# WCDMA Network Deployments: Asynchronous vs. Synchronous

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CONTENTS

## 1.0 ABSTRACT

A basic design decision facing an operator of a WCDMA network is the nature and level of synchronization between base stations in the network. The WCDMA standard allows asynchronous operation in which each base station uses its own independent timing reference. The standard also allows base stations to be synchronized and, in fact, provides explicit signaling support that allows the benefits of synchronous operation to be realized. In this paper, we contrast these two approaches to synchronization and provide qualitative and quantitative analyses showing the beneficial effects on communication system performance of synchronizing WCDMA base stations. We show that synchronizing WCDMA base stations increases handset standby time by up to 2.5 times, improves paging performance and enhances system capacity.

## 2.0 INTRODUCTION

Wideband CDMA (WCDMA) has been designed for deployment in a wide variety of scenarios. Determining the nature and level of synchronization between base stations is a basic system design decision facing an operator of a WCDMA network.

One approach would be to deploy the network *asynchronously*. In asynchronous operation, each base station (referred to as a node B) has an independent time reference, and the user equipment (UE), typically a mobile phone or other handheld device, does not have prior knowledge of the relative time difference between various base stations. The advantage of asynchronous operation is that it eliminates the need to synchronize node Bs to an accurate external timing source. Availability of an accurate external timing source may be of concern in certain situations such as deep in-building coverage or underground deployments.

Another approach is to synchronize the node Bs by observing and controlling their timing relative to one another (self-synchronizing), just controlling their timing relative to one another (GPS), or just observing (quasi-synchronous). The WCDMA standard delineates requirements for signaling support by the network. The network has the option to keep the UE informed of the relative timing between node Bs as well as their synchronization accuracy. This information will permit the UEs to operate more efficiently and can result in significant performance improvements compared to asynchronous deployments.

In this paper, we will contrast these two approaches to synchronization and provide qualitative and quantitative analyses showing the beneficial effects of synchronizing node Bs. To emphasize the differences between the two approaches, our analyses consider networks in which either all node Bs operate asynchronously or all node Bs are synchronized. In practice, however, it is possible to derive the benefits of synchronous operation in a part of the network by synchronizing node Bs in certain contiguous areas even when node Bs in other parts of the network operate asynchronously.

There are no technical disadvantages to synchronizing base stations. A system design that assumes an accurate external timing source is no worse than an asynchronous system, even if the external timing source is unavailable for an extended period of time, since the loss of synchronization can be communicated to neighboring node Bs and broadcast to the UE. The UE can then operate as it would in an asynchronous system. Any synchronization of base stations can only improve performance.

Synchronous deployment offers two main advantages over asynchronous deployment:

1. In a synchronous system, the UE is informed of the timing of neighboring base stations. The residual uncertainty in timing is much smaller than the uncertainty in an asynchronous system. This results in reduced search times for handover searching (both intra- and inter-frequency searching), which produces a significant improvement in standby time as well as potential improvements to system capacity.

2. Improved availability and reduced time for position location calculations.

Since the benefits of position location services are beyond the scope of this document, we will restrict our analysis to the first of these two advantages that synchronous deployments offer. Also, for synchronous deployment we will only consider optimizations that do not require a change in the WCDMA standard. If physical layer and protocol layer changes were considered, then further optimizations may be feasible.

This paper is organized as follows. In Section 2.1, we provide a more precise definition of the word *synchronous*. This is necessary because it is feasible to operate with different types of synchronization, and the complexity/benefit tradeoff for each type of synchronization is different. In Section 3, we provide qualitative arguments describing the potential benefits of synchronous deployment. Given the complexity of cellular systems, it is not practical to quantify the benefits of synchronization under all possible operating conditions. Quantitative comparisons for representative conditions are presented in Section 4. Section 5 discusses some of the techniques that can be used for synchronizing base stations.

### 2.1 DEFINITIONS

In this section, we define terms that are used throughout this paper.

- *Asynchronous* – Each base station has an independent time reference. The UE has no knowledge of the relative time difference between base stations. For an asynchronous system, the UE has to demodulate the broadcast channel (BCH) of each base station and read its system frame number (SFN) to measure the relative time difference between base stations (as measured at the UE).

- *Quasi-synchronous* – Each base station has an independent time reference. However, each base station measures the relative time difference between itself and its neighbors, and broadcasts that information to the UE (through system information broadcast messages). A mechanism for measuring this time difference is presented in Section 5.

- *Clock-synchronous*: In this design, the clocks of all base stations are synchronized and each base station transmits its pseudo noise sequence (PN-sequence) at the same time. This synchronization could be accomplished using a common clock source such as GPS or using self-synchronization schemes such as those described in [7], [8] and [10].

For both quasi-synchronous and clock-synchronous deployments, different levels of synchronization are feasible. The current 3GPP specification [1] supports synchronization to an accuracy of 2560 chips [666 microseconds (μs)], 256 chips (66.6 μs) and 40 chips (10.4 μs).

For the remainder of this document, we will use the term *synchronous* to refer collectively to both quasi-synchronous and clock-synchronous deployments.

## 2.2 ACRONYMS

| ACRONYM | DEFINITION |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| AWGN | Additive White Gaussian Noise |
| BCH | Broadcast Channel |
| CPICH | Common Pilot Channel |
| DRX | Discontinuous Reception |
| GPS | Global Positioning System |
| NodeB | Base Station |
| PI | Paging Indicator |
| PICH | Paging Indicator Channel |
| PN-sequence | Pseudo Noise Sequence |
| PSC | Primary Synchronization Channel |
| SCH | Synchronization Channel – composed of PSC and SSC |
| SFN | System Frame Number |
| SSC | Secondary Synchronization Channel |
| UE | User Equipment – typically a mobile phone or other handheld device |
| WCDMA | Wideband CDMA |

## 3.0 PERFORMANCE ADVANTAGES DUE TO SYNCHRONIZATION – QUALITATIVE DISCUSSION

Many of the potential performance improvements in WCDMA systems using a synchronous deployment would result from more efficient searching of the neighboring cells' pilots prior to handover. Before we discuss the details of handover searching, we will provide a brief summary of the WCDMA acquisition procedure. The WCDMA standard allows each base station's primary scrambling code PN-sequence to be chosen from among 512 truncated Gold code sequences that are periodic (with a period of 38400 chips, which is referred to as a radio frame). To allow the UE to acquire the scrambling code and frame timing, the primary scrambling code is broadcast throughout the cell without any data modulation. This is the common pilot channel (CPICH). Since it is not practical for a UE to search through all 512 Gold codes for each of the 38400 PN-code phases, the base station transmits additional synchronization channels – the primary synchronization channel (PSC) and the secondary synchronization channel (SSC) – to help the UE perform this search efficiently. The PSC is a fixed sequence that is transmitted once per 2560 chips (referred to as a slot).

By searching for the PSC, the UE can acquire the slot timing (called a Step 1 search). After acquiring slot timing, the UE must synchronize itself to the base station's frame timing and identify the scrambling code used by the base station. This is accomplished using the SSC. The SSC is a comma-free sequence that allows the UE to identify frame timing and narrow the scrambling code down to a group of eight possibilities. Acquiring the SSC is referred to as a Step 2 search. Step 3 requires searching the CPICH using the eight scrambling codes identified in Step 2 to determine which is actually in use. These three searches comprise the 3-step search procedure [4, Annex C].

With asynchronous deployment, the UE has no knowledge of the PN code phase of any of the neighboring base stations. The UE must then search the entire range of possible PN code phases for each base station. A sequential search of all possibilities for each neighboring base station becomes prohibitively time consuming in dense urban deployments where the number of neighbors is large. This is true even if the scrambling codes of all the neighbors are known. A more efficient alternative is to perform the 3-step search. The UE has to go through Step 2 and Step 3 for each multipath for each base station (a single Step 1 search will return the positions of all possible distinguishable multipaths).

The efficiency of a 3-step search can be increased using the procedure described below. In handover searching, the scrambling codes of the neighbors are known. This information can be used to avoid performing Step 2 and Step 3.

- Step A - The UE performs a Step 1 search to acquire the slot timing of the neighboring cells.
- Step B - For each multipath detected in Step A, the UE determines the corresponding scrambling code and frame timing. The number of scrambling code hypotheses is equal to the number of neighbors N. Since a frame (38400 chips) consists of 15 slots (2560 chips), the UE has 15 hypotheses for frame timing, so the UE must correlate the received signal with 15N hypotheses for each multipath.

The procedure above (Step A and Step B) is called a 2-step search. For the system parameters and assumptions in Section 4.1, the 2-step search procedure results in shorter search times than a 3-step search. All quantitative results for asynchronous systems in this paper are based on the 2-step search procedure. In this paper, references to an "asynchronous search" include both "2-step" and "3-step" searches unless they are referred to individually.

When the UE has knowledge of the relative time difference between base stations (through clock-synchronous or quasi-synchronous deployment), the search space is significantly smaller than in an asynchronous deployment. The ambiguity in received PN code phase is determined by the accuracy of synchronization and the maximum cell radius. The current 3GPP specification allows the uncertainty in PN code phase to be defined as one of three possibilities – 40 chips, 256 chips or 2560 chips. Assuming chip-level synchronization, these numbers correspond to cell radii of 1.5 km, 10 km, and 100 km, respectively. Using a synchronous deployment for a typical cell radius, the UE has to search a much smaller range than the uncertainty range of 38400 chips required in an asynchronous deployment. For a given search horsepower, the time required for searching for handover is significantly shorter for a synchronous deployment.

Search times are a function of a number of factors: search horsepower, cell radius, level of synchronization between node Bs, number of neighboring cells in the neighbor set, pilot strengths, and the number of strongest neighbors whose pilots need to be acquired. Table 1 shows typical search times with synchronous and asynchronous deployment for a cell radius of 1.5 km and chip-level synchronization between base stations. The table is constructed based on system parameters and assumptions specified in Section 4.1.

TABLE 1 SEARCH TIMES WITH ASYNCHRONOUS AND SYNCHRONOUS DEPLOYMENTS, CELL RADIUS 1.5 KM, CHIP-LEVEL SYNCHRONIZATION

| DEPLOYMENT | MODE | SEARCH TIME |
|---|---|---|
| Synchronous | Find strongest of 32 neighbors | 1.7 ms |
| Synchronous | Search all neighbors | 1.7 ms |
| Asynchronous | Find strongest of 32 neighbors | 30.5 ms |
| Asynchronous | Search all neighbors | 34.5 ms |

The performance advantage of synchronous systems decreases as cell size increases and the level of accuracy in synchronization decreases. The more accurately base stations are synchronized, the greater the benefits; however, a synchronous deployment will never be less efficient than an equivalent asynchronous deployment. This is because the UE can always utilize the asynchronous search procedure regardless of the level of synchronization between base stations. An asynchronous deployment provides the upper bound to the handover search time of a UE. Now, let's look at the benefits a reduction in handover search times provides.

### 3.1 STANDBY TIME

When the UE is idle, its main task is to monitor the paging channel (PCH) and respond to any pages received. To minimize the time the UE spends demodulating the PCH, the node B transmits an additional channel denoted as the paging indicator channel (PICH). The UE is required to monitor the PICH channel periodically to demodulate the paging indicator (PI). If the UE detects that its PI has been set, it listens to the paging channel in the following PCH frame. During those periods when it is not required to monitor the PICH, the UE typically conserves power by powering off its receiver. This process is referred to as discontinuous reception (DRX) mode. The time between the transmission of successive PIs for a given UE is the DRX cycle length. The UE's power consumption when its receiver is switched off is orders-of-magnitude less than its power consumption when turned on. The UE's power consumption in DRX mode determines its standby time.

The UE should constantly try to receive the strongest signal; otherwise, probability of missed pages increases. Since the DRX cycle is generally on the order of a few seconds, it is important that, on wake up, the UE searches the neighboring base stations and selects the strongest signal. To reduce power consumption, the UE must minimize the time it needs to wake up (i.e., the receiver is on) and search neighboring base stations. Standby time is a strong function of the required search horsepower and search time. As shown in Table 1, search times with asynchronous base stations are significantly larger than those with synchronous base stations.

An important parameter in asynchronous systems is the rate at which a complete asynchronous search is performed. For a stationary user, a complete asynchronous search needs to be performed only at power up. Subsequently, it can maintain a database of all detected paths and do a search around the previous measured position. As user mobility increases, the asynchronous search must be performed more often, since the user may not have any prior information on its new neighbors. Unless the UE can reliably measure its speed, it is not feasible for it to modify its search rate based on mobility. The search rate must be fast enough to provide robust performance for both low- and high-mobility users. In Section 4.3, we calculate relative standby times between synchronous and asynchronous systems. Given the assumptions specified in Section 4.1, we estimate that standby time will increase 2.5 times with synchronous deployment. Actual gains depend on several parameters, including search rates, search horsepower, pilot strengths and power consumption of the UE.

### 3.2 MISSED PAGES

When the UE is in DRX mode, it wakes up once per DRX cycle to monitor the PICH. Attempts to improve standby time come at the expense of higher page-error-rate probability. Consider the situation described in Case 2 in Section 4.3.1, in which the UE does an asynchronous search of all of its neighbors once every 30 seconds. By performing searches relatively slowly, standby time is improved; however, paging reliability is compromised. In a fading channel (typical for urban cellular deployments), there is a reasonable probability that the strongest base station signal may be temporarily faded at the time of the asynchronous search. For the remaining 30 seconds, the UE may not be listening to the PICH from the strongest base station. This translates directly into a higher page-error probability. As a result, incoming phone calls may be missed more often.

Page-error probability is an important system performance metric. Reducing page-error probability requires increasing the search rate, and any increase in search rate in an asynchronous system comes at a significant price. As Figure 4-3 shows, if the UE does a full search every DRX cycle, then the standby time with synchronous deployment may be almost four times as much as that with asynchronous deployment.

Another technique used to improve the reliability of paging is to repeat the page multiple times. An asynchronous system can be made more reliable by repeating the page more often than would be required in a synchronous system. However, this strategy increases the required data rate on the paging channel, which increases the power transmitted on the paging channel. Since the paging-channel power needs to be set so that it can be received reliably by a UE at the edge of the cell, the increase in power could be significant.

Clock-synchronous systems have an advantage over quasi-synchronous and asynchronous systems in terms of page response time. In asynchronous or quasi-synchronous systems, different nodeBs transmit PIs to a given UE at different times. The time difference between a UE's reception of PIs from two node Bs can be as much as a DRX cycle. For long DRX cycles (which are desirable to maximize standby time), this can be a significant period of time. Consider a UE that uses a DRX cycle of 2.56 seconds. In an asynchronous or quasi-synchronous system, if the UE detects loss of its current cell, it needs to perform a neighbor search. Even after the neighbor is found, the UE may have to wait up to 2.56 seconds before it can receive a PI on the neighboring cell. In a clock-synchronous system, however, in which all the nodeBs use the same time reference (e.g., GPS), there is no extra delay incurred after an idle handover since the PIs would be transmitted in neighboring cells during the same radio frame.

Another advantage of clock-synchronous systems is that the PIs received from multiple base stations in the same registration area can be soft-combined before making a decision. This is possible if all of these base stations use the same DRX cycle, which leads to significantly fewer missed pages, especially at the edges of coverage.

### 3.3 CAPACITY

Because a WCDMA system is interference limited, and a reduction in transmit power results in a corresponding reduction in interference, capacity can be increased by reducing the transmit power required to close the link on both the uplink and downlink. And since a WCDMA system uses power control on both the uplink and downlink, transmit power increases with path loss. So the UE should always try to close the link with the nodeBs with minimum path loss. Failure to do so not only results in decreased capacity, but also may result in dropped calls in situations where the signal power is insufficient to close the link.

Capacity in handover situations, therefore, is determined by how quickly the UE can detect a strong neighbor and include it in its active set. This, in turn, is determined by how often the UE can measure the strength and relative timing of the neighbors, and report them to the network. Given the same searcher complexity, a UE in a synchronous system can perform neighbor-set searches much more frequently than a UE in an asynchronous system. As shown in Table 1, search times with synchronous deployments are almost 20 times better than with asynchronous deployments. A single pass of a 2-step search produces the PN code phase of the strongest path. For improved handover performance [1], the UE needs to detect paths weaker than the strongest paths, which requires the UE to do multiple Step-B searches. The handover search times for an asynchronous system would be somewhere in between the “Find strongest of 32 neighbors” and “Search all neighbors” reported in Table 1.

For an asynchronous node B, the UE must demodulate the BCH (on the PCCPCH physical channel) of the neighboring base station, read the system frame number and report the relative time difference (SFN-SFN [1]) to the network. The received signal should be strong enough for reliable demodulation of the BCH. There could be areas in which a neighbor’s BCH cannot be reliably received, but it would still be beneficial, for greater system capacity and improved call reliability, for the UE to include the neighbor in its active set. In such situations in an asynchronous system, the UE may not be able to report a rising pilot signal from a neighboring base station soon enough.

System capacity is hard to quantify, since it is a function of a variety of factors, including channel conditions, mobile speed, and network planning. Capacity degradation in an asynchronous system, however, is likely to be significant when a large fraction of the users are mobile and in handover with multiple base stations.

### 3.4 INTER-FREQUENCY HANDOVER

For inter-frequency handover searching, the UE tunes to a new RF channel, then searches for the desired signal. While it is tuned to the new RF channel, a UE that does not have dual RF chains cannot transmit or receive on the frequency on which it is currently connected to the base station. To avoid data loss during this period, WCDMA defines a “compressed mode.” In compressed mode, transmission gaps are created on the uplink/downlink. No data is transmitted or received from the UE during its transmission gap. Since real-time constant bit-rate services cannot tolerate such momentary interruptions in data flow, the data that would have been transmitted during the transmission gap is transmitted in the radio frame or frames containing the transmission gap by temporarily increasing the data rate. Various studies have shown that frequent use of compressed mode significantly reduces system capacity [2], [3].

With inter-frequency searching, the total search time equals the combination of intra-frequency searching plus the time required to retune the synthesizers. For synchronous deployment, a single transmission gap a few slots wide is sufficient to achieve good detection probabilities on an inter-frequency search. To get equivalent detection probabilities in an asynchronous system, much longer search times are required, which means transmission gaps must be longer. Even the longest transmission gap permitted by the WCDMA standard may not be sufficient to achieve good detection probabilities. Multiple transmission gaps would then be required for a single asynchronous search. As discussed above, frequent use of compressed mode results in a reduction in system capacity.

### 3.5 UPLINK HANDOVER SEARCHING

When a UE that is connected to a node B (B1) performs a handover (either hard or soft) to a new node B (B2), B2 must first acquire the uplink pilot signal of the UE. To acquire the uplink pilot, B2 must search a timing range equal to the round-trip delay of the farthest point from which a UE can perform a handover to it. With synchronous deployment, it is possible to significantly shrink this search space. The mechanism for doing so is described in [8] and is outlined here.

1. B1 obtains the round-trip delay time from the UE to itself by measuring the time difference between its downlink transmission to the UE and its reception of the uplink signal from the UE. The propagation time (t1) between the UE and B1 equals one-half of the round-trip delay.

2. The UE reports its observed SFN-SFN time difference (x12) between B1 and B2.

3. The network knows the true timing difference (y12) between the downlink transmissions of B1 and B2. In the case of a clock-synchronous system, this timing difference is implicitly known. In the case of a quasi-synchronous system, this timing difference can be measured using techniques described in Section 5.

4. It can be shown [8] that the propagation time (t2) from the UE to B2 is equal to (t1 + y12 - x12). Knowing t2 and the timing of its own downlink transmission to the UE allows B2 to estimate the time of arrival of the UE's uplink signal at B2.

This mechanism allows the use of much smaller search windows at B2. Since the uplink pilot received at B2 is typically very weak, long integration lengths are required for good detection performance. Reduction in the search space allows the speed of the search to be increased significantly, which translates into improved handover performance.

## 4.0 QUANTITATIVE ANALYSIS OF STANDBY TIME

In this section we present numerical results for some reference conditions. This analysis is not comprehensive and the results will change with differing assumptions. Combined with the arguments presented in Section 3, this section should provide insight on the tradeoffs between synchronous and asynchronous deployment. We focus on the calculation of standby time, since significant improvements in standby time are possible with synchronous deployments.

### 4.1 ASSUMPTIONS

Following are the assumptions underlying our calculations:

- *Channel Assumptions* – To simplify the analysis, we consider an additive white Gaussian noise (AWGN) channel.

- *Neighbor Set Size* – A neighbor set size of 32 is assumed. This is the largest number of intra-frequency neighbors that the UE is required to monitor as per [5]. The performance advantage of synchronous systems compared to asynchronous systems diminishes as the number of neighbors increases. By choosing a large number of neighbors, we are biasing our results in favor of asynchronous systems.

- *Pilot Strengths* – For good handover performance, the UE must be capable of detecting pilots with CPICH Ec/Io stronger than -20 dB [4]. Since the SCH is typically transmitted 2 dB weaker than the CPICH, as specified in the reference cases in [9], this corresponds to SCH Ec/Io stronger than -22 dB (equally distributed among PSC and SSC). We design search algorithms consistent with the above requirements.

- *Detection Probabilities* – In DRX mode, the sleep cycle is typically a few seconds. If a search fails to find a peak, it will be several seconds before another search is performed. The probability that a peak is detected in a single search needs to be high to keep the cell acquisition time small. A detection probability of 90 percent has been chosen.

- *Search Window* – A search window of 40 chips for synchronous search is assumed. This corresponds to a cell radius of 1.5 km if the relative time difference between neighboring base stations is known accurately. Any inaccuracy in synchronization would add to this search window.

- *Search Horsepower* – Step 1 is by far the most expensive step in terms of number of operations. We assume a searcher with horsepower that is adequate to search all Step-1 hypotheses in parallel. This corresponds to a matched-filter implementation of the Step-1 searcher. To keep the comparisons fair, we assume that a searcher with equivalent horsepower is used for synchronous search. Such a searcher can be thought of as searching 256 chip hypotheses in parallel. For the Step-2 searcher, we assume that we can search 1 peak in real time. For the Step-3 and Step-B searcher, we assume the same horsepower as in Step 1.

- *Asynchronous Search Procedure* – The 2-step search procedure described in Section 3 is used to estimate search times in an asynchronous system. Since the 3-step search procedure requires more time than a 2-step search, it is clear that the standby times with a 3-step search will be worse than those obtained using the 2-step procedure.

- *DRX Cycle Length* – A DRX cycle length of 2.56 seconds is assumed.

### 4.2 INTEGRATION LENGTHS

Table 2 lists the probability of detection (Pd) for a 3-step search for different coherent integration lengths (Nc) and non-coherent integration lengths (Nn) at CPICH Ec/Io = -20 dB and SCH Ec/Io = -22 dB (PSC Ec/Io = SSC Ec/Io = -25 dB).

TABLE 2: DETECTION PROBABILITIES FOR 3-STEP SEARCH

| | | Nc | Nn | Pd |
|---|---|---|---|---|
| | Step 1 | 256 chips | 2 frames | 0.77 |
| | | 256 chips | 3 frames | 0.95 |
| | Step 2 | 256 chips | 4 frames | 0.91 |
| | | 256 chips | 5 frames | 0.96 |
| | Step 3 | 256 chips | 1 | 0.77 |
| | | 512 chips | 1 | 0.99 |

The optimum choice of parameters consistent with Pd > 90% is: Step 1 (256,3), Step 2 (256,5), Step 3 (512, 1). Based on the assumptions in Section 4.1, the three steps require 30ms, 50ms and 0.13ms, respectively.

As discussed in Section 3, an alternative to the 3-step search is the 2-step search procedure, which is composed of a Step-1 search and a Step-B search. Step B involves correlating the received signal against each of 32 scrambling codes (corresponding to the 32 neighbors) and 15 possible frame timings. In the following table, we derive the detection probabilities for this approach and justify our statement that the 2-step search procedure is more efficient than 3-step search.

TABLE 3: DETECTION PROBABILITIES FOR 2-STEP SEARCH

| | | Nc | Nn | Pd |
|---|---|---|---|---|
| | Step 1 | 256 chips | 2 frames | 0.77 |
| | | 256 chips | 3 frames | 0.95 |
| | Step B | 512 chips | 1 | 0.90 |
| | | 768 chips | 1 | 0.98 |

The optimum choice of parameters consistent with Pd > 90% is: Step 1 (256,3), Step B (768, 1). Based on the assumptions in Section 4.1, the two steps require 30ms and 0.44ms, respectively.

Using a 2-step search instead of a 3-step search decreases search times by about 50ms. In subsequent calculations, the 2-step search procedure will be used to estimate search times in an asynchronous system.

TABLE 4: DETECTION PROBABILITIES FOR SYNC SEARCH

| | | Nc | Nn | Pd |
|---|---|---|---|---|
| | Sync Search | 512 chips | 1 | 0.75 |
| | | 768 chips | 1 | 0.94 |

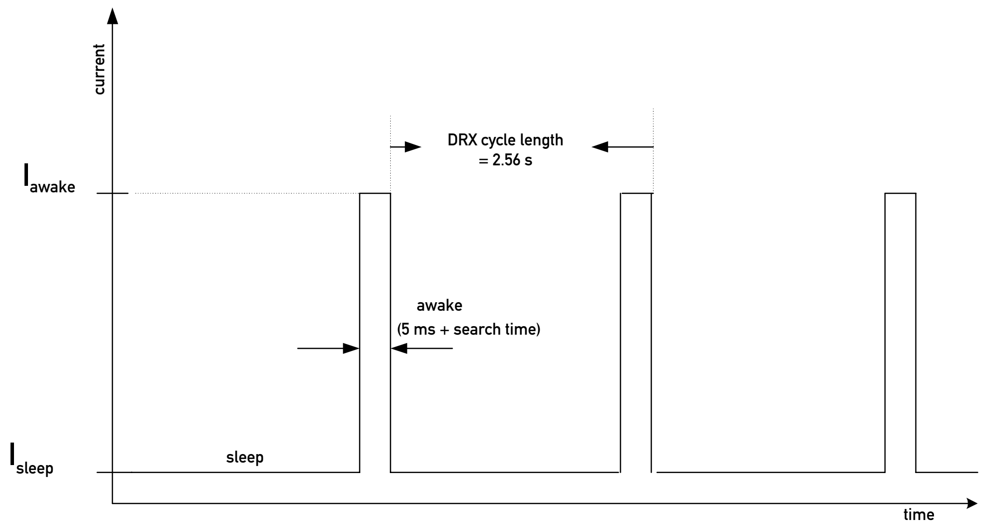
For a synchronous system, the optimum choice of parameters consistent with Pd > 90% is Nc = 768, Nn = 1 gives Pd = 94%.

Based on the assumption in Section 4.1, a synchronous search of all 32 neighbors requires 1.67 ms.

### 4.3 EFFECT ON STANDBY TIME

Figure 4-1 shows a simplified timeline of UE operation in DRX mode. The UE spends some time during each wakeup on tasks such as tuning various RF components and initializing various subsystems. The time spent is the same for both synchronous and asynchronous systems, typically several milliseconds. This time is assumed to be 5 ms. Add to this is the time taken to actually perform neighbor searching. The added uncertainty concerning the timing of asynchronous cells results in increased search times for an asynchronous system when compared to a synchronous system. This has a direct impact on the standby time of the UE.

FIGURE 4-1: DRX MODE TIMELINE




The additional cost (in terms of search times) incurred in an asynchronous system compared with a synchronous one depends on the particular algorithm used to detect neighbor cells and maintain their timing. What follows is an algorithm that conforms to the DRX-mode requirements imposed by the WCDMA standard [5] for a DRX cycle length of 2.56 seconds. The relevant requirements are (paraphrased):

1. The UE shall measure CPICH Ec/Io at least once every 2.56 seconds for intra-frequency cells that are detected and measured according to the measurement rules.

2. The UE shall filter CPICH Ec/Io using at least two measurements.

3. The UE shall be capable of evaluating whether or not a neighboring cell has become better than serving cell within 7.68 seconds from the moment the neighboring cell is at least 3 dB better than the serving cell.

The first requirement entails searching all cells that have been detected (i.e., whose timing has been acquired) at least once every DRX cycle. If the CPICH is transmitted with signal strengths as specified in the reference cases in [9], there can be, at most, 10 neighboring cells with CPICH Ec/Io greater than -20 dB. Synchronous searches must be performed on these 10 cells in every DRX cycle. This is true for both synchronous and asynchronous systems.

From the second and third requirement, we can infer that to detect a fast rising pilot from a neighboring cell that has not been previously detected, a complete search to detect the strongest of all 32 neighbors must be performed at least once in every two DRX cycles. In an asynchronous system, if the timing of even one neighbor is not known to the UE[1], it will be forced to perform an asynchronous search once in every two DRX cycles.

To summarize, the neighbor cell-search algorithm, compliant with 3GPP requirements that we use is:

For asynchronous deployment:

- On every other DRX cycle, perform an asynchronous search plus a synchronous search on the 10 previously detected cells.
- On the alternate DRX cycle, perform a synchronous search on the 10 previously detected cells.

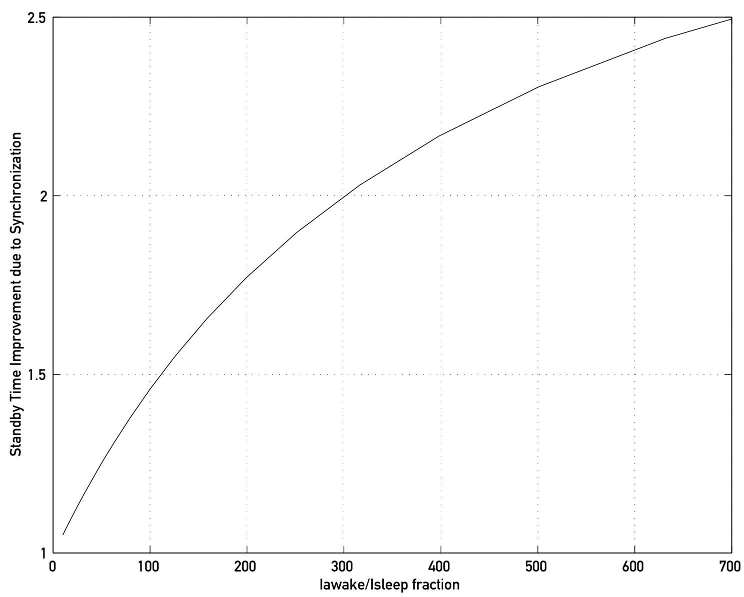
For synchronous deployment:

- On every other DRX cycle, perform a synchronous search on all 32 neighbors.
- On the alternate DRX cycle, perform a synchronous search on the 10 previously detected cells.

Based on the above algorithms, Figure 4-2 shows the improvement in standby time using a synchronous deployment as a function of $I_{awake}/I_{sleep}$ – the ratio of current consumption in wake-up and sleep modes. This ratio of currents is typically on the order of several hundred. Synchronizing node Bs results in impressive improvements in standby time.

[1] If a cell X can be detected by a UE in *any* part of a serving cell C, X will typically be included in C's neighbor list. A UE in a given location will typically have some neighbors in the neighbor list that it never detects.

FIGURE 4-2: STANDBY TIME IMPROVEMENT (TYPICAL SEARCH ALGORITHM)




#### 4.3.1 TRADE-OFF BETWEEN STANDBY TIME AND PAGING PERFORMANCE

Choosing a neighbor-cell search algorithm involves a trade-off between standby time and missed page probability. The more often a search is performed, the lower the probability of a missed page. However, this comes at a cost - poorer standby time. To illustrate algorithms that trade off standby time against paging performance to varying degrees, we now present two algorithms: one that performs asynchronous searches more often than required by the 3GPP specifications and one that performs asynchronous searches infrequently. In each case, we evaluate the improvement in standby time obtained as a result of synchronizing the node Bs.

Case 1 - Frequent Searches

- Search for the strongest cell on every DRX cycle and camp on it (make it the active cell).

Case 2 - Infrequent Searches

- Search for the strongest cell once in every 12 DRX cycles (30.72 seconds) and camp on it (make it the active cell).

- For the next 11 DRX cycles, search only the active cell.

Case 1 represents one extreme of the trade-off between standby time and paging performance. This algorithm searches the neighbor set as often as possible. It has the best paging performance. Figure 4-3 shows the improvement in standby time due to synchronous deployment when this algorithm is used for searching.

Case 2 sacrifices paging performance to improve standby time. In mobile environments, one could expect handovers to occur once every 30 seconds (e.g., in 30 seconds, a UE moving at 60 kmph traverses 1/2 km , a sizeable fraction of a cell). This algorithm would barely keep track of the strongest cell in such a situation. And by camping on the same cell for 30 seconds at a stretch, this algorithm can demodulate the PICH only from this cell. If the cell fades, there is no option but to take a hit in performance. This algorithm is not reliable when used in DRX mode, and does not comply with 3GPP requirements. It is included here only to represent one extreme of the trade-off between standby time and paging performance. Figure 4-4 shows the improvement in standby time due to synchronous deployment when this algorithm is used for searching.

FIGURE 4-3: STANDBY TIME IMPROVEMENT (CASE 1: FREQUENT SEARCHES)

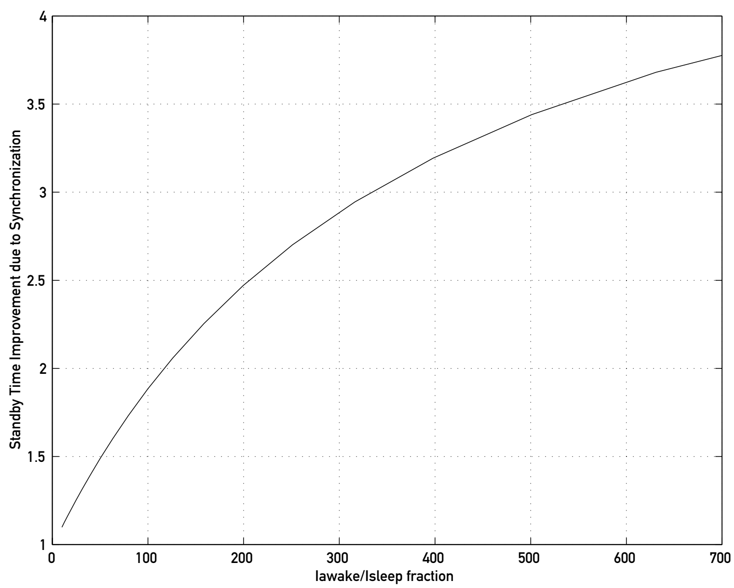
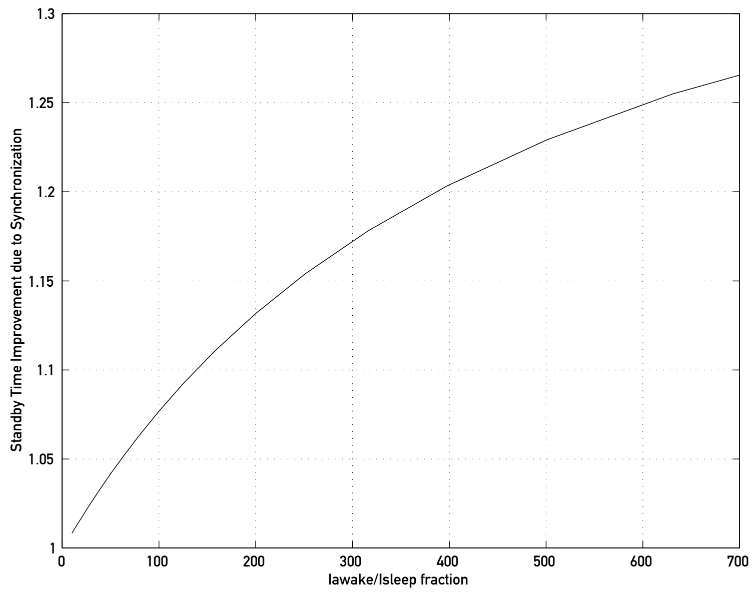


FIGURE 4-4: STANDBY TIME IMPROVEMENT (CASE 2: INFREQUENT SEARCHES)




#### 4.3.2 OBSERVATIONS

- With typical search strategies, compliant with 3GPP requirements, we expect standby times in synchronous deployments to be about 2.5 times longer than those in asynchronous deployments.

- **Effect of multipath** – For simplicity, the results presented in this section were derived assuming a single path AWGN channel. In practice, search algorithms must be designed with a multipath channel in mind. In a synchronous system, the presence of multipath components necessitates an increase in the size of the search window. However, since we already search in a window of size 40, this additional window size (say another 40 chips) may increase the overall search time in a synchronous system by, approximately, a factor of two. In an asynchronous system, the impact is much more severe.

    - During a Step-B search, the search must be conducted in a window around the 15 frame timing candidates instead of just a single hypothesis for each frame timing. The Step-B search time will increase linearly with the window size (40 times for a multipath delay profile spanning 40 chips).

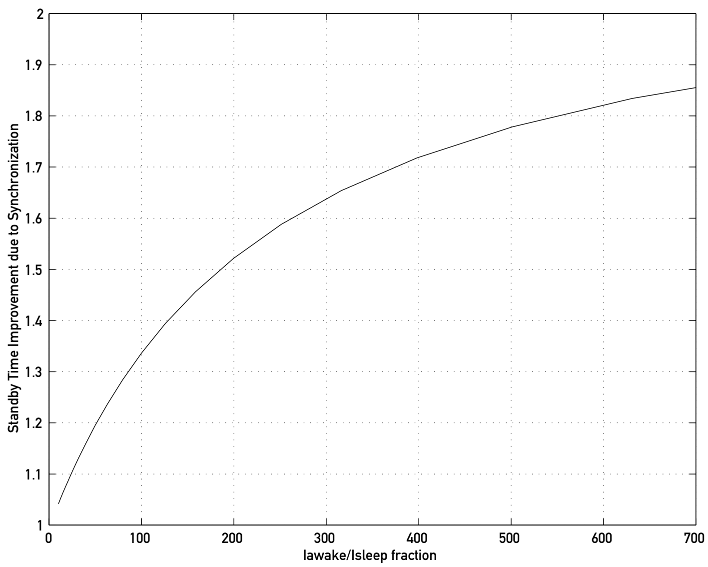
    - In addition, the strongest peak returned by Step 1 may not necessarily belong to the strongest cell. Even if we were to search for the strongest cell, we may need to apply Step B (or Steps 2/3) for more than one peak returned by Step 1. This drastically increases the search time.

- **Search Horsepower** – As the search horsepower increases, the time required for Step B and for a synchronous search decreases since more hypotheses can be processed in parallel. However, this does not affect the time required for Step 1, which is the limiting factor in an asynchronous system. Step 1 involves correlation with the PSC, which is transmitted in discontinuous bursts once per slot. For good detection, the UE must accumulate search energy over a sufficient number of slots. The matched filter that we assumed for Step 1 provides the necessary horsepower for real-time Step-1 searching. There is nothing to be gained by further increasing the horsepower of the Step-1 searcher.

- **Increasing PSC Power** – The Step-1 search is the primary limiting factor in an asynchronous system. One way to improve standby time performance in an asynchronous system is simply to boost the transmit power of the PSC. This improves detection probabilities in Step 1 and allows the search time to be reduced. Several problems arise, however. First, even a doubling of PSC power (relative to the power levels in the reference cases in [9]) is insufficient to reduce search time to anything close to that of a synchronous system. Second, an increase in PSC power decreases the power available for transmitting user-dedicated data, thereby decreasing capacity. Third, since the PSC is not orthogonal to other channels transmitted by the base station, increasing PSC power adds to the total interference power, further decreasing capacity.

- **Effect of Imperfect Synchronization and Increased Cell Size** – In a synchronous system, as cell size increases or as synchronization accuracy worsens, the uncertainty in the UE's knowledge of timing of neighboring cells increases. For example, in a chip-level synchronized system with a cell radius of 10 km, the UE knows the relative time difference between base stations only to an accuracy of 256 chips. Assuming a typical search algorithm compliant with 3GPP requirements, Figure 4-5 shows the improvement in standby time for a synchronous deployment compared to an asynchronous deployment with this level of uncertainty. Even with an accuracy of 256 chips, standby time improves significantly by synchronizing node Bs.

FIGURE 4-5: STANDBY TIME IMPROVEMENT (IMPERFECT SYNCHRONIZATION/LARGE CELL SIZE)




## 5.0 METHODS FOR SYNCHRONIZING BASE STATIONS

One well-known approach to synchronizing base stations is using GPS or other satellite-based timing sources. This approach is robust and provides a source of accurate timing. Studies [11] have shown that reliable synchronization can be maintained if even one GPS satellite is visible as seldom as twice per day. GPS receivers are a mature technology and are cheap enough to be integrated into many handheld devices. Nevertheless, GPS has some perceived drawbacks:

- Sole dependency on a US-owned GPS system for synchronization is of concern to some network operators.
- In situations of deep in-building coverage (or underground deployment), availability of GPS may be an issue.

To avoid dependence on an external timing source such as GPS, the networks could be "self-synchronized" using the schemes proposed in [7], [8] and [10]. Following is a simple scheme for achieving quasi-synchronization based on adapting the ideas of self-synchronization proposed in [8] to 3GPP signaling. For accuracies to +/- one cell radius, the network can simply use the SFN-SFN time difference measurements reported by the UE in the Measurement Report Message [1]. The network can filter measurements received from several UEs to form an estimate of the relative time difference between node Bs. Each node B then broadcasts the relative time difference with its neighbors in its System Information Message [1]. As noted earlier, the 3GPP specification already has a provision for reporting accuracies to within 40, 256 or 2560 chips.

This entire scheme could be implemented with no change to the 3GPP standard. The accuracy could be adjusted based on a variety of gathered statistics, such as number of previous measurements in a certain time window and variance in measurements. For example, the network could start as completely asynchronous and adaptively increase its level of quasi-synchronization as it gets handover measurement reports from the UE. The UE does not have to be aware of this self-adapting mechanism. It simply reads the Reference-Time-Difference-to-Cell information element in the System Information Message and adjusts its algorithm (asynchronous vs. synchronous) appropriately.

This description is not comprehensive, but indicates that quasi-synchronization between base stations can be accomplished using existing mechanisms specified in 3GPP. For WCDMA functionality (standby-time, capacity, inter-frequency handover), this level of accuracy provides many of the benefits of synchronization. Clock synchronization lowers page-miss probability (which is an important system performance metric) and provides further improvements in standby time and system capacity. It is fairly straightforward to extend any quasi-synchronization technique to implement clock-synchronization. Quasi-synchronization provides each node B with knowledge of its timing relative to other node Bs. Each node B can use this information to adjust its timing by small increments periodically until the timing difference between all of the node Bs is small enough. This idea has been explored in detail in [7], [8], and [10]. Any system that is deployed quasi-synchronously would find it worth the minor incremental effort to implement clock-synchronization as well.

Finally, as noted earlier, it is possible to have a mixed deployment where most of the base stations are synchronized with each other. The base stations for which such synchronization is prohibitively expensive can be operated asynchronously.

## 6.0 CONCLUSIONS

We have shown that synchronous deployment of WCDMA offers significantly improved performance as compared to asynchronous deployment - up to 2.5 times longer handset standby times, improved paging performance, and enhanced system capacity. We have also presented options for synchronizing base stations. System performance improves as more base stations are synchronized and the level of their synchronization becomes more accurate. A well-optimized network could have most of its base stations synchronized.

## 7.0 REFERENCES

[1] 3GPP TS 25.331 (2000-12 version) "RRC Protocol Specification (Release 1999)."

[2] "Impact of Compressed Mode on the Capacity of a WCDMA System," Telia AB, TSG-RAN WG4 Meeting#14(00)0960, November 2000.

[3] "Compressed Mode techniques for Inter-Frequency Measurements in a Wideband DS-CDMA System," M. Gustaffson, K. Jamal, and Erik Dahlman, pg. 231-235, The 8th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 1997.

[4] 3GPP TS 25.214 (2000-12 version) "Physical Layer Procedures (FDD) (Release 1999)."

[5] 3GPP TS 25.133 (2000-12 version) "Requirements for Support of Radio Resource Management (FDD) (Release 1999)."

[6] "Location Technologies for GSM, GPRS, and WCDMA Networks," Internal QUALCOMM document to be published.

[7] "A Synchronized Radio System Without Stable Clock Sources," S.T. Stanley Chia and William C.Y.Lee, IEEE Personal Communications Magazine, April 2001.

[8] "Self-Synchronizing A CDMA Cellular Network," Chuck Wheatley, pg. 320-328, Microwave Journal, May 1999.

[9] 3GPP TS 25.101 (2000-12 version) "UE Radio Transmission and Reception (FDD) (Release 1999)."

[10] "Some Algorithms for Synchronizing Clocks of Base Transceiver Stations in a Cellular Network," Jean-Louis Dornstetter, Daniel Krob, Michel Morvan, and Laurent Viennot, to appear in Discrete Applied Mathematics, Special Issue on Wireless Networks and Mobile Computing.

[11] "On Self-Synchronizing a CDMA Cellular Network," Chuck Wheatley, Presented at Wireless Technologies China Conference and Exhibition, Guangzhou and Shanghai, September 1999.