Some Recent EU-funded MIMO Research Activities

Constantinos Papadias

Technical Manager
Wireless Research Lab
Bell Laboratories, Lucent Technologies

Talk given at the 2004 Smart Antenna Workshop

Stanford University, Stanford, CA
July 29-30, 2004

Outline

- EU-funded wireless research:
  - Past activities
  - Current program: 6th framework program (FP6)
- MIMO-related projects where we are involved:
  - FITNESS (FP5)
  - WINNER (FP6) **[Integrated Project (IP)]**
  - ACE (FP6) **[Network of Excellence (NoE)]**
  - OBAN (FP6) **[Specific Targeted Research Project (STREP)]**
- Wireless World Research Forum: a next-G wireless forum
  - Recent contributions on intelligent antennas

Past European activites: 4th Framework Program (FP4)

- FP4-ACTS (Advanced Communication Technology Systems)
  - FRAMES (Future Radio Wideband Multiple Access Systems)
    Goal: *to define, develop and evaluate efficient multiple access schemes for UMTS*
  - TSUNAMI (Technology in Smart Antennas for Universal Mobile Infrastructure)
    Goal: *to demonstrate that it is feasible and cost effective to deploy Adaptive Antennas for UMTS*
  - SUNBEAM (Smart Universal Beamforming)
    Goal: *array processing for UMTS FDD and TDD*
- COST (European cooperation in scientific and technological research)
  - COST 231 - Evolution of Land Mobile Radio Communications
  - COST 259 - Wireless Flexible Personalised Communications
  - COST 273 - Towards Mobile Broadband Multimedia Networks

Fifth Framework program (FP5)

- Logistics:
  - Duration: 1999-2002; budget: €3.6B for Information Society Technologies (IST)
- Smart antenna related projects:
  - METRA(Multi-Element Transmit and Receive Antennas)
    MIMO techniques for UMTS
  - SATURN (Smart Antenna Technology in Universal Broadband wireless Networks)
    Adaptive antenna techniques for UMTS TDD and WLAN
  - ASILUM (Advanced Signal processing for Link capacity increase in UMTS)
    Beamforming and Multi-User Detection for UMTS
  - I-METRA (Intelligent Multi-Element Transmit and Receive Antennas)
    Re-configurable MIMO for UMTS
  - FITNESS: *Fourth-generation Intelligent Transparent Networks Enhanced through Space-time Systems*

FP6

- Sixth Framework Programme (FP6):
  - Information Society Technologies: €3.6B for 2003-2006
- First Call (April '03): €1.070B
  - Mobile and wireless systems beyond 3G: €90M
- Broad goal:

"Anywhere anytime natural and enjoyable access to IST services for ALL"

- Main "instruments":
  - Integrated Projects (IP's)
  - Networks of Excellence (NoE's)
  - Specific Targetted Projects (STREP's)

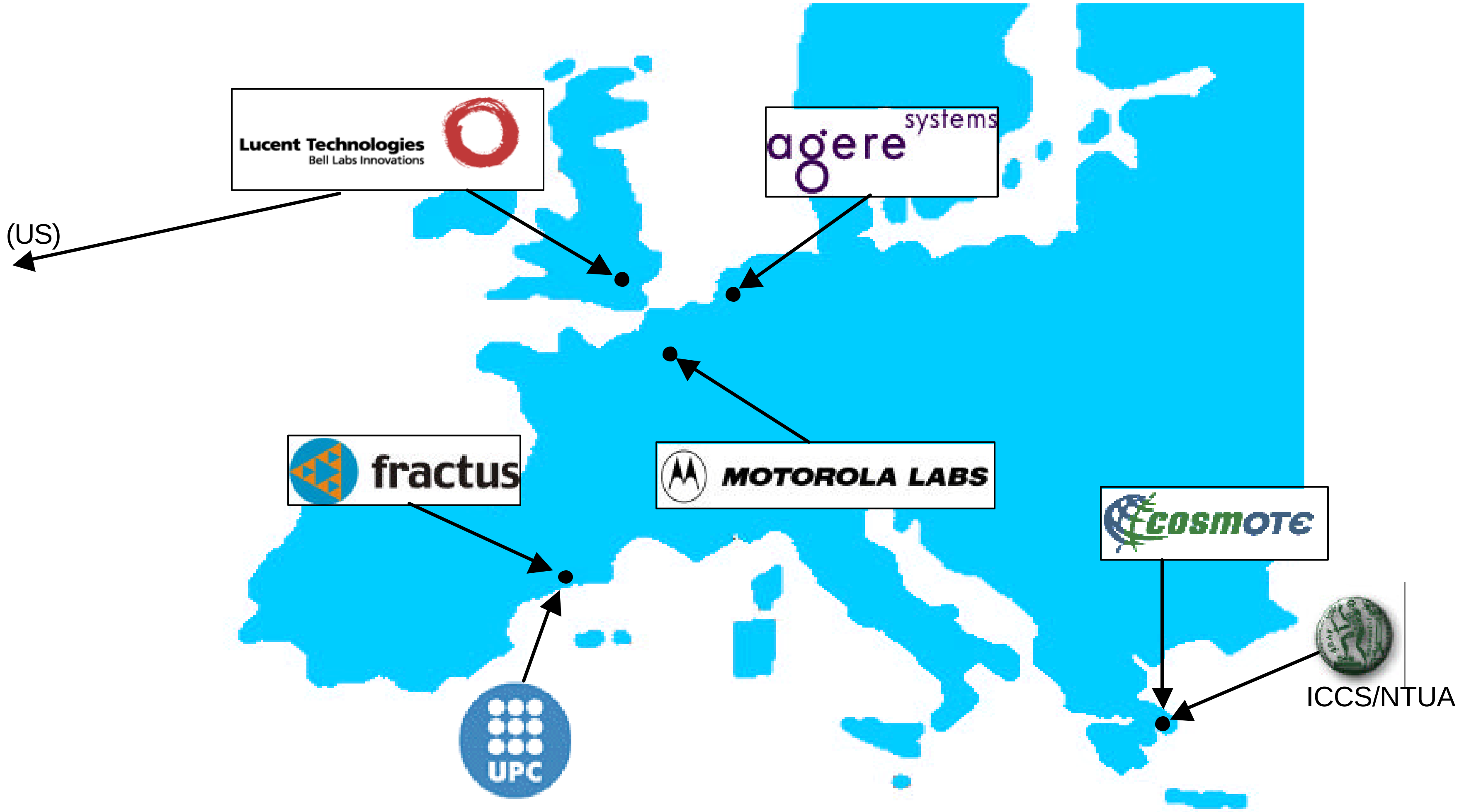
FITNESS:

Fourth-generation
Intelligent Transparent Networks
Enhanced through Space-time Systems

IST-2000-30116

FITNESS consortium & logistics

Lucent Technologies
Bell Labs Innovations



- Budget: 3,8 M€
- Starting date: 1 September, 2001; ending date: 30 November, 2003
- Web site site: http://www.telecom.ece.ntua.gr/fitness

FITNESS: vision - approach -objective

vision

MIMO processing based physical layer to achieve re-configurability to varying conditions and transparent operation in a multi-technology network (UMTS/WLAN)

approach

MIMO RE-CONFIGURABILITY AT THE LINK LEVEL

LINK-SYSTEM INTERFACE

INTER-OPERABILITY AT THE SYSTEM LEVEL

objective

To develop MIMO Re-configurable Techniques and Inter-operation Strategies, evaluate Performance Enhancements and investigate Implementation Issues

FITNESS main technical achievements

- ✓ **Reconfigurable algorithms for UMTS**
- ✓ **Reconfigurable algorithms for WLAN**
- ✓ **HSDPA test-bed**
- ✓ **WLAN test-bed**
- ✓ **Antenna studies**
- ✓ **Link-to-System Interface**
- ✓ **FITNESS System Level Simulations**

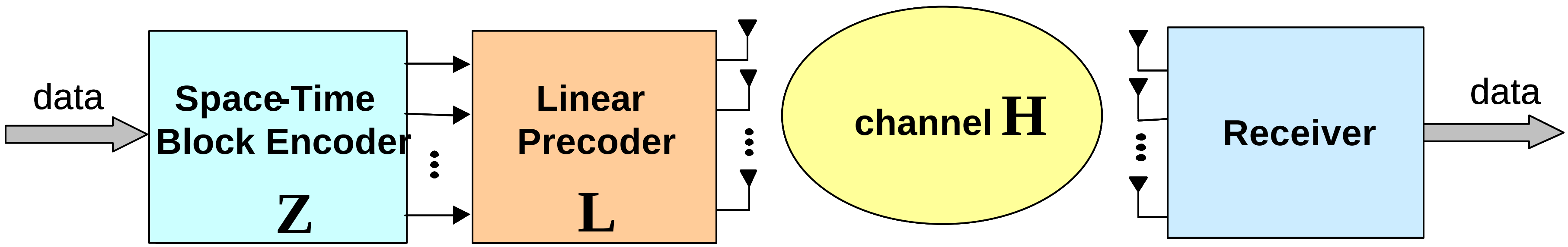
FITNESS: Link-level MIMO re-configurability

- Goal: to compensate for performance degradation in MIMO systems due to impairments such as:
  - – antenna correlation
  - – CSI reliability

- Application: space-time block coded (STBC) systems

- Approach:
  - – linear precoding at the transmitter
  - – precoder optimized based on different criteria

System Model



Received signal:

$$\mathbf{Y} = \mathbf{HLZ} + \mathbf{S}$$

H: NxM channel matrix
Z: MxQ matrix of codewords
L: MxM linear transformation

Correlation-based model:

$$\mathbf{H} = \mathbf{H}_W \mathbf{R}_T^{1/2}$$

$\mathbf{H}_W$: NxM i.i.d complex matrix
$\mathbf{R}_T$: MxM Tx antenna correlation matrix

A. Alexiou and M. Qaddi, "Re-configurable linear precoders to compensate for antenna correlation in orthogonal and quasi-orthogonal space-time block coded systems", IEEE VTC2004-Spring, Milan, May17-19, 2004.

Performance Criterion

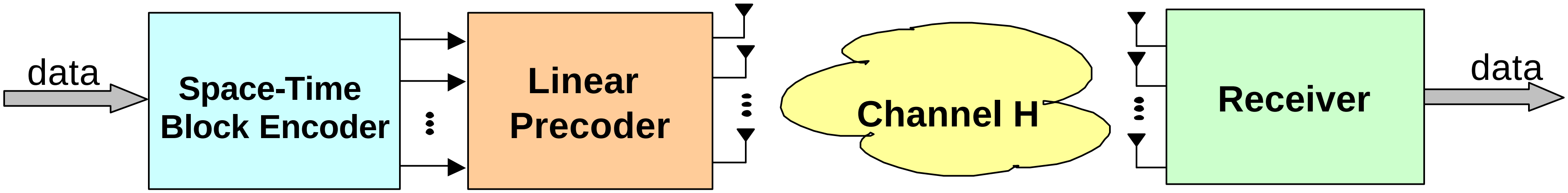
- Minimization of the Pairwise Error Probability:

$$\overline{PEP} \leq \left[\det\left(\mathbf{I} + \mathbf{D}\right)\right]^{-N}$$

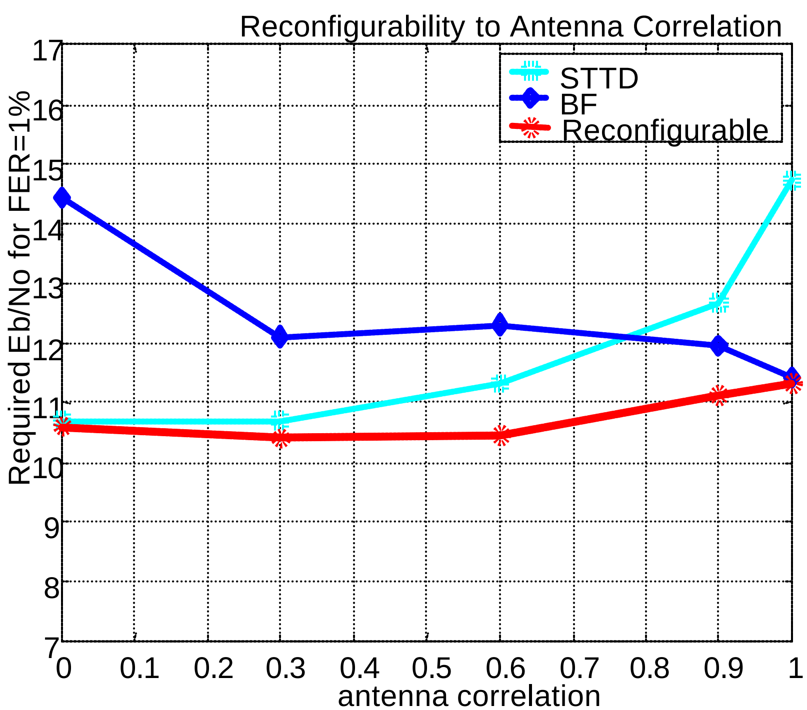
$$\mathbf{D} = \frac{E_s}{s^2} \mathbf{R}_{\mathbf{T}}^{\mathbf{1/2}} \mathbf{L} \mathbf{E} \mathbf{E}^H \mathbf{L}^H \mathbf{R}_T^{1/2^H}$$

$\mathbf{E}$: **minimum distance code error matrix**

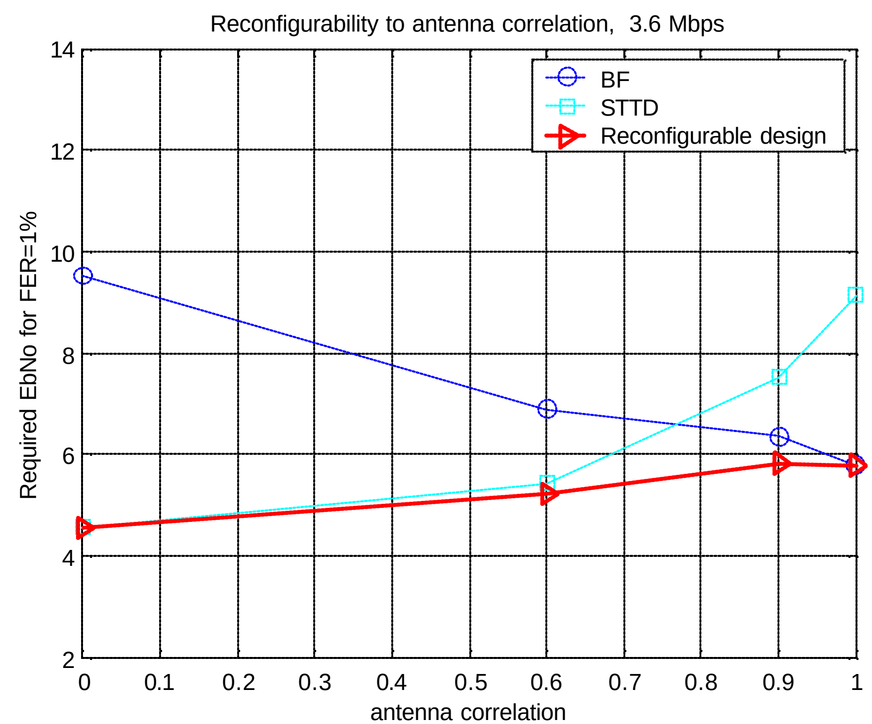
Simulation Results



Linear Precoding based on Pairwise Error Probability minimisation

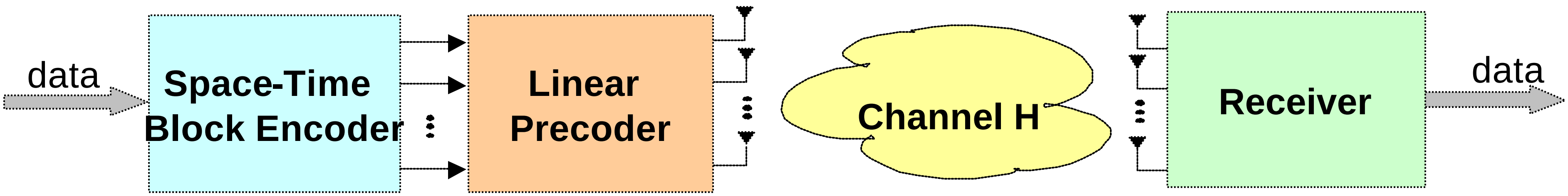


[2x1 @ 12.2kbps, UMTS FDD Correlation-based channel model]

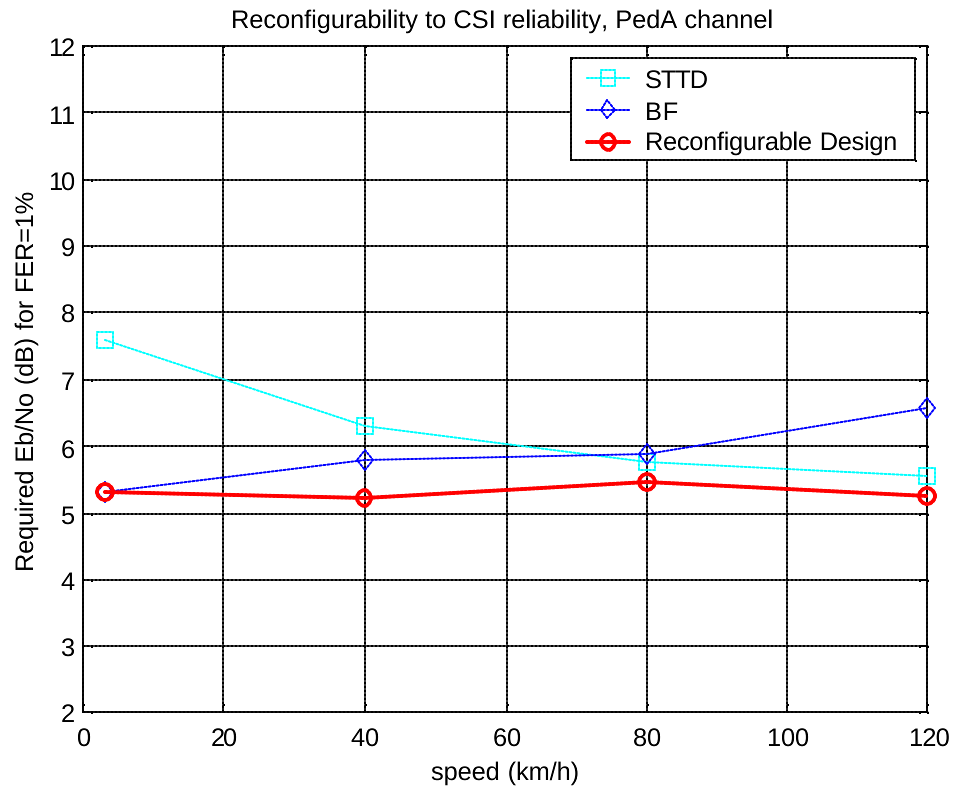


[2x2 @ 3.6 Mbps, HSDPA Correlation-based channel model]

Re-configurability to CSI reliability



Linear Precoding based on minimisation of the Chernoff bound on SER



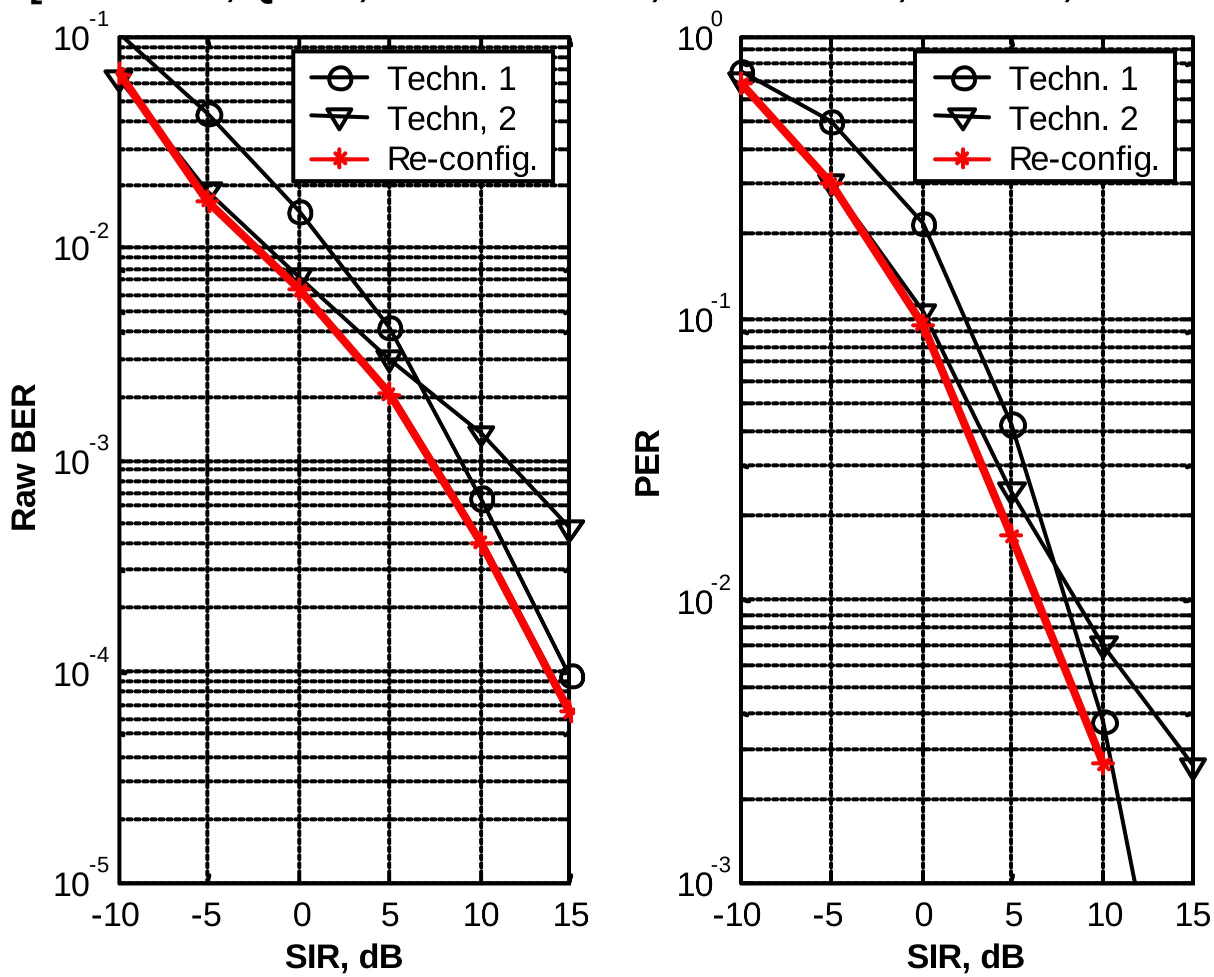
[Required Eb/No for FER=1%, 2x1 @ 12.2kbps PedA channel, UMTS FDD]

Re-configurability to interference

Lucent Technologies
Bell Labs Innovations

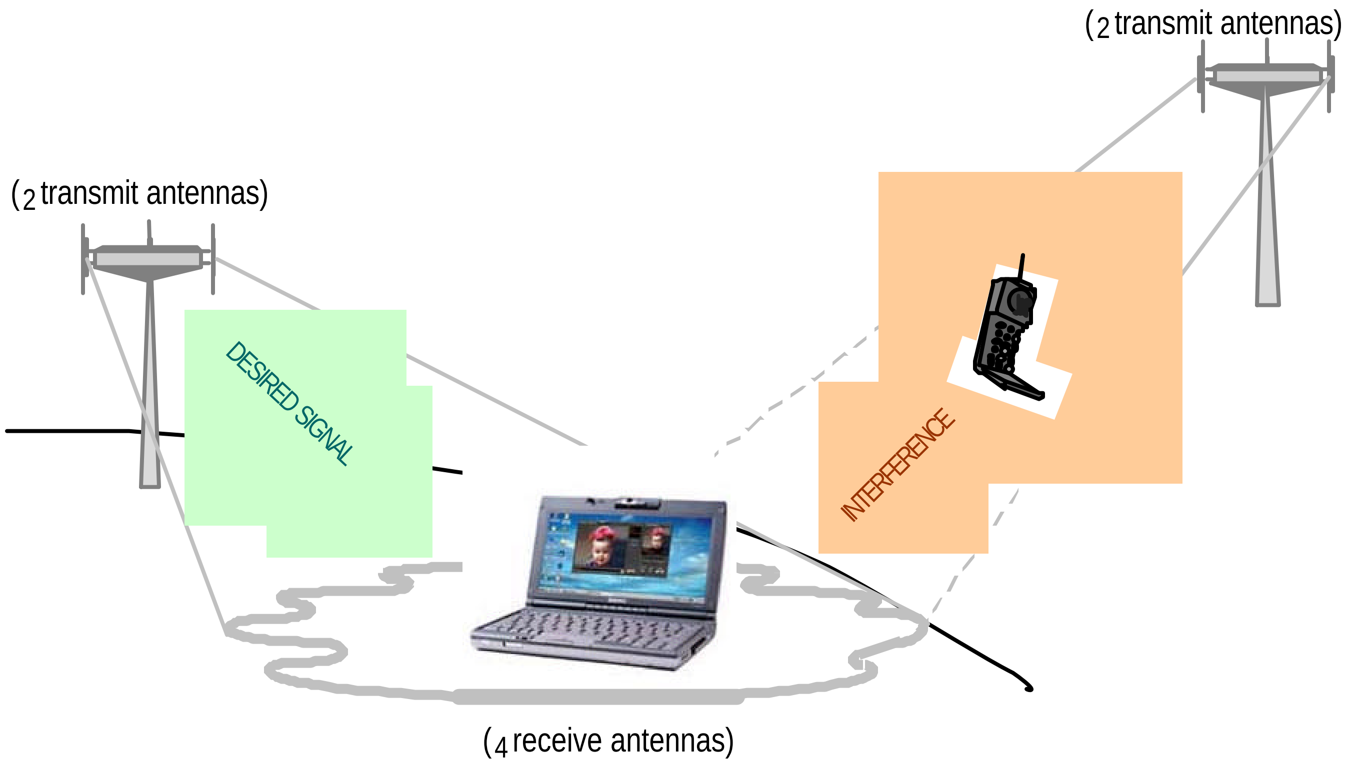
Robust interference mitigation with semi-blind processing

Asynchronous IC with an antenna array in Hiperlan/2
[2x4 MIMO, QPSK, 3/4 conv. code, “A” channel, 2x4 CCI, 36 Mbit/s]



A. Kuzminskiy, C. Papadias, ‘‘Semi-blind Cancellation of Asynchronous Interference with an Antenna Array,’’ In. *Proc. ICASSP 2004*, 2004.

MIMO interference mitigation demo for HSDPA



Over the air real-time interference mitigation
MIMO HSDPA demo using Lucent's BLAST chip

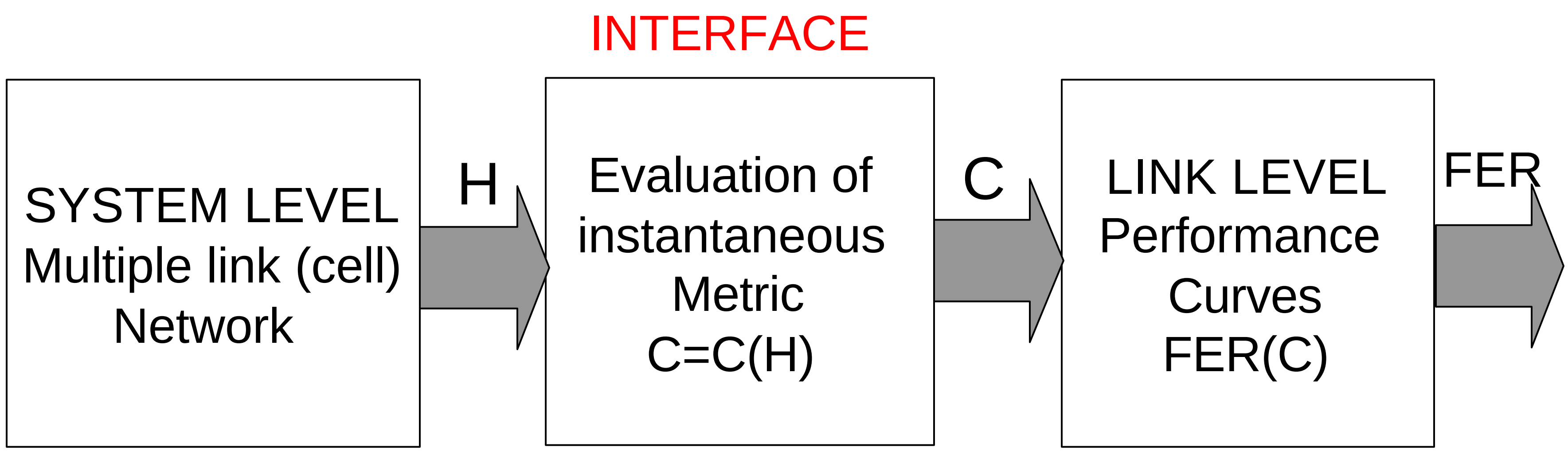
D. Samardzija, A. Lozano, C. Papadias, ''Experimental Validation of MIMO Multiuser Detection for UMTS High-Speed Downlink Packet Access,'' to appear, *IEEE Globecom 2004*, Dallas, Texas, Nov. 29 - Dec. 3, 2004.

MIMO interference mitigation demo setup

IST Mobile Summit, Aveiro, Portugal, June 2003

Lucent Technologies
Bell Labs Innovations

Link-to-system interface



- Performance gains at the link-level do not necessarily translate into equivalent gains at the system level
- System-level simulation, i.e. identifying the performance of the radio links between all mobiles and base stations, is of prohibitive complexity
- A new link-to-system interface needs to be identified which represents the receiver performance as a function of specific channel realisations over a coding-block

A. Alexiou, R. Karimi, K. Peppas, F. Lazarakis, D. Bourse, "System level simulation methodology for 4G wireless communication systems enhanced through space-time techniques", 7th WWRF Meeting, 3-4 December 2002, Eindhoven.

Link-to-system interface metric

Without linear precoding

$$FER = \Pr\left\{\text{Frame Error} \mid \mathbf{H}, \frac{E_b}{N_o}\right\} = f(C(\mathbf{H}, E_b, N_o))$$

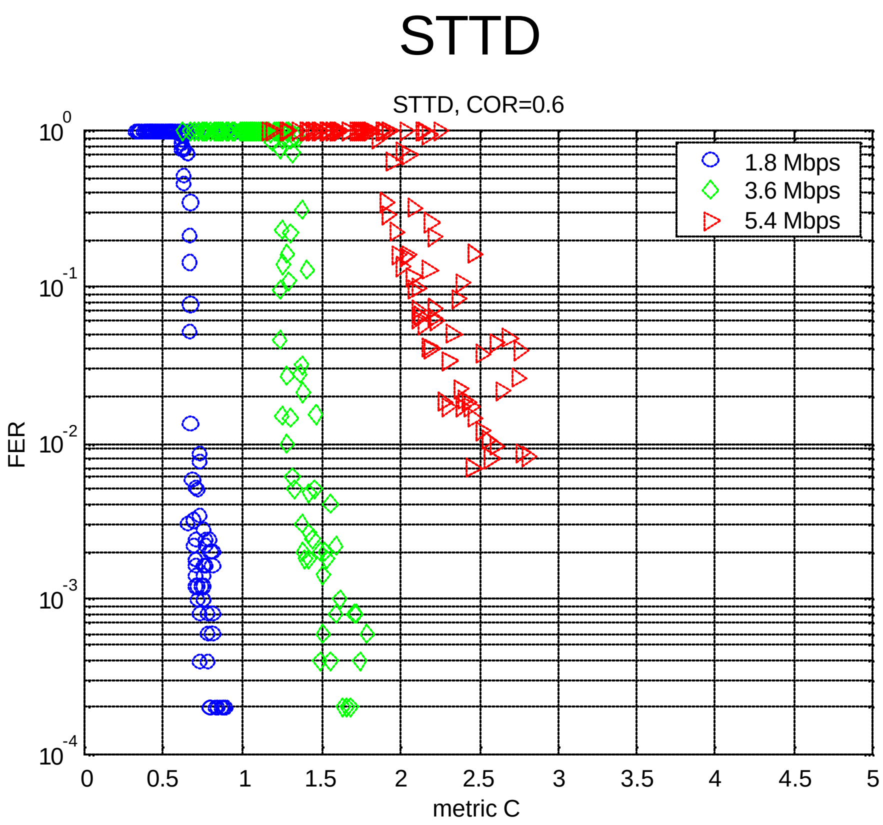
$$C = \log_2 \det\left(\boldsymbol{I}_N + \frac{1}{M}\frac{E_b}{N_o}\boldsymbol{H}\boldsymbol{H}^{\mathrm{H}}\right)$$

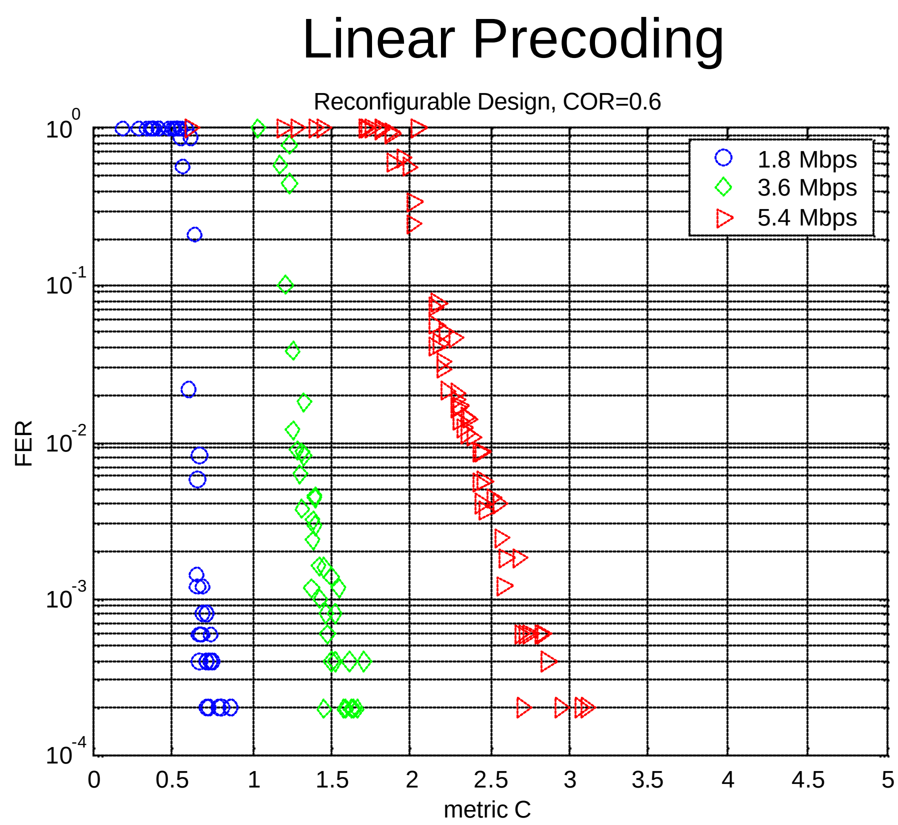
With linear precoding

$$FER = \Pr\left\{\text{Frame Error} \mid \mathbf{H}, \mathbf{F}, \frac{E_b}{N_o}\right\} = f(C(\mathbf{H}, \mathbf{F}, E_b, I_o, N_o))$$

$$C = \log_2 \det\left(\boldsymbol{I}_N + \frac{1}{M}\frac{E_b}{N_o}\boldsymbol{H}\boldsymbol{F}\boldsymbol{F}^{\mathrm{H}}\boldsymbol{H}^{\mathrm{H}}\right)$$

Link-to-system interface with linear precoding





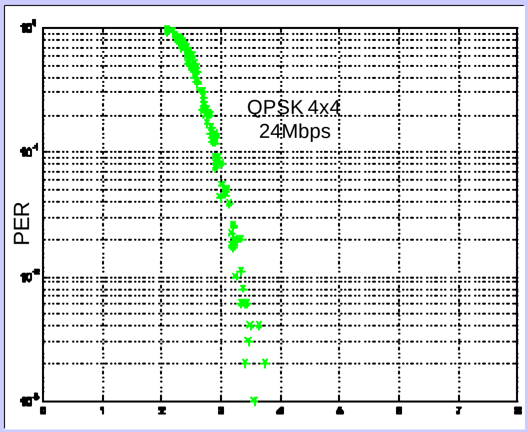
HSDPA 2x2 @ 1.8, 3.6, 5.4 Mbps

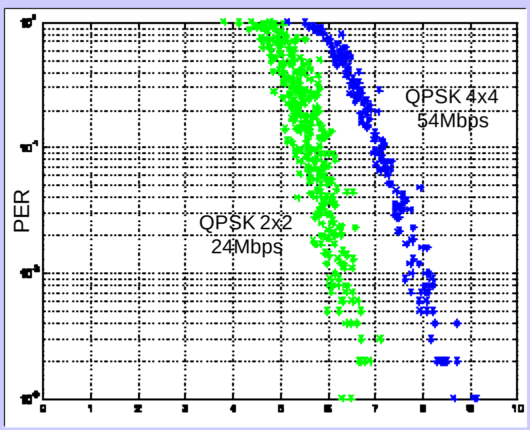
Correlation-based channel model, HSDPA

Link-to-System Interface for WLAN

Capacity

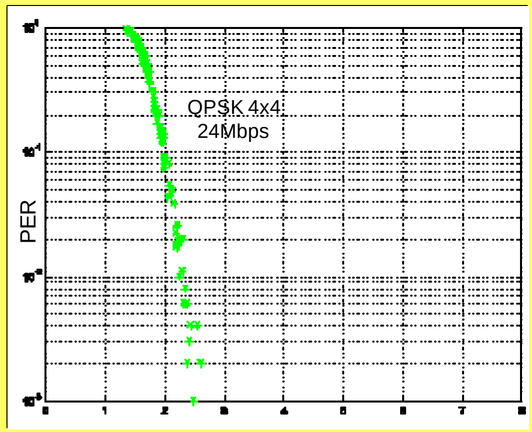
$$C = \frac{1}{K}\sum_{k=1}^{K}\log\left(\det\left(\mathbf{I} + \left(\mathbf{F}_k^H \mathbf{H}_k^H C_{wk}^{-1} \mathbf{H}_k \mathbf{F}_k\right)\right)\right)$$

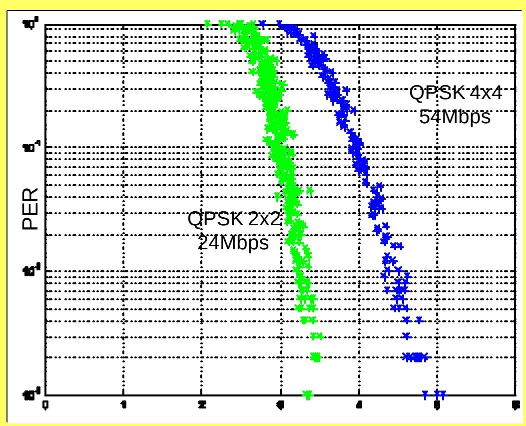




Cut-off Rate

$$R_o = -\tfrac{1}{K}\sum_{k=1}^{K}\log_2\left(\frac{1}{Q^{2M}}\sum_{\mathbf{c}_k,\hat{\mathbf{c}}_k} e^{\left(-\frac{1}{4}\left(\mathbf{H}_k\mathbf{F}_k\left(\mathbf{c}_k-\hat{\mathbf{c}}_k\right)\right)^H \mathbf{C}_{w_k}^{-1}\mathbf{H}_k\mathbf{F}_k\left(\mathbf{c}_k-\hat{\mathbf{c}}_k\right)\right)}\right)$$





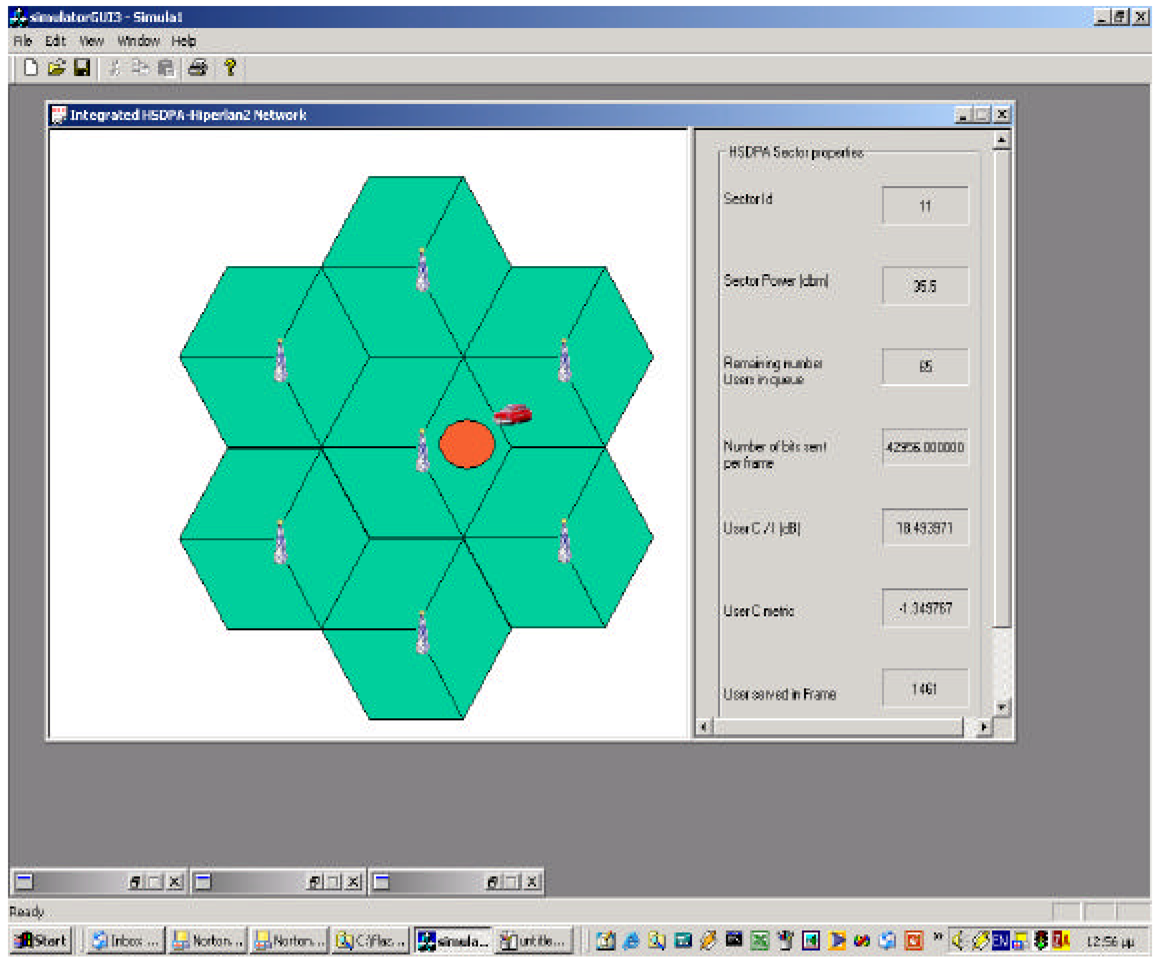
For the transmission schemes and scenarios considered in FITNESS the two metrics are nearly the same.

For other transmission schemes or scenarios the cut-off rate may provide a lower dispersion in the mapping.

System level simulation

- Objectives:
  - ❑ Evaluation of the enhancement of MIMO techniques at system level
  - ❑ Demonstration of HSDPA/HIPERLAN2 interoperability

- Scenarios:
  - ❑ HSDPA (macro deployment)
  - ❑ HIPERLAN2
    - airport hot-spot (indoor)
    - city centre (outdoor)
  - ❑ Interoperability between HSDPA and HIPERLAN2
    - in an airport hot-spot
    - in a city centre



HSDPA simulation assumptions

Num of cells	19
Shape	Three sectored, hexagonal cells
Radius	1400m
Propagation model	$PL = 34.5 + 35\log_{10}(d)$
Log-normal shadowing	8 dB
Mobility	Low mobility + vehicular speeds
Antenna pattern	$A(q) = -\min\left[12\left(\frac{q}{q_{3dB}}\right)^2,\ A_m\right]$ where $-180 \leq q \leq 180$
Fast fading MIMO channel	Geometry Based stochastic model
Link–system interface	$C = \log_2 \det\left(\mathbf{I}_N + SF \cdot \frac{1}{M} \cdot \frac{E_b}{N_o} \mathbf{H}\mathbf{H}^{\mathrm{H}}\right)$
Transmission rates for SISO and MIMO 2X2	1.8 Mbps, 3.6 Mbps, 5.4 Mbps, 10.8 Mbps
Transmission Schemes	STTD, Reconfigurable Scheme
Services	Web browsing (64kbps, SAF=0.6) FTP (384kbps, SAF=0.4)
Traffic load per sector	3 Mbps, 6 Mbps, 9 Mbps

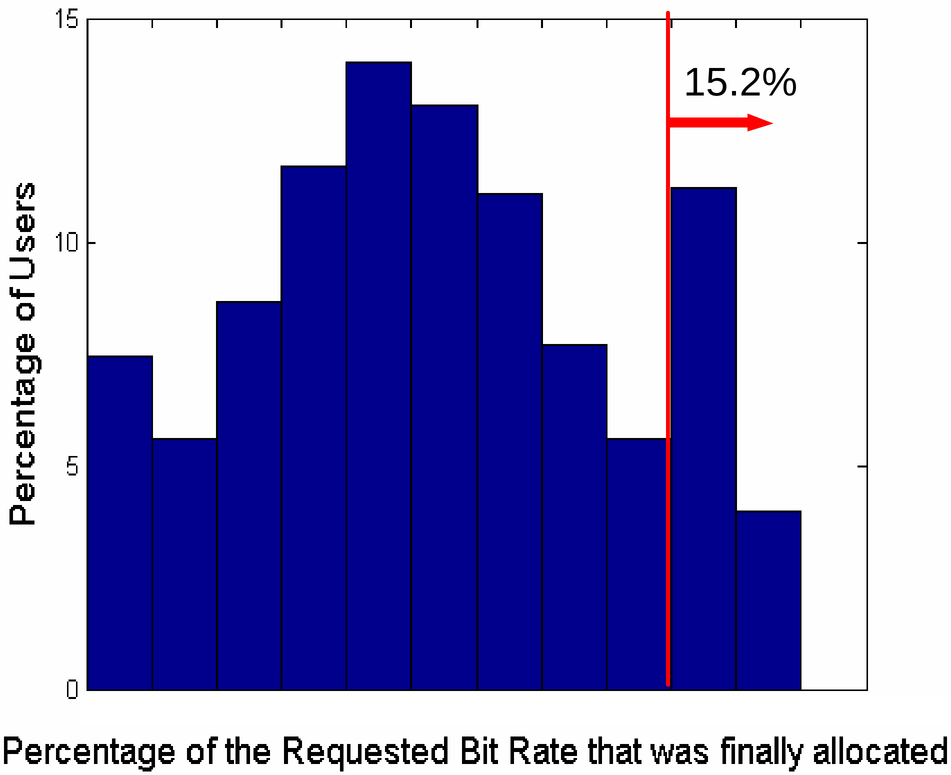
Hiperlan2 simulation assumptions

Deployment	16 square cells, range: 70 m
Propagation model	$P_L = 46.7+24\log_{10}d+S$ (indoor) $P_L = 46.7+20\log_{10}d+a.d+S$ (outdoor)
Log-normal shadowing	8 dB (indoor), 10dB (outdoor)
Mobility	3 km/h (outdoor), 1.8 km/h (indoor)
Antenna pattern	Omni directional
Fast fading MIMO channel	correlation-based stochastic channel model
Link –system –interface	$C = \frac{1}{K}\sum_{k=1}^{K}\log\left(\det\left(\mathbf{I}+\left(\mathbf{F}_k^H\mathbf{H}_k^H\mathbf{R}_k^{-1}\mathbf{H}_k\mathbf{F}_k\right)\right)\right)$
Transmission rates	SISO : 6, 12, 18 (Mbps) MIMO 2X2: 6, 12, 24, 36 (Mbps) MIMO 4X4: 24, 36, 54 (Mbps)
Transmission Schemes	SVD-based reconfigurable scheme
Services	Web browsing (64kbps, SAF=0.4) FTP (384kbps, SAF=0.6)
Traffic load per AP	SISO : 6, 12, 18, 27 (Mbps) MIMO 2X2: 12, 18, 27, 36 (Mbps) MIMO 4X4: 27, 36, 54 (Mbps)

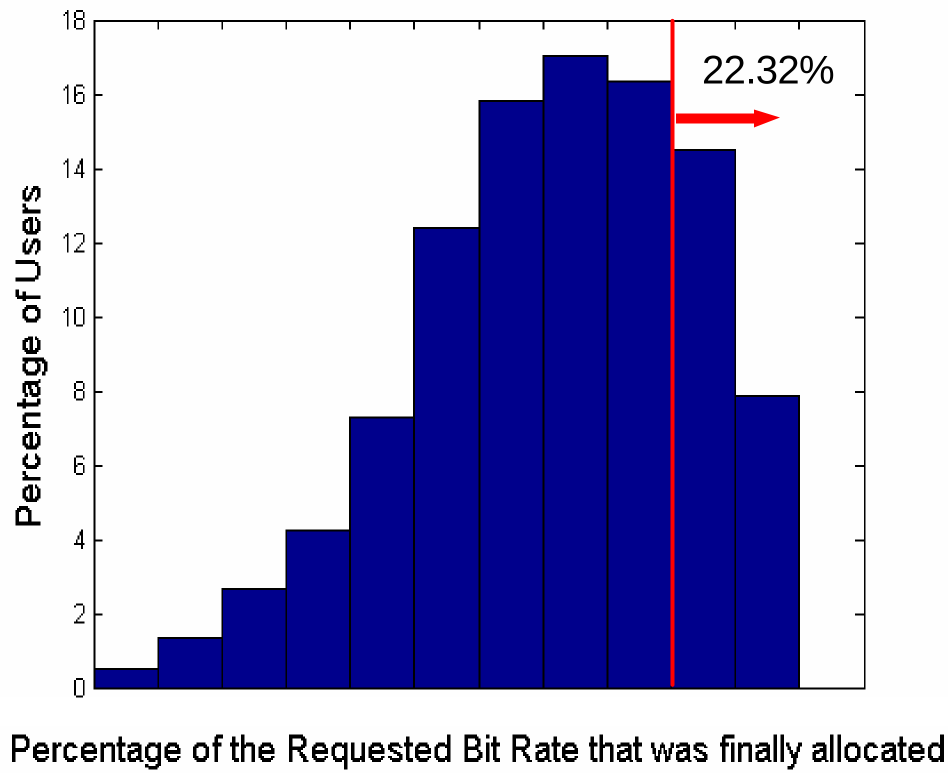
HSDPA system-level simulation results

Lucent Technologies
Bell Labs Innovations

Traffic Load: 6 Mbps/sector
- **web users/sector = 56**
- **FTP users/sector = 6**



SISO

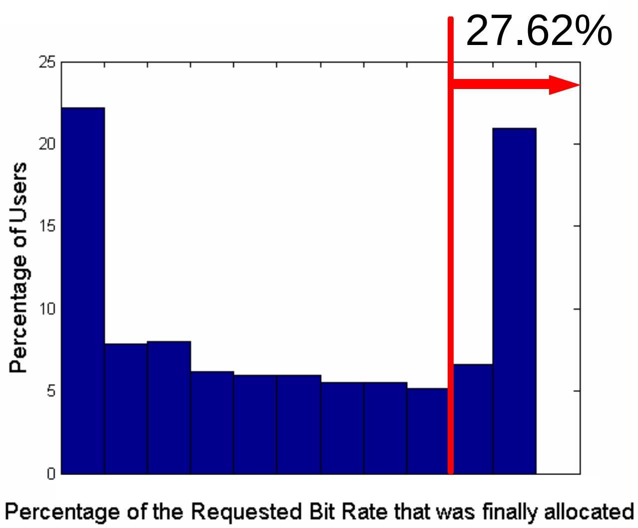


MIMO 2X2

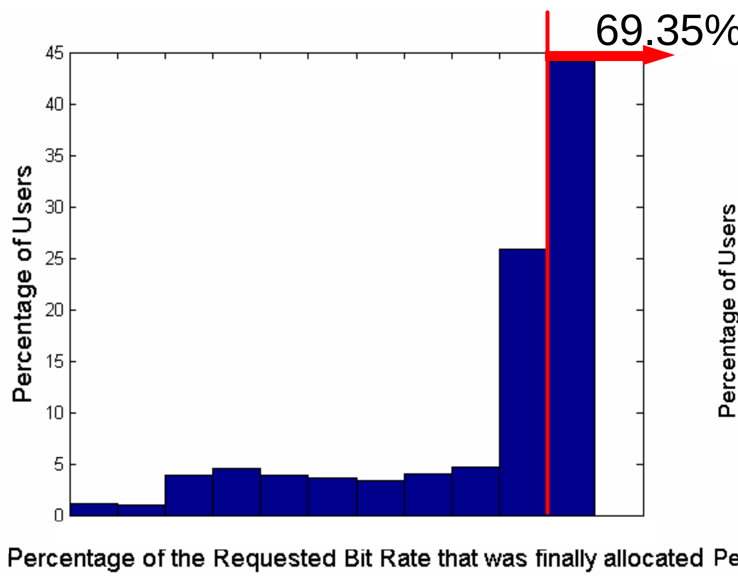
PDF of Users (Relative) Allocated Rate

Hiperlan2 system-level simulation results

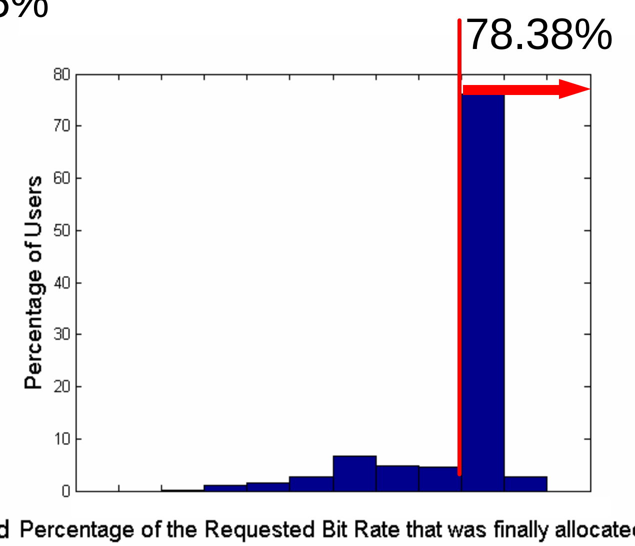
Traffic Load: 27 Mbps/AP
- **web users/AP = 169**
- **FTP users/AP = 42**



SISO



MIMO 2X2

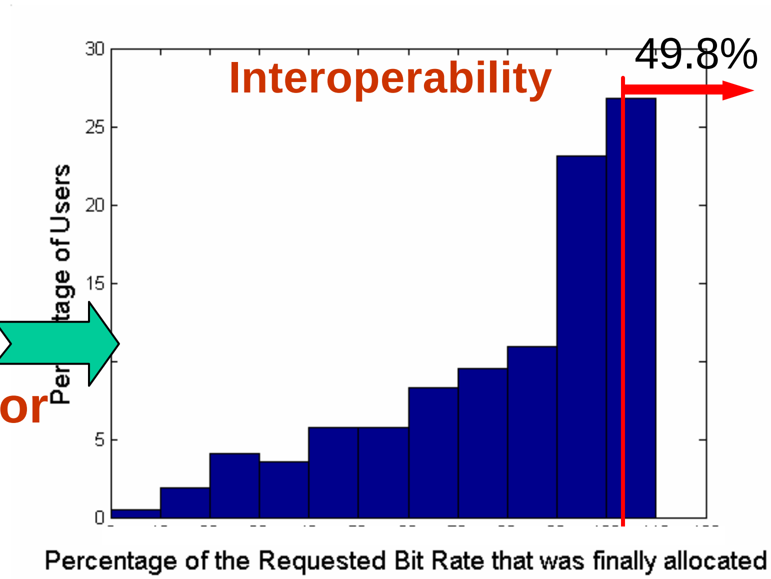


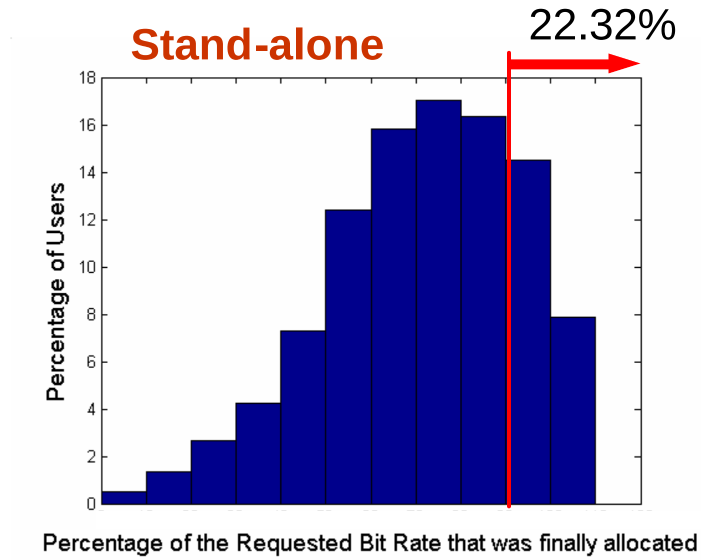
MIMO 4X4

PDF of Users (Relative) Allocated Rate

Satisfied users in airport interoperability scenario

HSDPA 2X2
Load=6Mbps/sector





Wireless World Research Forum (WWRF)

Lucent Technologies
Bell Labs Innovations

Major objectives:

- to develop and maintain a consistent vision of the Wireless World
- to generate, identify, and promote research areas and technical and society trends, including new technologies, for mobile and wireless systems towards a Wireless World
- to contribute to the definition of international and national research programs

Scope:

Web site: http://www.wireless-world-research.org

- concentrate on the definition of research items relevant to the future of mobile and wireless communications, including pre-regulatory impact assessments
- WWRF is not a standardization body
- Invites world-wide participation and is open to all players

6 working groups:

- WG1 - Business Models and End User Aspects
- WG2 - Service Platform Architectures
- WG3 - Heterogeneous networks (interworking)
- WG4 – New radio interfaces, relay based systems and smart antennas*
- WG5 – Short-range radio communication systems
- WG6 – Reconfigurability

* See, e.g. A. Alexiou and M. Haardt, ''Smart Antenna Technologies for Future Wireless Systems: Trends and Challenges,'' to appear, IEEE Communications Magazine.

Jointly Opportunistic Beamforming and Scheduling (JOBS) for downlink packet access

- Goal:

  To improve the QoS (throughput and delay)
  on the downlink of packet data systems
  (using multiple base station antennas)

- In doing so, stay as backward compatible to existing systems as possible, i.e.:
  - Single antenna terminals
  - Standard rate feedback per terminal
  - Minimal changes to the terminal, simple changes at the base
- Solution is based on original idea of opportunistic beamforming
- Submitted as contribution in WWRF's Working Group 4:

''Duplexing, Resource Allocation and Inter-cell Coordination-Design Recommendations for Next Generation Systems,'' WG4 White Paper.

Opportunistic Beamforming: background

Opportunistic Beamforming (OBF), proposed in 2002* amounts to replacing the BS antenna with multiple antennas, used as follows:

The BS generates a single beam that repetitively scans the cell/sector, progressing with a fixed angular step at the beginning of each timeslot

Main features:

- Simplicity and robustness
- Like OS, OBF requires the same small amount of uplink feedback.
- The beam generation algorithm runs independently of the scheduler
- Performance:

The standard OBF algorithm improves the system throughput, however it may still admit significant delays

*** P. Viswanath, D. Tse, R. Laroia, "Opportunistic Beamforming using Dumb Antennas", *IEEE Trans. Inf. Theory*, June 2002.**

JOBS*: an improved OBF algorithm

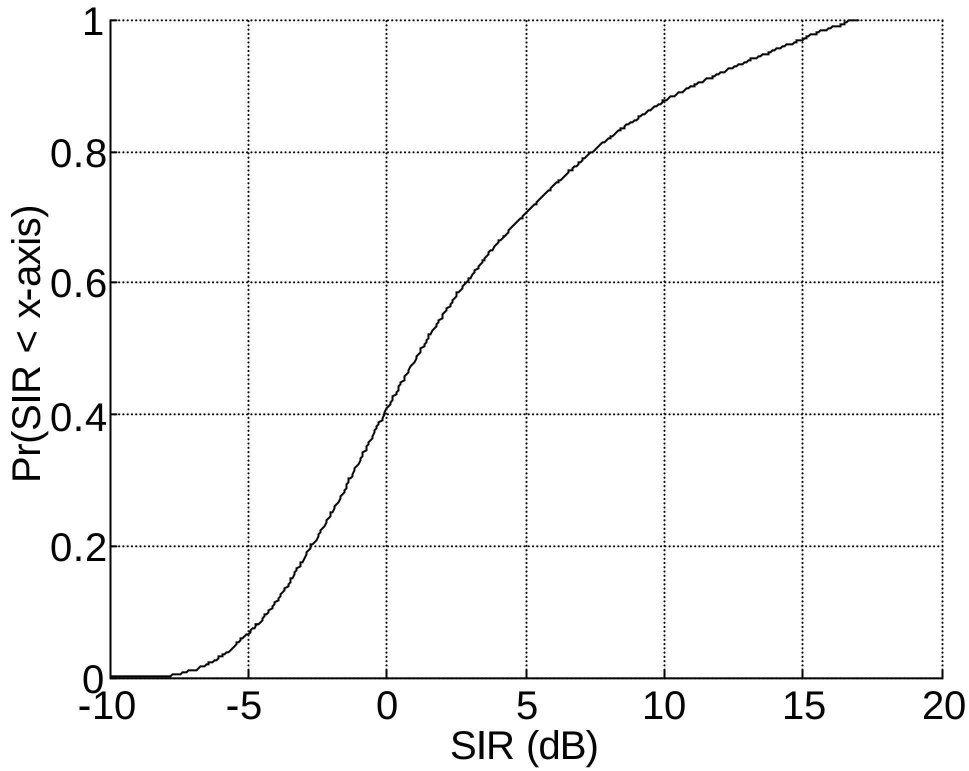
We propose a novel OBF scheduler that combines the PF algorithm with a simple "beam generating" algorithm that attempts to adjust priorities based on waiting times.

- The PF algorithm runs as is for scheduling
- The key idea is ***to point the beam toward mobiles "waiting longer," thus improving the delay outage statistics***

D. Avidor, J. Ling, C. Papadias, ''Jointly Opportunisitic Beamforming and Scheduling for Downlink Packet Access,''** ***International Conference on Communications (ICC-2004), **Paris, France, June 20-24, 2004.**

System-level simulation

CDF of SNR over 120deg. sector



Random mobile locations

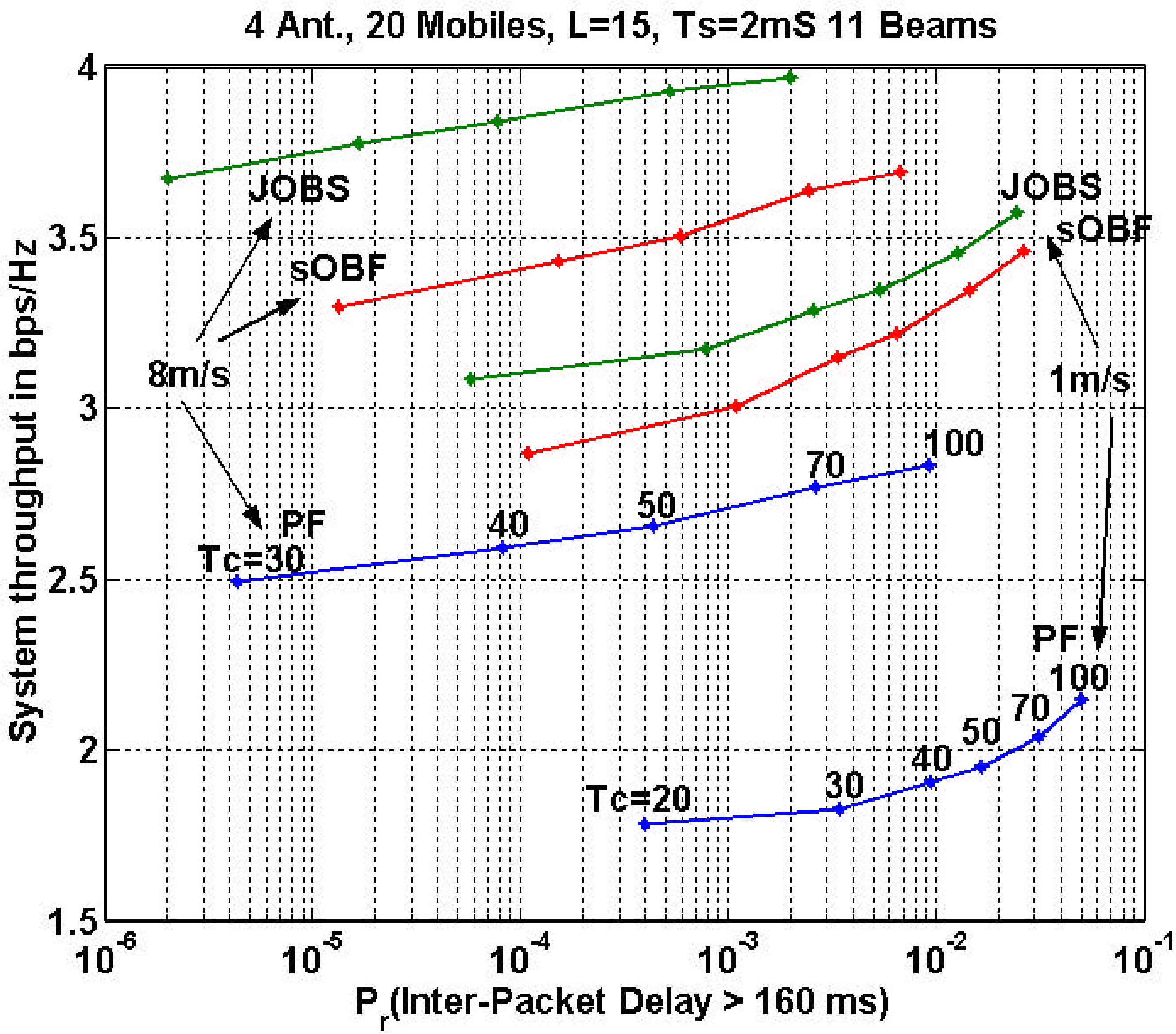
2 rings of interfering cells

Base transmits continuously

Distance dependent pathloss exponent 3.5, lognormal shadowfade 8 dB

Thermal noise neglected

System Throughput vs. Delay Outage



Wireless world INitiative NEw Radio: WINNER

The prime air interface Integrated Project of FP6

Partners:

Manufacturers: Siemens AG *Co-ordinator* (Germany), Alcatel SEL AG (Germany), Elektrobit Ltd (Finland), Ericsson AB (Sweden), Ericsson Eurolab Deutschland GmbH (Germany), Fujitsu Laboratories of Europe Ltd (UK), Lucent Technologies Network Systems UK Ltd (UK), Motorola S.A.S. (France), Nokia Corporation (Finland), Philips Electronics UK Limited (UK), Samsung Electronics UK Ltd (UK), Siemens Mobile Communications SPA (Italy), Siemens Aktiengesellschaft Österreich (Austria), Nokia (China) Investment Co., Ltd. (PR China)
Network operators: DoCoMo Communications Laboratories Europe GmbH (Germany), European Institute for Research and Strategic Studies in Telecommunications GmbH (Germany), France Telecom S.A. (France), Portugal Telecom Inovação S.A. (Portugal), Telefónica Investigación y Desarrollo Sociedad Anónima Unipersonal (Spain), Vodafone Group Services Ltd (UK)
Universities: Aalborg University (Denmark), Carleton University (Canada), Chalmers University of Technology (Sweden), Helsinki University of Technology (Finland), Kungl Tekniska Högskolan (Royal Institute of Technology) – KTH (Sweden), National Technical University of Athens (Greece), Poznan University of Technology (Poland), Rheinisch-Westfaelische Technische Hochschule Aachen (Germany), Swiss Federal Institute of Technology Zurich (Switzerland), Technische Universität Dresden (Germany), Technische Universität Ilmenau (Germany), University of Oulu-CWC(Finland),The University of Surrey (UK)
Research Centers: Centre Technològic de Telecomunicacions de Catalunya (Spain), China Academy of Telecommunication Research (PR China), Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany), Technical Research Centre of Finland VTT (Finland)

Task 2.5: “Advanced (Multi) Antenna Concepts for Future Broadband Radio Interface”

T2.5 Advanced Multi-Antenna Concepts

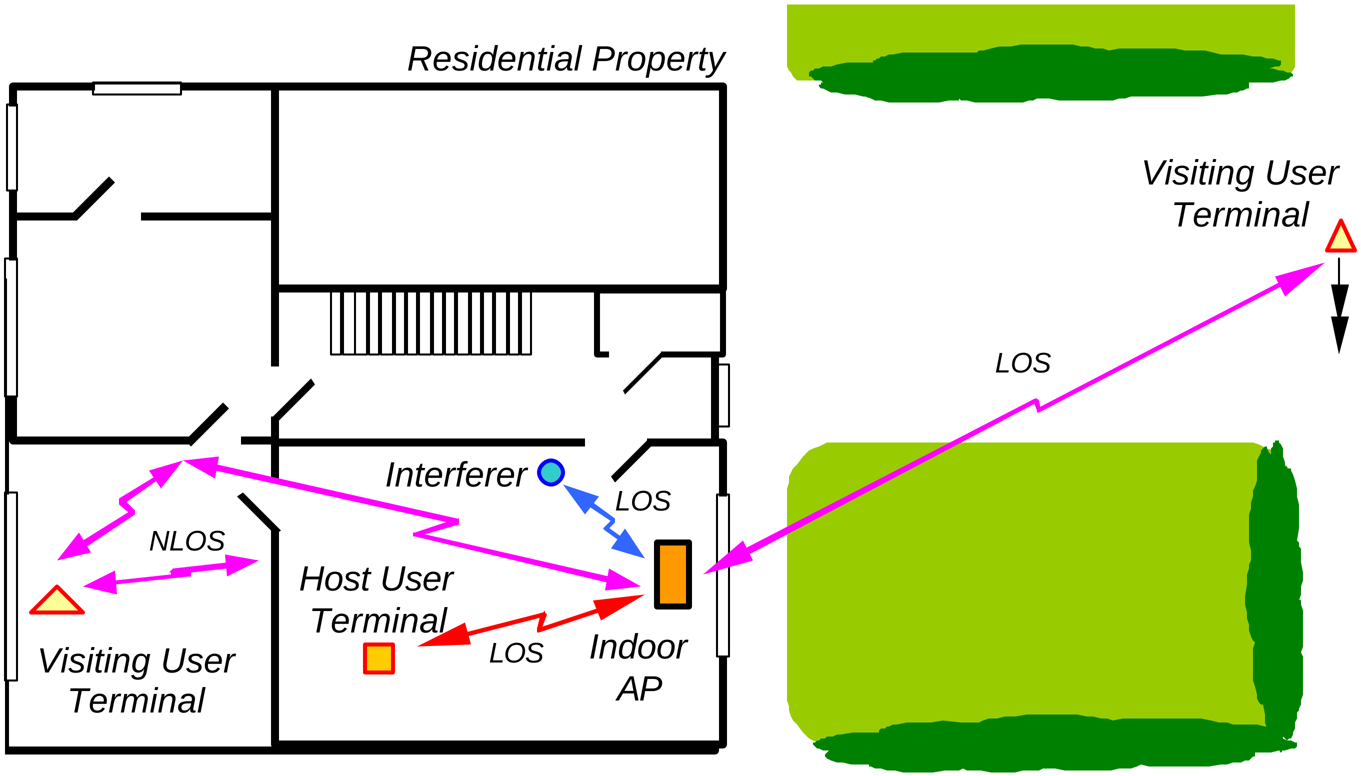
- Scenarios and Network Topology
- Duplexing Scheme
- Basic Transmission Scheme
- Mobility and Degree of Channel Knowledge
- SIMO/MISO/MIMO Signal Processing
- Single- vs. Multi-User Signal Design
- Optimization Criteria and/or Overall Goal
- Supporting Functions for Link Adaptation
- RRM and MAC/DLC Protocol Issues
- Multi-user MIMO information theory
- Link and system level simulation methodology (lead by Lucent)

Multiple Antenna Techniques for Open Broadband Access Networks (OBAN)

- An FP6 Specific Targeted Research Project (STREP)
- Objectives:
  - Privately-owned WLANs and broadband access lines are made available for public use. The owners (hosts) continue to use their WLANs as usual, while casual passing users (visitors) are also allowed access to the wireless access points
  - Visitors and hosts share the capacity of wireless LANs and access lines according to a general service agreement between users and the network operator
- Logistics: 14 partners, 3 years, started In Jan 2004
- Web site: www.ist-oban.org

Typical OBAN (residential) scenario

Lucent Technologies
Bell Labs Innovations



Regular residential WLAN system:

- **Indoor AP, User Terminal and Interferer are privately owned**
- **Co-existence is a local problem**

OBAN system:

- **Private indoor AP becomes OBAN AP**
- **Co-existence is a common problem**

OBAN work packages

WP1 – Scenarios & Requirements (16 MM).

WP2 – Open Access Environment Architecture (241 MM).
Mobility, QoS, Security, OAN Architecture, Terminals.
(Lucent is WP Leader)

WP3 – Prototyping & Integration (262 MM).
Residential gateway, Terminal, Personal QoS Profile Server, Interoperability, Service Demos.
(Lucent is is contributor)

WP4 – Network Coverage (142 MM).
Radio Performance & Coverage, Adaptive Coding-Modulation, Antenna Technologies.
(Bell Labs Wireless Research is contributor)

WP5 – Society Aspects (46 MM).
Market Impacts, Business Models, Charging Models, Techno-Economic Evaluation.

WP6 – Dissemination of Results (62 MM).

Antenna Centre of Excellence (ACE)

- An FP6 Network of Excellence (NoE)
- Consortium:
  - 9 Industrial (IDS, Lucent, Alcatel, France Telecom, Thales, Ericsson, SAAB Ericsson, BAE Systems, Antenna Systems Consulting)
  - 9 Research Centres
  - 27 Universities
- Effort
  - 846 person-months over 2 years (JAN04-DEC05)
  - 266 Researchers, 96 PhD Students
- Total budget 5.4MEuro

Lucent's role in ACE

- Lead the Smart Antenna research activities by being responsible for the technical management
- Research focusing on:
  - Reconfigurable Transceivers and Jointly Optimized MIMO
  - Requirements for Multi-antenna Terminals
  - System Level Reconfigurability Strategies and Cross Layer Optimisation
  - Context Aware Network Optimisation
  - Smart Antenna Deployment and Business Modelling Issues
- Members of the ACE Steering Committee responsible for the network management and the technical decisions