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Inter-Cell Interference Control in Heterogeneous Access Networks

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Outline

- Concept of Heterogeneous Networks (HetNets)
- Technical challenges in HetNets
- Interference coordination in Heterogeneous LTE-Advanced Access Networks
  - Interference scenarios in Heterogeneous LTE-Advanced Access Networks
  - Enhanced Inter-Cell Interference Coordination (eICIC) methods in HetNets (3GPP Rel. 10)
- Dense small cell deployment and interference mitigations through dynamic channel allocation
- A tool to study interference control in HetNets
- Conclusions
- References
- Acknowledgement

What is HetNet?

- HetNet could mean a network comprising of different RATs (WiFi, GSM, UMTS/HSPA, LTE, WiMAX)
- In LTE-Advanced term, a HetNet also means a network consisting macrocell, microcell, picocells, RRHs (Remote Radio Heads), femtocells, as well as relay stations.
  - These low-power overlaid Base Stations (BSs) can be either operator deployed or user deployed, and may coexist in the same geographical area, potentially sharing the same spectrum with macrocells.
- This talk focuses on HetNets with different types of access nodes

Why is HetNet important?

- Provide a cost effective roll-out plan with much reduced financial risks for operators.
  - E.g., a green field cable operator can deploy a femto alone network
- Deliver a seamless user experience across outdoor and indoor environments.
- Different RATs (Radio Access Technologies) are designed for different purposes, so are different types of access nodes.
  - One-size-fit-all approach does not work well.

Classification of HetNet access nodes in LTE-A

TABLE I
SPECIFICATION OF DIFFERENT ELEMENTS IN HETNET [1]

Types of nodes	Transmit Power	Coverage	Backhaul
Macrocell	46 dBm	Few km	S1 interface
Picocell	23-30 dBm	<300 m	X2 interface
Femtocell	<23 dBm	<50 m	Internet IP
Relay	30 dBm	300 m	Wireless
RRH	46 dBm	Few km	Fiber

[1] D. Lopez, I. Guvenc, G. de la Roche, M. Kountouris4, T. Q.S. Quek, **J. Zhang**, "Enhanced Inter-Cell Interference Coordination Challenges in Heterogeneous Networks", *IEEE Wireless Communications*, June 2011.

Technical challenges of HetNets

- **Interference**
- Mobility management and handover
- Self-organization
- Backhauling (4G: peak data rate 1Gbps; B4G > 10 Gbps)

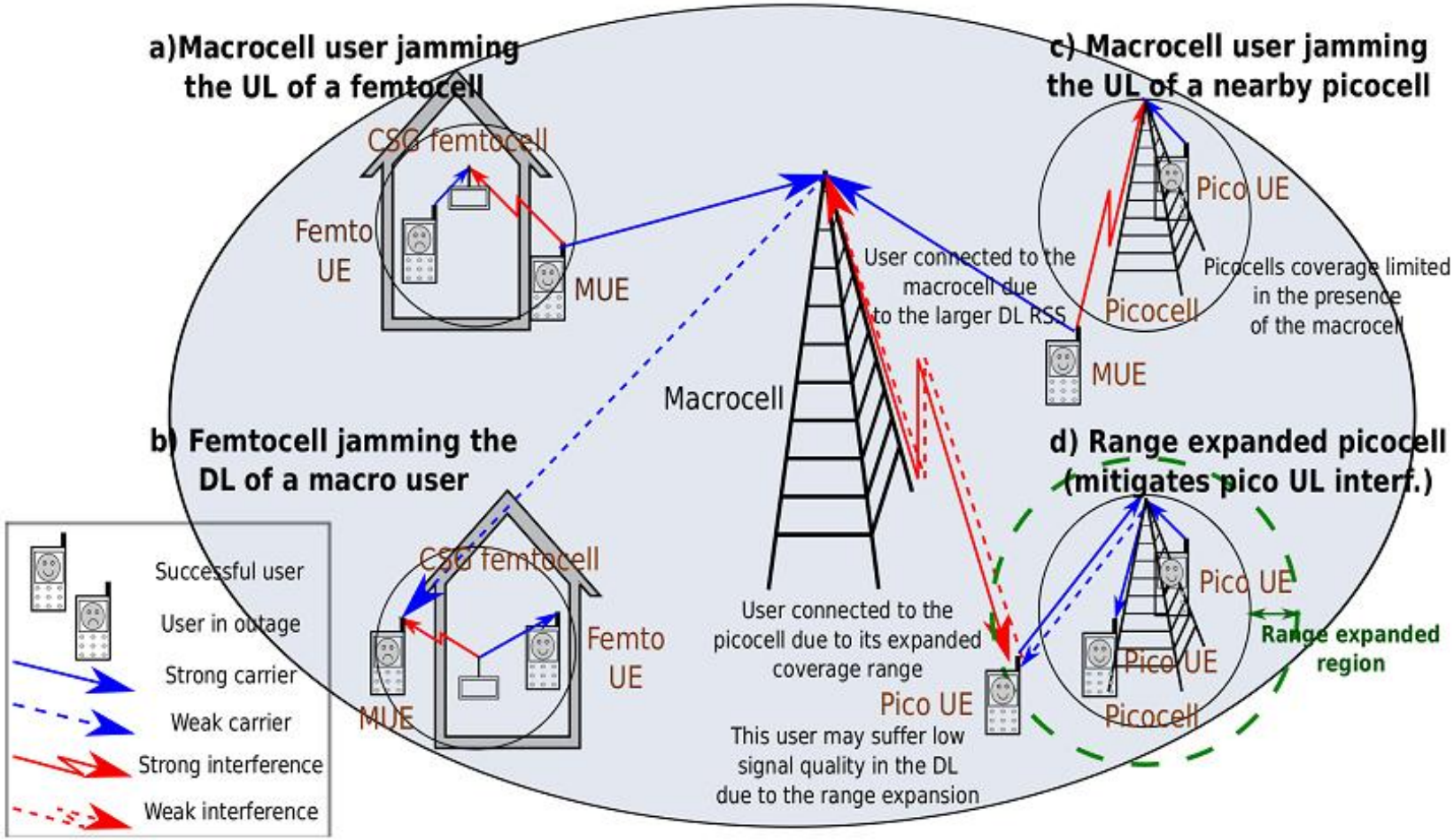
Technical challenges-Interference

- More random
- Dense
- CSG
- Power difference between nodes
- The backhaul network supporting different types of cells may have different bandwidth and delay constraints. E.g., femtocells are unlikely to be connected directly to the core network and thus only **limited backhaul signalling for interference coordination is possible**.

Source of Interference in HetNets

- **Range expanded users**:
  - To address the problems arising due to the power difference between the nodes in HetNets, new cell selection methods that allow user association with cells that provide a weaker DL pilot signal quality are necessary.
  - An approach under investigation is that of range expansion, in which an offset is added to the picocell's (or relay's) RSS in order to increase its DL coverage footprint. Even though range expansion significantly mitigates cross-tier interference in the UL, this comes at the expense of reducing the DL signal quality of those users in the expanded region.
  - Such users may suffer from DL SINRs below 0 dB since they are connected to cells that do not provide the best DL RSS.

Fig. 1 - Dominant DL and UL cross-tier interference scenarios in HetNets



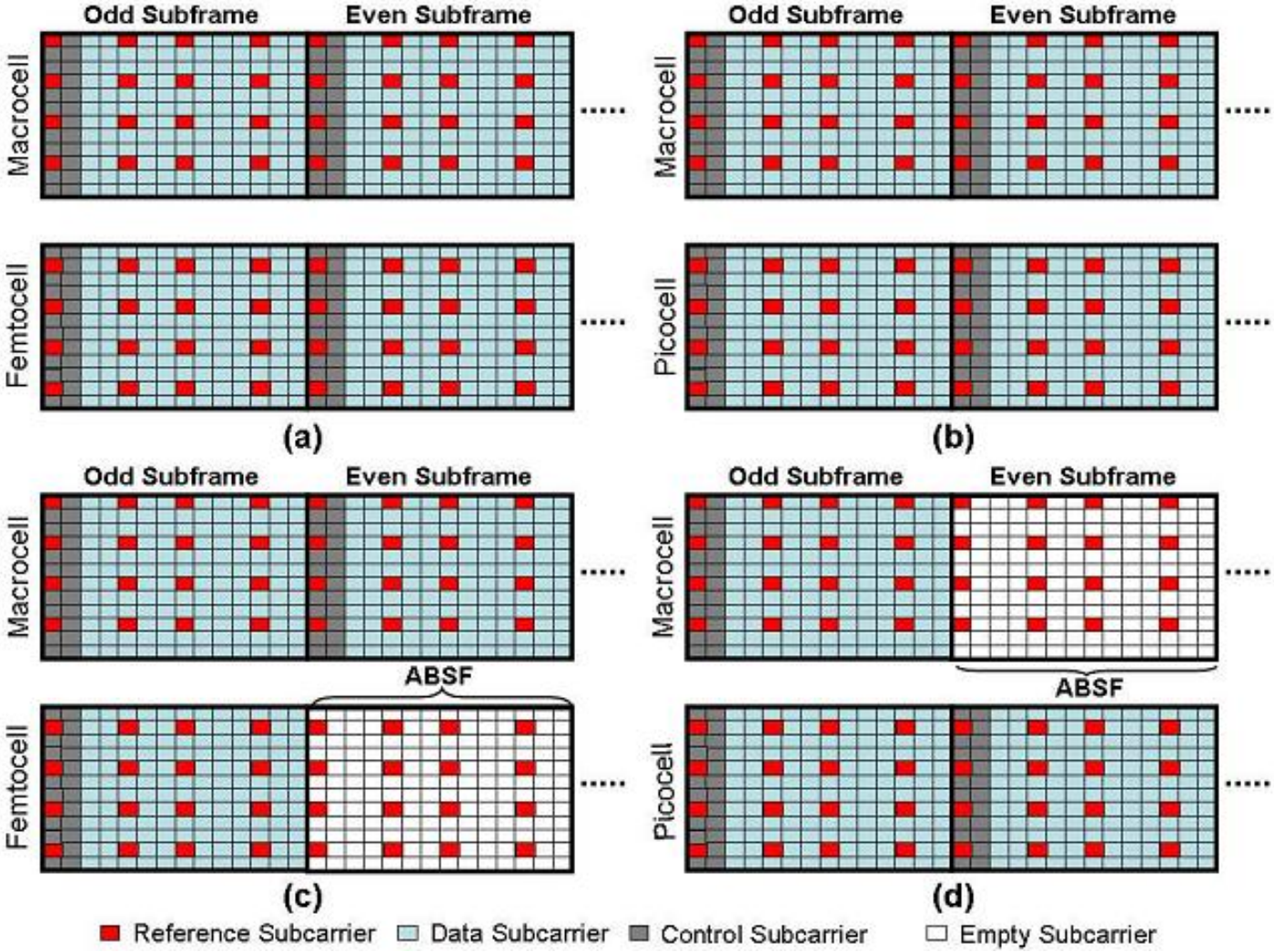
Standardization for HetNet eICIC

- The ICIC methods specified in Rel. 8 and Rel. 9 do not specifically consider HetNet settings and may not be effective for dominant HetNet interference scenarios (Fig. 1).
- In order to address such dominant interference scenarios, ***enhanced Inter-Cell Interference Coordination (eICIC)*** techniques were developed for Rel. 10, which can be grouped under three major categories according to:
  - Time-domain techniques.
  - Frequency-domain techniques.
  - Power control techniques.

eICIC – Time Domain Techniques: Subframe alignment

- **Almost Blank Subframes (ABSFs)** at femtocells
  - As shown in Fig. 2(c). In the ABSFs, no control or data signals, but only reference signals are transmitted.
- When there are MUEs in the vicinity of a femtocell, they can be scheduled within the subframes overlapping with the ABSFs of the femtocell, which significantly mitigates cross-tier interference.
- Similar eICIC approach using ABSFs can also be used to mitigate interference problems in **picocells (and relays)** that implement range-expansion.
  - When no interference coordination is used for range-expanded picocell users (Fig. 2(b)), they observe large DL interference from the macrocell. The interference problem can be mitigated **through using ABSFs at the macrocell**, and scheduling range-expanded picocell users within the subframes that are overlapping with the ABSFs of the macrocell.

Fig. 2 - ABSFs for time-domain eICIC for HetNets



eICIC – Frequency Domain Techniques

- In frequency-domain eICIC solutions, control channels and physical signals (i.e., synchronization signals and reference signals) of different cells are scheduled in **reduced bandwidths** in order to have totally **orthogonal transmission of these signals at different cells**. While frequency-domain orthogonalization may be achieved in a static manner, it may also be implemented dynamically through victim UE detection.
- For instance, victim MUEs can be determined by the macro eNBs by utilizing the measurement reports of the MUEs, and their identity may be signaled by the macro eNB to the home eNB(s) through the backhaul. Alternatively, victim MUEs may also be sensed by the home eNBs.

eICIC – Power Control Techniques

- Apply different power control techniques at femtocells.
  - While reducing the radiated power at a femtocell also reduces the total throughput of femtocell users, it may significantly improve the performance of victim MUEs.
- Let P_{max} and P_{min} denote the maximum and minimum home eNB transmit powers, respectively, P_M denotes the received power from the strongest co-channel macro eNB at a home eNB, α and β denote two scalar power control variables.
- Then, four different DL power control approaches at femtocells can be listed as follows (all values are in dBm) :

HetNet eICIC – Power Control Techniques

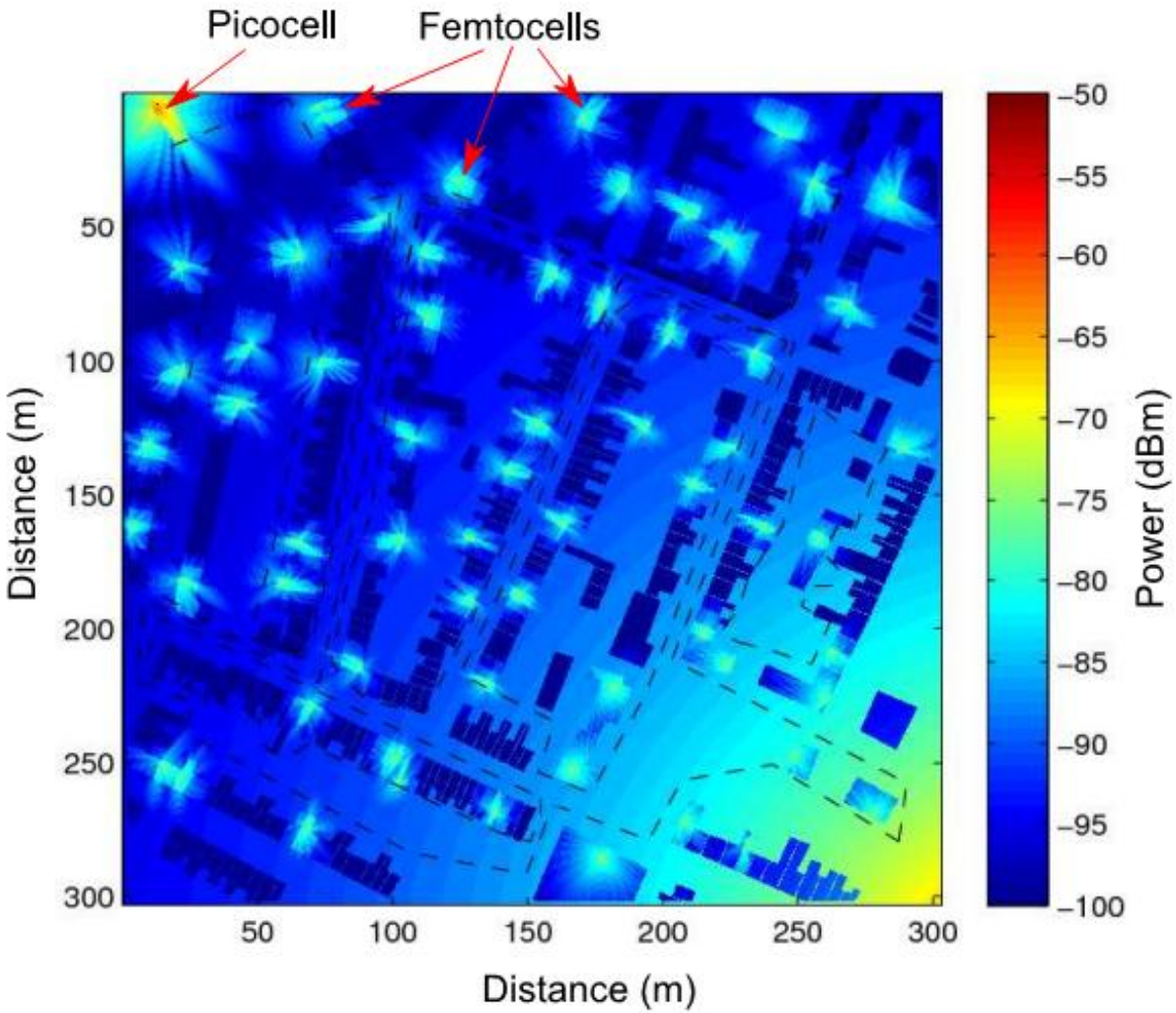
1) *Strongest macro eNB received power at a home eNB:* The femtocell transmission power can be written as $P_{\mathrm{tx}} = \max\left(\min(\alpha P_{\mathrm{M}} + \beta, P_{\max}), P_{\min}\right)$.
2) *Path loss between a home eNB and MUE:* The home eNB transmission power can be set as $P_{\mathrm{tx}} = \mathrm{med}\left(P_{\mathrm{M}} + P_{\mathrm{ofst}}, P_{\max}, P_{\min}\right)$, where the power offset is defined by $P_{\mathrm{ofst}} = \mathrm{med}\left(P_{\mathrm{ipl}}, P_{\mathrm{ofst-max}}, P_{\mathrm{ofst-min}}\right)$, with P_{ipl} denoting a power offset value that captures the indoor path loss and the penetration loss between home eNB and the nearest MUE, and $P_{\mathrm{ofst-max}}$ and $P_{\mathrm{ofst-min}}$ denote the minimum and maximum values of P_{ofst}, respectively.
3) *Objective SINR of HUE:* In this approach, the received SINRs of home eNB users (HUEs) are restricted to a target value and transmit power at a femtocell is

HetNet eICIC – Power Control Techniques

reduced appropriately to achieve this target SINR using the following expression: $P_{\mathrm{tx}} = \max\left(P_{\min}, \min\left(\widehat{PL} + P_{\mathrm{rec,HUE}}, P_{\max}\right)\right)$, where $P_{\mathrm{rec,HUE}} = 10\log_{10}\left(10^{I/10} + 10^{N_0/10}\right) + \mathrm{SINR}_{\mathrm{tar}}$, with I being the interference detected by the served UE, N_0 is the background noise power, $\mathrm{SINR}_{\mathrm{tar}}$ is the target SINR for the HUE, and $\widehat{PL}$ is the path loss estimate between the home eNB and the HUE.

4) *Objective SINR of MUE:* The goal of this approach is to guarantee a minimum SINR at the MUEs, and the home eNB transmit power is given by $P_{\mathrm{tx}} = \max\left(\min(\alpha P_{\mathrm{SINR}} + \beta, P_{\max}), P_{\min}\right)$, where P_{SINR} is the SINR of the MUE considering only the nearest femtocell interference.

Fig. 3 - Simulation set up



Simulation set up

- The scenario is a residential area of size 300m × 300m in Luton (UK), containing 400 houses of which 63 were selected to host a CSG femtocell
  - Assuming 3 operators with equal customer share, this corresponds to an approximate 50% femto penetration.
- The scenario is also covered by one macrocell located 200m south and 200m east from the scenario's center, and one picocell deployed at the macrocell edge.
- Both macrocell and picocell operate in open access.
- Eight VoIP mobile users move along predefined paths according to a pedestrian model of mean speed 1.1m/s.

Simulation set up

- The picocell and the femtocells are fully loaded and therefore utilize all subcarriers.
- The cell power is uniformly distributed between subcarriers, and a pedestrian user carrying a VoIP service is considered to fall in outage if it cannot receive control data (i.e., user SINR is smaller than −4 dB for a time interval of 200ms).

Macrocell - Femtocell Interaction

- Fig. 4 illustrates the SINR of a pedestrian user when passing by the front door of two different houses hosting a femtocell.
- It can be seen that when no action is taken at the femtocells (no eICIC), the SINR of the pedestrian user significantly falls due to the cross-tier interference, thus resulting in UE outage.
- On the other hand, when eICIC is applied, the MUE SINR recovers and outages vanish.
  - In this case, an eICIC action is triggered by the macrocell in the femtocells when MUEs report low signal quality using channel quality indicators, i.e., user SINR smaller than -3 dB.

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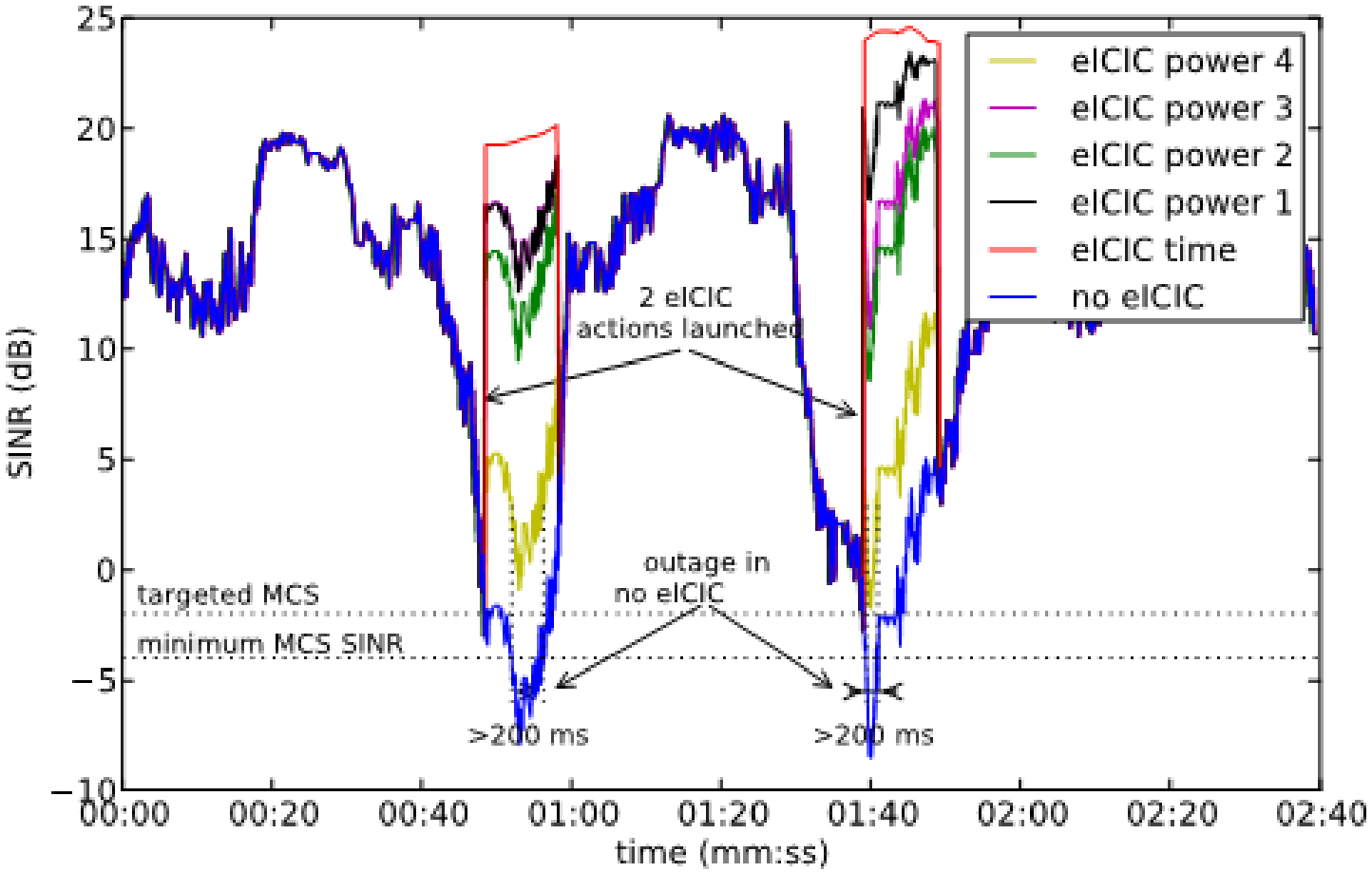
Fig. 4 SINR versus time of a victim MUE when passing close to two houses hosting a CSG femtocell.



Macrocell - Femtocell Interaction

- The *ABSF eICIC time* method provides the best MUE protection since those subframes overlapping with the ABSFs of femtocells are not interfered. The different eICIC power methods result in distinct levels of signal quality protection for the victim MUE.
- The behavior of these eICIC techniques depends on their nature and tuning, but there is always a tradeoff between the performance of both victim MUE and aggressing femtocell.

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TABLE II

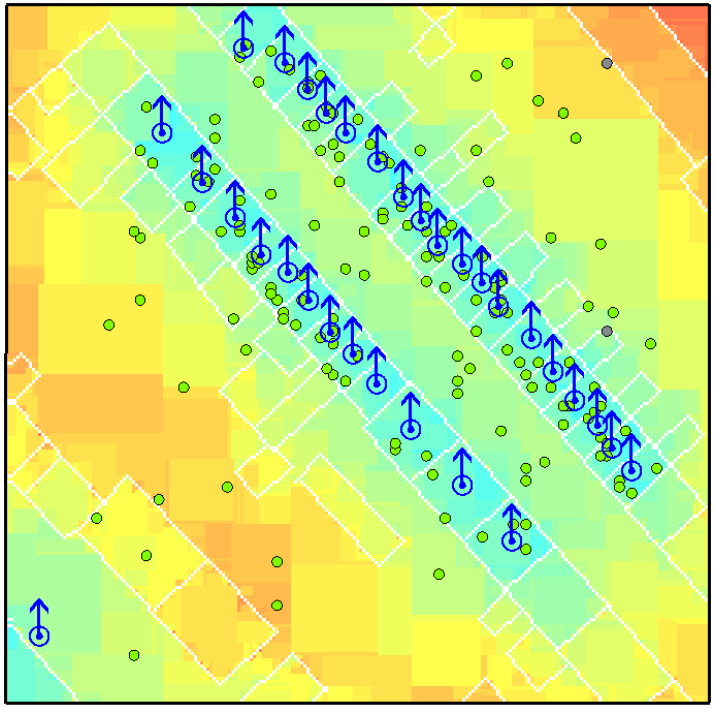
PERFORMANCE COMPARISON (600 SEC SIMULATION)

eICIC methods	Number of macro-pico HOs	Number of PUE outages	Number of MUE outages	Average eICIC TP gain at a femto [Mbps]	Average sum TP of pedestrian users [kbps]	Average sum TP of femtocell tier [Mbps]	*eICIC actions / femto·10 min*
no eICIC	5	5	267	73.32(100 %)	156.03	3974.25	-
eICIC time	5	0	0	0 (0 %)	2158.82	2990.50	14.81
eICIC power 1 $\alpha = 1, \beta = 60\text{dB}$	5	0	0	11.02 (15.03 %)	1937.26	3153.88	14.81
eICIC power 1* $\alpha = 1, \beta = 75\text{dB}$	5	0	25	46.49 (63.41 %)	1139.20	3725.88	56.23
eICIC power 2	5	0	0	34.49 (47.03 %)	1499.30	3558.75	20.80
eICIC power 3 $\text{SINR}_{\text{tar}}^{\text{FUE}} = 0\text{dB}$	5	0	0	22.55 (30.75 %)	1626.61	3333.75	17.47
eICIC power 3* $\text{SINR}_{\text{tar}}^{\text{FUE}} = 5\text{dB}$	5	0	19	33.74 (46.02 %)	1281.21	3520.75	47.52
eICIC power 4 $\text{SINR}_{\text{tar}}^{\text{MUE}} = 5\text{dB}$	5	0	0	33.74 (66.05 %)	1183.35	3751.13	39.78

System Level Femtocell Simulation

- Example: Feasibility of OFDMA WiMAX Femtocells

- **Traffic, mobility and user repartition.**
- **Computation of interference matrix.**
- **Optimization method for frequency planning.**
- **Computation of user data rates.**
- **Test of different allocation/density/access method scenarios.**



Sub-channel allocation strategies

- Same Channel (Worst Case)
- Random
  - Without knowledge of the macrocell sub-channels
  - Taking into account the macrocell sub-channels
- FRS 1X1X3 (1 BS *1 Cell * 3 Frequencies)
- Optimization method
  - Only femto
  - Femto and macro

DFP (Dynamic Frequency Planning)

- Minimization Problem and Constraints

The problem is to:

$$\min \sum_{i \in N} \sum_{j \in N} \sum_{k \in NF} \frac{W_{ij}}{D_i \cdot D_j} y_{i,j,k}$$

subject to:

$$\sum_{k=0}^{NF} x_{i,k} = D_i \quad \forall i,k$$

$$y_{i,j,k} \geq x_{i,k} + x_{j,k} - 1 \quad \forall i,j,k$$

$$y_{i,j,k} \geq 0 \quad \forall i,j,k$$

$$x_{i,k} \in \{0,1\} \quad \forall i,k$$

N number of sectors, $\{1, \ldots n_i, \ldots N\}$

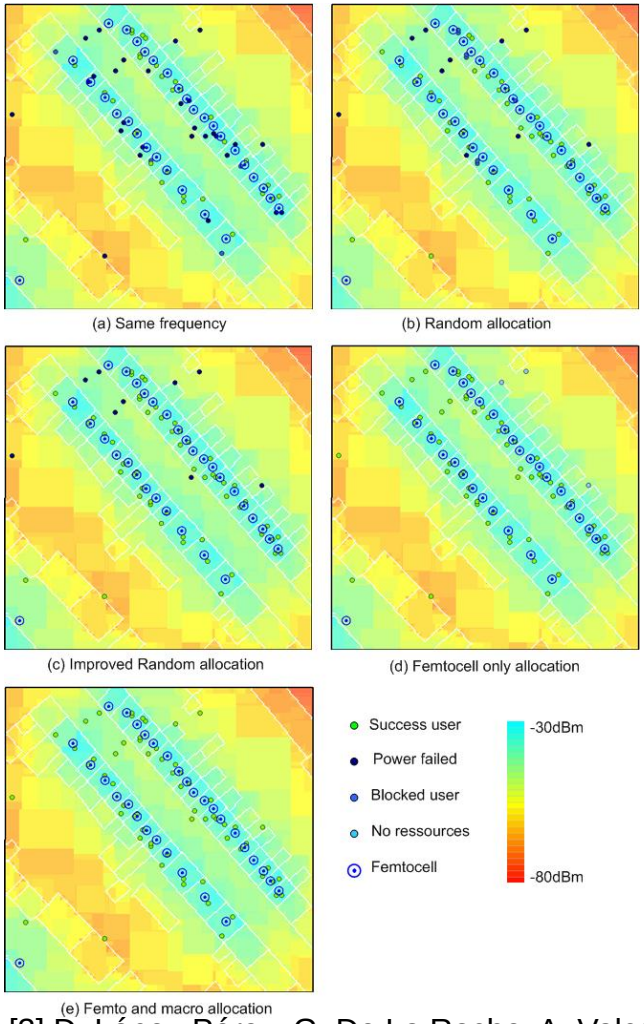
NF number of subchannels, $\{1, \ldots f_{k,} \ldots NF\}$

D_i requested subchannels by the i-sector

$W_{i,j}$ interference restriction between the i-sector and the j-sector

$$x_{i,k} \begin{cases} 0, \text{ the i-sector is not using the k-frequency} \\ 1, \text{ the i-sector is using the k-frequency} \end{cases}$$

Sub-channel allocation strategies results [3]



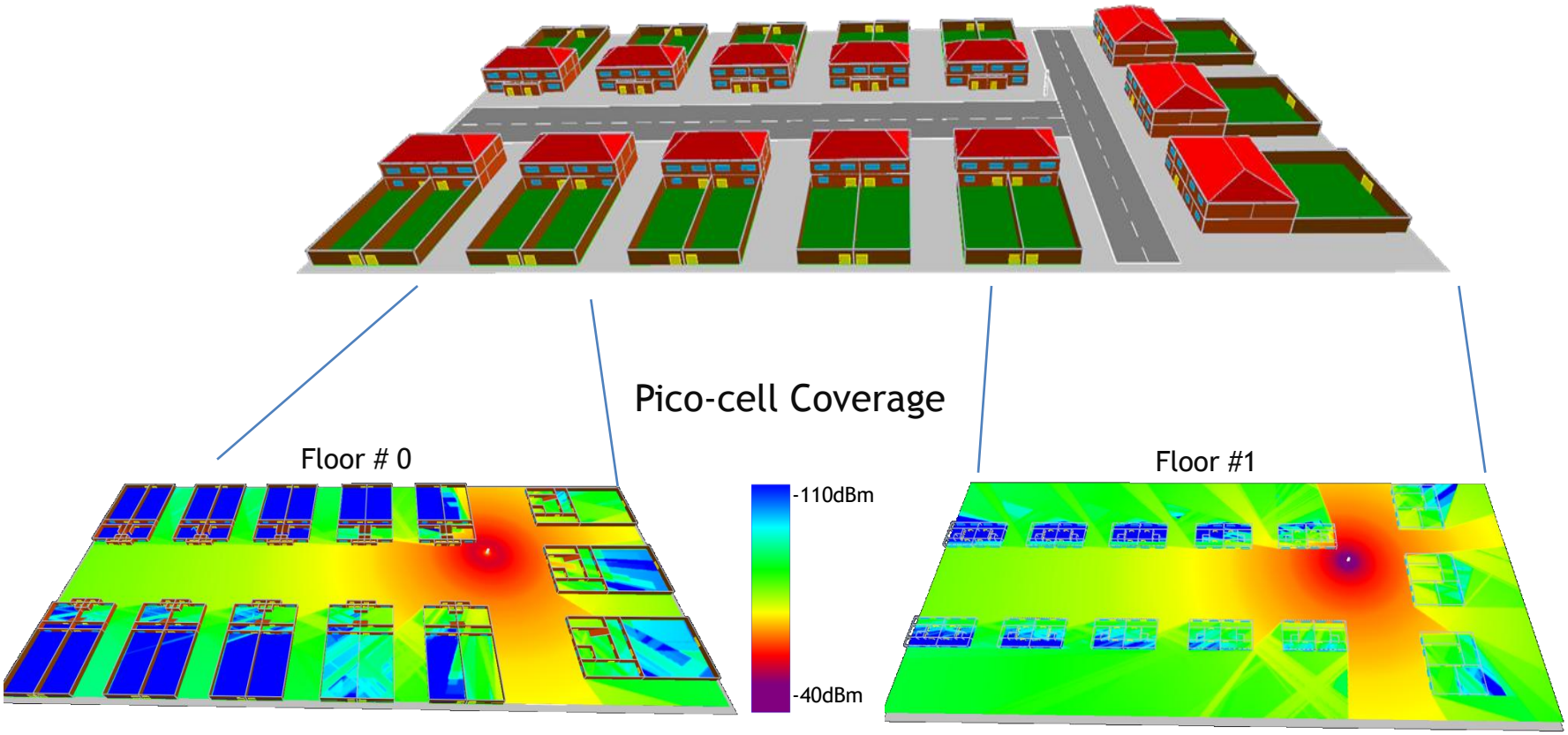
method	Cost function	Throughput kbps
Same channel	2256.0	3168.0
Unlucky random	607.9	4752.0
Lucky randon	325.7	5702.0
FRS 1X3X1	143.5	5913.6
Optim femto	22.5	6336.0
Optim femto &macro	12.5	6652.8

[3] D. López-Pérez, G. De La Roche, A. Valcarce, A. Jüttner, **J. Zhang**, “Interference Avoidance and Dynamic Frequency Planning for WiMAX Femtocells Networks,” IEEE International Conference on Communication Systems, November 2008.

Femto Deployment in a UK Residential Area (1/5)

Typical Scenario in Luton, UK – Pico cell coverage

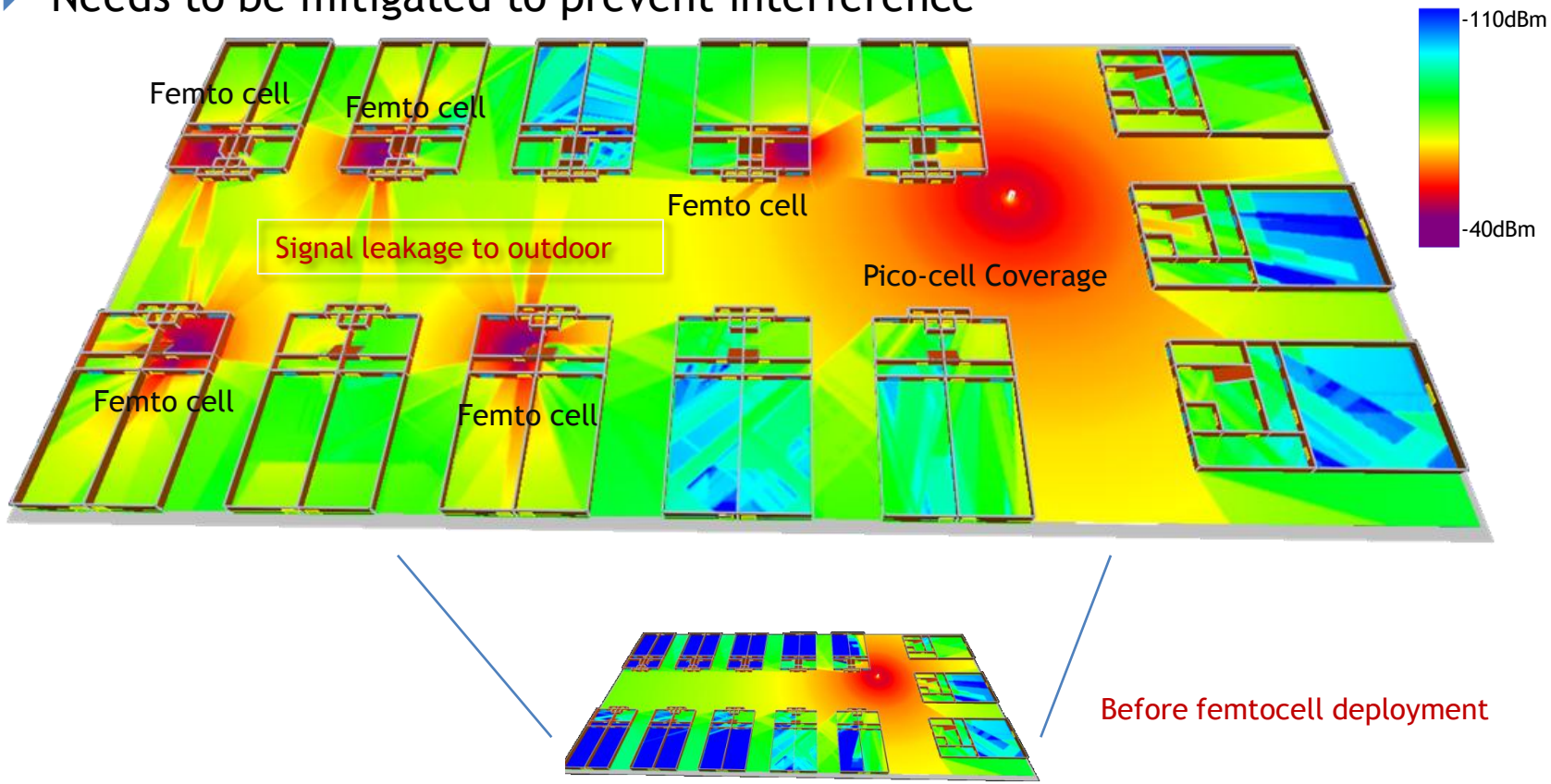
- Pico cell + Femto cell co-deployment
  - Pico cell for outdoor coverage
  - Femto cell for indoor coverage



Femto Deployment in a UK Residential Area (2/5)

Typical Scenario in Luton, UK - pico cell + femto cell

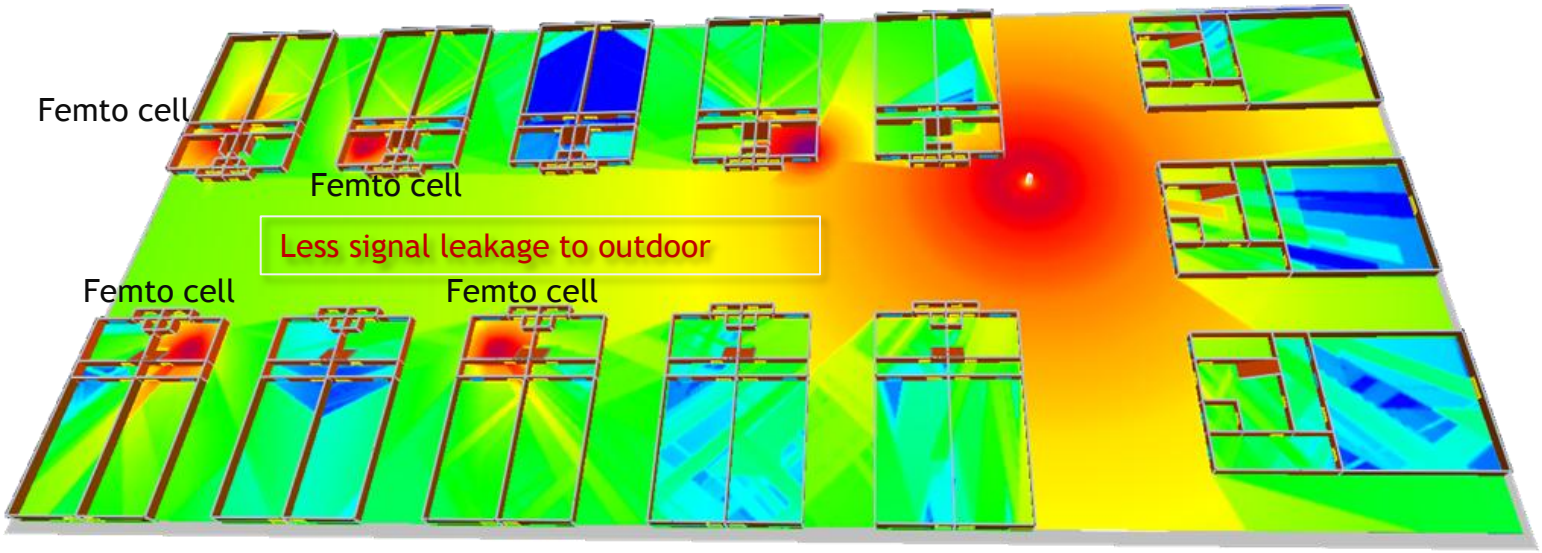
- Strong signal leakage to outdoor from femto cell
  - Ping-pong effect for outdoor users
  - Decreased signal quality
- Needs to be mitigated to prevent interference

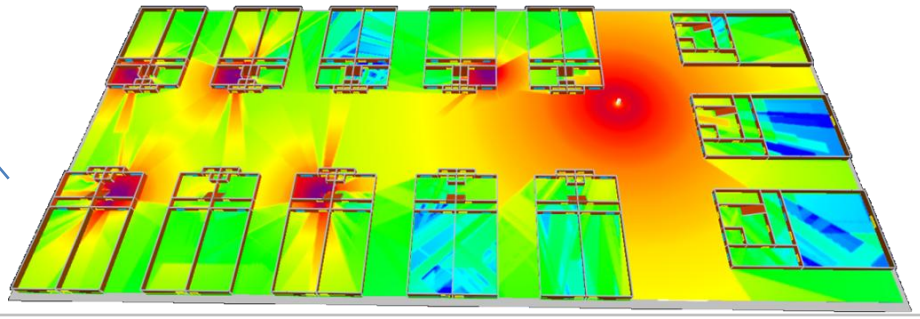


Femto Deployment in a UK Residential Area (3/5)

Typical Scenario in Luton, UK – Interference optimization

- Confine signal within indoor to minimize signal leakage
  - Reduce Tx power of HNB/HeNB
  - Adjust antenna orientation



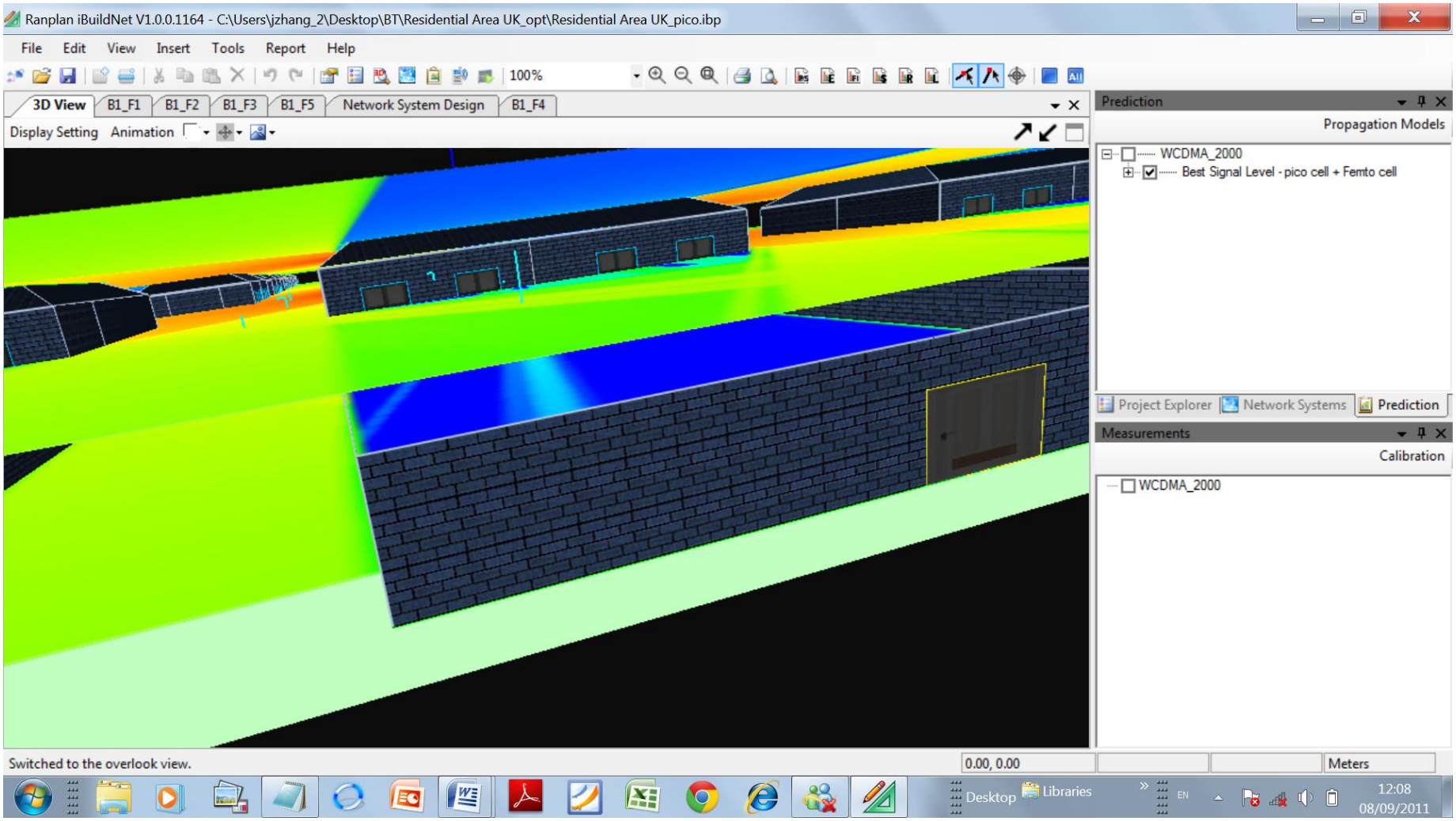


Before interference optimization

Femto Deployment in a UK Residential Area (4/5)

Typical Scenario in Luton, UK – Interference optimization

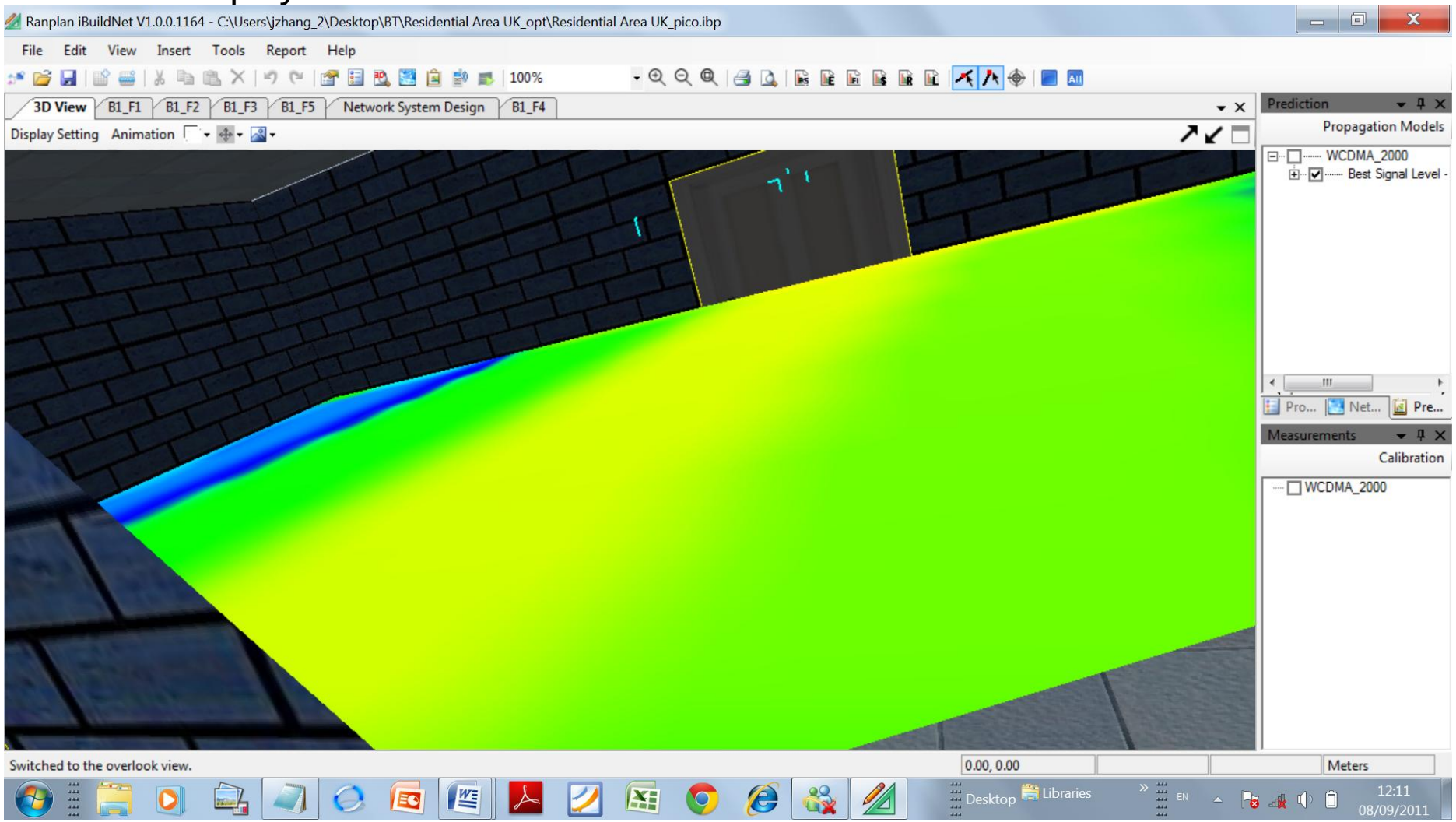
- 3D display with three cuts



Femto Deployment in a UK Residential Area (5/5)

Typical Scenario in Luton, UK – Interference optimization

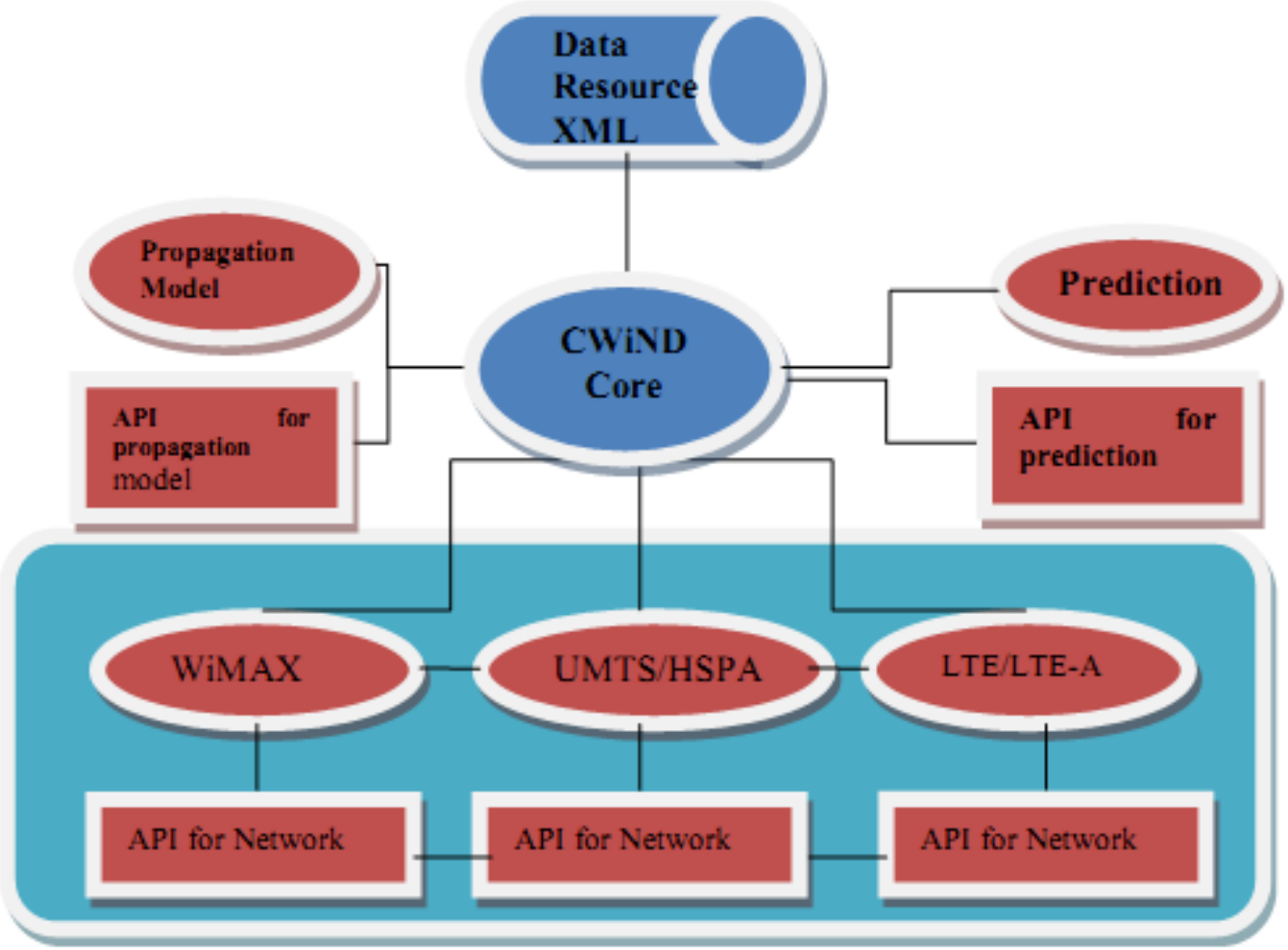
- 3D display inside a room.



Some of our early work on femtocells

- D. López Pérez, A. Valcarce, G. De La Roche**, J. Zhang**, “Access Methods to WiMAX Femtocells: A downlink system-level case study,” in IEEE ICCS (International Conference on Communication Systems), Guangzhou, China, November 2008.
- D. López-Pérez, G. De La Roche, A. Valcarce, A. Jüttner, **J. Zhang**, “Interference Avoidance and Dynamic Frequency Planning for WiMAX Femtocells Networks,” IEEE ICCS (International Conference on Communication Systems), Guangzhou, China, November 2008.
- D. Lopez, A. Valcarce, G. De La Roche and **J. Zhang**, "OFDMA femtocells: A roadmap on interference avoidance," *IEEE Communications Magazine*, vol. 47, no 9, pp. 41 - 48, Sept. 2009. **(ranked in 47 of top 100 documents accessed in IEEExplore in Oct. 2009. One of the most widely cited femto papers).** [>110 citations]
- A. Valcarce, G. De La Roche, A. Juttner, D. Lopez, and **J. Zhang**, "Applying FDTD to the coverage prediction of WiMAX femtocells," in *Eurasip Journal of Wireless Communications and Networking*, Feb. 2009, Article ID 308606**.**
- G. De La Roche, A. Valcarce, D. López-Pérez and **J. Zhang**, "Access Control Mechanisms for Femtocells," *IEEE Communications Magazine*, vol. 48, no 1, pp. 33 - 39, Jan. 2010.
- All the above papers attracted a large number of citations
- …… our other work (joint channel, power and MCS allocation, distributed approach, decoupling of DL and UL in HetNet, eICIC in HetNet)

CWiND simulation platform



iBuildNet ® – Main Features

3D Building Modeling

- Auto recognition of floor plan in CAD files
- Auto recognition of different kinds of walls
- Auto recognition of doors and windows
- Auto recognition of columns
- Ability to add floor, ceiling, and other objects
- Built-in apartment, lift models etc

3D DAS Design

- Passive/Active/Hybrid DAS design
- Repeaters, base stations as signal source
- Rich device database
- Femto/WiFi deployment
- Automatic antenna placement*

3D Wireless system evaluation

- Built-in accurate 3D propagation models
- Match most of typical building materials
- Tradeoff between accuracy and efficiency
- Cross-floor signal propagation
- Verification of prop. model with measurements
- Coverage prediction for different services
- Handover prediction and planning

Joint Indoor + outdoor HetNet P&O

- Hybrid Indoor/outdoor DAS planning & optimisation
- Campus wide joint indoor-outdoor HetNet planning & optimisation (P&O)
- High-rising building interference control & optimisation
- Indoor signal leakage mitigation
- Signal evaluation of Outdoor basestations

Multi-System and Multi-band

- WLAN
- GSM
- WCDMA
- TD-SCDMA
- CDMA 2000
- WiMAX
- LTE-FDD
- TD-LTE
- LTE-Advanced

Conclusions

- HetNets have the potential to significantly boost network performance, benefiting from transmitter-to-receiver distance reduction and enabling better spatial reuse of the spectrum.
- In this talk, the major advantages of HetNets, as well as their technical challenges are discussed.
- Particular attention has been given to the avoidance of cross-tier interference due to its crucial role in proper operation of multi-tier networks.
- Furthermore, the main eICIC techniques currently under discussion in 3GPP have been evaluated through realistic system-level simulations.

Conclusions

- Dense femto cell deployment is studied, automatic channel allocation based on reducing the overall system interference can significantly improve throughput
- A tool to study HetNet is illustrated in a femto/pico scenarios, by adjusting femto Tx power and antena orientation, interference can be significantly reduced.
- The tool opens many opportunities to study HetNets in indoor-outdoor scenarios.

References (Ours)

- D. López Pérez, A. Valcarce, G. De La Roche**, J. Zhang**, “Access Methods to WiMAX Femtocells: A downlink system-level case study,” in IEEE ICCS (International Conference on Communication Systems), Guangzhou, China, November 2008.
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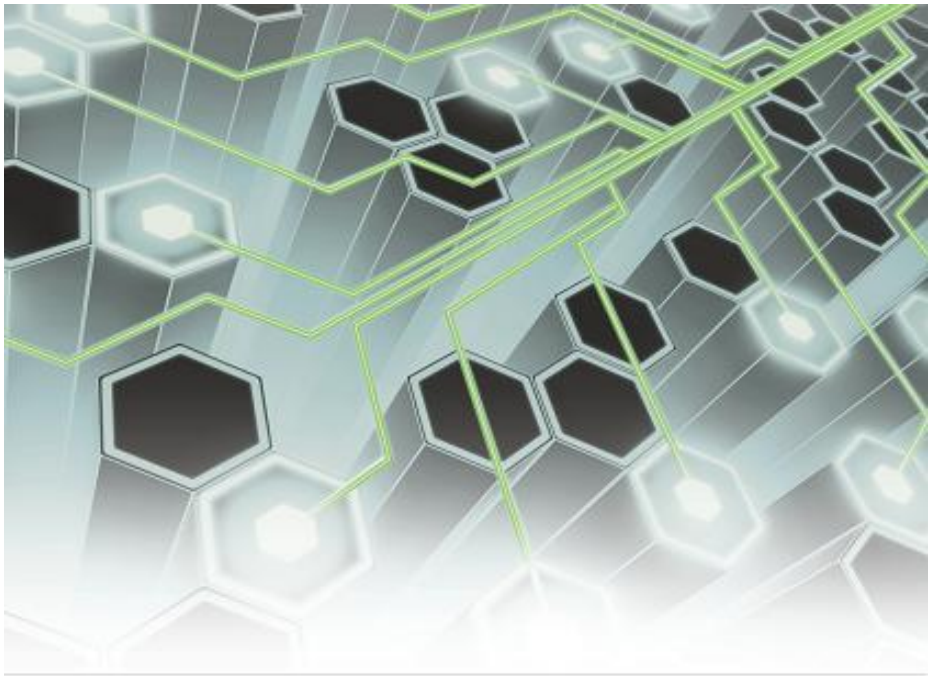

Femtocells

Technologies and Deployment

Jie Zhang | Guillaume de la Roche

WILEY

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- R1-104661, Comparison of Time-Domain eICIC Solutions, 3GPP Std., Madrid, Spain, Aug. 2010.
- CATT, “Evaluations of RSRP/RSRQ measurement (R4-110284),” Austin, TX, Jan. 2011.

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  - Dr David Lopez, former CWiND member
  - Dr Guillaume de la Roche, former CWiND member
  - Dr Hui Song, RANPLAN, **www.ranplan.co.uk**
  - Dr Alvaro Valcarce, former CWiND member

Thanks for your attention!

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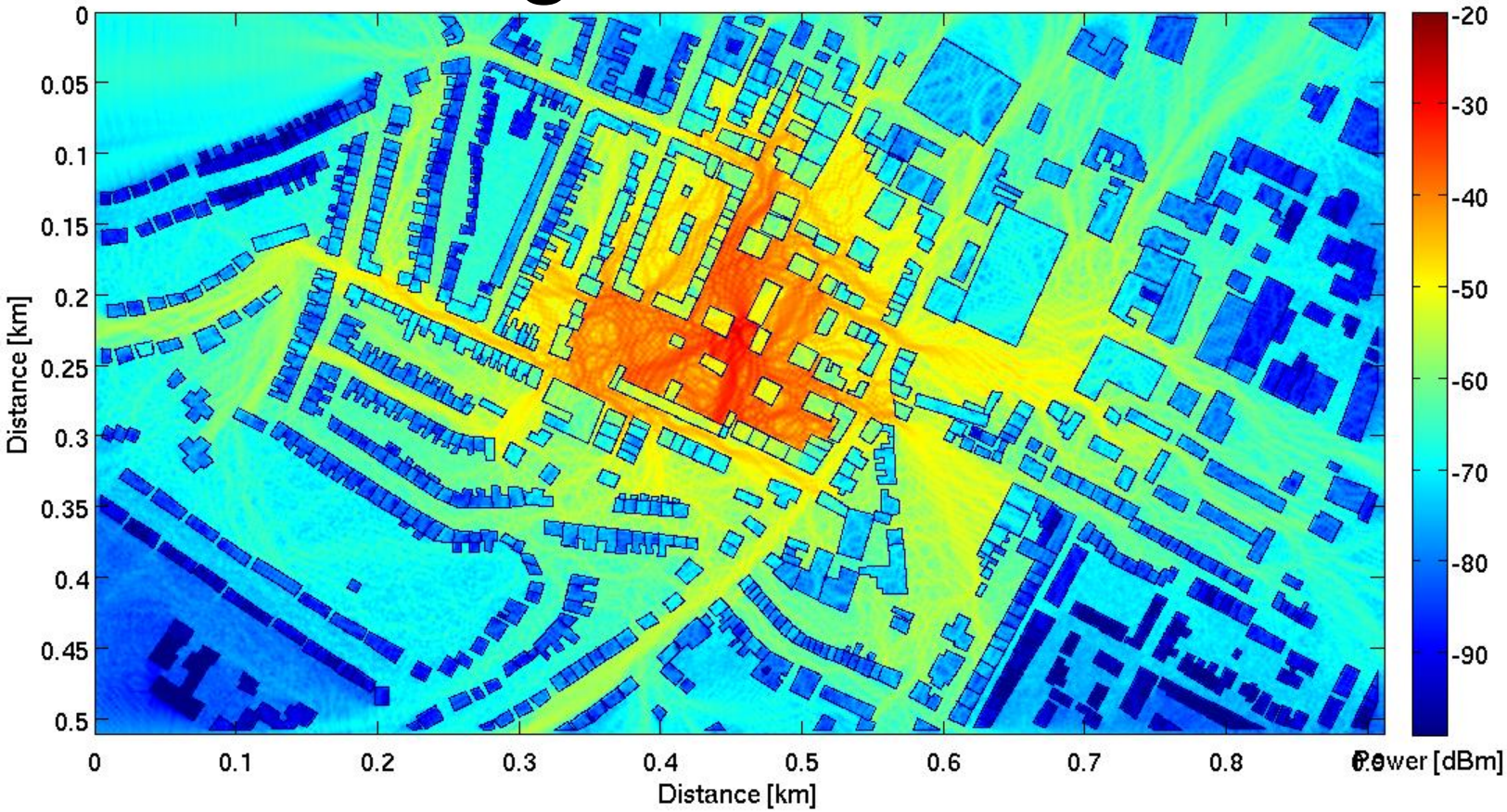
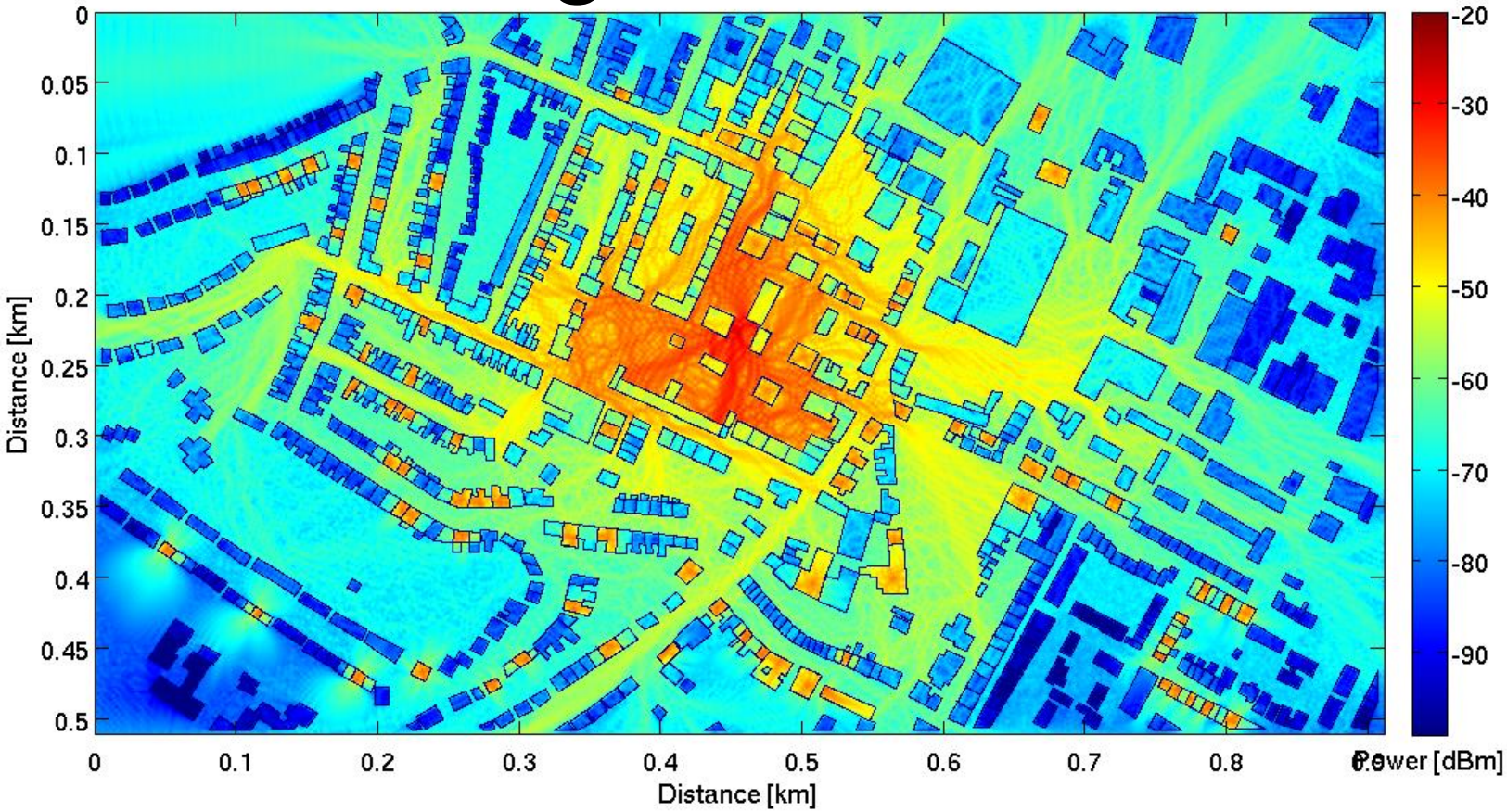
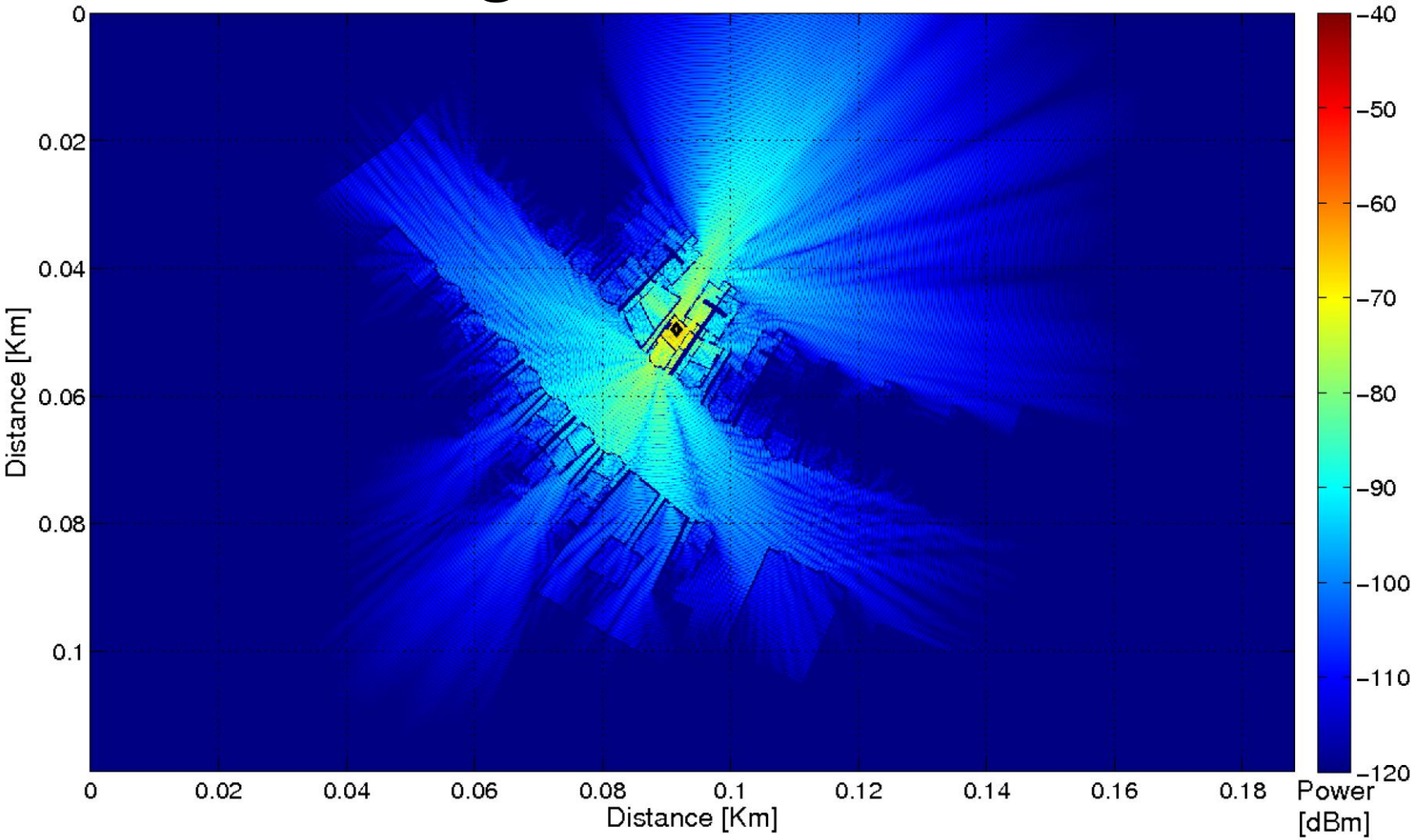
Coverage of a macrocell



Coverage of femtocells



Coverage of one femtocell



Technical challenges - SON

- **Self-configuration**: where newly deployed cells are automatically configured by downloaded software before entering into the operational state.
- **Self-healing**: where cells can automatically perform failure recovery or execute compensation mechanisms whenever failures occur.
- **Self-optimization**: where cells constantly monitor the network status and optimize their settings to improve coverage and reduce interference.
- **Self-planning**

Technical challenges - SON

- Without SON, HetNet can't work well.
- Self-organized HetNet is challenging task due to the following reasons:
  - Various type of coexisting cells
  - The increasing number of network parameters that need to be considered.
  - The random, uneven and time-varying nature of user arrivals and their resulting traffic load.
- SON is key to all types of access nodes, small cells highlight its importance.

Technical challenges - backhaul

- High data rates: e.g., 4G has 1Gbps peak data rate
- Complex topology of the various type of coexisting cells.
- Possible backhaul solutions
  - Some cells may have dedicated interfaces to the core network.
  - Some cells may form a cluster to aggregate and forward the traffic to the core.
  - Some other cells may rely on relays as an alternative interface.
- The backhaul solution is likely to be a mixture of both wireless and wired backhaul technologies.
  - To start with, LTE outdoor cells can use wireless backhaul
  - FTTx will be important when the network evolves

Technical challenges-handover

- In HetNets,due to the large number of small cells and the different types of backhaul links available for each type of cell, handover becomes a challenge.
- The probability of handover failure increases the probability of user outage.