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Title: Analysis of scrambling code grouping schemes

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1. Introduction

It has been proposed in [1] to change the number of scrambling code groups from 32 to 256. The goal of the proposal is to reduce the complexity and hardware requirements of the overall cell search procedure. Numerous comments and concerns have been raised in [2] and on the reflector. These issues have been addressed in [3] and the original contribution was modified to consider 64 and 128 scrambling code groups. Since most of the analysis and simulations has been done for the initial acquisition, it is necessary to investigate the handover scenario before a decision can be made. This is the purpose of this document. The following conclusions can be drawn from this document:

- The proposed scheme offers a significant complexity reduction.
- Memory requirements are virtually identical.
- The proposed scheme performs almost identically to the current scheme during handover.
- There is no processing peak during handover.
- The proposed scheme may allow more flexible cell planning for operators.
- The proposed scheme has a slight performance degradation over the current scheme during initial acquisition.
- The peak processing during initial acquisition is not considered significant because the DSP has additional resources available.

Considering references [1], [2] and [3] along with the results of this paper, it appears that the best compromise is 128 code groups. This provides significant complexity reduction with negligible performance degradation.

2. Review

The difference between the current and the proposed schemes is in stage 2. Recall that stage 2 allows the mobile to achieve frame synchronization and to decode the long code group [4]. By decoding the long code group, it is possible to reduce the complexity of the overall cell search procedure by reducing the number of long code searches that have to be performed in stage 3. Increasing the number of code groups reduces the number of long code searches that have to be done, therefore the complexity is reduced. The current scheme consist of 32 groups, each containing 16 long codes where the proposed schemes consist of 64, 128 or 256 groups each containing 8, 4 and 2 long codes respectively.

3. Complexity Analysis with OHG Harmonization

The following results will be used to evaluate the initial acquisition and handover case. The analysis considers harmonization and includes the number of non-trivial multiplies (other than by +-1) and adds (other than by 0) as well as the number of memory accesses (reads/writes).

Following the notation in [3]:

M: the number of scrambling code groups
L: the number of scrambling codes in a group
N1: number of frames used in stage 1
N2: number of frames used in stage 2
N3: number of frames used in stage 3
C1: number of operations (multiplies/adds) in stage 1
C2: number of operations (multiplies/adds) in stage 2
C3: number of operations (multiplies/adds) in stage 3
Y1: number of memory access (reads/writes) in stage 1
Y2: number of memory access (reads/writes) in stage 2
Y3: number of memory access (reads/writes) in stage 3
Z: total complexity (number of operations and memory access)

Assuming n samples per chip, the number of operations for stage 1 is

C1 = (13*2+3)*n*38400*N1 + n*2560*(15*N1-1)

Where 13*2+3 is the number of operations required to compute the energy per complex matched filter output assuming 3 operations to compute the norm of a complex number. The term n*2560*(15*N1-1) accounts for the accumulation of the energy from one slot to the next.

The number of operations for stage 2 is given by

C2 = (16*4+16*15)*2*15*N2 + 16*15*3*N2 + 14*15*M + 15*M-1 + 16*15*(N2-1)

Where (16*4+16*15) is for correlating with the 16 SSC utilizing the FWT. This term is multiply by 2 for correlation on both I and Q and then by 15*N2, for there are 15*N2 SSC symbols in N2 frames. The term 16*15*3*N2 is for coherent demodulation of SSC symbols assuming three operations for calculating the real part of a complex product or for non-coherent demodulation of the SSC symbols assuming 3 operations to compute the norm of a complex number. The term 14*15*M is for calculating the metric for decoding the Comma-

Free RS code. There are 15*M hypotheses (M code groups and 15 shifts) and each hypothesis requires 14 adds. The term 15*M-1 is for finding the maximum metric among the 15*M hypotheses. Finally the term 16*15*(N2-1) accounts for the accumulation of the SSC correlation from one frame to the next.

The number of operations for stage 3 is

$$C3 = 256*10*L*15*N3*(2+3) + (10*15*N3-1)*L$$

Where 256*10 is the number of chips in a slot scrambled by the scrambling code (on the CPICH channel). This term is first multiplied by L for there are L scrambling codes to be correlated against, and then by 15*N3 for there are 15*N3 slots used in stage 3. This term is multiply by (2+3) to correlate on both I and Q and to compute the energy of the signal. We assume that 3 operations are required to compute the norm of a complex number (non-coherent demodulation) or to compute the real part of a complex product (coherent demodulation). Finally the term (10*15*N3-1)*L accounts for the accumulation of the symbols energy for each scrambling code.

The number of memory accesses for stage 1 is

$$Y1 = 38400*2*N1*n$$

Where 38400*2*N1 is the number of memory accesses for accumulation of the matched filter output (one read and one write per output), this term is multiplied by n since there are n samples per chip.

The number of memory accesses for stage 2 is given by

$$Y2 = 16*15*2*N2 + 15*15*M + 15*M$$

Where 16*15*2*N2 is the number of read and write necessary for accumulation of the SSC correlation values. The term 15*15*M is the number of memory read to form the decision variables and the term 15*M is the number of memory read required to find the maximum value.

The number of memory accesses for stage 3 is given by

$$Y3 = 10*15*N3*L*2$$

Where 10*15*N3 is the number of symbols that we need to accumulate in N3 frames. This term is multiplied by L for there are L codes to search on and then by 2 since the accumulation requires one read and one write.

$$Z = 122880*n*N1 + 10560*N2 + 192450*L*N3 + 465*M - 2560*n - L - 241 \quad (1)$$

4. Initial Acquisition

4.1 Complexity

Using (1), the complexity of different schemes has been addressed and the results are summarized in Table 1.

n	N1	N2	N3	M	L	Z	Reduct.
1	0.5	1	0.5	32	16	1623663	---
1	0.5	1	0.5	64	8	868751	46.5%
1	0.5	1	0.5	128	4	513615	68.4%
1	0.5	1	0.5	256	2	380687	76.6%
1	1	1	1	32	16	3224703	---
1	1	1	1	64	8	1699991	47.3%
1	1	1	1	128	4	959955	70.2%
1	1	1	1	256	2	634577	80.3%
1	1	2	1	32	16	3235263	---
1	1	2	1	64	8	1710551	47.1%
1	1	2	1	128	4	970515	70.0%
1	1	2	1	256	2	645137	80.1%
2	0.5	1	0.5	32	16	1682543	---
2	0.5	1	0.5	64	8	927631	44.9%
2	0.5	1	0.5	128	4	572495	66.0%
2	0.5	1	0.5	256	2	439567	73.9%
2	1	1	1	32	16	3345023	---
2	1	1	1	64	8	1820311	45.6%
2	1	1	1	128	4	1080275	67.7%
2	1	1	1	256	2	754897	77.4%
2	1	2	1	32	16	3355583	---
2	1	2	1	64	8	1830871	45.4%
2	1	2	1	128	4	1090835	67.5%
2	1	2	1	256	2	765457	77.2%

Table 1: Complexity analysis for initial acquisition

4.2 Peak Processing Power

Because the mobile has to perform the RS decoding in a relatively short amount of time (1 slot), there is a peak in the processing load as it can be seen in Figures 1 - 4. This peak is higher for the proposed scheme than for the current scheme. Even though considerable, that increase is not that much of a concern since the DSP is free of his other involving tasks (like turbo decoding) during the initial acquisition.

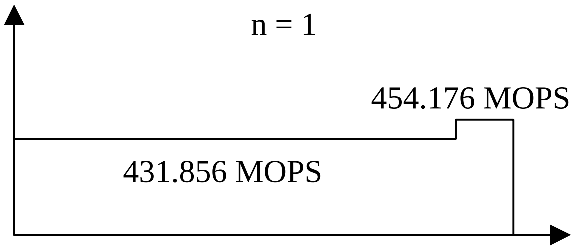

Figure 1: Load distribution (M = 32, L = 16)

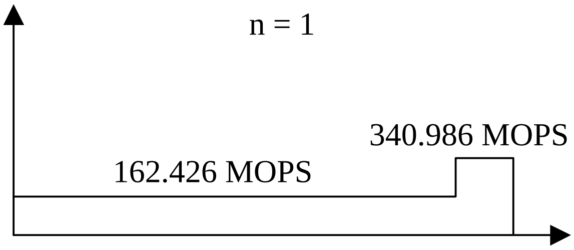

Figure 2: Load distribution (M = 256, L = 2)

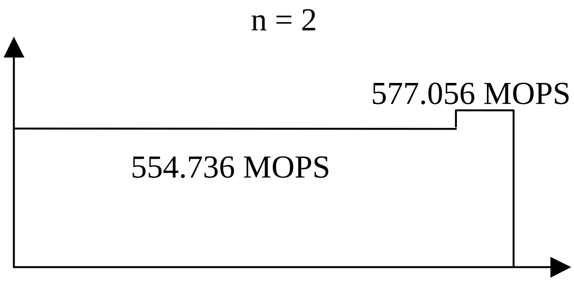

Figure 3: Load distribution (M = 32, n = 16)

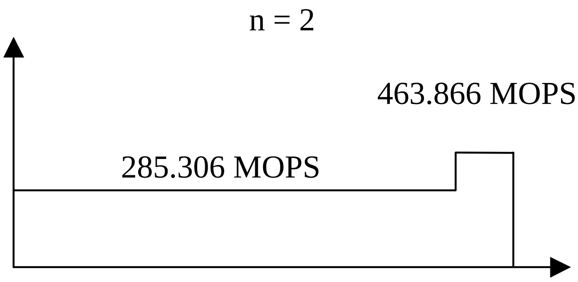

Figure 4: Load distribution (M = 256, L = 2)

4.3 Simulations

4.3.1 Simulation Model

The single base station model of Figure 5 is used for initial acquisition.

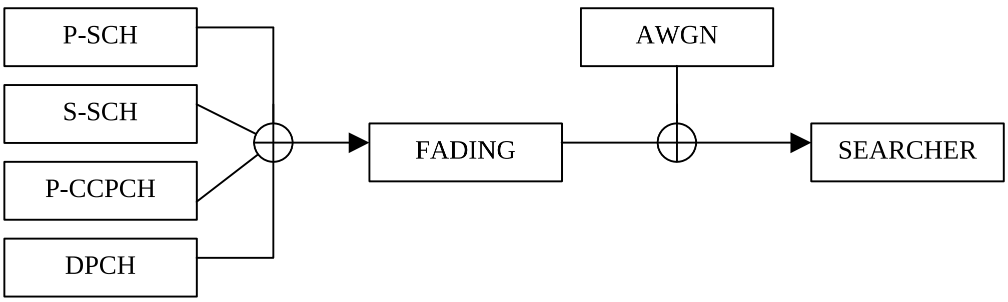

Figure 5: Model for the initial acquisition

The simulation conditions are summarized in Table 2.

Parameters	Values
P-SCH power	6 % of total base station power
S-SCH power	4 % of total base station power
P-CCPCH power	10 % of total base station power
P-CCPCH transmission	Discontinuous
DPCH power	90 % of total base station power
Number of averaged frame	1
Channel model	Single path rayleigh fading
Vehicular speed	5 km/h, 60 km/h, 250 km/h

Table 2: Simulation conditions for the initial acquisition

4.3.2 Simulation Results

Simulations have been performed for the current scheme (32 groups) and for the proposed scheme (256 groups). No simulations for the 64 or 128 grouping schemes have been performed because these results are bracketed by the 32 and 256 grouping schemes. Note that these simulations have been done prior to the OHG harmonization. However it has been shown in [5] that there is only a slight degradation between the RS code words generated over GF(16) and the RS code words generated over GF(17). Therefore the simulations have not yet been repeated. The results are shown in Figures 6 – 8.

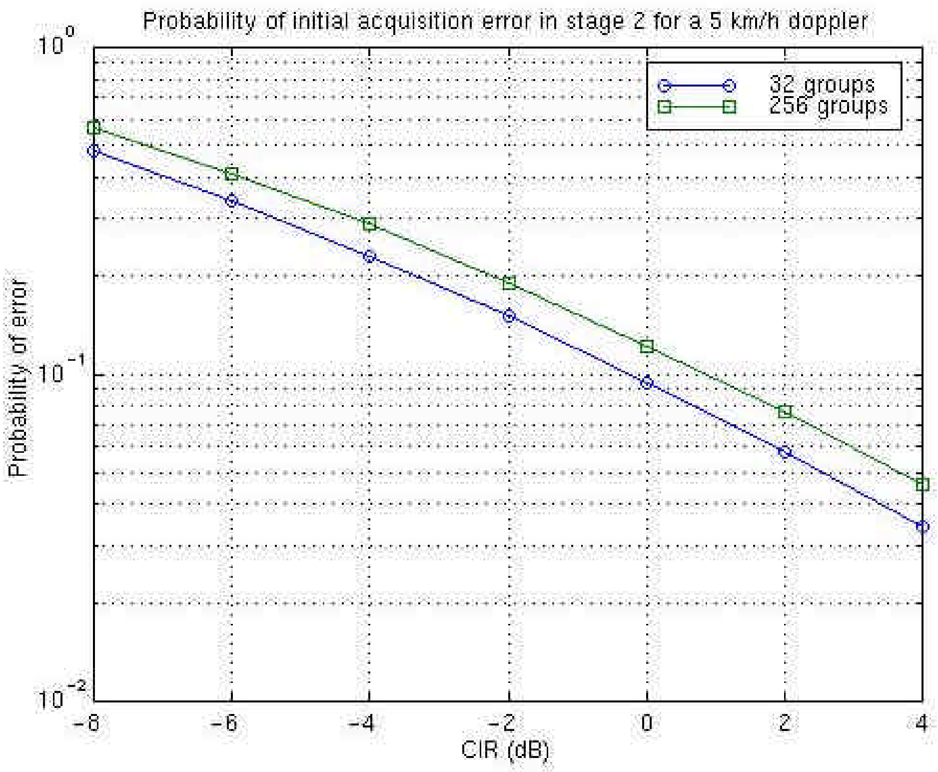

Figure 6: Probability of an initial acquisition error in stage 2 (5 km/h)

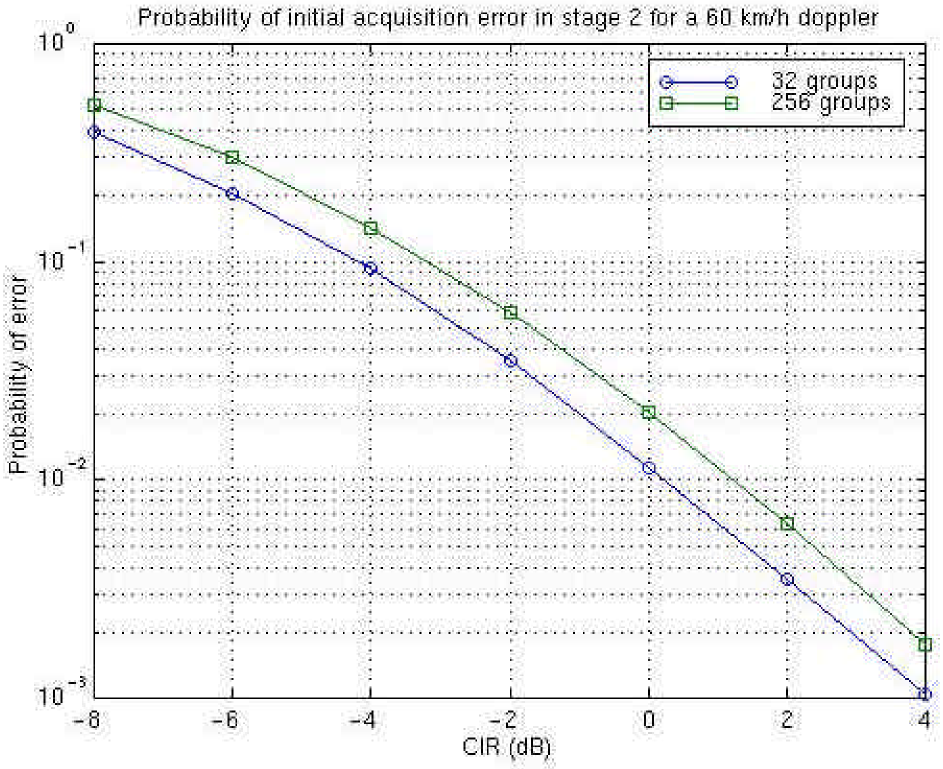

Figure 7: Probability of an initial acquisition error in stage 2 (60 km/h)

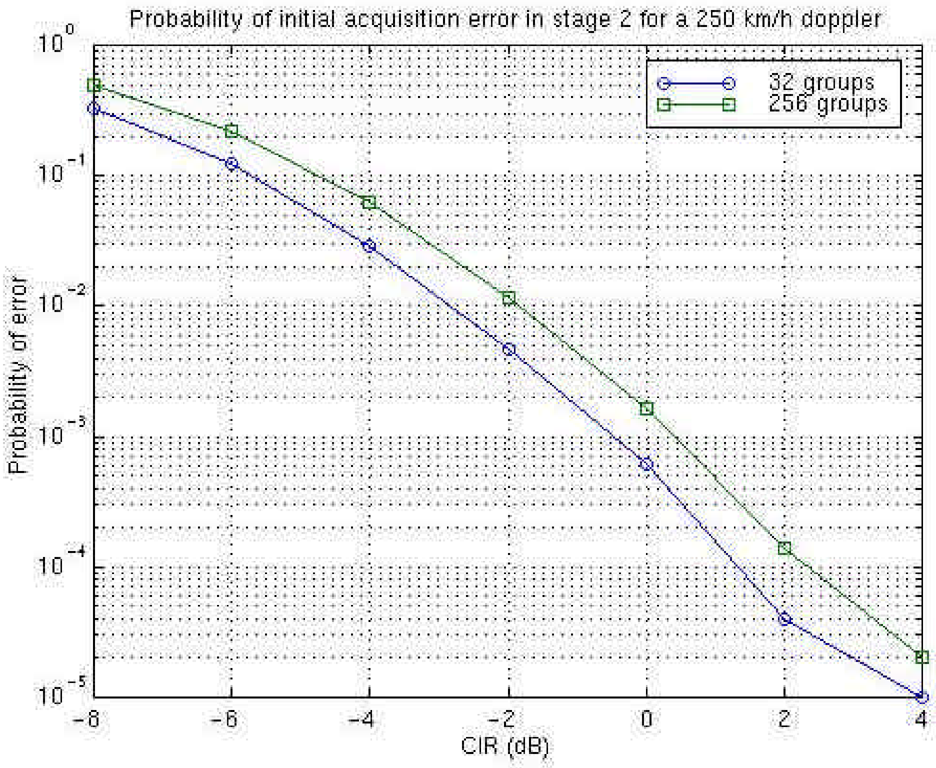

Figure 8: Probability of an initial acquisition error in stage 2 (250 km/h)

4.3.3 Simulations Conclusions

It can be seen from the simulations that the initial acquisition of the proposed scheme performs 1dB worse than the current scheme. This performance loss is negligible considering that the probability of error in stage 1 is dominant. As a result, the overall degradation is smaller than 1 dB. The performance loss is explained by the fact that there are an increased number of decision variables (512 to 4096), and therefore, there is a higher probability of making a wrong decision.

5. Handover

5.1 Complexity

The handover complexity is harder to evaluate because it is network dependent. The following analysis assumes that there are 16 candidates in the neighbor list. This seems to be a reasonable assumption considering a 3-sector cell planning. The worst complexity case would be when all the neighbors are in the same group or groups. The best complexity case (even though probably very hard to plan for the 32 and 64 grouping scheme) would be when they are all in different groups. For the 32-group scheme, there are 16 codes/group. The 16 candidates can then be all in the same group. For the 64-group scheme, there are 8 codes/group. The 16 candidates would then fill 2 groups. For the 128-group scheme, there are 4 codes/group. The 16 candidates would then fill 4 groups. For the 256-group scheme, there are 2 codes/group. The 16 candidates would then fill 8 groups. It may not be necessary to do stage 3 when there is a single code per group, but it can still be used for verification. If stage 3 is not used, the complexity numbers below may be reduced further.

N	N1	N2	N3	M	L	Z	Reduct.
1	0.5	1	0.5	1	16	1609248	---
1	0.5	1	0.5	2	8	839921	47.8%
1	0.5	1	0.5	4	4	455955	71.7%
1	0.5	1	0.5	8	2	265367	83.5%
1	0.5	1	0.5	16	1	172863	89.3%
1	1	1	1	1	16	3210288	---
1	1	1	1	2	8	1671161	47.9%
1	1	1	1	4	4	902295	71.9%
1	1	1	1	8	2	519257	83.8%
1	1	1	1	16	1	330528	89.7%
1	1	2	1	1	16	3220848	---
1	1	2	1	2	8	1681721	47.8%
1	1	2	1	4	4	912855	71.7%
1	1	2	1	8	2	529817	83.6%
1	1	2	1	16	1	341088	89.4%
2	0.5	1	0.5	1	16	1668128	---
2	0.5	1	0.5	2	8	898801	46.1%

2	0.5	1	0.5	4	4	514835	69.1%
2	0.5	1	0.5	8	2	324247	80.6%
2	0.5	1	0.5	16	1	231743	86.1%
2	1	1	1	1	16	3330608	---
2	1	1	1	2	8	1791481	46.2%
2	1	1	1	4	4	1022615	69.3%
2	1	1	1	8	2	639577	80.8%
2	1	1	1	16	1	450848	86.5%
2	1	2	1	1	16	3341168	---
2	1	2	1	2	8	1802041	46.1%
2	1	2	1	4	4	1033175	69.1%
2	1	2	1	8	2	650137	80.5%
2	1	2	1	16	1	461408	86.2%

Table 3: Complexity analysis for handover

5.2 Peak Processing Power

There is almost no processing power peak as it can be seen in Figures 9 - 12. This is because the mobile takes advantage of the neighbor list while performing stage 2. Therefore there are only a limited number of decision variables to compute, and this number of decision variables is similar for both schemes (it depends on the number of groups to search on and the number of codes/group).

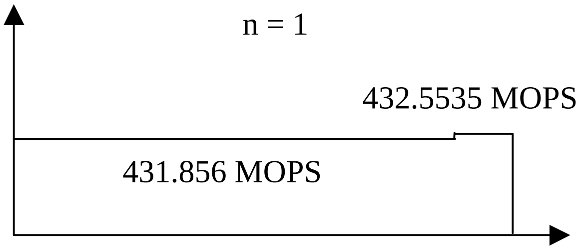

Figure 9: Load distribution (M = 1, L = 16)

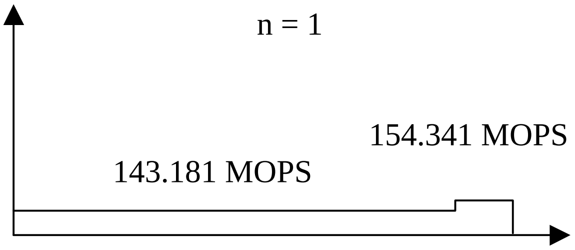

Figure 10: Load distribution (M = 16, L = 1)

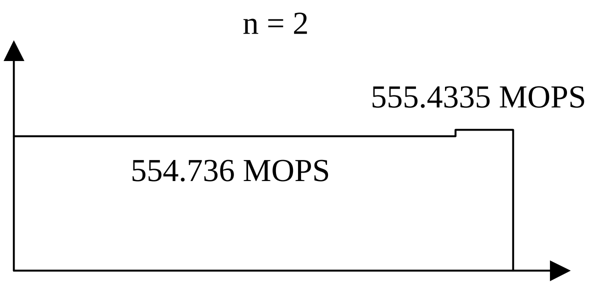

Figure 11: Load distribution (M = 1, L = 16)

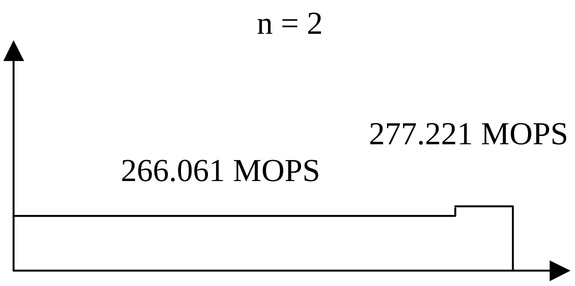

Figure 12: Load distribution (M = 16, L = 1)

5.3 Simulations

5.3.1 Simulation Model

The dual base station model of Figure 13 is used for the handover scenario.

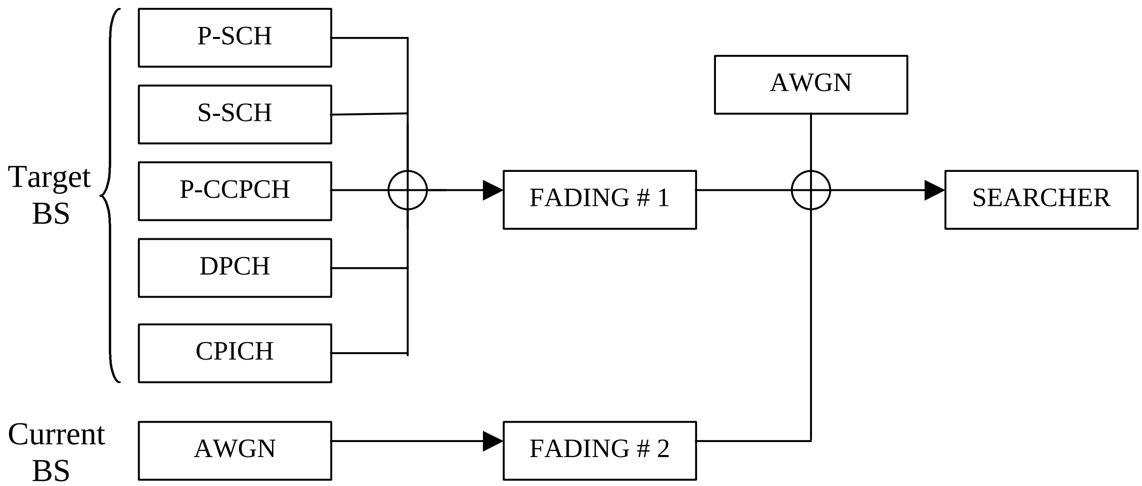

Figure 13: Simulation model for handover

The simulation conditions are summarized in Table 4.

Parameters	**Values**
P-SCH power	6 % of total base station power
S-SCH power	4 % of total base station power
P-CCPCH power	10 % of total base station power
P-CCPCH transmission	Discontinuous
CPICH power	10 % of total base station power
DPCH power	80 % of total base station power
Channel model	Single path rayleigh fading
Vehicular speed	5 km/h, 60 km/h, 250 km/h
Number of averaged frames	2
Number of candidates	15 (10 groups or 15 groups)
Target BS power / Current BS power	-6 dB
Current BS Model	AWGN

Table 4: Simulation conditions for handover

5.3.2 Simulation Results

Simulations have been performed for the current scheme and for the proposed scheme according to the OHG harmonization specifications. The results are shown in Figure 14 – 16. The following scenario has been used: it is assumed that the number of candidates in the neighbor list was 15. To allow a fair comparison of the systems, it is presumed for the current system that there are 10 groups to search where 5 groups contain 2 long codes and the remaining 5 contain only 1 long code. For the proposed scheme, it is assumed that all the candidates are in different groups.

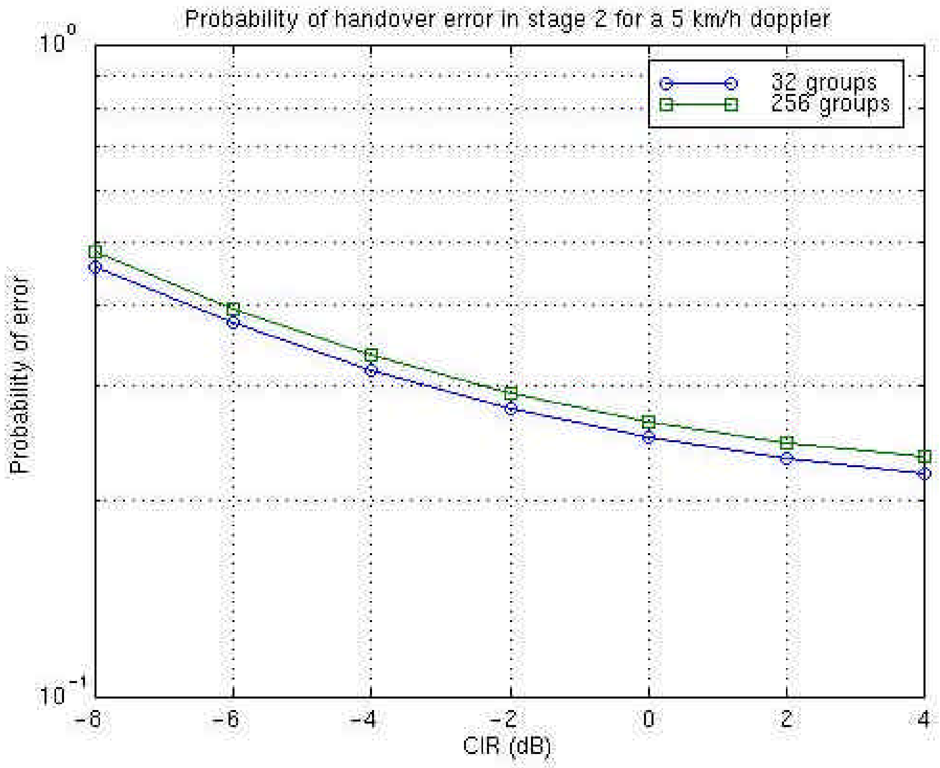

Figure 14: Probability of handover error in stage 2 (5 km/h)

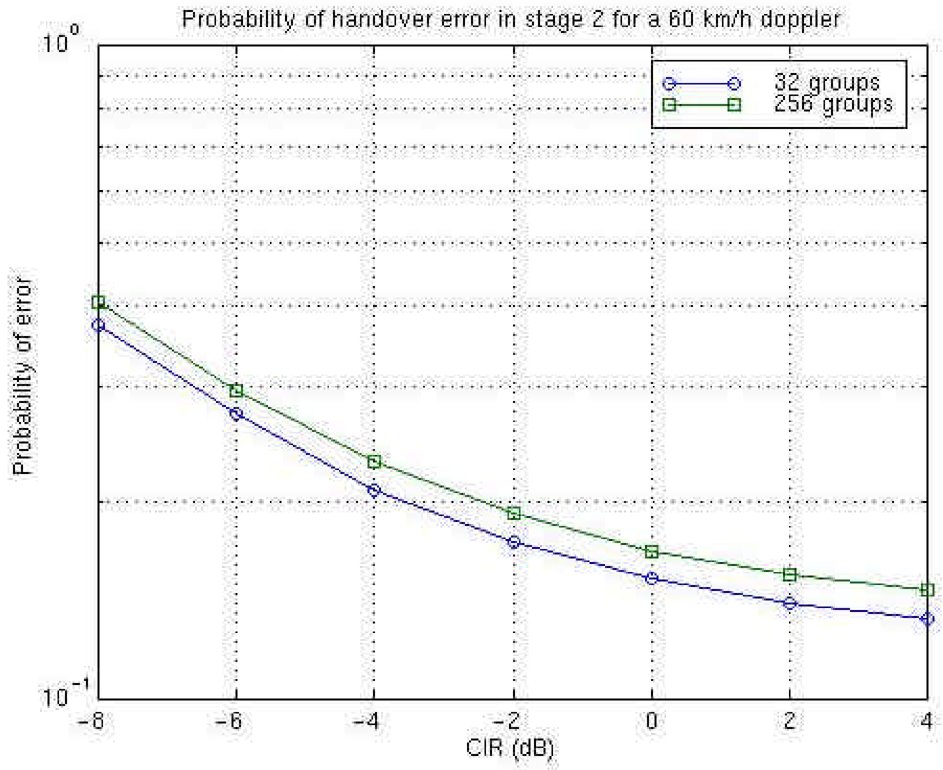

Figure 15: Probability of handover error in stage 2 (60 km/h)

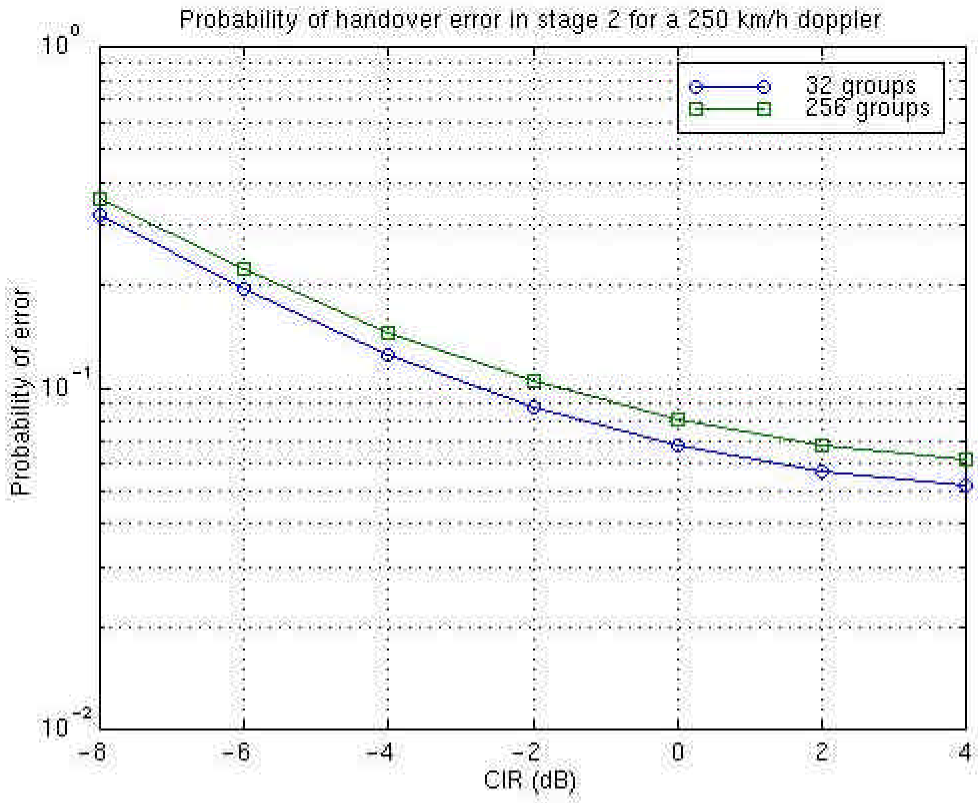

Figure 16: Probability of handover error in stage 2 (250 km/h)

5.3.3 Simulations Conclusions

It can be seen that the handover performance is worse for the proposed scheme by 0.5 dB (before the fading floors). But again, the probability of error in stage 1 is dominant and reduces the overall probability of incorrect synchronization. The scenario used in the simulation is the worst case for the proposed scheme because there are 15 neighbors (or groups for the proposed scheme) to search. The probability of error in stage 2 is reduced as the number of groups to search is reduced. As a result, the synchronization process will be dominated by stage 1, and the overall performance loss will be smaller than 0.5 dB.

6. Memory Requirements

Memory requirements are identical (within a few words) when the RS code words are generated on the fly. Because the RS code words are generated over GF(16), they can be easily reproduced by the DSP using binary arithmetic. Note that we do not need to generate the RS code words for all decision variables. It is only necessary to generate it once per group. Since the mobile will be in handover most of the time, this means that only a few (~15) RS code words need to be generated per search.

7. Implementation

We do not see any restriction imposed by the proposed scheme. As a matter of fact the proposed scheme seems to suggest a favorable way of performing the pipelining and parallelization of the different stages in handover.

The complexity and implementation of stage 1 are not affected by the choice of the current (32 groups) or proposed (256 groups) schemes. Therefore, they are not considered in this comparison. The processing requirements for stage 2 are well suited for a DSP. During initial acquisition, the proposed scheme places a slightly higher burden on the stage 2 DSP operations. At this time, however, DSP processing power is readily available. During handover when DSP resources are scarce, the stage 2 DSP processing requirements are identical for both schemes.

A hardware implementation is appropriate for stage 3 processing; therefore, it is this stage that has a significant impact on the size of the mobile receiver. For stage 3, the proposed scheme reduces the hardware complexity during both initial acquisition and handover. As a result, the size of the mobile receiver can be significantly reduced. Based on a parallel stage 3 implementation, the proposed method could reduce the stage 3 hardware size by as much as 88 % [(Lc-Lp)/Lc = 14/16] where Lc and Lp are the number of long codes in stage 3 for the current scheme and proposed scheme, respectively. This could result in a savings of nearly 20k gates.

8. Cell Planning

The proposed scheme also offers more flexible cell planning for the network operators because it will be easy for operators to assign neighboring cells to different code groups. In the current scheme, this may require significant code planning while in the proposed scheme this can be more easily accomplished since fewer codes are in each group.

9. Conclusion

The new scheme offers numerous advantages over the current scheme: reduced complexity for both initial acquisition and handover, the possibility of a more efficient implementation, and the possibility of a more flexible cell plan. These advantages are achieved at the price of a peak in the processing load and a small decrease in performance during initial acquisition. Since the mobile is free of other tasks at startup, it has additional resources to handle the peak processing. During handover the peak processing load does not exist and performance difference is negligible. Since acquisition only occurs a few times a day (when the terminal is powered on) but handover and target cell searching is an ongoing process, the benefits of the proposed scheme outweigh the slight performance penalty.

If 256 code groups cannot be agreed upon, we feel that 128 code groups may be the best compromise. This provides significant complexity reduction with negligible performance degradation.

10. References

[1]. TSGR1#5(99)541; New downlink scrambling code grouping scheme for UTRA/FDD, Ericsson, June, 1999

[2]. TSGR1#5(99)811; Number of Downlink Scrambling Code Groups in ITRA/FDD, Nokia, July, 1999

[3]. TSGR1#5(99)884; New downlink scrambling code grouping scheme for UTRA/FDD, revised, Ericsson, July, 1999

[4]. SMG2 UMTS-L1 121/98; Comma Free Codes for fast PN Code Acquisition in WCDMA Systems: A proposal for the UTRA concept, Texas Instrument, May, 1998

[5]. TSGR1#6(99)923; Secondary SCH structure for OHG harmonization: Simulations and Text Proposal, Texas Instrument, July, 1999