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Title: Inter-cell Interference Handling for E-UTRA
Agenda Item: 10.2
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1. Introduction

The possibility for intra-cell orthogonality, both in uplink and downlink, is supported by most E-UTRA proposals. With orthogonality within the cell, the main interference in an E-UTRA system will be inter-cell interference. It is therefore important to consider what techniques to be used in E-UTRA to handle inter-cell interference.

Three different techniques for mitigating inter-cell interference are discussed in this paper:

- Cell-specific scrambling vs cell-specific interleaving
- Fractional reuse
- Downlink macro diversity

Note that the techniques are not mutually exclusive, but can in many cases be combined.

2. Cell-specific Scrambling/Interleaving for Unicast Transmission

Cell-specific scrambling, briefly illustrated in Figure 1, has been proposed for E-UTRA by several companies as a tool for whitening the inter-cell interference in case of unicast transmission. In principle, scrambling for E-UTRA operates in the same way as for UTRA. Without scrambling, the UE decoder is matched not only to the intended signal, but also to signals intended for users in other cells. This would significantly decrease the performance and scrambling is therefore useful to whiten (randomize) the interference seen by the receiver. The interference suppression capability is proportional to the processing gain, i.e., the code rate of the turbo code in Figure 1. Furthermore, note that scrambling does not affect the bandwidth, i.e., it is *not* a spreading operation. Scrambling can also be applied to the uplink, in which case the scrambling sequence is UE-specific instead of cell-specific.

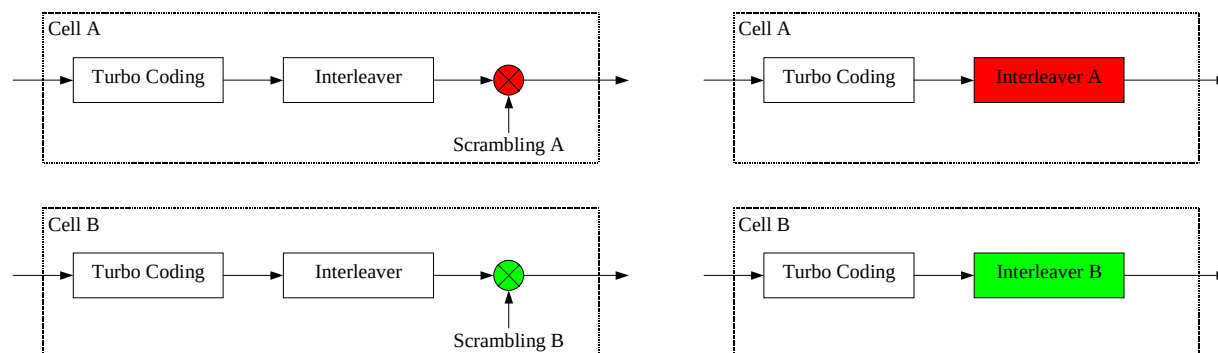


Figure 1: Cell-specific scrambling (left) and cell-specific interleaving (right).

As an alternative to cell-specific scrambling, cell-specific interleaving, also known as IDMA, has been proposed [1]. In this scheme, the signal transmitted in each cell is uniquely interleaved. According to [1], cell-specific interleaving serves two purposes:

- Whitening of the inter-cell interference.
- Improved performance for advanced inter-cell interference cancellation.

On the first aspect, interference whitening of the inter-cell interference, scrambling and interleaving have similar characteristics, although cell-specific scrambling appears somewhat simpler to implement.

On the second aspect, improved performance with advanced interference cancellation, cell-specific interleaving could allow for improved performance with iterative multi-user detection techniques. Such techniques are

interesting and well worth studying further to fully understand the potential gains. For example, techniques to find a sufficiently large number of well-performing interleavers, the performance with Turbo codes in fading channels and methods for reducing the decoder complexity all pose interesting and relevant research problems. The performance in asynchronous networks, when the received signal from the different cells are not time aligned, is another aspect to investigate.

Conclusion: From an interference whitening perspective, the two methods have similar performance and cell-specific scrambling is recommended due to simpler implementation. Cell-specific interleaving with iterative multi-user detection is a promising candidate for further studies.

3. Fractional Reuse

Fractional reuse, also known as soft frequency reuse or interference coordination, has been proposed as a means to increase the performance for cell-edge users [2][3][4]. With fractional reuse, only a part of the total resources is used for transmission to/from cell-edge users, thereby reducing the interference experienced by these users (at the cost of a reduced bandwidth). Typically, fractional reuse is implemented as fractional frequency reuse, although other possibilities may exist as well. Figure 2 illustrates the principle of fractional frequency reuse. In the figure, only cell 1 is allowed to transmit with full power using the “blue” part of the spectrum while cells 2-7 only are allowed to transmit in the blue part of the spectrum using a reduced power. This will reduce the downlink interference seen by cell-edge users served by cell 1. Similarly, cell-edge UEs received by cell 1 will only transmit in the uplink using the blue part of the spectrum in order not to cause excessive interference in cells 2-7. UEs located in the inner parts of cell 1 may use the full part of the spectrum as the attenuation to the other cells keeps the interference at a reasonable level, assuming slow power control combating and log-normal fading path loss.

The radio resources used for transmission to/from UEs in a cell are controlled by the scheduler in the Node B and fractional reuse can therefore be implemented as part of the scheduling decision. Downlink (uplink) fractional reuse can thus simply be seen as constraints to the downlink (uplink) scheduler. The constraints can either be configured semi-statically by a higher node, e.g., the RNC, or derived and continuously updated by the Node B using an adaptive algorithm (self-configuration). The update rate of the scheduler constraints is typically significantly slower than the TTI rate. Note that there is no direct impact on the physical layer to be taken into account in the design of E-UTRA. Finally, note that the use of fractional reuse is a deployment aspect and can be enabled in the cells where it is beneficial without enforcing it in all cells.

Conclusion: Fractional reuse can increase the performance for cell-edge users. It is recommended to support fractional reuse as part of the scheduler operation.

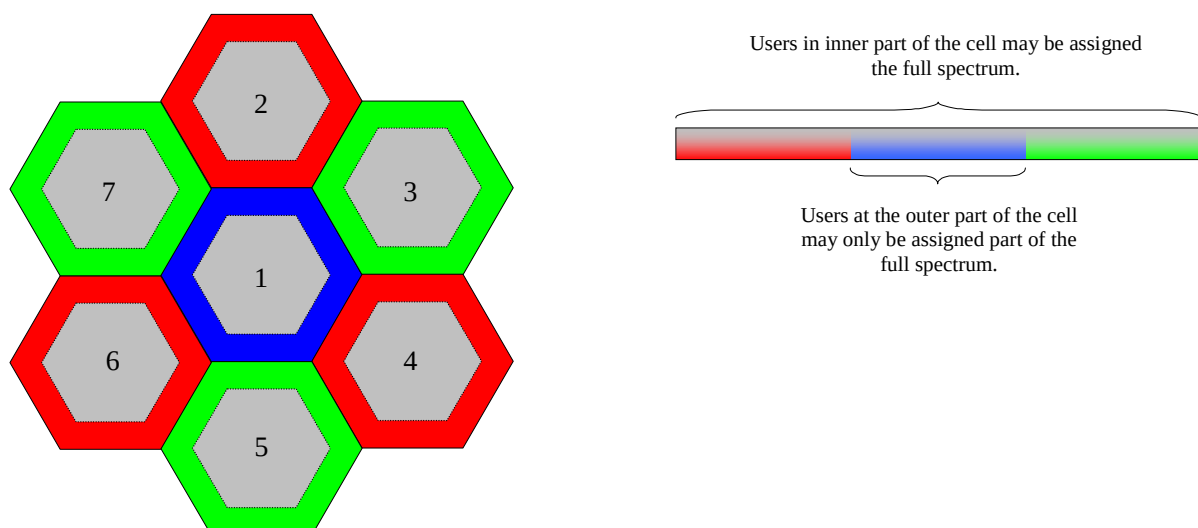


Figure 2: Example illustrating fractional reuse for cell-edge users (a continuous spectrum for the fractional reuse is assumed for illustrative purposes, distributed approaches could equally well be used).

4. Downlink Macro Diversity

Downlink macro diversity may take different forms, depending on the service type (unicast or broadcast/multicast) and the cell structure.

For broadcast (MBMS) services, soft combining of signals transmitted from multiple cells can give a significant performance benefit. A central node (e.g. RNC) distributes the same signal to the Node Bs controlling the cells covering the desired broadcast area. Clearly, it is beneficial if broadcast transmissions in the cells use the same scrambling sequence and are time aligned within the cyclic prefix as the OFDM receiver in this case can exploit the benefits without additional processing.

For unicast transmissions, downlink macro diversity through fast cell selection has been proposed by several companies. In such schemes, the UE provides measurements to the network and, based on this reports, the network transmits unicast data from *one* of the cells in the active set. In conjunction with fast cell selection, it is beneficial to distinguish between intra-Node B and inter-Node B scenarios. In an intra-Node B scenario, all involved cells are controlled by the same Node B, while in the inter-Node B scenario, two or more Node Bs are involved. This leads to significant differences on the switching rate:

- Intra-Node B cell selection is straightforward as the same scheduler can handle all the involved cells and in principle the cell selection mechanism can operate on a TTI basis, thus exploiting variations in the instantaneous channel quality.
- Inter-Node B cell selection involves multiple Node Bs and cannot be as fast as there is a need to move the scheduling responsibility to a new Node B. The situation thus resembles hard handover for mobility reasons and the decision to switch cell is based on the long-term average channel quality.

Note that a Node B is a *logical* node and may or may not correspond to a three-sector site as illustrated in Figure 3. Hence, fast cell selection is *not* constrained to sector selection in a three-sector site only.

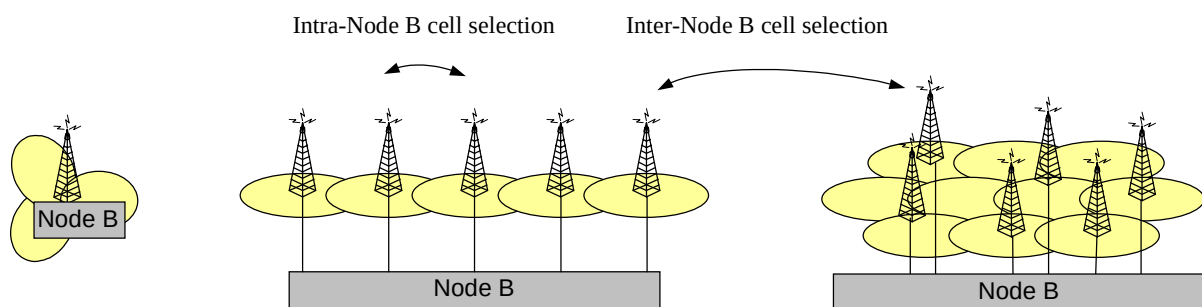


Figure 3: Examples of different deployments.

As an alternative or complement to fast intra-Node B cell selection, downlink intra-Node B soft combining has been proposed [5]. With downlink intra-Node B soft combining, the same signal is simultaneously transmitted to a single UE from multiple cells controlled by the same Node B. The benefit of soft combining is that the overall transmit power used for transmission to a single UE can be increased, leading to an improved link budget and thus the possibility for higher downlink data rates for UEs at the cell border.

At least two different approaches to downlink soft combining can be envisioned:

- **Alternative 1 (implementation approach):** In addition to the same data transmission, identical UE-specific reference signals are transmitted from each of the involved cells. In this case, multi-cell transmission will look exactly as a transmission from a single cell using a dynamic beam [6]. Thus, under the assumption that E-UTRA should anyway support adaptive beam forming, no additional specification is needed to support downlink multi-cell transmission. As the reference signal in the resulting beam only is present when data is transmitted, the Node B has to derive an estimate of the channel quality in the composite beam based on the CQI reports for each individual cell. In this alternative, soft combining of the transmission is obtained “for free”, similarly to the case for MBMS
- **Alternative 2 (specification approach):** The UE relies on the (static) cell-specific reference signals for channel estimation [6]. In this case, the UE need to perform channel estimation and demodulation individually for each cell, followed by soft combining in the UE. Hence, additional specifications are needed.

Assuming that adaptive beam forming is to be supported by E-UTRA, alternative 1 is implicitly supported. Hence, the study item should therefore investigate whether there are sufficiently large performance gains with alternative 2 to motivate the additional specification and UE implementation effort.

Conclusion: For broadcast/multicast services, it should be possible to transmit identical (time-aligned) signals from multiple cells to support soft combining. For unicast services, fast intra-Node B cell selection should be supported. Assuming support for adaptive beam forming, unicast soft combining is implicitly supported. Further studies are needed to investigate whether explicit support of unicast soft combining is required.

5. Conclusion

Based on the above discussion, the following conclusions are made:

- Cell-specific scrambling and cell-specific interleaving have similar characteristics regarding interference whitening and cell-specific scrambling is recommended due to its simpler implementation.
- Fractional reuse can increase the performance for cell-edge users. It is recommended to support fractional reuse as part of the scheduler operation.
- For broadcast/multicast services, it should be possible to transmit identical (time-aligned) signals from multiple cells to support soft combining.
- For unicast services, fast intra-Node B cell selection should be supported. Assuming support for adaptive beam forming, unicast soft combining is implicitly supported. Further studies are needed to investigate whether explicit support of unicast soft combining is required.

6. References

- [1] R1-050608, "Inter-cell Interference Mitigation based on IDMA", RITT
- [2] R1-050476, "Evolved UTRA uplink scheduling and frequency reuse", Siemens
- [3] R1-050593, "Interference coordination for evolved UTRA uplink access", Alcatel
- [4] R1-050629, "Inter-cell Interference Mitigation", Huawei
- [5] R1-050615, "Investigations on Inter-Sector Diversity in Evolved UTRA Downlink", NTT DoCoMo
- [6] R1-050769, "Downlink reference signal aspects for E-UTRA", Ericsson