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Re:	Response to IEEE 802.16m-08/052 “Call for Comments on Project 802.16m System Description Document (SDD)”
Abstract	This document proposes a new approach to randomize inter-cell interference based on cell/sector-specific interleaver pattern.
Purpose	For discussion and approval by TGm.
Notice	
Release	
Patent Policy	

Inter-cell Interference Randomization based on Cell/Sector-specific Interleaver Pattern

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1.0 Purpose

This contribution proposes a approach to randomize inter-cell interference based on cell/sector-specific interleaver pattern. Meanwhile, some simulation results to verify the advantages of the approach are presented in this contribution, too.

2.0 Introduction

Inter-cell-interference randomization is a necessary component to make sure the cellular system with high efficiency of frequency reuse work smoothly. In the traditional system, inter-cell-interference randomization can be done by scrambling, applying (pseudo) random scrambling after channel coding/interleaving or by frequency hopping. Sometimes a spreading is also included. The cell/sector-specific randomization in general help the subscribe stations to correctly detect and receive the information from the desired cell.

However, in this contribution we recommend a randomization approach based *cell/sectorl-specific interleaving* instead of *cell/sector-specific scrambling.*

3.0 Why and how to use *cell/sector-specific interleaving*

3.1 User-specific interleaver patterns

As showed in Fig. 1, users employ user-specific interleaver patterns, which would be used to extract multiple users' signals from received signal. All redundancy in system can be utilized in encoder, so the more coding gain can be achieved.

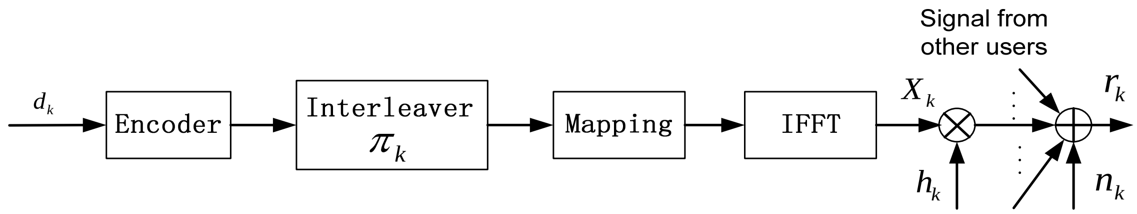

Figure 1. Illustration of transmitter of proposed system

The two types of receivers in this kind of system are showed in Fig. 2. Single user detection has a low complexity with the performance similar to a CDMA system with single-user match filter. Multiuser detection (MUD) would achieve considerable performance gain at the cost of complexity. In general, the performance of system with MUD substantially outperforms CDMA.

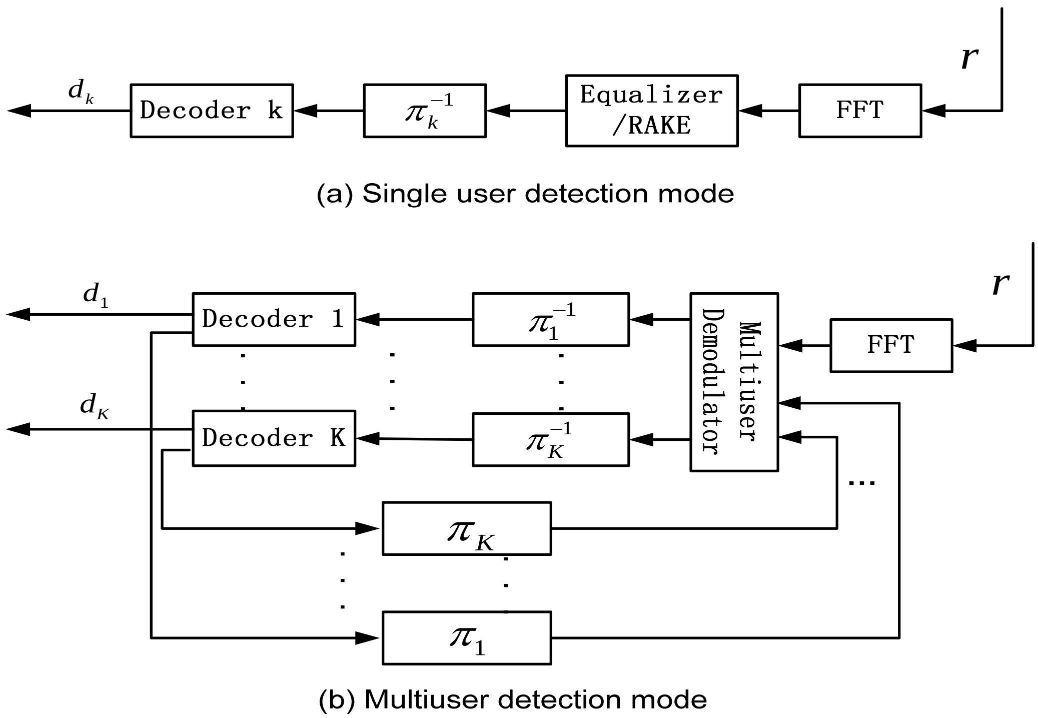

Figure 2. Illustration of two kind of detection mode in receiver of proposed system.

In Fig. 2(b), the multi-user demodulators calculate and output the soft information based on the received signal, channel information and extrinsic information for each user. The user decoders calculate the decision information and the extrinsic information based on the signal delivered from the multi-user demodulator. Then the decision information and extrinsic information are fed back to the multi-user demodulator. The interleaver and de-interleaver in Fig. 2(b) would be able to remove the correlation between the multi-user demodulator and the decoders, just like the role of the interleaver in Turbo codes.

In a multi-user system, each user's amplitude, phase, and modulation may be different, therefore resulting in random constellation patterns. An example is shown in Fig.3, for constellations of a three-QPSK-user system with equal amplitude and equal phase space. In the random constellation patterns, some constellation points have relatively large distance from other constellation points, therefore are easy to be detected. On the other hand, the constellation points close to each other may be difficult to be detected. In this case, the extrinsic information from channel decoder can help the detection.

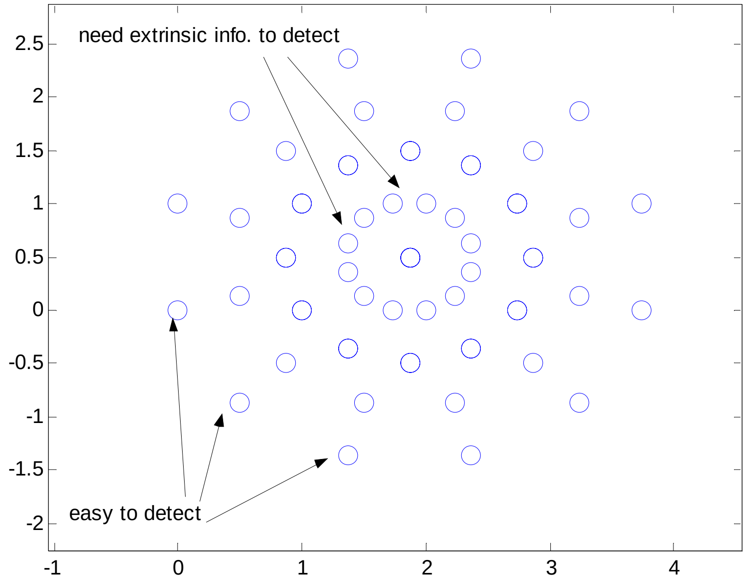

Fig.3 constellation of three-QPSK-user system with equal amplitude and equal phase space

Some may be concerned about the complexity of implementing iterative multi-user detection. Fortunately, in the considered OFDM system, the number of neighbouring cells sharing the same chunk is limited to 2~3. Therefore even the algorithms with a complexity at a rate of exponential to user number, such as MCE algorithm, can also be considered.

3.2 Performance of proposed system vs. that of DS-CDMA

Firstly, DS-CDMA system can be regarded as a system with a channel coding concatenated with a repeated coding (repeated coding does not have any coding gain). Both the FEC and repeated coding will lead to spectrum spreading. While for proposed system, all spread spectrum can be used to FEC coding for achieving larger coding gain.

On the other hand, proposed system can achieve single-user performance with iterative multi-user decoding. Take a two-user system for instance. After deinterleaving, the interference to N adjacent symbols of the desired data sequence come from N random-distributed symbols of the interfering sequence. Therefore the decodings of the two users are fully uncorrelated, thus the iterative reception can achieve a significant gain. However, in a system using scrambling codes to distinguish users, a desired data segments (consists of N adjacent symbols) coincides with the interfering segment. Thus a severe positive feedback will take place in the iterative decoding. This effect can be easily illustrated with generalized Tanner graphs analysis [2].

Unlike that in uplink, the most severe CCI in downlink appears at the cell edge, where an SS may receive strong interference from 1 or 2 adjacent base stations (SIR up to 0dB). In this case, we should evaluate the performance of multiple access with a small number of users, but with much higher coding rate (compared with uplink).

3.3 How to use cell/sector-specific interleaving in the system

As discussed above, cell/sector-specific interleaving brings more robust performance than cell/sector-specific scrambling. The advantage of interleaving over scrambling seems very important for cell-edge subscriber stations to receive broadcast services, such as common signaling broadcasting, because some advanced transmitting techniques (ex. Beamforming) for unicasting can't be used for broadcasting.

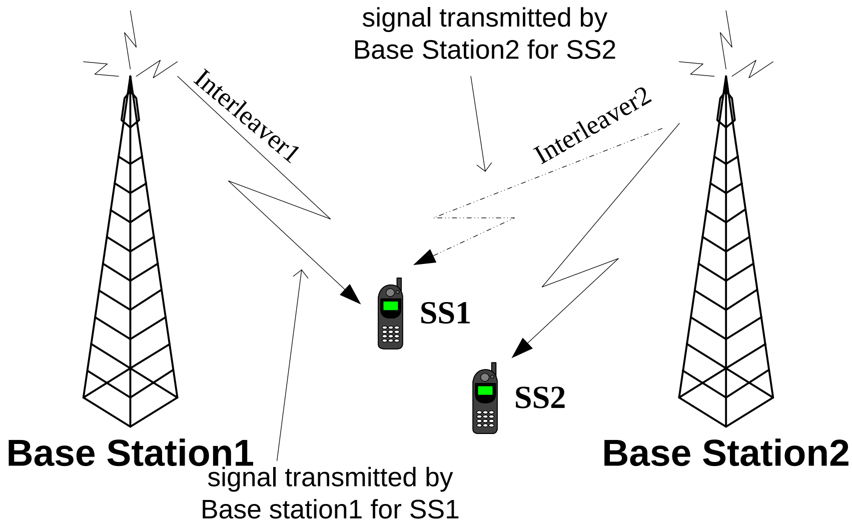

Figure 4. An example of scenario using cell/sector-specific interleaving in downlink.

3.4 Benefit of using cell/sector-specific interleaving

With cell/sector-specific interleaving, different cells/sectors use different interleavers for inter-cell/sector-interference randomization, which aims at randomizing the interfering signal(s) and thus to allow for interference suppression at the receiver in line with the processing gain. All transmitted data on each subband of one cell/sector is interleaved using the cell/sector specified interleaver. The users that are far away from the cell/sector edge may use ordinary detection and decoding algorithm to extract their desired information since they suffer little interference from the adjacent cells/sectors. However, the users at the cell/sector edge may use additional algorithm like iterative multi-user detection algorithm in order for more opportunities to achieve high spectrum efficiency at the cell/sector edge. Using cell/sector-specific interleaving, the frequency resources are reused at the cell/sector edges, e.g., while one base station is transmitting data to a user at the cell/sector edge on some subband, the same subband can also be used by the adjacent cells/sectors without degrading much the performance of the cell/sector-edge user as long as the user has the ability of implementing multi-user detection and interference cancellation.

It is important to note that, as an interference whitening technique, cell/sector-specific interleaving enables frequency reuse among adjacent cells/sectors, no matter which kind of resource allocation scheme is used, and no matter which multiple access technique is used for intra-cell/sector multiple access.

4.0 Generation and allocation of cell/sector-specific interleaver patterns

Usually, an interleaver is used as a component of a channel encoder to enhance the coding gain, or as a channel interleaver to combat the time/frequency coherent fading by scrambling burst errors into random errors. However, cell/sector-specific interleaving can also be used to randomize the inter-cell interference. Simple random interleaving is suitable for the cell/sector-specific interleaving, which can provide sufficient number of interleaver patterns with satisfactory anti-fading performance and correlation property. A method to generate randomized interleaver patterns is introduced below:

Considering an interleaver with length L, and m is the minimum k which satisfies $2^k > L$, we will introduce an positive integer parameter α, which is less than 2^m. The input sequence is $\{x_i\}$, each element can be a coded bit. Let I_j denote the original index of the input sequence for the j^{th} output element, i.e., the output sequence $\{y_j\}$ is $\{y_0 \quad y_1 \quad y_2 \quad \cdots \quad y_{L-1}\} = \{x_{I_0} \quad x_{I_1} \quad x_{I_2} \quad \cdots \quad x_{I_{L-1}}\}$.

Let the m sequence generator with order m be $g_m(x)$, and can be written in binary form g_m, e.g., $g_3(x)=x^3+x^2+1$ can be written as g_m=1101(B).
The I_j, j=0~L-1 can be generated by the following steps, the operator ⊕ means bit-by-bit module 2 sum. a<<b means the left shifting a by b bits. A>>b means the right shifting a by b bits.

```
s=α;
j=0;
for k=0: 2^m-1
        t=s-1;
        if t<L
                I_j=t;
                j=j+1;
        end if;
        if s>>(m-1)==1
                s=(s<<1)⊕g_m;
        else
                s=s<<1;
        end if;
end;
```

Different generating seeds α will lead to different interleaving patterns for different cells. The number of the different interleaver patterns generated with the above method is up to the length of interleaver.
Regarding the allocation of cell/sector-specific interleavers, different interleaver patterns can be allocated to different cells, by generating the interleavers with the corresponding seeds. A base station or subscriber station can identify the interleaver pattern (seed) of each cell by checking its interleaver pattern ID.
In principle, hundreds of distinct seeds can be provided. However, using a distinct pattern for each cell in the system is unnecessary. Hence, it is recommend to reuse a relatively small number of interleaver patterns (seeds) generation seed. The reuse of the seeds can be realized in a manner similar to that of frequency reuse in a cellular system.

5.0 Simulation results

Here we present some simulation results to illustrate the performance of multi-user cell/sector-specific interleaving system. In the following, we first give a performance comparison between cell/sector-specific interleaving -OFDM and OFDM with scrambling under AWGN channel, and then present the performance of cell/sector-specific interleaving -OFDMA system under multi-path channel.

As described above, whitening techniques could be employed in downlink for co-channel reuse between adjacent cells, including cell/sector-specific interleaving system and random scrambling (DS-CDMA). Actually, it is easy to find that the two approaches provide the same performance with single-user detection/decoding. However, their performances with iterate multiuser decoding are substantially different, as shown in the following simulation.

In our simulation, the following parameters are assumed:
Modulation: QPSK
FEC: rate 1/2 or 1/4 convolutional code
Channel: AWGN
User number: 2 or 3
Iteration times: 3

Definition of SNR: received signal power of one user to the noise power
MA methods comparison: cell/sector-specific interleaving, CDMA without repeating (Random scrambling)

Fig. 5 suggests that, if using scrambling for co-channel reuse between two cells, the coding rate should be reduce to 1/4 in order to achieve reasonable BER performance. The total spectral efficiency is: 2cells*(2*1/4)bit/s/Hz/cell=1bit/s/Hz. On the contrary, if cell/sector-specific interleaving is used in the same case, rate 1/2 coding can be used for both the cells. The total spectral efficiency is 2cells*(2*1/2)bit/s/H/cell=2bit/s/Hz, which is twice of that of DS-CDMA.

Fig. 6 shows the co-channel reuse capability of a three-cell system. DS-CDMA system with rate 1/4 code cannot even provide satisfactory performance whereas cell/sector-specific interleaving can still work with rate 1/2 code, resulting a total spectral efficiency of 3bit/s/Hz.

Fig. 7 demonstrates the performance of multiuser system based on cell/sector-specific interleaving will be converge to that of single user in high SNR region, which implies and encourages us to enhance the throughput of users around by using cell/sector-specific interleaving at the cost of affordable complexity.

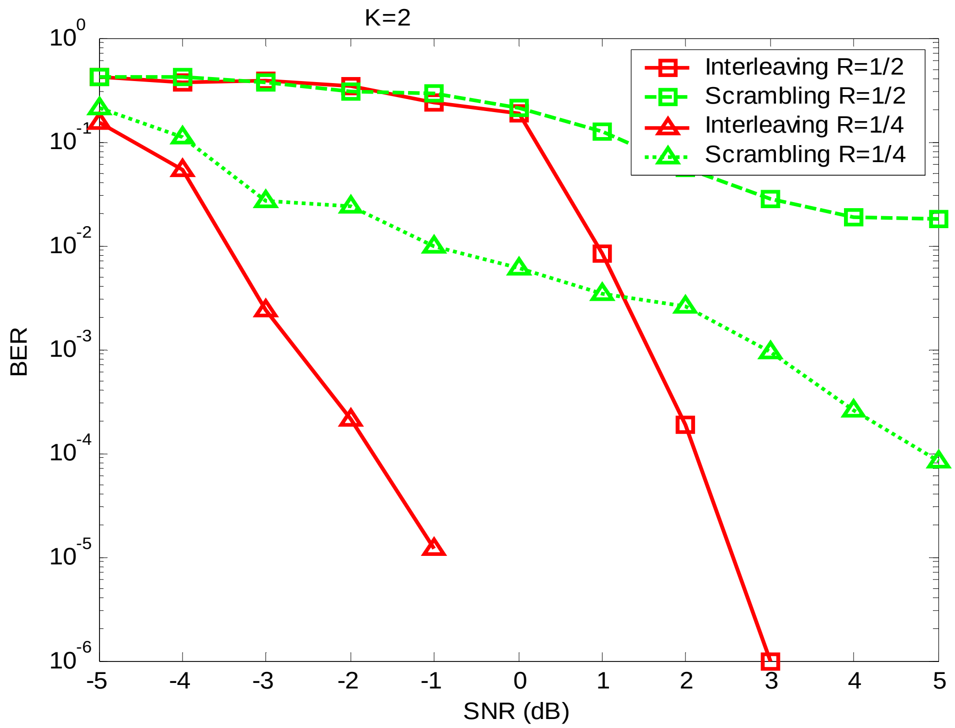

Fig. 5 BER performance Comparison between Scrambling and Interleaving, under the conditions of AWGN channel, Two Users, QPSK, convolutional code with constraint length 5

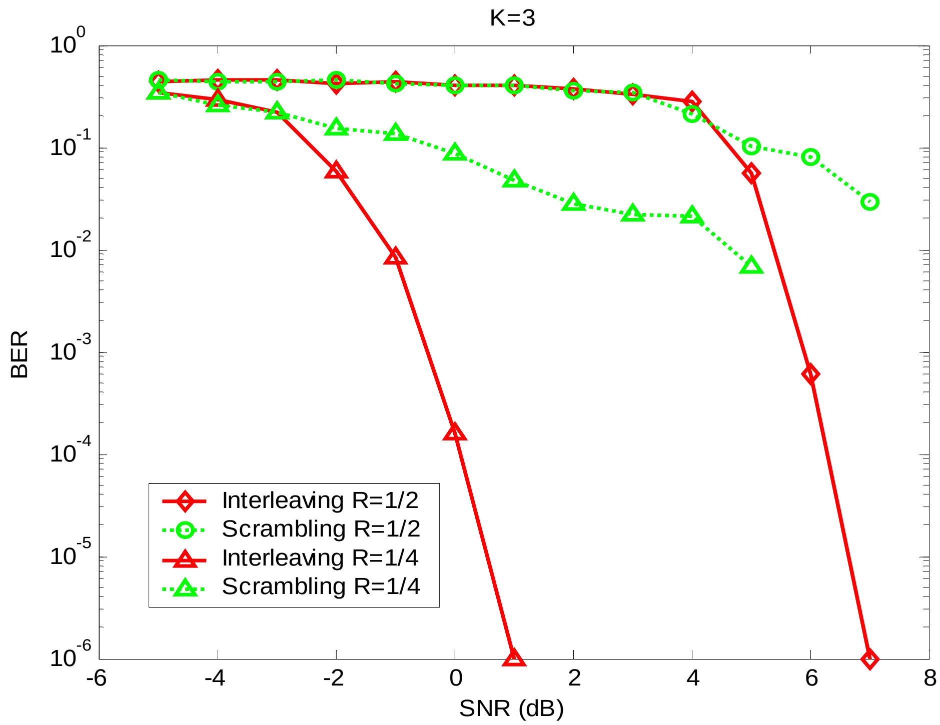

Fig. 6 BER performance Comparison between Scrambling and Interleaving, under the conditions of AWGN channel, Three Users, QPSK, convolutional code with constraint length 5

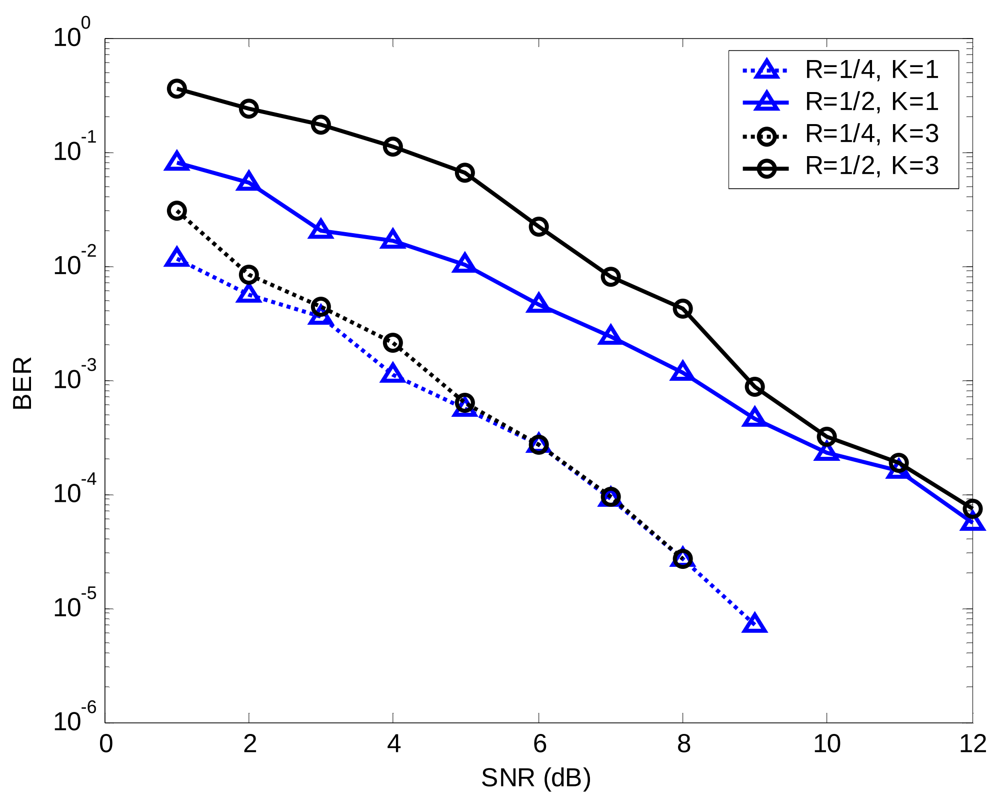

Fig. 7 BER performance Comparison between single user and multi-user (K=3), under the conditions of Rayleigh channel, Three Users, QPSK, convolutional code with constraint length

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6.0 Conclusion

Fundamentally, inter-cell-interference randomization aims at randomizing the interfering signal(s) and thus to allow for interference suppression at the receiver in line with the processing gain.
Methods considered for inter-cell-interference randomization includes:

- *Cell-specific scrambling,* applying (pseudo) random scrambling after channel coding/interleaving
- *Cel/sectorl-specific interleaving,* applying cell/sector-specific interleaving

A third means for randomization is to apply different kinds of frequency hopping.
With regards to inter-cell-interference randomization, cell/sector-specific scrambling and cell-specific interleaving basically have the same performance (regarding inter-cell interference cancellation, see below). A pseudo-random method can be used to generate the cell/sector-specific interleaver patterns. The number of the available patterns (seeds) is determined by the length of interleaver. A SS can identify the interleaver pattern of the cell by checking its interleaver pattern ID. The seeds can be reused between “far-spaced” cells in a manner similar to that of frequency reuse in a cellular system.

7.0 Reference

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Proposed Text for SDD

Section 20.5 should be added to Chapter 20 as written below:

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20.5 Interference mitigation using cell/sector-specific interleaving

Cell/sector specified interleaving maybe be used to randomize the transmitted signal, in order to allow for interference suppression at the receiver in line with the processing gain. Different cells or sectors may use different seeds in generating pseudo random interleavers. This interleaver can be also used as channel interleaver, i.e., it is not necessary to apply additional interleavers for interference randomization.

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