3GPP TSG RAN WG1#16 R1-00-1181

Pusan / Korea
October 10th - 13th, 2000

Agenda Item: **AH30**

Source: **Mitsubishi Electric**

Title: **Sequences for the Node B synchronisation burst**

Document for: **Discussion**

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1 Summary

For Node B synchronisation via air interface in TDD, Gold codes of length 2047 chip have recently been proposed as synchronisation sequence [1]. Gold codes exhibit very good periodic auto-correlation properties, which remain approximately valid in the aperiodic case for not too big shifts away from the main correlation peak. However, other choices for the synchronisation sequence are possible in the particular context of Node B synchronisation via air interface.

This document proposes to build the synchronisation sequence from **C**oncatenated, e.g. time-multiplexed, and periodically **E**xtended **C**omplementary pairs. CEC-sequences for Node B synchronisation would offer the following advantages:

?? A perfect channel estimation window, e.g. no auto-correlation side lobes at all around the main correlation peak in a window of adjustable size, whilst still exhibiting excellent auto-correlation properties for the overall aperiodic auto-correlation function of the CEC-sequence.

?? Reduced computational complexity due to the existence of low complexity receiver structures for polyphase complementary pairs.

Section 2 of this document gives a short summary on the underlying constraints for the choice of the synchronisation sequence for Node B synchronisation via air interface. Section 3 explains the construction of the proposed CEC-sequences and corresponding receiver structures. Finally, section 5 makes a comparison of the correlation complexity for CEC-sequences and Gold codes.

2 Introduction

Node B synchronisation via air interface is based upon infrequent transmissions of synchronisation sequences in PRACH timeslots. Nothing else but the synchronisation sequence is allowed to be transmitted in these reserved PRACH timeslots. Typically, any given Node B would itself transmit one of these special synchronisation sequences every 10-20 sec and receive around once per second such a synchronisation sequence. Node B's receiving these synchronisation sequences from the neighbouring Node B's, can perform timing offset measurements which in turn are reported back to the RNC and from which clock corrections are derived. For Node B synchronisation via the air interface, 2 scenarios with respect to the timing uncertainty must be considered:

- Initial synchronisation: Node B's are coarsely time-aligned with a precision in the order of several radio frames by signalling from the RNC [2]. This situation occurs prior to "normal" network operation. The uncertainty period of where to find the synchronisation sequence is thus in the order of several radio frames.
- Tracking: once all Node B's in a neighbourhood have been time-aligned, the maximum clock drift that neighbouring Node B's will experience is in the order of several us, e.g. a search window of around 10 ?s is sufficient [1].

The synchronisation sequence in the reserved PRACH timeslot can have a length of up to 2400 chips, taking into account an extended guard period of (96+64)=160 chips. The high processing gain of the synchronisation sequence together with the possibility of maximum transmit power (due to the absence of any other simultaneous DPCH transmission) allow an additional path loss compensation of around 16dB [3].

For assuring inter-operability even in uncoordinated TDD deployment scenarios, at least 4 different synchronisation sequences must be specified for the purpose of Node B synchronisation [1].

The synchronisation sequence should have good aperiodic auto-correlation properties, especially for small shifts around its main correlation peak, as this region is mainly concerned in the tracking scenario. Furthermore, it should possess very good aperiodic cross-correlation properties with the other possible synchronisation sequences in the system. Also, the computational complexity necessary for the offline correlation being done in the Node B in both initial synchronisation and tracking scenarios should be as low as possible for a low cost implementation on general purpose DSP.

3 Concatenated periodically extended complementary sequences

3.1 Complementary sequences

The proposed synchronisation sequences are based on the application of Golay complementary pairs. The major property of such a pair of complementary sequences is that the sum of their aperiodic auto-correlation function is a perfect Dirac-function, e.g. zero for all non-zero time shifts. Thus, when $[s(n), g(n)]$ designate such a pair of complementary sequences and $[?_{s,s}(m), ?_{g,g}(m)]$ their respective aperiodic auto-correlation functions,

$$?_{s,s}(m) ? ?_{g,g}(m) ? ?(m)$$

Golay complementary pairs of particular length $N ? 2^{?}$ with arbitrary $? ? 0$ are a special binary case of more general polyphase complementary pairs which can be derived by a recursive relationship [6]. An efficient matched-filter implementation, e.g. the Enhanced Golay Correlator (EGC) is known for polyphase complementary pairs, which performs the simultaneous correlation of $[s(n), g(n)]$ with the received signal. The related complexity for length N sequences is $\log_2(N)$ multiplications and $2 ? \log_2(N)$ additions [6], while for a straightforward FIR-filter implementation for correlation with an arbitrary length N sequence it would be $N ? 1$ multiplications and additions.

For the special binary case of Golay complementary sequences, the EGC-implementation can be further simplified, as the particular weights which are used to derive the Golay complementary pairs are either 1 or –1 and thus multiplications with the complex-conjugated weights reduce to simple sign inversions. Therefore, no multiplications need actually to be executed any more.

3.2 Construction of the synchronisation sequence

The construction principle of the synchronisation sequence $e(n)$ for Node B synchronisation in TDD is shown in Figure 3-1. Each of the sequences $[s(n), g(n)]$ from the Golay complementary pair of length $N ? 2^{?}$ chips is cyclically extended to $[s_{ext}(n), g_{ext}(n)]$ respectively of length $N ? 2 ? K$ chips. The overall synchronisation sequence $e(n)$ is then simply a serial concatenation of these cyclically extended complementary sequences $s_{ext}(n)$ and $g_{ext}(n)$. The first transmitted chip of the sequence $e(n)$ is $s_{N ? K ? 1}$.

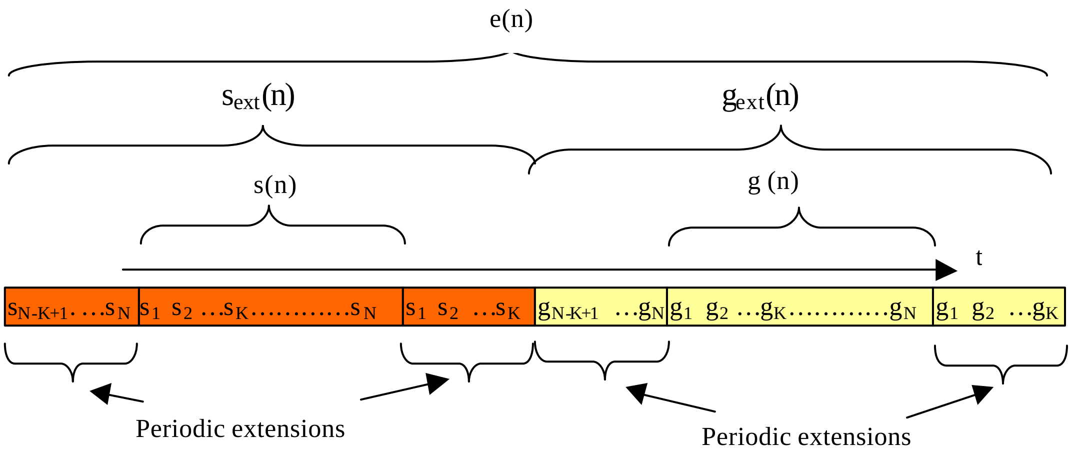

Figure 3-1: Construction principle for the synchronisation sequence e(n)

3.3 Receiver structure

Instead of a simple correlation with the overall synchronisation sequence $e(n)$, the receiver

(1) correlates the received signal with a local replica of $s(n)$,

(2) correlates the received signal at a $N + 2 \cdot K$ chip offset with a local replica of $g(n)$,

(3) adds the matched-filter outputs from (1) and (2) in order to compute the auto-correlation sum

Step (1) and (2) are efficiently implemented by EGC's. The resulting auto-correlation sum from step (3) exhibits a maximum correlation peak of 2N at zero time offset and has no secondary peaks inside the interval $n \in [-K, K]$. The auto-correlation sum inside this interval is a Dirac.

4 Correlation properties

In the particular context of Node B synchronisation, a good choice for the length of the Golay complementary sequences is $N = 1024$ chips. For $K = 25$ chip as length of the cyclic extensions and $N = 1024$ chip as length of the Golay complementary sequences, an auto- correlation sum as displayed in Figures 4-1 and 4-2 is typically obtained. Figure 4-1 and 4-2 also show a typical aperiodic auto-correlation for Gold codes.

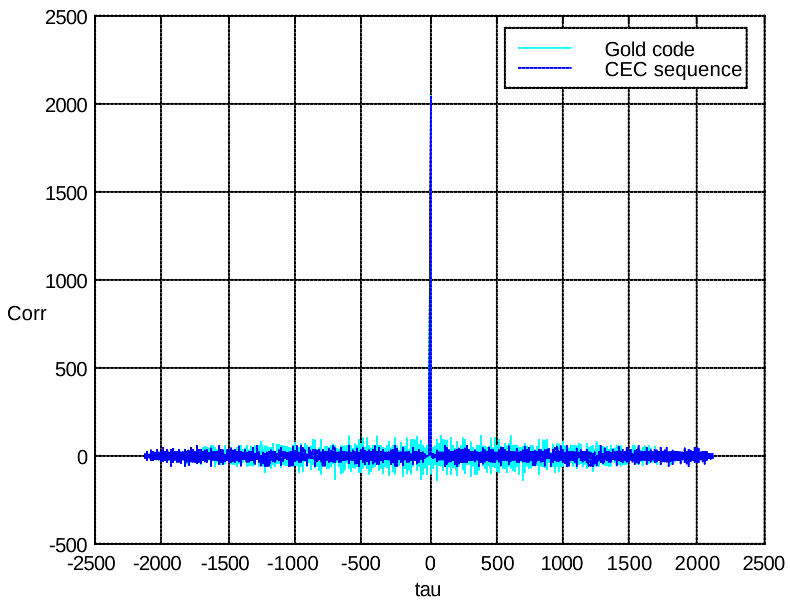

Figure 4-1: Aperiodic auto-correlation properties for CEC- and Gold sequences

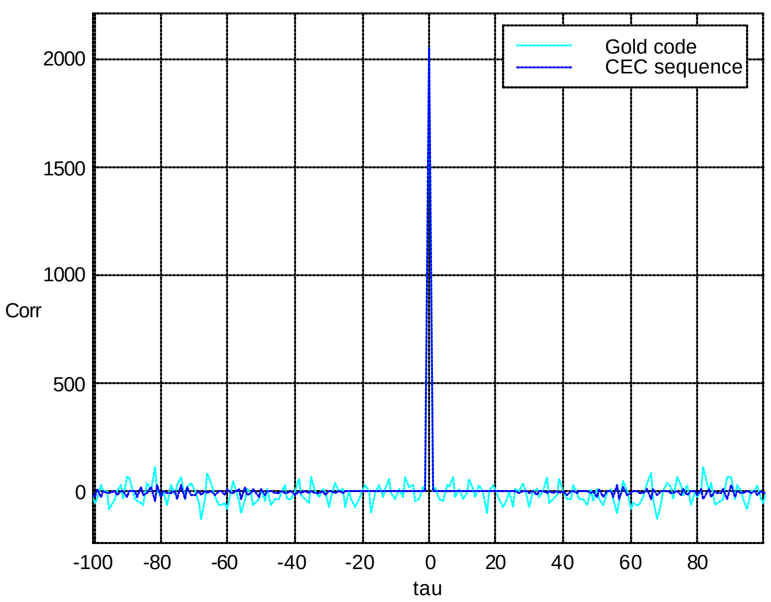

Figure 4-2: Aperiodic auto-correlation properties for CEC- and Gold sequences: zoom

Table 4-1 compares maximum-peak-to-side correlation (MAS) values and root-mean-square (RMS) values for both CEC- and Gold sequences. The values for the CEC-sequences are obtained for a Golay complementary pair as derived by the recursive relationship given in [6] with weight vector **W**=[W_1 W_2 … W_{10}]=[1 -1 1 1 -1 -1 -1 -1 -1 -1] and permutation vector **P**=[P_1 P_2 … P_{10}] =[9 0 8 1 7 2 6 3 5 4] for $N ? 2^{10} ? 1024$ and $K ? 25$. The Gold codes are derived from octal generators [4005] and [7335]. Among the 2049 Gold codes that can built with this generators, the one with the lowest MAS has been selected for the comparison.

	MAS	RMS
Gold sequence	-25.8 dB	32.2
CEC sequence	-30.0 dB	19.2

Table 4-1: Comparison of aperiodic auto-correlation properties for CEC- and Gold sequences

It can easily be seen, that CEC-sequences represent a very attractive choice as synchronisation sequences. Their aperiodic auto-correlation sum is zero inside an interval of adjustable size, which is the ideal case for the tracking scenario, where the approximate timing is known and has only to be searched for in a limited uncertainty period. The interval size, e.g. the choice of the parameter K therefore depends from the maximum expected clock derivation in the tracking scenario described earlier in section 2.

Furthermore, the overall aperiodic auto-correlation properties remain excellent even for time shifts larger than just this limited window, e.g. they are slightly better or at least equal to the Gold codes proposed in [1]. The latter property is important for the initial synchronisation scenario described earlier in section 2.

Because more than but one sequence is needed for synchronisation purposes, it is interesting to compare the aperiodic cross-correlations for given pairs of CEC-sequences and Gold codes. Table 4-2 compares maximum peak (MP) values and root-mean-square (RMS) values. For the same settings of N and K as above, the pair of CEC-sequences has been derived with weight vectors $\mathbf{W_1}$ = [1 -1 1 1 -1 -1 -1 -1 -1 -1], $\mathbf{W_2}$ = [1 1 1 1 1 1 -1 -1 1 -1] and permutation vectors $\mathbf{P_1}$=[9 0 8 1 7 2 6 3 5 4], $\mathbf{P_2}$=[1 4 3 2 8 5 7 9 0 6] respectively.

	MP	RMS
Gold sequences	119	31.9
CEC sequences	112	32.0

Table 4-2: Comparison of aperiodic cross-correlation properties for pairs of CEC- and Gold sequences

It seems obvious that pairs of CEC-sequences can be found which have aperiodic cross-correlation properties equal or actually better than those obtained for Gold codes.

5 Receiver complexity

As stated earlier in section 2, the Node B synchronisation problem has 2 aspects, the initial sync and the tracking. The first one leads to a correlation over a long period (5 frames) while the second needs only a few tens of correlation points. This implies that different receiver structures would be used for these 2 cases. Therefore, when comparing the receiver complexities, it is necessary to treat separately thes e 2 cases.

5.1 Initial synchronisation

Prior to the initial Node B synchronisation on the air, the Node B is coarsely synchronised by higher layer signalling with a timing uncertainty of +/- 25 ms, then on the air synchronisation is used to reduce this uncertainty below 5 us. Hence, during its initial sync, the node B has to correlate the received signal with its local replica over a period of 50 ms (192000 chips). Typical computational complexities are derived hereafter for both Gold and CEC sequences for an over sampling ratio of 2 and assuming an optimised FFT-based correlation for the Gold codes and an EGC-based one for the CEC sequences.

Gold codes

Due to the size of the correlation window, the correlation is advantageously processed by a bank of FFT's in overlap save mode. The 50ms correlation is processed through 188 overlapping 4096-bit FFT's followed by 188 times 4096 complex multiplications and 188 overlapping 4096-bit IFFTs. Based on the well known FFT complexity the number of complex operations necessary for each initial synchronisation procedure is obtained as follows (M = 2047 is the code length and N=4096 the FFT size):

Number of complex multiplications = 188 * [2 * (N/2)log2(N) + N]
= 10 010 624

Number of complex additions = 188 * [2 * Nlog2(N) + M-1]
= 18 865 800

CEC sequences

Thanks to the Golay codes structure of CEC sequences, the correlation steps (1) and (2) can be processed by 1 EGC activated during 192000 + N2 + 2K chips and a 192000 + N2 + 2K chips sum, which leads to the following complexity (N2 = 1024 is the length of the Golay codes and K=25 the size of the periodic extensions used to build the CEC sequence):

Number of complex multiplications = (192000 + N2 + 2*K) * 2 * [log2(N2)]
= 3 861 480

In the EGC, for the specific case of binary signal, multiplications are replaced by simple sign inversion, which means that the number of complex multiplications is in fact 0.

Number of complex additions = (192000 + N2 + 2*K) * 2 * [2 * log2(N2)] + (192000 + N2 + 2*K)*2
= 8 109 108

	Complex Adds	Complex mults
Gold sequences	18 865 800	10 010 624
CEC sequences	8 109 108	0

Table 5-1: Comparison of initial synchronisation complexities for CEC- and Gold sequences

5.2 Tracking synchronisation

For the tracking, due to the small number of correlation points to process, the respective correlations will be typically FIR-based for Gold codes and EGC-based for the CEC sequences. Assuming a maximum uncertainty of +/- 5 us [7] the synchronising node B must correlate its local replica with the received synchronisation sequence over a period of 10 us, i.e. 38 chips which leads to the respective computational complexities detailed hereafter.

Gold codes

Since the correlator is a simple FIR filter of length 2047 which is activated over 38 correlation points with an over sampling ratio of 2 , the complexity is simply:

Number of complex multiplications = 38 * 2 * M
= 155 572

Number of complex additions = 38 * 2 * M
= 155 572

CEC sequences

The same receiver structure as for the initial synchronisation could be used with 1 EGC activated for 38 + N2 +2K = 1112 correlation points but since N2+2K >> 38, it is far more efficient to use 2 EGC's activated for 38 correlation points each with a time delay of N2+2K chips to process respectively the steps (1) and (2) of the receiver:

Number of complex multiplications = 38 * 2 * 2 * log2 (N2)
= 1520

Number of complex additions = 38 * 2 * 2 * [2 * log2(N2)] + 38 * 2
= 3116

In the FIR and in the EGC, for the specific case of binary signal, multiplications are simplified to simple sign inversions, which means that the number of complex multiplications is in fact 0.

	Complex Adds	Complex mults
Gold sequences	155572	0
CEC sequences	3114	0

Table 5-2 Comparison of tracking synchronisation complexities for CEC- and Gold sequences

6 Conclusion

A new set of synchronisation sequences and a new correlation process are proposed for inclusion in UTRA/TDD node B synchronisation. The benefits of this proposal are:

? ? The new sequences provide perfect correlation within an analysis window which can be scaled to cover all the tracking synchronisation window.

? ? The new sequences exhibit very good auto-correlation properties outside of the previously mentioned analysis window. Its MAS is at least 4 dB lower than that of the best Gold code derived from octal generators [4005] and [7335].

? ? The new sequences allow the use of very efficient correlation methods, measured in terms of the number of complex multiplications and additions required.

? ? There are 3.7E9 available CEC sequences among which it will be easy to find some more optimised cross-correlation properties if needed.

References:

[1] R1-00-0946, "Sequences for the Cell Sync burst", Siemens

[2] R1-00-0074, "Node B Synchronisation for TDD", Siemens

[3] R1-99-g42, "Synchronisation of Node B's in TDD via Selected PRACH timeslots", Siemens

[4] R1-99-0205, "New RACH preambles with low auto-correlation side-lobes and reduced detector complexity", Ericsson

[5] M.J.E.Golay, " Complementary Series", IRE Trans. on Information Theory, Vol.IT-7, pp.82-87, April 1961

[6] S.Z.Budisin, "Efficient pulse compressor for Golay complementary sequences", Electronics Letters, Vol.27, No.3, pp.219-220, Jan. 1991.

[7] R1-00-0472, "Accuracy Requirements for Node B Synchronisation", Interdigital