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Vodafone Chair Mobile Communications Systems, Prof. Dr.-Ing. G. Fettweis

vodafone chair

Challenges in Next Generation Cellular Communications And Possible Ways Forward

Gerhard Fettweis – Vodafone Chair Professor – TU Dresden

NCC 2011 - Bengaluru

vodafone Chair and Its Partners

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32	Ph.D. students
25+	Ms students
4	sen. scientists
1	post-doc
1	professor
1	project mgr
2	secretaries
4	engineers

IPP 2008

Oct-1

Sponsors

Agilent Technologies – Innovating the HP Way
Asahi KASEI
AMD
CoWare
ANALOG DEVICES
ROHDE & SCHWARZ
ERICSSON
CINTERION WIRELESS MODULES
HUAWEI
TEXAS INSTRUMENTS
TietoEnator
SIGNALION
tensilica
synopsys
digades
infineon
ST-NXP Wireless
actix
ALTERA
GWT forschung + innovation

Projects

Alcatel·Lucent
ERICSSON
SIGNALION
HUAWEI
infineon
Tyco Electronics
vodafone
ZMD
Freistaat Sachsen – Staatsministerium für Umwelt und Landwirtschaft
Bundesministerium für Bildung und Forschung
Deutsche Forschungsgemeinschaft DFG
7 – 2007 - 2013

Numbers

Scientific:

52 Ph.D. grads

200+ Ms. grads

500+ publications

45+ patents

Innovation:

9 spinouts

200+ engineers

Funding:

€ 40M Chair

€ 45M VC

€ 250M projects.

The Vodafone Chair‘s Startup History

1999	OnDSP™ based WLAN chip-sets
2000	UMTS/3G network optimization and planning
2003	LTE FDD & TDD test mobile
2004	Module and reference board design
2005	MPSoC semiconductor IP
2007	Wireless embedded technology
2008	Network performance measurement
2008	LTE Cellular Technology Provider
2010	The “dirty RF” experts for satcom

Numbers

Year 2020

100B transistors per chip

➔1M processors per chip

100B cellular terminals on planet Earth

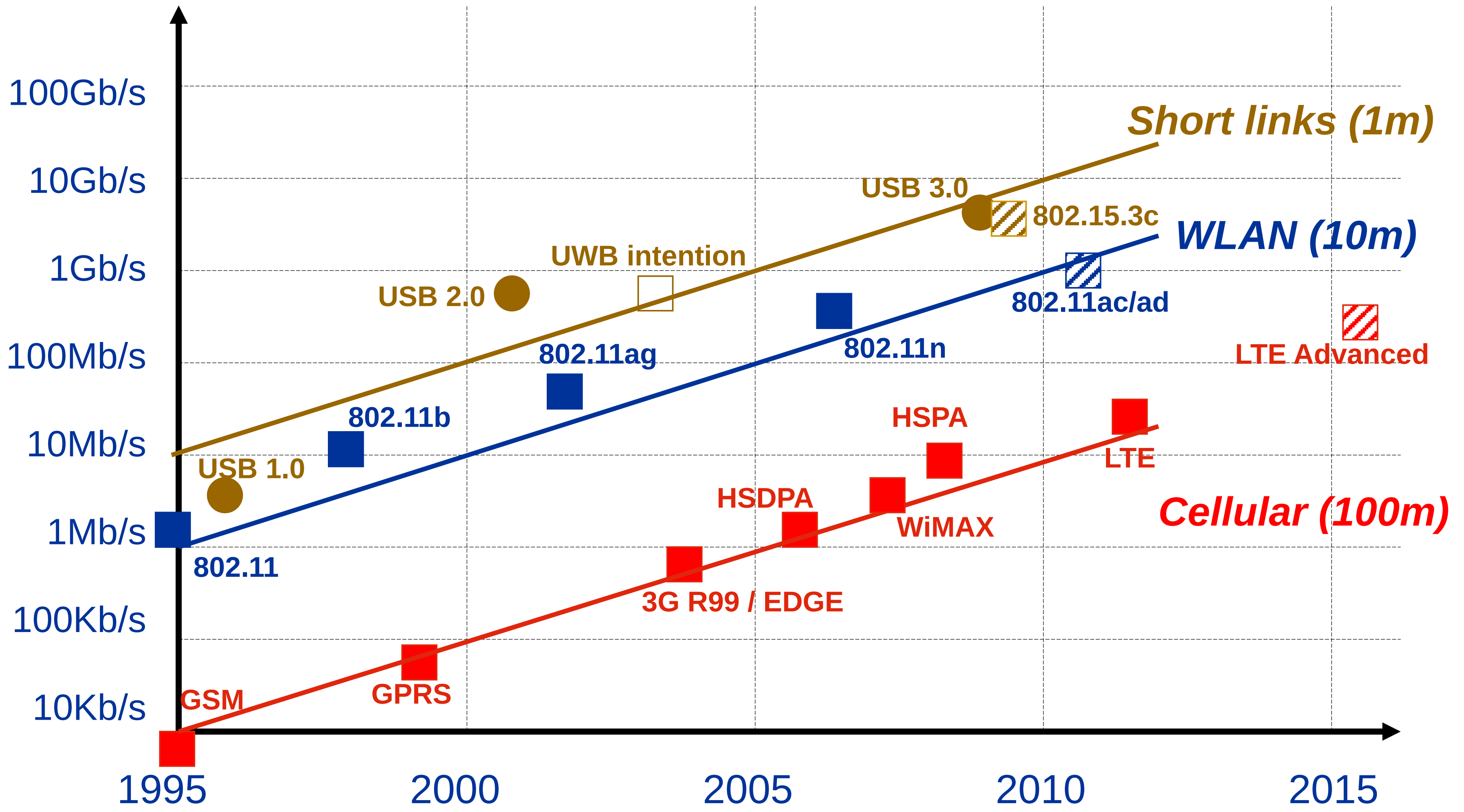
➔ how

➔ for what

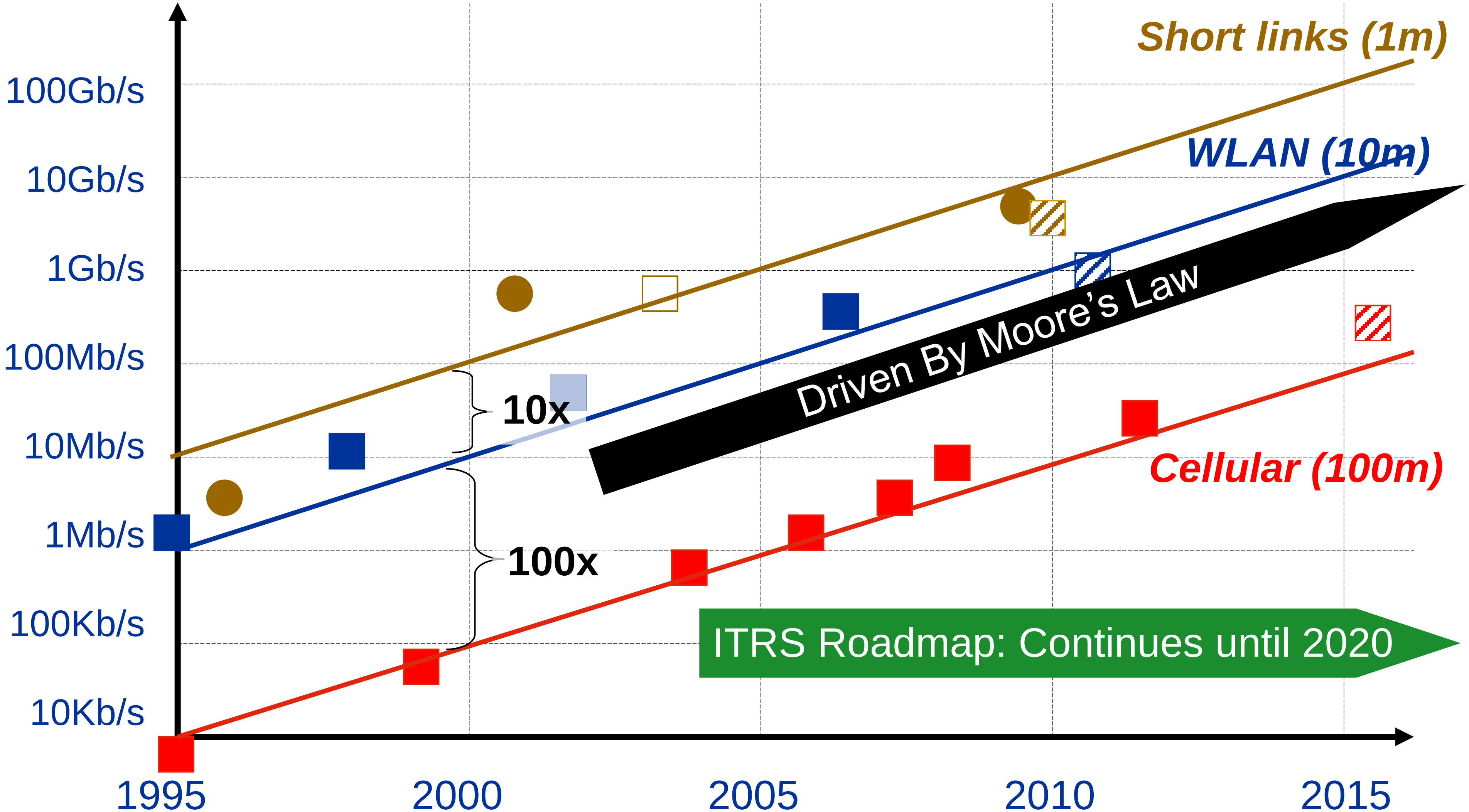
➔ LTE-Advanced enough?

Data Communications
Thoughts & Trends

Coverage: Cellular



The Wireless Roadmap



Moore's Law for Low-Power Cellular ICs

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Transistor density

➔ 2x every 2 years

➔ 1000x in 20 years (1024x ☺)

Clock rate

➔ 10x in 20 years

Computational power

➔ 10x in 5 years or ➔ 10'000x in 20 years

Identical to data rate in cellular ➔ 10'000x in 20 years

LTE 2x2 MIMO 10MHz Bandwidth Chip: Tomahawk Die Photo

- Taped out on May 7, 2007
- Returned on Aug 15,2007 & Jan 07, 2008

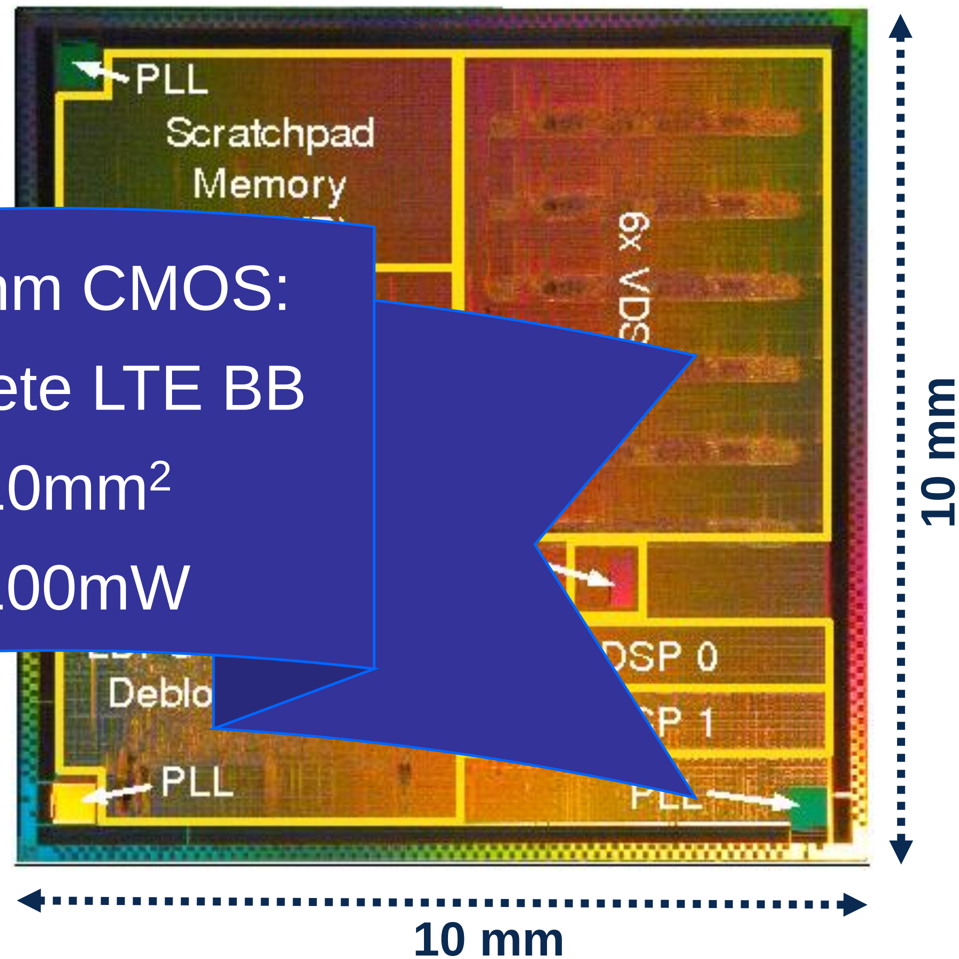
- UMC 130nm
- 8 metal l
- 57 mil. tran
- 40 GOPS @
- 12 Process
  - 2x RI
  - 6x VDSP
  - 2x SDSP
  - 2x ASIP
- On chip SRAM ~ 7.3 MBit

In 28 nm CMOS:

Complete LTE BB

< $10mm^2$

< 100mW



Moore Versus Cellular

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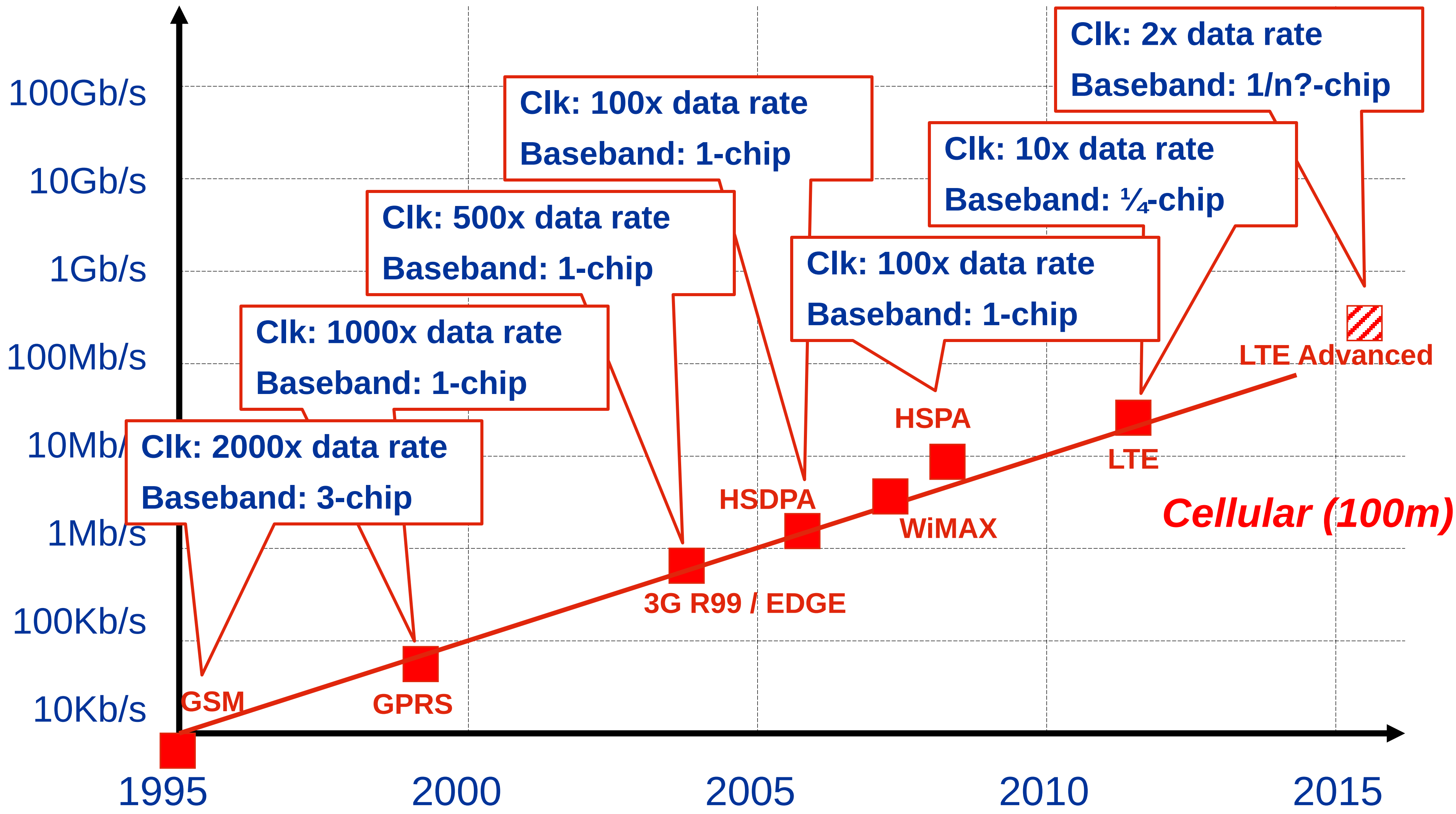

Moore Versus Cellular

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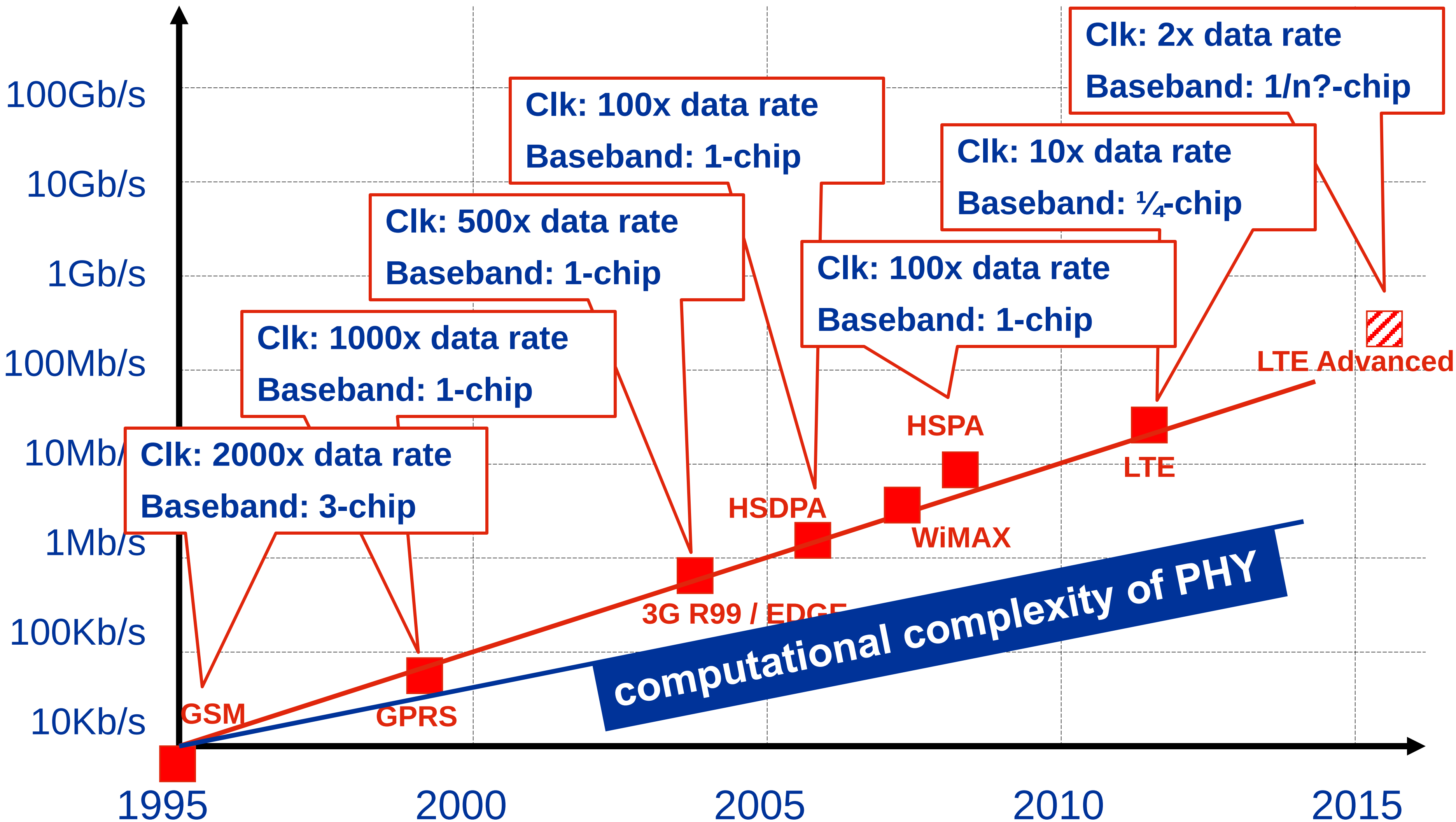

Receiver Complexity Reduction

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2G: MLSE

Equalizer Complexity
Grows Exponentially
With Length of Echoes!!

3G: RAKE

Receiver Complexity
Grows Linearly
With number of Echoes!

4G/LTE: OFDM

Receiver Complexity
Grows Logarithmically
With Length of Echoes!!

What do We Need

LTE-Advanced Research Challenge

- 10x Data Rate over LTE
- 5x DSP/bit over

➔ 50x DSP complexity increase!

➔ ~~**KISS**: **K**eep **I**t **S**imple **S**tupid~~

➔ **SMAC**: **S**mart **M**ajor **A**ddition of **C**omplexity ☺

CAPEX

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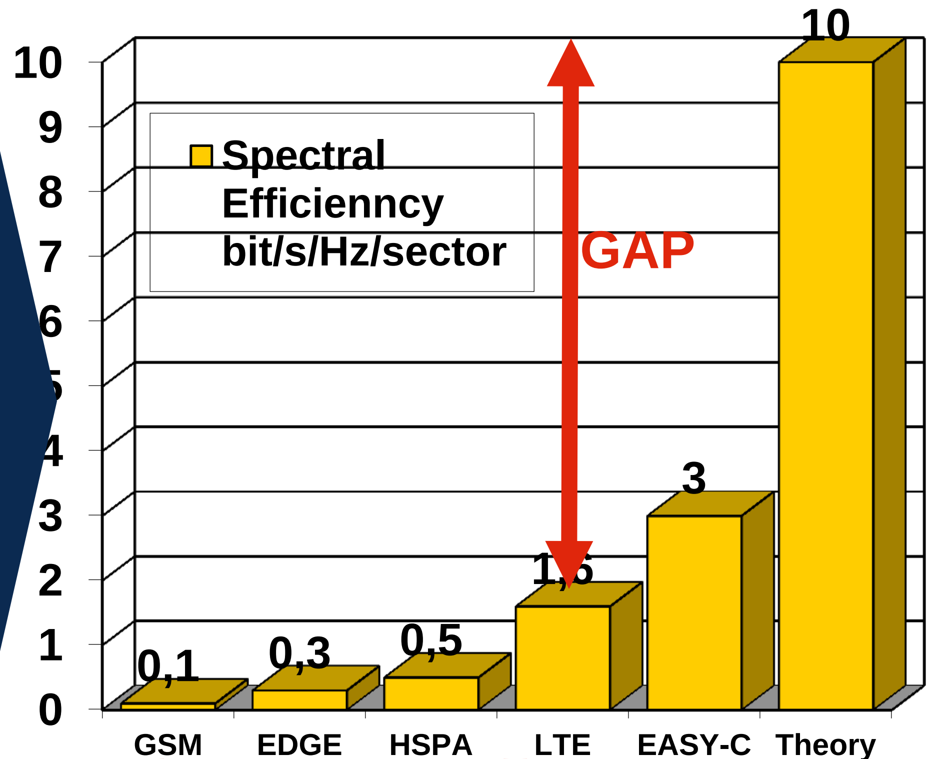
- Our Challenge:
  Finding **good reasons** for spending money !

- Good Reasons
  - Operators like it
  - Customers like it
  - Complexity ok

Spectral Efficiency

License Cost (GER)

- 1Hz paired ~ EUR 1000
- 100Mb/s /sector goal:
  - GSM: 1GHz → €1T
  - LTE: 80MHz → €80B
  - Theory: 10MHz → €10B



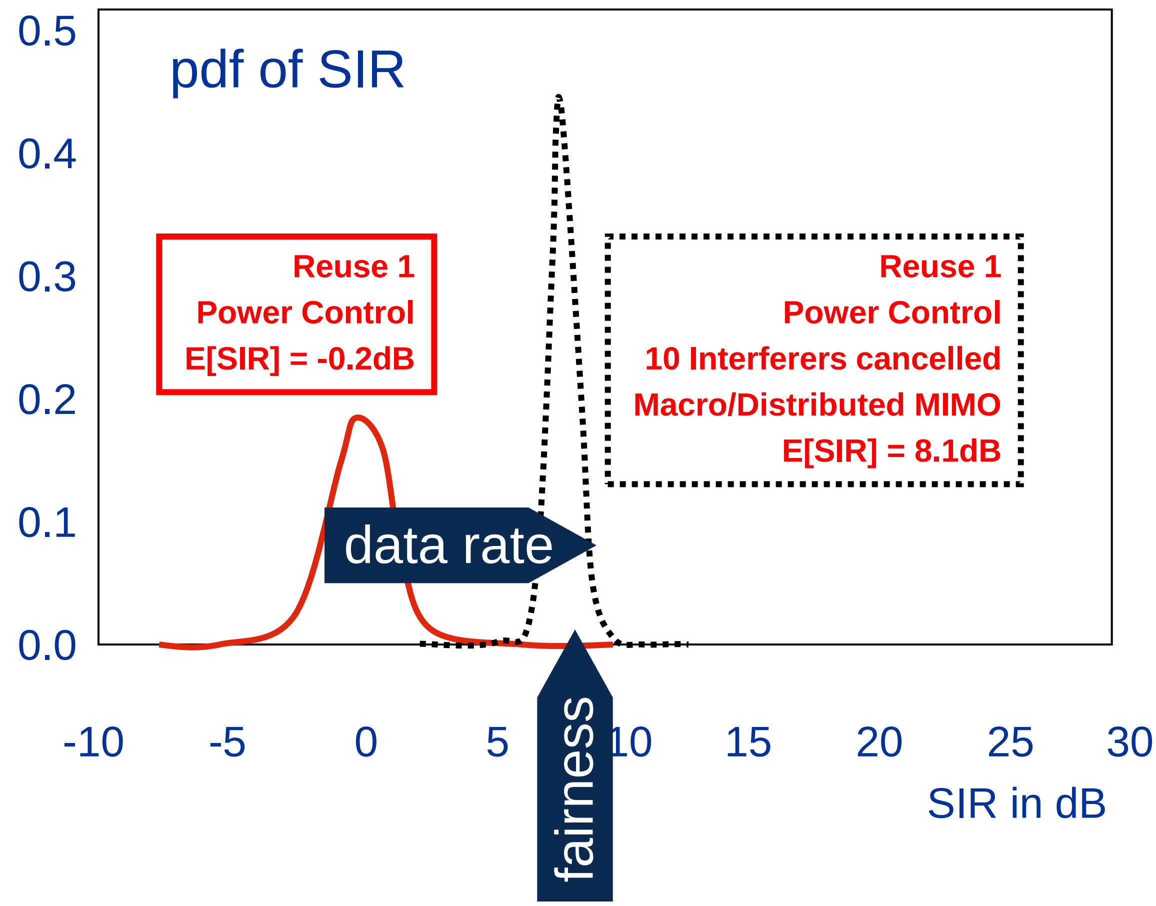
20 YEARS Of Engineering 1987 - 2007

20 further YEARS Of Engineering 2007-2027?

Cellular Challenges: “**FAST SPEED**” and “**FAIRNESS**”

The Next Step

Fairness & Data Rate & Spectral Efficiency



Interference Cancellation: Fairness & High Data Rate

CoMP: Coordinated Multi-Point

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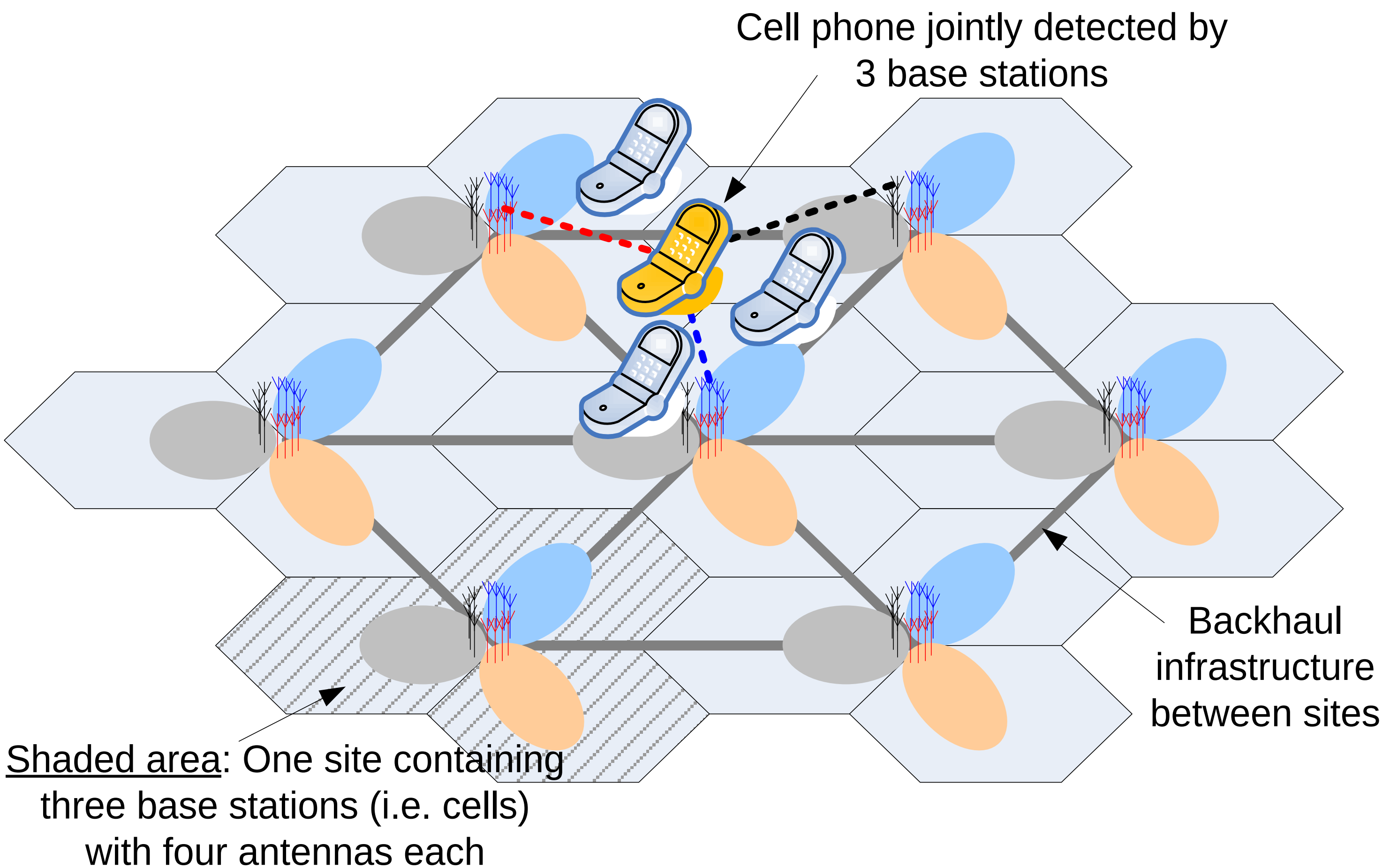
- We thus believe that next generation systems will include multi-cell cooperative signal processing (“network MIMO” or CoMP):



Potential Gains of CoMP

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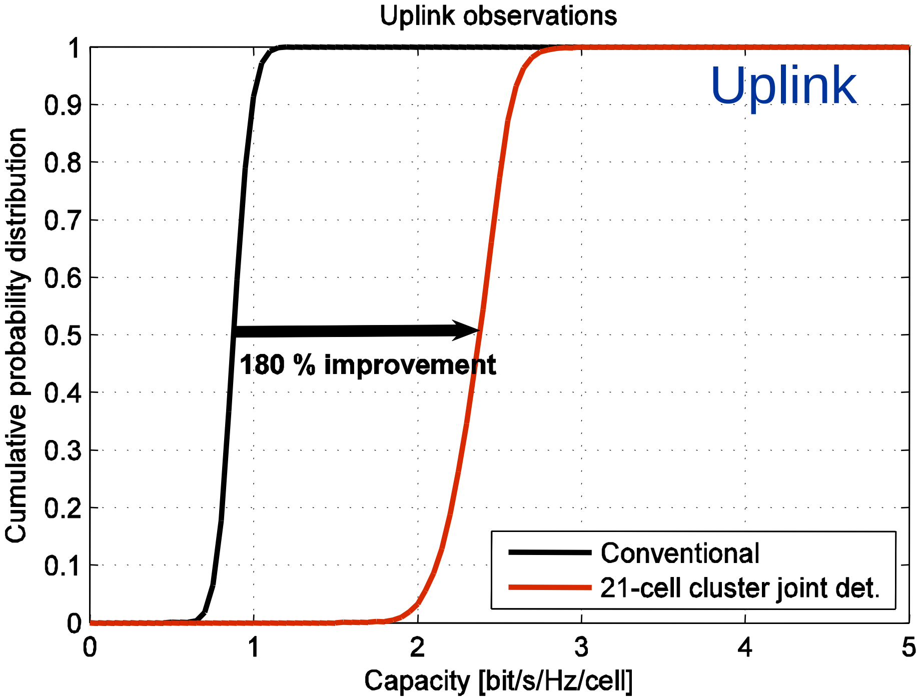
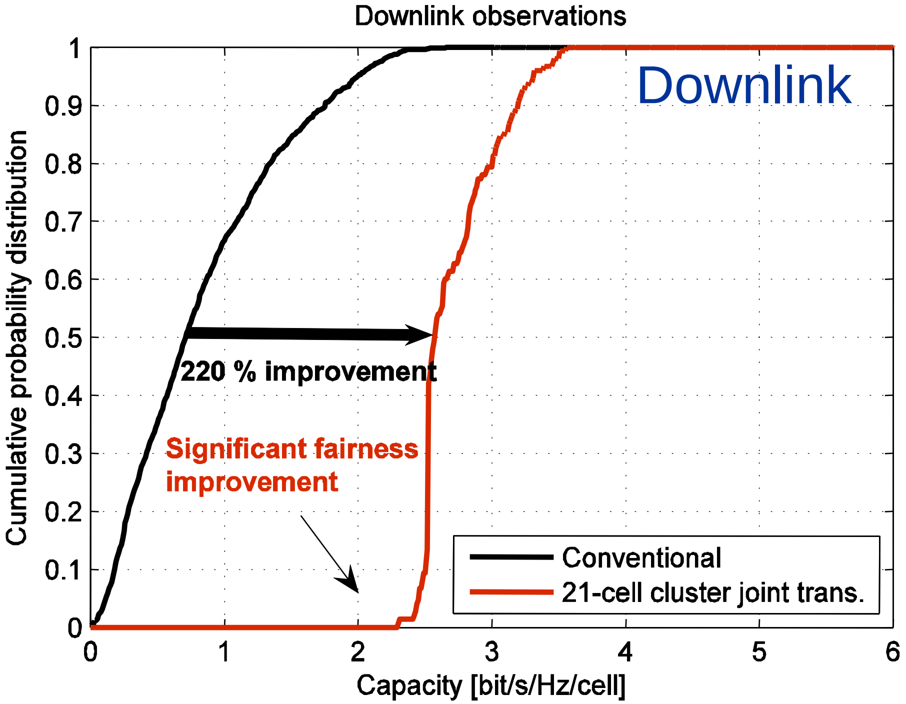


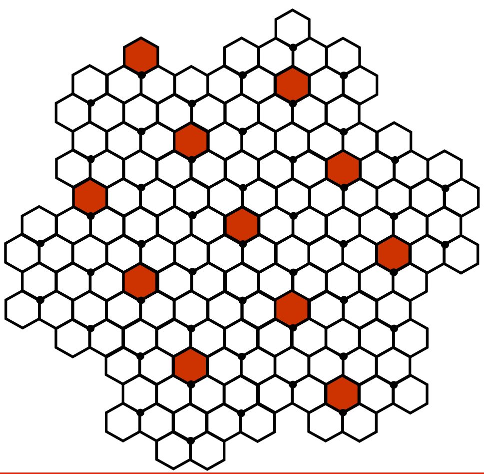


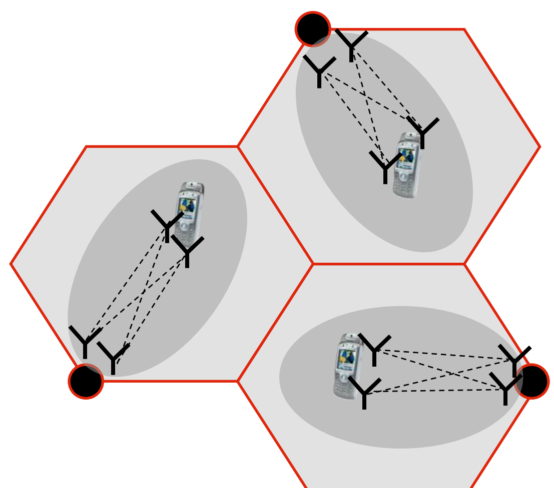
- Okumura-Hata pathloss model, ITU pedestrian A
- Link-to-system mapping (MIESM), 8 MCS schemes
- Spectral eff. losses through guard bands / intervals
- Assuming perfect channel est., 2 rx ant. per eNB

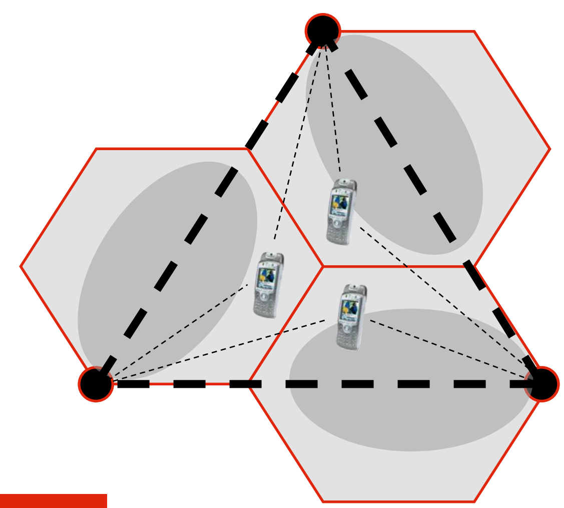
- Linear joint transmission, assuming perfect channel knowledge at the eNBs
- 2 tx ant. per eNB

Generations of Cellular Networks

1st/2nd generation	HSPA+ / LTE Rel. 8	LTE Advanced
Poor spectral efficiency through high reuse factors	Reuse=1, interference suppression through classical MIMO	Interference shaping & cancellation through distrib. MIMO & relaying





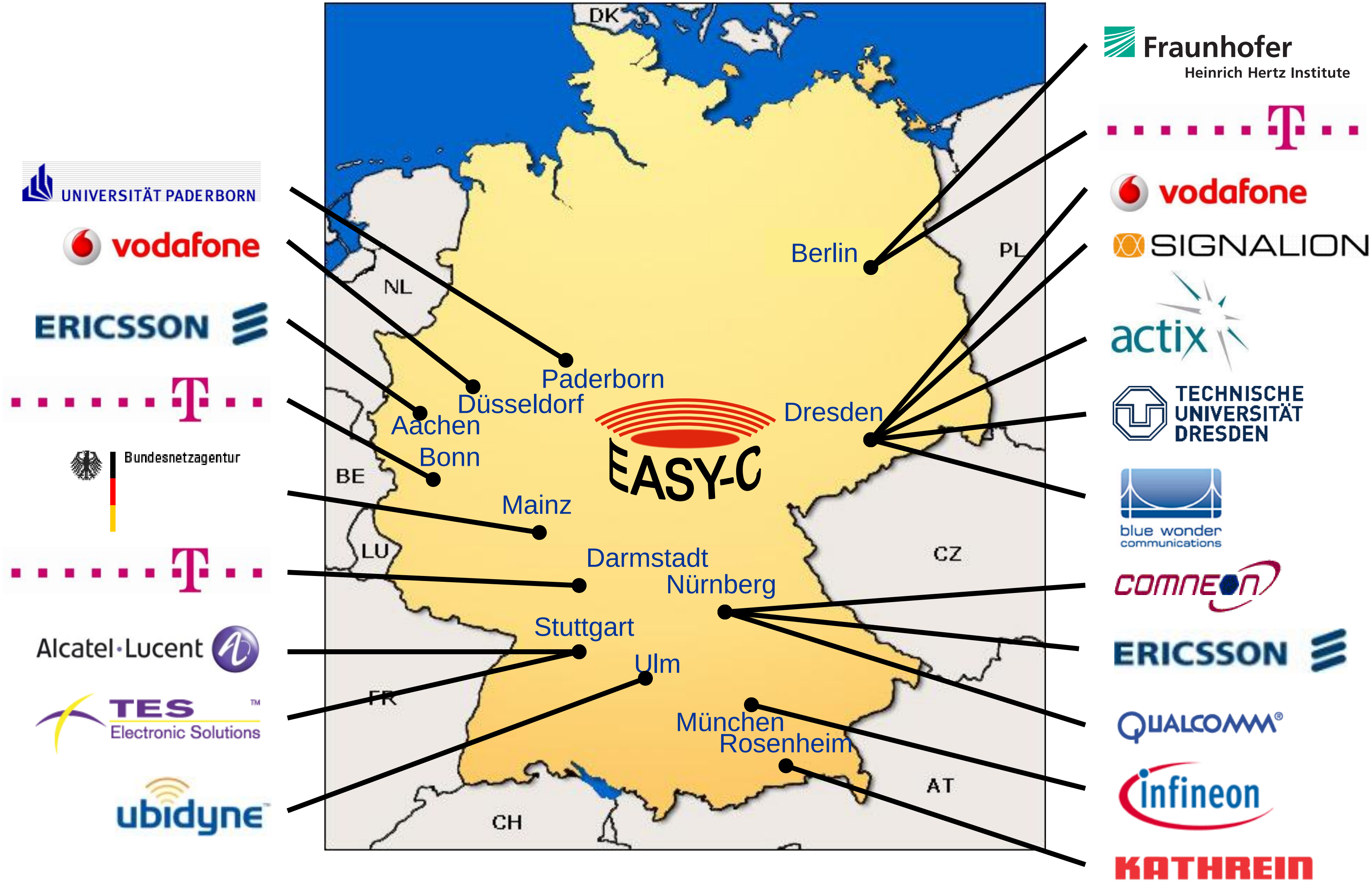


➔ LTE rel. 8 still strongly limited through interference !!!

Project Overview

Overview on the Project EASY-C

The Project Consortium



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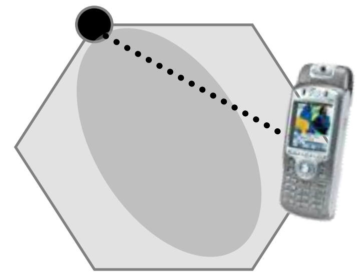
Overview on the Project EASY-C

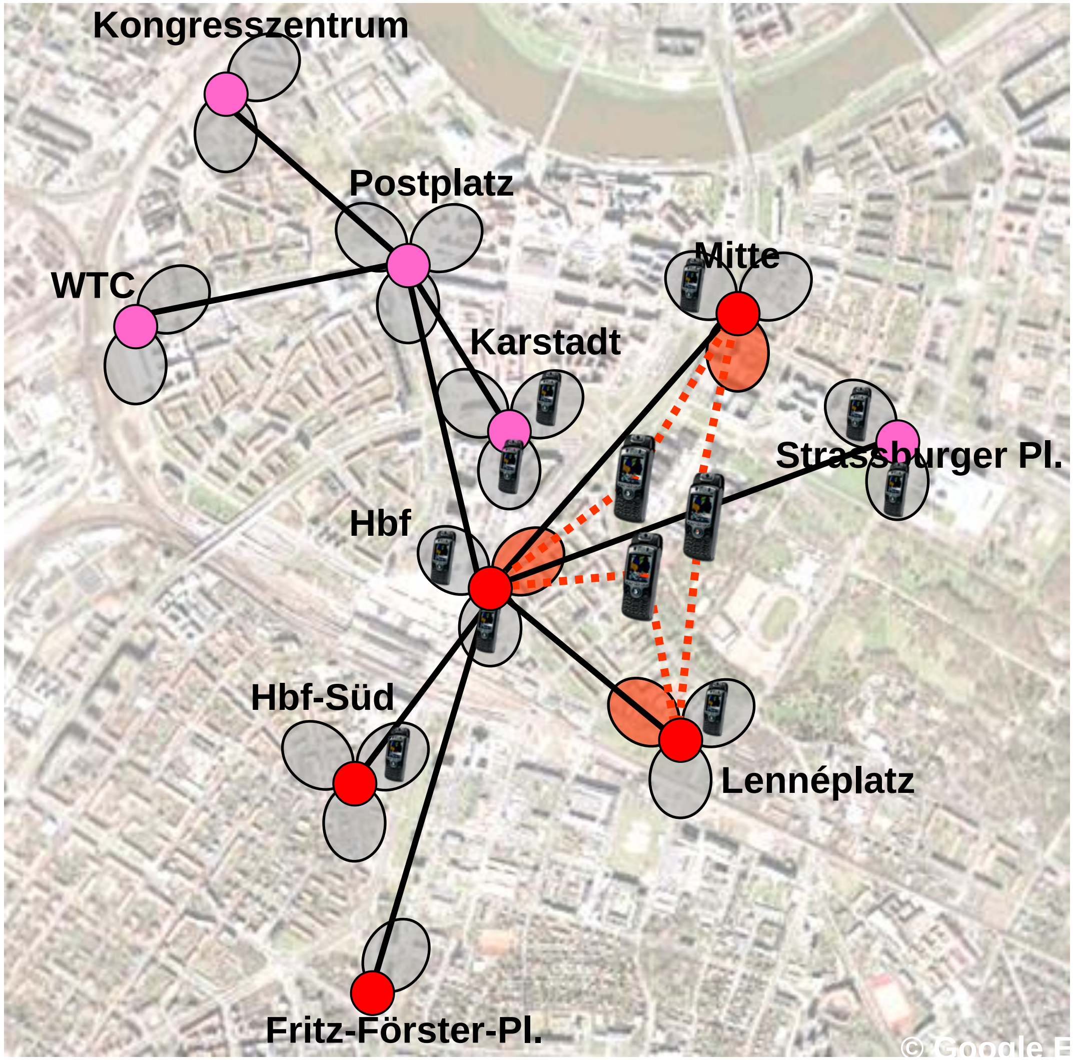
Fairness and Spectral Efficiency Targets



	Average	Cell-edge
UL	+100%	+200%
DL	+50%	+100%

*) all figures relative to LTE rel. 8

World's Largest Operational LTE-Advanced Algorithm Testbed



IEEE ICC 2009 Dresden

LSTI LTE/SAE Trial Initiative April 2010 Dresden

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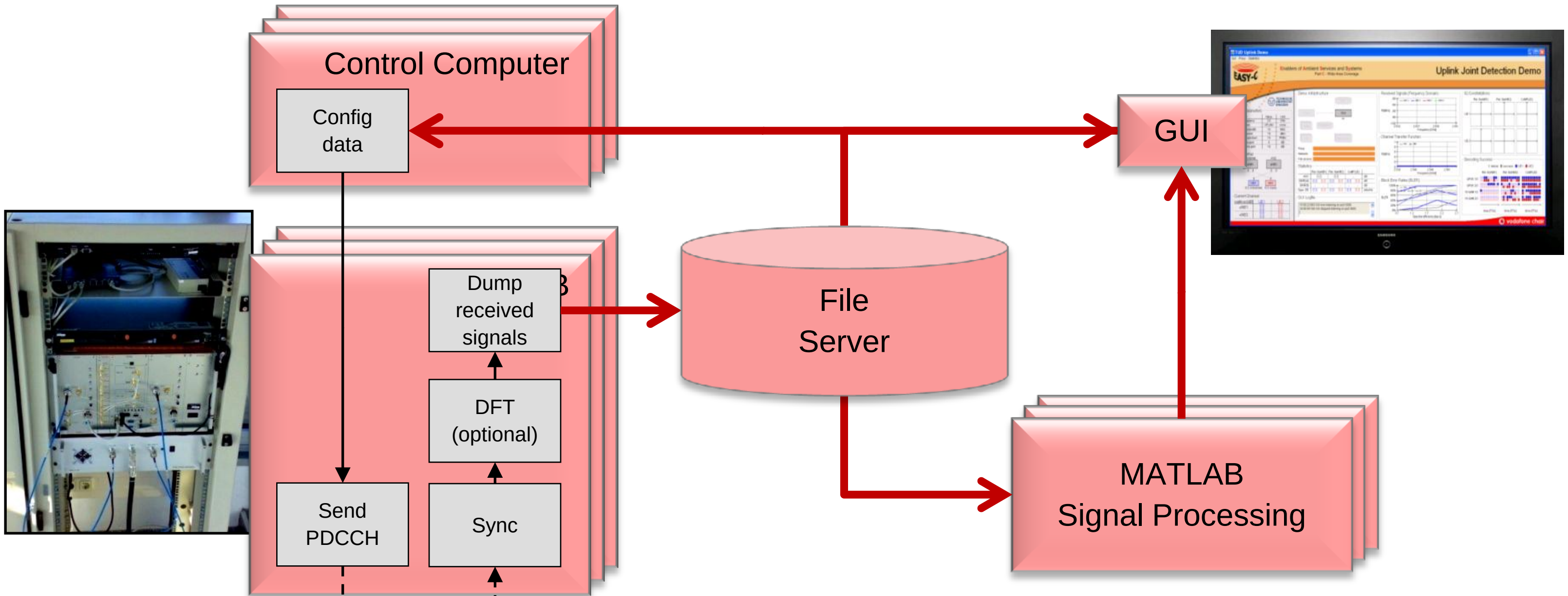
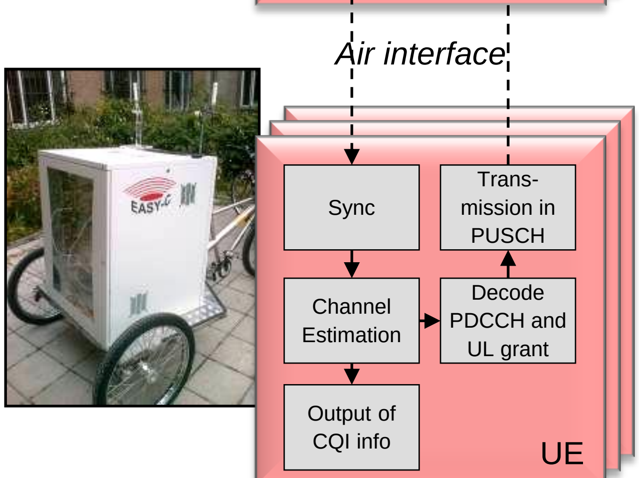
Recent Uplink Field Trial Results

Dresden Test Platform Uplink Setup



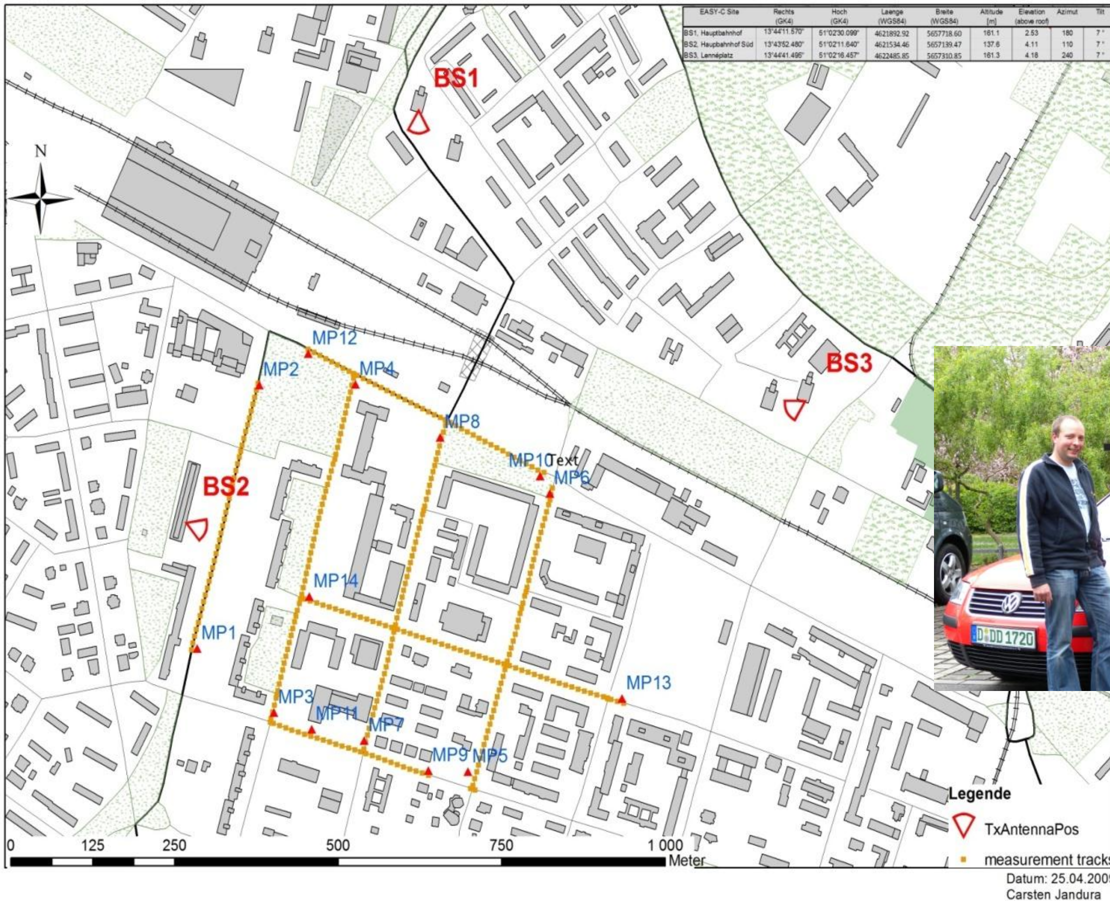


- Uplink Features
  - Focus on PHY
  - Partial compatibility to LTE Rel. 8
  - Sequential test of different MCS
  - Offline signal processing
  - Quasi-realtime scheduling possible

Recent Results

Channel Sounding Campaign

- A second channel sounding campaign took place in April 2009



- CoMP scenario with 3 base stations
- SPULA as transmit antenna, 110° HBW / 7° tilt
- SPUCA as receive antenna
- Measurement BW 100 MHz
- 174960 snapshots collected

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Recent Results

Alcatel-Lucent Measurement Campaign

- An LTE-Advanced Measurement Campaign took place from April 17 to May 15 2009 in Dresden

Test campus / routes / sites for SoA1

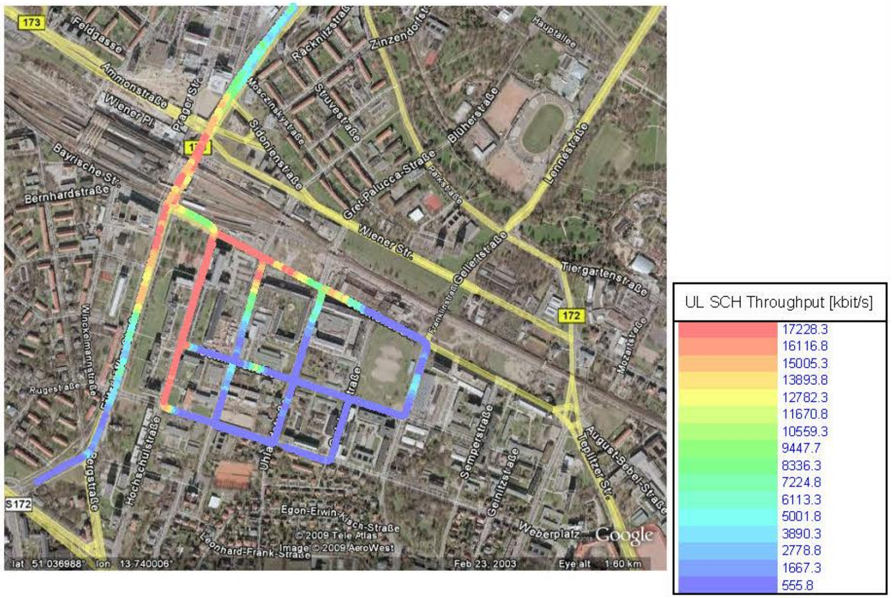
Test Cases

- Downlink SIMO
- Uplink SIMO
- Downlink SU MIMO
- Uplink MU MIMO
- Downlink SIMO with Interferer

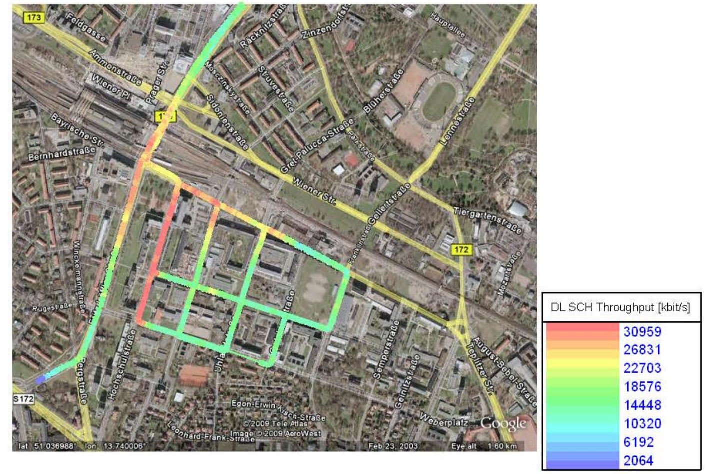
Recent Results

Alcatel-Lucent Measurement Campaign

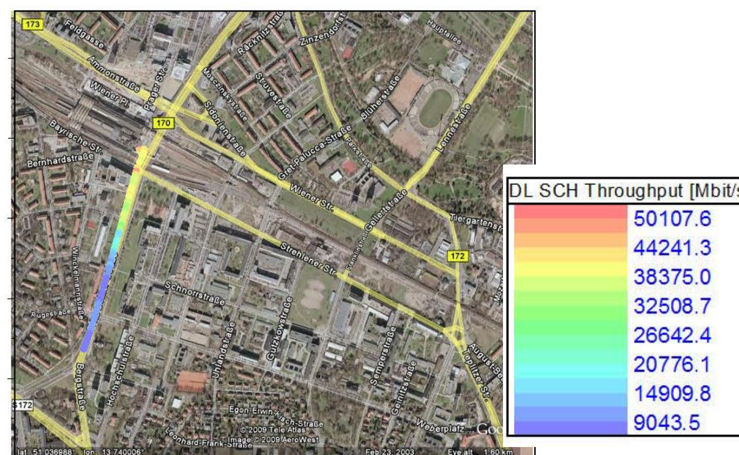
- Uplink SIMO (peak: 17 Mbit/s)



- Downlink SU SIMO (peak: 35 Mbit/s)



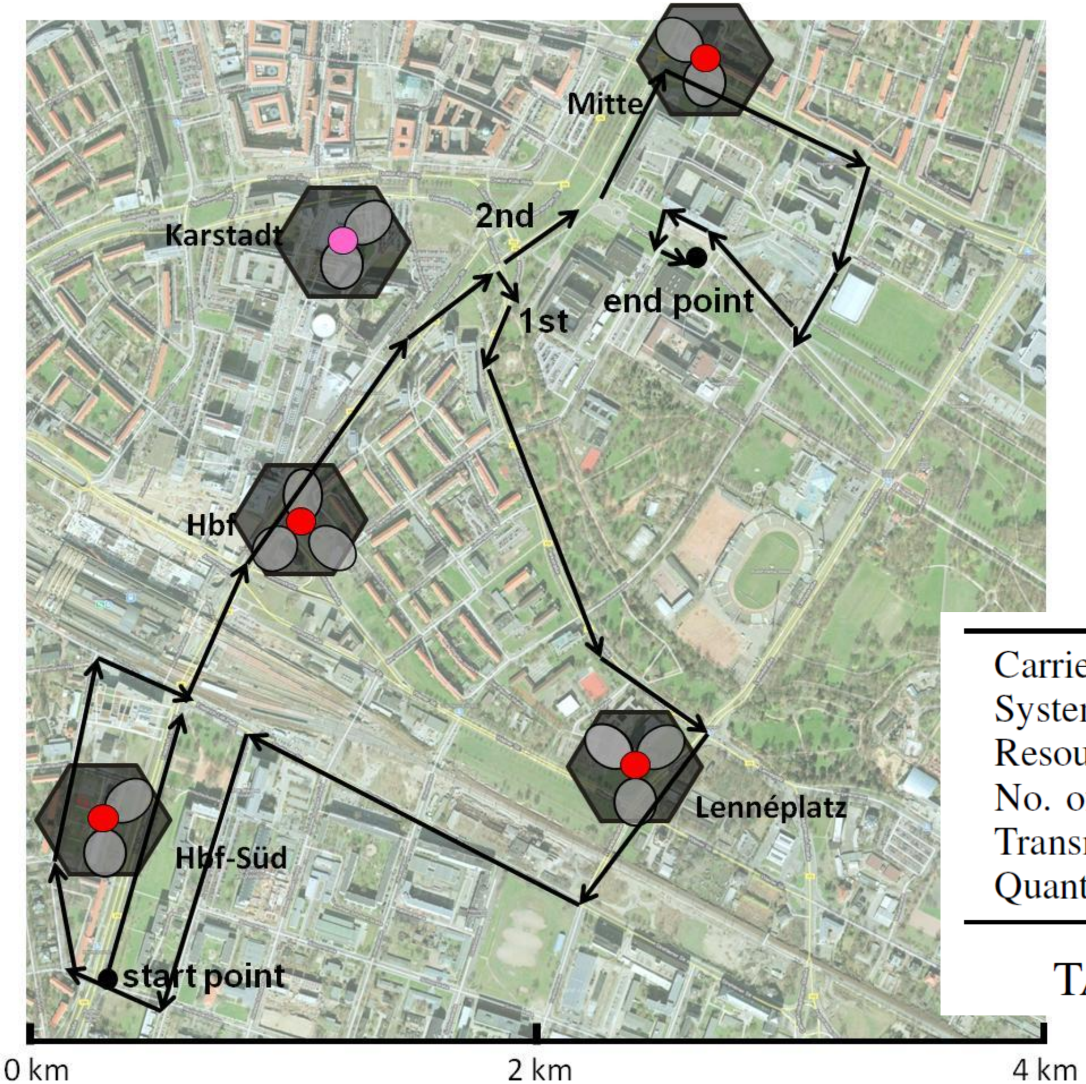
- Downlink SU MIMO (peak: 70 Mbit/s)



- In addition, first MU-MIMO tests were performed in the uplink
- Downlink tests with up to three interferers
- 20MHz Channel @ 2.6GHz carrier

Recent Uplink Field Trial Results

Trial Setup and Trajectory



- **Base stations involved: 12**
- **2 UEs transmitting, one „moving BS“**
- **Distance: ca. 7.5 km**
- **UE speed ≈ 6 km/h**
- **One dump of ca. 80 TTIs every 5 seconds**
- **Evaluation of the uplink CoMP gain vs. IRC**

Carrier frequency	2.53 GHz
System bandwidth	20 MHz
Resource blocks (PRBs)	30
No. of sub-carriers per PRB	12
Transmit Power	18 dBm
Quantization resolution	12 bit per real dim.

TABLE I: Transmission parameters

Channel estimation

- LTE pilot positons
- Code orthogonal pilot positions

MCS#	Mod. scheme	Code rate	Peak rate	Bit per channel use
1	4QAM	3/16	1.30 Mbps	0.375
2	4QAM	1/2	3.46 Mbps	1
3	16QAM	2/5	5.62 Mbps	1.60
4	16QAM	4/7	7.99 Mbps	2.29
5	16QAM	2/3	9.29 Mbps	2.66
6	16QAM	3/4	10.6 Mbps	3.00
7	16QAM	6/7	12.3 Mbps	3.43
8	16QAM	99/100	14 Mbps	3.96

TABLE II: Modulation schemes and code rates used for transmission, assuming turbo codes as used in LTE Rel. 8.

Noise covariance estimation

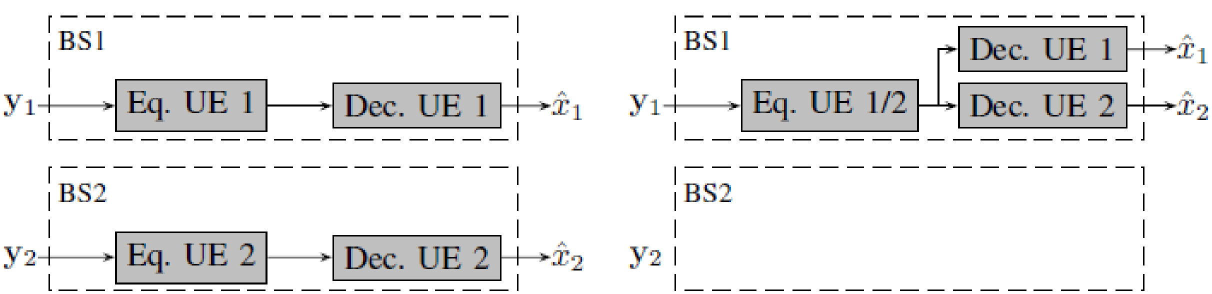
- Autocorrelation based approach

Soft demodulation and decoding

- Standard soft demodulation and decoding
- Error vector magnitude SINR estimation

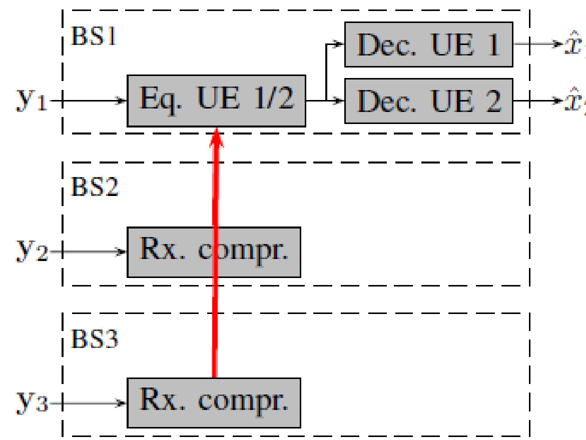
Rate adaptation

- offline evaluation; emulation of optimal rate adaptation



(a) Conv. BS-UE assign., no coop.

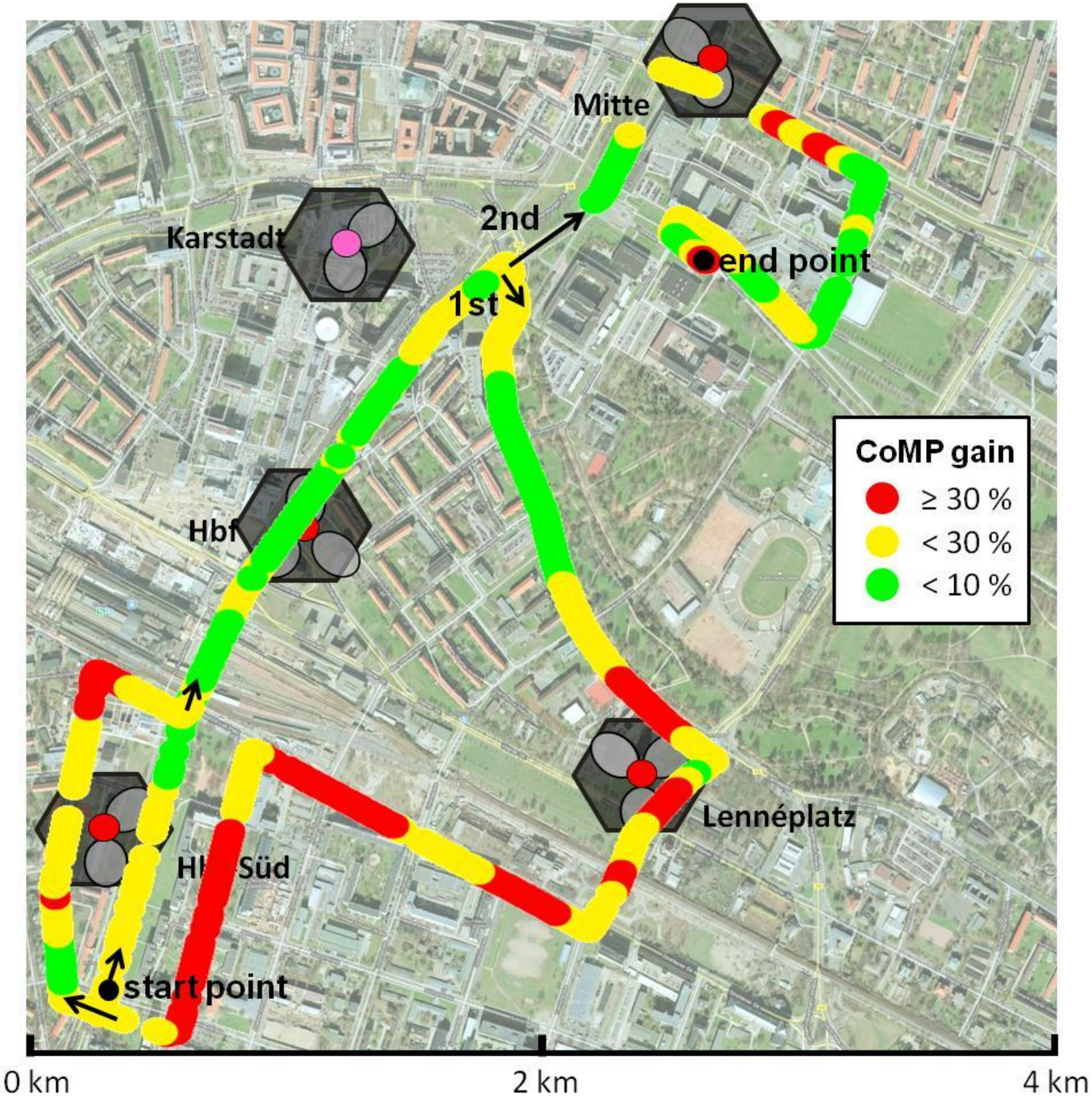
(b) Both UEs assigned to same BS



(c) Cooperative detection; cluster size either $C = 2$ or $C = 3$.

Recent Uplink Field Trial Results

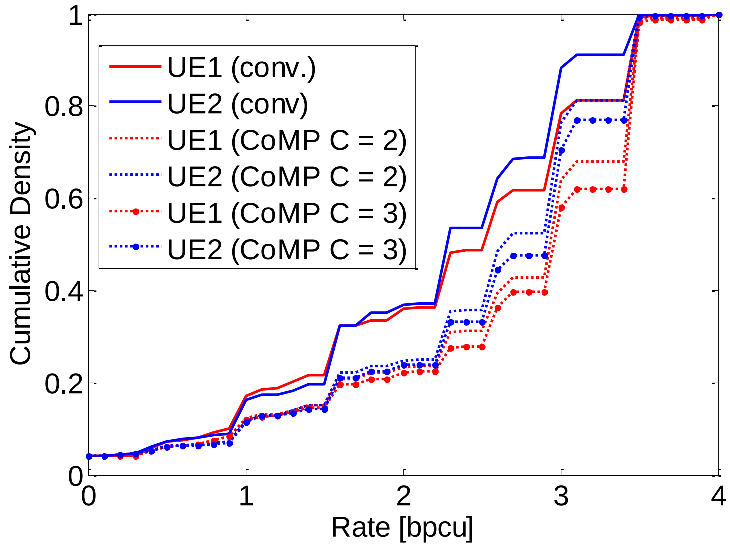
Observed CoMP Gains



- **Moderate average gains**

Scheme	Avg. gain
Conv.	-
CoMP C = 2	19.0 %
CoMP C = 3	22.6 %

- **Peak CoMP gains up to 150%**



Recent Downlink Field Trial Results

Scenario I: North

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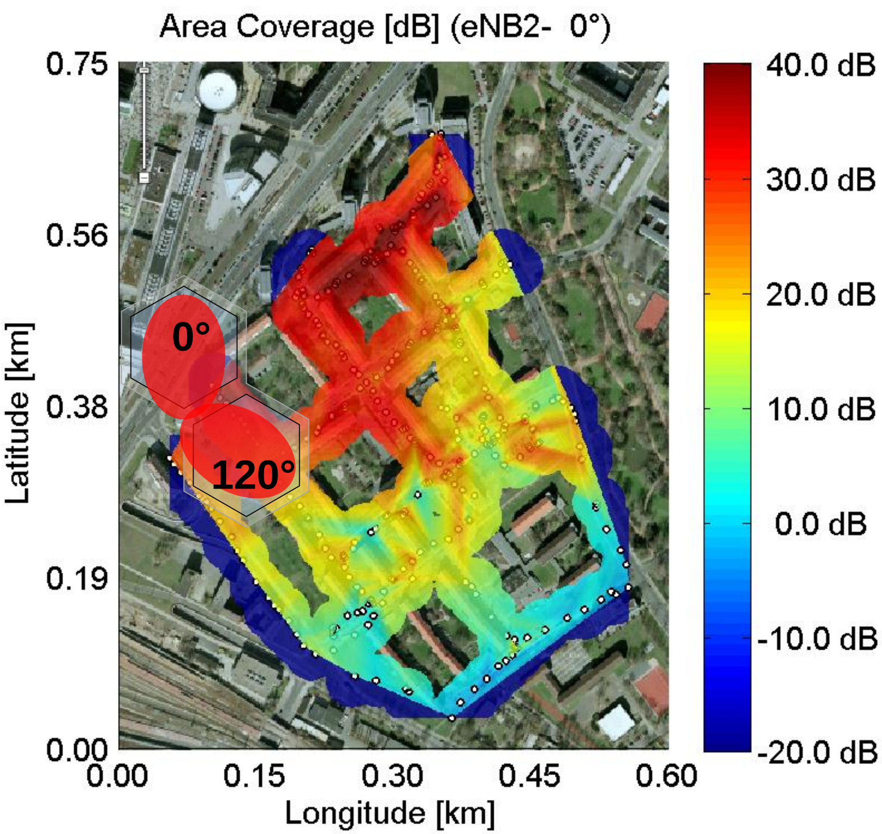
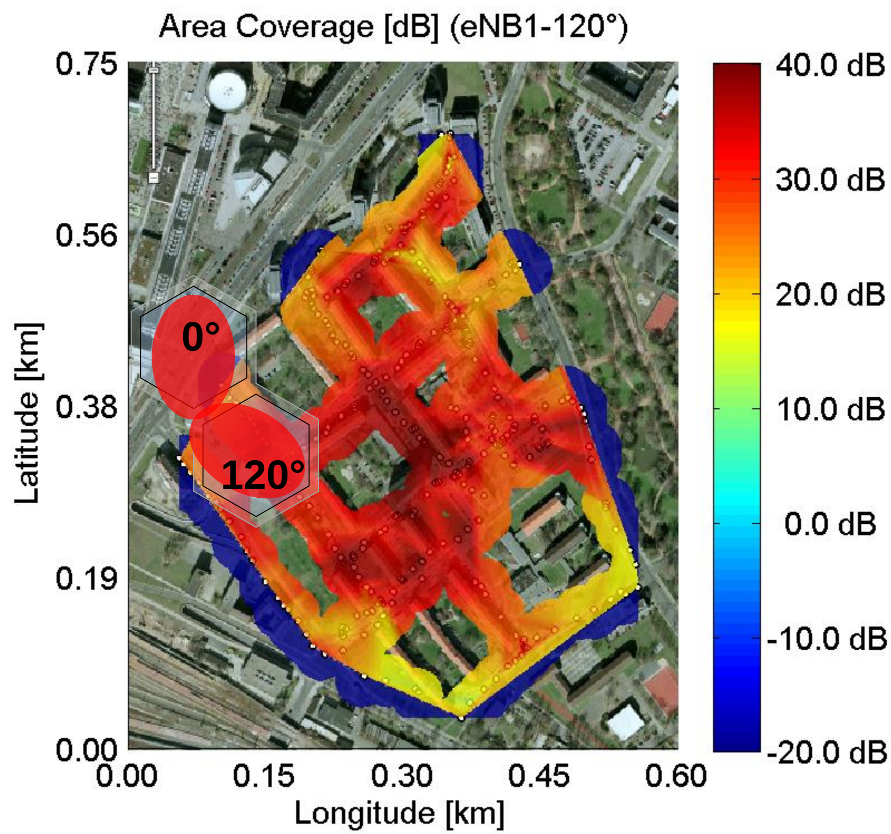
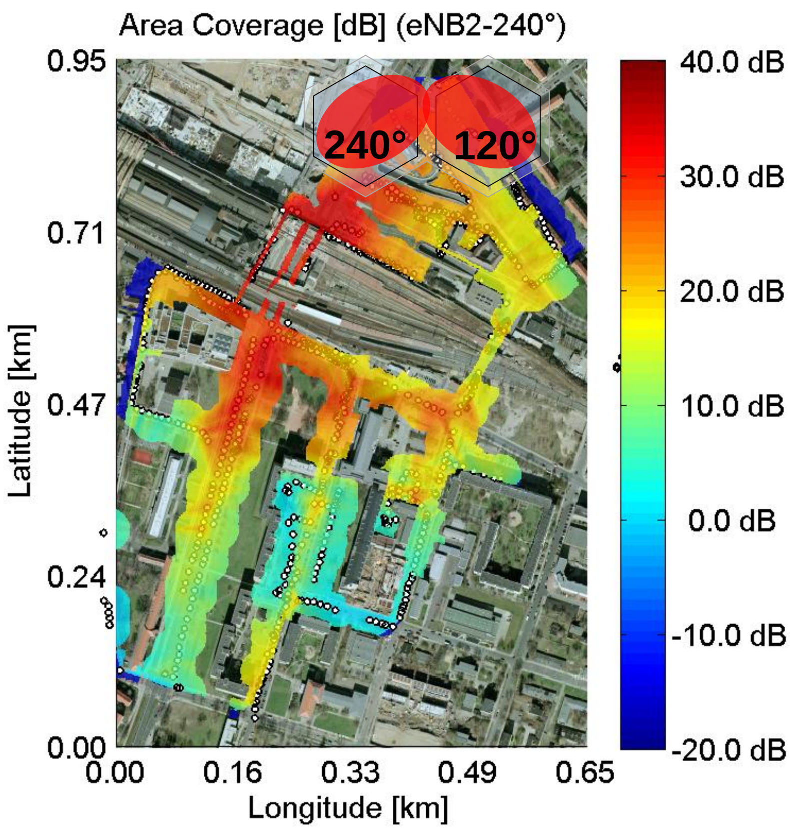


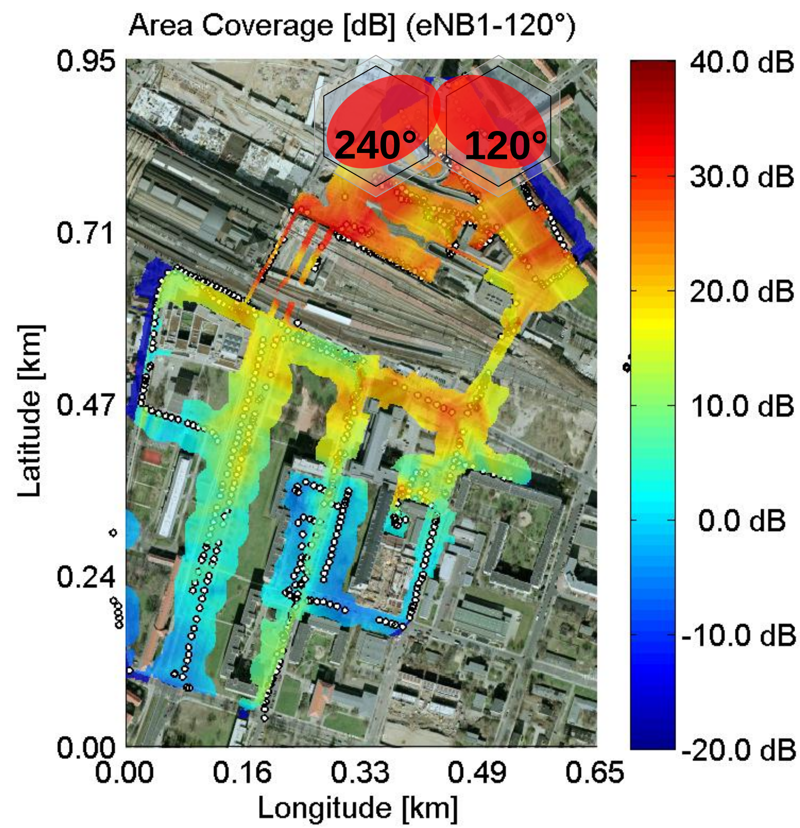


Area	Characteristics		
500 x 650 m^2	NLOS	Manifold shadowing	Typical residential area with dense building

Recent Downlink Field Trial Results

Scenario II: South

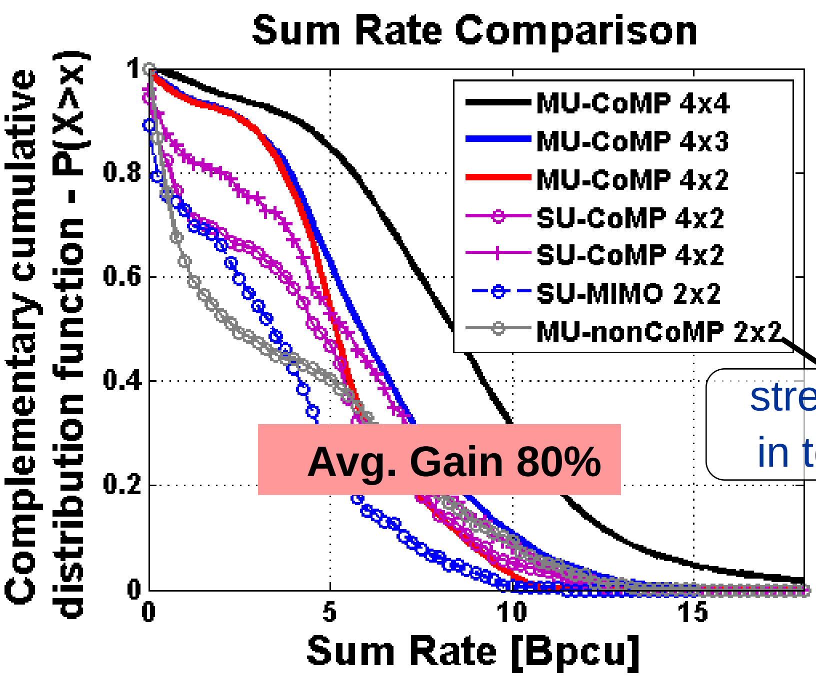




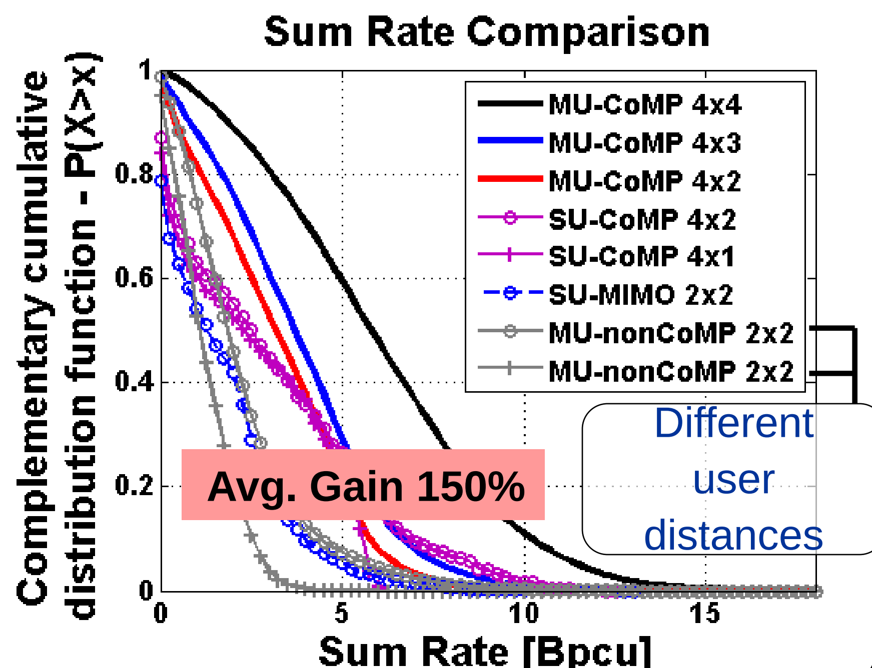
Area	Characteristics		
650 x 900 m^2	LOS	Large overlapping cell areas	Urban area with low building density

Recent Downlink Field Trial Results
CoMP Gains

Scenario I: North



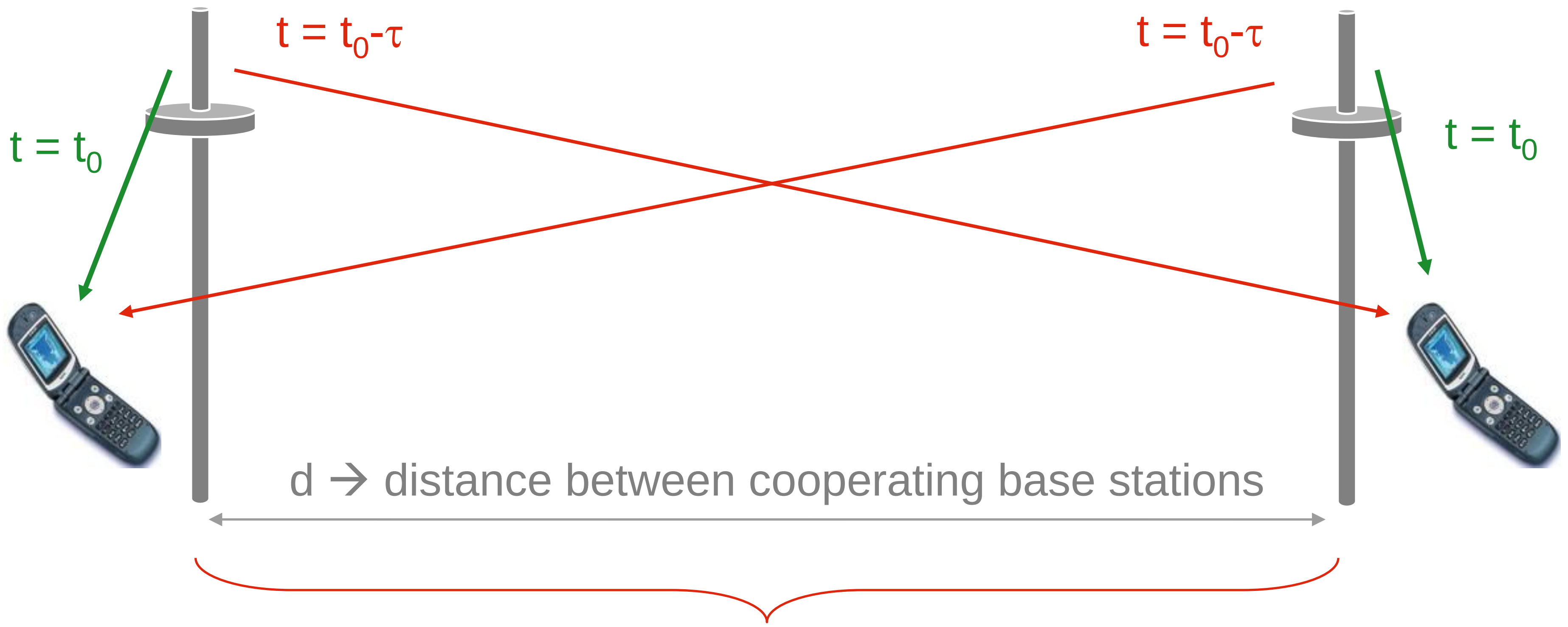
Scenario II: South



Relative Gains	MU-CoMP 4x4 (8,59)	MU-CoMP 4x3 (6,24)	MU-CoMP 4x2 (5,43)		MU-CoMP 4x4 (6,09)	MU-CoMP 4x3 (3,91)	MU-CoMP 4x2 (3,33)
	2,44 2,04	1,77 1,48	1,54 1,28	(3,52) **SU-MIMO 2x2** (1,80) (4,21) **MU-non CoMP** (1,36)	3.38 4,47	2,17 2,87	1,85 2,44

Some Results / Key Learnings

OFDM for Downlink CoMP

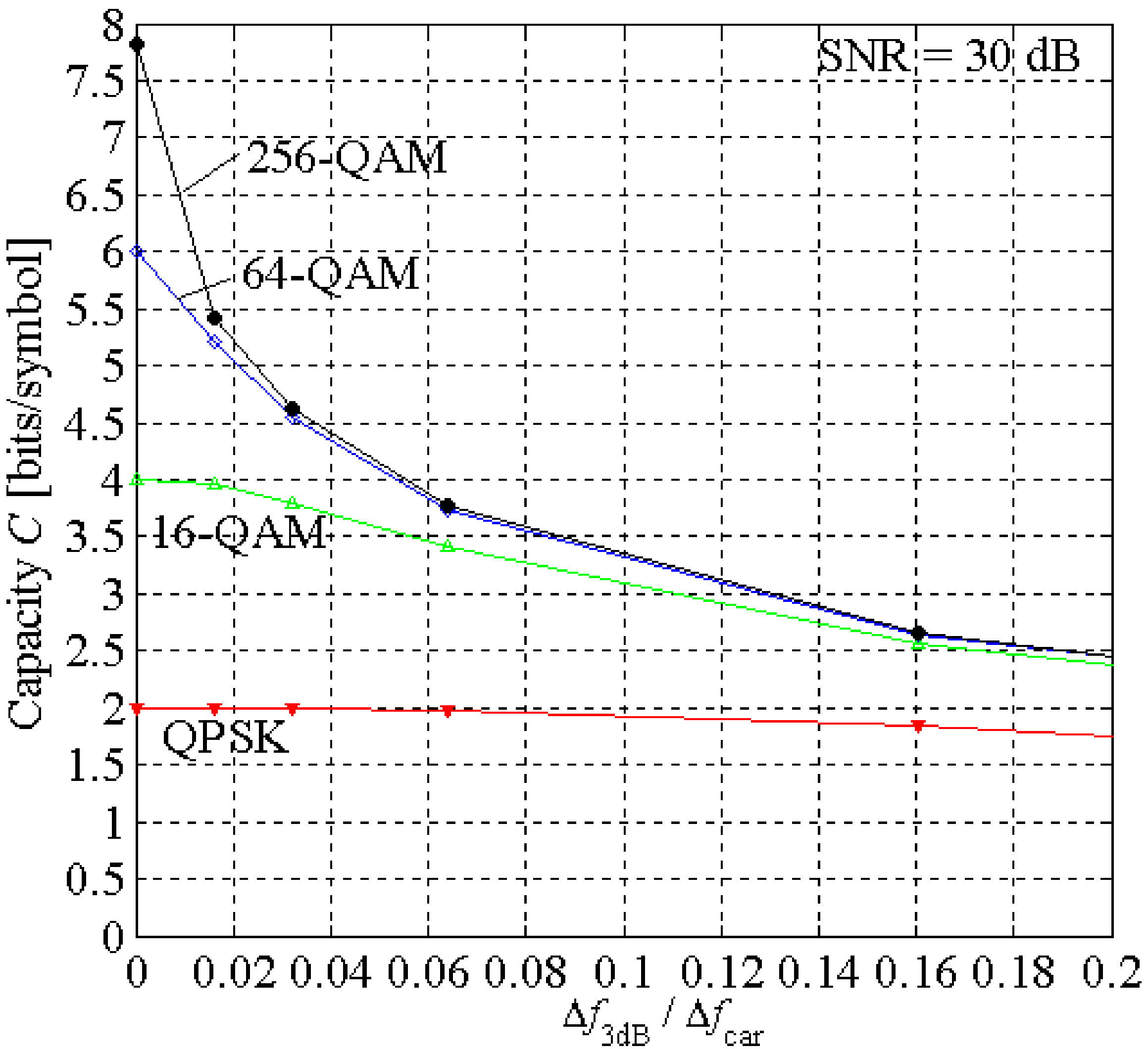


$\tau \approx d/c$

Use CP to compensate?

LTE: d=360m

OFDM: Phase Noise Impairing Capacity

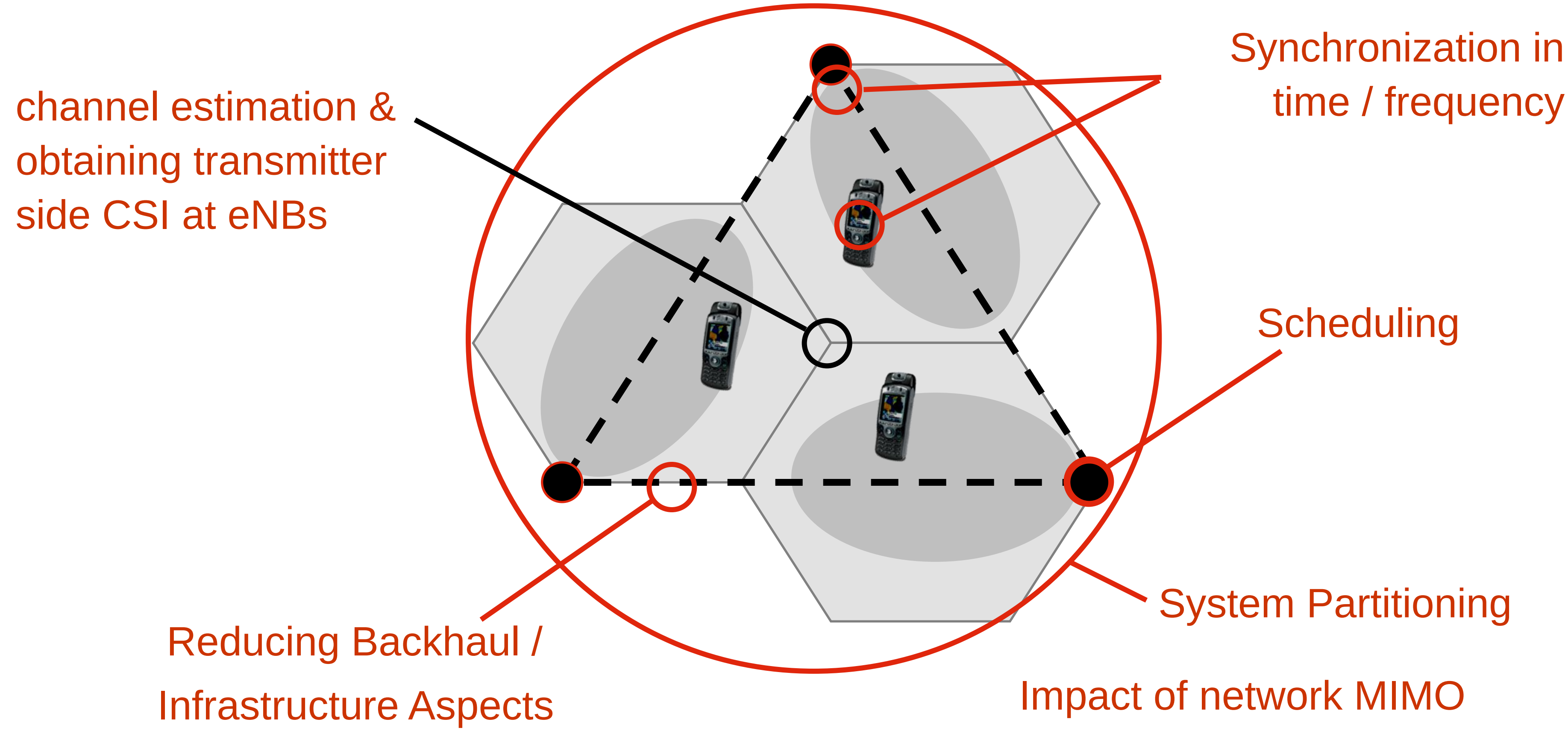


Δf_{car} sub-carrier spacing

Key Learnings

Key CoMP Challenges Identified

- The EASY-C consortium has gained vast experience in the implementation and challenges connected to coordinated multi-point (CoMP):



Key Challenges & Solutions

Clustering:	M.Source:	Applies to:	Impact:
• Static clustering: close-to-optimal performance, verified w. Dresden 3D	TUD	All CoMP schemes	Good option
• Dynamic clustering: can provide additional gain at reasonable effort	Qualcomm	All CoMP schemes	Good option
• Cluster size: depends heavily on propagation and inter-site distances	DTAG	All CoMP schemes	Further study reqd.

Synchronization:			
• Asymmetric propagation delays → ISI → ISI-cancelation required	TUD	All CoMP	Limits CoMP
• DL full CoMP requires highly precise synchronization of oscillators at BSs	TUD/HHI	DL full CoMP	Potential show stopper

Key Challenges & Solutions

Channel Estimation:	M.Source:	Applies to:	Impact:
• Inaccurate estimation: moderately strong interference required	TUD	DL full CoMP	Limits any CoMP
• Required DL pilot overhead: adaptive usage preferable	HHI/TUD	DL full CoMP	Severe limit of DL CoMP
• Code-orthogonal pilots over multiple TTIs: overhead vs. CSI performance	HHI/TUD	Any UL or DL CoMP	Good option

CSI Feedback:			
• Limited DL CSI Feedback at BSs: CSI exchange between BSs	HHI/TUD	DL full CoMP	solvable, delay incr.
• Bandwidth for DL CoMP CSI Feedback: adaptive usage required	TUD	DL full CoMP	Severe issue, more research

Project Evolution

EASY-C → Artist4G

Achievements
Technology Evolution

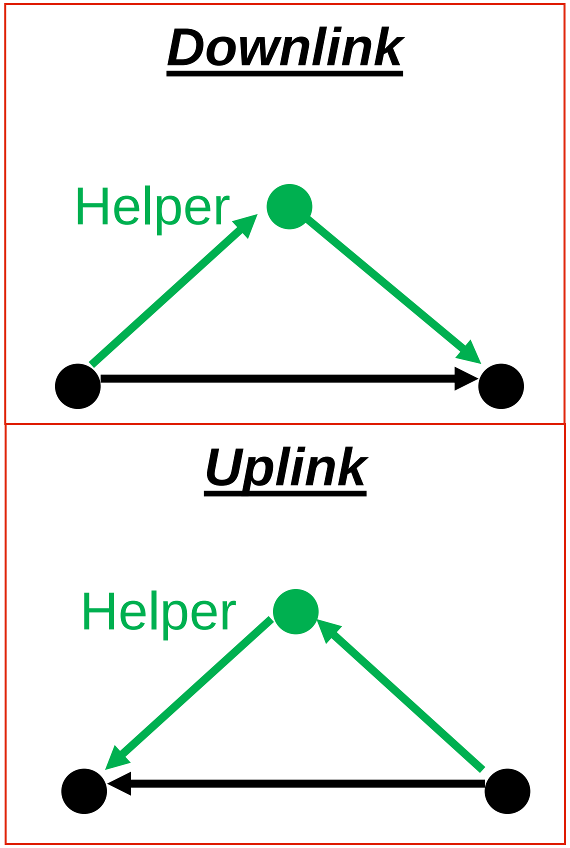
EASY-C identified major challenges concerning

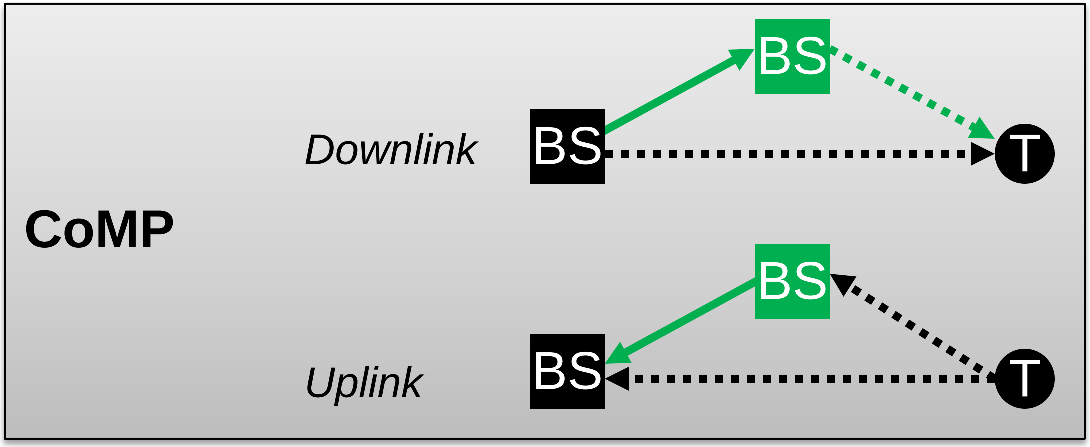
- Synchronization requirements,
- Multi channel estimation,
- Feedback compression,
- Backhaul requirements,
- UE Complexity

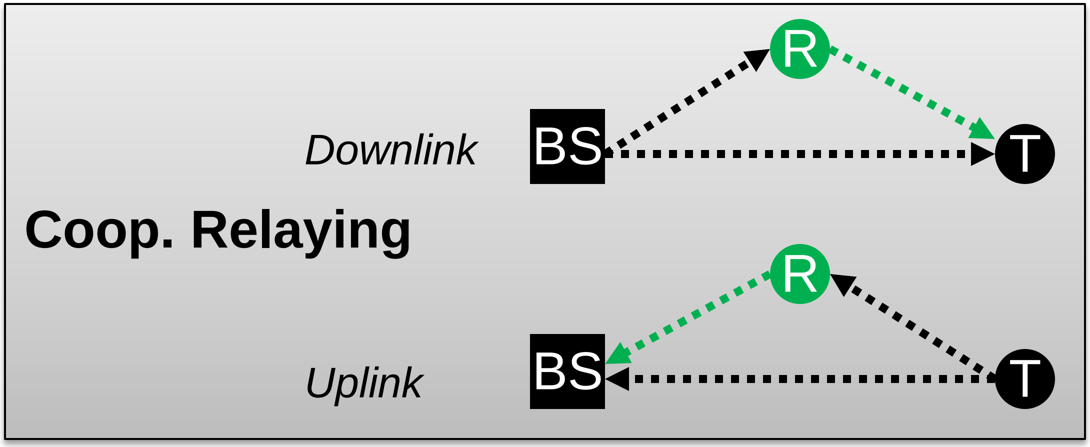
and proposed efficient solutions

Conclusions

The Basic "Helper Principle"







A Piece of The Bigger Picture
3dim PHY / 3dim Traffic / 3dim design space

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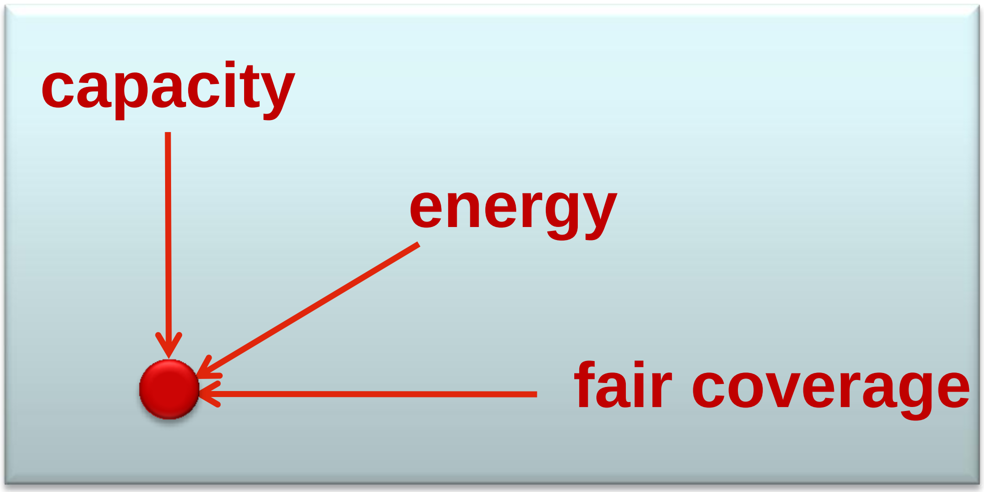

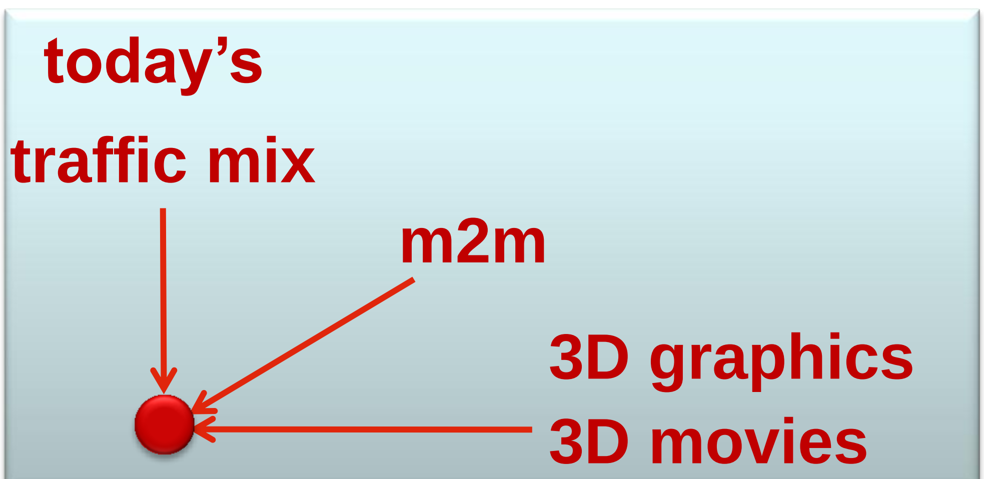

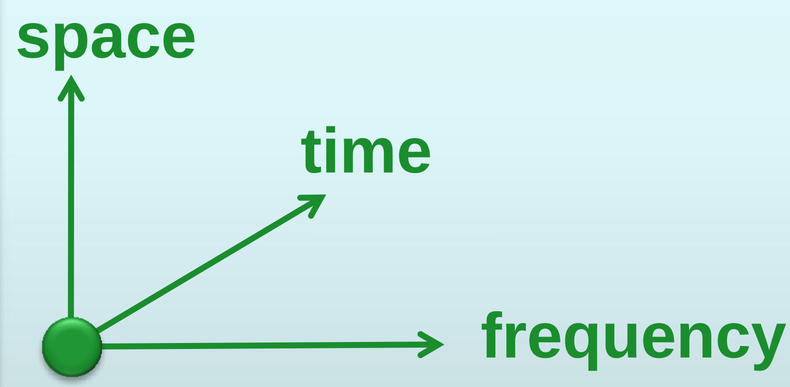

No modulation buys us orthogonality anymore !!!

Time to rethink for 5G !?!

Thanks *!*

Thanks to Vodafone for 16 years of continued support of the team

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