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Shin Yokohama, Japan

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Agenda Item:

Source: **Nortel Networks**

Title: **Synchronization Channel with cyclic hierarchical sequences and its low complexity detection**

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. Several options are provided for how these cyclic hierarchical sequences might be used on the Secondary SCH.

1. Introduction

In this contribution, we present new results with Synchronization Channel using cyclic hierarchical sequences and Comma Free codes for the Secondary Synchronization Codes (SSCs).

This paper is organized as follows: the next section provides background to the problem. Previous proposals are analyzed and some problems identified. This is followed by a brief description of the Synchronization Channel with cyclic hierarchical sequences and several options are introduced.

Then for the Option-2 (Nortel-2 proposal), simulation results with the Secondary Synchronization Channel (SSCH) and Primary Synchronization Channel (PSCH) are provided. This is followed by an evaluation of the average acquisition time for combined 1st step, 2nd step and 3rd step of the initial cell acquisition.

After that, complexity evaluation is made.

2. Background

3GPP proposal [1,2]

The current proposal for the 3GPP Synchronization Channel (SCH) consists of the two sub channels, the Primary and Secondary SCH [1, 2]. For better reliability, the matched filter output should be non-coherently accumulated over a number of slots (typical accumulation times are 5 and 10 ms). Because of this accumulation procedure, the 3GPP synchronization scheme needs main storage memory (5120 memory cells if a half-chip step size is used for the search) for the acquisition of the Primary SCH.

CPM proposal [3,4]

The new proposed CPM based cell search eliminates the need for a Secondary SCH (and Secondary Search Codes) for signalling the long code group and frame timing information. Such information instead is signaled by the time hopping of the Primary Synchronization Code (PSC). Since the SSC is not transmitted, according to the proposed scheme, the transmitted power of the PSC can be increased, while maintaining the same power allocation for the synchronization channels as in [1]. In [3,4], it was shown that the proposed CPM based cell search scheme outperforms the 3GPP scheme.

From [5], we can see that the performance and computational complexity of the 3GPP scheme and CPM are approximately the same, while the memory requirements of the CPM scheme are less than the 3GPP scheme for a half-chip step size in the searcher. We would like to underline here that the reason CPM has good performance is that it uses only one search code but with double the power.

Nortel Proposal [6]

Previously, we proposed the use of a set of cyclic hierarchical sequences on the Secondary SCH that does not change the slot structure. It was shown that these new cyclic hierarchical sequences have a structure that allows very efficient detection and in many cases improves the cell site acquisition performance (in comparison to the existing 3GPP scheme).

In [6], it was shown that with cyclic hierarchical sequences the complexity of the second step of the initial cell acquisition is approximately 10% of the complexity of the first step (matched filter for the Primary SCH). The complexity of implementation of the new Secondary SCH is low and, depending on the implementation, might be even less than the current 3GPP scheme.

With cyclic hierarchical sequences, the code distance between the decision variables is larger than with the existing comma free scheme. 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 burst* can be used to correctly decode the code group/slot location pair. This is a *very important advantage* of the proposed cyclic hierarchical sequences.

In [7], it was shown that several variations on our base line proposal are possible that might further improve the performance and reduce the complexity. We will describe the different options that are available and provide some results in this contribution

3GPP proposal, coherent detection and handoff problem

We would like to make clear that the current 3GPP acquisition scheme has very serious problems in handoff if *coherent detection* is used. Without going into details too greatly, we provide two references [8],[9] to explain this point.

While introducing Comma Free Codes, it was shown in [8] that non-coherent detection is *much more robust* than coherent detection. It was explained that coherent detection method has problems because “as the primary SCH symbol is common to all base stations, there is a possibility that these symbols from different base stations overlap. The probability of this happening increases during handoff, since the mobile is equidistant from more than one base station. In all such situations, the estimated channel parameters from the primary SCH symbols is clearly incorrect, resulting in severe degradation in synchronization performance when using such an erroneous channel estimate.... Assuming a relative clock drift of about 0.02 ppm between the base stations, it takes about 10 seconds to be out of collision once it occurs. Thus, paradoxically, the collision situation worsens as the base station clock accuracy improves. Also, as the Primary SCH symbols are repeated, due to the clock drift these collisions must occur periodically between base stations.”

In [9] it was confirmed that “the target cell search might fail when the slot timings between the adjacent cells are overlapped within 1 chip. This overlapping problem arises regardless of the detection types - coherent or noncoherent. This problem means that handover is not supported and the ongoing calls drop.... The problem gets more serious because the current algorithm adopts the coherent detection.”

We can conclude that coherent detection might create problems for the cell acquisition process and it is necessary to do more research to justify coherent detection in the 3GPP scheme.

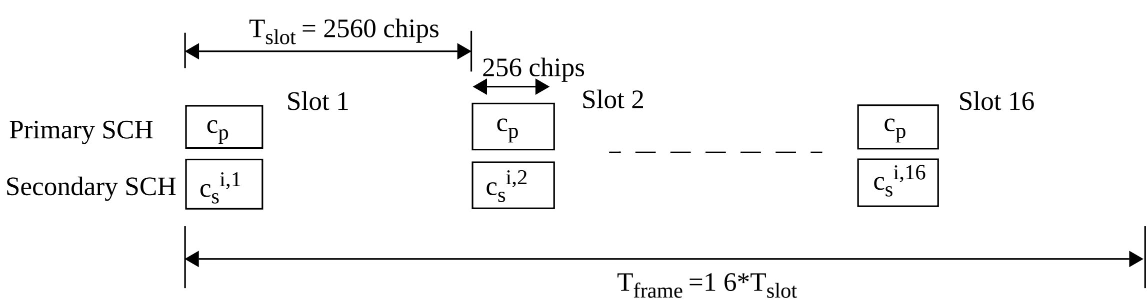
3. Brief description of SCH with cyclic hierarchical sequences and some possible options

The previous base-line proposal (described as Nortel-1 later in this contribution) for the Synchronization Channel with cyclic hierarchical sequences was introduced in [6]. In the following section, we briefly review this proposal and in section 3.2 we will provide a number of important options to the base-line.

Before beginning, we would like to point out that the key to the 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.

3.1. Synchronization Channel

The SCH, consisting of two subchannels: the Primary and Secondary SCH, is 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 1. 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:

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

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 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. (Please see contribution R1-99090 for details of forming the cyclic hierarchical sequences).

Several important options can be derived from the base-line proposal.

3.2. Base line options of Nortel proposal with cyclic hierarchical sequences

We introduce a power profile (PP) for the Primary SCH (PSCH) and the Secondary SCH (SSCH) to describe the various available options. In this power profile, we have assumed the same average power for each frame and that the power is equally divided between PSCH and SSCH. Unequal divisions of power between the PSCH and SSCH are also possible.

Option 1 (Nortel-1) is the base line proposal as described in R1-99090 [6] by Nortel

PP_PSCH=$\{\mathbf{0.5}_1\ \mathbf{0.5}_2\ \mathbf{0.5}_3\ \mathbf{0.5}_4\ \mathbf{0.5}_5\ \mathbf{0.5}_6\ \mathbf{0.5}_7\ \mathbf{0.5}_8\ \mathbf{0.5}_9\ \mathbf{0.5}_{10}\ \mathbf{0.5}_{11}\ \mathbf{0.5}_{12}\ \mathbf{0.5}_{13}\ \mathbf{0.5}_{14}\ \mathbf{0.5}_{15}\ \mathbf{0.5}_{16}\}$

PP_SSCH=$\{\mathbf{0.5}_1\ \mathbf{0.5}_2\ \mathbf{0.5}_3\ \mathbf{0.5}_4\ \mathbf{0.5}_5\ \mathbf{0.5}_6\ \mathbf{0.5}_7\ \mathbf{0.5}_8\ \mathbf{0.5}_9\ \mathbf{0.5}_{10}\ \mathbf{0.5}_{11}\ \mathbf{0.5}_{12}\ \mathbf{0.5}_{13}\ \mathbf{0.5}_{14}\ \mathbf{0.5}_{15}\ \mathbf{0.5}_{16}\}$

This option uses the base-line proposal of [6] where all 512 cyclic hierarchical codes used. In this option, power is divided equally between Primary SCH and Secondary SCH. The performance has been shown to be better than the 3GPP proposal in a single path fading channel.

Option 2 (Nortel-2), as suggested in [7]

PP_PSCH=$\{\mathbf{1.0}_1\ 0.0_2\ \mathbf{1.0}_3\ 0.0_4\ \mathbf{1.0}_5\ 0.0_6\ \mathbf{1.0}_7\ 0.0_8\ \mathbf{1.0}_9\ 0.0_{10}\ \mathbf{1.0}_{11}\ 0.0_{12}\ \mathbf{1.0}_{13}\ 0.0_{14}\ \mathbf{1.0}_{15}\ 0.0_{16}\}$

PP_SSCH=$\{0.0_1\ \mathbf{1.0}_2\ 0.0_3\ \mathbf{1.0}_4\ 0.0_5\ \mathbf{1.0}_6\ 0.0_7\ \mathbf{1.0}_8\ 0.0_9\ \mathbf{1.0}_{10}\ 0.0_{11}\ \mathbf{1.0}_{12}\ 0.0_{13}\ \mathbf{1.0}_{14}\ 0.0_{15}\ \mathbf{1.0}_{16}\}$

The power is doubled for each burst transmitted with 8 bursts in the PSCH and 8 bursts in the SSCH transmitted in alternating slots. Only 256 cyclic hierarchical codes are used. Some performance results for this option will be presented later in this contribution using non-coherent detection and the 3GPP cell search strategy. It should be noted that the CPM cell search strategy could also be used and might help to reduce the complexity further.

Option 3 (Nortel-3)

PP_PSCH={$\mathbf{1.0}_1$ 0.0_2 $\mathbf{1.0}_3$ 0.0_4 $\mathbf{1.0}_5$ 0.0_6 $\mathbf{1.0}_7$ 0.0_8 $\mathbf{1.0}_9$ 0.0_{10} $\mathbf{1.0}_{11}$ 0.0_{12} $\mathbf{1.0}_{13}$ 0.0_{14} $\mathbf{1.0}_{15}$ 0.0_{16}}

PP_SSCH={$\mathbf{1.0}_1$ 0.0_2 $\mathbf{1.0}_3$ 0.0_4 $\mathbf{1.0}_5$ 0.0_6 $\mathbf{1.0}_7$ 0.0_8 $\mathbf{1.0}_9$ 0.0_{10} $\mathbf{1.0}_{11}$ 0.0_{12} $\mathbf{1.0}_{13}$ 0.0_{14} $\mathbf{1.0}_{15}$ 0.0_{16}}

For this option, the power for each burst is doubled and 8 bursts are transmitted for each of the PSCH and SSCH, time-aligned in the same slots. This method requires 256 cyclic hierarchical codes for the code family.

Option 4 (Nortel-4)

PP_PSCH={$\mathbf{2.0}_1$ 0.0_2 0.0_3 0.0_4 $\mathbf{2.0}_5$ 0.0_6 0.0_7 0.0_8 $\mathbf{2.0}_9$ 0.0_{10} 0.0_{11} 0.0_{12} $\mathbf{2.0}_{13}$ 0.0_{14} 0.0_{15} 0.0_{16}}

PP_SSCH={0.0_1 0.0_2 $\mathbf{2.0}_3$ 0.0_4 0.0_5 0.0_6 $\mathbf{2.0}_7$ 0.0_8 0.0_9 0.0_{10} $\mathbf{2.0}_{11}$ 0.0_{12} 0.0_{13} 0.0_{14} $\mathbf{2.0}_{15}$ 0.0_{16}}

The power is quadrupled in each slot with 4 bursts per frame in each of the PSCH and SSCH, alternating in every second slot. Only 128 cyclic hierarchical codes are used for the code family. The high power in each burst may be an issue for the PA (power amplifier) but we do not perceive it to be a significant problem.

With a high power in each burst, it becomes possible to take one or several maximums to detect the PSCH and SSCH and thus 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.

In all the above options, equal distribution of power between the PSCH and the SSCH has been considered but unequal distributions are possible. Further simulation is necessary to see how the power should be divided between the two channels while maintaining a fixed average power per frame.

4. Simulation results

In this section, simulation results are presented for the Secondary SCH and Primary SCH separately for the Nortel-2 option. Results are given for an AWGN and single path Rayleigh fading with vehicle speeds of 5 km/h, 60 km/h and 250 km/h.

4.1. Simulation results with Secondary SCH (SSCH)

A set of simulations were performed for the 3GPP Comma Free scheme and the Nortel 2 option using non-coherent detection. To simulate the Secondary SCH, it was assumed that Step 1 was successful in identifying the slot (1 or 16 possibilities) with the slot number chosen as a uniform random number. The acquisition of the SSC 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)

With the Nortel-2 approach, the number of SSC codes is reduced to 256 and as a result the complexity of the second step is reduced by a factor of 2 times in comparison with the base-line Nortel-1 proposal.

The results of the simulations are summarized in Figures 2 - 9 for the following test cases:

- Figure 2, AWGN, 5 ms integration
- Figure 3, AWGN, 10 ms integration
- Figure 4, 5 km/h, 5 ms integration
- Figure 5, 5 km/h, 10 ms integration
- Figure 6, 60 km/h, 5 ms integration
- Figure 7, 60 km/h, 10 ms integration
- Figure 8, 250 km/h, 5 ms integration
- Figure 9, 250 km/h, 10 ms integration

The results indicated that with the new set of cyclic hierarchical sequences we have a gain of **1.6 - 1.9 dB** compared with the old set of Comma Free codes (R-S codes). This will be the overall gain for the system if the results of the first step are the same for the two approaches. However, the gain can be increased if the first step of the cell search is made more accurate. If coherent detection were performed with the 3GPP scheme, it will have approximately the same performance as the Nortel-2 scheme (non-coherent detection) but with higher complexity as a larger number of bits are required for the multiplications in the coherent detection process. At the same time, the remarks in Section 2 indicate that *coherent detection might be not feasible* in a *real* system.

One further point to note is that the Nortel-2 proposal will require fewer bits to represent the 512 decision variables (two hypothesis, H0 and H1, each with 256 codes to check). This means that each memory cell for the decision variables will be less complex.

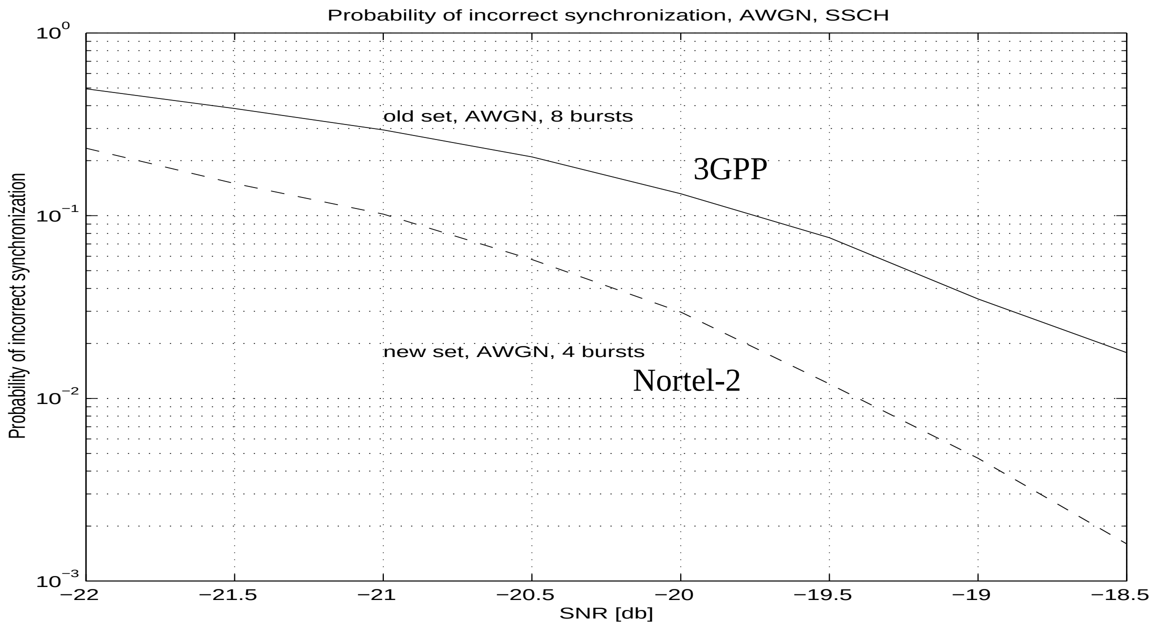


Figure 2: AWGN, 5 ms integration

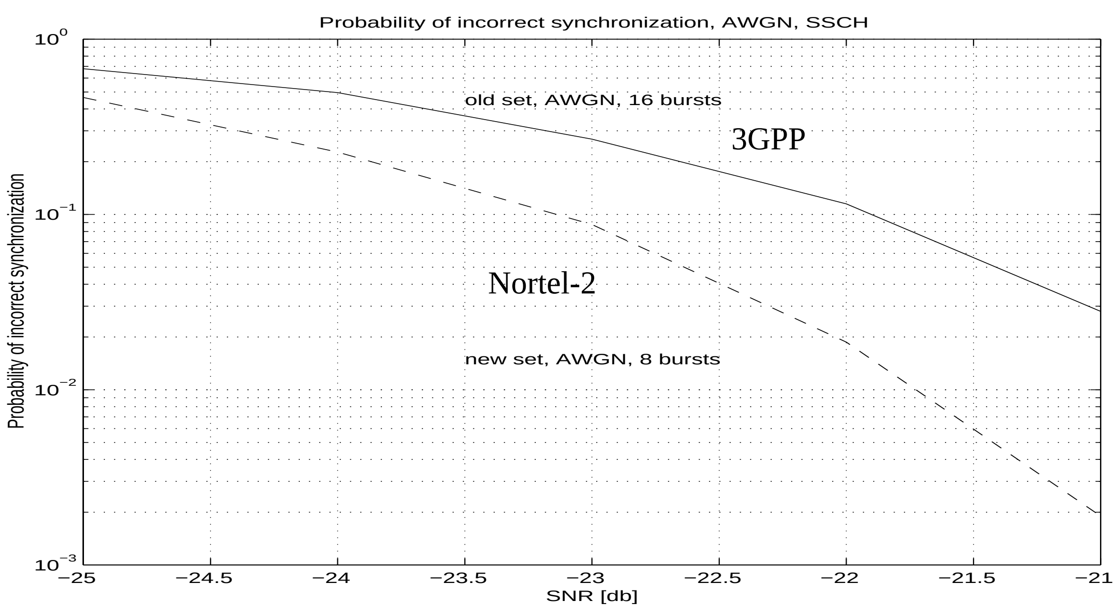


Figure 3: AWGN, 10 ms integration

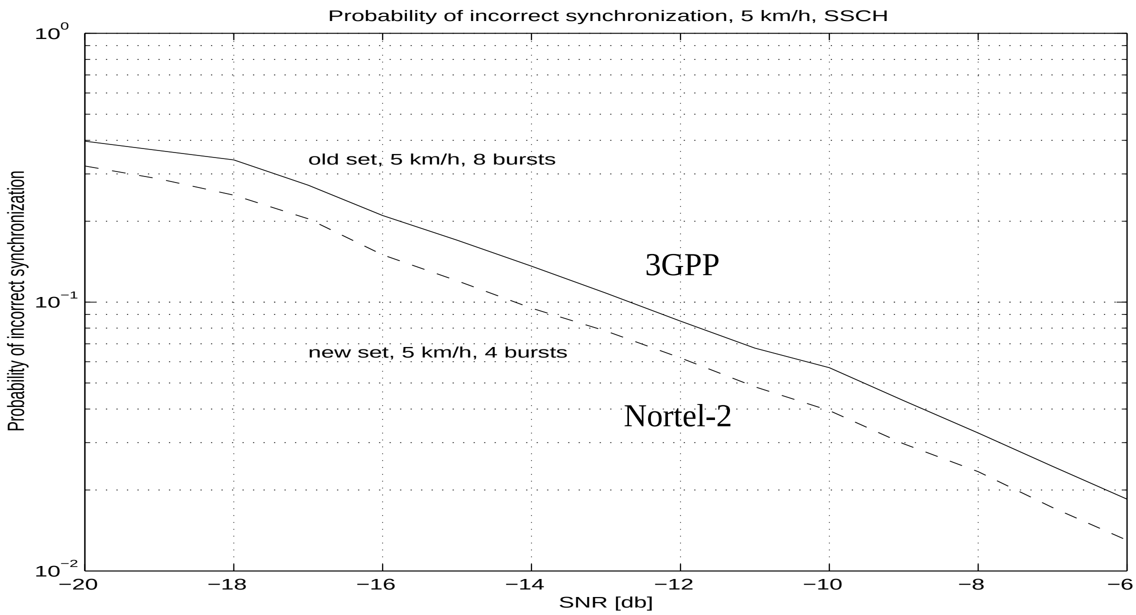


Figure 4: 5km/h, 5 ms integration

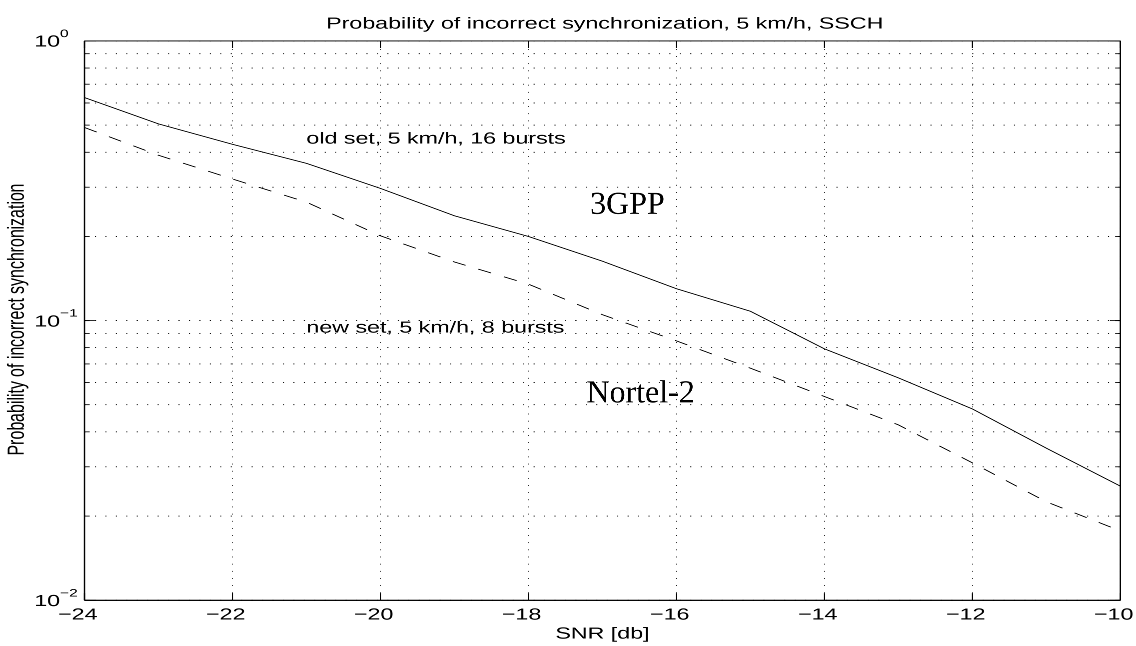


Figure 5: 5 km/h, 10 ms integration

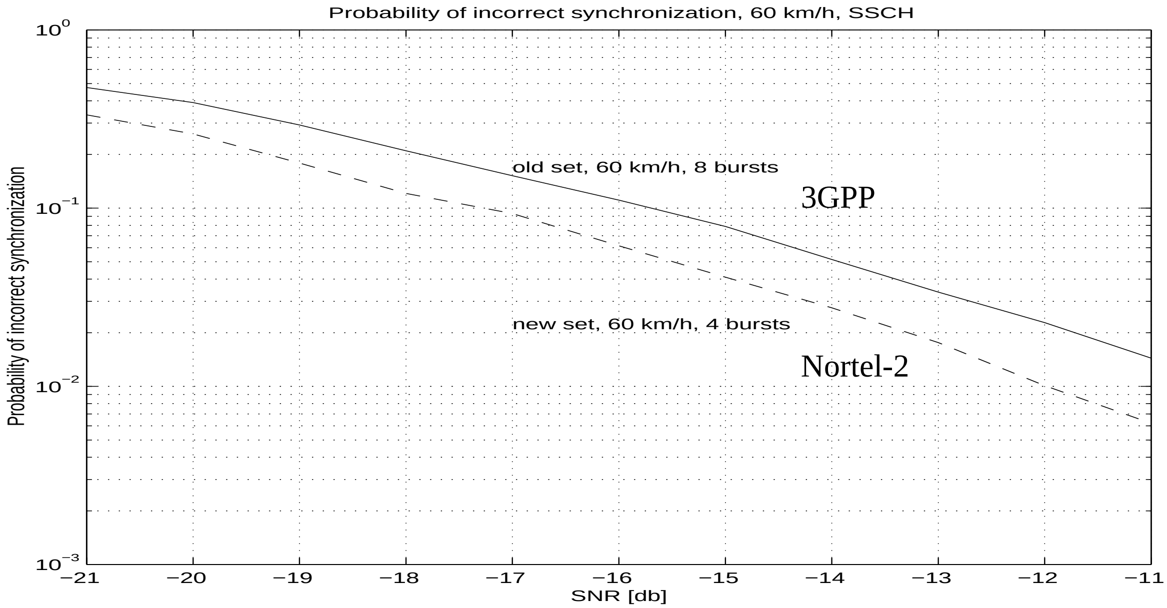


Figure 6: 60 km/h, 5 ms integration

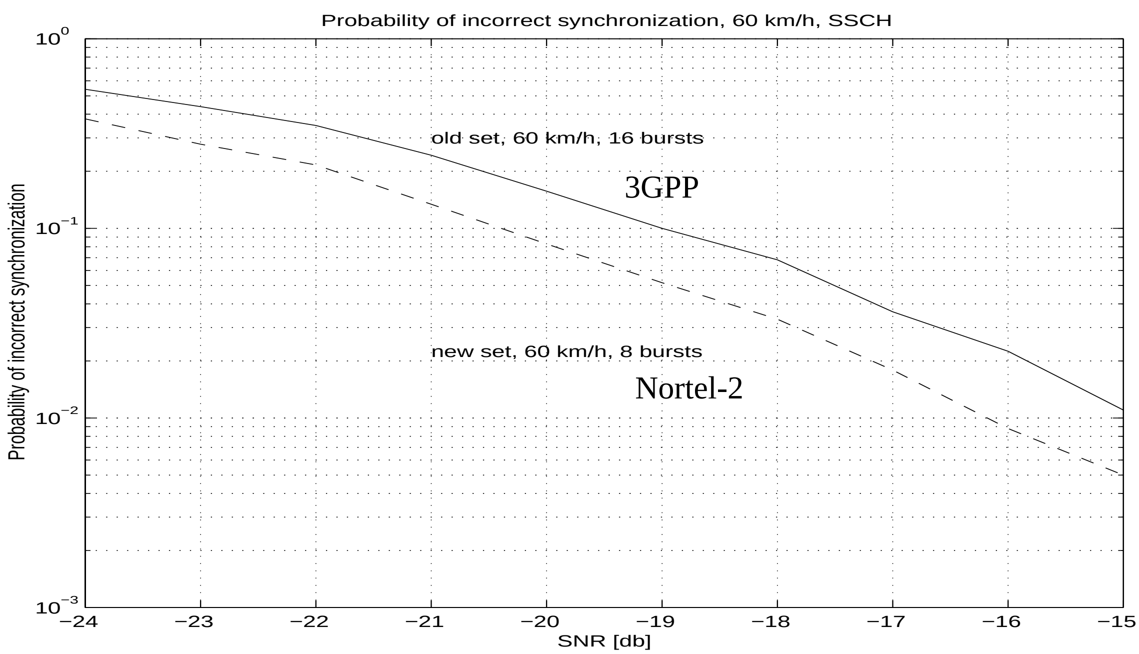


Figure 7: 60 km/h, 10 ms integration

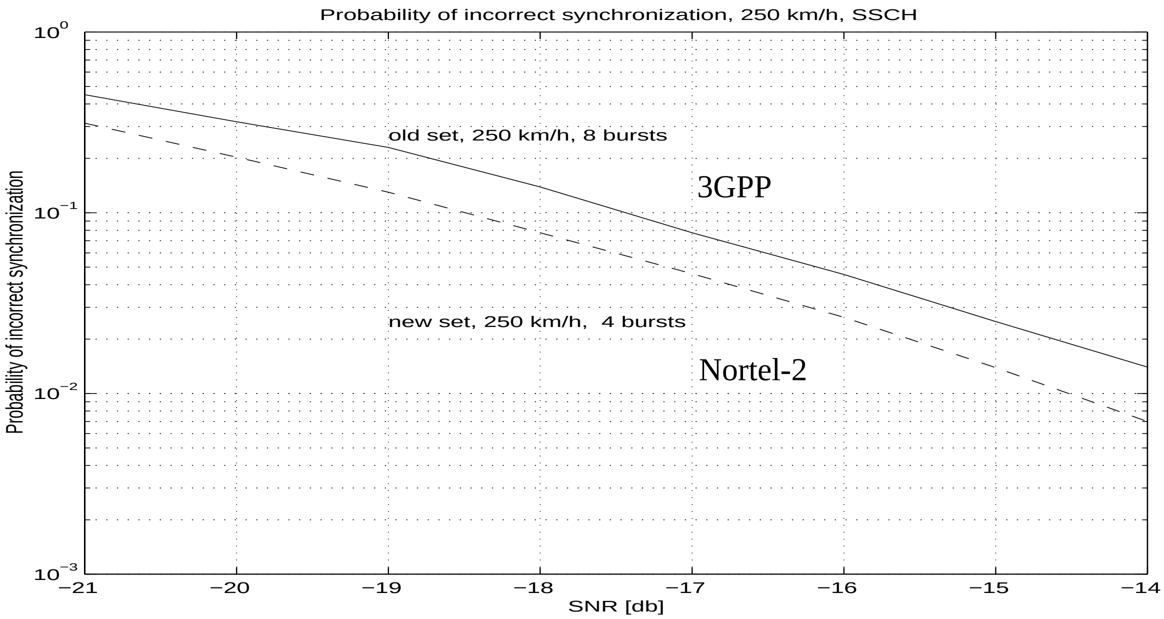


Figure 8: 250 km/h, 5 ms integration

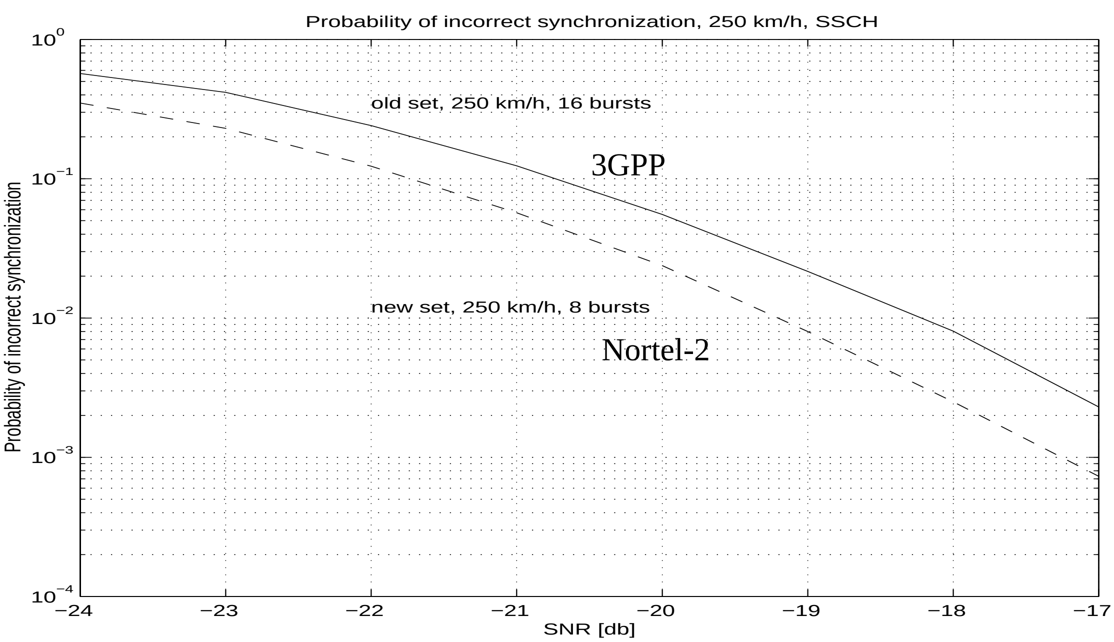


Figure 9: 250 km/h, 10 ms integration

4.2. Simulation results with Primary SCH (PSCH)

For the slot acquisition, the same uncertainty region of 2560 chips was assumed as with the 3GPP scheme to save memory in the first step. This allows a simpler comparison between with the 3GPP scheme but puts the Nortel-2 proposal at a slight disadvantage.

Simulation results with the PSCH are shown in Figures 10 and 11 with the old approach when 16 burst are used in PSCH and the new approach when 8 burst are used in PSCH (double power). The integration time is 10 ms and speed 5 km/h and 60 km/h are used. Both results show the performance to be the same for PSCH with the present proposal and the Nortel-2 proposal.

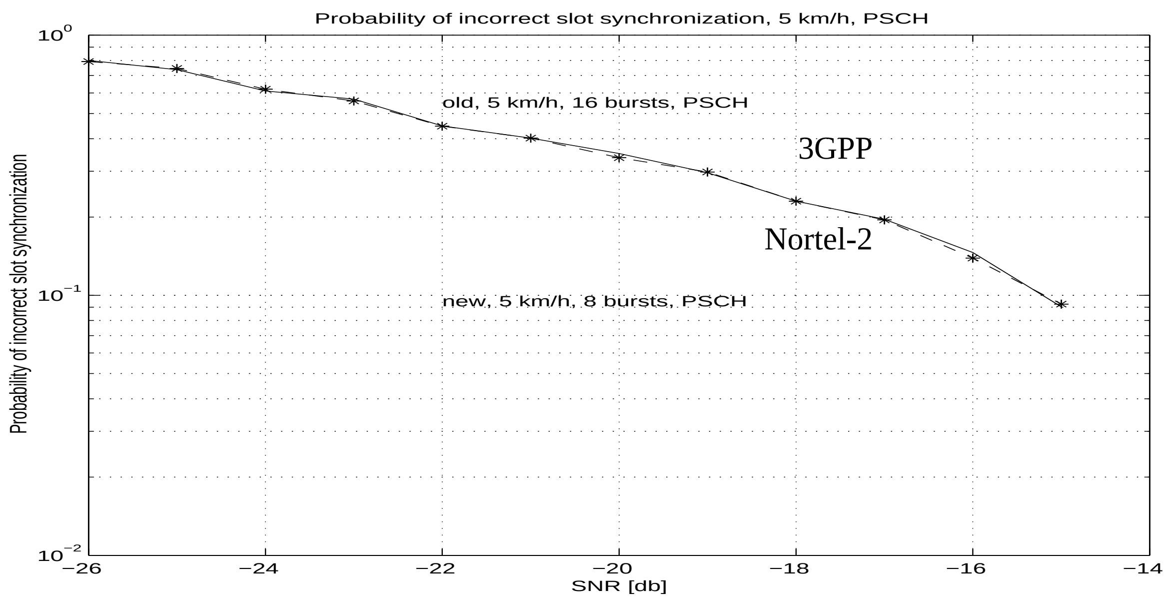


Figure 10: PSCH, 5 km/h, 10 ms integration

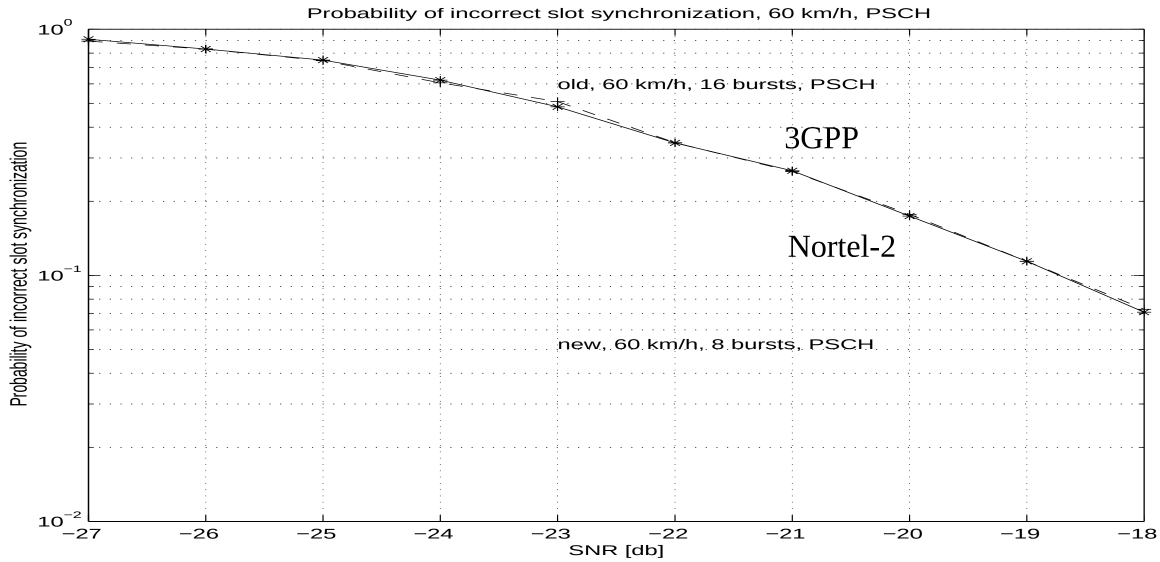


Figure 11: PSCH, 60 km/h, 10 ms integration

5. Evaluation of average acquisition time

Using the results of the simulations for the SSCH and PSCH, we can evaluate the average acquisition time for 5 km/h and 60 km/h. The integration time of the PSCH is 10 ms, for the SSCH it is 10 ms and the integration time of 3^{rd} step is 5 ms. The power is evenly split between the Primary SCH and Secondary SCH. (The results for the SSCH are redrawn in Figures 12 and 13 to cover a sufficiently low signal-to-noise ratio.)

Results for the average acquisition time are shown in Figures 14 and 15. The **advantage** of the Nortel-2 proposal is clear over the 3GPP scheme. Despite differences in fading rate (Doppler frequency), the results for the 3GPP scheme are comparable to those given in [10].

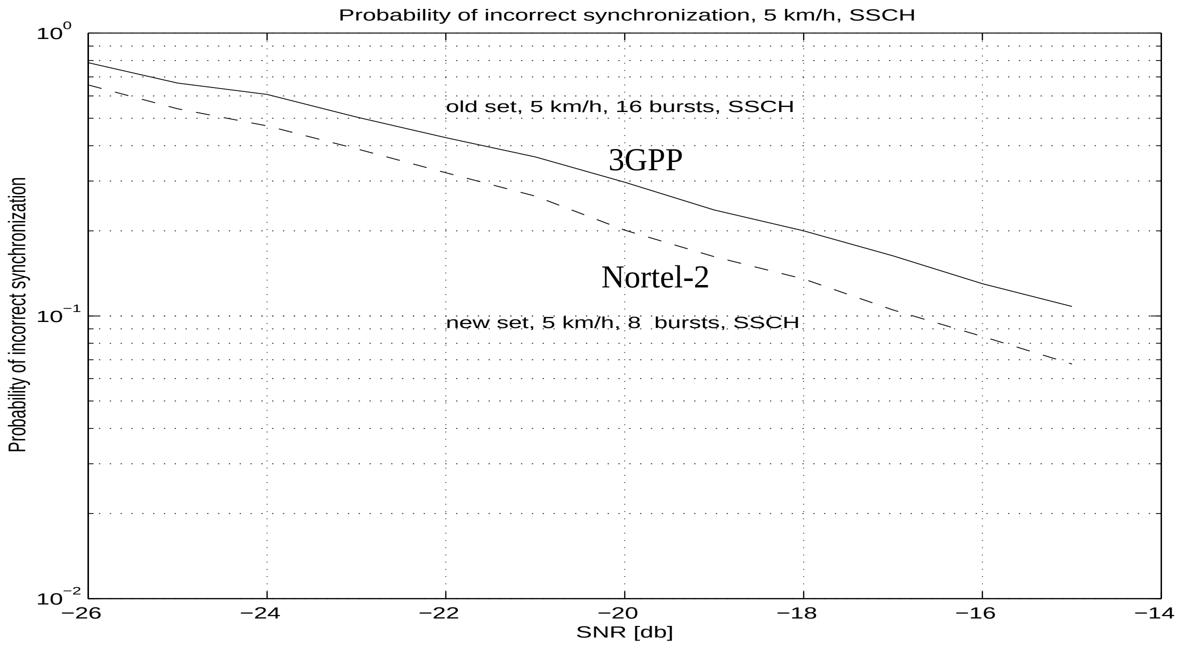


Figure 12: SSCH, 5 km/h, 10 ms integration

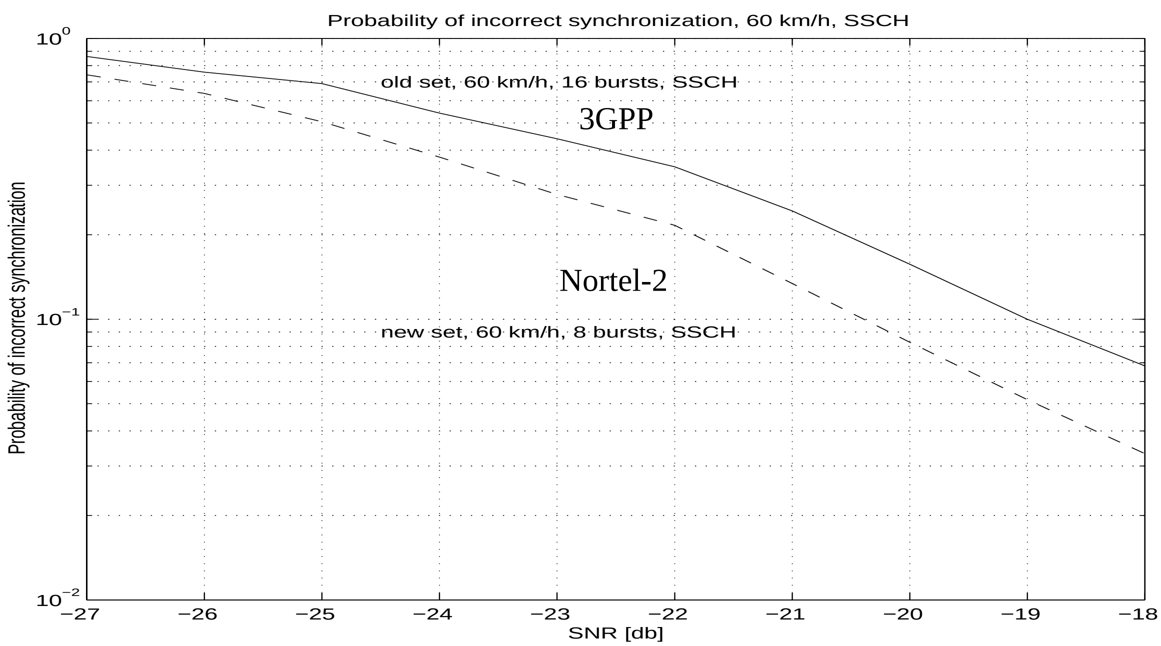


Figure 13: SSCH, 60 km/h, 10 ms integration

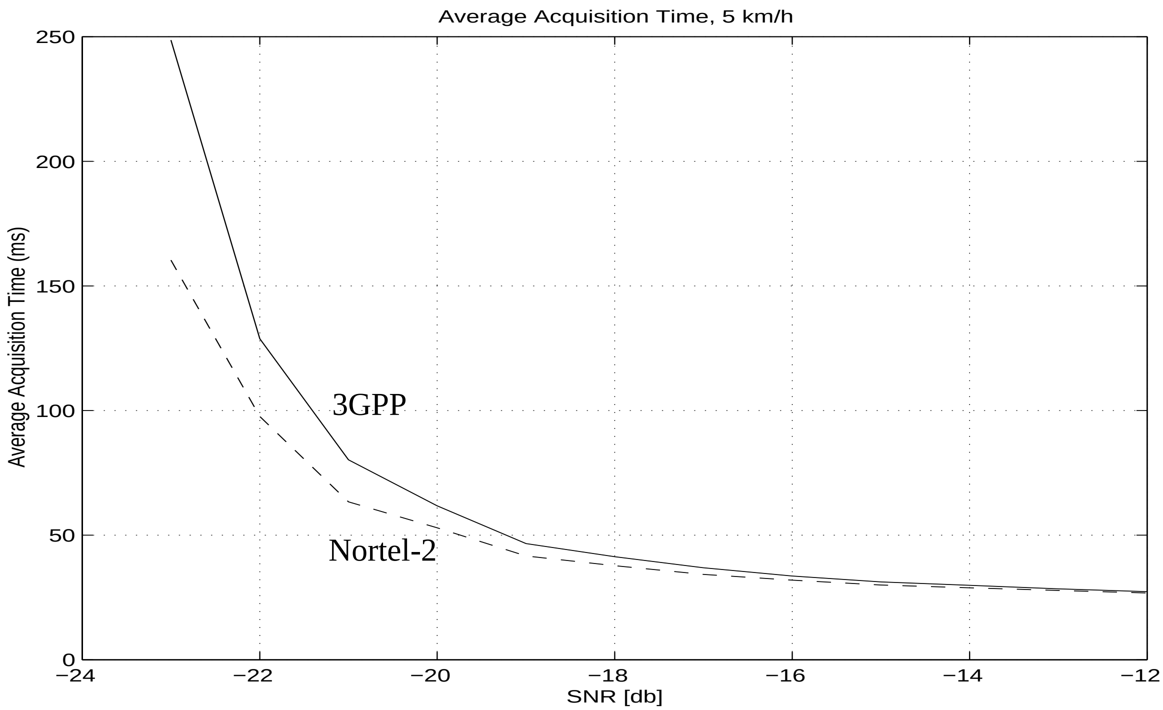


Figure 14: Average acquisition time, 5 km/h,

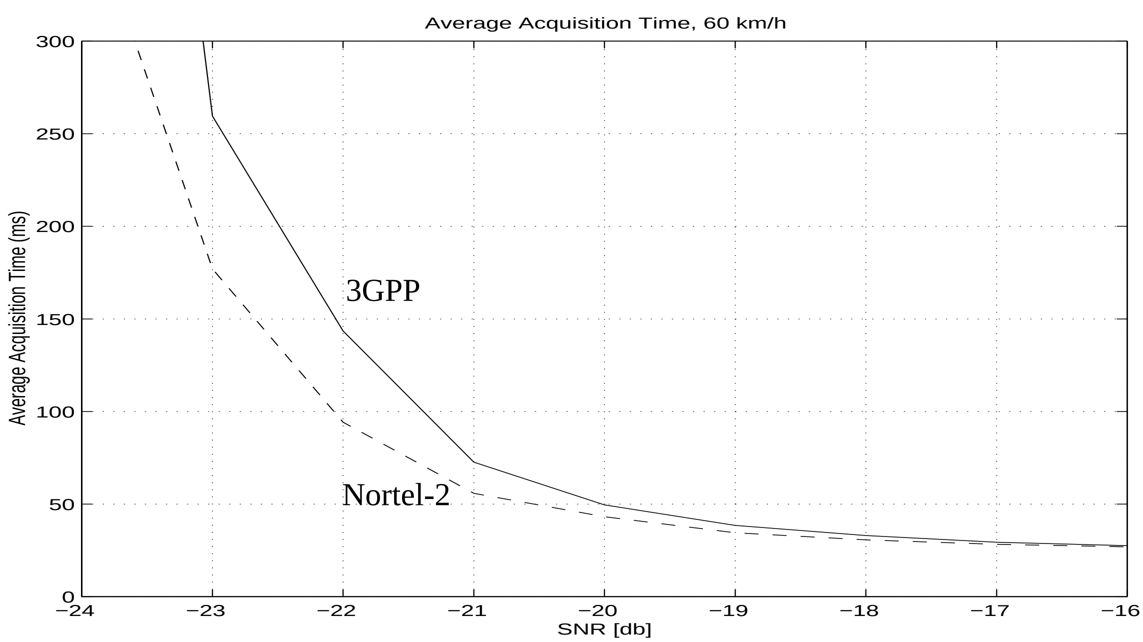


Figure 15: Average acquisition time, 60 km/h

6. Complexity evaluation

To analyze the complexity, we follow the method previously used in [6].

Nortel-1 proposal

Complexity of operations (computation power)

- Step 1: (same complexity for the 3GPP scheme)
  - 163840 complex additions per slot
  - 163840*2/625= 524 Madds/sec
  - 163840*2*16=5,242,880 adds/frame
- Step 2:
  - 16384 complex additions per slot (for 32 code group)
  - 16384*2/625= 52.5 Madds/sec
  - 16384*2*16=524,288 adds/frame
- Step 3:
  - 40960*16 adds/frame (same as 3GPP)

As we can see, the complexity of Step 2 is 10% of the complexity of Step 1 for initial cell acquisition with the Nortel-1 proposal. During handoff if we assume that 8 code groups will be verified, the computation requirements for the Step 2 will be further reduced and represent only 2.5% of Step 1 complexity.

We see that computation requirements in the Step 2 are *modest* when compared to Step 1. Later we will show that the computation requirements for the Nortel-2 proposal are further reduced compared to Step 1.

Memory Requirement (main memory storage)

Nortel-1: 2560*2+512 = 5632 memory cells

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

Nortel-2 proposal

The procedure for evaluating the complexity is similar to the evaluation of the Nortel-1 proposal.

Complexity of operations (computation power)

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

  - 163840 complex additions per slot

  - 163840*2/625= 524 Madds/sec

  - 163840*2*16=5,242,880 adds/frame

- Step 2: (2 times less the number operations than Nortel-1 proposal)

  - 8192 complex additions per slot (for 32 code group)

  - 8192*2/625= 26.2 Madds/sec

  - 8192*2*16=262144 adds/frame

- Step 3:

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

With the reduction in the number of codes, the complexity of Step 2 is half the value of the Nortel-1 proposal. For initial cell acquisition, it is now 5% of the complexity of Step 1. During handoff, if we assume that 8 code groups will be verified, the computation requirements in Step 2 will be further reduced to only 1.25% of Step 1. It may be possible to further optimize the computation to reduce the complexity of Step 2 below 1% of the complexity of Step 1.

We see that the computation requirements for Step-2 are very modest.

Memory Requirements (main memory storage)

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

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

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 the 3GPP scheme requires the storage and transformation of 272 correlation values into 512 decision variables within a very short period of time after integrating and this will significantly increase the instantaneous computation load of the 3GPP scheme. Thus we can conclude that the Nortel-2 proposal, using the 3GPP search strategy, *has less complexity* than the current 3GPP scheme.

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.

If a search strategy similar to that of CPM is followed of selecting one of several maximums to detect the PSCH and proceeding directly to the SSCH, then the complexity of the Nortel-2 proposal can be further reduced. This search strategy is possible because the power in the PSCH and SSCH has been doubled in comparison with the 3GPP and Nortel-1 proposals. Although simulations have yet to be performed, we expect that this scheme will perform better than CPM because of the regular, periodic structure of the Synchronization Channel with the Nortel-2 proposal and the new cyclic hierarchical sequences allow the *code group/slot location* with only one Secondary Synchronization Code burst.

It clear that with the Nortel-3 and Nortel-4 proposals the complexity of the cell search can be further reduced and the performance can be further increased because the number of SSCs is 128 and power of the PSCH and SSCH bursts are quadrupled.

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 results can be improved further by following a similar approach to that in the CPM scheme of selecting one of several maximums to detect the PSCH and proceeding directly to the detection of the SSCH. This would eliminate the need for memory to store the decision variables for the PSCH and the SSCH.

8. 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.

9. References

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

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[5] “Comparison of the 3GPP and CPM Schemes,” 3GPP TSG-RAN WG1 R1-99328, Texas Instruments

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