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Source: **Nortel Networks**

Title: **Synchronization Channel with cyclic hierarchical sequences**

Document for: Ad Hoc 2 SCH

Abstract

This contribution proposes a new set of cyclic hierarchical sequences for use on the Secondary SCH. These new cyclic hierarchical sequences have a structure that allows very efficient detection and in many cases improves the cell site acquisition performance by several dB.

1. Introduction

In the downlink, a three step cell search algorithm [1,2,4,5] has been chosen for the initial cell-site acquisition. The first step of this algorithm is for the mobile station to detect the short spreading code common to all cell sites. Following this, the mobile station determines the code group of the base station and frame synchronization, and finally acquires the (long) scrambling code.

During the first step of the cell search algorithm, the Primary Synchronization Code (PSC) is used for slot acquisition. In [8], a hierarchical sequence was proposed for the PSC.

In the second step, the Secondary Synchronization Codes (SSCs) are used for the initial cell search. For this set of codes, it has been suggested in [3] that a comma free code word be used for coding the code group and slot location.

In this paper, we present a new set of *cyclic hierarchical sequences* for the SSCs. The benefits of using the proposed new sequences are:

- improved performance for the cell search,
- the implementation complexity of the SSCs is low and might be less than the comma free method if properly designed, and
- the proposal does not alter the three step cell search procedure, only the codes used for the Secondary SCH.

This paper is organized as follows: the next section provides background to the problem, then previous proposal is analyzed and some problems identified. This is followed by a detailed description of the new proposal, a possible of implementation and an evaluation of its complexity. The contribution ends with a short discussion of the correlation properties of synchronization channel and some simulation results.

In the course of the development of the UTRA FDD model, various cell search schemes [2,4,5] have been considered based on the same concept of a PSC/SSC structure, but with different ways of encoding information. It should be emphasized that the present contribution has a close connection to all of these proposals since it belongs to the same family of cell-search schemes. This contribution is aimed at improving the performance of the cell site acquisition while maintaining low detector complexity and integrating with the existing W-CDMA synchronization technologies (including continuous or discontinuous mode of common control channel BCCH (CCPCH)).

2. Background

The Synchronization Channel (SCH) is a downlink signal used for cell search in the first and second step of the initial cell site acquisition. The SCH consists of two sub channels, the Primary and Secondary SCH.

The Primary SCH consists of an unmodulated code of length 256 chips, the Primary Synchronization Code (PSC), that is transmitted once every slot. The PSC is a hierarchical sequence common to every cell in the system. This hierarchical sequence was proposed in [8] as a low complexity alternative to the original Gold codes used in the ETSI and ARIB RTT proposals.

The Secondary SCH consists of repeatedly transmitting a length 16 sequence of unmodulated codes each of length 256 chips, the Secondary Synchronization Codes (SSCs). These codes are transmitted in parallel with the Primary SCH. In [3] it was suggested that the SSCs be structured to form a comma free code word within 16 consecutive slots. The symbols in the code word are taken from a set of 17 different codes of length 256. The order of symbols and which symbols to use are determined by a group specific Reed-Solomon code word.

Each comma free code word represents a scrambling code group identity, and since all code words are distinct under symbol wise cyclic shifts also the frame timing can be determined. In particular, 32 sequences are used to encode the 32 different code groups each containing 16 scrambling codes. The 32 sequences are constructed such that their cyclic-shifts are unique, i.e., a non-zero cyclic shift less than 16 of any of the 32 sequences is not equivalent to some cyclic shift of any other of the 32 sequences. Also, a non-zero cyclic shift less than 16 of any of the sequences is not equivalent to itself with any other cyclic shift less than 16. This property is used to uniquely determine both the long code group and the frame timing in the second step of cell acquisition (see ETSI UMTS XX.03, Section 5.3.2.3 Synchronization Channel and ARIB Volume 3 Specifications of Air-Interface for 3G Mobile System, Section 3.2.6.1. Cell Detection Control, Section 3.2.4.2.3.1.3.2. Spreading Code Allocation for Second Search Code. See also 3GPP, document S1.11 Transport Channels and physicals channels, document S1.13 Spreading and modulation).

Each of the 17 SSCs is constructed by the position wise addition modulo 2 of a Hadamard sequence (different for each SSC) and a hierarchical sequence used also for the PSC on Primary SCH (see ETSI UMTS XX.05, Section 7.2.3 Synchronization codes and ARIB Volume 3 Specifications of Air-Interface for 3G Mobile System, section 3.2.4.2.2.1.1.1.2. Spreading Code Generation for Search Codes).

3. Analysis

Our analysis of the existing Synchronization Channel has revealed that the cross correlation values of the PSC with different SSCs are not as low as desired. In fact, the existing Synchronization Channel has some drawbacks.

By definition, the PSC and SSCs are mutually orthogonal. However, the aperiodic cross correlation properties between the PSC and the SSCs are not very good. In some cases, the aperiodic cross correlation values between PSC and SSCs can be up to 70% of the main peak of the autocorrelation function of the PSC. Some specific examples are shown in Figures 1-3.

- Figure 1 shows the aperiodic auto correlation of the Primary code
- Figure 2 shows the aperiodic cross correlation of the Primary code with Secondary code #2
- Figure 3 shows the aperiodic cross correlation of the Primary code with Secondary code #4.

(Secondary code #2 is generated using hadamard sequence 17 (1+2*8), while Secondary code #4 is generated via hadamard sequence 33 (1+4*8)

We can see from these figures that the maximum of the aperiodic cross correlation values is 96 for the cross-correlation with SCC#2 and 176 for the cross-correlation with SSC#4. These are the maximum values but, within Figures 2 and 3, we can see many more significant cross-correlation peaks. Similar situation (large cross correlation values) is with many others cross correlations of PSC with SSCs.

The large cross-correlation values between the PSC and the SSCs are a result of scrambling the hierarchical PSC with Hadamard sequences to generate 17 SSCs. In the first cell search scheme developed for UTRA FDD mode, where Gold codes were used for the PSC, the aperiodic cross correlation peaks between the PSC and the SSC sequences were relatively small [6]. However, the hierarchical sequences suggested in [8] significantly reduce the complexity of implementation for the Primary SCH and are therefore seen as highly desirable.

While poor aperiodic cross-correlation properties between the PSC and SSCs is not fatal, it might have a negative impact on the performance of the cell acquisition depending on the integration period. Fortunately, a more detailed analysis has revealed that it is possible to reduce the aperiodic cross-correlations between the PSC and the SSCs by making some modifications to the SSCs while maintaining the PSC. These changes have also been found to improve the cell site search performance.

In this contribution, we propose a better Synchronization Channel with cyclic hierarchical sequences for SSCs (of Secondary SCH) and provide a simple method for the detection of these sequences that yields low detector complexity.

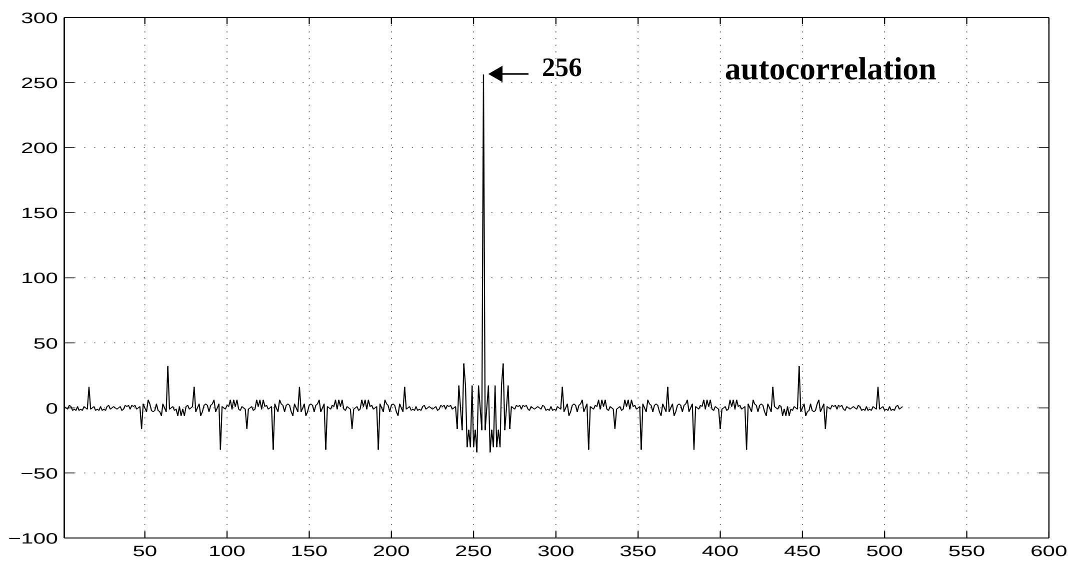


Figure 1: Aperiodic auto correlation function of the (hierarchical) Primary code

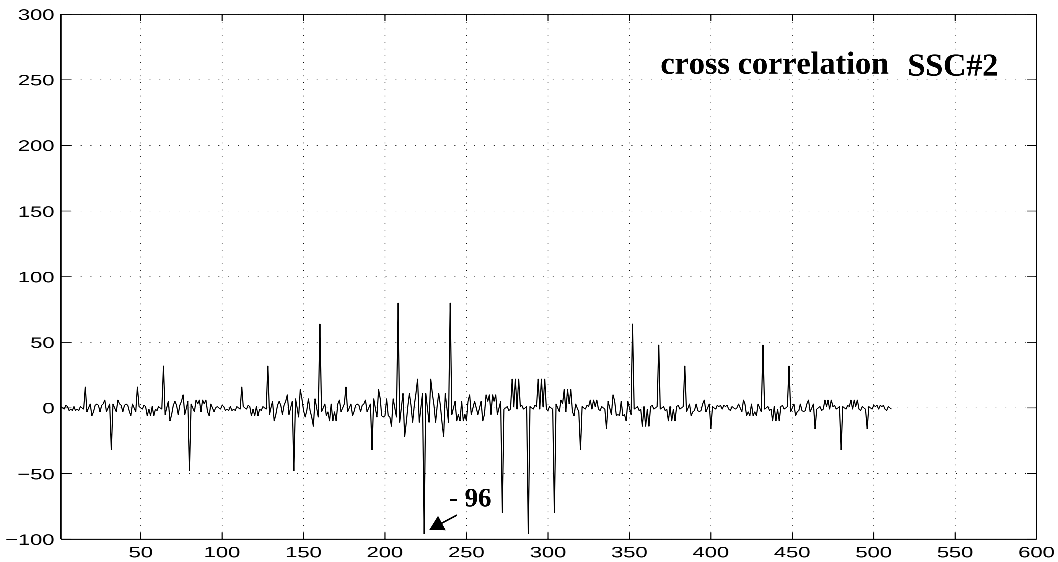


Figure 2: Aperiodic cross-correlation of the Primary code with Secondary code #2

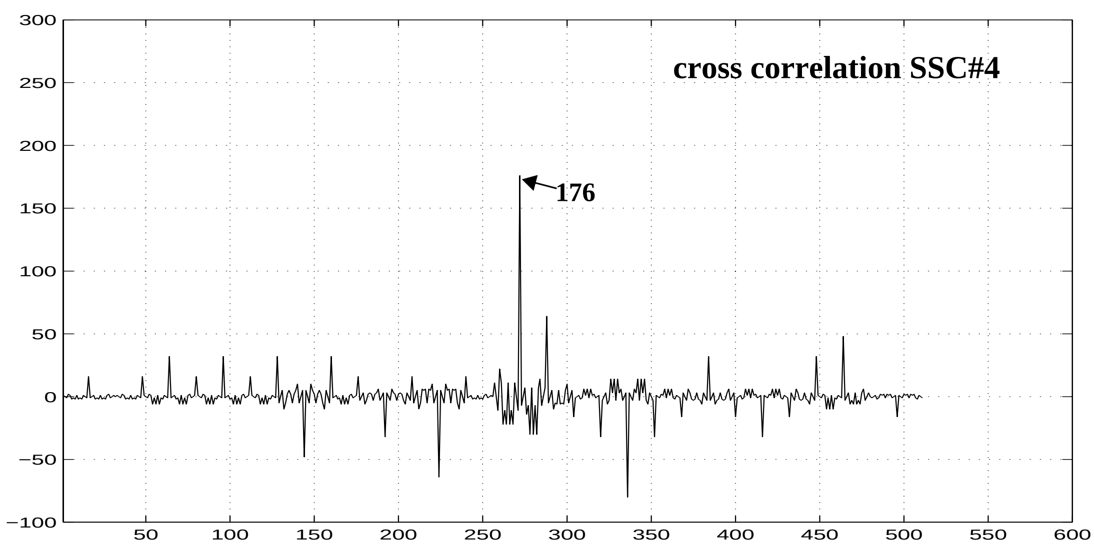


Figure 3: Aperiodic cross-correlation of the Primary code with Secondary code #4

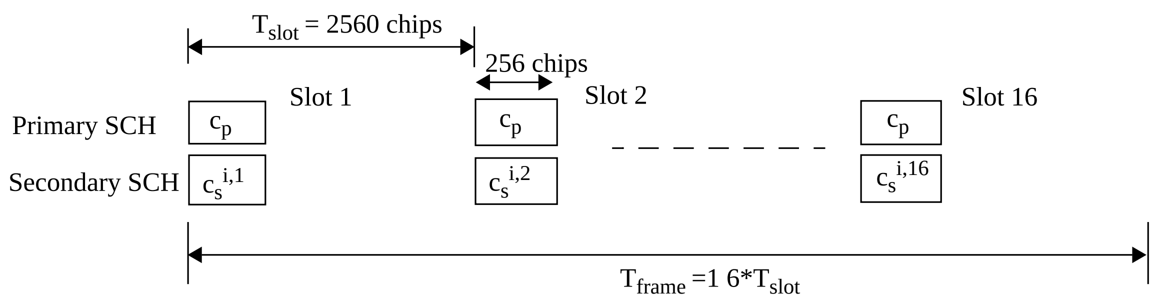
4. Detailed description

The key to this proposal is the use of a separate code (a length 256, so called cyclic hierarchical sequence) for each *code group/slot location* pair (of which there are 512 possible pairs). This new set of cyclic hierarchical sequences has good quasi-orthogonal properties and it is also possible to implement a low complexity detector for these sequences.

The Primary SCH is not planned to modify.

4.1. Synchronization Channel

The SCH, consisting of two subchannels: the Primary and Secondary SCH, is illustrated in Figure 4.



c_p: Primary Synchronization Code (PSC), *hierarchical sequence*

$c_s^{i,k}$: One of 512 possible Secondary Synchronization Codes (SSC), *cyclic hierarchical sequence*

$(c^{i,1}, c_s^{i,2}, \ldots, c_s^{i,16})$ 16 *cyclic hierarchical sequences* to encode the cell specific long scrambling code group i

Figure 4: Structure of Synchronization Channel (SCH) with cyclic hierarchical sequences

The Primary SCH consists of an *unmodulated* hierarchical sequence of length 256 chips, the Primary Synchronization Code, transmitted once every slot. The Primary Synchronization Code (PSC) is the same for every base station in the system and is transmitted time-aligned with the BCCH slot boundary as illustrated in Figure 4. The PSC is chosen to have good aperiodic auto correlation properties. The hierarchical sequences is constructed from two constituent sequences X_1 and X_2 of length n_1 and n_2, respectively, using the following formula:

$$c_p(n)= X_2(n \bmod n_2)+X_1(n \operatorname{div} n_1) \text{ modulo } 2,\ n=0\ldots (n_1 * n_2)-1 \qquad (1)$$

The constituent sequences X_1 and X_2 are chosen to be identical and to be the following length 16 sequence:

$X_1 = X_2 = < 0, 0, 1, 1, 1, 1, 0, 1, 0, 0, 1, 0, 0, 0, 1, 0 >$

(Note that the sequences X_1 and X_2 are those proposed in [8, 9] as a base line for the Primary SCH).

The Secondary SCH consists of repeatedly transmitted 16 sequences belonging to a family of *cyclic hierarchical sequences* (Secondary Synchronization Codes), each of length 256 chips. These Secondary Synchronization Codes (SSCs) are transmitted in parallel with the Primary SCH. The procedure for constructing the *cyclic hierarchical sequences* is similar to that of the *hierarchical sequence* (equation 1) for the Primary SCH but using specific constituent length 16 sequences for each code group.

For slot 1, the cyclic hierarchical sequences is constructed from two constituent sequences $X_{1,i}$ and $X_{2,i}$ of length n_1 and n_2 respectively using the following formula:

$$c_s^{i,1}(n)= X_{2,i}\,(n \bmod n_2)+X_{1,i}\,(n \operatorname{div} n_1) \text{ modulo } 2,\ n=0...\ (n_1*n_2)-1 \qquad (2)$$

where i is the code number

The constituent sequences $X_{1,i}$ and $X_{2,i}$ in each code group are chosen to be identical and to be the following length 16 sequence (X_2 is inner constituent sequence, X_1 is outer constituent sequence

:

Length 16 constituent sequences $X_{1,i}$ and $X_{2,i}$ for	
code groups from 1 to 8	code groups from 17 to 24
0 0 0 1 1 1 0 1 1 0 0 1 0 1 0 0	0 1 0 0 1 0 1 0 0 0 1 0 0 0 1 0
0 1 0 0 1 0 0 0 1 1 0 0 0 0 0 1	0 0 0 1 1 1 1 1 0 1 1 1 0 1 1 1
0 0 1 0 1 1 1 0 1 0 1 0 0 1 1 1	0 1 1 1 0 1 1 0 0 0 0 1 1 1 1 0
0 1 1 1 1 0 1 1 1 1 1 1 0 0 1 0	0 0 1 0 0 0 1 1 0 1 0 0 1 0 1 1
0 0 0 1 0 0 1 0 1 0 0 1 1 0 1 1	1 1 1 0 0 1 1 0 0 1 0 1 0 0 1 1
0 1 0 0 0 1 1 1 1 1 0 0 1 1 1 0	1 0 1 1 0 0 1 1 0 0 0 0 0 1 1 0
0 0 1 0 0 0 0 1 1 0 1 0 1 0 0 0	1 1 0 1 0 1 0 1 1 0 0 1 1 1 1 1
0 1 1 1 0 1 0 0 1 1 1 1 1 1 0 1	1 0 0 0 0 0 0 0 1 1 0 0 1 0 1 0
code groups from 9 to 16	code groups from 25 to 32
0 0 1 0 1 1 1 0 0 1 0 1 1 0 0 0	1 0 0 0 1 1 0 0 0 1 1 1 1 1 1 0
0 1 1 1 1 0 1 1 0 0 0 0 1 1 0 1	1 1 0 1 1 0 0 1 0 0 1 0 1 0 1 1
1 0 1 1 1 1 1 0 0 0 0 1 0 1 0 1	1 0 0 0 0 0 1 1 0 1 1 1 0 0 0 1
1 1 1 0 1 0 1 1 0 1 0 0 0 0 0 0	1 1 0 1 0 1 1 0 0 0 1 0 0 1 0 0
0 1 1 1 0 1 1 0 1 1 1 0 0 0 0 1	1 0 1 1 0 0 0 0 0 1 0 0 0 0 1 0
0 0 1 0 0 0 1 1 1 0 1 1 0 1 0 0	1 1 1 0 0 1 0 1 0 0 0 1 0 1 1 1
0 1 1 1 1 0 0 1 0 0 0 1 0 0 0 1	1 0 0 0 1 1 0 0 1 0 0 0 0 0 0 1

0 0 1 0 1 1 0 0 0 1 0 0 0 1 0 0	1 1 0 1 1 0 0 1 1 1 0 1 0 1 0 0
Table 1: Constituent sequences for cyclic hierarchical sequences	

We can see that the procedure for constructing the *cyclic hierarchical sequence* $c_s^{i,1}$ for slot 1 is exactly the same as constructing the *hierarchical sequence* c_p for the Primary SCH. The sequence $c_s^{i,1}$ for slot 1 will be referred to as the *zero cyclic shift sequence* as no shift is applied to the constituent sequence $X_{1,i}$.

For slots 2 to 16, the cyclic hierarchical sequences are constructed from the two constituent sequences $X_{1,i,k-1}$ and $X_{2,i,k-1}$ of length n_1 and n_2 respectively using the following formula:

$$c_s^{i,k}(n)= X_{2,i,k-1} (n \bmod n_2)+X_{1,i,k-1} (n \operatorname{div} n_1) \text{ modulo } 2,\ n=0... (n_1*n_2)-1 \qquad (3)$$

where i is code group number, k=2,...,16 is slot number, n is chip number in slot

The constituent sequences $X_{1,i,k-1}$ and $X_{2,i,k-1}$ in each code group i are chosen to be the following length 16 sequences from the above Table 1.

- The constituent sequence $X_{2,i,k-1}$ (inner sequence) is *exactly equal* to the base sequence $X_{2,i}$ in every slot, i.e. $X_{2,i,k-1} = X_{2,i}$ at all k.
- The constituent sequence $X_{1,i,k-1}$ (outer sequence) are formed from the base sequence $X_{1,i}$ by cyclic shifts of $X_{1,i}$ on k-1 positions (from 0 to 15) clockwise for each slot number k, from 1 to 16.

For example, for the first code group:

$X_{1,1,0} = X_{1,1}$ = < 0 0 0 1 1 1 0 1 1 0 0 1 0 1 0 0 >, k=1 for slot 1, No cyclic shift

$X_{1,1,1}$ = < 0 0 0 0 1 1 1 0 1 1 0 0 1 0 1 0 >, k=2 for slot 2, cyclic shift by 1 position

...

$X_{1,1,15}$ = < 0 0 1 1 1 0 1 1 0 0 1 0 1 0 0 0>, k=16 for slot 16, cyclic shift by 15 positions

The same procedure for forming the cyclic hierarchical sequences will be used for other code groups.

Thus, for the 32 codes groups and 16 slots (in one frame), we will construct 512 *different* cyclic hierarchical sequences with a length of 256 chips each. In other words, we will construct 16 cyclic hierarchical sequences in each of 32 code groups, altogether 512 different cyclic hierarchical sequences.

It can be easily shown that this set of 512 cyclic hierarchical sequences has good correlation properties that make it them good candidates for the Secondary Synchronization Codes. We can observe that many pairs of cyclic hierarchical sequences (from the 512*511/2 possible pairs) are fully orthogonal, some pairs have small cross correlation properties and only a small percent (3-5%) of these pairs have cross correlation values reaching up to 25% of the auto correlation value of the PSC (desired correlation value of the Primary code). Consequently, this set of 512 cyclic hierarchical sequences is a set of quasi-orthogonal codes. We also can observe that cross correlation of each cyclic hierarchical sequence $c_s^{i,k}$ with c_p code of Primary SCH is small (In section 6, we will discuss further the correlation properties of this set of cyclic hierarchical sequences).

These 512 cyclic hierarchical sequences are unique for each *code group/slot locations* pair. Thus, it is possible to uniquely determine both the (long) scrambling code group and the frame timing in the second step of the initial cell search. In addition, when the signal-to-noise ratio is high, it is possible to determine both the correct code group and frame timing by search only 1 slot, however, integration of correlation results over several slots is typically necessary in fading environments to increase the reliability of detection.

4.2. Cell search

During the initial cell search, the mobile station searches for the base station to which it has the lowest path loss. It then determines the down link scrambling code and frame synchronization of that base station. The initial cell search follows a 3 step procedure using the synchronization channel (SCH) shown in Figure 4. We outline the modified cell search procedure below with the principal difference coming in step-2.

Step-1: Slot synchronization. During the first step of the initial cell search procedure the mobile station uses the Primary SCH to acquire slot synchronization to the strongest base station. This is done with a matched filter (or any similar device) matched to the Primary Synchronization Code (PSC) c_p that is common to all base stations. The hierarchical sequence used for the PSC allows a low complexity implementation as suggested in [8, 9]. For better reliability, the matched filter output should be non-coherently accumulated over a number of slots.

Step-2: Frame synchronization and code group identification. During the second step of the initial cell search procedure, the mobile station uses the Secondary SCH to find frame synchronization and identify the scrambling code group of the base station found in the first step. This is done by correlating the received signal of the Secondary Synchronization Codes (SSCs) with all 512 possible *cyclic hierarchical sequences* used for the SSCs. Note that the position of the SSC in the slot is known after the first step. Consequently, for each Secondary SCH location (slot), we should correlate with all possible 512 cyclic hierarchical sequences. In Section 5, we will show how these correlations can be implemented such that the complexity of this step is approximately 10% of the complexity of step-1.

The complex outputs of 512 correlations for each Secondary SCH location are used to form the 512 decision variables. The decision variables are obtained by *non-coherently* summing the outputs of 512 correlations corresponding to all 512 possible *code group*/*slot location* pairs. Thus, by identifying the *code group*/*slot location* pair that gives the maximum correlation value, the code group as well the frame synchronization is determined. Note that 1 slot search period time (2560 chips) is enough to uniquely identify the correct code group and the frame timing in the second step of acquisition when the signal-to-noise ratio is high. This is one major difference with the Comma Free method where at least 3 slots are necessary to uniquely identify the correct code group and frame timing.

Step-3: Scrambling code identification. During the third and last step of the initial cell search procedure, the mobile station searches all 16 downlink (long) scrambling codes and determines the exact scrambling code used by the chosen base station. The scrambling code is identified through symbol-by-symbol correlation over the fixed Primary CCPCH (this is broadcasting control channel, BCCH) with all scrambling codes within the code group identified in the second step.

5. Implementation details and complexity evaluation

In this section, we provide a possible implementation of the new scheme. Since step-1 and step-2 are tied together, we begin by reviewing the implementation and complexity of step-1.

Step-1 of the initial cell search and its complexity

During the first step of the initial cell acquisition, we must use a matched filter (or any similar device) for acquisition of the Primary Synchronization Code (PSC) of the Primary SCH. The PSC is a hierarchical sequence of length 256 chips (please see section 4.1 for details of forming PSC). that is transmitted once per time slot (625 μs =2560 chips, see Figure 4).

It has been shown in [8] that the use of hierarchical sequences allows a very efficient calculation of the correlation sum P at the output of the matched filter. The receiver can perform the following for every input sample:

- Perform a length 16 correlation of the received data with inner constituent sequence X_2 and store the result (Ps) in a (ring-) *Primary Buffer* of length 256. Each memory cell in this buffer is 8-10 bits assuming that at the input to the digital receiver we have sampled the signal with a 4-6 bit A/D convertor.
- Perform a length 16 correlation P of the sequence that has been buffered in the Primary Buffer using only every 16-th value while correlating with outer sequence X_1. This value P is the required matched filter output to be used for slot accumulation and synchronization for the Primary SCH.

Sub correlation sums Ps(k) can be reused for the calculation of the matched filter correlation sums P. This fact is the reason for the efficiency of the hierarchical correlation sequences used for calculation of the matched filter correlation value P. For a new correlation sum P(k) it is not necessary to perform 16*16 operations but only 16+16 accumulation operations, which leads to a considerable reduction in complexity [8].

Let us calculate the complexity of implementing the matched filter. In one slot period (2560 chips), the receiver has to perform at <u>least 163840 complex additions per slot</u>, assuming double oversampling (2560 * 2 samples per chip * (16+16)). We need 16+16=32 complex additions per correlation point as shown in [8]. (Note that for a general sequence without the hierarchical correlation structure we would need 256 complex additions - a saving of a factor of 8). Complexity of the first step in terms of real additions (I and Q branches of complex signal) per second is 525 Madds/sec (163840*2/625). Thus, in **step-1** of the initial search, we require:

- **163840 complex additions in 1 slot and computing power of 525 Madds/sec**

In addition, we need also a (ring) Primary Buffer with 256 complex memory cells (8-10 bits in each memory cell), 5120 memory cells for accumulator, possibly some other circuitry, and control logic.

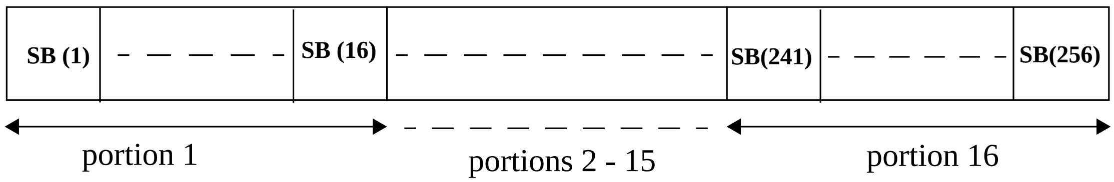
Step-2 of the initial cell search and its complexity

During the second step of the initial cell acquisition, we must correlator with the SSCs of the Secondary SCH. The SSCs are cyclic hierarchical sequences of length 256 chips (please see section 4.1 for details of forming SSCs). This SSCs appear periodically every time slot (625 μs =2560 chips, see Figure 4).

In the following, we give an example of one possible approach to acquiring the Secondary SCH. For convenience, we have separated the acquisition process into 3 stages.

First stage. During the 1st stage of acquiring the Secondary SCH, we need to store the input data samples for the SCH (combined Primary SCH and Secondary SCH) in some buffer with 256 complex memory cells. These input data samples are produced after *waveform* matched filtering and sampling at the chip rate (Note that sampling at the chip rate is possible because we know the beginning of the slot with accuracy better than 1/2 chip after step-1 of the initial cell acquisition). We will call this buffer, with 256 complex memory cells SB, the *Secondary Buffer* and use it to store input data for every slot. If 4-6 bits are used for A/D conversion at the receiver input, then each memory cell of Secondary Buffer will require 5-7 bits. For convenience, we separate the 256 complex memory cells into 16 portions with 16 complex memory cells in each portion as shown in Figure 5.

Secondary Buffer



portion 1: SB(1), SB(2),..., SB(16)

portion 2: SB(17), SB(18),..., SB(32)

....

portion 16: SB(241), SB(242),..., SB(256)

SB(1) corresponds to the 1-st chip in slot

SB(256) corresponds to the 256-th chip in slot

Figure 5: Structure of Secondary Buffer

Second stage. For the code group i during the 2nd stage of the acquiring of the Secondary SCH, we need to produce 16 complex *common variables* (CV). These common variables CV should be calculated in a special way (by despreading data *SB* taken from the Secondary Buffer with sequence $X_{2,i}$ and integrating). Sequence $X_{2,i}$ should be taken from Table 1 according to the number i of the code group under test.

- variable CV (1) is calculated from *portion 1* and $X_{2,i}$
- variable CV (2) is calculated from *portion 2* and $X_{2,i}$
- ...
- variable CV (16) is calculated from *portion 16* and $X_{2,i}$

Thus, after despreading with $X_{2,i}$, we produce 16 complex common variables CV(1),..., CV(16). It is evident that we need 256=16*16 complex additions to form these 16 common variables CV. The number of bits necessary to represent the common variables CV with fixed point can be in the range of 9-11 bits (approximately 4 bits more than is required for each memory cell in the Secondary Buffer).

Third stage. For the code group i during the 3rd stage of the acquiring of the Secondary SCH, we need to calculate 16 complex *correlation outputs* in each slot (using data from common variables CV). This is done by clockwise cyclically shifting the outer constituent sequence $X_{1,i}$ by k-1 positions (k=1...16) to produce $X_{1,i,k-1}$ and correlate each of these codes with the common variables CV(1)... CV(16).

Thus for each slot and code group i, we need to produce 16 complex correlation variables $CorVar_{i,1}$,..., $CorVar_{i,16}$ to determine the correct slot number. It is evident that we need 256=16*16 complex additions to correlate the codes $X_{1,i,k-1}$ with the common variables CV(1)... CV(16) to produce the 16 correlation variables CorVar. Together with the 256 complex additions needed to produce the common variables CV, we need a total of 512=256+256 complex additions to form the correlation variables CorVar for each code group i.

After the correlation variables CorVar are formed, they are used to form *decision variables* and the complex memory cells used for the *common variables* and the *correlation variables* can be reused.

The operations for the second stage and third stage are repeated for each of the 32 code groups. Thus, we need a total of 16384=32*512 complex additions to form 512 complex correlation variables for all 32 code groups. The complexity of the second step in terms of real additions (I and Q branches of complex signal) per second is 52.5 Madds/sec (16384*2/625).

- **16384 complex additions in 1 slot and computing power 52.5 Madds/sec**

The memory required for the second step of the acquisition process consists of 256 complex memory cells for the Secondary Buffer (5-7 bits in each cell), 16 complex memory cells for the common variables (9-11 bits in each cell), 16 memory cells for the correlation variables (13-15 bits in each cell), and 512 memory cell for the accumulator. There is also additional circuitry and control logic required.

We can conclude from our complexity evaluation that the second step of the initial cell acquisition is approximately 10% of the complexity of the first step (matched filter for the Primary SCH). We can also see that our Secondary SCH design is reasonable in that the 512 decision variables required for the Secondary SCH is exactly 10% of the 5120 decision variables required for the Primary channel.

From our description we can see that complexity of implementation of the Secondary SCH (with SSCs) is low and might be less than the comma free approach depending on its implementation.

6. Correlation properties

Our analysis of the auto- and cross-correlation properties of the PSC and SSC sequences has revealed:

- The sidelobes of the auto correlation function of the PSC are small: average maximum sidelobe equals 34 (-17.5 dB) when main correlation peak is equal to 256 and the average sidelobe is equal to 5 (-36 db) (see [8] for details).
- Many cross-correlation pairs of the PSC with the SSCs are mutually orthogonal. However, in general the PSC and the SSCs are not mutually orthogonal. In the worst case, the level of non-orthogonality between them is small and the maximum in the cross-correlation function is -18 dB below the peak of the auto-correlation function of the PSC.
- Typical maximum periodic cross-correlations between different Secondary cyclic hierarchical sequences are also small and approximately equal to the maximum sidelobe of the auto-correlation function of the PSC. Only a small amount (3-5%) of these cross-correlations reach 25

percent of the main peak.

The maximum values of the aperiodic cross-correlations between the Primary code and the new cyclic hierarchical sequences are small than with old set of 17 Hadamard-based Secondary codes in [9]. Typical examples of the aperiodic cross-correlation between the Primary code and the cyclic hierarchical sequences proposed for the Secondary codes are shown in Figures 6-9.

We can conclude that the correlation properties of the PSC and the SSCs are quite acceptable for synchronization purposes and we can expect good results for the acquisition of the Primary SCH and the Secondary SCH with these codes (cyclic hierarchical sequences).

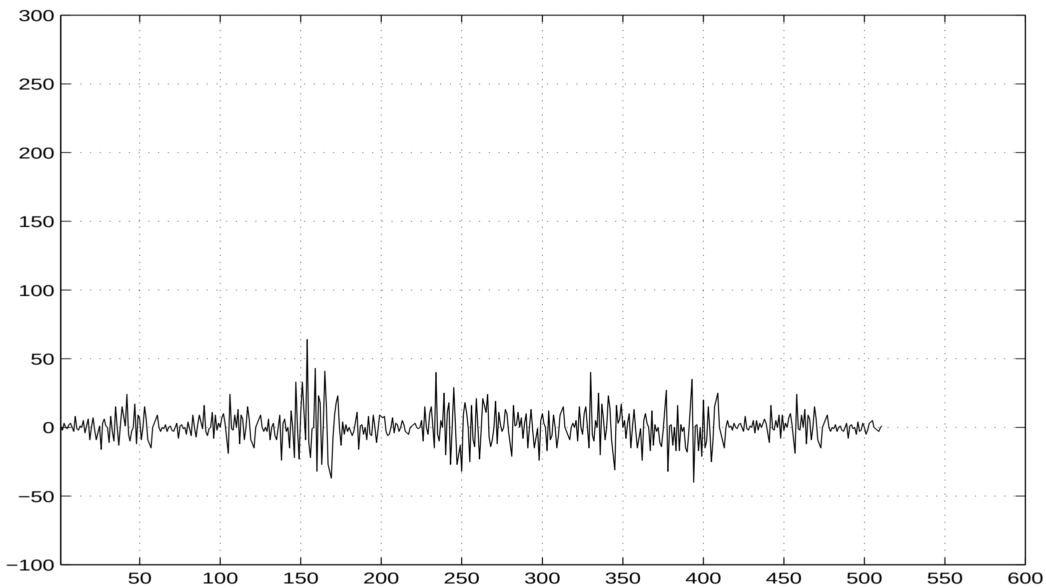


Figure 6: Aperiodic cross-correlation of the Primary code with the cyclic hierarchical sequence (code group 2, slot 1= no cyclic shift)

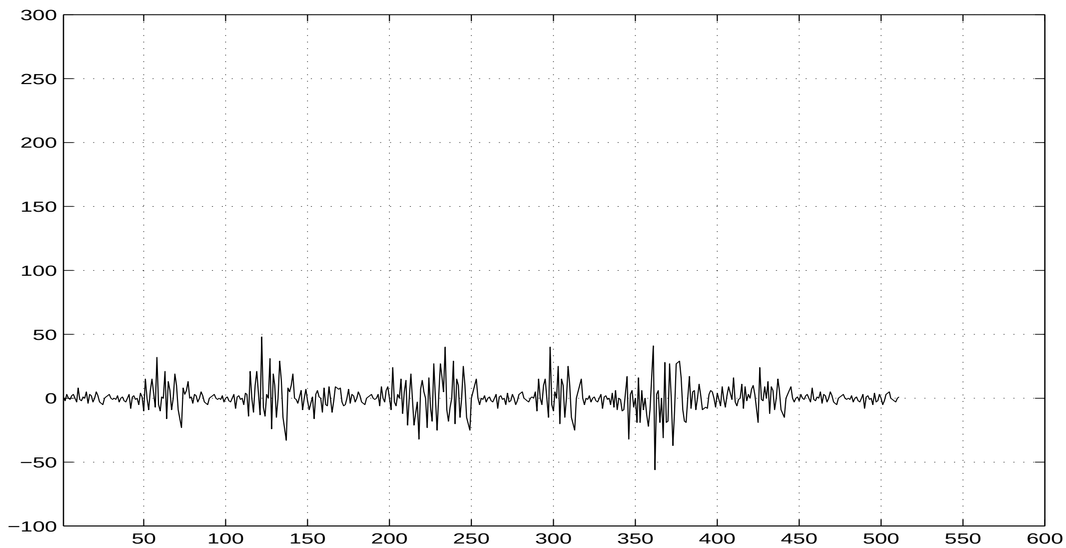


Figure 7: Aperiodic cross-correlation of the Primary code with the cyclic hierarchical sequence (code group 2, slot 3)

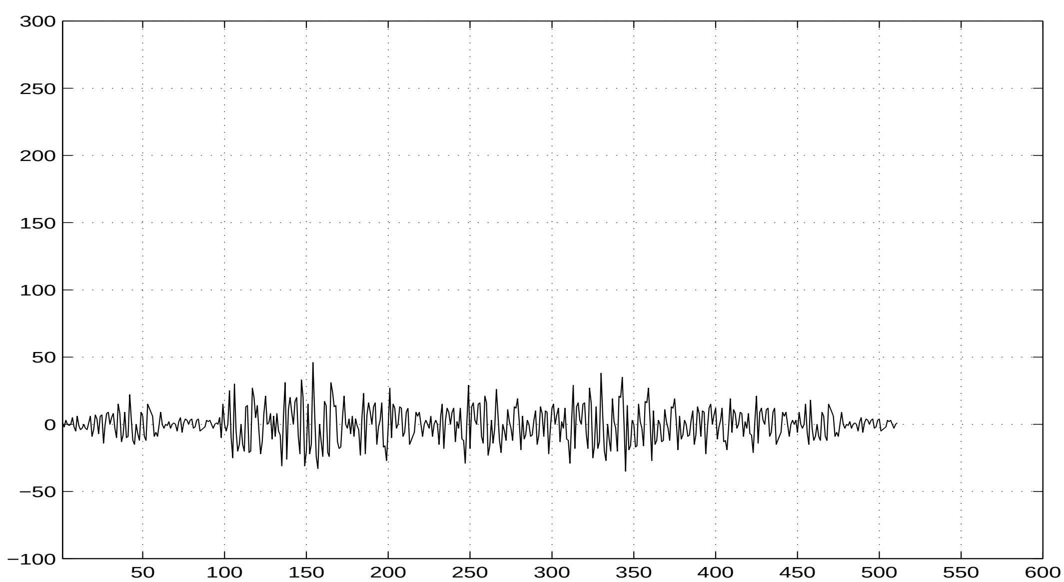


Figure 8: Aperiodic cross-correlation of the Primary code with the cyclic hierarchical sequence (code group 22, slot 1= no cyclic shift)

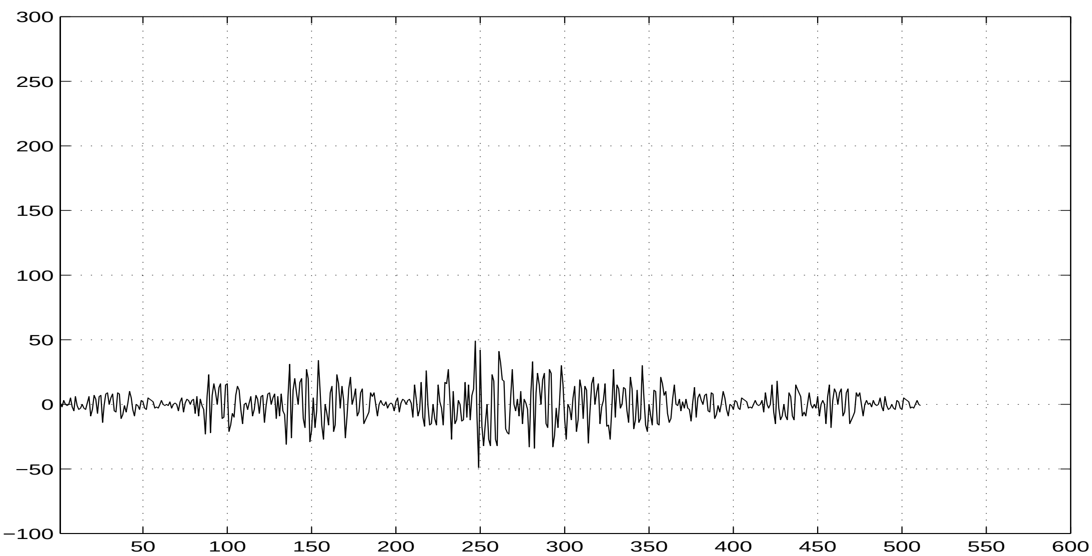


Figure 9: Aperiodic cross-correlation of the Primary code with the cyclic hierarchical sequence (code group 22, slot 8)

7. Simulation performance

Our simulations confirmed that the Secondary SCH with a new set of cyclic hierarchical sequences has better performance than with old set of comma free codes. With cyclic hierarchical sequences, the code distance between the decision variables is larger than with old comma free coding. In particular, with comma free coding we need at least 3 slots to uniquely identify the *code group/slot location*, even in the noiseless case. However, with the new set of cyclic hierarchical sequences, input data from as little as 1 slot can be used to correctly decode the code group/slot location pair. Because of this we should expect a significant improvement in the cell acquisition performance, especially in a fading environment.

We have simulated the second step of the initial cell acquisition (code group/slot location identification) on an AWGN channel and for single path Raleigh fading (3 km/h, 60 km/h, 180 km/h and 500 km/h) while using different numbers of post detection integration (from 1 to 48 slots of integration). At the same chip energy-to-interference density ratio (labelled here as SNR), the probability of incorrect code group/slot location synchronization is *always* better with the new set of cyclic hierarchical sequences. In many cases of practical interest, the gain was more than 2 dB over the comma free approach.

Some results for the probability incorrect detection of the *code group/ slot location* with 8 slot integration are shown in Figures 10-13 for an AWGN channel and single path Rayleigh fading (60, 180 and 500 km/h). From these figures we can see that the Secondary SCH with the new set of cyclic hierarchical sequences out-performs the old comma free codes in all cases and the performance improvement can be more than 2 dB in fast fading.

8. Conclusion

We have proposed a new cyclic hierarchical sequences for the Secondary SCH that provide performance improvements over the existing Secondary SCH with comma free codes. The complexity of implementation of the new Secondary SCH is low and, depending on the implementation, might be even less than with comma free method.

We recommend that these new cyclic hierarchical sequences be adopted for the Secondary SCH.

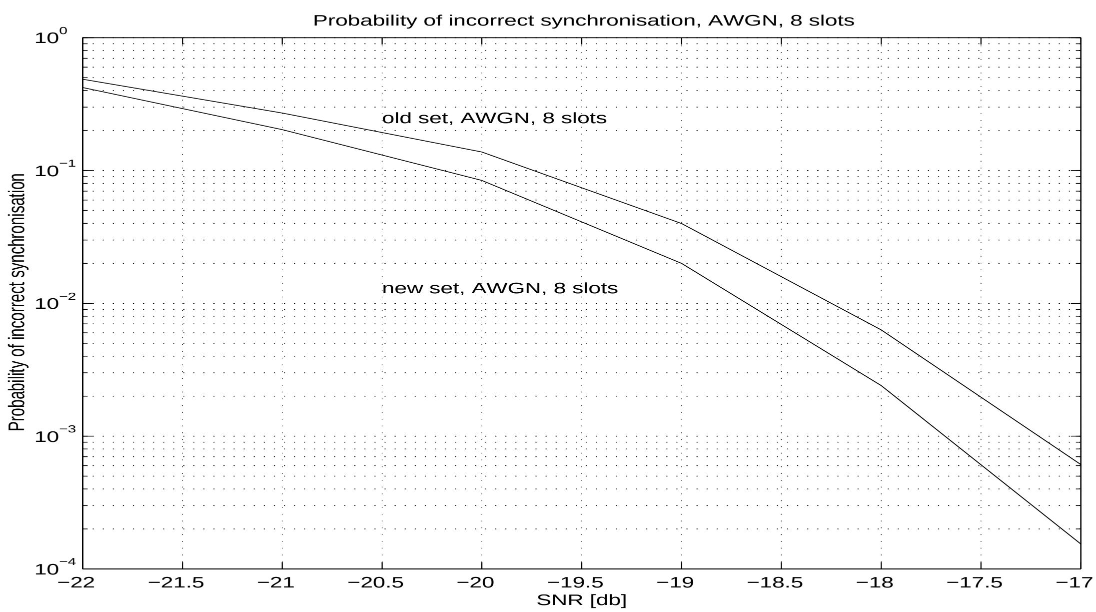


Figure 10: Probability of incorrect code group/slot location synchronization in AWGN vs. SNR, 8 slots integration

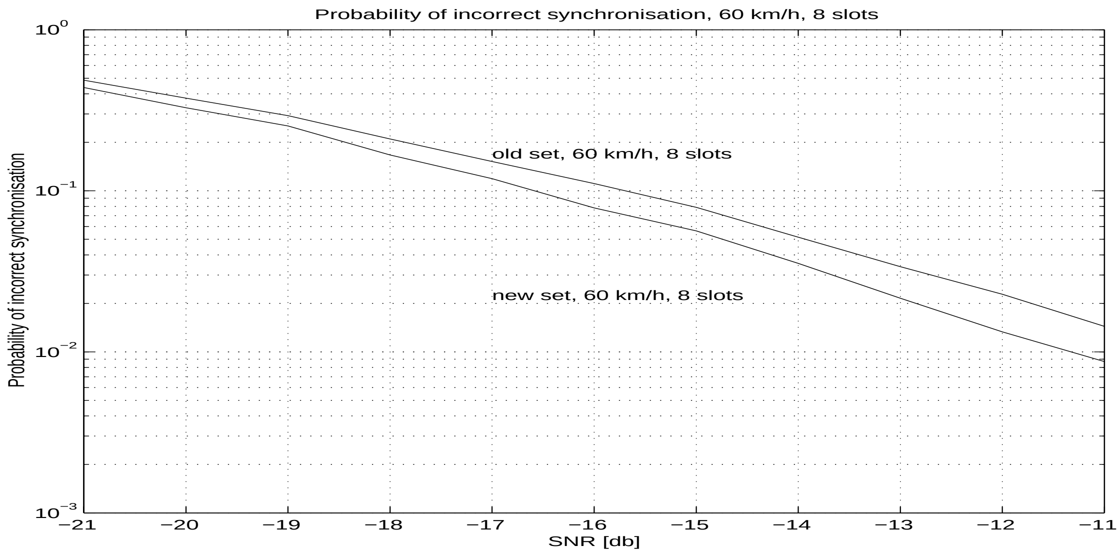


Figure 11: Probability of incorrect code group/slot location synchronization in one ray Rayleigh fading vs. SNR, 8 slots integration, 60 km/h

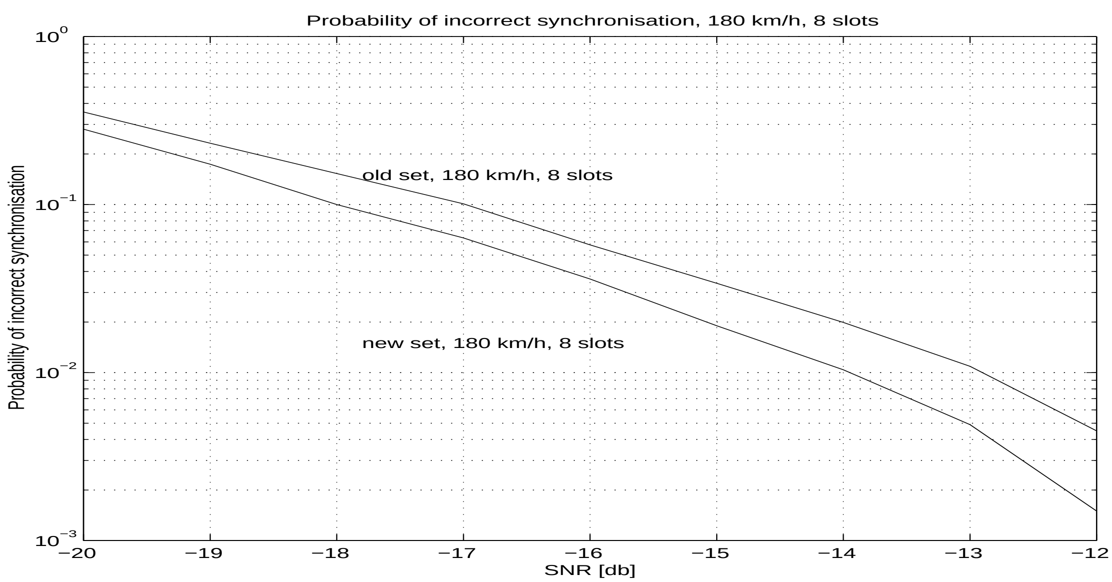


Figure 12: Probability of incorrect code group/slot location synchronization in one ray Rayleigh fading vs. SNR, 8 slots integration, 180 km/h

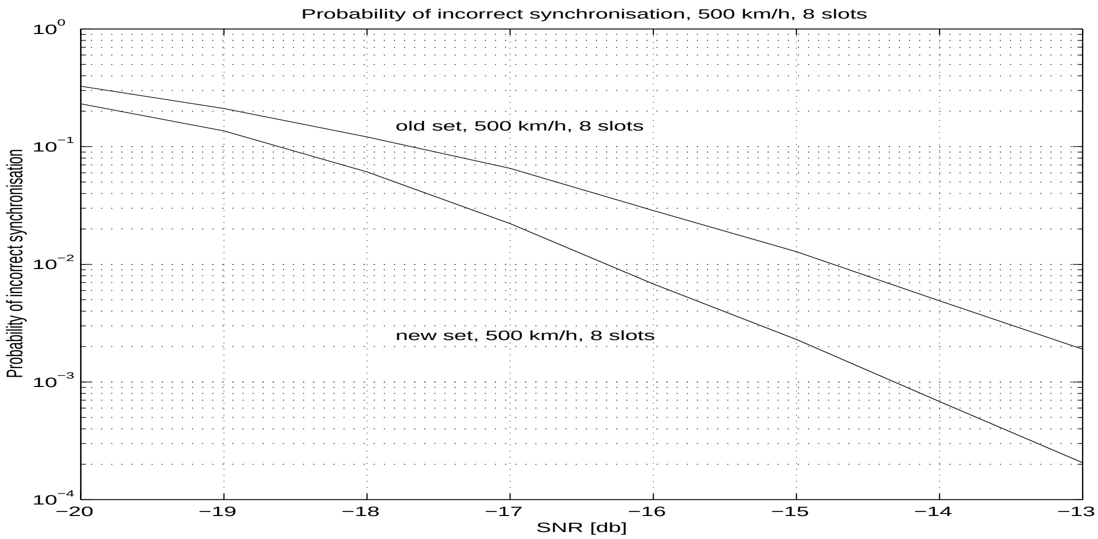


Figure 13: Probability of incorrect code group/slot location synchronization in one ray Rayleigh fading vs. SNR, 8 slots integration, 500 km/h

9. References

[1] K. Higuchi, M. Sawahashi, and F. Adachi, “Fast cell search algorithm in DS-CDMA mobile radio using long spreading codes, “Proc. VTC’97 Conf., Phoenix, AZ, May 1997.

[2] Wideband direct-sequence CDMA (WCDMA), Evaluation document (version 3.0), source ETSI SMG2, 1-5 December, 1997

[3] Comma Free Codes for Fast PN Code Acquisition in WCDMA Systems: A Proposal for UTRA concept, Tdoc SMG2 UMTS-L1 72 /98, April 28, 1998, Texas Instruments

[4] The ETSI UMTS Terrestrial Radio Access (UTRA) ITU-R RTT Candidate Submission, ETSI SMG2, May/June 1998

[5] Japan’s Proposal for Candidate Radio Transmission Technology on IMT-2000: W-CDMA, 26th June, 1998

[6] An orthogonal set of codes for SCH with good correlation properties and low detector complexity, Tdoc SMG2 UMTS-L1 323/98, Sept 8-11, 1998, Ericsson

[7] Text proposal for Hadamard-based synchronization codes, Tdoc SMG2 UMTS-L1 409/98, Ericsson

[8] A new correlation sequence for the Primary Synchronization Code with good correlation properties and low detector complexity, Tdoc SMG2 UMTS-L1 427/98, Oct. 14-16, 1998 Siemens

[9] Text Proposal for Hierarchical Synchronization Code, Tdoc SMG2 UMTS-L1 502/98, Nov. 9-12, 1998, Siemens