Interference Management in Beyond 4G

Professor H. Haas
with support from Dr S. Sinanovic and Dr B. Ghimire

in collaboration with

Dr G. Auer
NTT DOCOMO Euro Labs/Munich

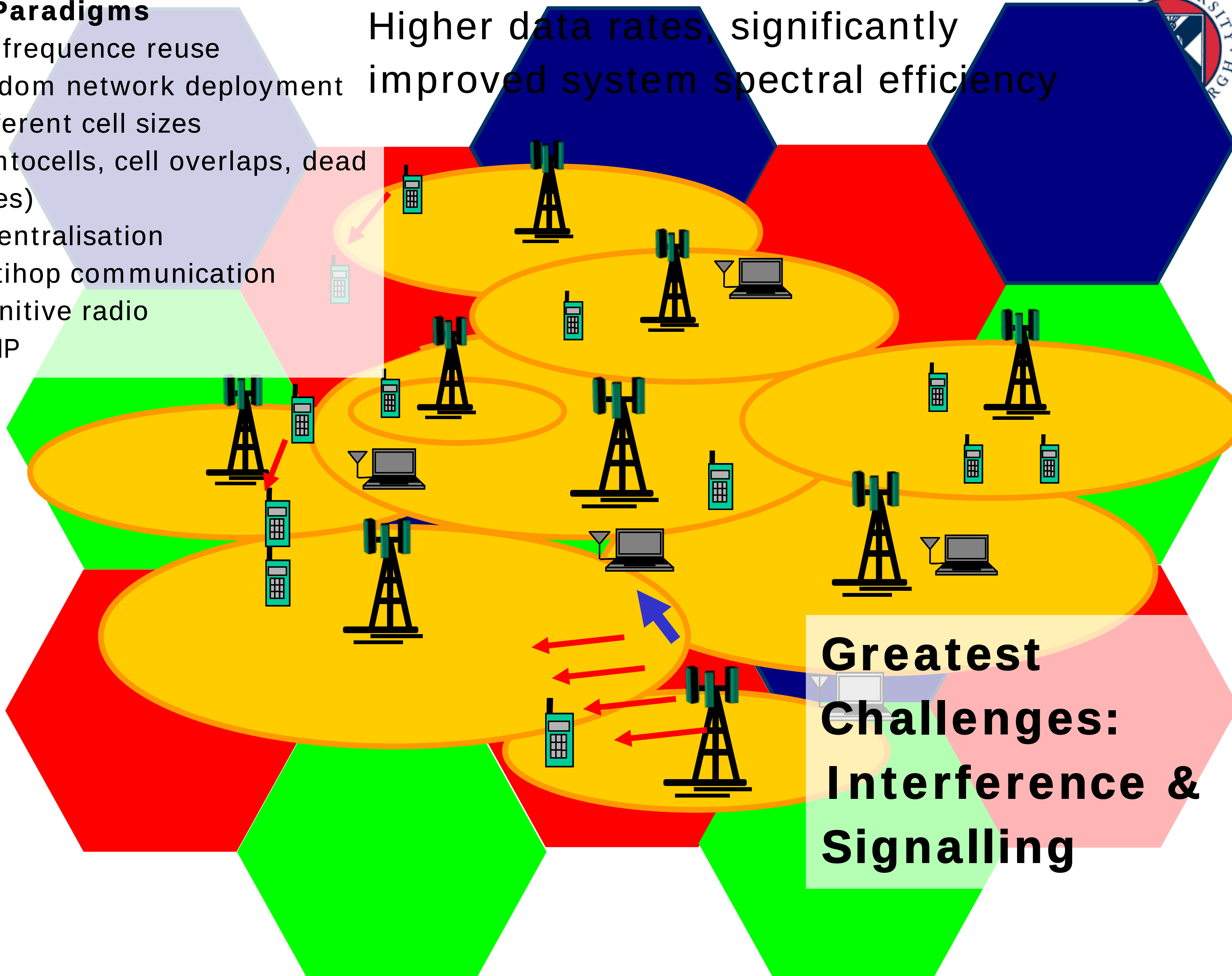
Content

- Introduction
- Interference Avoidance with Busy Burst Signalling for TDD Systems
- Busy Burst integrated into Grid of Beam Transmission
- Summary

B4G Paradigms

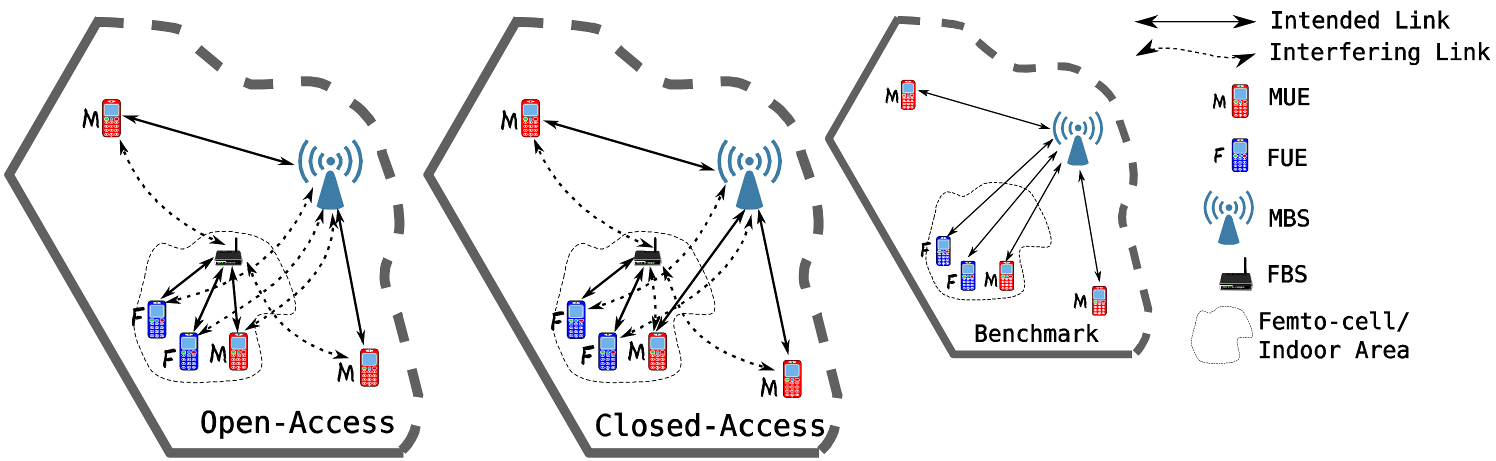
- Full frequence reuse
- Random network deployment (different cell sizes (femtocells, cell overlaps, dead zones)
- Decentralisation
- Multihop communication
- Cognitive radio
- CoMP

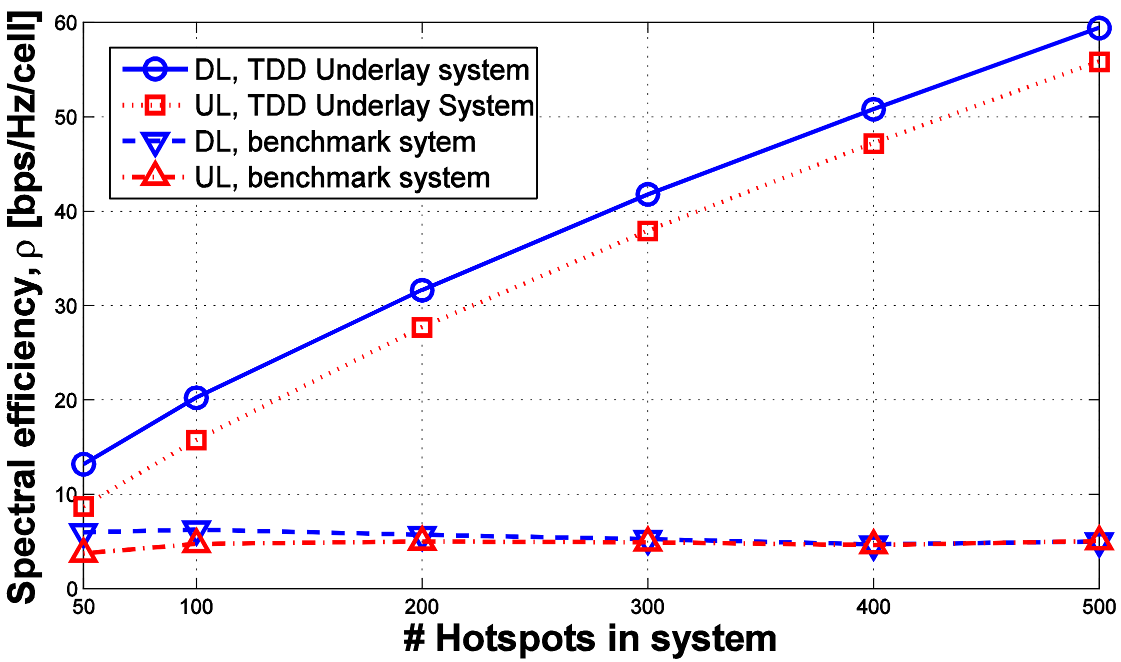
Higher data rates, significantly improved system spectral efficiency



Greatest Challenges: Interference & Signalling

Femto Cell Deployment

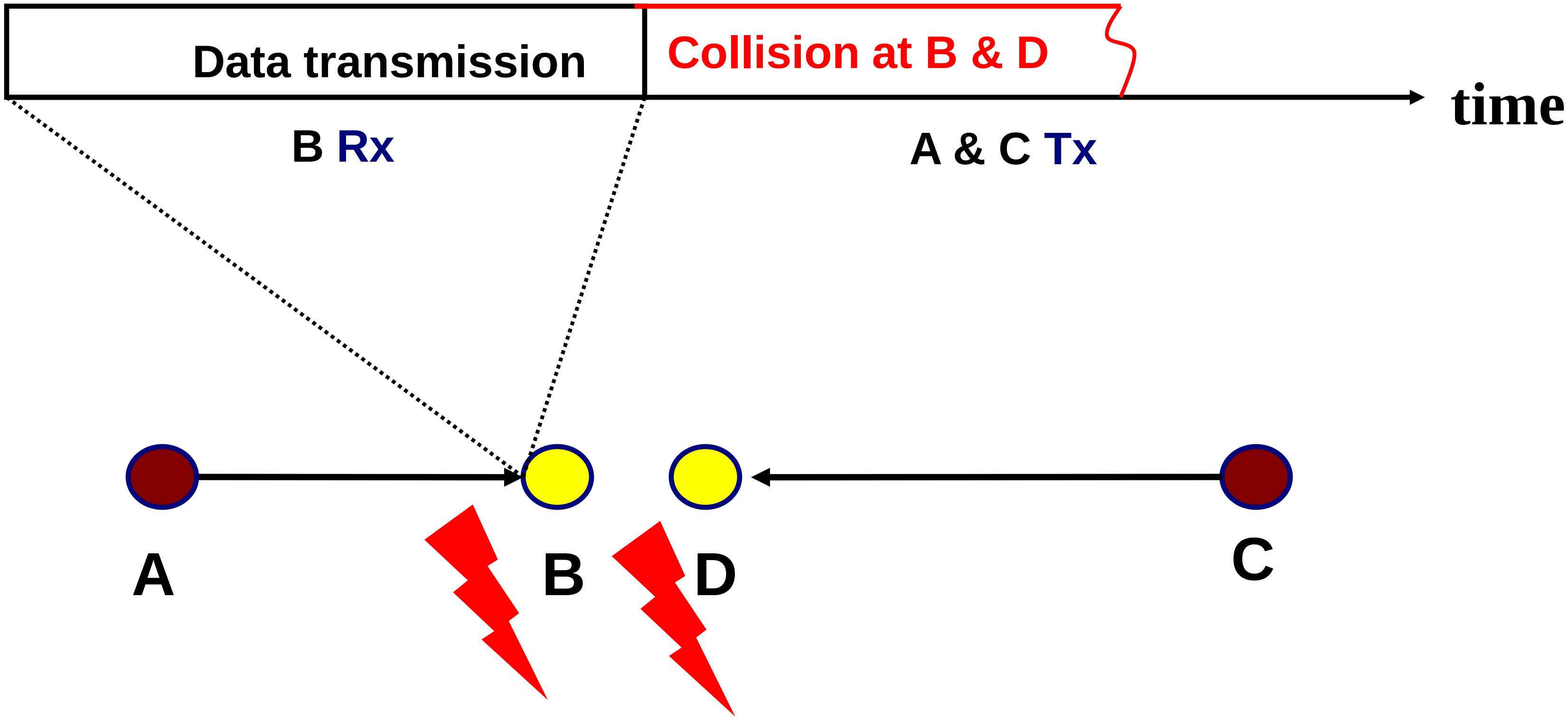


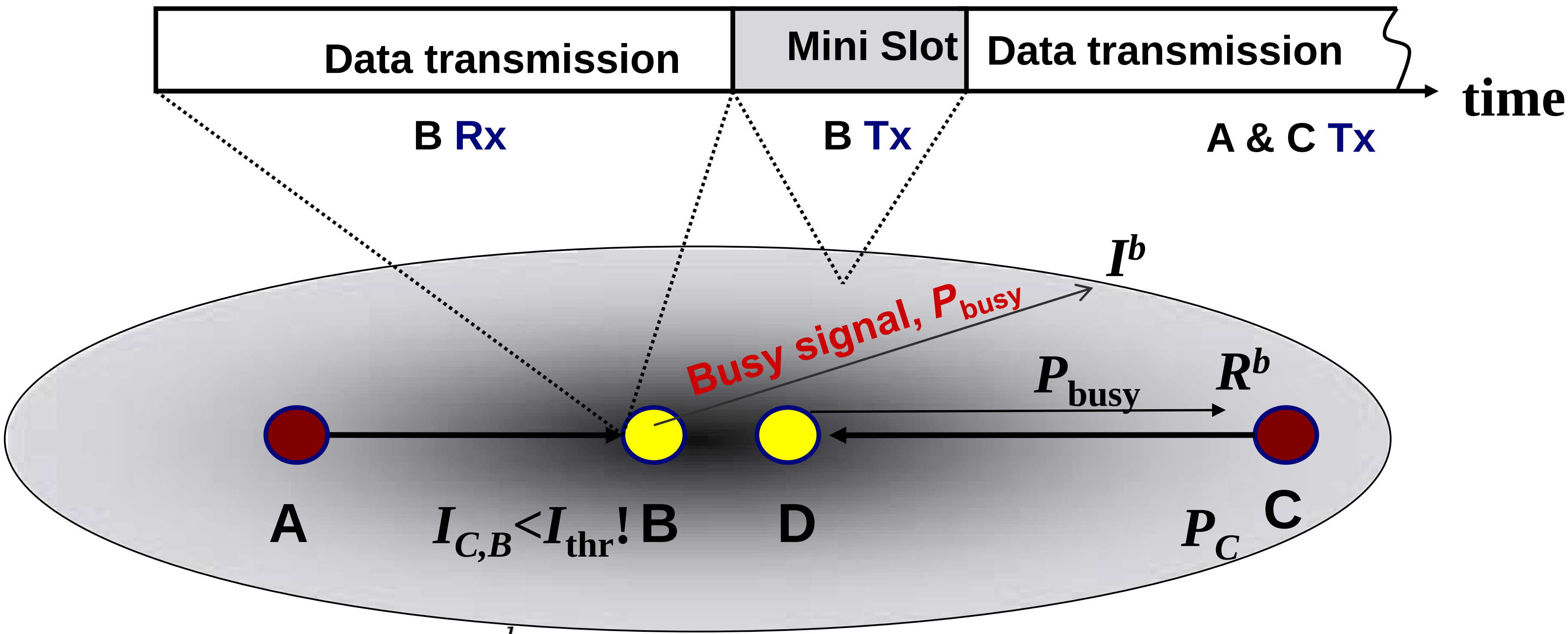


Z. Bharucha, "Downlink Interference Avoidance in Self-Organising Wireless Networks with Femto-Cell Deployment", ***PhD Thesis, The University of Edinburgh, June 2010***

Introduction

- Future data-centric traffic is characterised by
  - Traffic asymmetry
  - High peak-to-average data rate ratio
- Hybrid cellular and multihop deployment envisaged
- Additional interference in TDD (same-entity)
- Full frequency reuse might potentially create high interference
- Keys to solving these problems:
  - interference aware channel access
  - dynamic channel assignment (DCA) and scheduling
  - decentralised self-organised multiple access in a spectrum sharing environment
  - exploitation of statistical user multiplexing


Data transmission
Collision at B & D
time
B Rx
A & C Tx
A
B
D
C



$$I_{\mathrm{C,B}} = G_{\mathrm{B,C}}\, P_{\mathrm{C}} = \frac{I_C^b}{P_{\mathrm{busy}}}\, P_{\mathrm{C}} \leq I_{\mathrm{thr}}$$

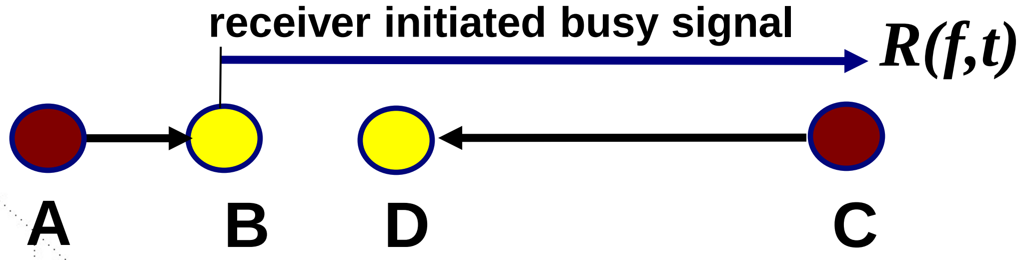
C transmits iff: $I^b \leq \frac{P_{\mathrm{busy}}}{P_{\mathrm{C}}} I_{\mathrm{thr}}$ **and continues iff:** $R^b \geq I_{\mathrm{thr}}\, \gamma_{\mathrm{tar}}\, \Delta$

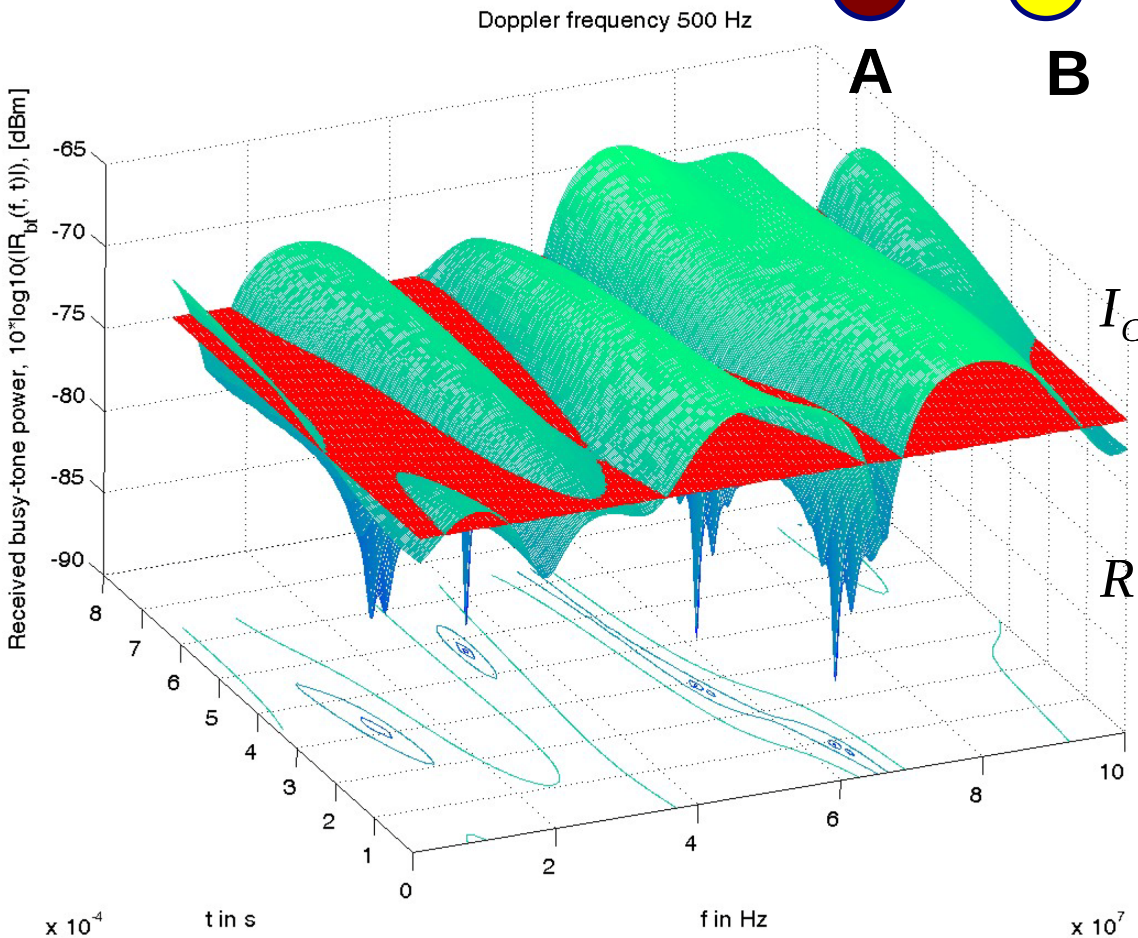
Key factor: Channel reciprocity (TDD)!

Busy Burst TDD

- Protocol exploits **channel reciprocity** of TDD in order to achieve:
  - **Interference avoidance:** The protocol ensures that ongoing transmissions are protected. This means that any transmitter is aware of the level of interference it would cause to ongoing transmissions.
  - **Link Adaptation:** Once those resources are identified that can be used for transmission (from the interference point of view), by the same mechanism as for the interference avoidance, in general a particular subset of those resources are then selected for transmission on the basis of certain QoS criteria. The QoS criteria are based on the SINR at the location of the intended receiver.

Busy Burst TDD



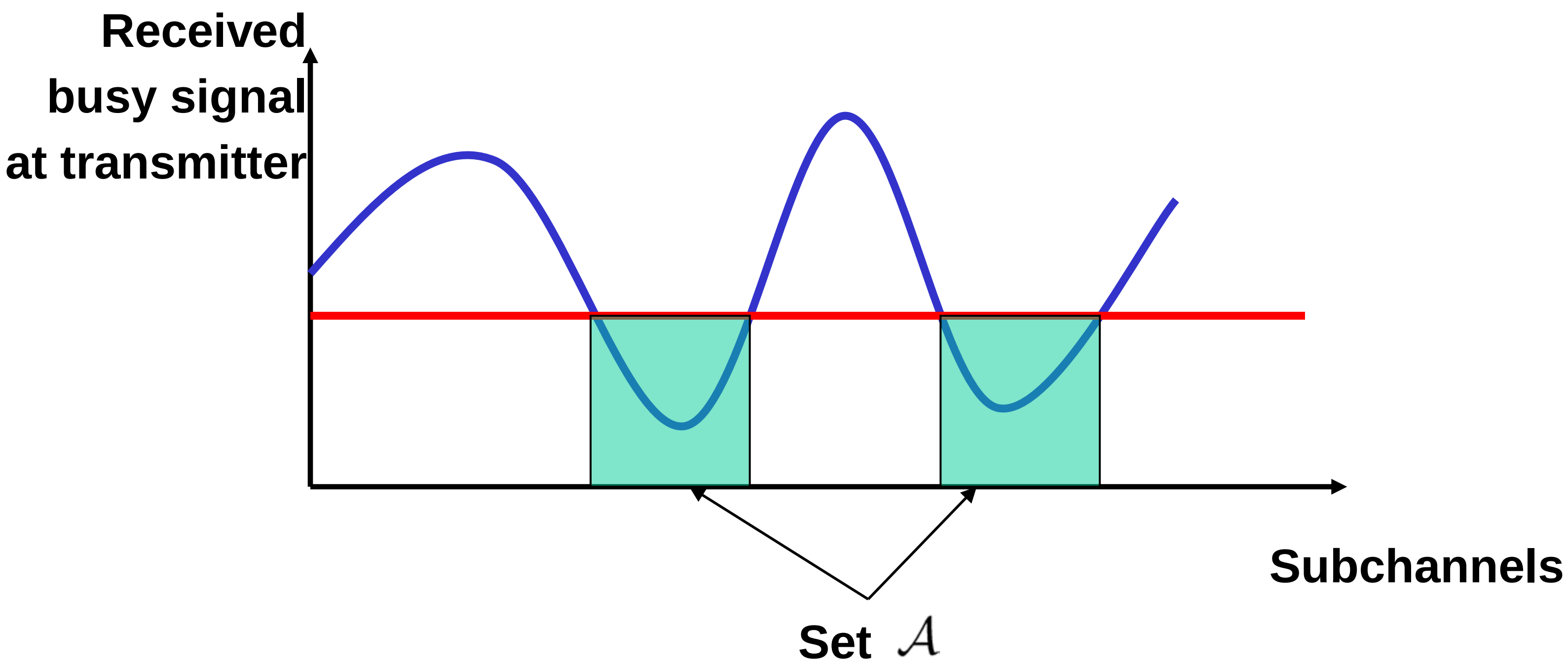


$$I_{C \to B} = \frac{R(t,f)}{P_{busy}} P_C(t,f) \leq I_{threshold},$$

$$R(t,f) \leq \frac{P_{busy}}{P_C(t,f)} I_{threshold} = R_{busy}^{(\mathrm{thres})}.$$

BB Applied to OFDMA

- **Transmitter (initial access)**

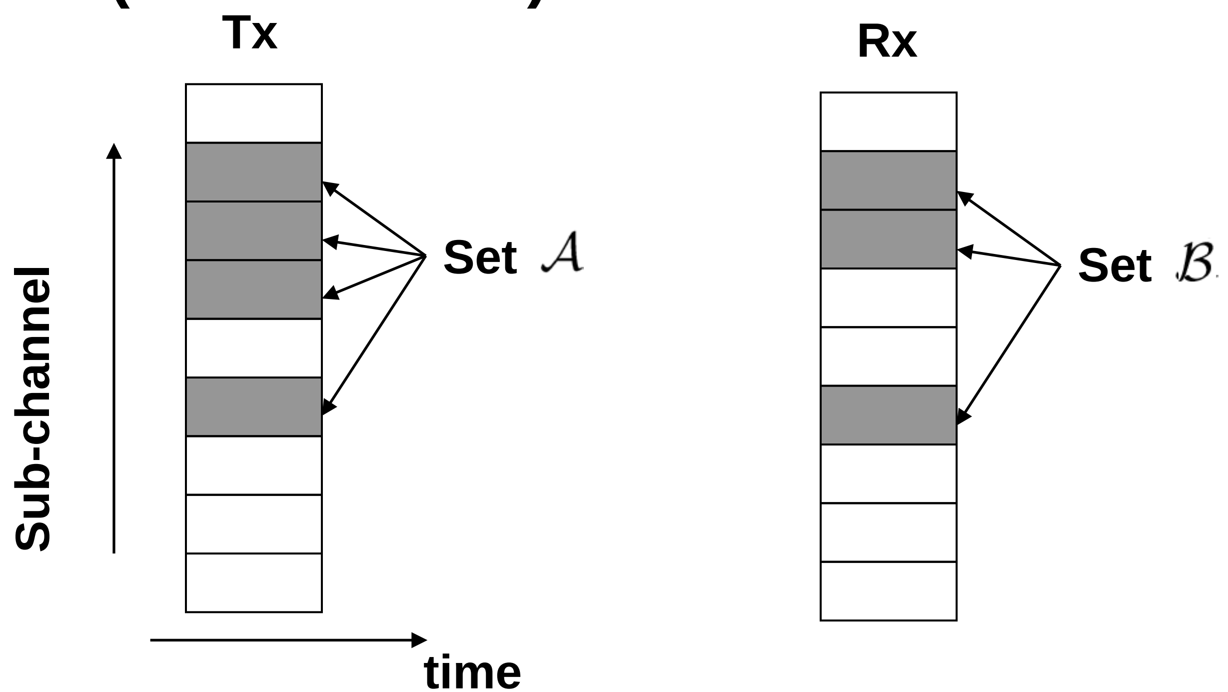


Set $\mathcal{A}$ determination for the *i-th* MAC-Frame:

$$a_{l,i}^{k,m} = \begin{cases} 1 & \text{if} \quad |\hat{B}_{l,i}^{m}|^2 \leq I_{thr} \\ 0 & \text{otherwise,} \end{cases}$$

BB Applied to OFDMA (2)

- **Receiver (initial access)**

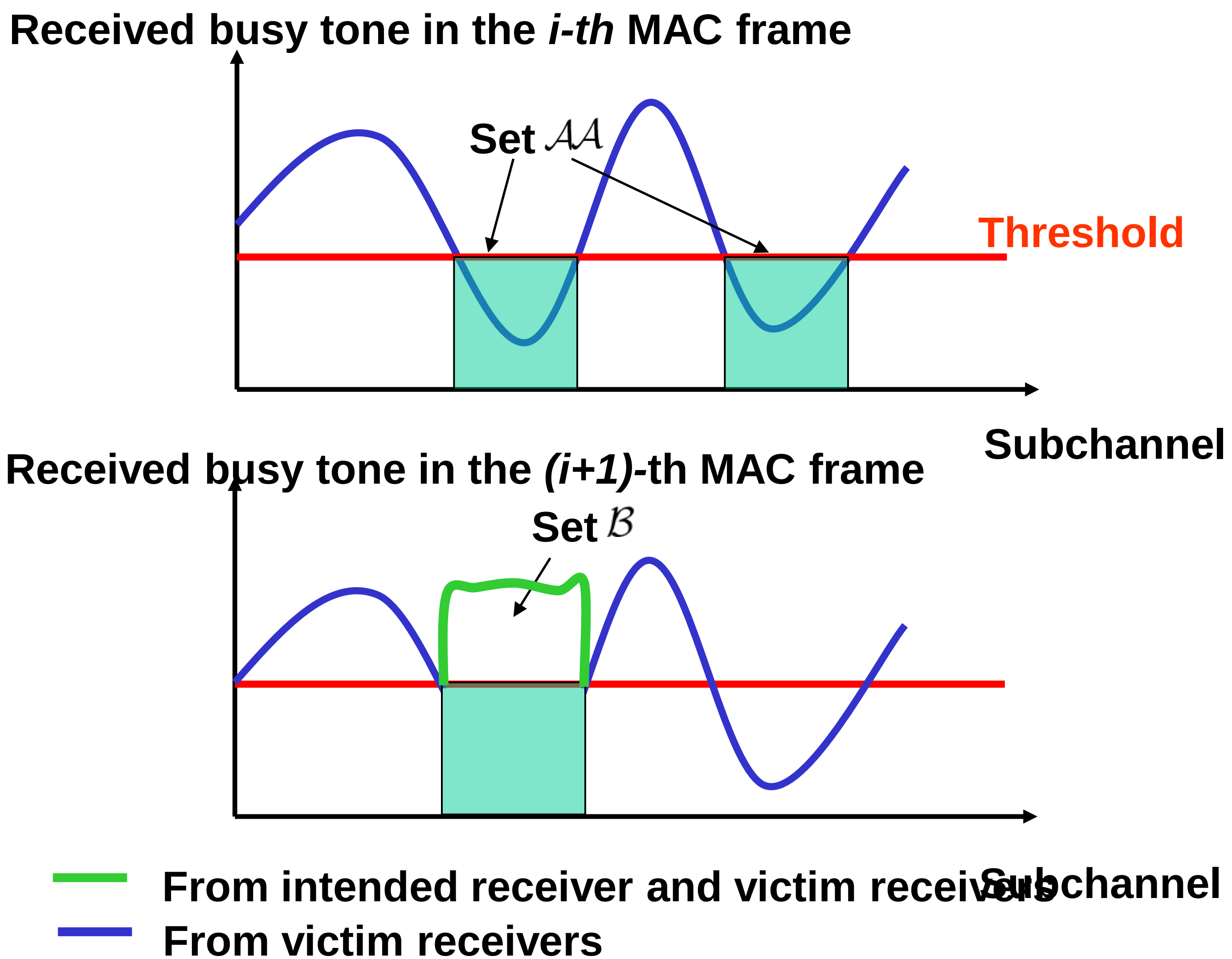


Intended receiver "releases" sub-carriers which do not meet the required SINR (set $\mathcal{B}$ determination):

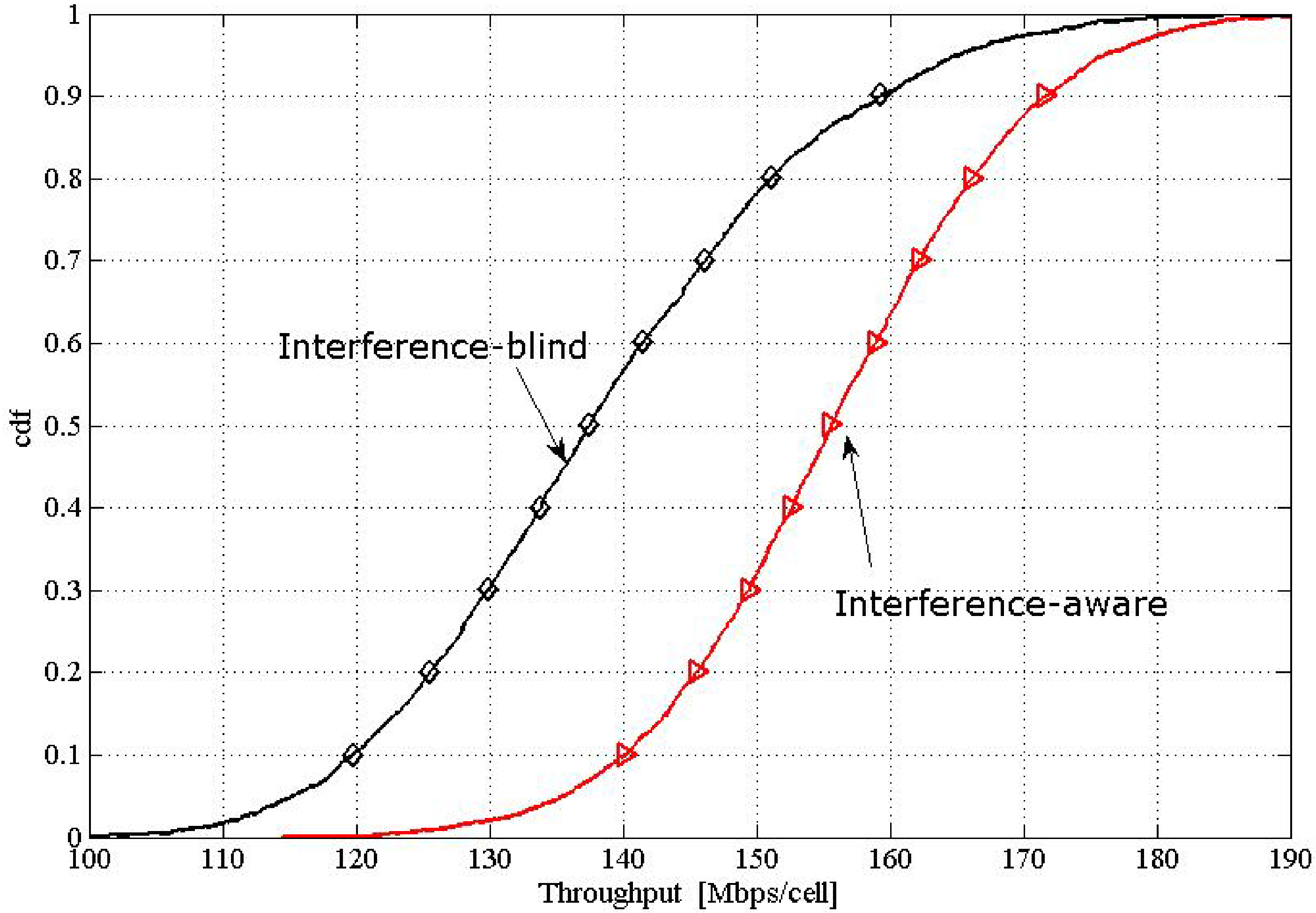
$$b_{l,i-1}^{k,m} = \begin{cases} 1 & \text{if } (a_{l,i-1}^{k,m} = 1) \text{ and } (\breve{\gamma}_{l,i-1}^{k} \geq \gamma_{\text{req}}) \\ 0 & \text{otherwise,} \end{cases}$$

BB Applied to OFDMA (3)

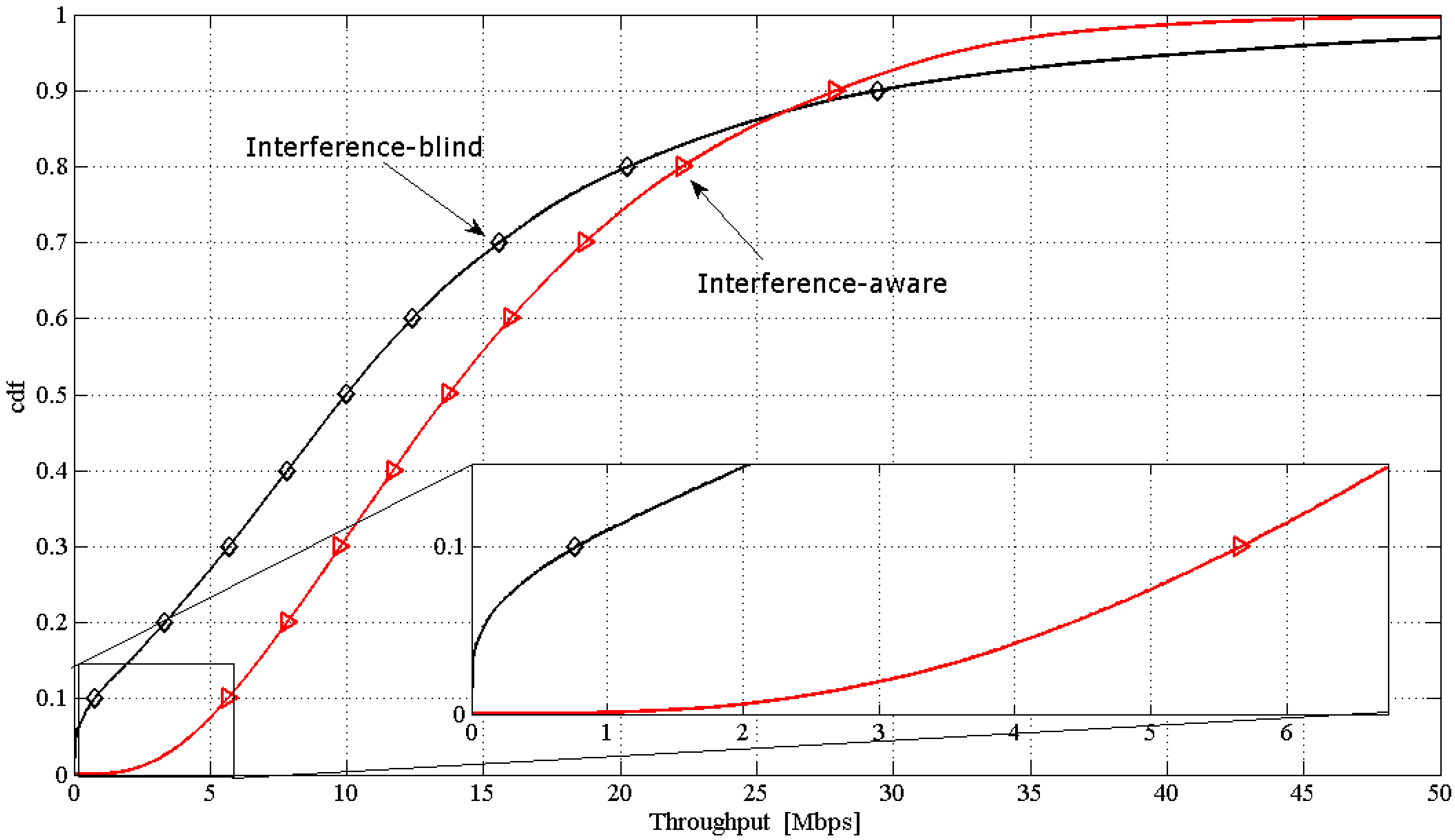
- **Determination of set $\mathcal{B}$ at the transmitter**



Cellular System with beamforming and sectorisation

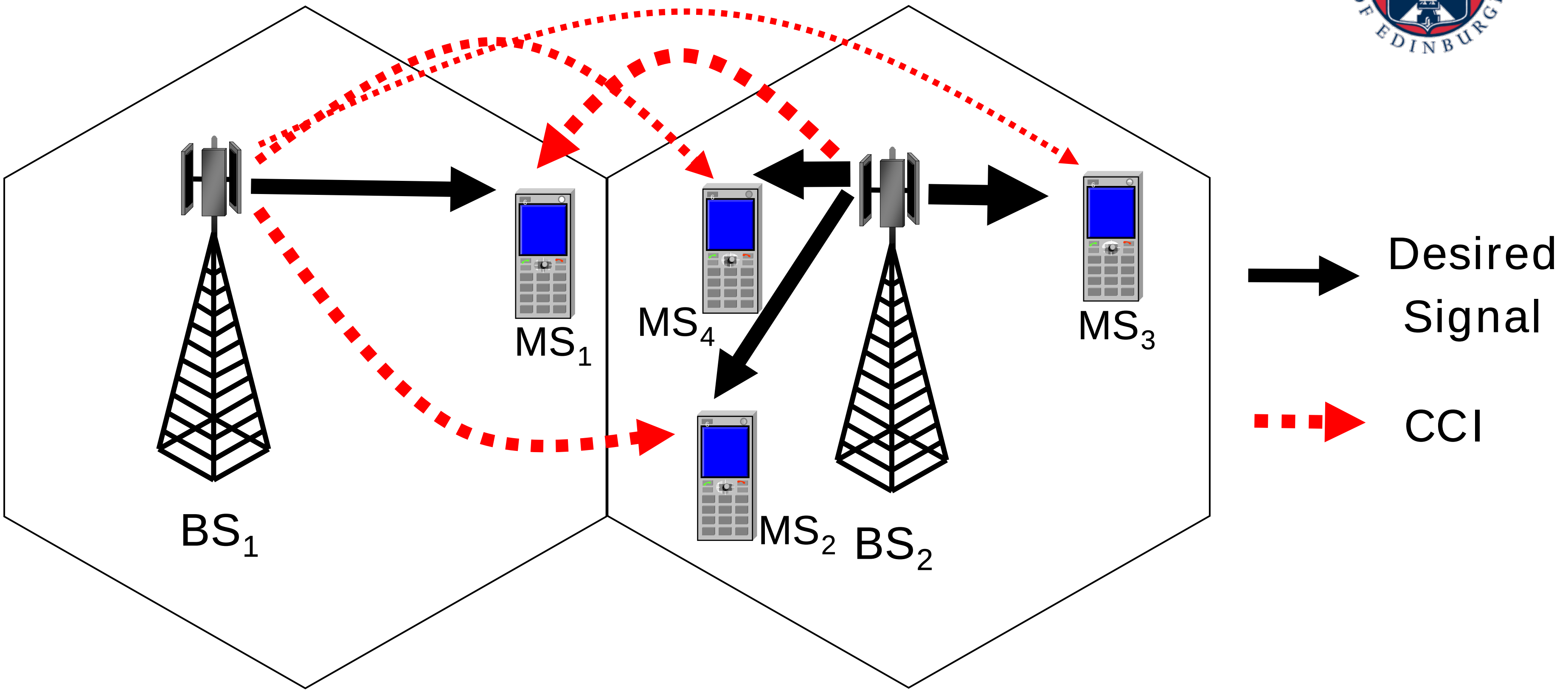


Cellular System with beamforming and sectorisation



BUSY BURST WITH BEAMFORMING

Problem Statement



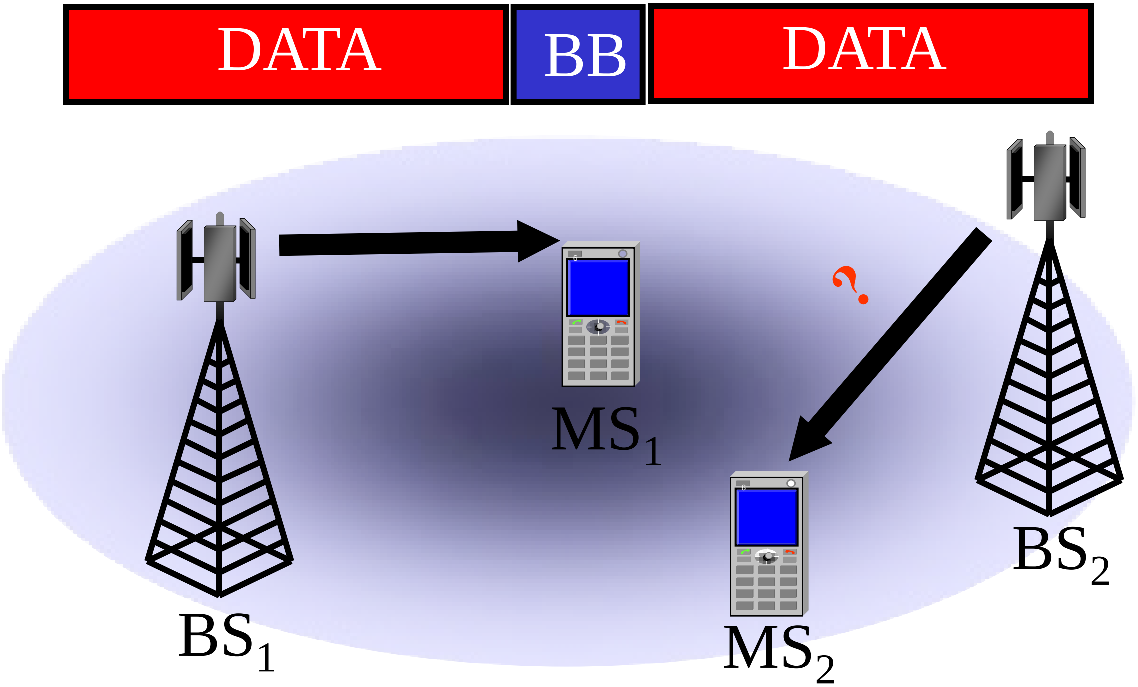
Cell-edge users:

1) Weaker desired signals

2) Strong CCI

→ Necessitates interference avoidance and mitigation

Busy Burst Signaling



BS_1 is transmitting to MS_1 and BS_2 intends to reuse the radio resource

$$I_\mathrm{d} = I_\mathrm{b} \cdot \left(\frac{T_\mathrm{d}}{T_\mathrm{b}}\right)$$

Key: Channel Reciprocity

Transmit iff:

$$I_\mathrm{b} \cdot \left(\frac{T_\mathrm{d}}{T_\mathrm{b}}\right) < I_\mathrm{th}$$

If $T_\mathrm{d} = T_\mathrm{b}$

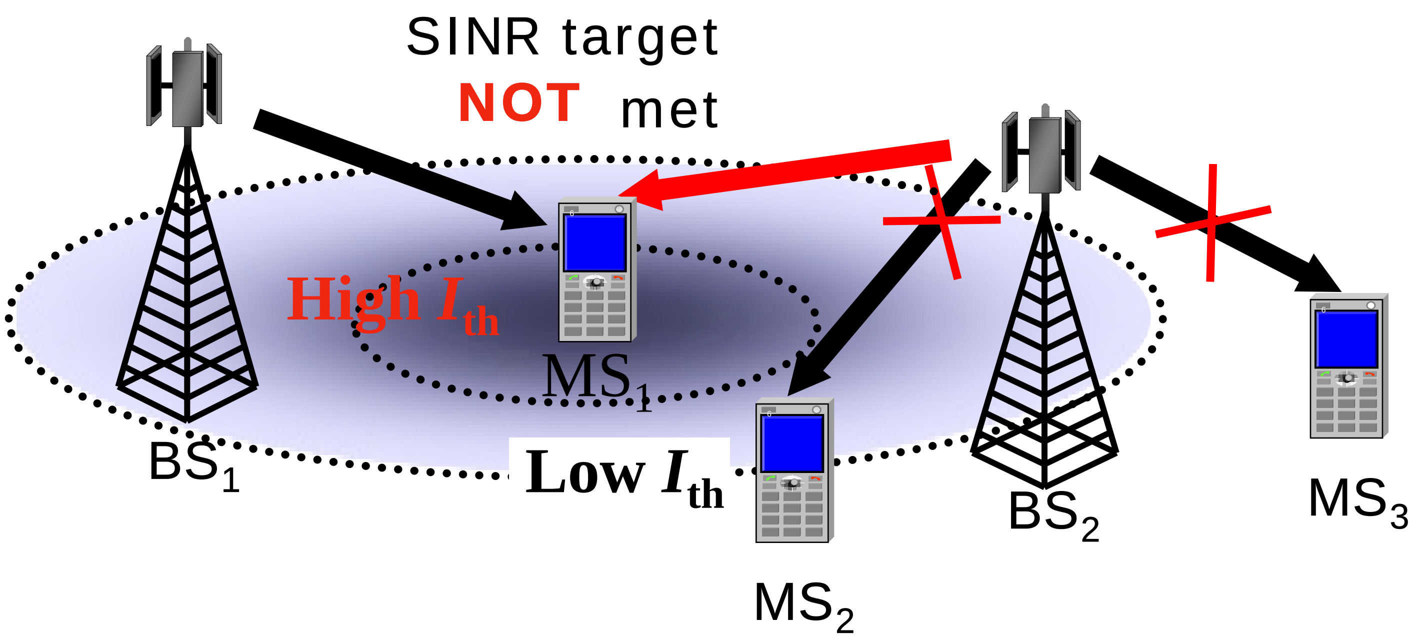
$$I_\mathrm{b} < I_\mathrm{th}$$

Continue iff:

$$R_\mathrm{b} \geq \Delta \cdot N \cdot \Gamma$$

Impact of Threshold

- A chunk may be (re)used if : $I_{\mathrm{b}} < I_{\mathrm{th}}$

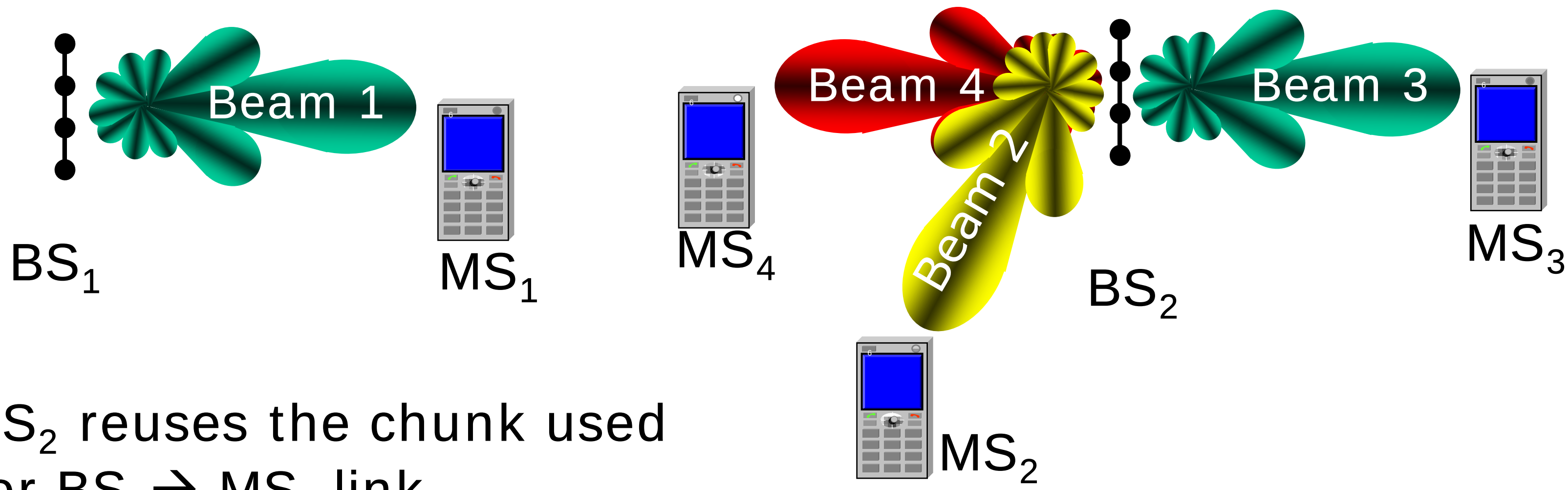


- Using high I_{th}
  - Improves reuse
  - Cell-edge users suffer
- Low I_{th}
  - Lowers reuse
  - Improves fairness

Beam Switching

User is served by the beam providing highest channel gain

Pre-computed coefficients applied to array for beam switching



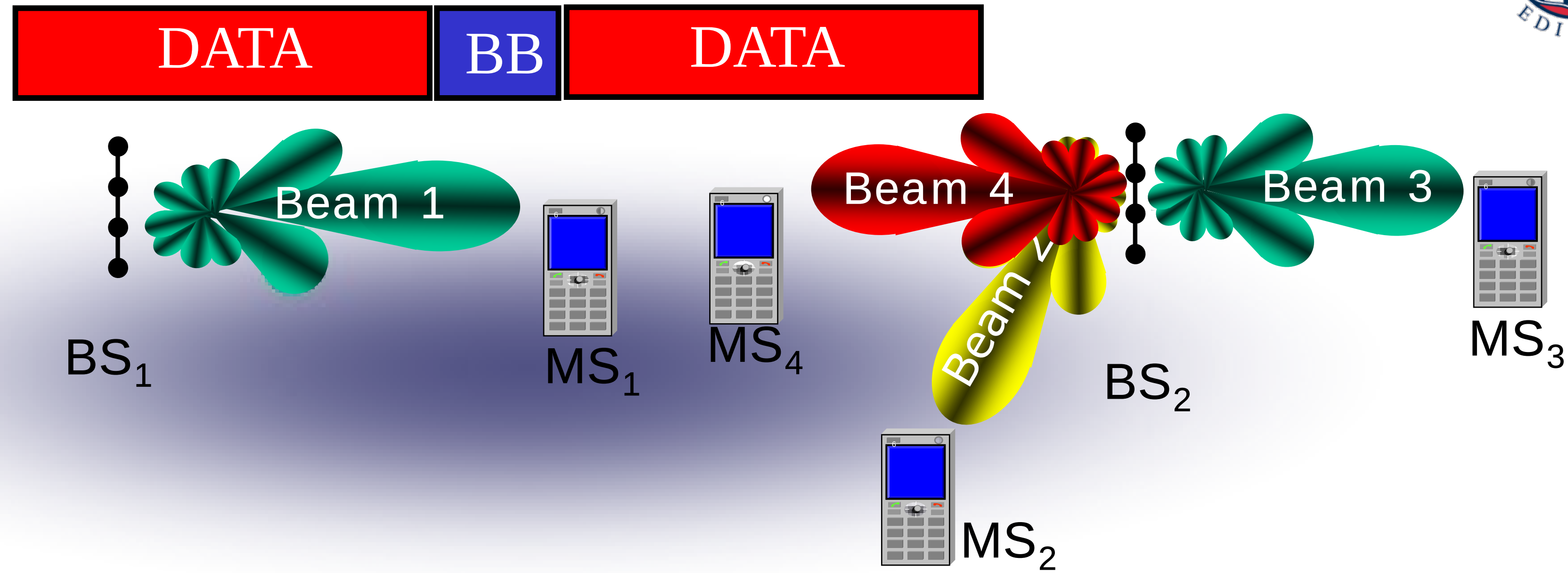
BS_2 reuses the chunk used for $BS_1 \rightarrow MS_1$ link

BS_2 allocates the chunk to MS_3 → Least CCI caused to MS_1

Problem:

Location of users served by BS_1 is not known at BS_2

BB enabled beam switching

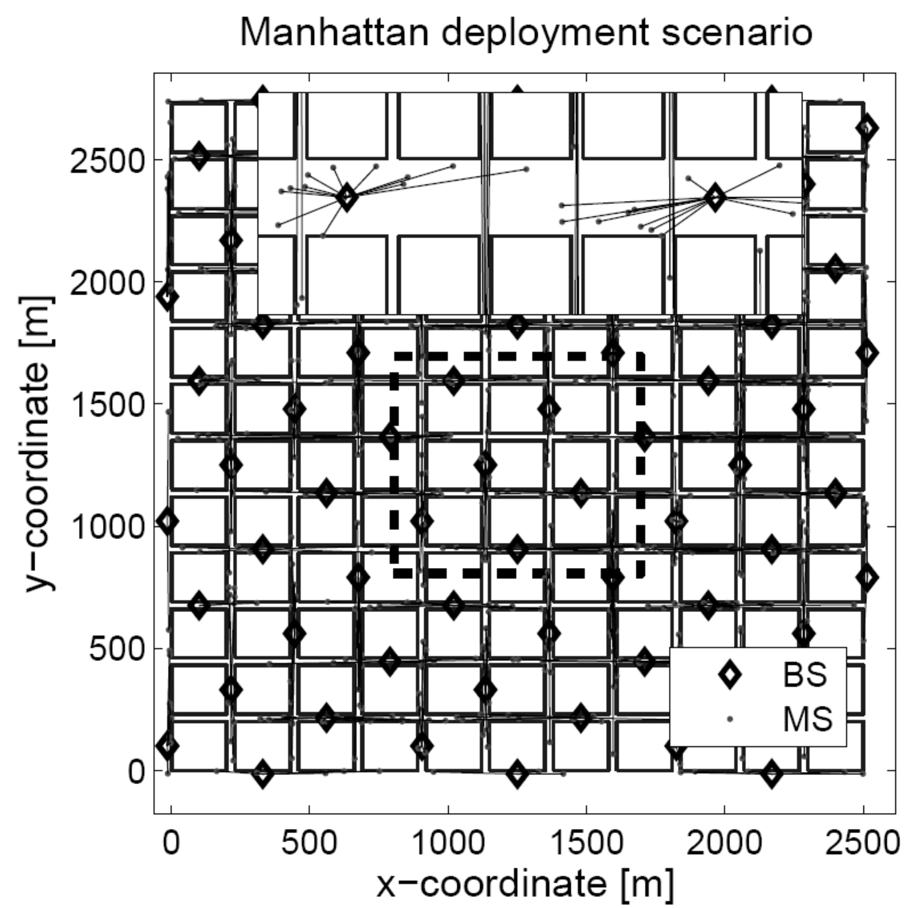


- Apply the coefficients for activating each beam
  →Measure the received BB power on each beam
- Channel reciprocity → BS_2 becomes aware of the amount of interference potentially caused to MS_1 with each of the beams
- Reuse chunks at BS_2 using one of the beams where

$$I_{\mathrm{b}} < I_{\mathrm{th}}$$

System Model

- Manhattan environment
- Outdoor users considered
  - Uniform distribution
  - Pedestrian (5km/hr)
  - Connected to BS with least path loss
- Channel model: WINNER-TDD scenario B1 (urban Manhattan environment)
- Full buffer traffic model

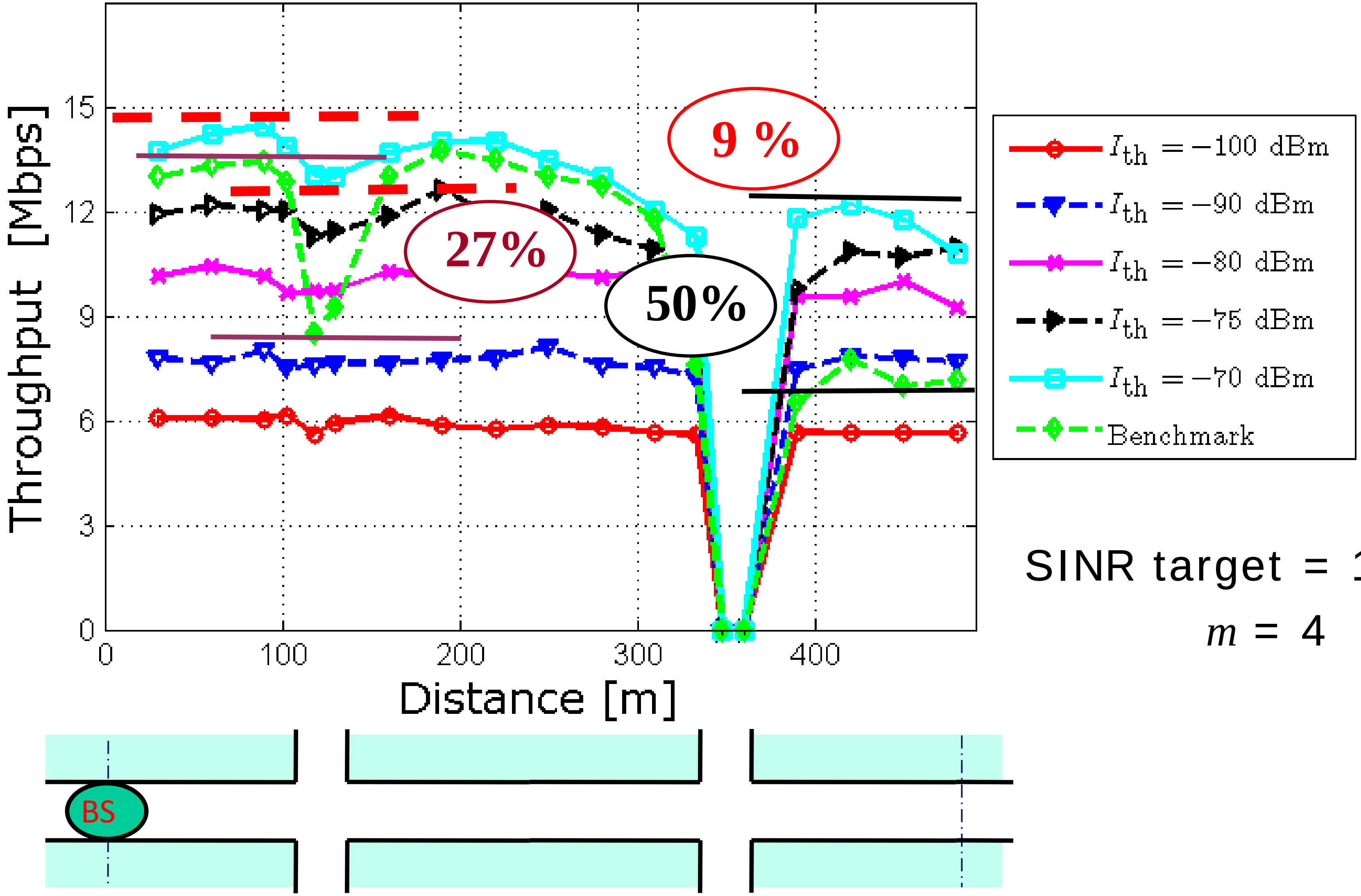


Depiction of Manhattan Grid

Simulation Parameters

Parameters	Value
Total symbol length	22.48 μs
Carrier centre frequency	3.95 GHz
System bandwidth B	89.84 MHz
Number of subcarriers (SC)	1840
Frame duration	0.6912 ms
OFDM symbols/frame	30
Chunk size	15 (time) $\times$ 8 (frequency) = 120
Number of chunks/frame	2 (time) $\times$ 230 (frequency)
Access probability p	0.3
Bits/symbol m	4 and 8
SINR target Γ	11.3 dB and 22.5 dB
Number of sectors/cell	2
Number of antenna elements/sector	4
Average number of users/cell U	10
Transmit power per chunk T^{d}	16.4 dBm
Elevation antenna gain A_{e}	14 dBi
Azimuth antenna element gain	$-\min\left[12\left(\frac{\theta}{\theta_{3\mathrm{dB}}}\right)^2, A_{\mathrm{m}}\right]$ [dB] where, $A_{\mathrm{m}} = 20$ and $\theta_{3\mathrm{dB}} = 70^\circ$
Noise level N	-117.8 dBm/chunk
Number of snapshots	50
Simulation duration per snapshot	50 ms

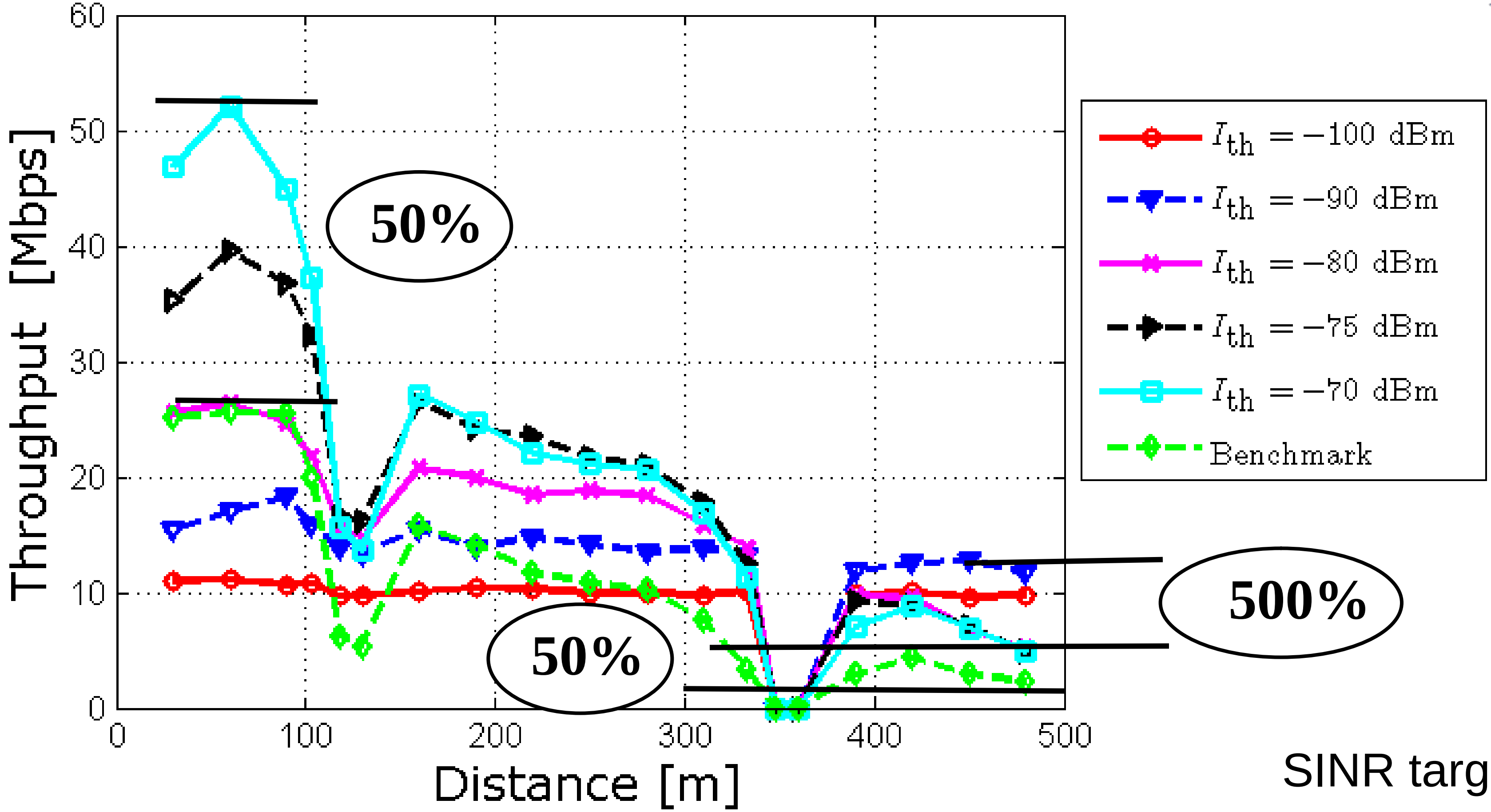
Results: Throughput

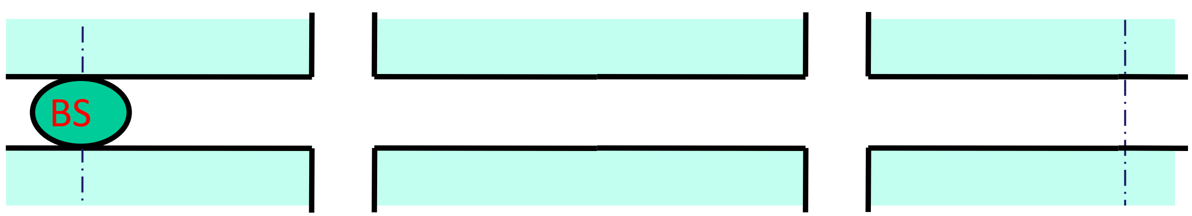


SINR target = 11.3 dB,

m = 4

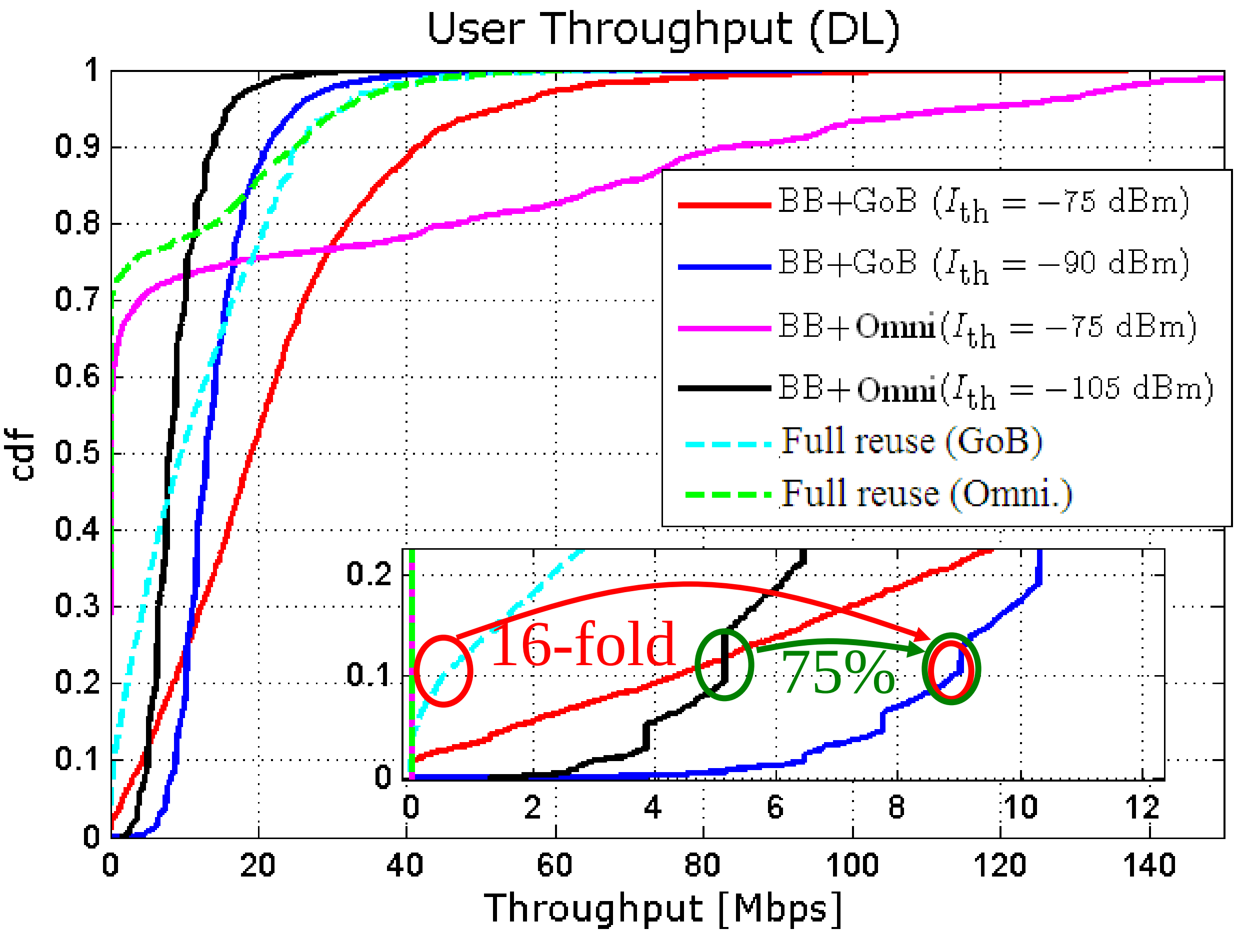
Results: Throughput





SINR target = 22.5 dB, m = 8

User Throughput (DL)

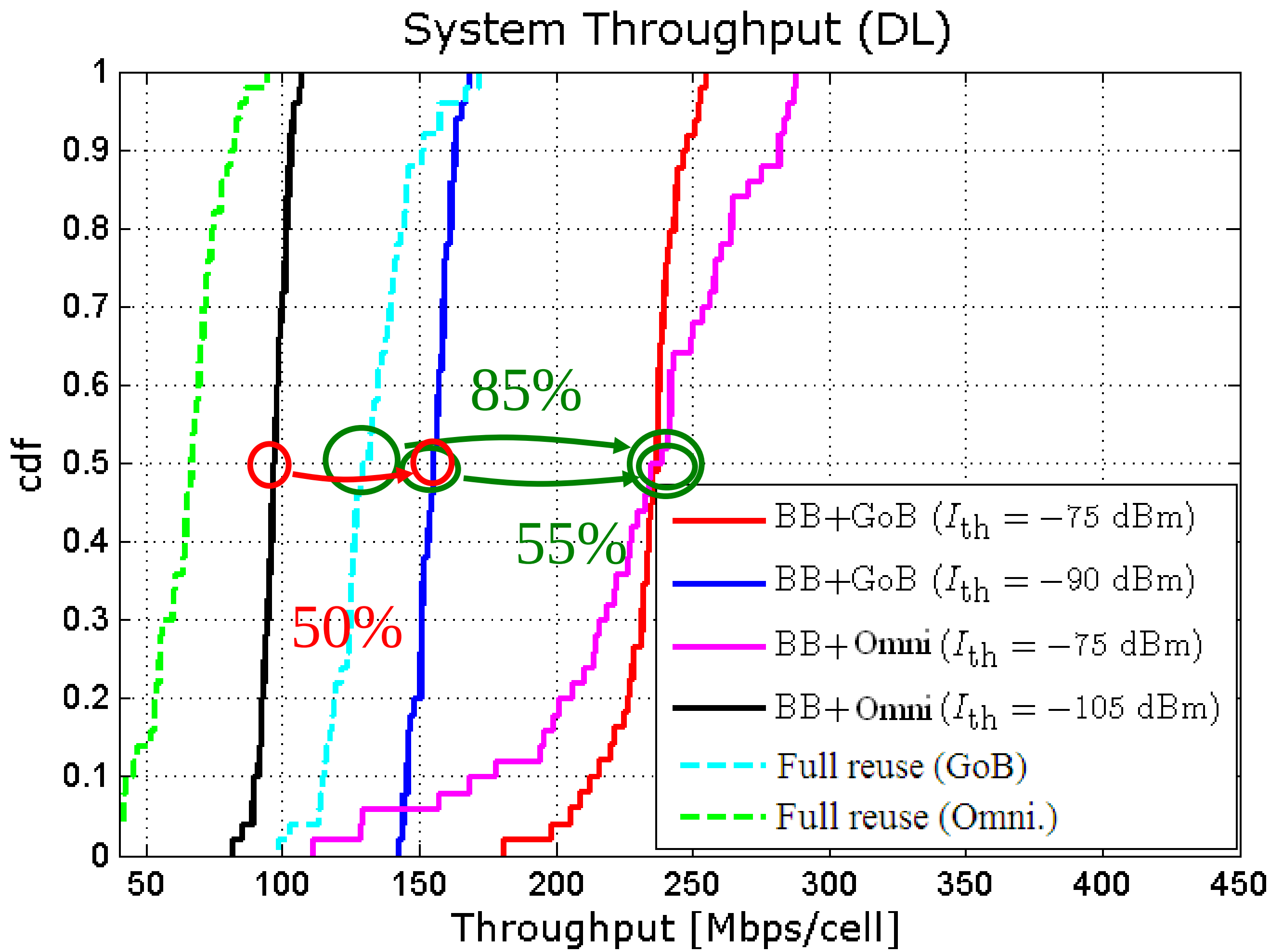


At lower 10%-ile BB+GoB results in:

- 75% improvement compared to BB+Omni directional.
- 16-fold increase compared to GoB with full reuse.

SINR target = 22.5 dB, $m = 8$

System Throughput (DL)



SINR target = 22.5 dB, $m = 8$

Conclusions:

- Proposed a hybrid CCI mitigation approach that combines beam switching and BB signalling

- Observed performance enhancements were:

  Compared to beam switching approach alone:

  – **16-fold** improvement in **cell-edge user throughput** and

  – **85%** increase in **median system throughput**.

  Compared to BB approach with omni-directional antennas:

  – **75%** increase in **cell-edge user throughput** and

  – **50%** increase in **median system throughput**

Summary

- Time multiplexed BB technique is a simple and easy to implement technique, but has very beneficial properties for systems such as:
  - Cognitive radio systems
  - Hierarchical networks
  - Decentralised self-organising full frequency reuse networks
  - Sensor networks
- The BB technique results in novel:
  - MAC protocols
  - Scheduling algorithms
  - Power control algorithms

  for cellular TDD systems resulting in significantly improved system performance by being able to arbitrate trade-offs between throughput, delay, fairness and QoS in general.