Current Frontiers in Wireless Communications: Fast & Green & Dirty

Gerhard Fettweis

vodafone Chair and Its Partners

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

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
AsahiKASEI
AMD
CoWare
Analog Devices
Rohde & Schwarz
Ericsson
Cinterion Wireless Modules
Huawei
Texas Instruments
Signalion
TietoEnator
Synopsys
tensilica
digades
Infineon
ST-NXP Wireless
actix
Altera
GWT forschung+innovation

Projects

Alcatel·Lucent
Ericsson
Signalion
NXP founded by Philips
EPCOS
Infineon
Tyco Electronics
vodafone
ZMD
NEC
Freistaat Sachsen – Staatsministerium für Umwelt und Landwirtschaft
Bundesministerium für Bildung und Forschung
Deutsche Forschungsgemeinschaft DFG
2007 - 2013

Numbers

Scientific:

44 Ph.D. grads
175+ Ms. grads
500 publications
40+ patents

Innovation:

8 spinouts
200 engineers

Funding:

€ +35M Chair
€ +40M VC
€ 250M projects.

The Vodafone Chair's Startup History

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

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

2002 NXP founded by Philips

2006 actix

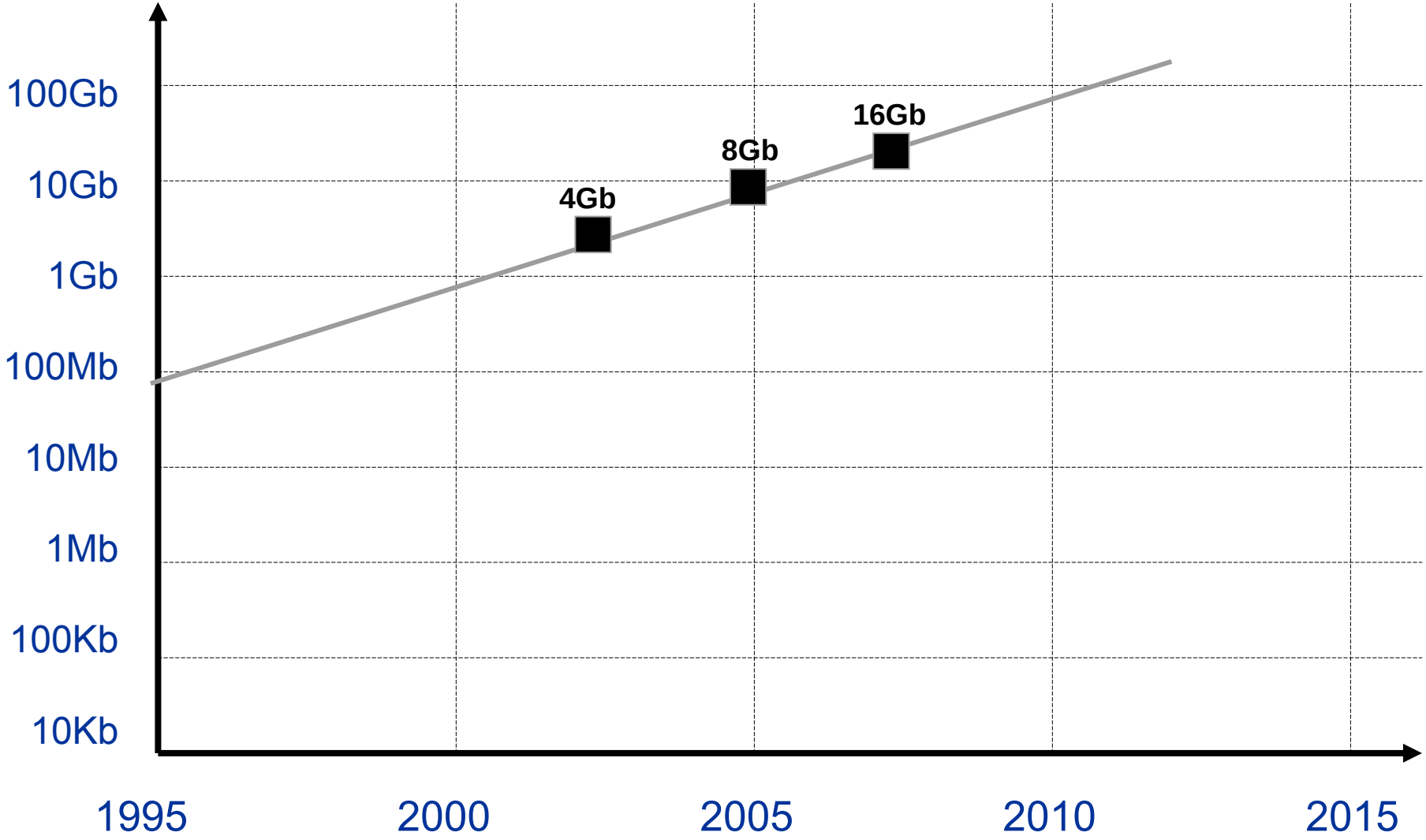
2007 SIGNALION

FAST

Embedded Mobile Memroy: Single-Chip Flash Memory Trend

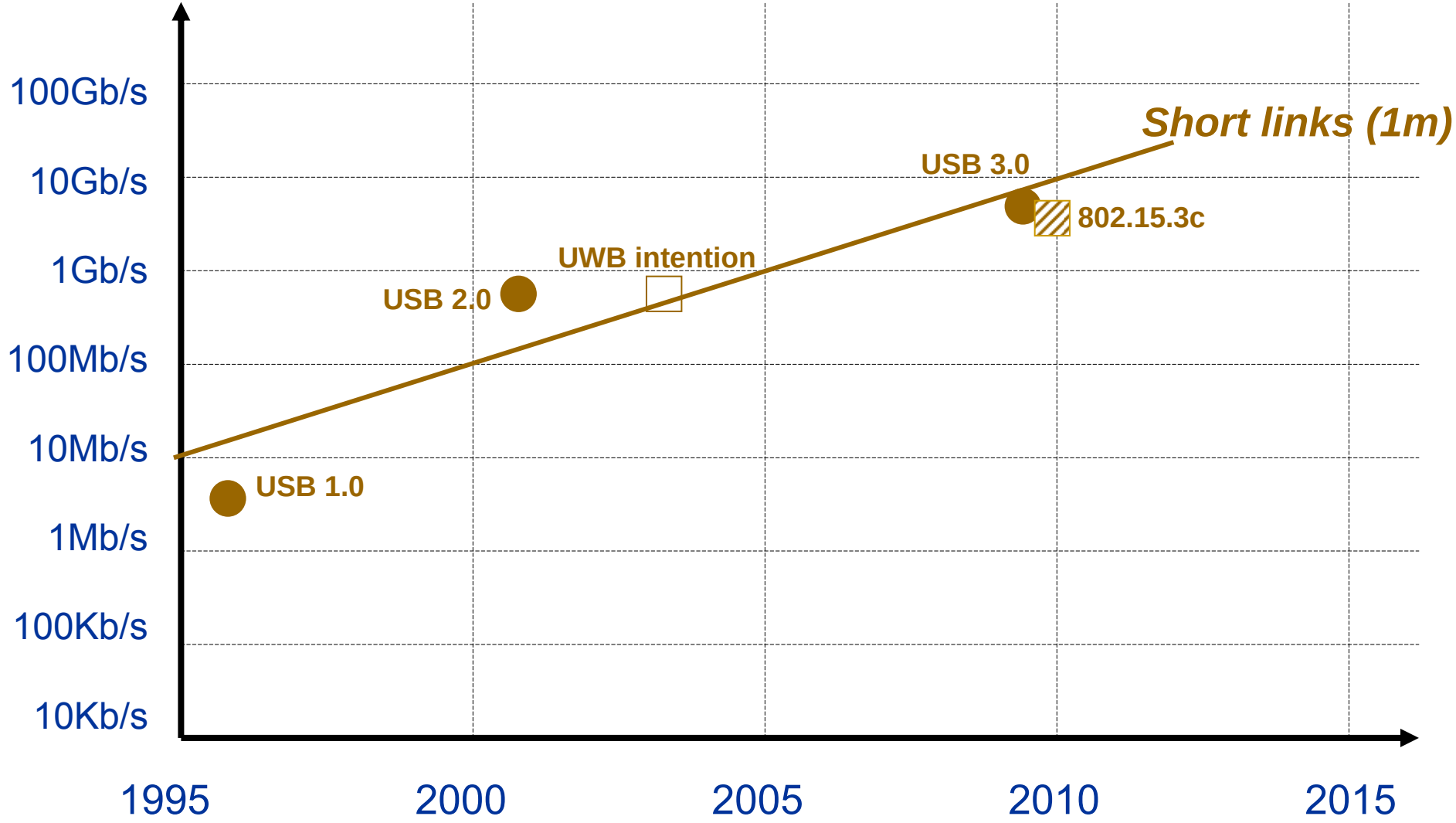
TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

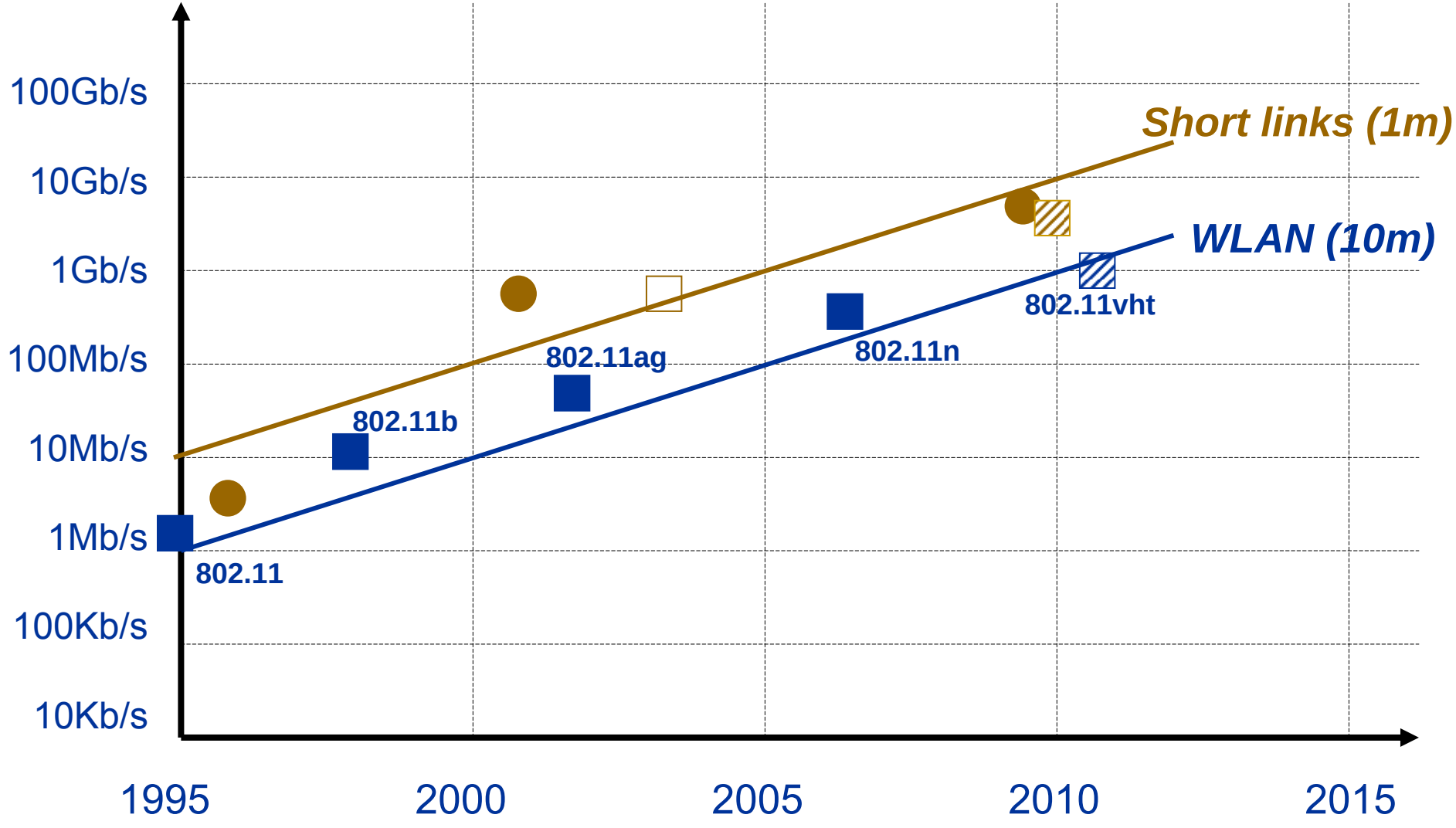


“The Wireless Roadmap”

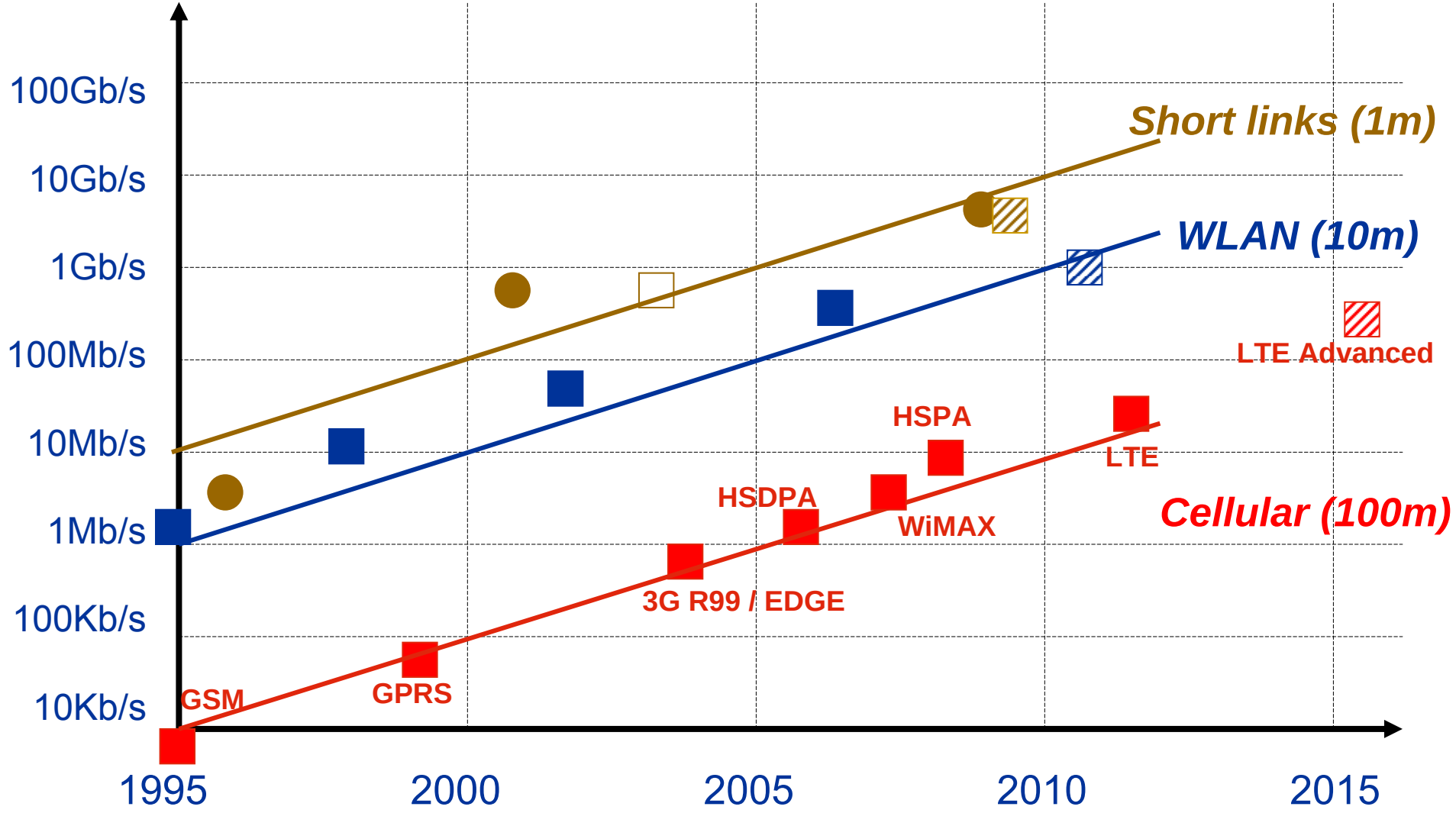
Data Synchronization: Point-to-Point



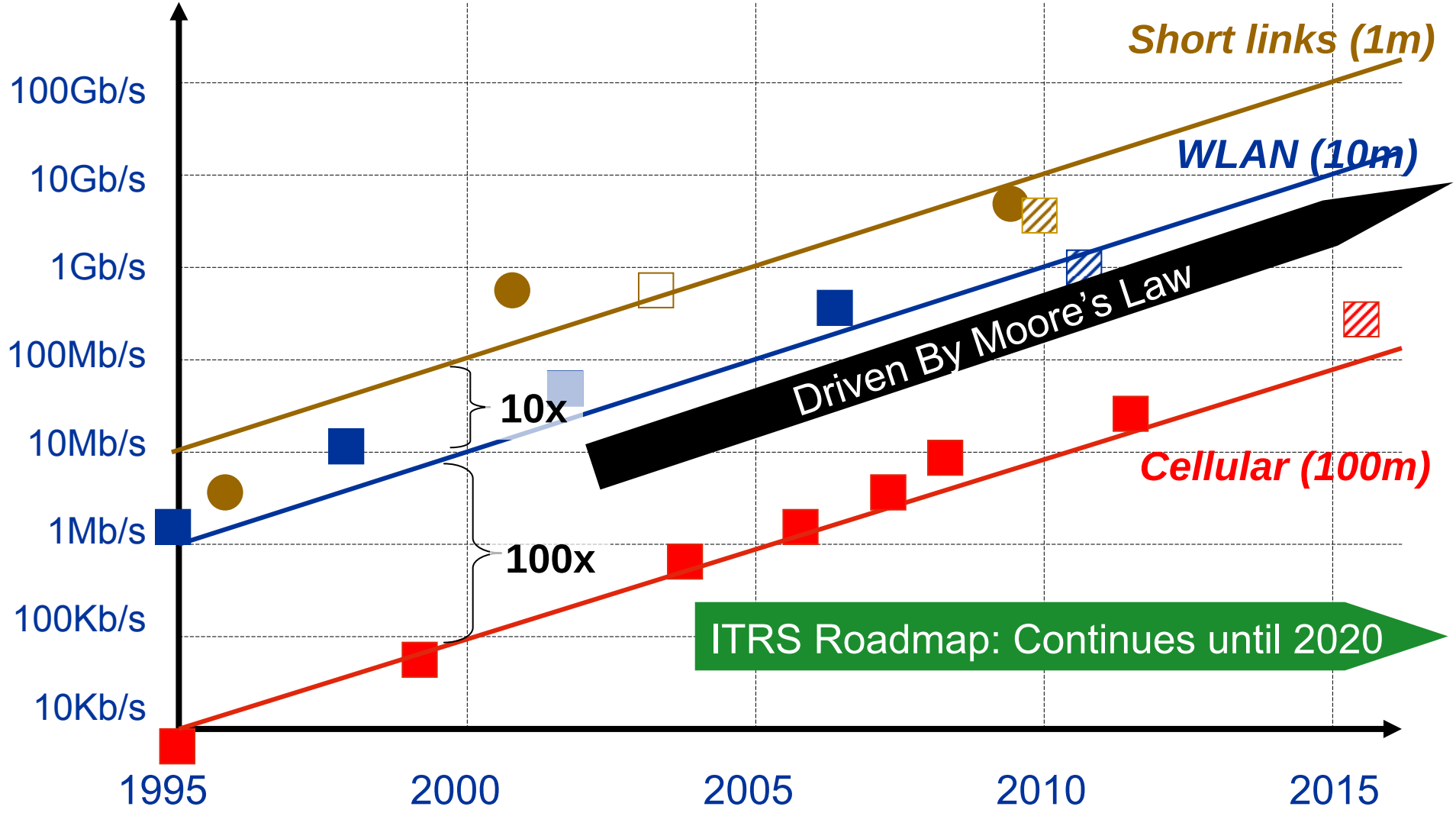
Client Server Applications: WLAN



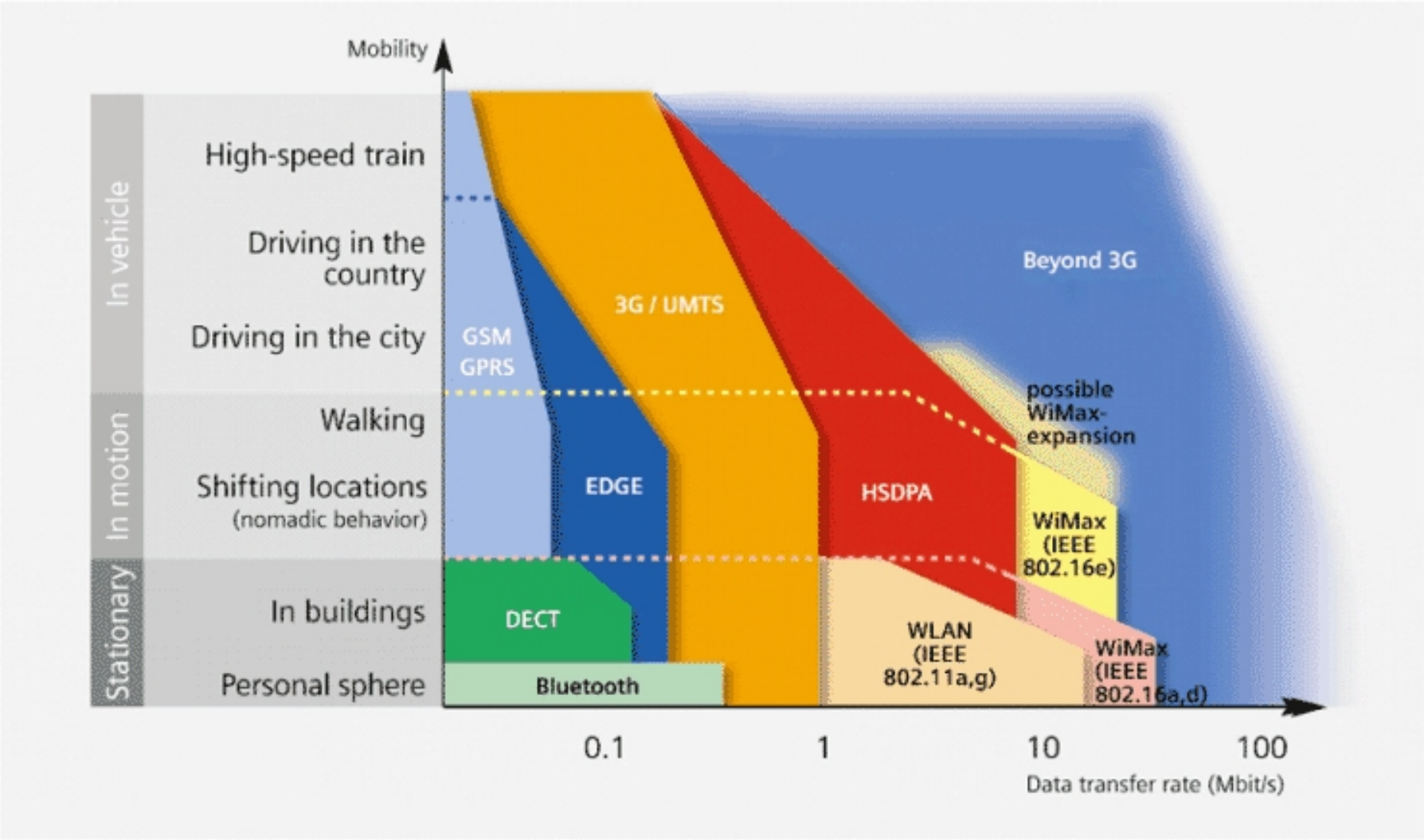
Coverage: Cellular



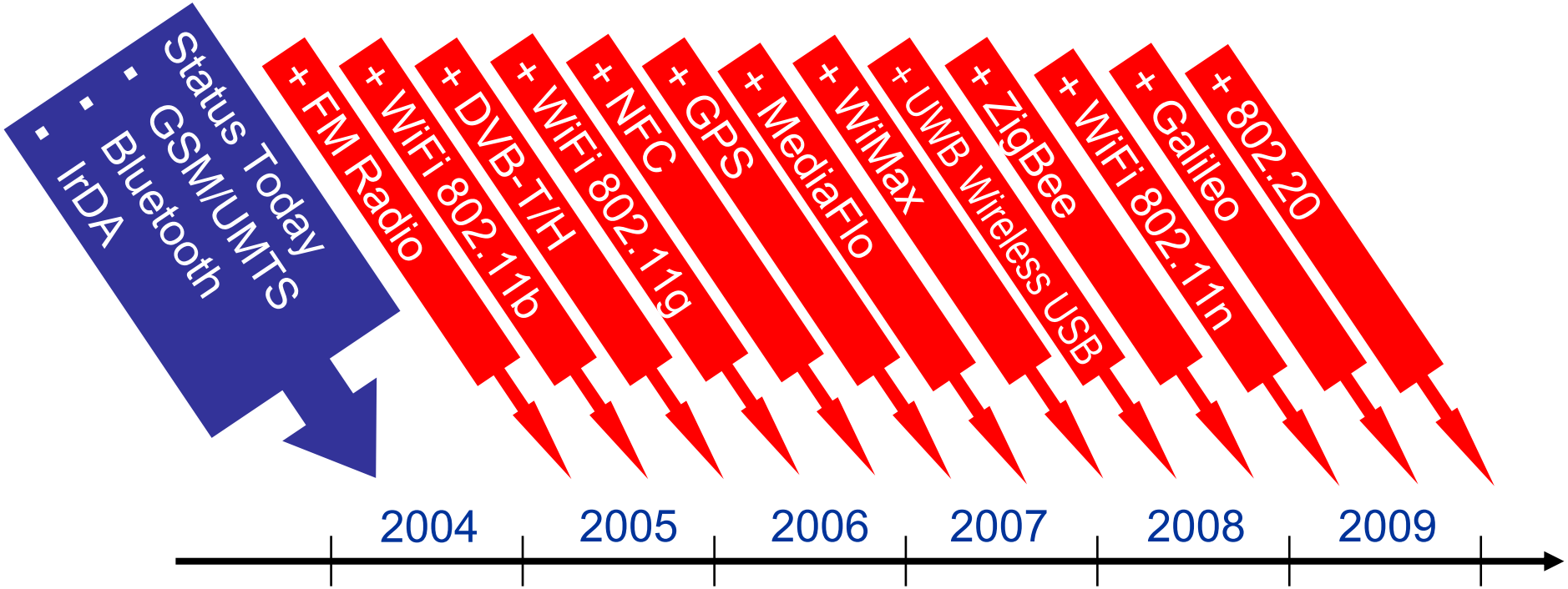
The Wireless Roadmap



The ITU "Van" Diagram

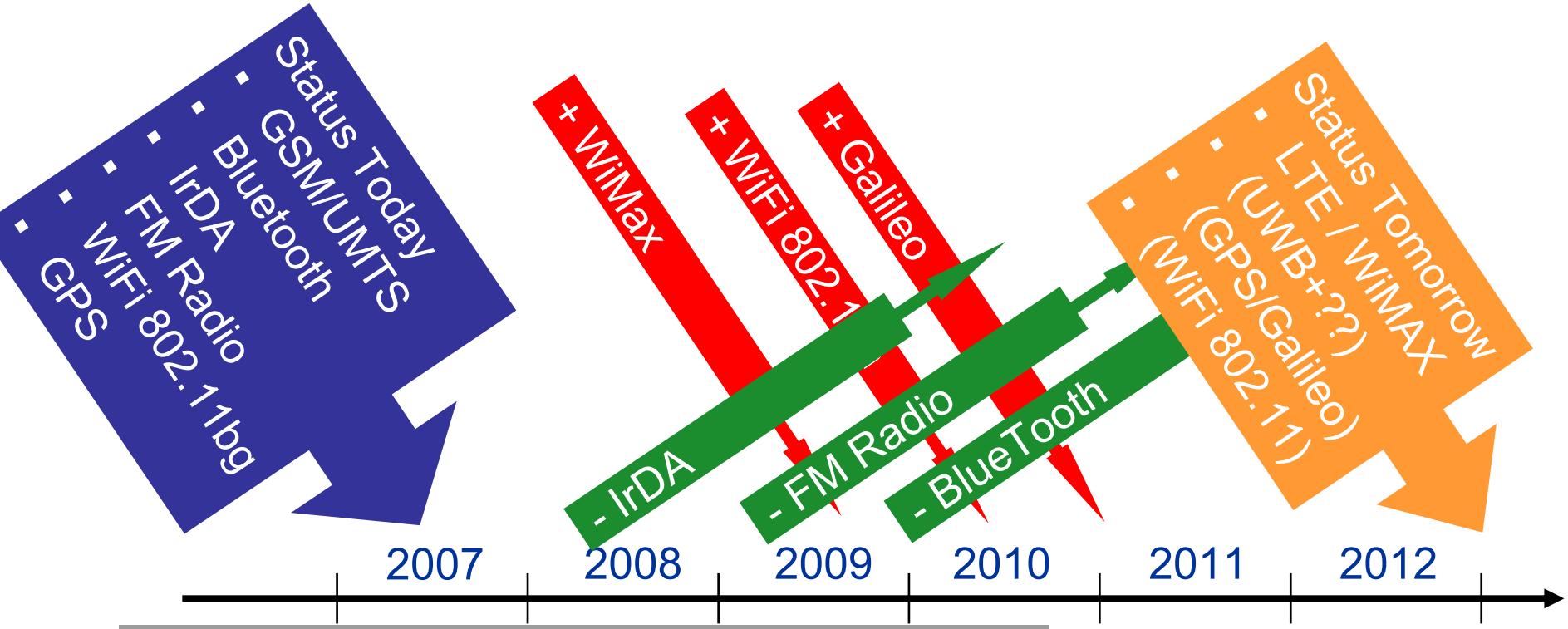


2004: Integration Nightmare Roadmap of Wireless Standards into Handsets



- WiFi
  - IEEE 802.11b: 11Mb/s wireless LAN @ 2.4GHz (up to 100m)
  - IEEE 802.11a/g: 54Mb/s wireless LAN @ 2.4/5GHz (up to 100m)
  - IEEE 802.11n: 250Mb/s wireless LAN @ 5GHz (up to 30m)
- UWB (IEEE 802.15.3a): 480Mb/s wireless USB2.0 (typ. 1m)
- WiMax (IEEE 802.16d/e): ~10Mb/s broadband wireless access
- NFC: Near Field Communications (RF-ID, wireless payment,…)
- ZigBee: (IEEE 802.15.4)
  - Sensor networks, remote control
- Bluetooth
  - Version 2: TBD?

2009: Integration Cleanup Roadmap of Wireless Standards into Handsets



Loosers:

- MediaFlow
- UWB
- DVB T/H
- NFC
- ZigBee
- 802.20

The Only Wireless Features We Need?

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

- Cellular Connectivity ➔ Fast
- Broadband Local Connectivity ➔ Fast
- Positioning

How to Achieve “**FAST**” in Cellular

Shaping the SINR Distribution

TECHNISCHE UNIVERSITÄT DRESDEN

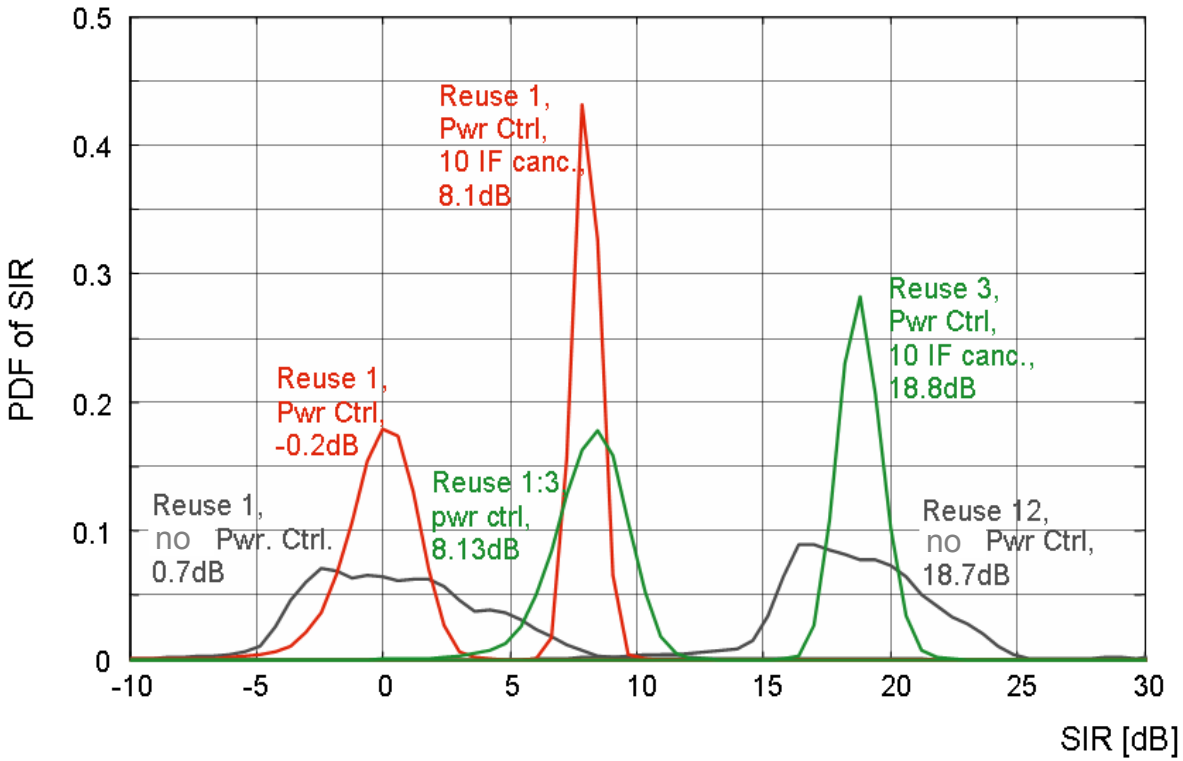
vodafone chair

Active „shaping“ of SINR

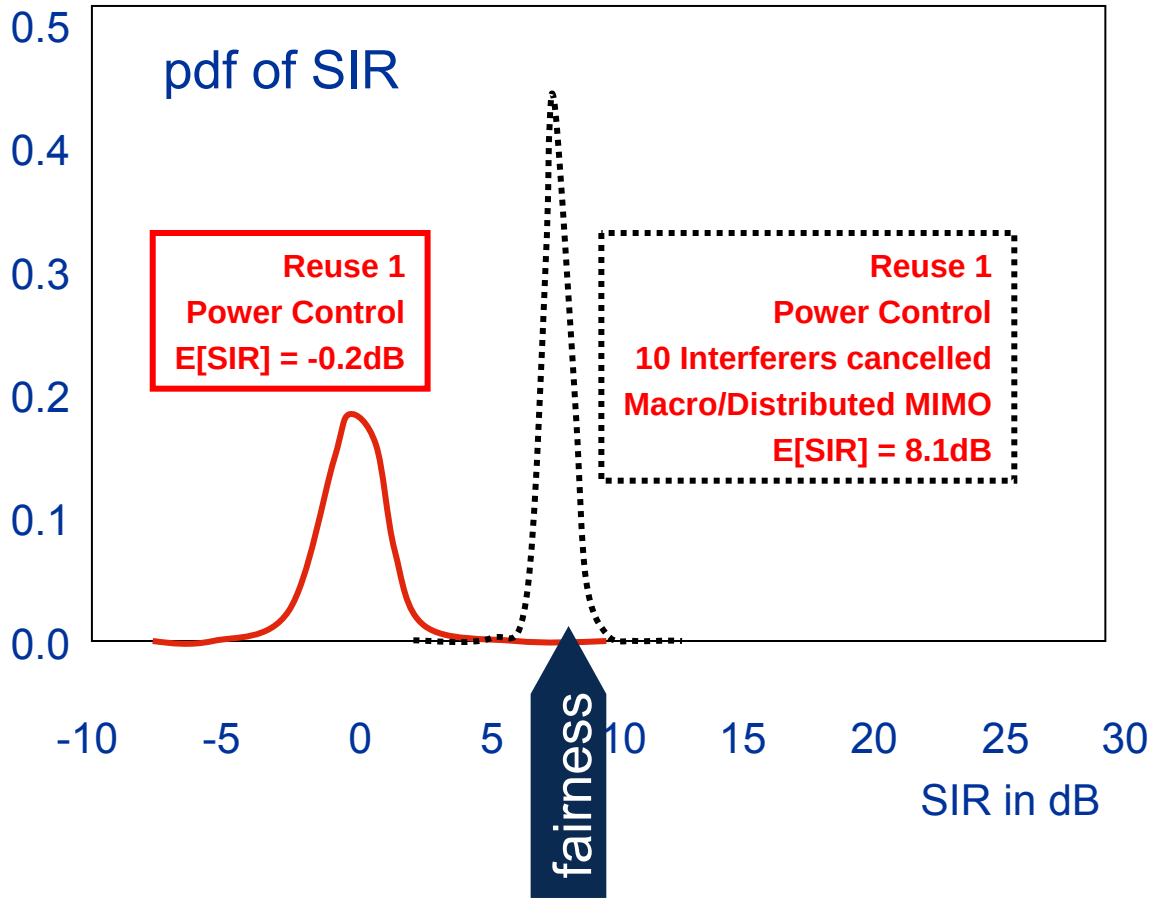
- Interference **Cancellation**
- Power Control

Advantages

- High average SINR
  - High spectral efficiency
  - Enabler for MIMO
- Small Variance
  - High grade of fairness



Fairness & Data Rate & Spectral Efficiency



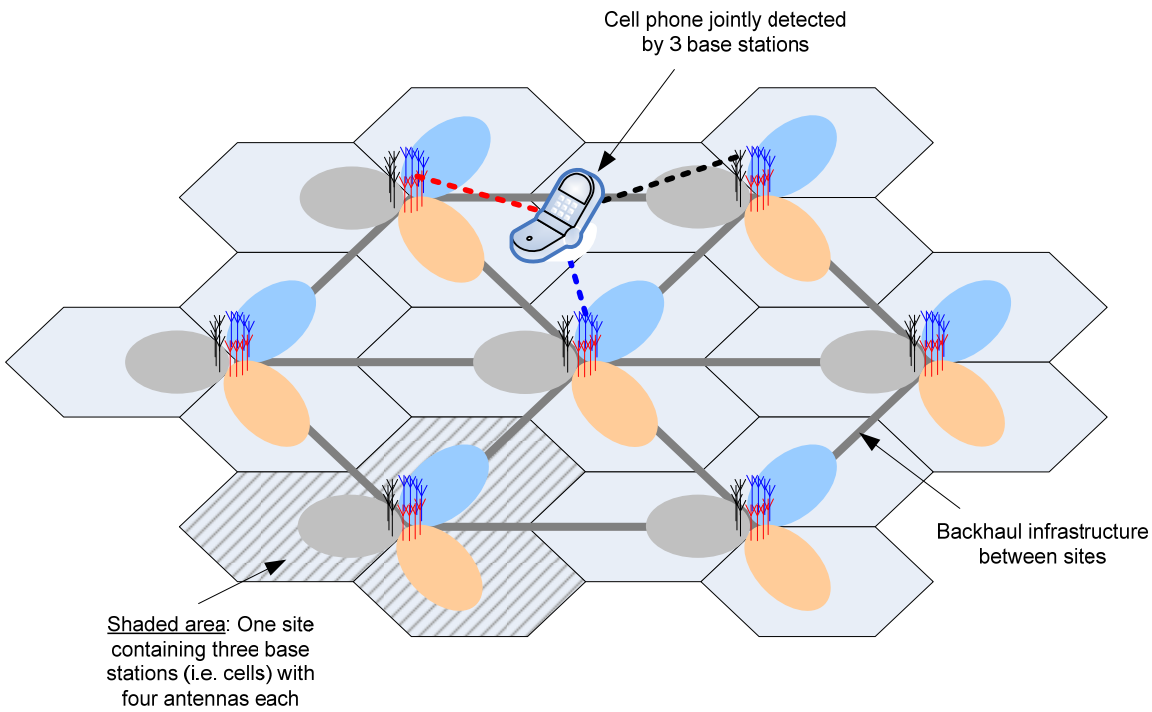
Interference Cancellation: Fairness & High Data Rate

CoMP: Coordinated Multi-Point

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

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

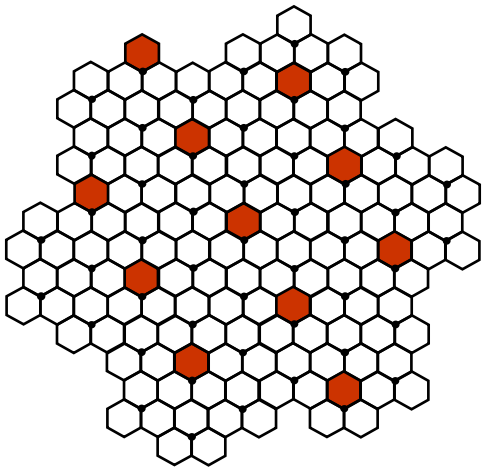


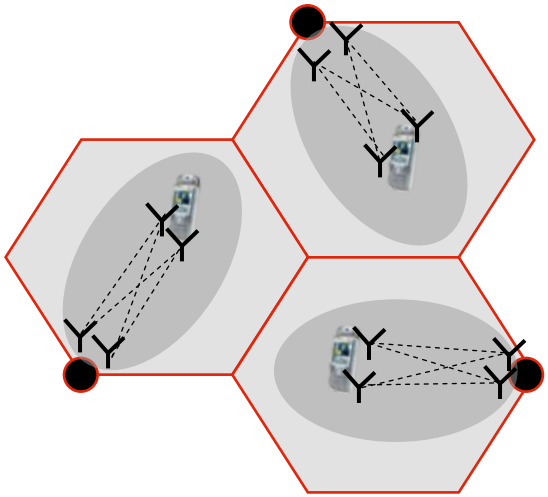
Roadmap View

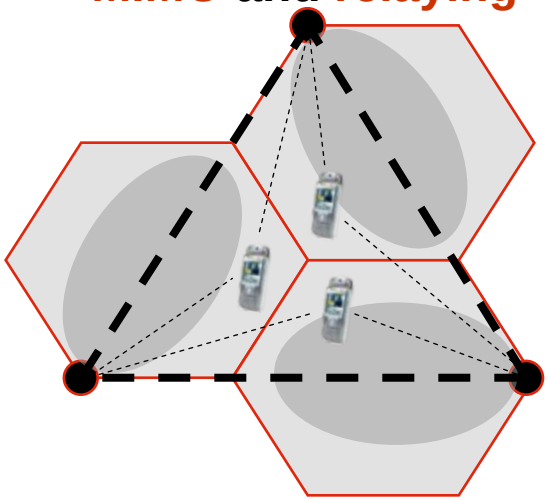
TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

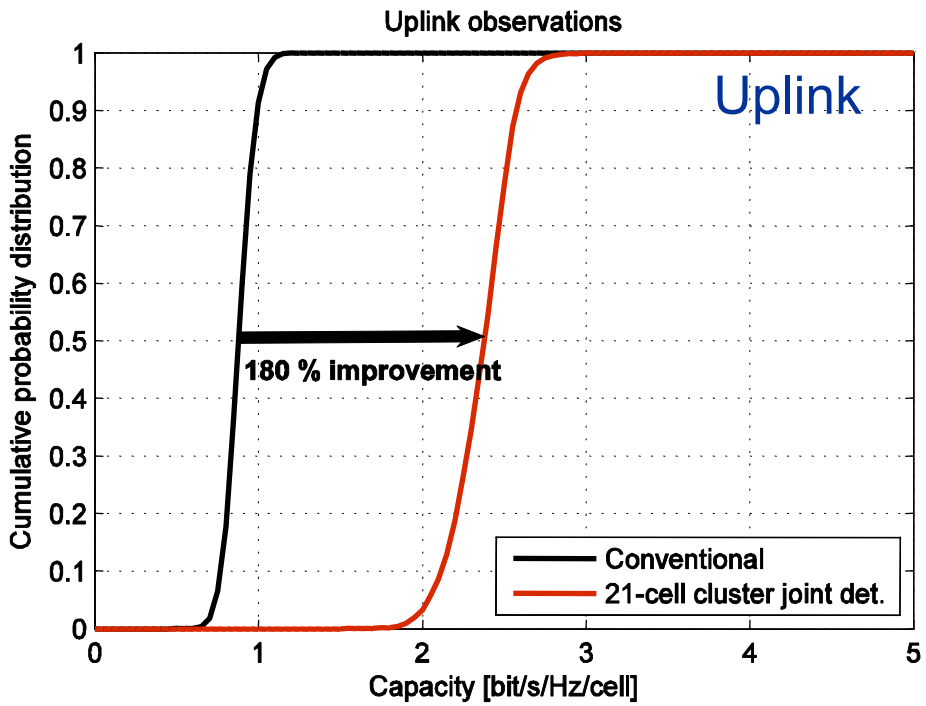
1st/2nd generation	3rd generation	4th generation
• **Interference avoidance through high reuse factors**	• **Interference suppression through classical MIMO**	• **Interference shaping and exploitation through distributed MIMO and relaying**

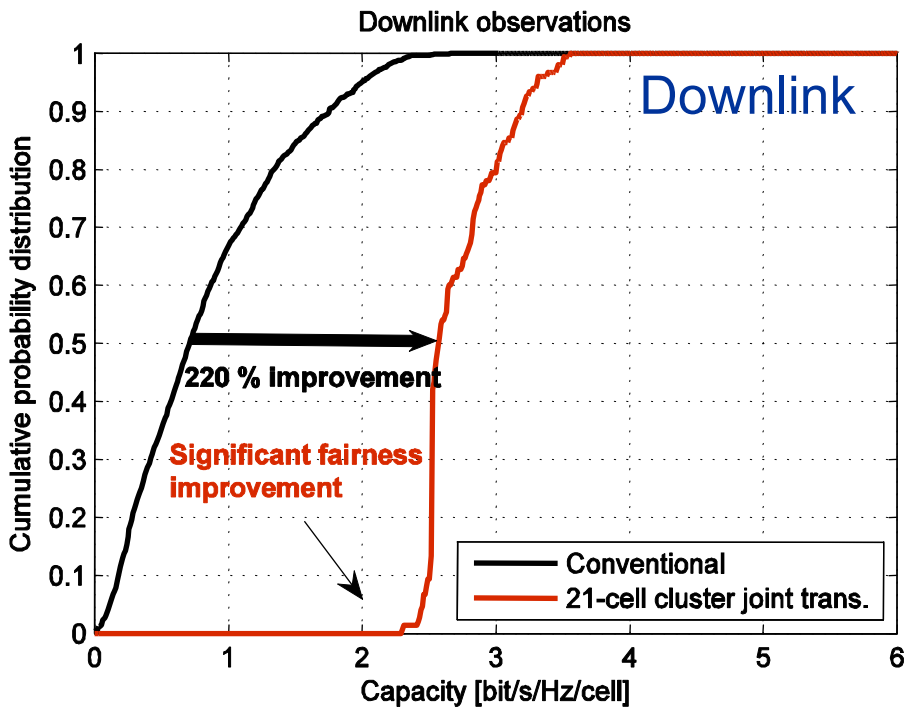






Potential Gains of CoMP





- 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

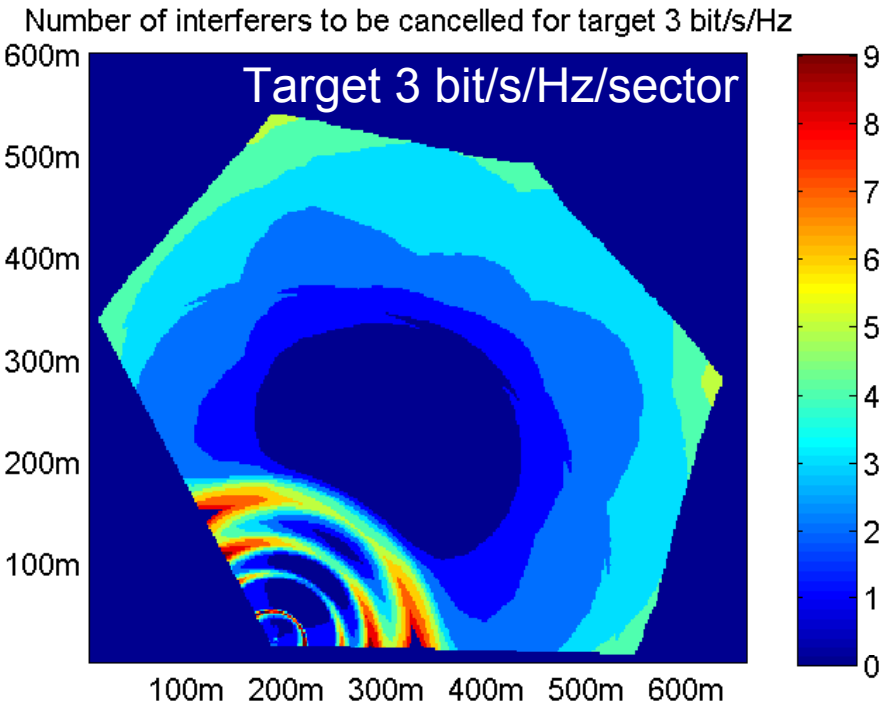
Limits in Clustered Virtual MIMO

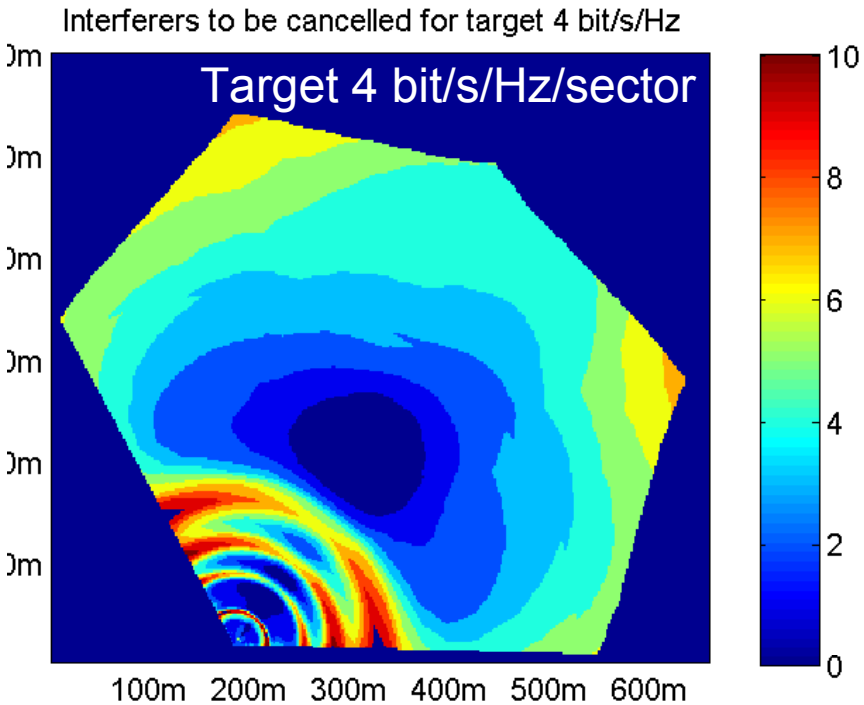
A Graph Theory Approach

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

- We can easily observe how many interferers would have to be perfectly cancelled for a user at any location within a cell, to achieve a ***capacity target***:





- Note that we are assuming ***perfect interference cancellation*** (optimistic), but do not take into account increased diversity (pessimistic)

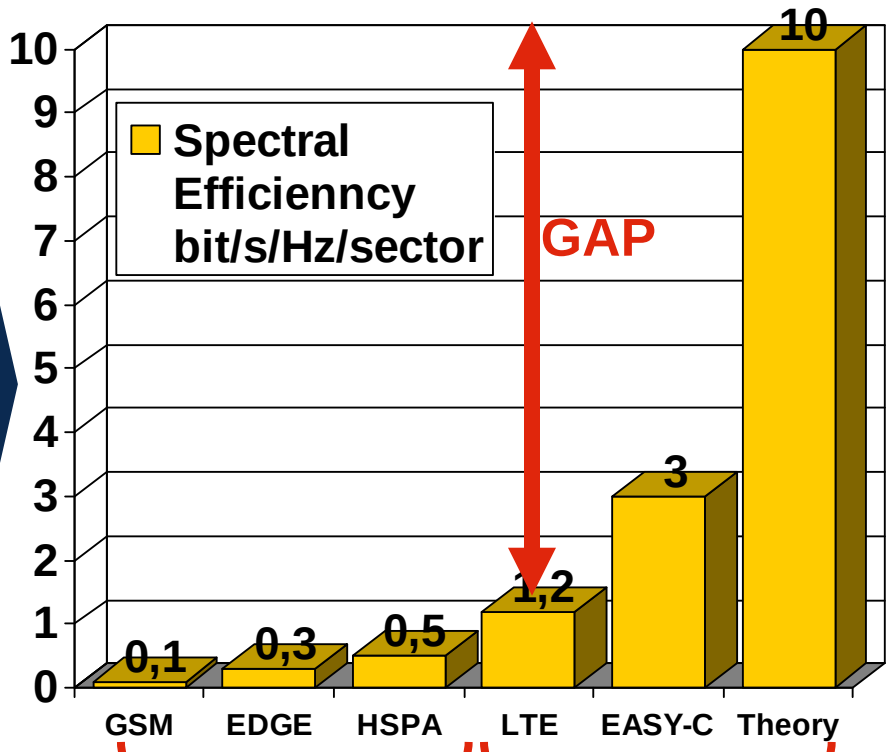
Spectral Efficiency

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

License Cost (GER)

- 1Hz ~ EUR 1000
- 100Mb/s/sector required:
  - GSM: 1GHz ➔ €1T
  - LTE: 100MHz ➔ €100B
  - Theory: 10MHz ➔ €10B



20 YEARS Of Engineering 1987 - 2007

20 further YEARS Of Engineering 2007-2027?

Enablers for Ambient Services & Systems
Part C: Wide Area Coverage

EASY-C

EASY-C Update

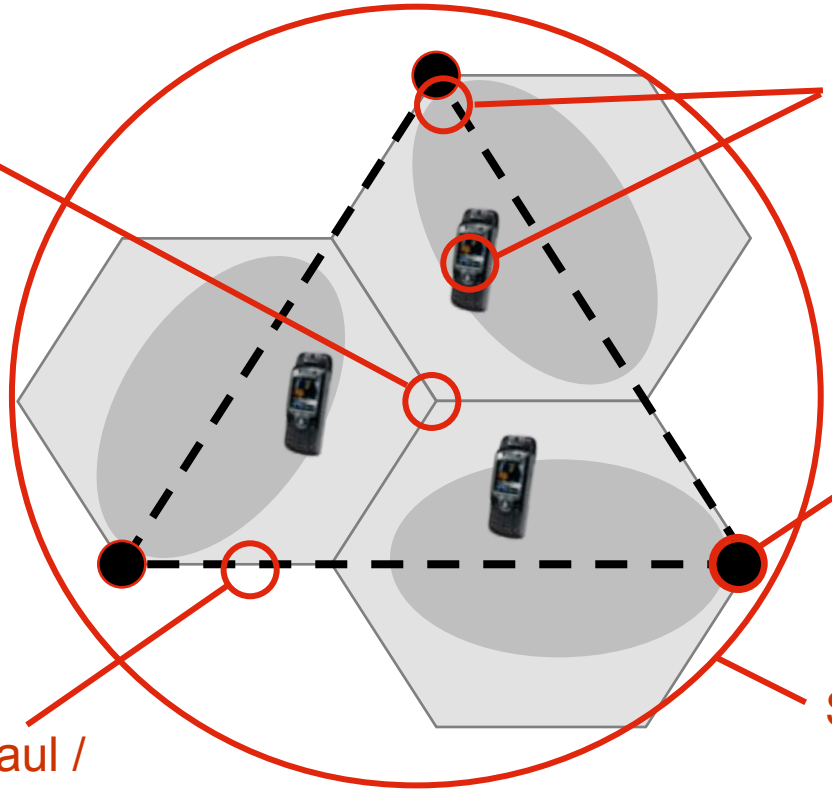
Project Partners

Coordinator: Gerhard Fettweis

Volume:
€ +47M project
€ +27M funding

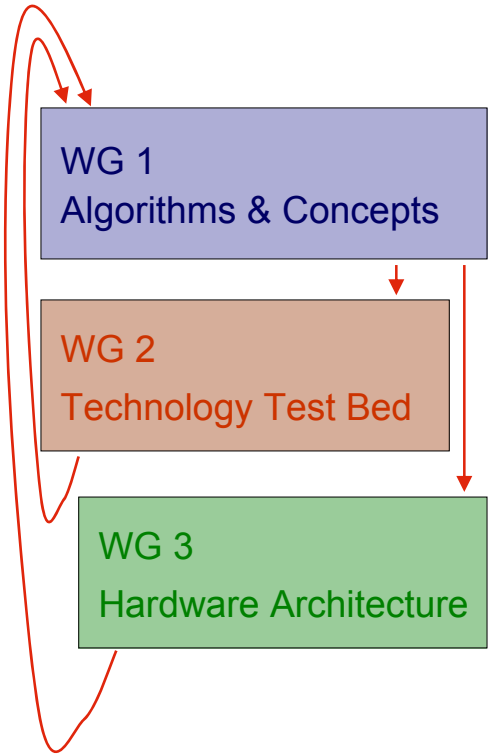
Current View on Network MIMO

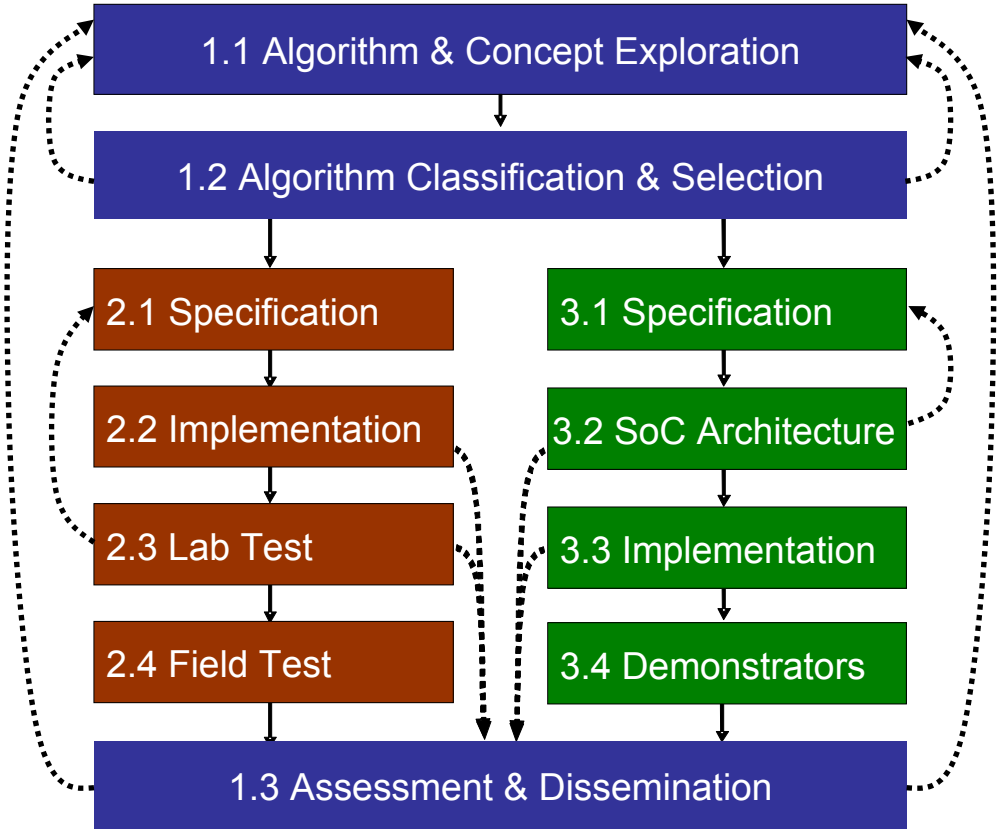
- See the following challenges connected to network MIMO:



Project Workflow

Working Groups





- Alcatel-Lucent
- BNetzA
- Dt. Telekom
- Ericsson
- FhG HHI
- IFX/Comneon
- Kathrein
- NXP
- Qualcomm
- Radioplan
- Signalion
- TES
- TU Dresden
- Ubidyne
- Uni Paderborn
- Vodafone

Mini Out-to-Indoor Testbed Dresden

TUD Indoor Test, Southern View

- Two sectors are installed on the roof of TUD building:

Mini-Testbed Dresden

TUD Lab Test

Lab Site:

- 2 sites at the chair
- Antenna: 1700-2700Mhz
- Microwave link between the sites

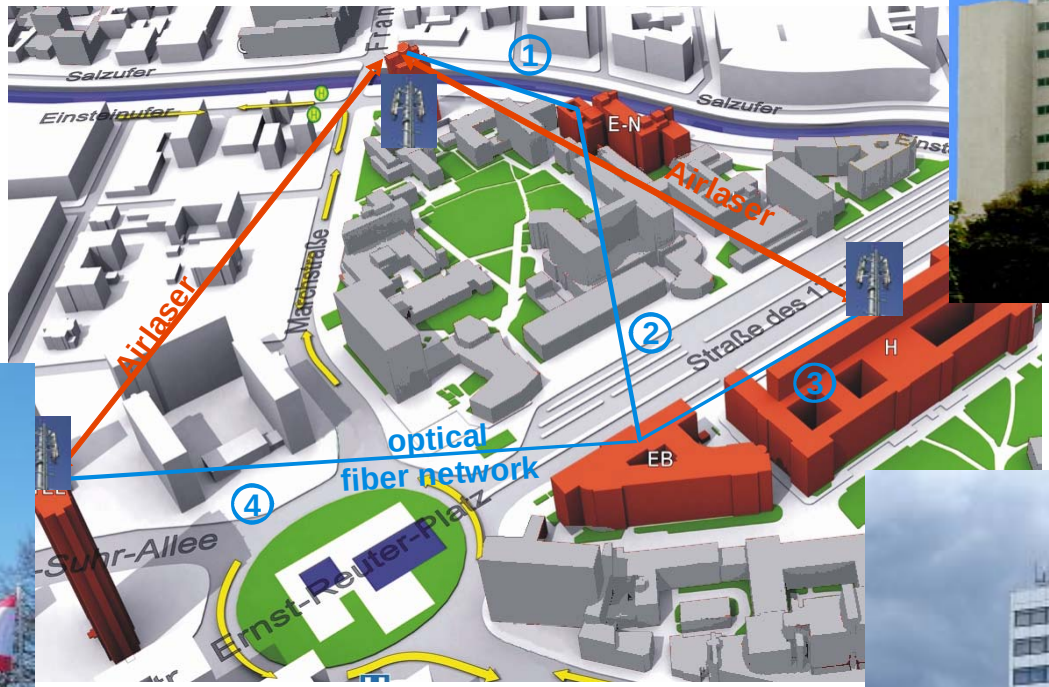
Mobile Lab UE:

- Sorbas UE
- 12V Battery
- Notebook

Field Test Berlin

Overview

- In Berlin, a second test bed is being set up, with a focus on services and applications

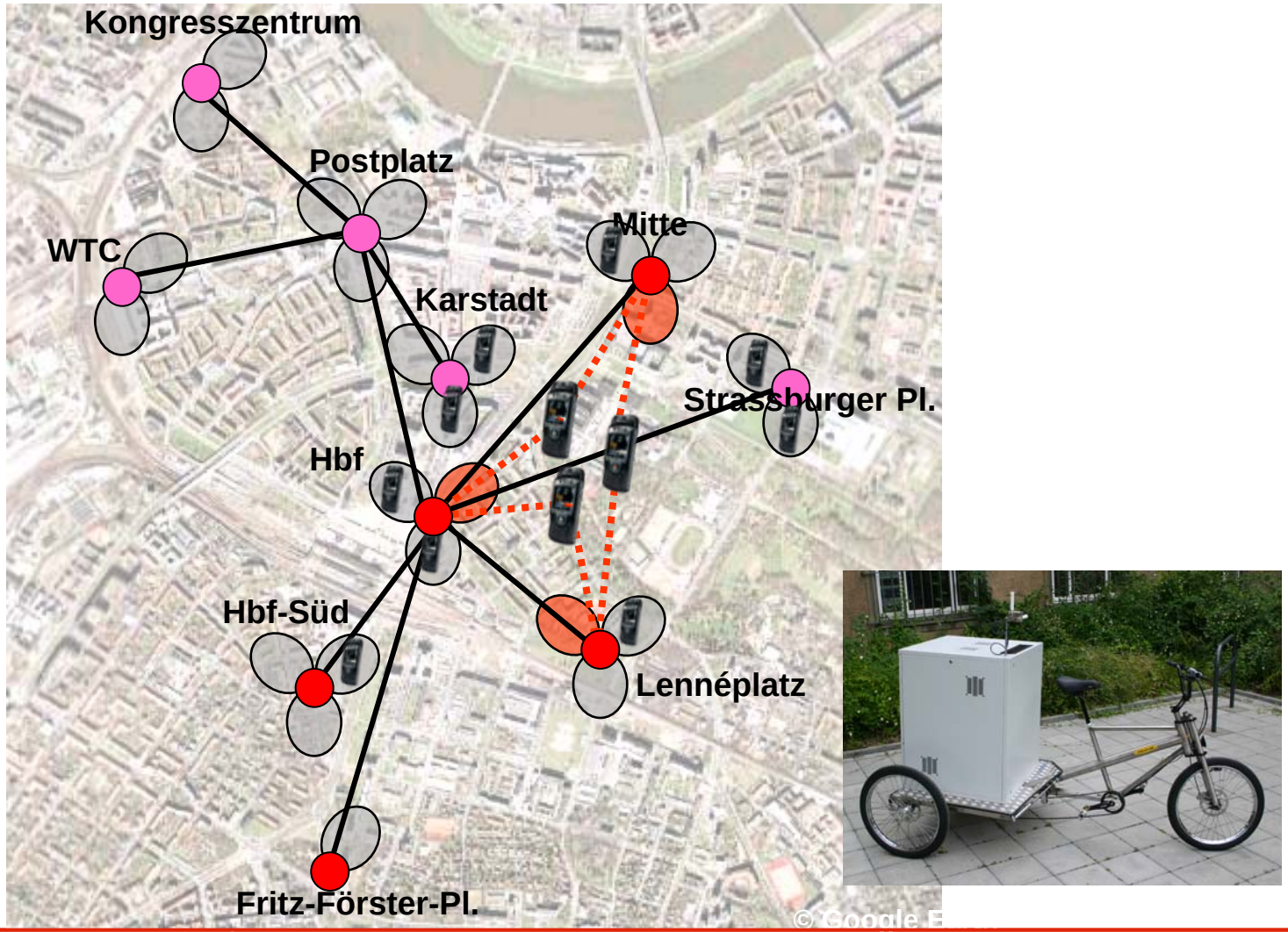


HHI

T-Labs

TU Berlin

Cellular After 2015



IEEE

ICC 2009

Dresden

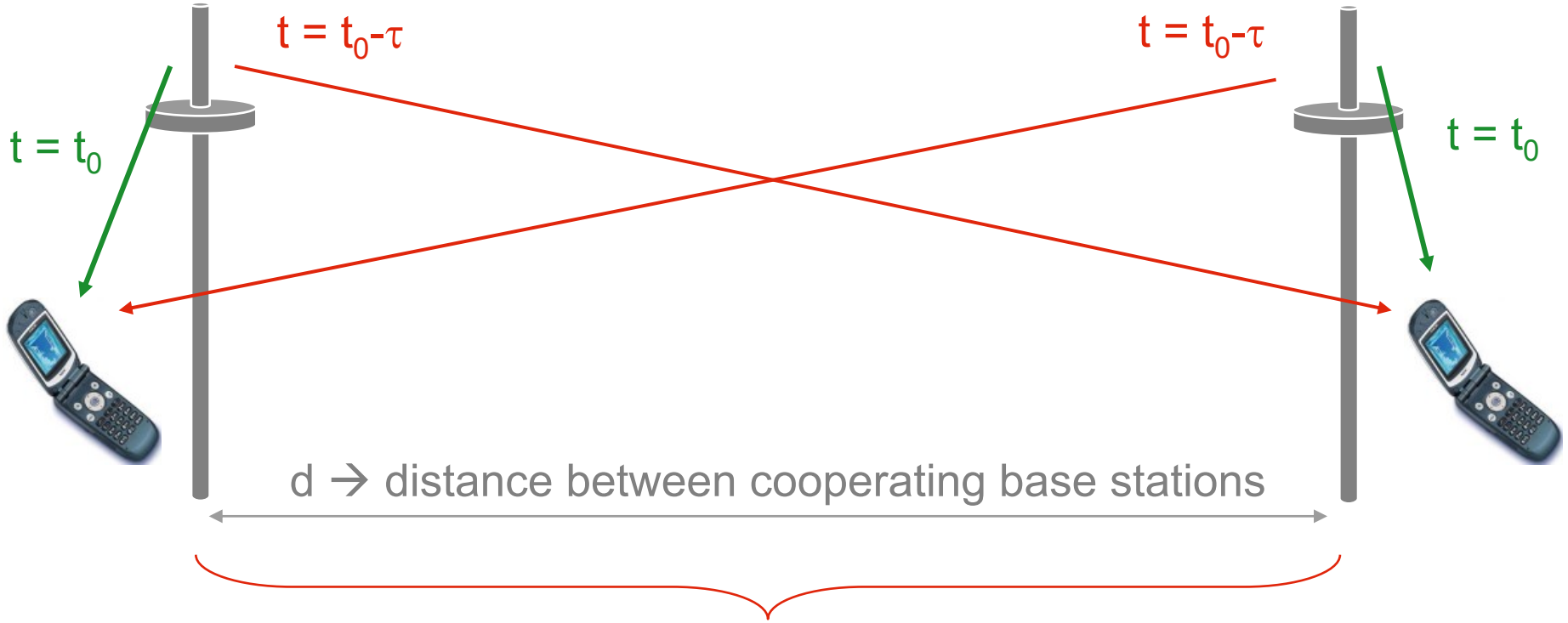
Testbed Dresden

Field Test

- LTE+ antennas co-located at real 3G sites (downtown, hight of antennas 30-55m)
- Support from project partner (Vodafone, T-Mobile)
- Backhaul realized with Motorola Canopy PTP600 system (250 Mbit/s TDD system)

Additional Challenges:
“Lessons Learned”

OFDM for Downlink CoMP



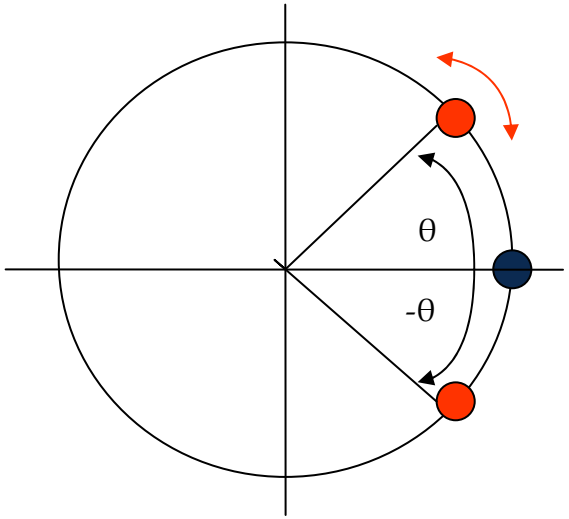
$\tau \approx d/c$

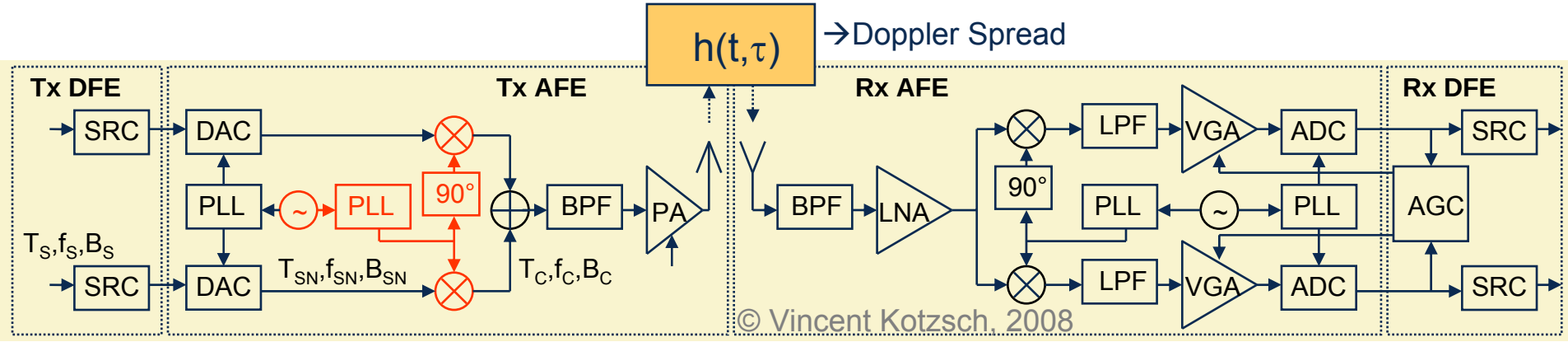
Use CP to compensate?

LTE: d=360m

Carrier Phase Offset, Phase Noise

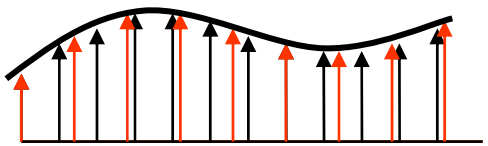
- Carrier Phase Offset (*CPO*)
  - Caused by LO imperfections
- Phase Noise (*PN*)
  - Caused by LO jitter due to non perfect sine generation
- CoMP ➔ PN increased by 3-5dB

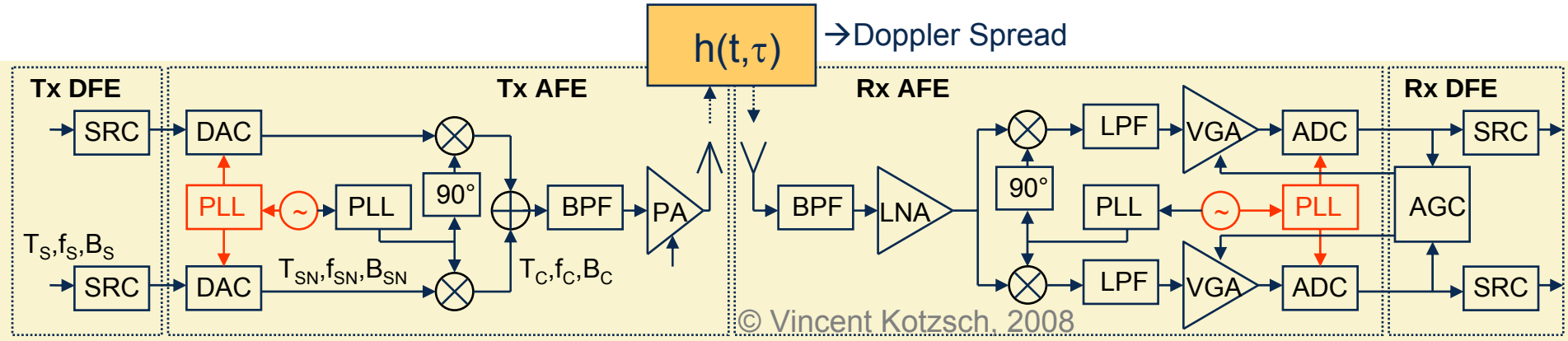




Sampling Clock Offset

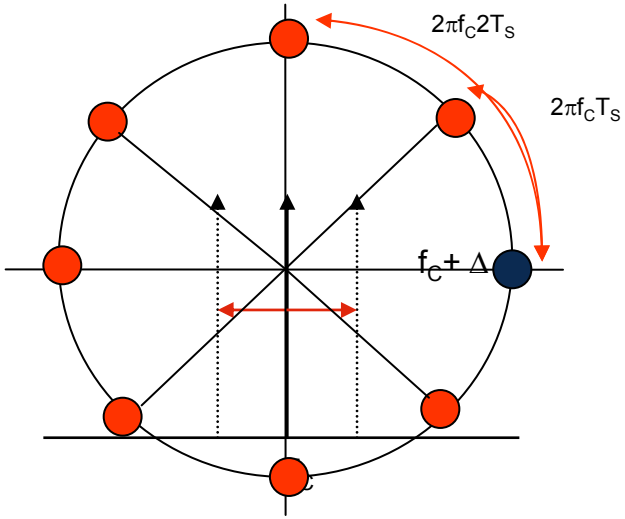
- Sampling Clock Offset (*SCO*)
  - Sampling offset between ADC and DAC
  - Caused by LO imperfections
  - Range: 10^{-5} - 50ppm related to sampling rate
  - CoMP ➔ "negligible asynchronous OFDM"

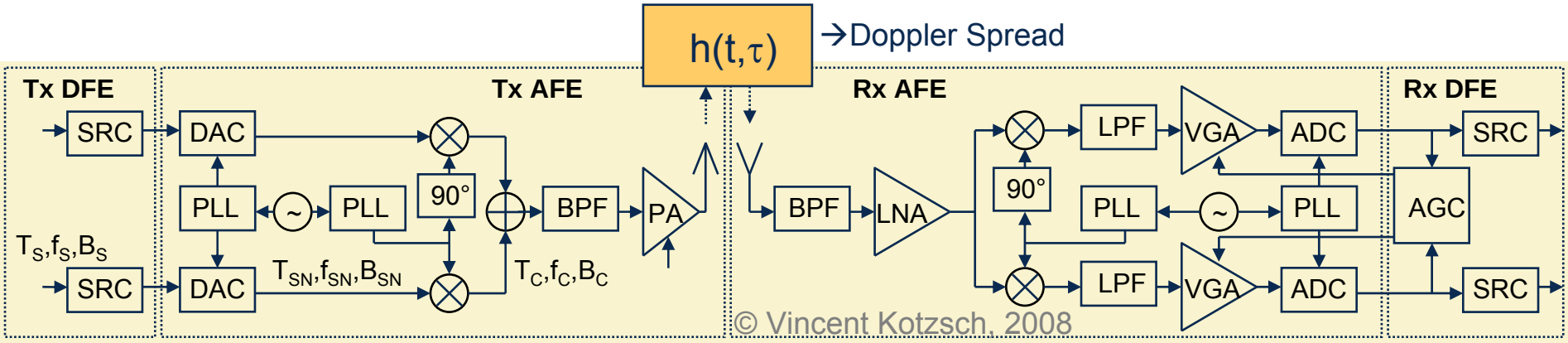




Carrier Frequency Offset

- Carrier Frequency Offset (*CFO*)
  - Continuously phase shift over time
  - Caused by LO-imperfections and Doppler
  - Range: 10^{-5} - 50ppm related to f_C
  - CoMP ➔ "artificial Doppler"



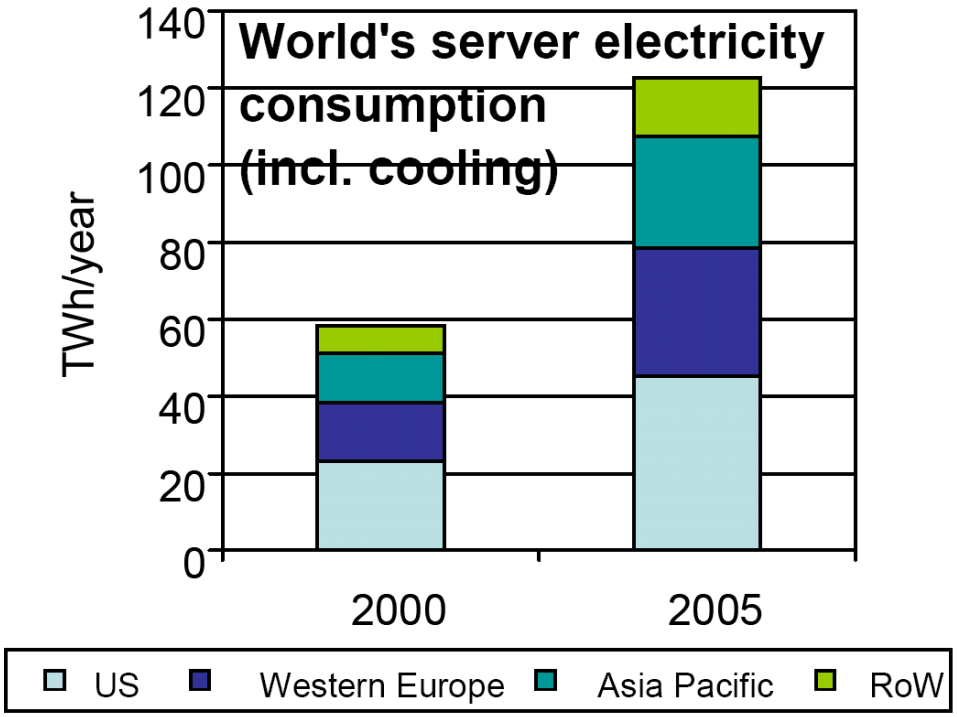


Requirement “FAST” will not end soon

GREEN

cool

The Server Farms Are Growing



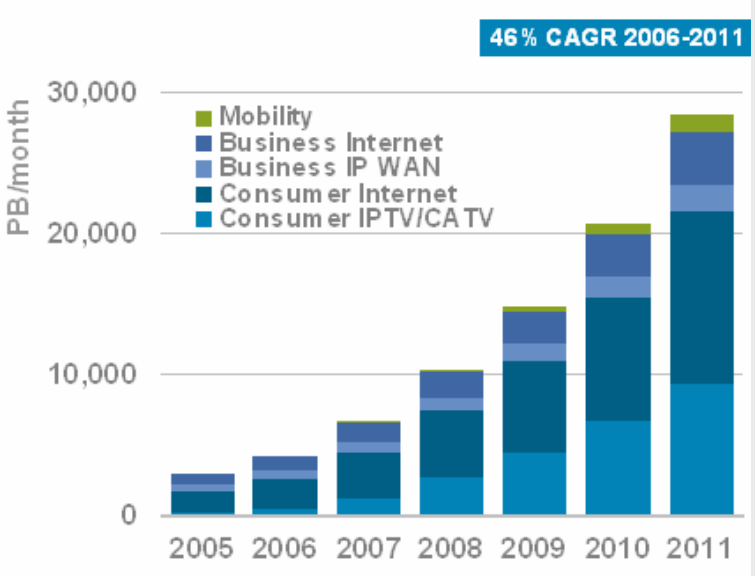
- Moore's law for logic:
  5x every 5 years
- Moore's law for flash
  10x every 5 years
- RESULT:
  2x power consumption every 5 years

The Challenge

TECHNISCHE UNIVERSITÄT DRESDEN

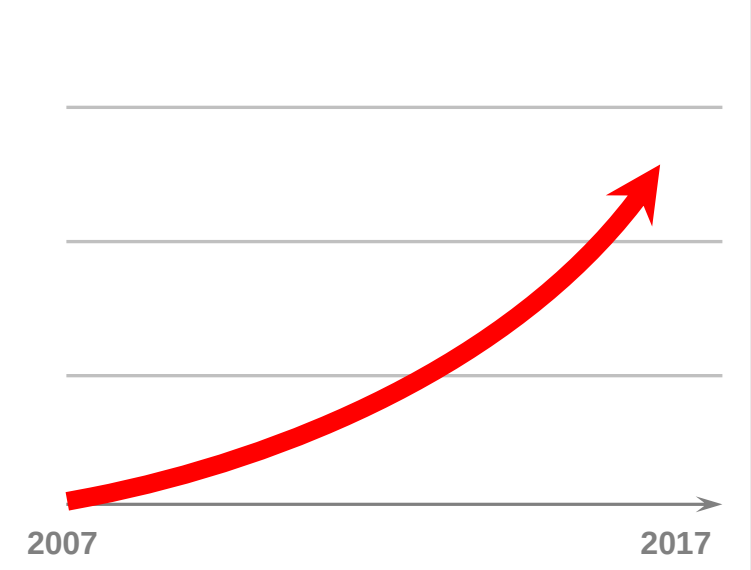
vodafone chair

Classic Internet
(Computing & Mobile)



Cisco IP Traffic Forecast 2008

Internet of Things
(networked sensors)



In 2007 the Energy supply of ICT produced CO_2-output at level of 25% of worldwide cars

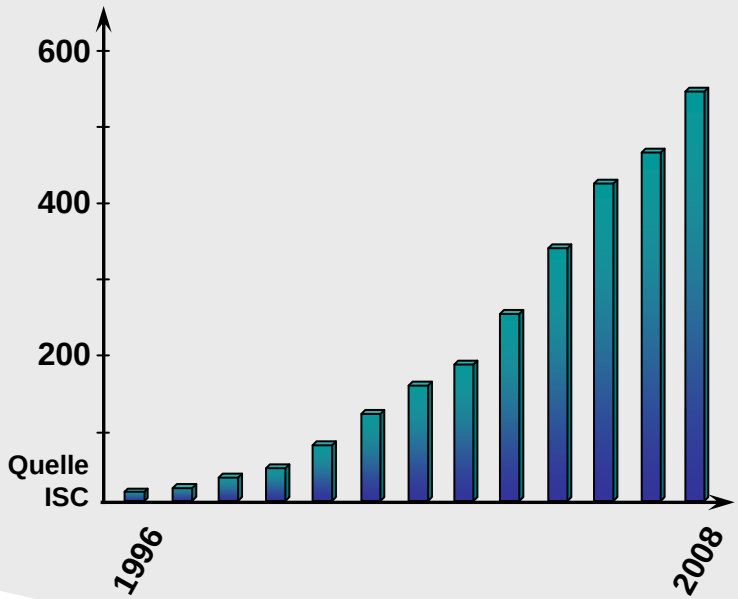
Paradigm Change

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

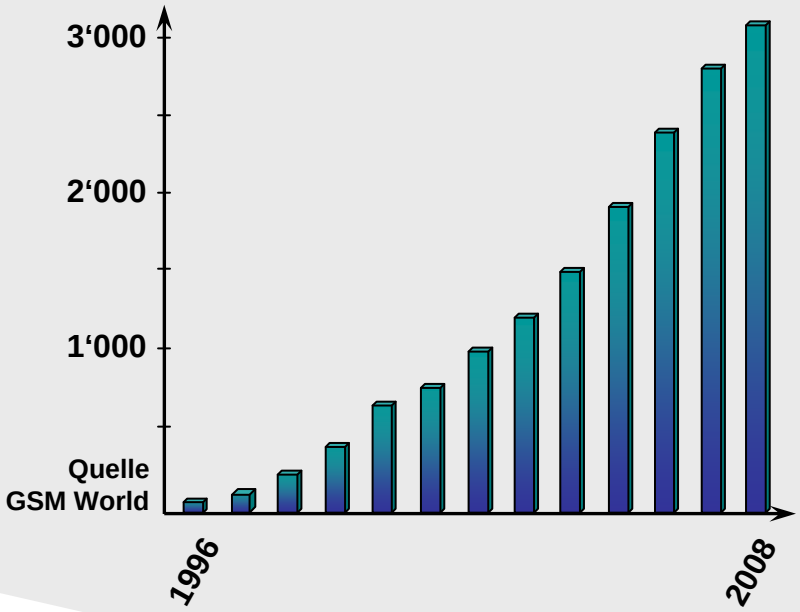
Computing

Internet-Server (Mio.)



Cellular

Customers (Mio.)



Energy Costs = Invest

2007

Energy Costs = Personnel

Energy Demand & CO_2 of ICT

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

- **Server farms & telco infrastructure**
  - Currently 3% of world electric energy consumption
  - Increasing by 16-20% / year
  - → **Doubling world el. energy consumption by 2030 driven by ICT**

- **ICT: 10% of el. energy demand within industrialized nations**
  - 900 Bill.. kWh / year = Central and South Americas
  - → **Worldwide proliferation: 40% of world el. energy production**

→ **Dramatic improvement in energy efficiency needed *!***

Cellular: What Do We Know

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

Cellular networks: 0.5% of world-wide electrical energy

- Handsets: 1% of total cellular energy consumption
- Network: 99% of total cellular energy consumption

Running the network:

- Expected energy bill: 3x (200%) over next 7 years
- 80% of energy consumed at base station site
  - 50% for cooling
  - E.g. UMTS CDMA: 25% power in “pilot pollution” !!!
  - “Always on” the wrong strategy?!

Need of “border-crossing” optimization:

System Engineering

COOL SiLiCON*

Coordinator
Prof. Gerhard Fettweis

energy efficiency innovations

from silicon saxony

Key Facts of Cool Silicon

- Partners
  - Companies
    - Currently around 40 companies involved
  - Universities
    - TU Dresden
    - TU Chemnitz
    - HTW Dresden
  - Research Institutes

- Money
  - EUR 100M funding
  - EUR 150M total volume

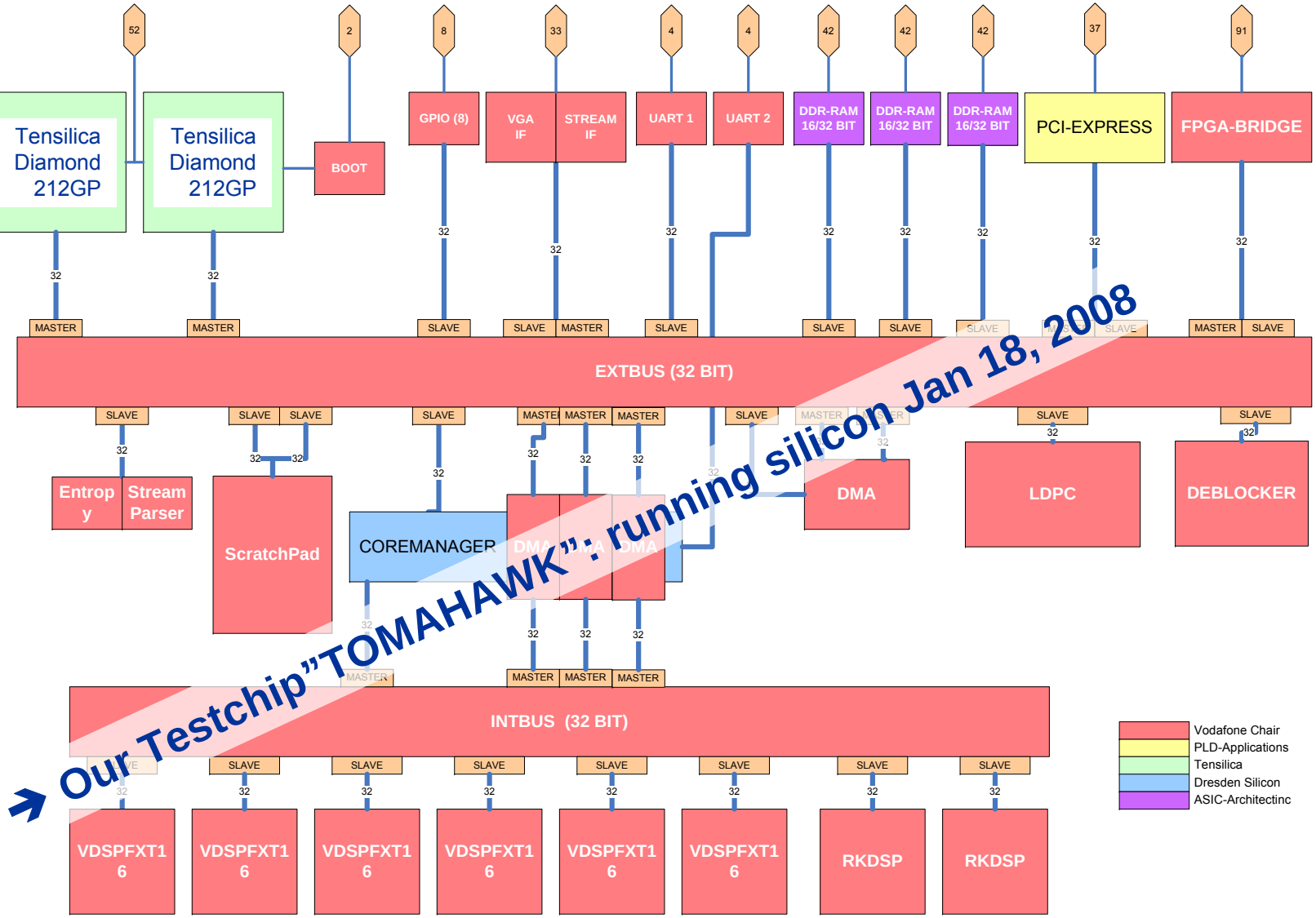
- Duration: Feb-2009 to Feb 2014

How to Achieve "**GREEN**" in Handsets (& Base Stations)

LTE FDD & TDD / WiMAX Single-Chip SDR: Tomahawk – Block-Diagram

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair



Our Testchip"TOMAHAWK": running silicon Jan 18, 2008

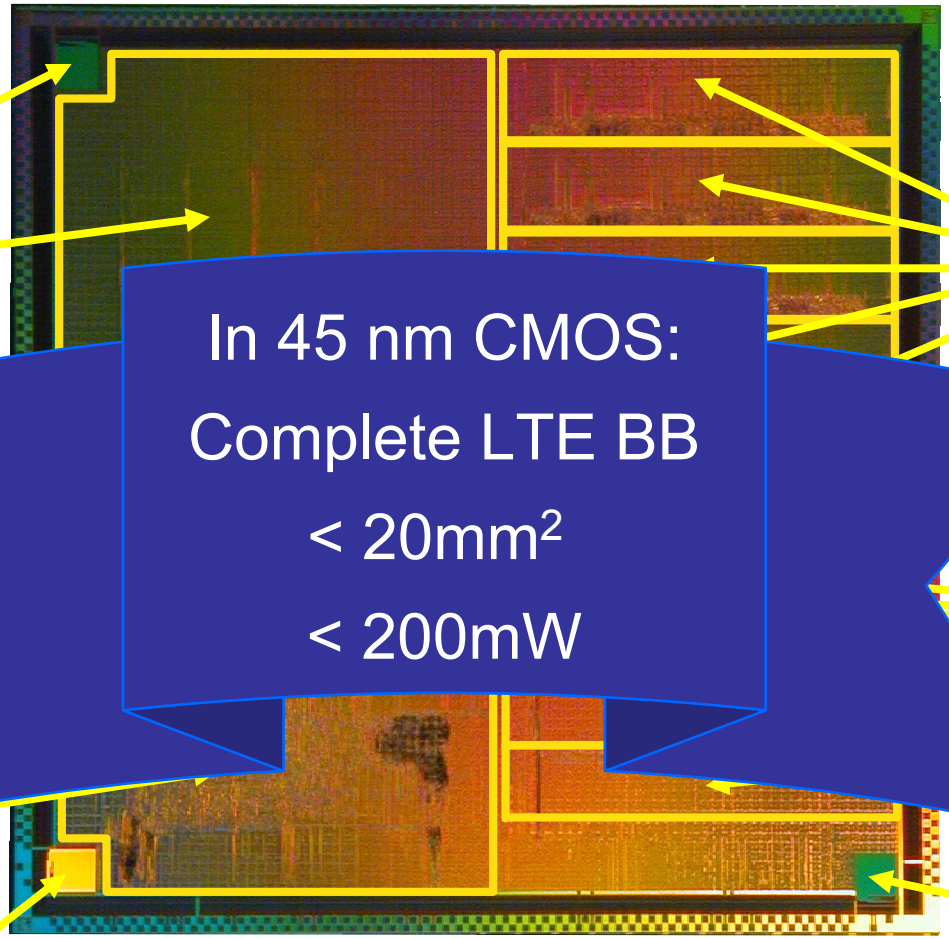
LTE FDD/ TDD/ WiMAX Single-Chip SDR: Tomahawk - Die Photo

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

130nm UMC
57M transistors

Silicon on
Jan 18 2008



PLL

Scratchpad

Core
Manager

10 m

2x Xtensa
DC212GP

STA
LDPC Decoder/
Deblocker
ASIP

PLL

STA Vector DSP

3x DDR Controller

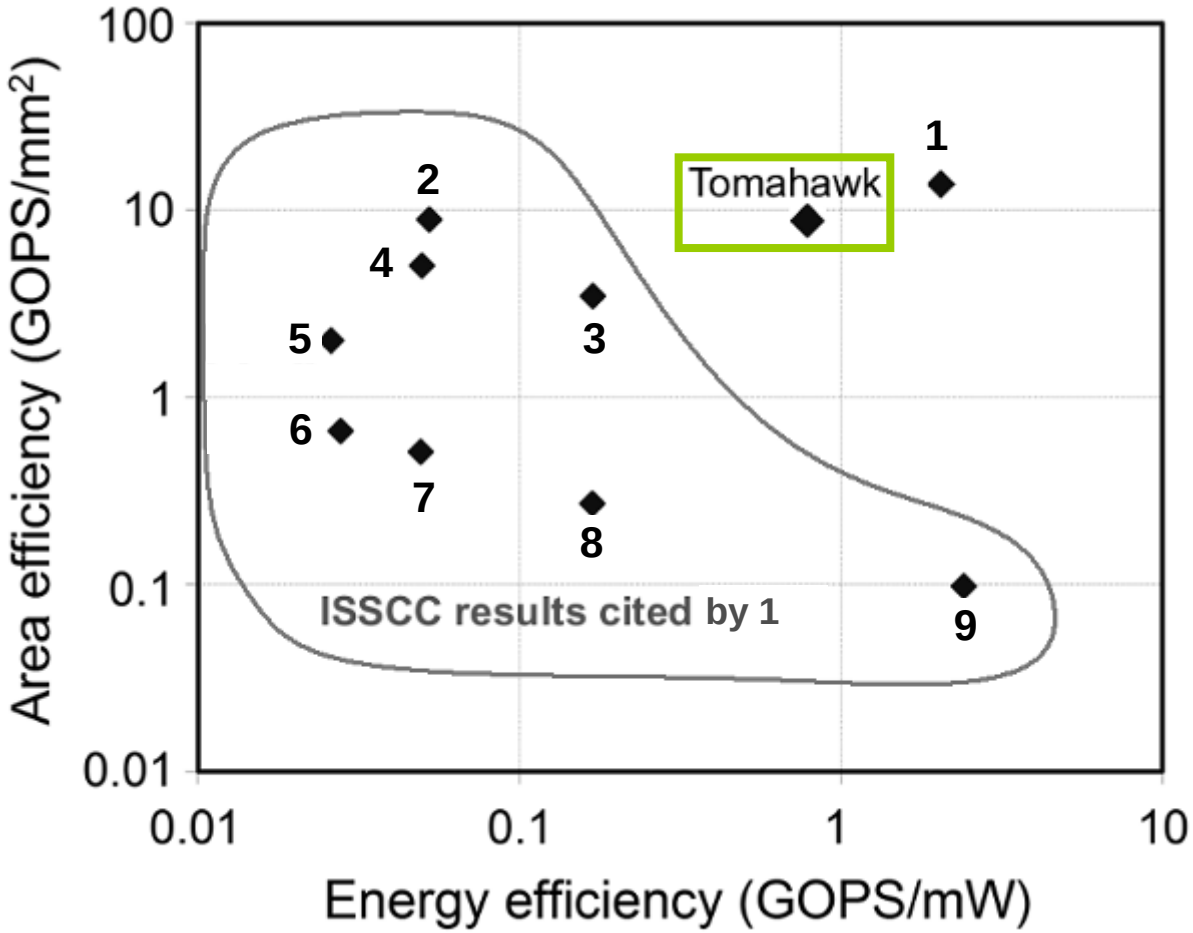
2x STA SIOUX

PLL

10 mm

In 45 nm CMOS:
Complete LTE BB
< 20mm²
< 200mW

Area & Power Efficiency



1. MIMO SVD ASIC
2. Consumer RISC
3. Multimedia DSP
4. FFT Processor
5. RISC CPU with Media Processor
6. Communications DSP
7. CAM LSI
8. Video Stream Multi-Processor
9. Hearing Aid DSP

Source: Markovic et. al., Power and Area Minimization for Multidimensional Signal Processing, IEEE J. Solid-State Circuits, vol. 42, no. 4, pp. 922-934, April 2007. Results scaled to 90 nm, operations are 12 bit add equivalents

How to Achieve “**GREEN**” in Networks

Some Issues

- Network topology
- Network architecture

- Network components
- Network interconnections

- Network supported features
- Network delivered bandwidth

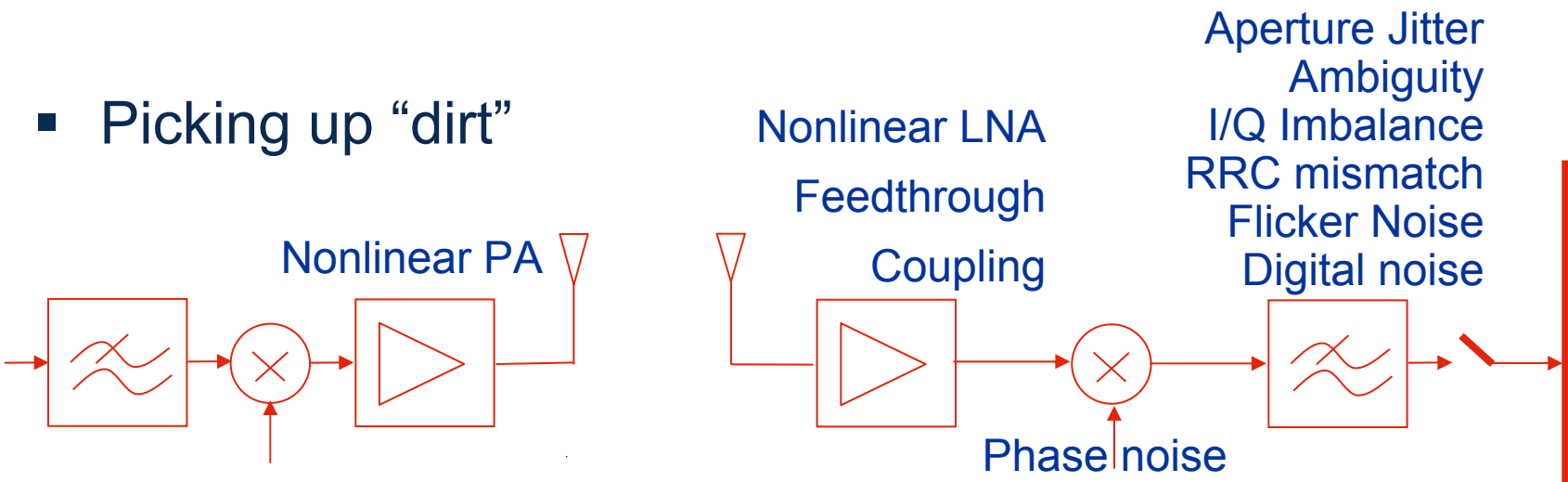
DIRTY RF

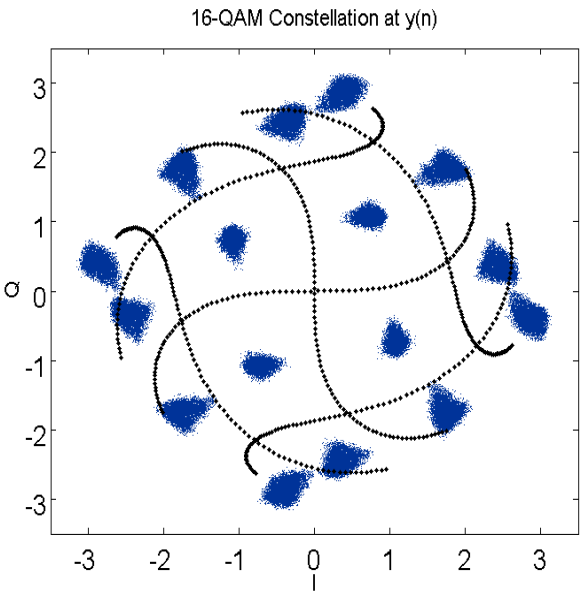
Dirty RF

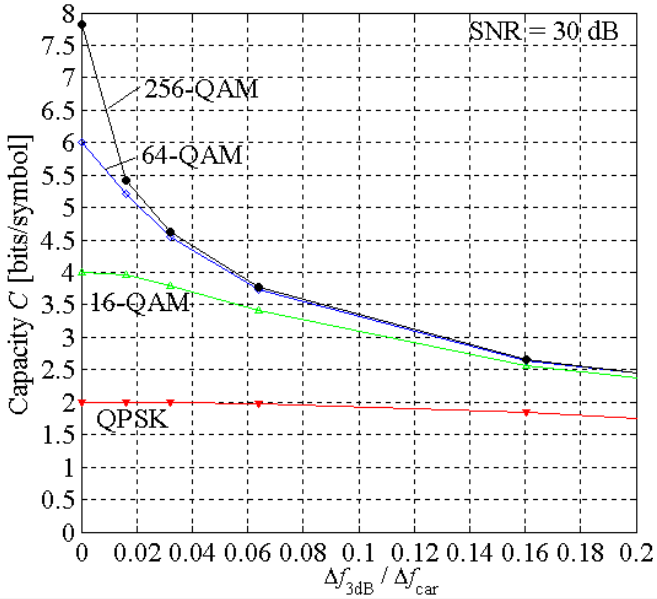
TECHNISCHE UNIVERSITÄT DRESDEN

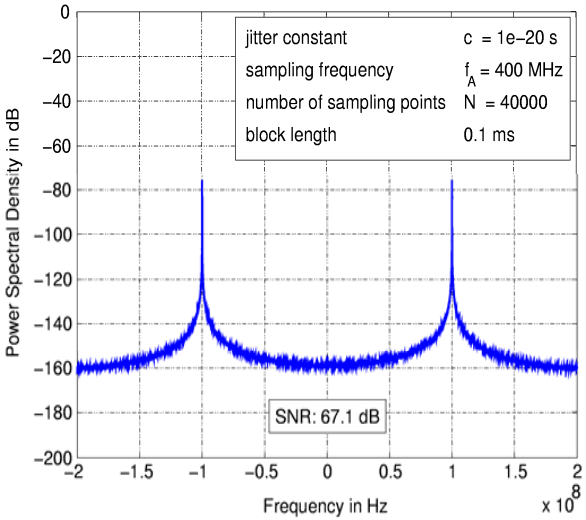
vodafone chair

- Picking up “dirt”







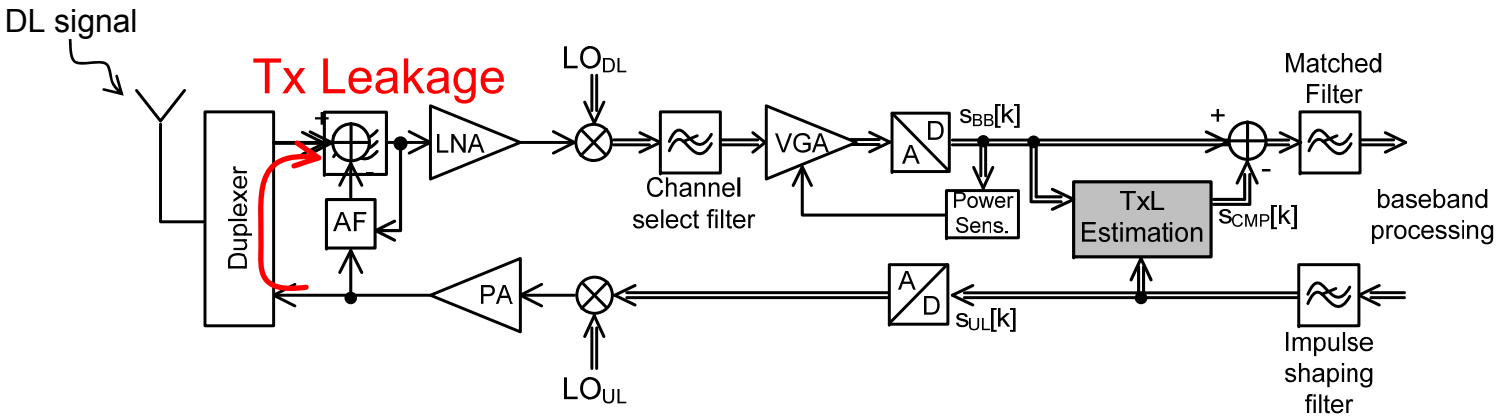


Transmit Leakage in FDD and Direct Conversion

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

Problem: Tx Leakage in FDD Terminals



- Limited Tx-Rx Isolation due to miniaturization and frequency agility
  → Tx Leakage (TxL)
  → Strong out-of-band interference in Rx branch

Approaches for Solution:

- Additional bandpass filter
- Adaptive filter in parallel to duplexer

  - Limited reconfigurability
  - Increased analog complexity

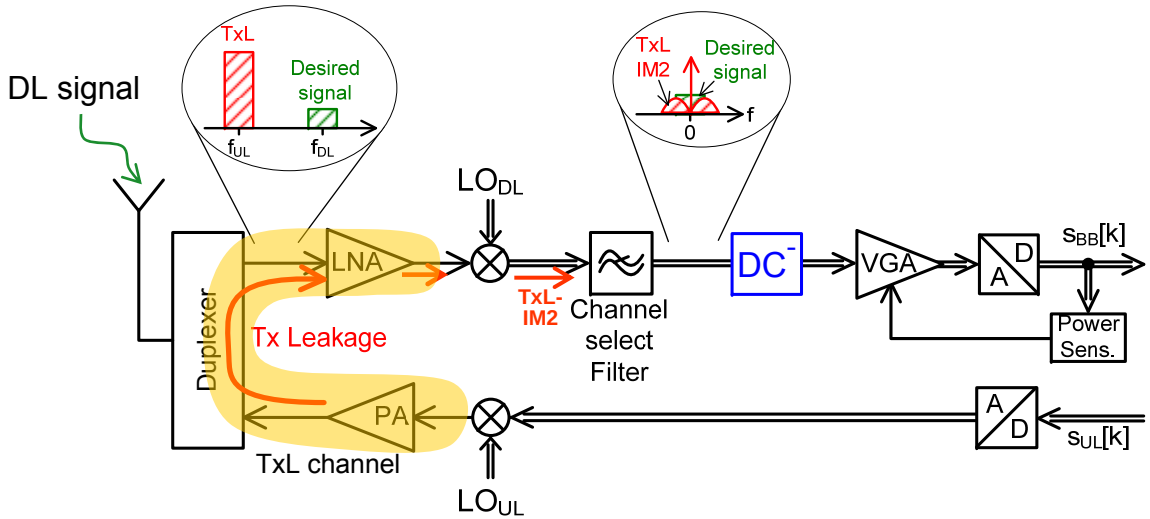
- *Dirty RF*: Compensation of analog impairments by digital signal processing
  + Reconfigurable / standard independent / relaxed RF requirements

Tx Leakage in Zero-IF Receivers

TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair

Tx Leakage intermodulation products 2nd order (TxL-IM2)



- Nonlinearity of I/Q down converter
  → Intermodulation product 2nd order of Tx Leakage (TxL-IM2)
- Low freq. TxL-IM2 interfering desired, down converted DL signal

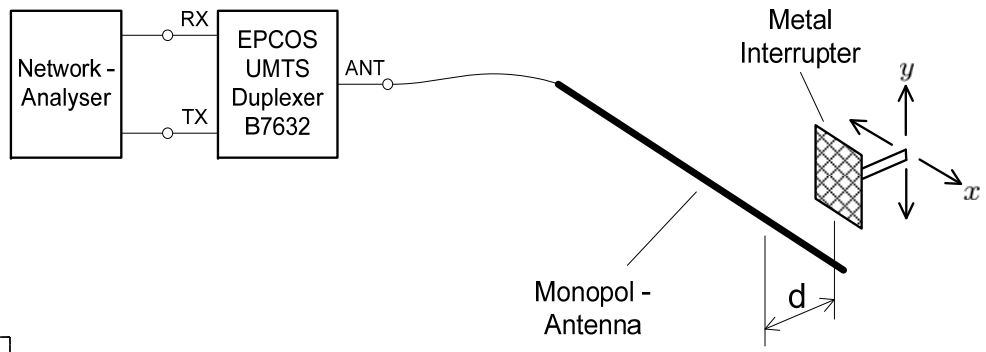
Tx-Rx Isolation

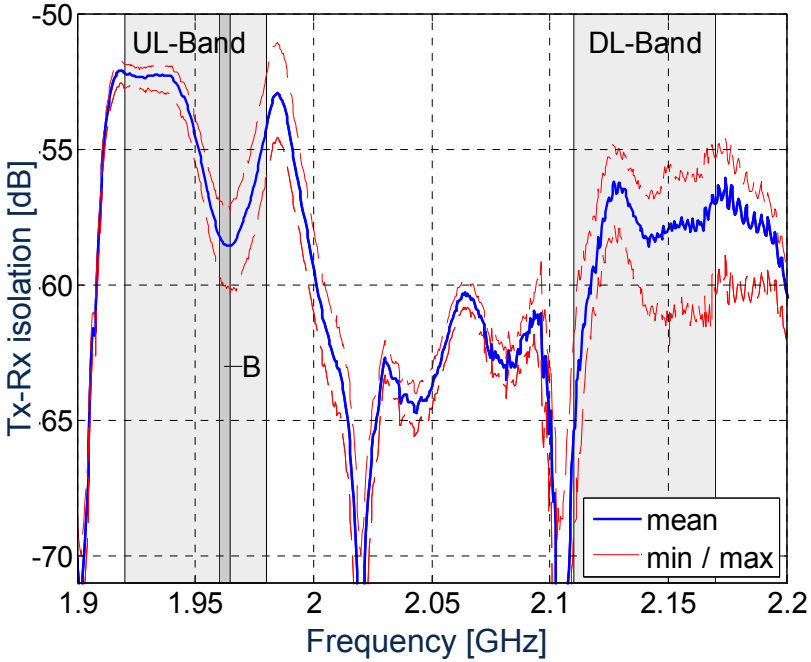
TECHNISCHE UNIVERSITÄT DRESDEN

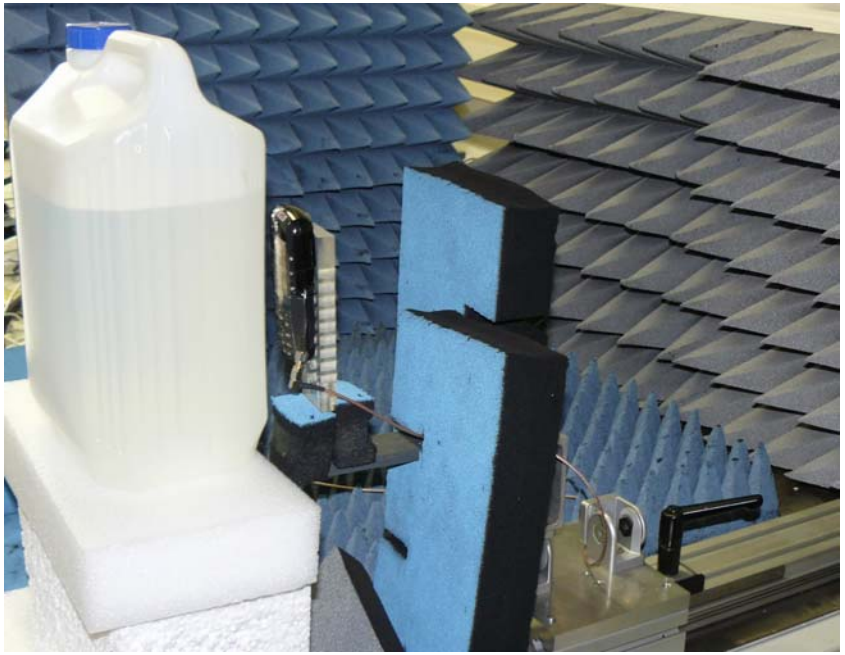
vodafone chair

Measurement with UMTS SAW Duplexer B7632 (EPCOS AG)

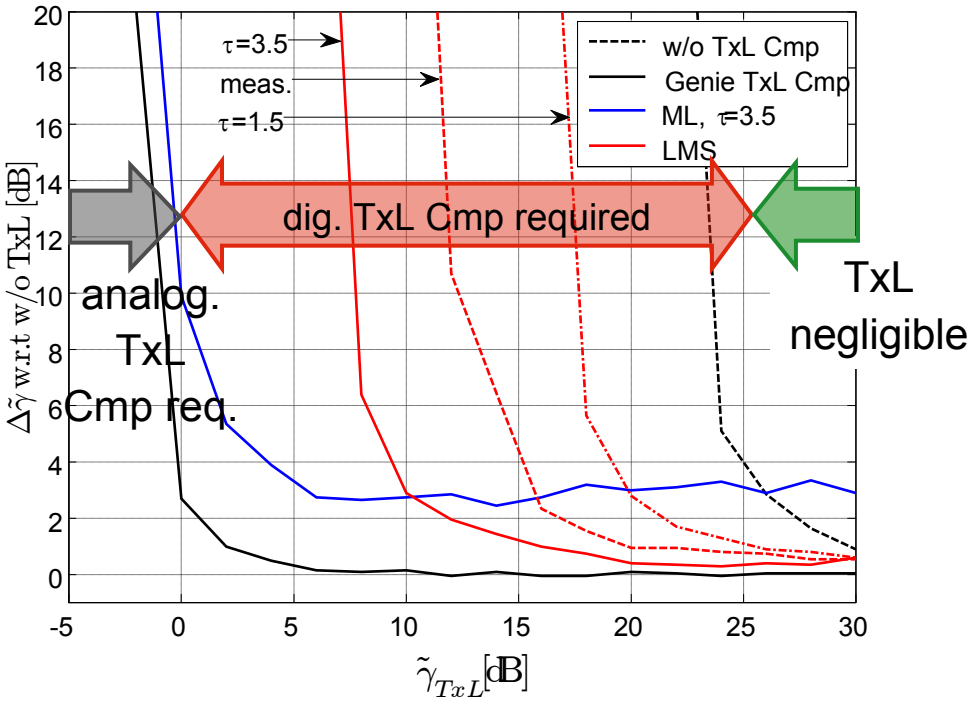
- Antenna nearfield distorted by metal interrupter moved within distance [0.036, 0.303] m to the antenna







SNR loss due to TxL



Simulation Parameters:

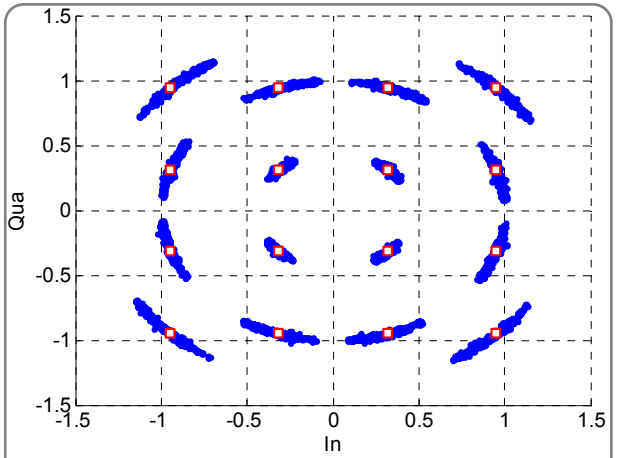
- DL / UL: 802.11a, 16QAM
- DL channel: HiperLAN A
- CSF EQ in TxL Est.
- analog DC^{-1}
- ADC: 8-bit lin. mid-rise, η=2
- TxL:
  - TxL ch: 6-tap exp PDP and meas. IR
  - TxL SIR γ_{TxL} = 10dB
  - no TxL I/Q mismatch
- TxL Est: - N_B=4000, $\hat{L} = L$

- OFDM susceptible to TxL for γ_{TxL} < 30dB
- digital TxL compensation suitable for γ_{TxL} > 0dB

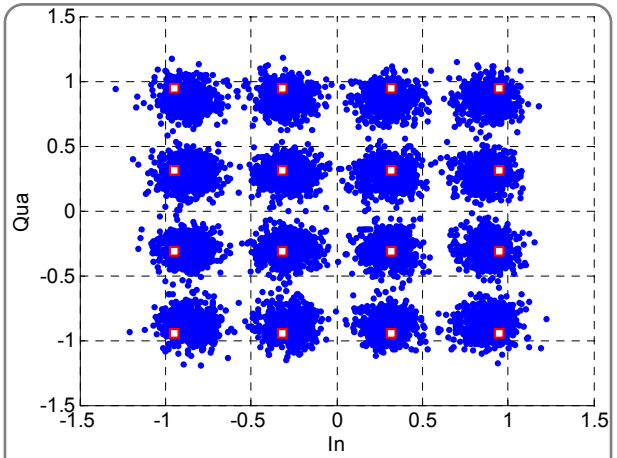
→ TxL can be mitigated digitally up to 30 dB

- ML reaches almost Genie Cmp. limit, but suffers from high min. SNR loss
- LMS performance strongly depending on TxL channel property

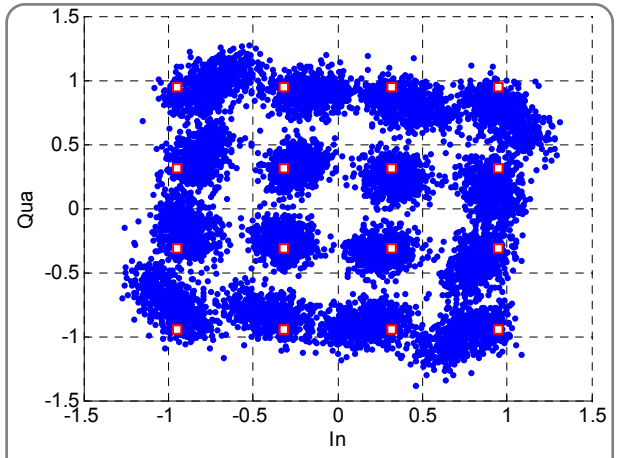
Phase Noise and Clippping



- **Phase Noise:**
  - Kalman Tracking
  - Complete Sync

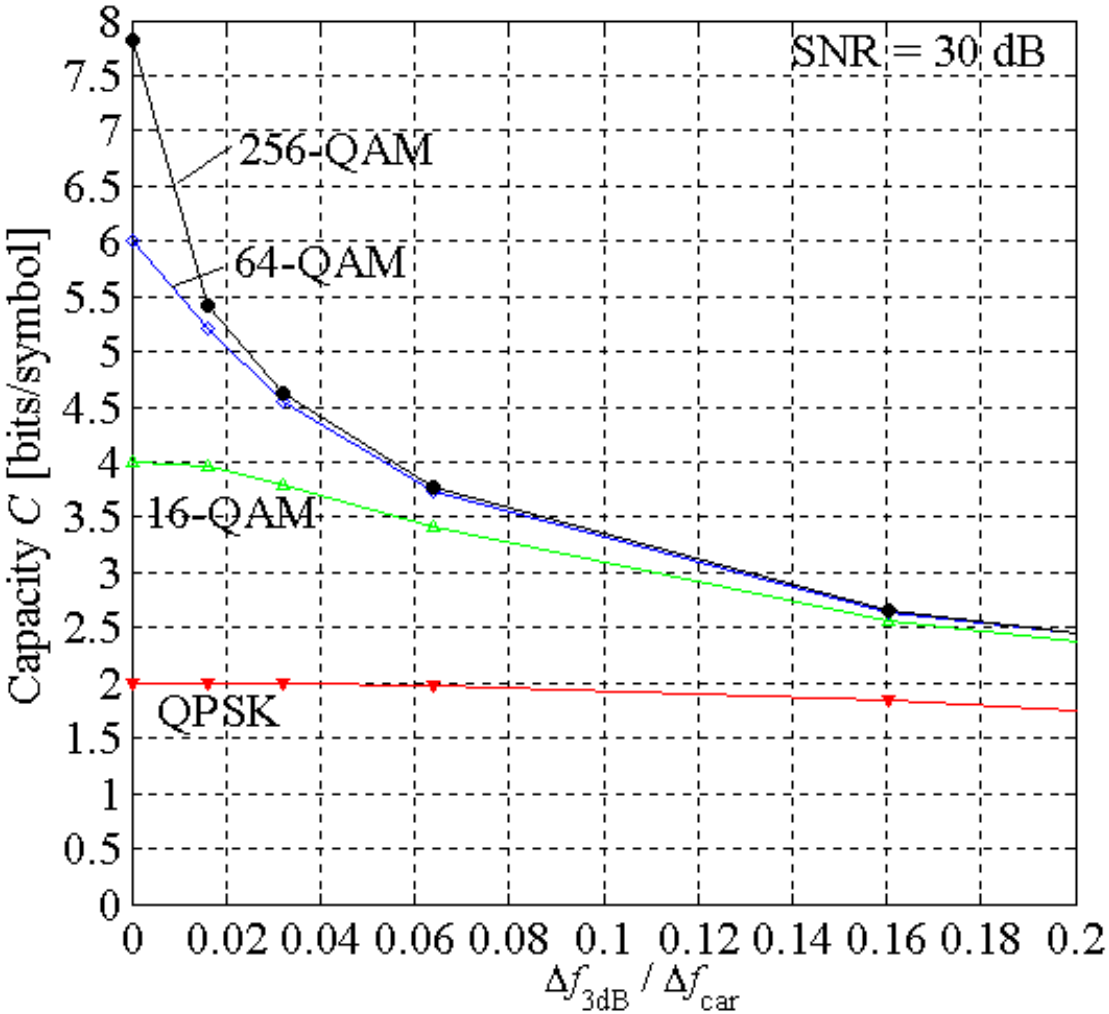


- **Clipping:**
  - Analogue PAPR
  - Saleh Model
  - AM/PM distortion

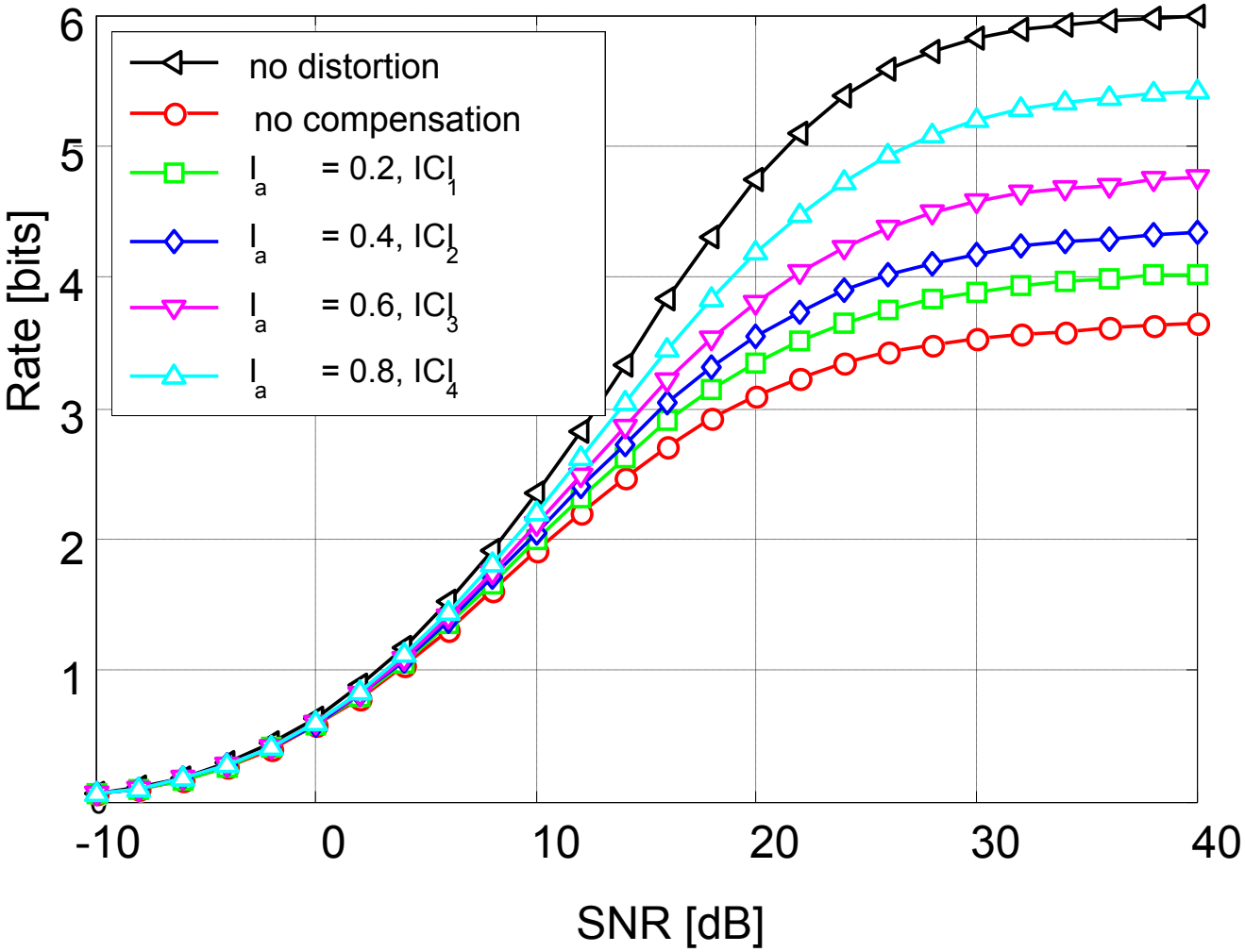


- **Clipping & PN:**
  - Rate

Phase Noise in OFDM



Rate under Phase Noise & Clipping



Setup:

IEEE 802.11a SISO

Exponential PDP, 8 taps

64-QAM f = 4GHz, IBO = 0dB

$c_{vco} = 3 \cdot 10^{-17}$

Many Further Issues

"Estimation and Detection" algorithm design

- Nonlinearities
- Phase noise
- I/Q imbalance
- Sampling jitter
- Transmit leakage
- …

Conclusions

- **FAST** increasing data transmission rates
- **GREEN** much lower-power “cool communications”
- RF impairment estimation with **DIRTY RF** approach

➔ We need much more further research !

Thanks !

Thank you Vodafone for the continued support of the chair

www.vodafone-chair.com