Correlation Properties of W-CDMA Synchronisation Codes

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I INTRODUCTION

Third generation (3G) mobile systems are currently being standardised in different standardisation associations. Higher data rate with improved quality of service and capacity has been main objectives. Among considered 3G air interface technologies CDMA 2000 and Wideband CDMA (W-CDMA) has been approved. In these systems, in the downlink, each base station uses a pseudonoise (PN) sequence (scrambling code) to separate different transmitters. The physical channels are distinguished by using orthogonal channelisation codes (spreading codes). Before any communication with base station (BS) takes place mobile station (MS) has to time synchronise to the scrambling code used in the serving cell.

In the CDMA 2000 each BS (cell) employ the same scrambling code but shifted in time (synchronous system). Cell is unique identified by phase shift of the scrambling code. A global positioning system (GPS) is usually applied to achieve synchronism between BSs. On the other hand, in W-CDMA neighbouring BSs use distinct downlink scrambling code from a set of possible codes. Acquisition problem in this (asynchronous) system consists not only in determining the timing of received code but also in identifying the particular scrambling code. Since there can be 512 scrambling codes in the system, the acquisition time could be very large. The process of searching for a cell and synchronising to its PN code is referred to as cell search. In the paper [1] three steps fast cell search algorithm is proposed and later is accepted in 3rd Generation Partnership Project 3GPP [2]. There are three circumstances when cell search has to be performed: initial cell search after MS is switched on, idle mode cell search for finding suitable cell to camp on and active cell search to identify handover candidates.

This paper discusses choice of synchronisation codes in W-CDMA system and its correlation properties.

II SYNCHRONISATION CHANNELS AND CELL SEARCH IN W-CDMA

In order to ease MS cell search all BS transmit three downlink channels: Primary Synchronisation Channel (P-SCH), Secondary Synchronisation Channel (S-SCH) and Common Pilot Channel (CPICH). The P-SCH together with the S-SCH are also referred as Synchronisation Channel (SCH).

The 10 ms radio frames of the Primary and Secondary SCH are divided into 15 slots, each of length 2560 chips. Figure 1 illustrates the structure of the SCH radio frame.

Fig. 1: Structure of Synchronisation Channel (SCH)

The Primary SCH consists of a 256 chips long code, denoted as $c_p$ in Figure 1, and transmitted once every slot. The PSC is the same for every cell in the system. The Secondary SCH contains a code with 256 chips. The Secondary SCH is transmitted in parallel with the Primary SCH and consists of 16 sequences used to generate a total of 64 different code words that identify 64 code groups. The secondary synchronisation code (SSC) is denoted $c_{si,k}$ in Figure 1, where $i = 0, 1, \ldots, 63$ is the number of the scrambling code group, and $k = 0, 1, \ldots, 14$ is the slot number. Each SSC is chosen from a set of 16 different codes of length 256. This sequence on the Secondary SCH indicates which of the 64 code groups the cell's downlink scrambling code belongs to.

The common pilot channel (CPICH) is scrambled with the cell-specific scrambling code. Spreading sequence of CPICH is taken from the set of orthogonal channelisation codes (all ones), maintaining mutual orthogonality with other downlink channels.

Initial cell search

During the initial cell search, the mobile station searches for the base station to which it has the lowest path loss. Following this, the MS determines the code group of the BS, a frame synchronisation, and finally acquires the scrambling code. The initial cell search is carried out in three steps:

1) Slot synchronisation;
2) Frame synchronisation and code-group identification;
3) Scrambling-code identification.

During the first step of the cell search procedure the mobile station uses the primary SCH to acquire slot synchronisation to the strongest base station. This is done with a single matched filter (or any similar device) matched to the primary synchronisation code $c_p$, which is common to all base stations. The output of the matched filter will have peaks for each base station signal path within a range of the mobile station, see Figure 2. Detecting the position of the strongest peak gives the timing of the strongest base station. For better reliability, the matched filter output could be accumulated over a number of slots. This step of the acquisition algorithm forms searcher, which is always active and searches new
paths or BSs irrespective of whether the receiver is in initial cell search or in idle and active mode.

![Diagram of matched filter P-SCH sequence search for slot synchronisation](image)

**Fig. 2: Matched filter P-SCH sequence search for slot synchronisation**

During the second step of the cell search procedure, the mobile station uses the secondary SCH to find frame synchronisation and identify the code group of the base station found in the first step. There are 16 S-SCH sequences. In frame of 15 slots 15 S-SCH sequences create a code-word taken from code-book of 64 code-words. In each frame same code-word is transmitted in the cell. Code-group can be detected by identifying code-word. All 64 code-words are chosen to have distinct phase shift. To maximise the minimum code distance of the code-book, between different cyclic shifts of the same code-word or between different code-words, in [3] use of comma free Reed Solomon code was proposed and later accepted in 3GPP [2].

During the third step of the cell search procedure the mobile station determines the exact scrambling code used by the found base station. From previous step, the frame boundary and consequently the start of the scrambling code is known. The scrambling code is identified through correlation over the CPICH with all scrambling codes within the code group identified in the second step. For initial cell search number of scrambling codes in identified code group is $N_c = 8$.

**Idle mode cell search**

When in idle mode, the mobile station continuously searches for new base stations on the current and other carrier frequencies. The cell search is done in basically the same way as the initial cell search. The main difference compared to the initial cell search is that an idle mobile station has received a neighbouring cell list from the network. This cell list describes in which order the downlink scrambling codes are to be used. All 64 code-words are chosen to have distinct phase shift. To maximise the minimum code distance of the code-book, between different cyclic shifts of the same code-word or between different code-words, in [3] use of comma free Reed Solomon code was proposed and later accepted in 3GPP [2].

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**Active mode cell search**

When in active mode, the mobile station continuously searches for new base stations on the current carrier frequency. This cell search is carried out in basically the same way as the idle mode cell search. The mobile station may also search for new base stations on other carrier frequencies using the slotted mode. For idle and active mode search, a detected scrambling code in the third step is time-tracked and signal to interference ratio (SIR) is measured and reported back to the BS.

### III SYNCHRONISATION CODES

Since P-SCH sequence is common to all base stations in the network, there is a possibility that sequences from different BS overlap. The probability of this happening increases during handover, since the mobile is equidistant from more than one BSs. To assess the probability of collision of the primary SCH sequences, assume reception of single path from three BS. The probability that sequences from two of these BS collide is $3/2560$, where a time slot contains 2560 chips. This probability is significant and it will increase for more BS and multipaths. Also, the less strong paths from handover candidates base stations (cells) can be masked with autocorrelation sidelobes (Figure 3). The sidelobes are generated in process of correlation PSC with received P-SCH of the serving cell. Considering this it is important to choose primary synchronisation code (PSC) with good autocorrelation properties.

**Fig. 3: A matched filter output and problem with sidelobes that can mask paths from neighbouring BSs.**

The best PSC would be sequence without any autocorrelation sidelobes. Unfortunately such sequence does not exist. To minimise “self interference” caused by sidelobes it is desirable to select PSC with smaller maximum absolute autocorrelation sidelobes (MAS). PSC and SSC are transmitted in parallel and by definition are mutually orthogonal. Hence, secondary synchronisation codes (SSC) must have very small cross-correlation with each other and with the PSC.

Standardisation of synchronisation codes started in the European telecommunications standards institute (ETSI) and Associations of radio industries and business (ARIB) continued in 3GPP. Initially in ETSI document [4] for primary SCh an orthogonal Gold code of length 256 chips and for secondary SCh 16 sequences of orthogonal Gold codes of length 256 chips was proposed. PSC with orthogonal Gold code has low MAS ($-23.1$ dB) but implementation complexity of code acquisition hardware is too high. The major part of overall complexity of this scheme is assigned to the first step. A hierarchical sequence approach in [5] for PSC and Hadamard sequences for SSC with Fast Hadamard Transform correlation method in [6] is proposed to reduce the first and the second synchronisation step.

Hierarchical sequence $C_p$ of length $n = n_1 \times n_2$ where length of the sequences are $n_1$ and $n_2$ respectively is defined as:

$$C_p(i) = X_{(i \mod n_2)} \ast X_i (i \div n_2), \quad \text{for } i = 0 \ldots n-1 \quad (1)$$
with two constituent sequences $X_1$ and $X_2$.

This sequence allows a very efficient calculation of the correlation sum:

$$R(k) = \sum_{i=0}^{n-1} C(i) \cdot r(i+k) = \sum_{i=0}^{n-1} X_1(i \mod n_1) \cdot X_2(i \div n_2) \cdot r(i+k) = \sum_{i=0}^{n-1} X_1(i) \cdot R_s(i \div n_2 + k)$$

(2)

Here $r(k)$ is the received signal, $R(k)$ the desired correlation sum starting at sampling time $k$ and $Rs$ are sub correlation sums defined as:

$$Rs(k') = \sum_{j=0}^{n_2} X_2(j) \cdot r(j+k')$$

(3)

In this approach complexity of the 1st step is lowered by factor 8 and with sequences $X_1 = X_2 = \{1, 1, -1, -1, 1, -1, 1, -1, 1, -1, 1, 1, 1, -1, 1\}$ MES is -18.2 dB.

Further in 3GPP paper [7] hierarchical Golay sequence approach is proposed for additional complexity reduction. Proposal is based on Budisin’s paper [8] where efficient correlator for Golay sequences is proposed. And finally, in latest technical specification for 3GPP PSC [2], it is constructed as a so-called generalised hierarchical Golay sequence. The correlator for Golay sequences is proposed. And finally, in 3GPP paper [7] hierarchical Golay sequence is $-1, 1, 1, -1, 1, 1, 1, -1, 1}$. MES is -18.2 dB.

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$$R_s(k') = \sum_{j=0}^{n_2} X_2(j) \cdot r(j+k')$$

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In this approach complexity of the 1st step is lowered by factor 8 and with sequences $X_1 = X_2 = \{1, 1, -1, -1, 1, -1, 1, -1, 1, -1, 1, 1, 1, -1, 1\}$ MES is -18.2 dB.

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$X_1$ is defined to be the length 16 ($N^{(1)}=4$) Golay complementary sequence obtained by the delay matrix $D^{(1)} = \{8, 4, 1, 2\}$ and weight matrix $W^{(1)} = \{1, -1, 1, 1\}$.

$X_2$ is a generalised hierarchical sequence using the following formula, selecting $s=2$ and using the two Golay complementary sequences $X_1$ and $X_2$ as constituent sequences. The length of the sequence $X_1$ and $X_2$ is $n_3$ and $n_4$ respectively.

$$X_2(i) = X_1[\{i \mod s + s \cdot (i \div s) n_3\}] \cdot X_2[\{i \div s \mod n_4\}]$$

(4)

$X_1$ and $X_2$ are defined to be identical and the length 4 ($N^{(3)}=N^{(0)}=2$) Golay complementary sequence obtained by the delay matrix $D^{(3)} = D^{(4)} = \{1, 2\}$ and weight matrix $W^{(3)} = W^{(4)} = \{1, 1\}$.

The Golay complementary sequences $X_1$, $X_3$ and $X_4$ are defined using the following recursive relation:

$$X_3(k) = \delta(k)$$

and $b_0(k) = \delta(k)$;

$$X_4(k) = X_3(k) + W^{(0)} \cdot b_{n_1}(k-D^{(0)})$$;

(5)

$$b_0(k) = X_3(k) - W^{(0)} \cdot b_{n_1}(k-D^{(0)})$$;

$$k = 0, 1, 2, \ldots, 2^{*N^{(0)}} - 1;$$

$$n = 1, 2, \ldots, N^{(0)}.$$}

The $\delta$ is Kronecker delta function.

The Hadamard sequences are obtained as the rows in a matrix $H_8$ constructed recursively by:

$$H_0 = (1)$$

$$H_k = \left( \begin{array}{c} H_{k-1} \\ H_{k-1} \end{array} \right), \quad k \geq 1$$

(6)

Denote the $m^{th}$ Hadamard sequence as a row of $H_m$ numbered from the top, $m = 0, 1, 2, \ldots, 255$, in the sequel. Let $h_m(i)$ and $z(i)$ denote the $i^{th}$ symbol of the sequence $h_m$ and $z$, respectively where $i = 0, 1, 2, \ldots, 255$ and $i = 0$ corresponds to the leftmost symbol.

The $k^{th}$ SSC, $C_{ssc,k}$, $k = 1, 2, 3, \ldots, 16$ is then defined as:

$$C_{ssc,k} = \left[ h_m(0) \cdot z(0), h_m(1) \cdot z(1), \ldots, h_m(255) \cdot z(255) \right]$$

(7)

where $m=16\times(k-1)$ and the leftmost chip in the sequence corresponds to the chip transmitted first in time.

### IV CORRELATION PROPERTIES

In order to provide reliable slot synchronisation and minimise cross-channel interference PSC and the SSCs should be orthogonal to it and to themselves. Also these sequences should exhibit small cross-correlation picks.

To examine synchronisation channel characteristic autocorrelation of PSC and cross-correlation between PSC and PSC + SSC is determined. Figure 4 shows the auto correlation of the primary synchronisation code. The sidelobes of the auto correlation function of the PSC are equals 64 (-12.04 dB) when main correlation peak is equal to 256.

By definition, the PSC and SSCs are mutually orthogonal. However, the cross-correlation properties between the PSC and the SSCs are not very good. In some cases, the cross-correlation values between PSC and SSCs can be up to 43% of the main peak of the PSC autocorrelation function. Table 1 shows the maximum absolute cross-correlation values of the PSC with SSCs. We can see from table that maximum of the cross-correlation values is 111 (-7.26 dB) for cross-correlation with SSC #10. It has consequence on the level of maximum absolute correlation values of the PSC and PSC+SSC (Table 2). In slot boundary detection the sidelobes interfere with main-lobes from other BSs.
In asynchronous system such as W-CDMA neighbouring base stations use different spreading codes and mobile station first have to determine the spreading code used by BSs to which it has the lowest path loss. The acquisition process is conducted in three-step search procedure. To facilitate that, BS transmit synchronisation channel. Two synchronisation codes are used in synchronisation channel. It is important to select primary synchronisation code (PSC) with good autocorrelation properties and secondary synchronisation codes (SSC) to have very small cross-correlation (PSC) with good autocorrelation properties and low detector complexity (SSC) to have very small cross-correlation (PSC) with good autocorrelation properties and low detector complexity. While poor cross-correlation properties between the PSC and SSCs are not fatal, it might have a negative impact on the performance of the cell acquisition depending on the integration period.

**References**


[4] ETSI STC SMG2 UMTS-L1, Tdoc SMG2 221/98 “UTRA Physical Layer Description FDD parts (v0.4)”


[6] ETSI SMG2 UMTS L1, Tdoc SMG2 323/98; “An orthogonal set of codes for SCH with good correlation properties and low detector complexity”


**ABSTRACT:**

In asynchronous system such as W-CDMA neighbouring base stations use different spreading codes and mobile station first have to determine the spreading code used by BSs to which it has the lowest path loss. The acquisition process is conducted in three-step search procedure. To facilitate that, BS transmit synchronisation channel. Two synchronisation codes are used in synchronisation channel. It is important to select primary synchronisation code (PSC) with good autocorrelation properties and secondary synchronisation codes (SSC) to have very small cross-correlation with each other and with the PSC. The less strong paths from handover candidates base stations (cells) can be masked with autocorrelation sidelobes.

In this paper correlation properties of the PSC and SSCs are investigated. Current 3GPP technical specification for synchronisation sequences mostly takes care of the acquisition hardware complexity on the MS side while MAS of the PSC and cross correlation values of the SSCs are not as low as desired.

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