuming Scenario 9 ($S_{intrasearch}$ / $S_{intersearch}$ /Inter-freq $Q_{offset,s,n}$ = 12/10/0) as reference scenario (B_{tot1}) for this study.

Figure 3 shows the percentage of idle mode battery consumption increase for Scenarios 1 through 16 ($Q_{offset,s,n}$ for inter-frequency neighbor cells = 0 dB).

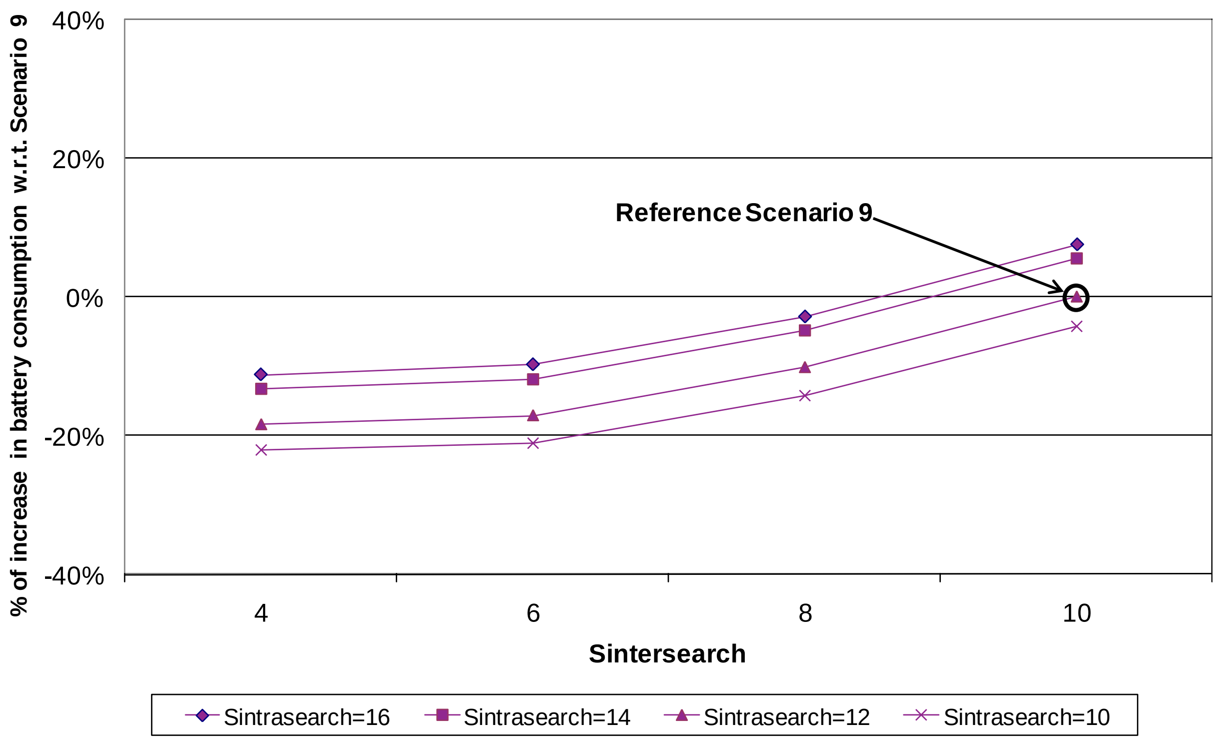

Figure 3: UE Battery Consumption Increase, Relative to Scenario 9, as a Function of $S_{intrasearch}$ and $S_{intersearch}$ for Scenarios 1 through 16.

The following observations can be derived from Figure 3:

- A variation (increase) of 2 dB in $S_{intrasearch}$ results in a relative battery consumption increase of 5% (max).
- A variation (increase) of 2 dB in $S_{intersearch}$ results in a relative battery consumption increase of 10% (max), for $S_{intersearch} \geq 6$ dB, while no relevant change is noted below 6 dB. The large impact of (high) $S_{intersearch}$ values is expected given the setting of Inter-freq $Q_{offset,s,n}$ = 0 dB, which would make inter-frequency reselections relatively easier (compared to larger values).

Figure 4 shows the percentage of idle mode battery consumption increase for Scenarios 17 through 32 ($Q_{offset,s,n}$ for inter-frequency neighbor cells = 3 dB).

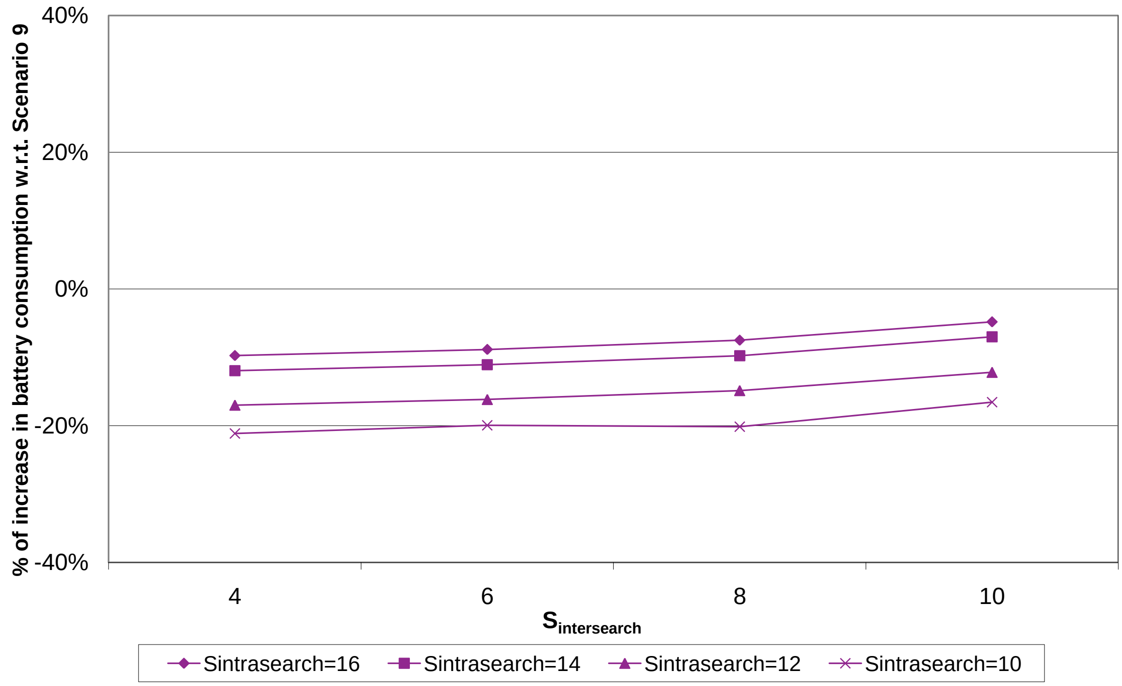

Figure 4: UE Battery Consumption Increase, Relative to Scenario 9, as a Function of $S_{intrasearch}$ and $S_{intersearch}$ for Scenarios 17 through 32.

The following observations can be derived from Figure 4:

- $S_{intrasearch}$ impact on battery consumption is very similar to Figure 3, as expected given the negligible correlation between intra-frequency measurements and reselections (governed by $S_{intrasearch}$ and the Intra-freq $Q_{offset,s,n}$) and the Inter-freq $Q_{offset,s,n}$.
- $S_{intersearch}$ impact on battery consumption is not very significant, i.e., less than 5% over the entire $S_{intersearch}$ simulated range (4-10 dB). This is mostly due to the fact

that Inter-freq $Q_{offset,s,n}$ = 3 dB makes inter-frequency reselections harder (compared to a value of 0 dB), thus the effect of $S_{intersearch}$ would be limited to inter-freq measurements.

By comparing results from Figure 3 and Figure 4 you can see an increase of Inter-freq $Q_{offset,s,n}$ from 0 dB to 3 dB results in a battery consumption decrease of around 12% for high $S_{intersearch}$ values (8-10 dB), whilst impacts are negligible for lower $S_{intersearch}$ values (below 8 dB).

4.2. Impact on RF Quality

The other important cell reselection aspect to consider when optimizing the parameter settings is the quality of the serving cell, which can be expressed in terms of CPICH Ec/No. More conservative parameter settings will result in delayed cell reselection and thus lower serving cell signal quality prior to reselections; analogously, more aggressive parameter setting will make cell reselection more responsive to the quality of the overall radio environment. Therefore, the analysis focuses on the impact of parameter settings on the signal quality immediately before cell reselection occurs.

In Figure 5, the Ec/No of the camping cell, averaged over the last 15 seconds prior to cell reselection events, is shown for Inter-freq $Q_{offset,s,n}$ = 0 dB and few selected $S_{intrasearch}$ / $S_{intersearch}$ Scenarios. As the figure shows, the impact of $S_{intrasearch}$ and $S_{intersearch}$ is low (almost null for $S_{intrasearch}$, and less than 1 dB variation for $S_{intersearch}$) for those selected parameter values.

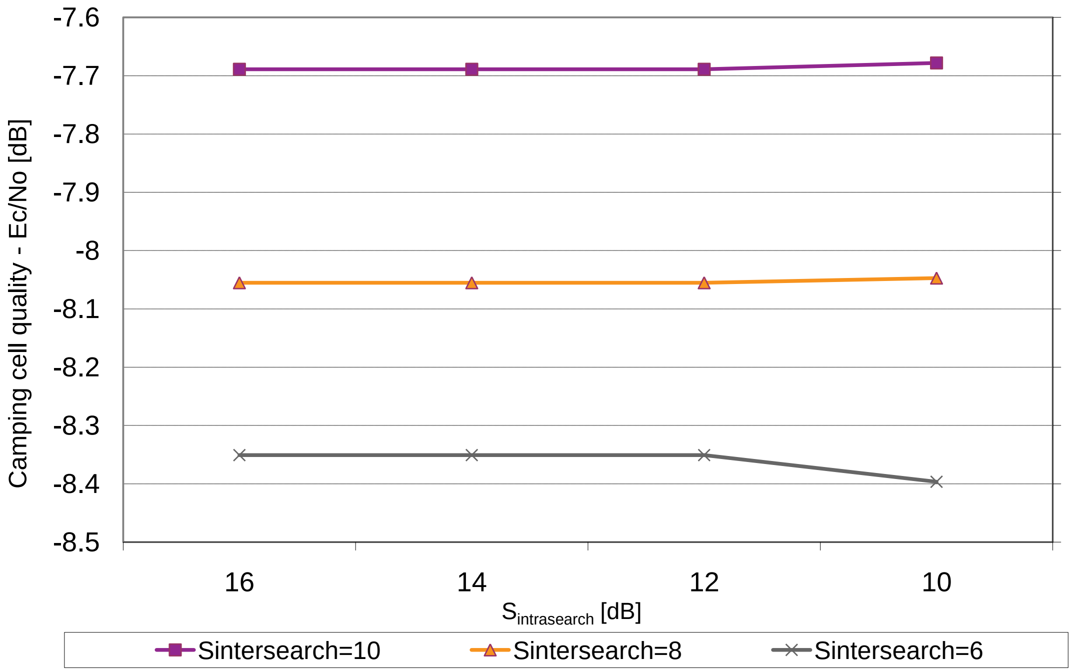

Figure 5: Camping Cell Ec/No (Averaged Over Last 15 sec. Prior to Reselection) for $Q_{offset,s,n}$ for Inter-Frequency Cells of 0 dB.

In Figure 6, the Ec/No of the camping cell , averaged over the last 15 seconds prior to cell reselection, is shown for Inter-freq $Q_{offset,s,n}$ = 3 dB (same $S_{intrasearch}$ / $S_{intersearch}$ Scenarios as in Figure 5).

Results are similar to Figure 5, i.e., the impact of $S_{intrasearch}$ and $S_{intersearch}$ is low. Furthermore, a comparison between Figure 5 and Figure 6 shows that the impact of $Q_{offset,s,n}$ (0 vs. 3 dB) on cell quality is insignificant: less than 0.7 dB for $S_{interserach}$=10, negligible for lower $S_{interserach}$ values.

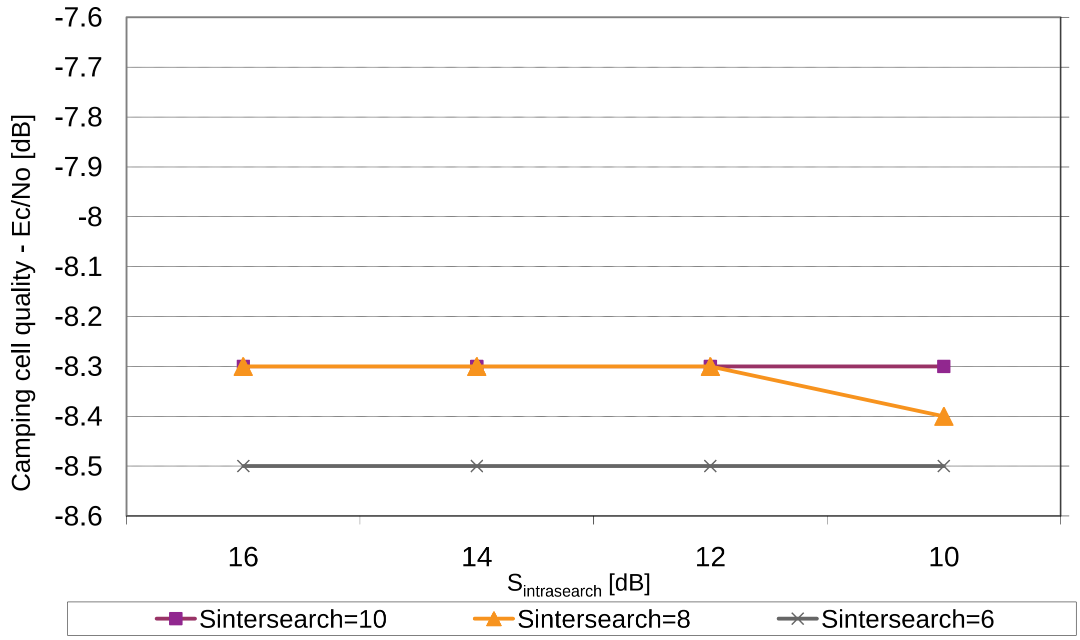

Figure 6: Camping Cell Ec/No (Averaged Over Last 15 sec. Prior to Reselection) for $Q_{offset,s,n}$ for Inter-Frequency Cells of 3 dB.

Figure 5 and Figure 6 in combination with Figure 3 and Figure 4 allow quantifying the tradeoff between the serving cell quality and battery consumption due to parameter settings. Figure 7 and Figure 8 summarize such trade-off for few selected scenarios:

- varying $S_{intersearch}$ and Inter-freq $Q_{offset,s,n}$ for a given $S_{intrasearch}$ (Figure 7);
- varying Inter-freq $Q_{offset,s,n}$ with different "$S_{intrasearch}$ = $S_{intersearch}$" combinations (Figure 8).

In Figure 7 and Figure 8, same shape markers are used to represent the same settings of $S_{intrasearch}$ and $S_{intersearch}$ parameters, filled markers correspond to an Inter-freq $Q_{offset,s,n}$ value of 0 dB while markers with no filling correspond to an Inter-freq $Q_{offset,s,n}$ value of 3 dB.

Results shown in both figures are normalized with respect to Scenario 9 ($S_{intrasearch}$ / $S_{intersearch}$ /*Inter-freq* $Q_{offset,s,n}$ = 12/10/0).

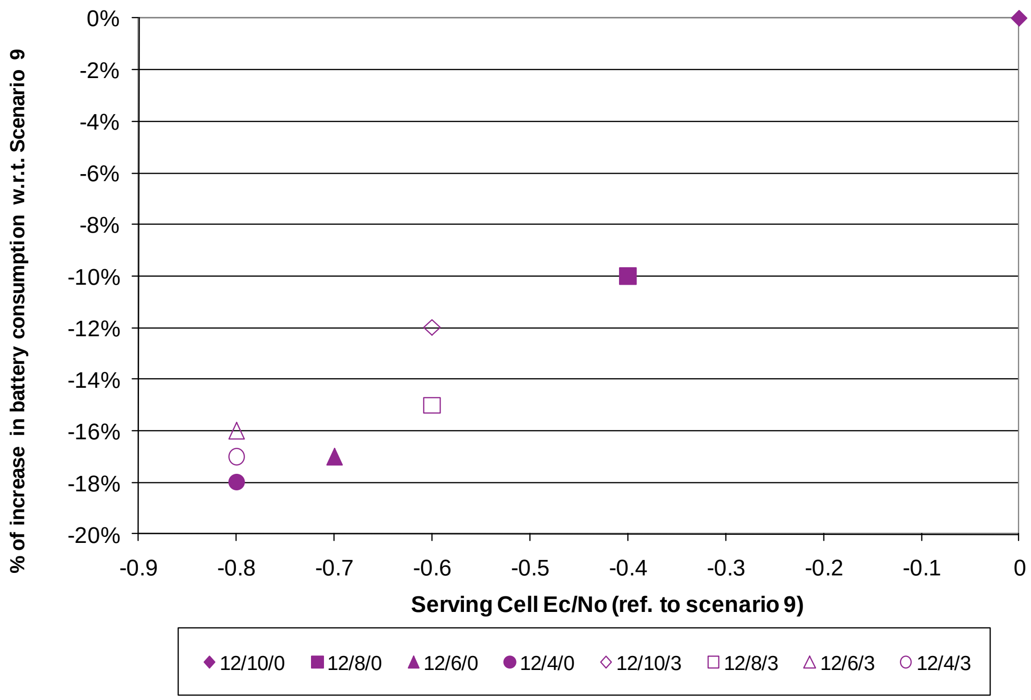

Figure 7: Battery Consumption And Serving Cell Ec/No as a Function of $S_{intersearch}$ and $Q_{offset,s,n}$ for Inter-Frequency Neighbors, Relative to Scenario 9.

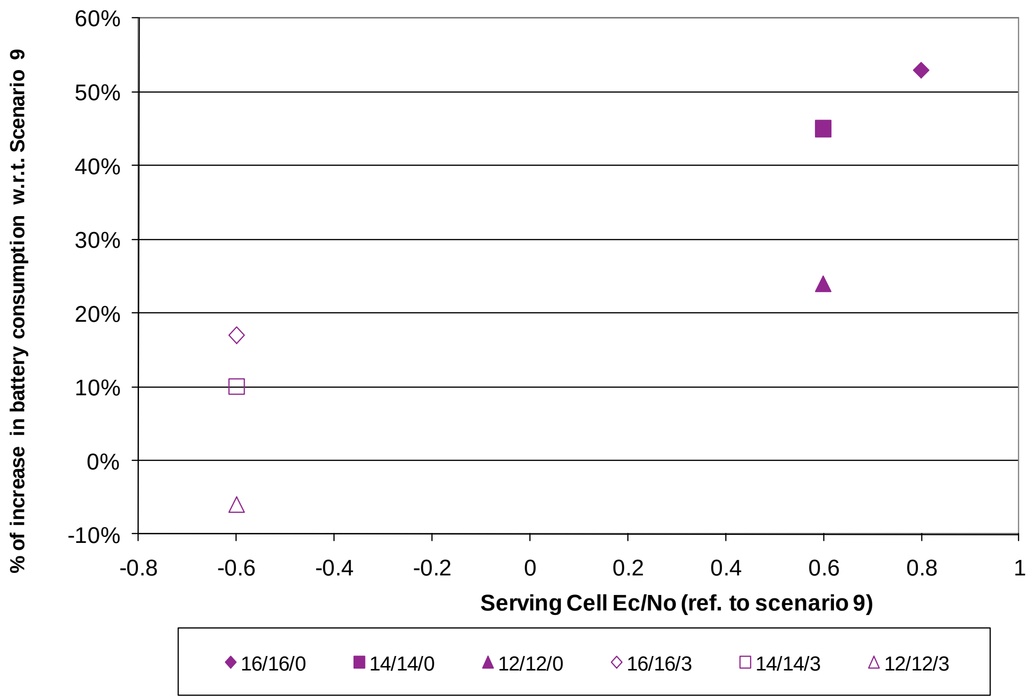

Figure 8: Battery Consumption and Serving Cell Ec/No as a Function of $S_{intrasearch}$, $S_{intersearch}$ and $Q_{offset,s,n}$ for Inter-Frequency Neighbors, Relative to Scenario 9.

Looking at the graph in Figure 7, the following conclusions can be derived where $S_{intersearch}$ is set above 6 dB:

- Lowering $S_{intersearch}$ results in high battery gain (~10% every 2 dB step) and minimal cell quality loss (0.4 dB every 2 dB step).
- Q_{offset} impact is also significant on battery gain (up to 12% for 3 dB increase in case of $S_{intrasearch}$ / $S_{intersearch}$ = 12/10) and minimal on Cell Quality (< 0.6 dB for 3 dB variation in Q_{offset}).

No relevant impacts are observed for low values of $S_{intersearch}$.

With regard to Figure 8, the following additional observations can be made:

- High $S_{intrasearch}$ and $S_{intersearch}$ (> 10 dB) increase battery drain (up to 20% for 2 dB step) but have minimal effect on cell quality.
- For high $S_{intrasearch}$ and $S_{intersearch}$ values (>10 dB), Q_{offset} impact is very large on battery (~ 35% gain for +3 dB offset) while it is minimal on cell quality (~ 1 dB gain for +3 dB offset).

4.3. Summary of Results for Typical Scenarios

Table 3 summarizes and compares the results for a few selected parameter setting scenarios, listing battery consumption and cell quality relative to Scenario 9 ($S_{intrasearch}$ = 12 dB, $S_{intersearch}$ = 10 dB and Inter-freq $Q_{offset,s,n}$ = 0 dB) derived from the plots shown in the previous sections.

Table 3: Summary Comparison Of Typical Parameter Setting Scenarios ($Q_{offset,s,n}$ = 0, Relative to Scenario 9)

Parameters (Sintra/Sinter/Qoff)	Note	Battery drain Increase	Serving cell Ec/No
16/10/0	Higher Sintra	+8%	+0.1 dB
14/10/0		+5%	0 dB
12/12/0	Higher/Lower Sinter	+24%	+0.5 dB
12/8/0		-10%	-0.4 dB
16/16/0	High Sintra = Sinter	+53%	+0.8 dB
14/14/0		+45%	+0.6 dB

5. Conclusion

In this paper, we analyzed and quantified the impact of intra-/inter-frequency cell reselection parameter settings, namely $S_{intrasearch}$, $S_{intersearch}$, and *Inter-freq* $Q_{offset,s,n}$, on the idle mode UE battery life and camping cell quality in multi-carrier UMTS networks. The simulation results indicate that the fine tuning of a few cell reselection parameters has the potential to considerably improve UE battery life with minimal or no degradation in serving cell quality Ec/No. In particular:

- 2 dB decrease in $S_{intrasearch}$ and $S_{interserach}$ can increase stand-by time up to 25%.
- 3 dB increase in Inter-freq Q_{offest} can increase stand-by time up to 35%.
- Cell quality (Ec/No) impact is minimal, ranging from 0 to 1 dB.

Future work will focus on analyzing the impact on UE stand-by time due to different network or traffic environments/conditions, other cell reselection parameters (intra-/inter-frequency, inter-system and HCS), and parameter trade-offs related to inter-frequency load balancing (using idle mode cell reselection) and Femto-cell (or Home NodeB) deployments.

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