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Agenda Item: **ad-hoc 12**

Source: **Nortel Networks**

Title: **Synchronization Channel with cyclic hierarchical sequences and Option 2**

Document for: For discussion at Ad Hoc 12 Synchronization Channel

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Abstract

This contribution provides new results with 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 [3], we proposed a set of cyclic hierarchical sequences for the Secondary Synchronization Channel (SSCH) [1,2] that provide improved performance with low detector complexity. This proposal was followed by [4] and [5] where further options to the original scheme were provided and some performance results given. In this paper, we further elaborate on the Nortel-2 option of [5] and provide performance results for this option when used with the current Primary Synchronization Channel (PSCH) of the 3GPP proposal.

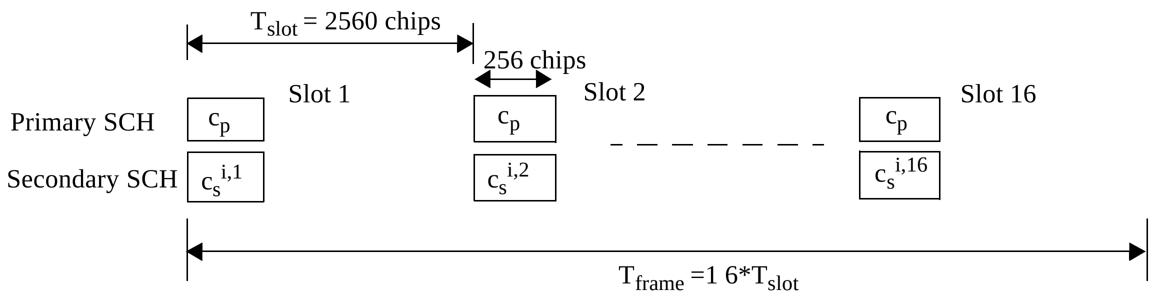
2. Brief Description of the SCH with Cyclic Hierarchical Sequences

In this section, we briefly review the cyclic hierarchical sequences first introduced in [3] and then explain the application of these sequences to the Nortel-2 option introduced in [4],[5].

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.

2.1. Synchronization Channel

The SCH, consisting of two subchannels: the Primary and Secondary SCH, as illustrated in Figure 1.



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

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

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

Figure 1: 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 sequence is constructed from two constituent sequences X_1 and X_2 of length n_1 and n_2, respectively, using the following formula:

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

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

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

The Secondary SCH consists of a set of 16 sequences (each 256 chips in length). In the scheme proposed here, these sequences belong to a *cyclic hierarchical sequences*. 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.

The first element of the family of cyclic hierarchical sequences (generally transmitted in the first slot of the SCH frame) is constructed from two constituent sequences $X_{1,i}$ and $X_{2,i}$ of length n_1 and n_2, respectively, using the formula:

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

where i is the code number.

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

There a large number of ways of selecting the constituent sequences $X_{1,i}$ and $X_{2,i.}$ The proposal here is to choose $X_{1,i} = X_{2,i}$ in each code group. Table 1 lists a set of length 16 sequences can be used to generate $c_s^{i,1}$ for each 32 code groups using equation 2 (X_2 is the inner constituent sequence, X_1 is the 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 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

To construct the other elements of the family of cyclic hierarchical sequences that are transmitted in successive slots (for slots k=2...,16), we use the two constituent sequences $X_{1,i,k-1}$ and $X_{2,i,k-1}$ of length n_1 and n_2 respectively with the formula:

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

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

Using Table 1, 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:

- The constituent sequence $X_{2,i,k-1}$ (inner sequence) is set 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) for each slot number k, from 1 to 16.

For example, in 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, 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, 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, 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 may construct 512 *different* cyclic hierarchical sequences with a length of 256 chips each. It can be easily shown that this set of 512 cyclic hierarchical sequences has good correlation properties that make 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 the Primary Synchronization Code c_p is small.

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 with the information in only only 1 slot, however, integration of correlation results over several slots is typically necessary in fading environments to increase the reliability of detection.

3. SCH with Cyclic Hierarchical Sequences and Option 2

In the previous section, we introduced the cyclic hierarchical sequences for the SSCH. There are a number of different options for how these sequences might be used with the SSCH.

From the previous section, **Option 1 (Nortel-1)** is again the baseline where the PSCH and SSCH are transmitted in parallel according to:

PSCH = $\{c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p \ c_p\}$

SSCH = $\{c_s^{i,1} \ c_s^{i,2} \ c_s^{i,3} \ c_s^{i,4} \ c_s^{i,5} \ c_s^{i,6} \ c_s^{i,7} \ c_s^{i,8} \ c_s^{i,9} \ c_s^{i,10} \ c_s^{i,11} \ c_s^{i,12} \ c_s^{i,13} \ c_s^{i,14} \ c_s^{i,15} \ c_s^{i,16}\}$

With this option there are 512 cyclic hierarchical codes $c_s^{i,k}$ (i = 1,...,32, k=1,...,16). The power of the Synchronization Channel can be divided between the PSCH and SSCH in a number of ways but here we will assume that equal power is put into the PSCH and SSCH.

A second possibility, **Option 2 (Nortel-2)**, is to alternate transmission of the PSCH and SSCH in successive slots as in

PSCH = $\{c_p \ \mathbf{0} \ c_p \ \mathbf{0} \ c_p \ \mathbf{0} \ c_p \ \mathbf{0} \ c_p \ \mathbf{0} \ c_p \ \mathbf{0} \ c_p \ \mathbf{0} \ c_p \ \mathbf{0}\}$

SSCH = $\{\mathbf{0} \ c_s^{i,2} \ \mathbf{0} \ c_s^{i,4} \ \mathbf{0} \ c_s^{i,6} \ \mathbf{0} \ c_s^{i,8} \ \mathbf{0} \ c_s^{i,10} \ \mathbf{0} \ c_s^{i,12} \ \mathbf{0} \ c_s^{i,14} \ \mathbf{0} \ c_s^{i,16}\}$

With this option, the power is doubled for each burst transmitted. Only 256 cyclic hierarchical codes are used by taking the sequences from the even numbered slots. A similar scheme could also be arrived at by taking the sequences in the odd numbered slots.

For noncoherent detection of the PSCH and SSCH, the increase in power by alternating transmission of the two channels improves the probability of detection. Diversity is decreased by having fewer burst per frame but the signal-to-noise ratio for each burst improves and this more than compensates for the loss of diversity.

4. Search Strategy

With the Nortel-2 option there are two approachs to the search strategy for the Synchronization Channel.

A *simplified* search strategy can use a search window of 2560 chips as with the current 3GPP scheme. In this strategy, we attempt to acquire the PSCH by correlating at each of the 2560 chip positions within a slot and accumulating energy over successive slots. This strategy reduces the number of positions that must verified but because the Nortel-2 option alternates transmission of the PSCH and SSCH in successive slots, we are adding noise in every second slot (3 dB more noise). This will reduce the hardware slightly but the performance is also reduced by ~2dB for the Nortel-2 option, compared to the *advanced* strategy described later. This strategy also introduces ambiguity as to whether the current slot contains the Primary or the Secondary Synchronization Channel because of the alternation between the two, however, this ambiguity can be removed in the second step by using two hypotheses in the detection process (further details are provided below).

An *advanced* search strategy would use search window 5120 chips for the Nortel-2 option to take into account the alternating transmission between the PSCH and SSCH. This search window maximizes the performance of the Nortel-2 option, giving an improvement of ~2 dB in Step-1 performance relative to the *simplified* search strategy as well as ~0.3 dB improvement in the performance of Step-2 by removing the need to verify two hypotheses in this case.

5. Simulation results and assumptions

5.1. Simulation assumptions

Results are presented below using the **simplified search strategy to allow a simpler comparison between the Nortel-2 option and the current 3GPP synchronization scheme**.

In all cases, noncoherent detection is used for both the PSCH and SSCH.

The PSCH is based on the presently documented scheme (New hierarchical sequences)

5.2. Simulation results with Primary SCH (PSCH) in Step-1

Simulation results are presented in Figures 2 and 3 for Step-1 of the cell search for single path Rayleigh fading with vehicle speeds of 5 km/hr and 60 km/hr, respectively. In this simulation both the PSCH and SSCH are transmitted. In the case of the 3GPP scheme the power of the SCH is evenly divided between the PSCH and SSCH, while for the Nortel-2 option the PSCH and SSCH take the full power of the Synchronization Channel in alternating slots. The simplified search strategy of a 2560 chip search window is used with the Nortel-2 option as with the 3GPP scheme but it can be seen that the two schemes have identical performance. This is due to the fact that the power of the PSCH is doubled but its duty cycle is reduced by half and noise is accumulated in every second slot. The net conclusion is that the Nortel-2 option does not degrade the performance on the first step of the cell search scheme and if we adopt the advanced search stragey we can improve the performance of Step-1 further.

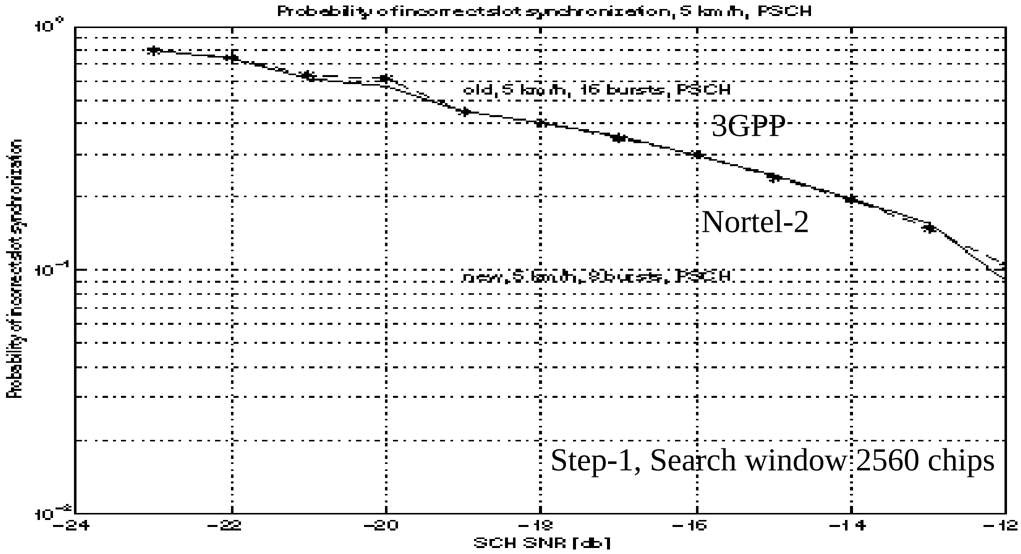


Figure 2: PSCH acquisition in Step 1.
PSC and SSC power on, 10 ms integration for single path Rayleigh fading with a vehicle speed of 5 km/hr.

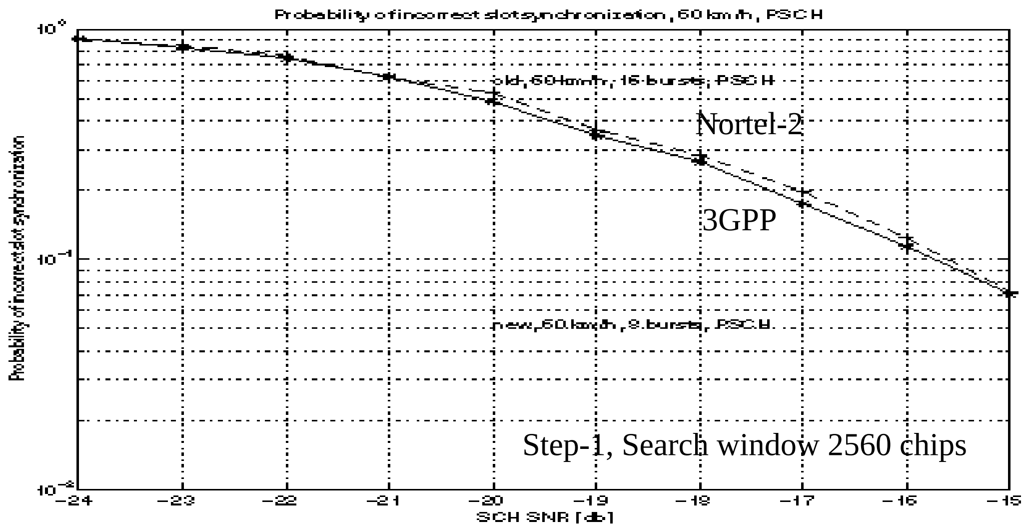


Figure 3: PSCH acquisition in Step 1.
PSC and SSC power on, 10 ms integration for single path Rayleigh fading with a vehicle speed of 60 km/hr.

5.3. Simulation results with Secondary SCH (SSCH) in Step-2

The acquisition performance of the 2nd step were simulated with the assumption that Step-1 was successful (i.e., Step-2 only) but again with power in both the PSCH and SSCH. The number of decision variables is 512 (32 code groups * 16 slot locations) as with the 3GPP scheme but the acquisition of the SSCH for the Nortel- 2 option was simulated using two hypotheses:

H0: acquisition is assumed to start in an odd numbered slot (1, 3,..., 15)

H1: acquisition is assumed to start in an even numbered slot (2, 4..., 16)

We can see from Figures 4 and 5 that the Nortel-2 option gives **1.6-1.9 dB gain** in comparison with the 3GPP scheme.

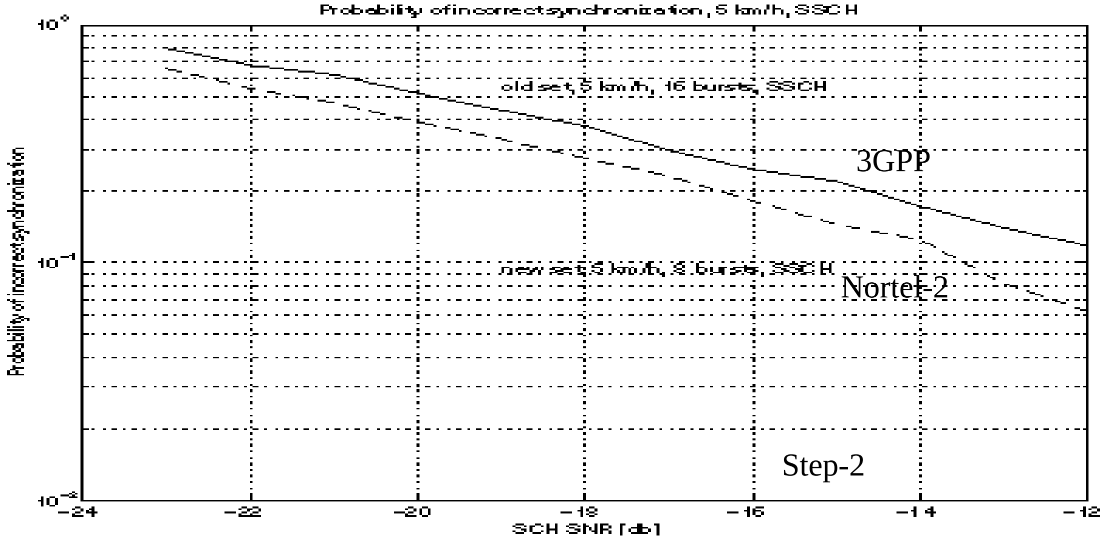


Figure 4: SSCH acquisition Step-2
PSC and SSC power on, 10 ms integration for single path Rayleigh fading
with a vehicle speed of 5 km/hr.

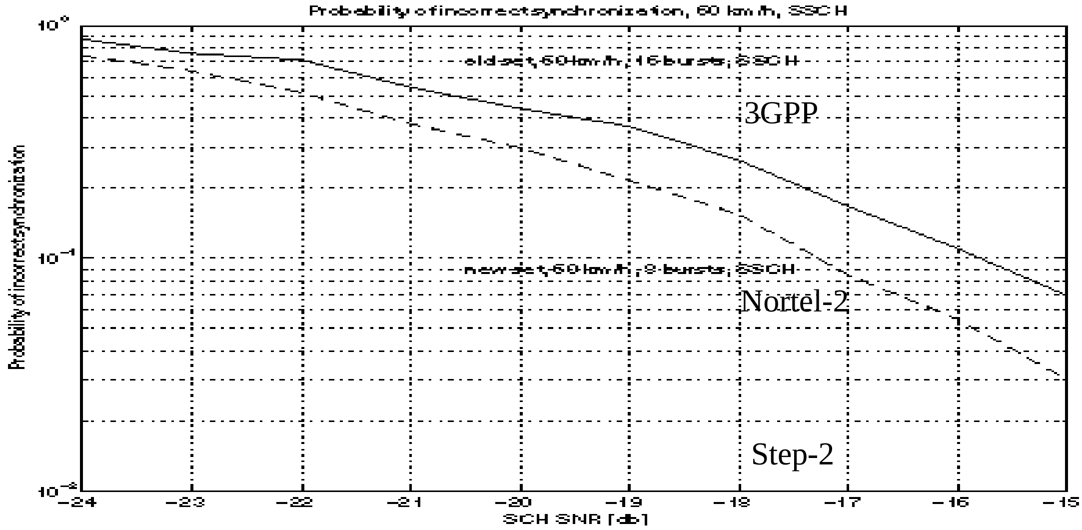


Figure 5: SSCH acquisition in Step-2.PSC and SSC power on, 10 ms integration for single path Rayleigh fading
with a vehicle speed of 60 km/hr.

5.4. Simulation Results With Combined Step-1+Step-2

To better understand the overall performance of the cell search scheme, a set of simulations were performed for the current 3GPP scheme and the Nortel-2 option that combined Steps 1 and 2. The simulation was performed with a 15 ms integration interval for Step-1 and a 5 ms integration interval for Step-2. The channel was again a single path Rayleigh fading channel with a vehicle speed of 60 km/hr. Figure 6 shows a gain in performance for the Nortel-2 option of 1.2-1.5 dB over the 3GPP scheme. This gain reflects approximately the gain of Step-2. Note that further optimization is needed to maximize the gain in the combined performance of Step-1+Step-2.

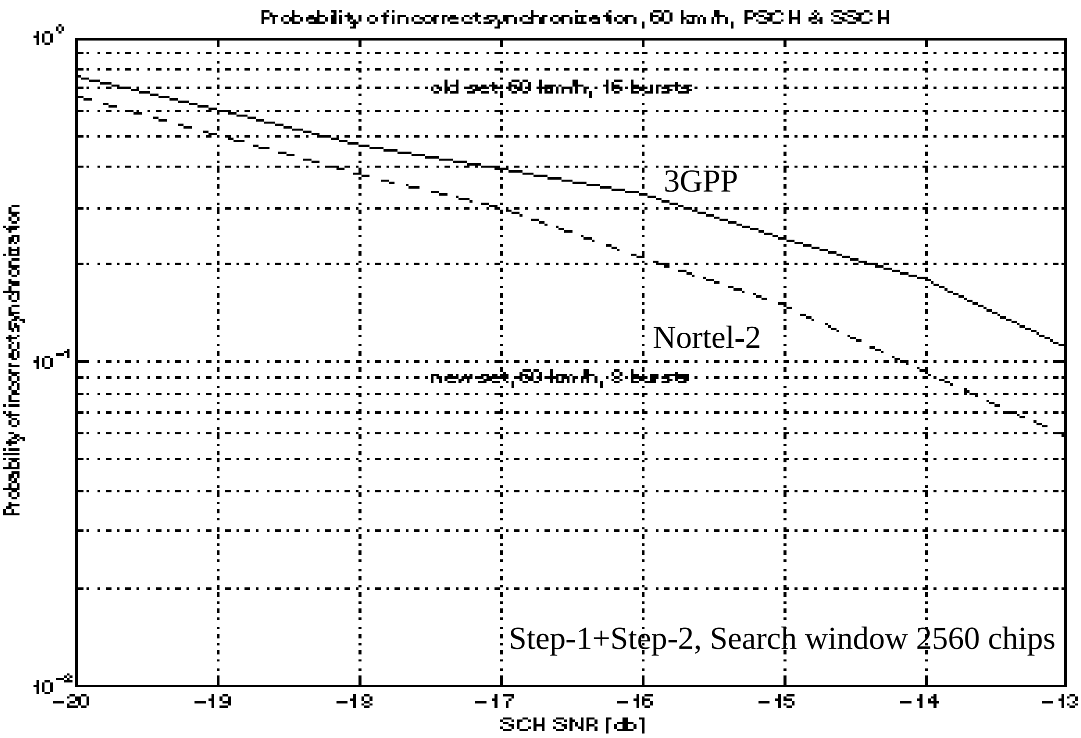


Figure 6: Performance of combined Step-1+Step-2 with single path Rayleigh fading and a vehicle speed of 60 km/h

6. Complexity evaluation

Nortel-2 proposal

The procedure for evaluating of the complexity is similar to the evaluation of the Nortel-1 proposal [ref]

Step-1: (3GPP and Nortel-2 have the same complexity)

- 163840=2560*32*2 complex additions

(32 code groups, 2 samples per chip and 2560 chips/slot)

- 163840*2/625=524 Madds/sec
- 163840*2*16=5,242 880 adds/frame

Step-2:

For 2 hypotheses (2560 chips search window)

- 32*(256+16*8)*16*2=393216 real additions per slot
  (32 code groups, 256=16*16 complex additions to form common variables [3], 16 common variables * 8 decisions, 16 slots * 2 components (I and Q))

For 1 hypotheses (5120 chips search window):

- 32*(256+16*8)*8*2=192608 real additions per slot
  (32 code groups, 256=16*16 complex additions to form common variables [3], 16 common variables * 8 decisions, 8 slots * 2 components (I and Q))

Step 3:

- 40960*16 adds/frame (same as 3GPP)

For initial cell acquisition, the complexity of Step-2 in the Nortel-2 option is approximately 3.5% - 7.5% of the complexity of Step 1. During handoff, if we assume that only 8 code groups need to be searched rather than the full 32 code groups, the computation requirements in Step-2 will be further reduced to approximately 1% - 2% of Step 1. It may be possible to further optimize the computation to reduce the complexity of Step 2.

Memory Requirements (main memory storage)

For a search window of 2560 chips with a 1/2 chip step size and 512 decision variables, the memory requirements for the Nortel-2 and 3GPP schemes are:

Nortel-2: 2560*2+512=5632 memory cells

3GPP: 2560*2+272+512=5904 memory cells.

The additional figure of 272 memory cells in the 3GPP scheme are used for the storage and transformation of 272 correlation values into 512 decision variables. The requirement for these additional memory cells gives the Nortel-2 option a slightly advantage in main storage memory over the 3GPP scheme.

In addition, we would like to add that with our proposal we do not require the Comma Free Table, an FHT, and Hadamard scrambling in the base stations. We would also like to point out that transformation of 272 correlation values into 512 decision variables must occur within a very short period of time after integrating and this will significantly increase the instantaneous computation load of the 3GPP scheme.

Although we have concentrated on a search strategy that is equivalent to the current 3GPP search strategy, other strategies are possible. For example, instead of integrating over multiple slots before selecting the maximum for the PSCH, we might correlate with the PSC over a single slot, select one or more maximums and proceed directly to the SSCH. This would reduce the memory requirements but becomes possible with the Nortel-2 option because the power in the PSCH and SSCH is double what is used with the current 3GPP proposal. Although simulations have yet to be performed, we believe this scheme could be very promising because of the regular, periodic structure of the Synchronization Channel with the Nortel-2 proposal and the new cyclic hierarchical sequences allow the unique identification of the code group/slot location with only one SSC burst. With a high power in each burst, it becomes possible to remove the need for main storage memory to store the 5120 decision variables for the PSCH and 512 for the SSCH. Thus the complexity of implementation might be very small.

7. Conclusions

The advantages of the Nortel-2 proposal have been outlined and the performance of the cell acquisition has been shown to be superior to that of the current 3GPP scheme with non-coherent detection. Although we do not believe that coherent detection is practical, the 3GPP scheme with coherent detection would have the same performance as the Nortel-2 scheme using non-coherent detection.

The search strategy used to perform the simulations is equivalent to that used with the current 3GPP scheme and does not take full advantage of the Nortel-2 option. The results presented can be improved further by using an advanced search strategy with search window of 5120 chips. This would add approximately 2 - 2.5 dB to the 1 - 1.5 dB provided by the Nortel-2 option using the simplified search strategy. On the whole, this would mean that the Nortel-2 option can provide 3 - 4 dB improvement over the existing 3GPP scheme. Better performance could hence be achieved without any need to change the standard as technology evolves and memory cost decreases.

Other search strategies are also possible that exploit the increased power in the PSCH and SSCH obtained by transmitting them in alternating slots. One suggest is to correlate over a single slot, select one or more maximums to detect the position of the PSCH and proceed directly to the SSCH search.

Our scheme is flexible enough so that it can be combined with any of the latest proposals for the PSCH(6) and (7). Initial tests, in the form of output of detector, were done for Golay codes used for the PSCH, Golay or Nortel-2 being used on the SSCH. Results indicated that the same performance is reached with Nortel-2 on the SSCH whatever primary code is used, Golay, or generalised Golay. Additionaly the use of Nortel-2 on the secondary brings performance improvement over Golay codes on the SSCH, Golay codes being used on the secondary for both cases. As a consequence the use of Nortel-2 for the SSCH brings performance improvement over other SSCH, while being compatible with PSCH that allow a complexity decrease, such as (6) and (7).

8. Future Work.

- Investigate the possibility of increasing the number of code groups. This was already mentioned on the reflector (8) and also by Ericsson in (9). 64 code groups can be created for free since only half of the 512 available codes are used. However more code groups can be possibe, since more code elements can be created as mentioned in earlier e-mails.
- Investigate different search strategies that might significantly reduce the complexity and memory requirements of the search. This is however outside the scope of the standard but can be used as example.

9. Recommendations

We recommend that these new cyclic hierarchical sequences be adopted for the Secondary SCH with the Nortel-2 proposal as a base-line for 3GPP.

10. References

[1] 3GPP document S1.11. Transport channels and physical channels (FDD), March 1999

[2] 3GPP document S1.13. Spreading and modulation (FDD). March 1999

[3] Synchronization Channel with cyclic hierarchical sequences", 3GPP RAN WG1 R1-99090, source Nortel Networks, February 1999

[4] "Status of the discussion on Nortel proposal for SSC and possible way forward", 3GPP RAN WG1 R1-99310, source Nortel Networks, March 1999

[5] "Synchronization Channel with cyclic hierarchical sequences and its low complexity detection," 3GPP RAN WG1 R1-99463, source Nortel Networks, April 1999

[6] Generalised Hierarchical Golay sequences for PSC with low complexity correlation using pruned efficient Golay correlators, Siemens, Texas Instruments, R1-99567.

[7] Reduced complexity Primary and secondary synchronisation codes with good aperiodic correlation properties for WCDMA system, R1-99373, Texas Instrument

[8] E-mail From Nortel Networks, on the ad-hoc 12 reflector, May 4th

[9] New downlink scrambling code grouping scheme for UTRA/FDD, Ericsson, R1-99xxx