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Title: Modulated Length 2 and Length 4 CFC with Greater Minimum Distance

Source: Texas Instruments and InterDigital Communications Corp.

It was shown that, BPSK Modulated Secondary Synchronization Codes (SSC's) for the second step of cell search procedure are better suited to UTRA TDD cell search rather than RS(16,3) Comma Free Codes (CFC's) that are proposed for UTRA FDD [1]. In [2], Length 2 and Length 4 CFC's were introduced and shown that they can be optimized for UTRA TDD. In [3], A QPSK based Modulated SSC's were proposed. In this document we give the comparison results of the QPSK Modulated SSC algorithm and the Length 2,4 CFC algorithm.We also propose to merge the desirable properties of both the algorithms to produce a better algorithm in terms of performance and complexity for the UTRA TDD.

The new proposal also addresses the GSM handover requirement which is not supported by the current working assumption.

Length 2 and Length 4 CFC's proposed in [2]:

In [2], the Length 2 CFC's of the form $\pm\{(s_i+s_j), (s_i-s_j)\}/sqrt(2)$ and $\pm j\{(s_i+s_j), (s_i-s_j)\}/sqrt(2)$ were proposed. These codes had a minimum distance of 1 over 1 slot. To obtain the Length 4 CFC's a length 2 CFC of the form $\{(s_i+s_j), (s_i-s_j)\}/sqrt(2)$ or $j\{(s_i+s_j), (s_i-s_j)\}/sqrt(2)$ was transmitted in the even frames and its negative in the odd frames. The cyclic shift of the CFC encodes both the slot position information and frame numbering (cf. [2]).

QPSK Modulated SSC method:

In this method, the SSC's are QPSK modulated. The QPSK modulation carries the following information:

- The code group that the base station belongs to (5 bits; Cases 1,2,3)
- The position of the frame within an interleaving period of 20 mesec (1 bits, Cases 1,2,3)
- The position of the slot within the frame (1 bit, Cases 2,3)
- The location of the primary CCCH (3 bits, Case 3)

The secondary synchronization codes are partitioned into four (possibly overlapping) code sets – code_set_1, code_set_2, code_set_3, code_set_4. The set used provides the following information:

Code Set	Code Group
1	0-7
2	8-15
3	16-23
4	24-31

The secondary codes may be transmitted either by the I channel or by the Q channel. The selection of I/Q provides an additional bit of informaiton which can be used for frame timing.

Performance:

In this section we compare the performance of the Old CFC method and the QPSK modulated SSC method. We can see from the figures that the performances of both schemes is comparable for the 7bit case and the Old CFC method performs a little better for the 10bit case.

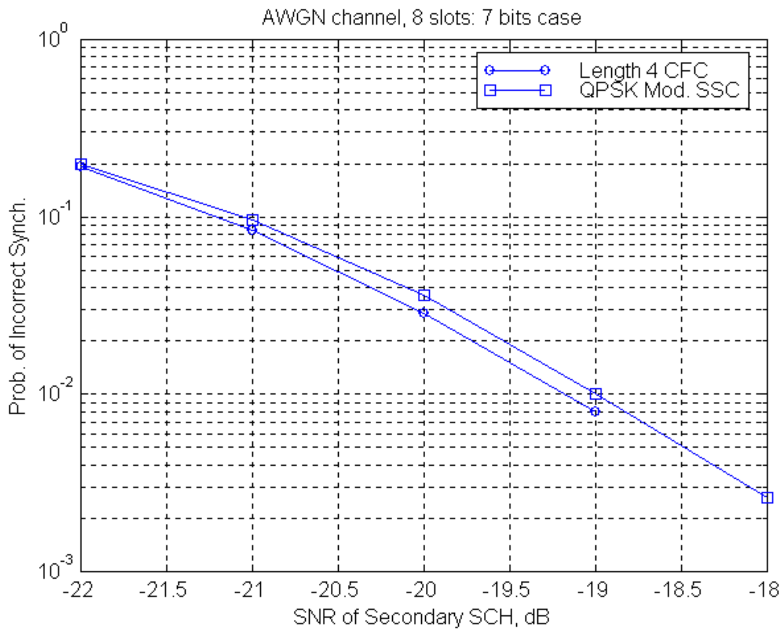

Figure 1. Performance of the CFC codes proposed in [2] as compared to the modulated QPSK method, 7 bit case, AWGN channel

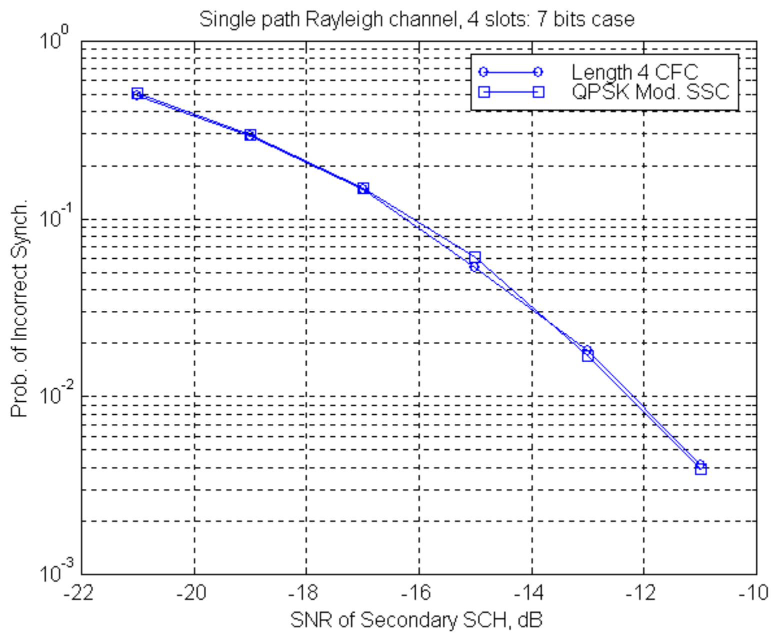

Figure 2. QPSK modulated SSC vs. CFC codes proposed in [2], Rayleigh channel, 10 bit case

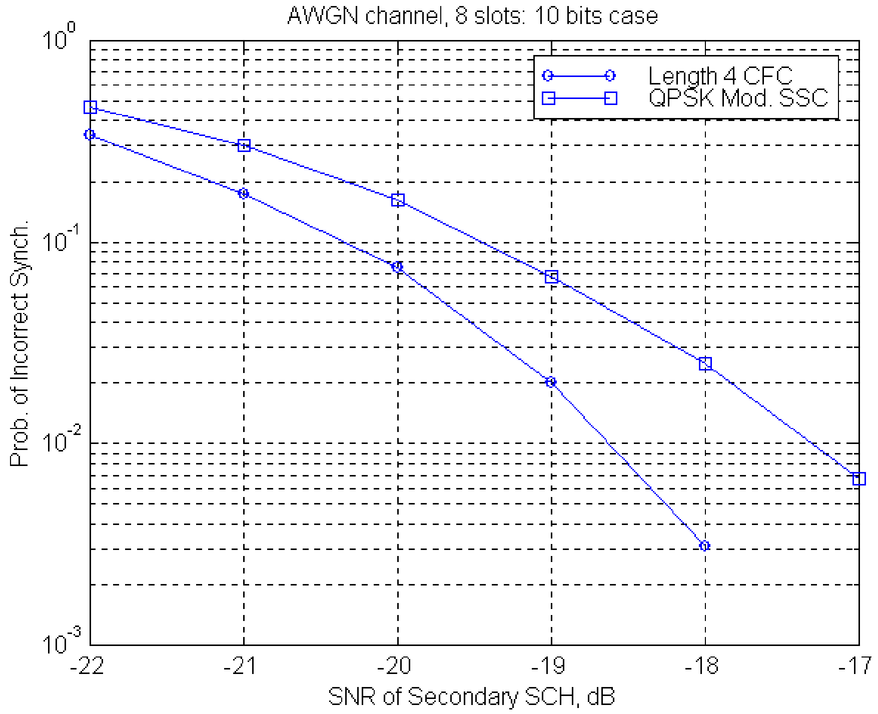

Figure 3. Performance of CFC codes proposed in [2] vs. QPSK modulated SSC method, 10 bit case, AWGN channel

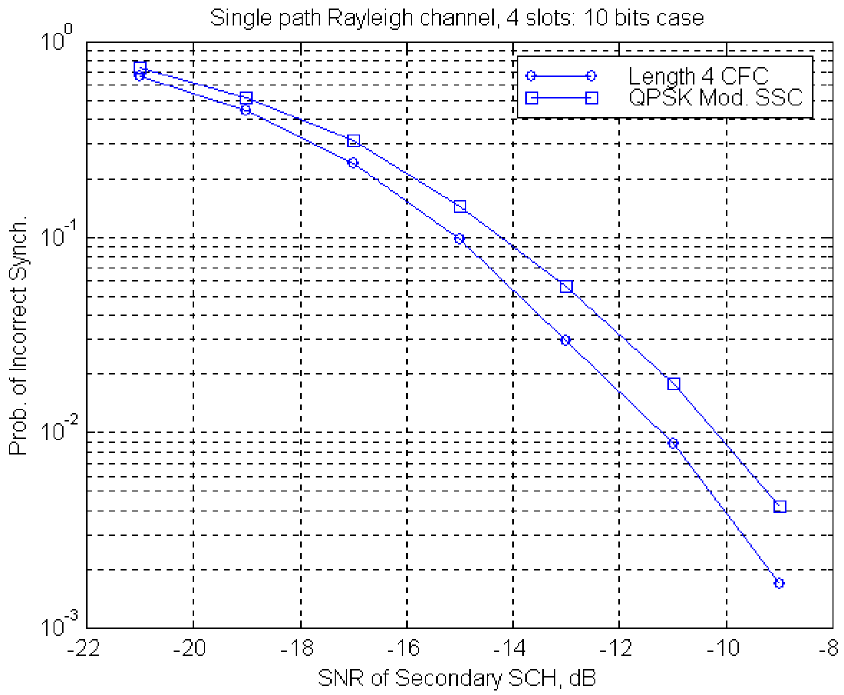

Figure 4. Performance of the CFC codes proposed in [2] vs. the QPSK modulated SSC algorithm, Rayleigh channel.

Merged Proposal:

In order to increase the minimum distance, for the 32 group (6 bit) case we now propose new codes (length 2 CFC's/QPSK modulated SSC) which have a minimum distance of 2/sqrt(3) over 1 slot[1]. The following codes to represent the 32 groups which have a minimum distance of 2/sqrt(3) over 1 slot (bit case).

Construction for the 6 bit case:

Group	slot 1	slot 2	Group	slot 1	slot 2
1	$\{s_1+s_2+s_3,$	$s_1+s_2-s_3\}$/sqrt(3)	17	$\{s_4+s_5+s_6,$	$s_4+s_5-s_6\}$/sqrt(3)
2	$\{s_1-s_2+s_3,$	$s_1-s_2-s_3\}$/sqrt(3)	18	$\{s_4-s_5+s_6,$	$s_4-s_5-s_6\}$/sqrt(3)
3	$\{-s_1+s_2+s_3,$	$-s_1+s_2-s_3\}$/sqrt(3)	19	$\{-s_4+s_5+s_6,$	$-s_4+s_5-s_6\}$/sqrt(3)
4	$\{-s_1-s_2+s_3,$	$-s_1-s_2-s_3\}$/sqrt(3)	20	$\{-s_4-s_5+s_6,$	$-s_4-s_5-s_6\}$/sqrt(3)
5	$\{j(s_1+s_2)+s_3,$	$j(s_1+s_2)-s_3\}$/sqrt(3)	21	$\{j(s_4+s_5)+s_6,$	$j(s_4+s_5)-s_6\}$/sqrt(3)
6	$\{j(s_1-s_2)+s_3,$	$j(s_1-s_2)-s_3\}$/sqrt(3)	22	$\{j(s_4-s_5)+s_6,$	$j(s_4-s_5)-s_6\}$/sqrt(3)
7	$\{j(-s_1+s_2)+s_3,$	$j(-s_1+s_2)-s_3\}$/sqrt(3)	23	$\{j(-s_4+s_5)+s_6,$	$j(-s_4+s_5)-s_6\}$/sqrt(3)
8	$\{j(-s_1-s_2)+s_3,$	$j(-s_1-s_2)-s_3\}$/sqrt(3)	24	$\{j(-s_4-s_5)+s_6,$	$j(-s_4-s_5)-s_6\}$/sqrt(3)
9	$\{j(s_1+s_3)+s_2,$	$j(s_1+s_3)-s_2\}$/sqrt(3)	25	$\{j(s_4+s_6)+s_5,$	$j(s_4+s_6)-s_5\}$/sqrt(3)
10	$\{j(s_1-s_3)+s_2,$	$j(s_1-s_3)-s_2\}$/sqrt(3)	26	$\{j(s_4-s_6)+s_5,$	$j(s_4-s_6)-s_5\}$/sqrt(3)
11	$\{j(-s_1+s_3)+s_2,$	$j(-s_1+s_3)-s_2\}$/sqrt(3)	27	$\{j(-s_4+s_6)+s_5,$	$j(-s_4+s_6)-s_5\}$/sqrt(3)
12	$\{j(-s_1-s_3)+s_2,$	$j(-s_1-s_3)-s_2\}$/sqrt(3)	28	$\{j(-s_4-s_6)+s_5,$	$j(-s_4-s_6)-s_5\}$/sqrt(3)
13	$\{j(s_2+s_3)+s_1,$	$j(s_2+s_3)-s_1\}$/sqrt(3)	29	$\{j(s_5+s_6)+s_4,$	$j(s_5+s_6)-s_4\}$/sqrt(3)
14	$\{j(s_2-s_3)+s_1,$	$j(s_2-s_3)-s_1\}$/sqrt(3)	30	$\{j(s_5-s_6)+s_4,$	$j(s_5-s_6)-s_4\}$/sqrt(3)
15	$\{j(-s_2+s_3)+s_1,$	$j(-s_2+s_3)-s_1\}$/sqrt(3)	31	$\{j(-s_5+s_6)+s_4,$	$j(-s_5+s_6)-s_4\}$/sqrt(3)
16	$\{j(-s_2-s_3)+s_1,$	$j(-s_2-s_3)-s_1\}$/sqrt(3)	32	$\{j(-s_5-s_6)+s_4,$	$j(-s_5-s_6)-s_4\}$/sqrt(3)

Construction for the 7 bit case:

For the 7 bit case, we use 12 SSCs and the new codes are constructed as:

Group	slot 1	slot 2	slot 3	slot 4
1	$\{s_1+s_2+s_3,$	$s_1+s_2-s_3,$	$-s_1-s_2+s_3,$	$-s_1-s_2-s_3\}$/sqrt(3)
2	$\{s_1-s_2+s_3,$	$s_1-s_2-s_3$	$-s_1+s_2+s_3,$	$s_1+s_2-s_3\}$/sqrt(3)
3	$\{j(s_1+s_2)+s_3,$	$j(s_1+s_2)-s_3$	$j(-s_1-s_2)+s_3,$	$j(-s_1-s_2)-s_3\}$/sqrt(3)
4	$\{j(s_1-s_2)+s_3,$	$j(s_1-s_2)-s_3,$	$j(-s_1+s_2)+s_3,$	$j(s_1+s_2)-s_3\}$/sqrt(3)
5	$\{j(s_1+s_3)+s_2,$	$j(s_1+s_3)-s_2,$	$j(-s_1-s_3)+s_2,$	$j(-s_1-s_3)-s_2\}$/sqrt(3)
6	$\{j(s_1-s_3)+s_2,$	$j(s_1-s_3)-s_2,$	$j(-s_1+s_3)+s_2,$	$j(s_1+s_3)-s_2\}$/sqrt(3)
7	$\{j(s_2+s_3)+s_1,$	$j(s_2+s_3)-s_1,$	$j(-s_2-s_3)+s_1,$	$j(-s_2-s_3)-s_1\}$/sqrt(3)
8	$\{j(s_2-s_3)+s_1,$	$j(s_2-s_3)-s_1,$	$j(-s_2+s_3)+s_1,$	$j(s_2+s_3)-s_1\}$/sqrt(3)
9	$\{s_4+s_5+s_6,$	$s_4+s_5-s_6,$	$-s_4-s_5+s_6,$	$-s_4-s_5-s_6\}$/sqrt(3)
10	$\{s_4-s_5+s_6,$	$s_4-s_5-s_6,$	$-s_4+s_5+s_6,$	$s_4+s_5-s_6\}$/sqrt(3)
11	$\{j(s_4+s_5)+s_6,$	$j(s_4+s_5)-s_6$	$j(-s_4-s_5)+s_6,$	$j(-s_4-s_5)-s_6\}$/sqrt(3)
12	$\{j(s_4-s_5)+s_6,$	$j(s_4-s_5)-s_6$	$j(-s_4+s_5)+s_6,$	$j(s_4+s_5)-s_6\}$/sqrt(3)

[1] We also have a code construction method to increase the minimum distance further to sqrt(2) over 1 slot. However, this code construction does not generalize well for more than 32 groups. We therefore present only the codes with a minimum distance 2/sqrt(3) over 1 slot.

13 {$j(s_4+s_6)+s_5$, $j(s_4+s_6)-s_5$, $j(-s_4-s_6)+s_2$, $j(-s_4-s_6)-s_5$}/sqrt(3)
14 {$j(s_4-s_6)+s_5$, $j(s_4-s_6)-s_5$, $j(-s_4+s_6)+s_2$, $j(s_4+s_6)-s_5$}/sqrt(3)

15 {$j(s_5+s_6)+s_4$, $j(s_5+s_6)-s_4$, $j(-s_5-s_6)+s_4$, $j(-s_5-s_6)-s_4$}/sqrt(3)
16 {$j(s_5-s_6)+s_4$, $j(s_5-s_6)-s_4$, $j(-s_5+s_6)+s_4$, $j(s_5+s_6)-s_4$}/sqrt(3)

The remaining groups 17 to 32 are constructed using the short code sets {s_7 s_8 s_9} and {s_{10} s_{11} s_{12}} as shown above for the short code sets {s_1 s_2 s_3} and {s_4 s_5 s_6}. Note that using the construction procedure above, each of the short code sets results in 8 comma free codes per short code set.

Construction for the 10 bit case:

In the above construction, more comma free codes can be obtained without sacrificing the minimum distance if short code sets such as {s_1 s_4 s_7} are also used to obtain the 8 CFC words possible using such a short code set. In fact the rule is that two short code sets can have at most one short code in common.

Using this rule, and 16 short codes, the 32 possible short code sets for the 256 group case are:
{s_1 s_2 s_3}, {s_4 s_5 s_6}, {s_7 s_8 s_9}, {s_{10} s_{11} s_{12}}, {s_{13} s_{14} s_{15}}, {s_1 s_4 s_7}, {s_1 s_5 s_8}, {s_1 s_6 s_9}, {s_1 s_{10} s_{13}}, {s_1 s_{11} s_{14}}, {s_1 s_{12} s_{15}}, {s_2 s_4 s_8}, {s_2 s_5 s_7}, {s_2 s_6 s_{10}}, {s_2 s_9 s_{11}}, {s_2 s_{12} s_{13}}, {s_2 s_{14} s_{16}}, {s_3 s_4 s_9}, {s_3 s_5 s_{10}}, {s_3 s_6 s_7}, {s_3 s_8 s_{11}}, {s_3 s_{12} s_{14}}, {s_3 s_{13} s_{16}}, {s_4 s_{10} s_{14}}, {s_4 s_{11} s_{13}}, {s_4 s_{12} s_{16}}, {s_5 s_9 s_{12}}, {s_5 s_{11} s_{15}}, {s_6 s_8 s_{12}}, {s_6 s_{11} s_{16}}, {s_7 s_{10} s_{15}}, {s_8 s_{10} s_{16}}.

By appropriately modulating and transmitting the short codes from each of the short code set (as shown above for the 7 bit case), 8 Comma Free codes are obtained per short code set giving a total of 256 comma free code words. It can be easily seen that the minimum distance of these CFC's is 2/sqrt(3), thus improving performance over the case where only two short codes are transmitted per SCH slot.

Again, similar to the 6 bit case, receivers with lower computational complexity during the decisions can be easily obtained.

The following tables lists the complexity of the Modulated CFC algorithm

Algorithm	Complexity at each SCH slot	Complexity during decision
Modulated CFC	813 real adds+28 real mult.	16 real adds

Table 1. Complexity for 6 bits.

Algorithm	Complexity at each SCH slot	Complexity during decision
Modulated CFC	903 real adds+52 real mult.	34 real adds

Table 2. Complexity for 7 bits.

Algorithm	Complexity at each SCH slot	Complexity during decision
Modulated CFC	895 real adds+68 real mult.	258 real adds

Table 3. Complexity for 10 bits.

Handover from GSM to UTRA TDD:

A problem not addressed in the current working assumption is the handover from GSM to UTRA TDD mode. Currently, a 5ms monitoring window is used every 120ms for handover from GSM to UTRA TDD. However, in the current working assumption, only one SCH slot is transmitted in 5ms. Thus, the UE will see only one SCH position. The current description more than one SCH slots to obtain the full synchronization information. Any amount of averaging will therefore not remedy this problem. *The modulated CFC method*, on the other hand *allows full synchronization by observing only one SCH slot*.

Performance:

The following figures show the performance improvement of the new length 2 CFC as compared to the length 2 CFC proposed in [2].

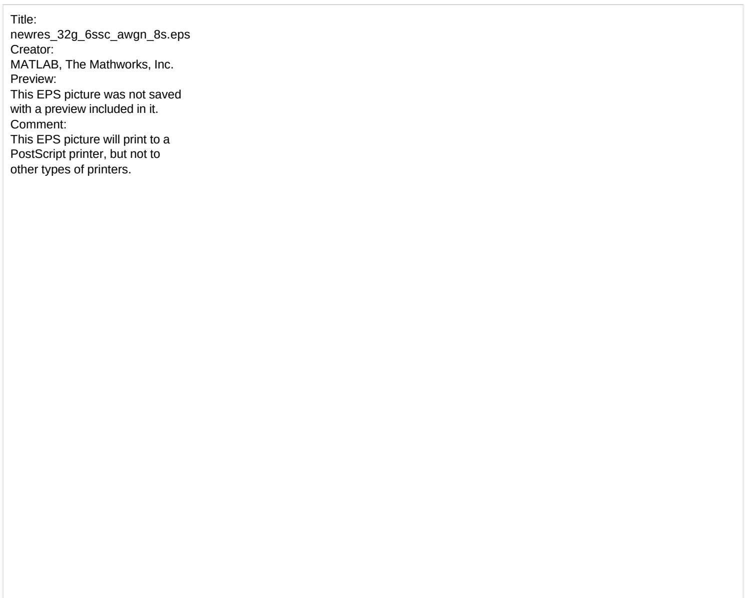

Figure 5. Performance of the CFCproposed in [2] vs. the Modulated CFC in AWGN channel for the 6 bit case. Eight SCH slots were used.

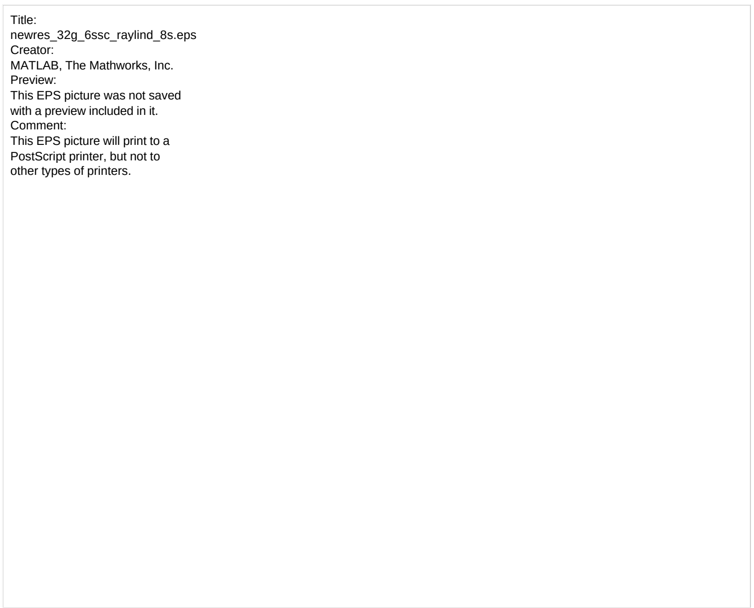

Figure 6. Performance of the CFC proposed in [2] vs. the Modulated CFC (merged proposal) in a single path Rayleigh fading environment for the 6 bit case. Eight slots were used

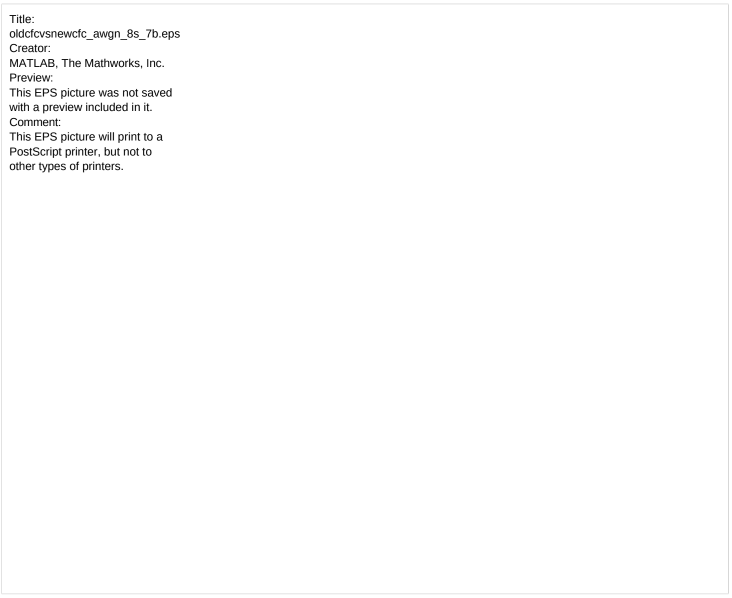

Figure 7. Performance of the CFC proposed in [2] vs. the Modulated CFC (merged proposal) in a AWGN environment for the 7 bit case.

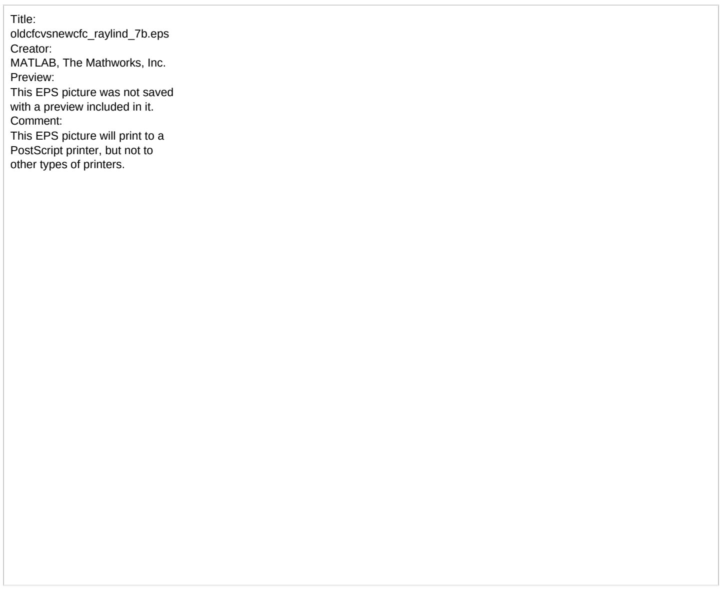

Figure 8. Performance of the CFC proposed in [2] vs. the Modulated CFC (merged proposal) in a single path Rayleigh fading environment for the 7 bit case.

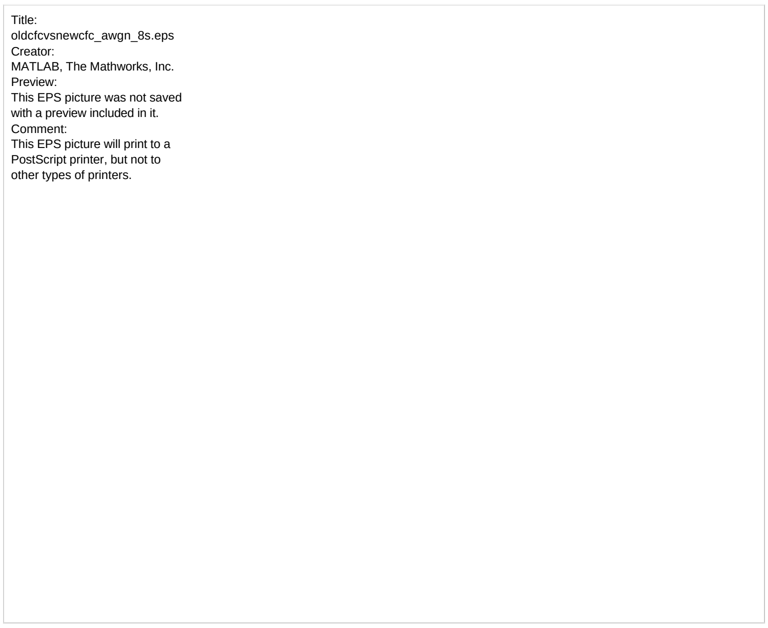

Figure 9. Performance of the CFC proposed in [2] vs. the Modulated CFC (merged proposal) in an AWGN environment for the 10 bit case.

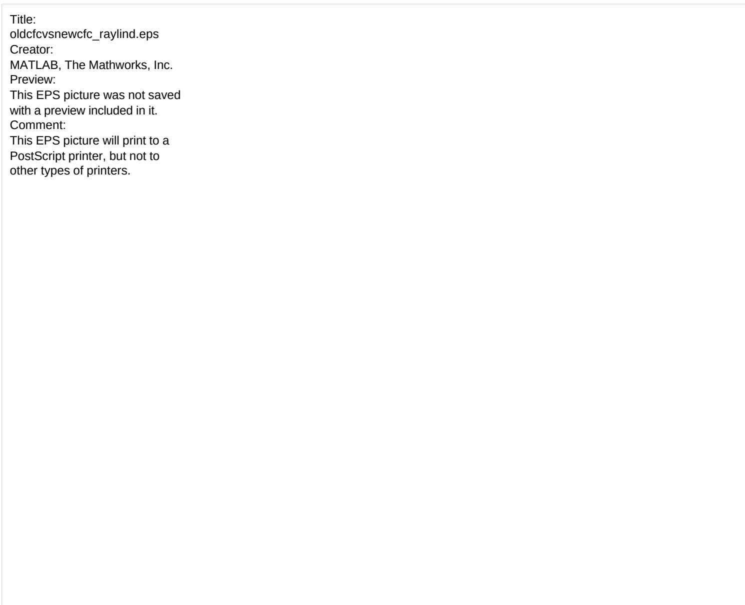

Figure 10. Performance of the CFC proposed in [2] vs. the Modulated CFC (merged proposal) with in a single path Rayleigh fading environment for the 10 bit case

Conclusions:

The merged proposal (modulated CFC's) perform better than both the CFC's proposed in [2] and the modulated QPSK method. The performance of this method should also be better than the current working assumption.

The handover from GSM to UTRA TDD mode is not addressed by the current working assumption. Currently, a 5ms monitoring window is used every 120ms for handover from GSM to UTRA TDD.

However, in the current working assumption, only one SCH slot is transmitted in 5ms. Thus, the UE will see only one SCH position. The current description requires more than one SCH slots to obtain the full synchronization information. Any amount of averaging will therefore not remedy this problem. *The modulated CFC method*, on the other hand *allows full synchronization by observing only one SCH slot*.

Reference:

[1] "A BPSK Modulated Secondary Synchronization Codes based Cell Search in UTRA TDD", TSGR1#5(99)578, InterDigital Comm. Corp.

[2] "A New Comma Free Code scheme for TDD Synchronization", TSGR1#6(99)815, Texas Instruments.

[3] "QPSK Modulated Secondary Synchronization Codes (SSC) Algorithm", E-mail contribution, August 9, 1999. InterDigital Comm. Corp.

[4] Comparison of IDC and TI proposals, IDC, e-mail contribution, August 26, 1999, InterDigital Communications Corp.