Extended Synchronization Signals for Eliminating PCI Confusion in Heterogeneous LTE

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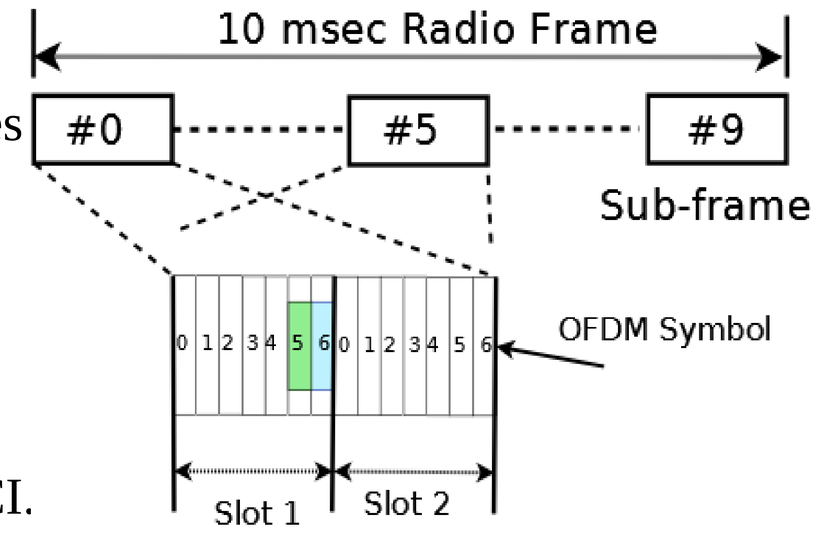
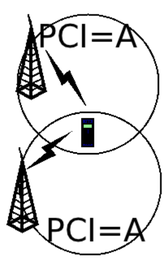
Introduction

- **Heterogeneous LTE** features extensive deployment of overlapping base stations with different footprints and capabilities
- **PCI (Physical Cell Identity)** represents a physical layer cell identifier required for network access and mobility procedures.
- Each base station (BS) periodically advertises two **synchronization signals (PSS and SSS)** in each LTE frame for synchronization and cell identification purposes.
- Once the MT decodes the PSS and SSS, it determines the cell PCI.
- The standards defines 504 PCIs as a combination of SSS (168 alternatives) and PSS (3 alternatives)

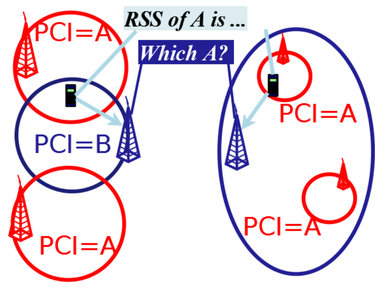


System Design Requirements

PCI Collision Free



PCI Confusion Free



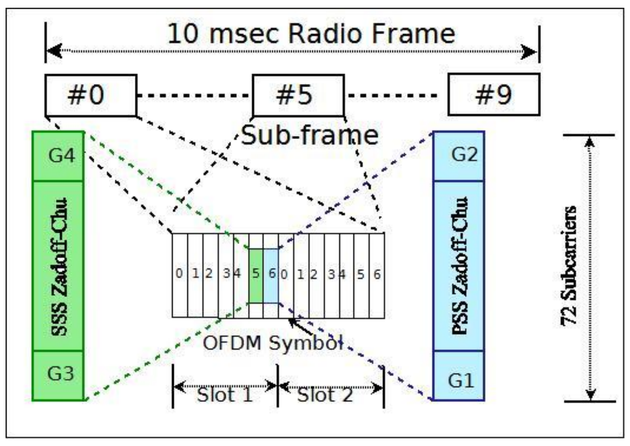
- In Heterogeneous-LTE, PCI design requirements seems to be unavoidable.

PCI Confusion Avoidance Approaches

- **Using additional identifier** such as the global cell identifier
  - Requires reading system information. Master information Block (MIB) is advertised over 40ms and SIB advertised over 80+ms
  - Risk the performance of real-time applications.
- **Segmenting the PCI range**
  - Femtocells has three access modes: closed, open, hybrid
  - Shrinking the PCI range of femtocells would magnify the problem of PCI confusion.

Extended Synchronization Signals (ESS)

- Introduce additional information about the femtocells in the physical layer.
- Currently, PSS and SSS use 62carriers of the available 72carriers in the LTE frame.
- Using ESS, one can add up to 40 additional information bits each frame.
- We propose sending 20 information bits with repetition to speed acquiring information.



SS

Extended Information bits

- One bits for femto access mode (1 → closed access, 0 → open/hybrid access). This bit targets reducing mobility signaling overhead.
- 19 least significant bits if the global cell identifier.
- Other designs for information bits can be used
- ESS can still be used with PCI range segmentation.
- ESS is compatible with legacy devices.

PCI Planning

- ESS works for both centralized and distributed PCI planning.
- In centralized planning, the central entity assignments ensure no PCI confusion
- In distributed planning, the ESS significantly reduces the PCI confusion probability.

Handoff Delay Analysis

- Cell search delay (d_s) [2.5 +5 = 7.5ms]
- measurement delay (d_m) [0.25ms]
- reading system information delay (d_i) [20+40=60ms]
- handover messages propagation delay (d_m) [20ms]
- processing delay (d_p) [5ms]

$$d_h^{BSS} = d_s + d_m + d_i + d_l + d_p \approx 92.75ms$$

$$d_h^{ESS} = d_s + d_m + d_l + d_p \approx 32.75ms$$

Confusion Probability Reduction

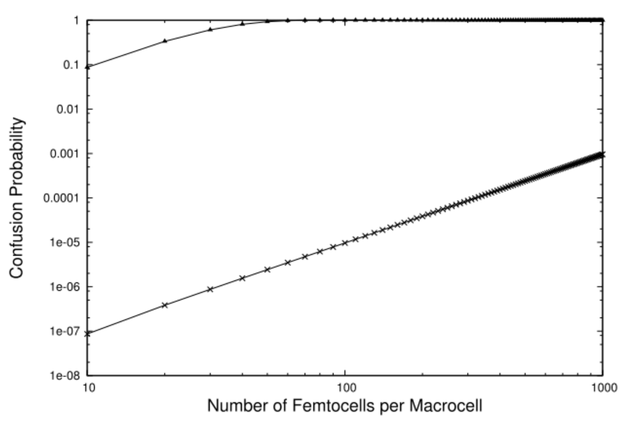
The confusion probability $P_c = 1 - \overline{P_c}$

- BSS: two or more femtocells use the same PCI under the same macrocell coverage

$$\overline{P_c^{BSS}} = \left\{ \begin{array}{cc} \frac{{}^{n_c}P_{n_f}}{n_c^{n_f}} & , n_f \leq n_c \\ 0 & , n_f > n_c \end{array} \right\}$$

- ESS: two or more femtocells have the same PCI, the same access mode bit and identical 19 least significant bits of GCI.

$$\overline{P_c^{ESS}} = \left\{ \begin{array}{cc} (\alpha^2 + (1-\alpha)^2)\frac{{}^{(n_c n_{id})}P_{n_f}}{(n_{id} n_c)^{n_f}} & , n_f \leq n_c n_{id} \\ 0 & , n_f > n_c n_{id} \end{array} \right\}$$



n_f number of femtocells in a macrocell
n_c the cardinality of Ω_c
α probability of closed access mode
n_{id} number of possible combinations of

Conclusions

- PCI confusion seems unavoidable in dense femtocell deployment.
- The proposed ESS framework
  - reduces both handoff delay and the probability of PCI confusion in distributed planning
  - ESS practically eliminates PCI confusion for centralized planning
  - reduces unnecessary signaling load.

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