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Agenda item:

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Title: Use of multiple scrambling codes in compressed mode

Document for: Decision

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1 Introduction

Different methods for transmission-time reduction in downlink compressed mode have been discussed for UTRA/FDD:

- Reducing the spreading factor by a factor of 2
- Increasing the code rate by puncturing
- Multi-code transmission using a common channel

The first and second alternatives are currently described within the UTRA/FDD specification [1] while the third alternative was proposed in [2].

The different proposals suffer from different drawbacks

- The second alternative (increase of code rate by puncturing) leads to complicated rate matching in case of multiplexed transport channels with different Transmission Time Intervals, see e.g. [3]. The length of the transmission gap is also limited with this approach.
- The third alternative (multi-code transmission using a common channel) implies complicated co-ordination between cells. It also requires that multi-code reception must be supported also for low-end terminals . This is not desirable from a terminal-complexity point-of-view.

Consequently, from a conceptual point-of-view, the first alternative (reducing the spreading factor by a factor of 2) is the preferred choice. However, concerns have been raised that the first alternative leads to excess allocation of downlink code resources. Assuming that downlink capacity is code-limited, the concern is that this may have a significant negative impact on downlink capacity.

A general solution to code-limited downlink capacity is the use of multiple downlink scrambling codes. This possibility is currently supported in UTRA/FDD, see [1]. However, the use of multiple scrambling codes will increase the effective downlink intra-cell interference (loss of orthogonality) and will thus, in itself, have a negative impact on the downlink capacity, assuming that downlink capacity is interference limited.

In this paper, we present the result from a study of multiple scrambling codes, with special focus on the use of multiple scrambling codes in case of compressed mode. The conclusion is that the general use of multiple scrambling codes may have a relatively large impact on downlink capacity in some environments (large increase in effective downlink interference). However, for the special case of using multiple scrambling codes in compressed mode, the capacity loss will be relatively small.

The paper also includes a discussion and proposal for code allocation in compressed mode.

2 Simulation assumptions

Simulations have been carried out using a model with both intra-cell and inter-cell interference, see Figure 1. The intra-cell interference is modelled by 10 downlink channels (I_1, …, I_{10}) transmitted with constant power. The inter-cell interference is modelled as AWGN. Closed-loop power control adjusts the transmit power of the desired signal S so that the received SIR target is fulfilled. Closed-loop power control is not applied to the intra-cell interferers.

The intra-cell interferers are all transmitted with the same scrambling code C_s and different channelization codes. The desired signal is either transmitted with the same scrambling code as the intra-cell interferers to evaluate the “single-scrambling-code” case or with a different scrambling code C_s’ to evaluate the “multiple-scrambling-code” case. No common pilot channel or other common channels are transmitted.

During the simulation, the following parameters are measured:

- The power of the desired signal *at the transmitter*, P_S
- The power of the intra-cell interference *at the transmitter*, P_{intra}
- The power of the intra-cell interference *at the receiver*, P'_{intra}
- The power of the inter-cell interference *at the receiver*, P_{inter}

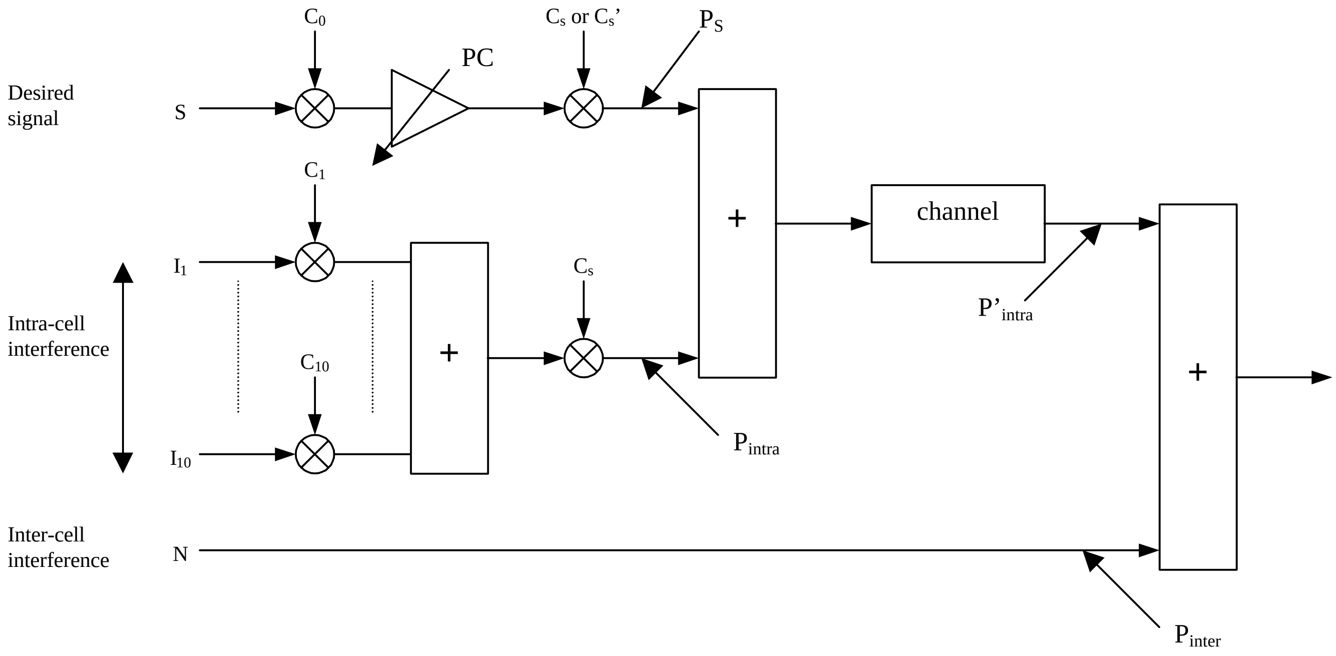


Figure 1 Simulation set-up

An important parameter is the ratio of intra-cell interference to inter-cell interference *at the receiver* (P'_{intra}/P_{inter}). This is a measure of how large part of the total interference originates from the own cell, i.e. how large part of the total interference is “potential” orthogonal interference. A large value of $_{intra}/P_{inter}$ indicates that a large part of the interference originates from the own cell and is typically experienced close to the cell site. It can be expected that the loss of using multiple scrambling codes will be larger for large values of P'_{intra}/P_{inter}. For smaller values of P'_{intra}/P_{inter}, a major part of the interference is anyway non-orthogonal, i.e. the loss with multiple scrambling codes should be lower.

The performance measure is the ratio of desired signal power to total power of the intra-cell interference *at the transmitter* (P_S/P_{intra}). This is measure of how large part of the total downlink capacity is used to transmit the signal S.

Table 1 summarises the parameters used in the simulations.

Channel model	Indoor A 3 km/h & Vehicular A 120 km/h
Number of intra-cell interferers	10
P'_{intra}/P_{inter}	0 dB, 5 dB, 10 dB
Chip rate	4.096 Mcps *[sorry]*
Spreading factor	SF = 128
Channel estimation	Perfect channel estimates
Power control – Closed loop – Outer loop	 Yes No (fixed SIR target)
Soft handover	Not included

Table 1 Simulation parameters

It should be noted that perfect channel estimates are used. With real channel estimation, the loss with multiple code sets will most likely be smaller, as the use of non-perfect channel estimates in itself removes some of the downlink orthogonality.

3 Simulation results

Table 2 summarises the simulation results. The table shows the increase in P_S/P_{intra} (the "excess power fraction") when the signal S is transmitted using a different scrambling code compared to the intra-cell interferers. The excess power fraction is measured at a frame-error rate of 2%.

Channel	P_{inter}/P'_{intra}	Excess power fraction	Average excess power fraction ($\gamma = 1/12$)	Capacity loss ($\gamma = 1/12$) [upper bound]
Indoor A	-10 dB	4.7 dB	0.6 dB	14%
	-5 dB	2.5 dB	0.3 dB	6%
	0 dB	0.9 dB	0.08 dB	2%
Vehicular A	-10 dB	3.7 dB	0.5 dB	10%
	-5 dB	2.7 dB	0.3 dB	7%
	0 dB	1.6 dB	0.2 dB	4%

Table 2 simulation result

As can be seen, the excess power fraction is relatively large for the case of high intra-cell interference (high values of P'_{intra}/P_{inter}), i.e. the capacity loss of using multiple scrambling codes will be relatively large. For lower values of P'_{intra}/P_{inter}, the loss is significantly smaller.

At this stage, it should be noted that values of P'_{intra}/P_{inter} in the order of 10 dB is quite rare. Figure 2 shows a graph of the distribution of P'_{intra}/P_{inter} for an embedded 3-sector site. As can be seen, approximately 80% of the UEs will experience $P'_{intra}/P_{inter} \leq 5$ dB or less. Actually almost 50% of the UEs will experience $P'_{intra}/P_{inter} \leq 0$ dB. Only approximately 5% of the UEs experience a P'_{intra}/P_{inter} as high as 10 dB.

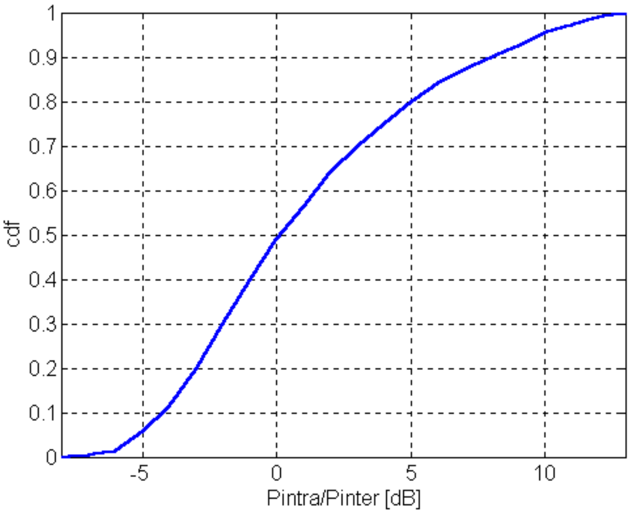


Figure 2 Distribution of P'_{intra}/P_{inter} for an embedded 3-sector site

Furthermore, in compressed mode multiple scrambling codes will only be used in the compressed frames. Assuming a compressed-mode duty cycle of γ (γ = [#compressed frames]/[#frames]), the *average excess power fraction* will be $\Delta' = 10\log_{10}((1-\gamma)+\gamma 10^{\Delta/10})$. Table 2 also shows this average excess power fraction, assuming a duty-cycle $\gamma = 1/12$, i.e. every 12th frame is compressed. In linear scale, this can be seen as the approximate capacity loss due to the use of multiple scrambling codes.

It should be noted that the capacity loss estimated in Table 2 is based on the estimated increase of transmit power, i.e. it assumes that capacity was power/interference limited when not in compressed mode. If that was the case, there would obviously have been no reason to use a different scrambling code for compressed frames, as multiple scrambling codes is only to be used in case of code-limited capacity. Consequently, the estimated capacity loss is only an upper bound, and the actual loss of capacity may be significantly lower.

4 Comparison with common-channel compressed mode

The results above should be compared to other proposals for compressed mode. In [2], there is a proposal for a common channel to be used during compressed frames. This proposal will also have a negative effect on downlink capacity, as one or several codes need to be allocated as “common channel”. Assuming a compressed mode duty cycle $\gamma = 1/12$, a maximum of 12 users can share this common channel. However, due to the different time-alignment of different downlink channels, this is normally not possible. In the worst case, the common channel can only be utilised to 50%, see [1], i.e. it can only be shared by 6 users. Consequently, there will be a capacity loss in the range 8-17 %. It should be noted that, in contrast to the capacity loss of Table 2, this is actual capacity loss and not an upper bound.

5 Code allocation

To allow for the use of a different scrambling code for compressed frames, some method for the UE to know exactly what channelization-code/scrambling code pair to be used for compressed frames should be defined.

One alternative is to allow for full flexibility in the allocation of codes for compressed frames. This implies that, at a set-up of a new radio link, the network must also inform the UE about the corresponding code pair (channelization code + scrambling code) to be used for compressed frames. The advantage with this approach is that it allows for full flexibility in the code allocation. The disadvantage is the extensive signalling needed (up to 7 bits for channelization code and up to 9 bits for scrambling code, i.e. a total of up to 17 bits).

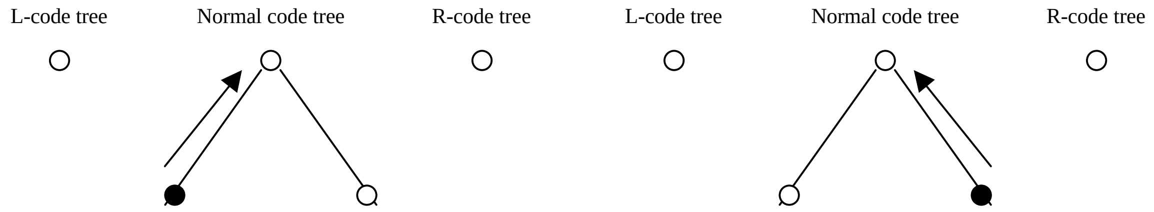
A second alternation is described below and is also illustrated in Figure 3.

Two additional scrambling codes are associated with each scrambling code used for normal transmission. These codes are called the L-code and the R-code respectively (L=Left, R=”Right”) and the corresponding code trees are called the L-code tree and the R-code tree. The code tree used for normal transmission is called the N-code tree (“Normal” code tree). The L/R-code trees are only used for transmission of compressed frames.

To transmit compressed frames, the UE always uses the channelization code of the next higher node (the CM-node) in either the normal-mode code tree or the L/R-code trees. The UE uses the CM-node of the N-code tree if that is available. However, if the CM-node in the N-code tree is not available, the CM-node of the L- and R- code trees are used by UEs in the left and right nodes respectively. The use of two code trees (L and R) guarantees that the corresponding node will always be available.

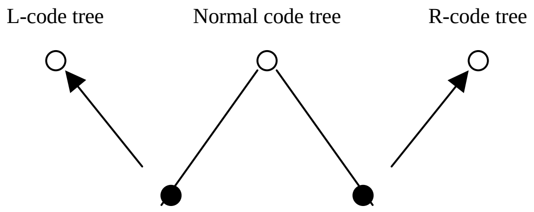
The advantage with this scheme is that only one bit of signalling is needed to inform the UE what code to use for transmission of compressed frames. This bit informs the UE whether the normal-mode code tree or the L/R-code tree should be used.

We recommend that the second alternative for code allocation in compressed mode is adopted.



Left node allocated
(use normal code tree for compressed frames)

Right node allocated
(use normal code tree for compressed frames)



Left and right nodes allocated
(use L/R-code tree for compressed frames)

Figure 3 Code allocation in compressed mode.

5 Conclusions

The performance loss of using multiple downlink scrambling codes has been discussed. It has been shown that the loss in capacity can be significant for the general use of multiple scrambling codes. However, for the case of intermittent use of multiple scrambling codes, e.g. the use of multiple scrambling codes for transmission of compressed frames in compressed mode, the capacity loss is relatively small. The reasons are the following:

- Only a fraction of the mobile stations are in positions were there is a significant loss with multiple scrambling codes, i.e. positions were the intra-cell interference is dominating.
- There will be a true capacity loss only if the capacity is power/interference limited. Multiple scrambling codes are to be used in case of code-limited capacity.

Consequently, the use of compressed mode based on a reduction of the spreading factor and with the option to use multiple scrambling codes seems to be the best alternative for downlink compressed mode. For this to be supported, some method for the UE to know exactly what channelization-code/scrambling code pair to be used for compressed frames should be defined. Two alternatives for code allocation in compressed mode were presented in this paper. We recommend that the second alternative is adopted as it leads to lower signalling requirements.

6 References

[1] TSG RAN WG1, “TS 25.212 (FDD)”

[2] “New scheme for downlink compressed mode using common channel”, TSGR1#6(99)842, Hyundai Electronics, Espoo, Finland, July 13-16 1999

[3] “Slotted transmission in UTRA/FDD”, Tdoc SMG2 UMTS-L1 232/98