Architektur von Point-to-Multipoint Systemen

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- **Drahtlose Anschlußnetze mit PMP Architektur**
- **Vielfach-Zugriffsverfahren, Kanaleigenschaften**
- **Adaptive Modulation**
- **Statistischer Multiplexgewinn**

The Digital Point-to-Multipoint System

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Access Networks Overview

Driving Forces

Integration of speech and data
De-regulation of markets
Frequency allocation in Europe

Services

Burst data traffic (TCP/IP, ATM)
Circuit switched traffic (ISDN, PSTN)
Broadband services (e.g. video-on-demand)

Competing Technologies for the *Last Mile*

Wireless microwave point-to-multipoint (25 Mbit/s)
Copper lines ADSL (8/0.8 Mbit/s), HDSL (2 Mbit/s), SDSL, VDSL
Cable modems
GSM (HSCSD, GPRS), UMTS (2 Mbit/s)
Satellite systems
Powerline communication

BRAN HiperAccess Main Features

General

- interoperable standard
- address residential and business markets
- support of various services and applications, provide managed QoS
- PMP technology, cellular/sectorized coverage
- TDM/TDMA as multiple access scheme
- harmonization with IEEE 802.16

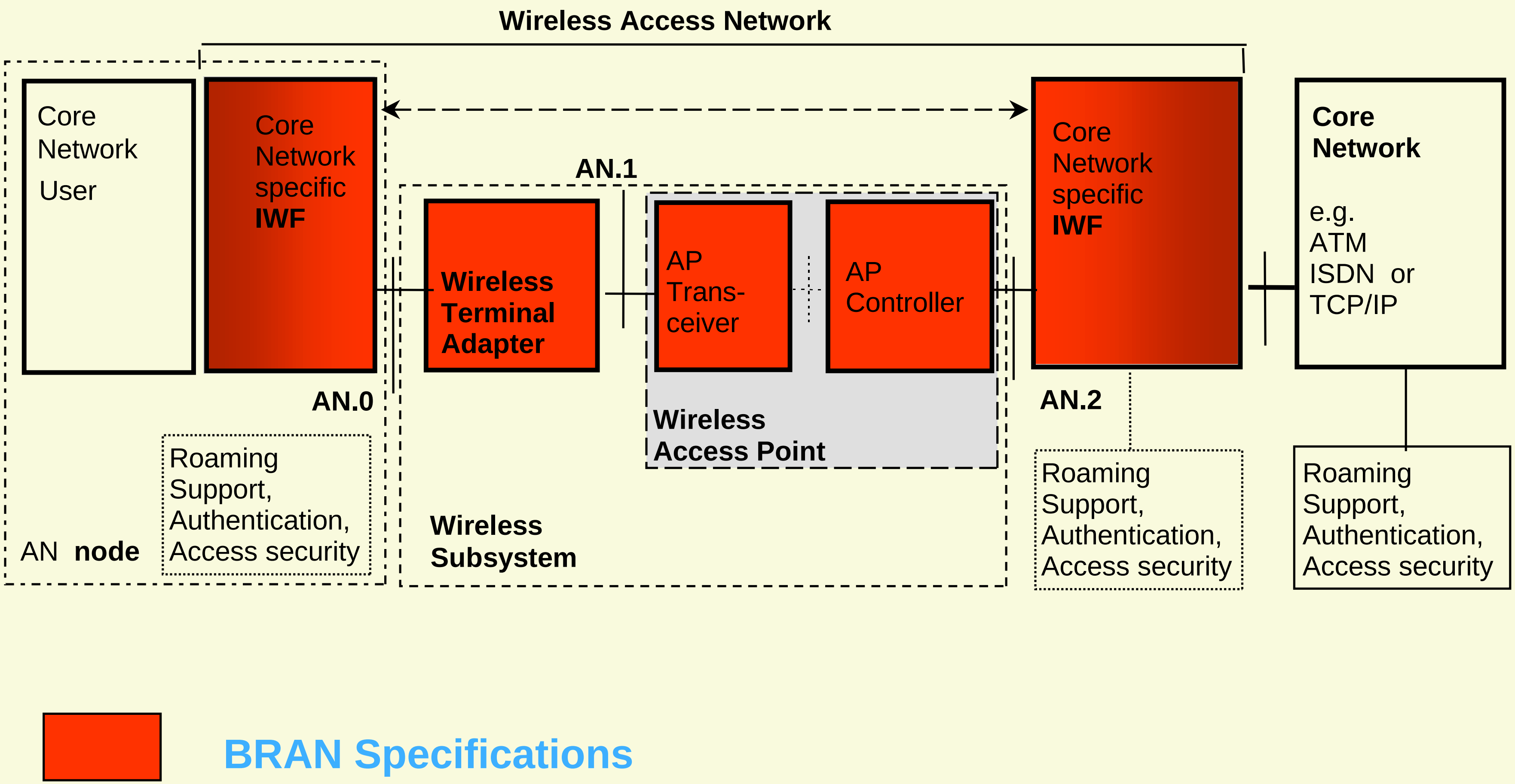
PHY layer

- operate in different frequency bands (e.g. 26, 32, 42 GHz)
- channelization mainly 28 MHz, duplexing FDD and H-FDD
- range 2...5km
- data rates up to 25 Mbit/s
- adaptive modulation: 4QAM to 64QAM
- adaptive antennas in base station for uplink as on option (tbd)

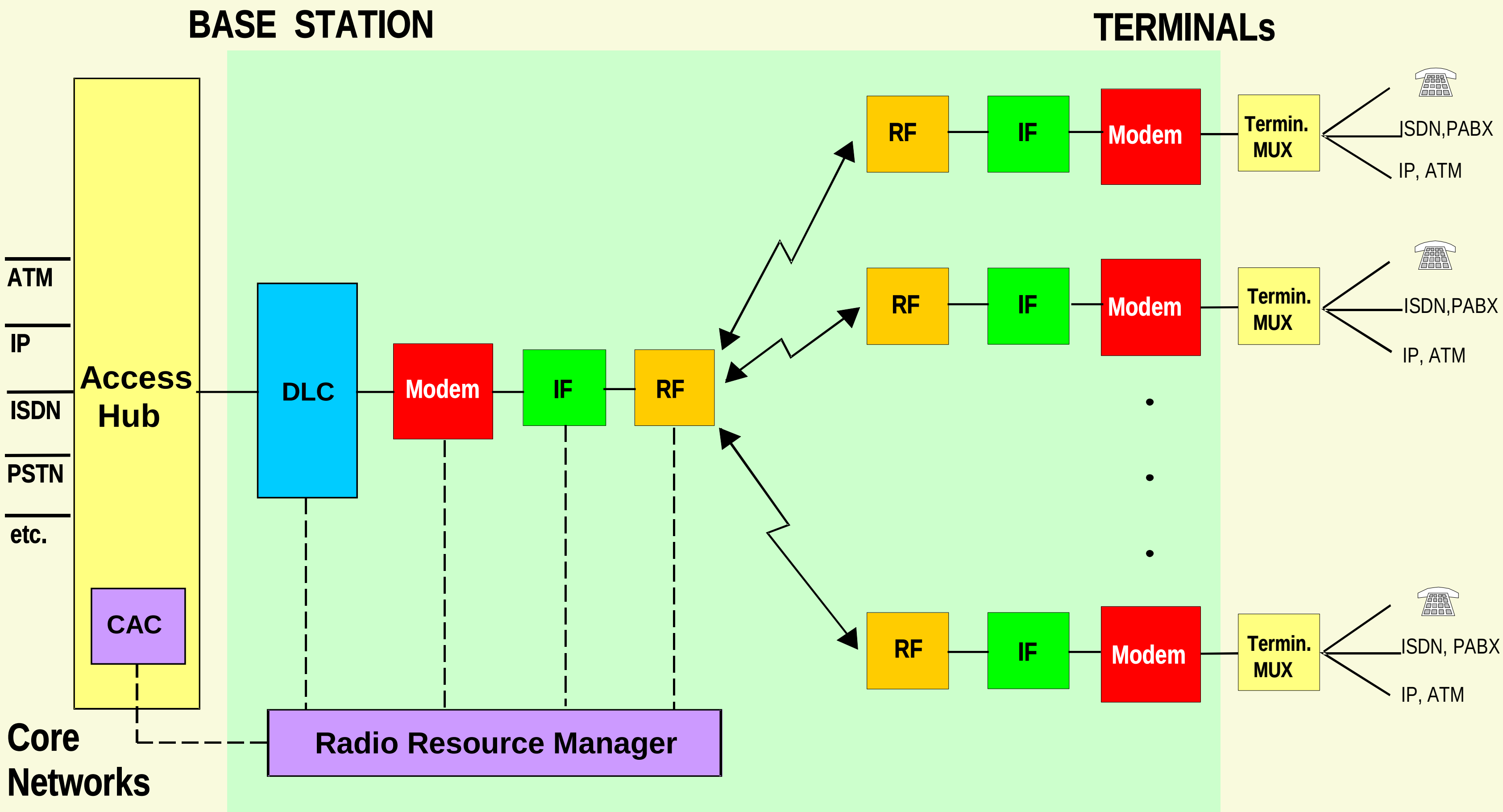
DLC layer

- fixed packet length
- tbd: traffic model, #terminals per carrier, #connections per terminal, frame structure, contention/polling, primary access, etc.

Reference Model in BRAN



Point-to-Multipoint (PMP) Architecture



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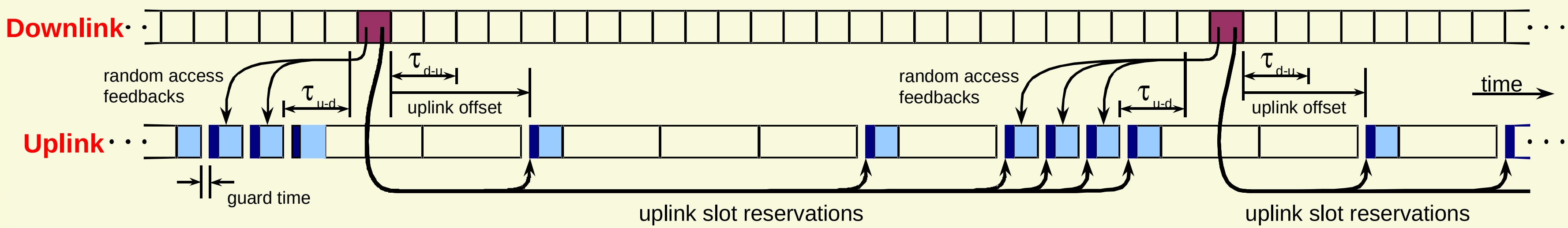
Medium Access Protocol (MAC) Example



downlink PDUs
- ATM cell
- Period-Control-PDU

uplink LLC PDUs
- MAC header
- ATM cell
- uplink capacity request

uplink MAC PDUs (bursts)
- 1 ATM cell in reserved slot
- 2 ATM cells in reserved slot
- capacity request in poll slot or random access

$\tau_{u\text{-}d}$ [$\tau_{d\text{-}u}$] processing delay for uplink bursts [downlink PDUs] in sender and receiver + propagation delay

τ_{offset} delay from end of Period-Control-PDU to start of first reserved uplink slot

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Comparison of Multiple Access Schemes

Criterium	FDMA	TDMA	async.CDMA	sync.CDMA	OFDMA
Suitable for burst data, variable bit rate, high stat. multiplex gain	burst data not possible, variable bit rate delayed	packet and slots could be associated	most suitable for voice applications or CBR services		
High data rates			requires broad bands		
Low data rates	sync difficult		best performance, but graceful degradation undesired		requires many subcarriers
Symbol delay	frame relevant				frame relevant
Flexible bandwidth per sector	use part of channel				use only some subcarriers
Spectrum efficiency			inefficient, even for reuse 1		
Reference system gain, frequency reuse			system must be designed for full data rates: no Rx sensitivity benefit		backoff
Robustness to channel impairments (ISI), but not a major problem due to LOS	depends on subcarrier size	more sensitive			
Robustness to interference			reuse 1 possible		
Terminal transmit power required		high, even for low data rates			
Implementation			backoff, UL power control synchronization		orthog. loss, high backoff
Maturity					acad. research

Legend: excellent | fair | poor

TDM/TDMA is the best compromise

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Characteristics of Main Frequency Ranges

Criterion	low frequencies (e.g. 3.5 GHz)	high frequencies (e.g. 26, 32, 42 GHz)
Spectrum availability	already occupied	about 2 GHz will be available
Radio channel characteristics • ISI • rain fading	 ISI possible no rain fading	 ISI usually negligible severe rain fading (depending on distance and availability)
Cell radius	large (e.g. 10...15 km)	small (e.g. 2...5 km)
Costs of feeder network	low (adapt to user density)	high
Costs of customer premises equipment (CPE)	low	high (frequency genera-tion, power amplifier)

Calculation of Required Transmit Power

$$P_{TX} = a_{pathloss} + P_{noise} - G_{TX\_antenna} - G_{RX\_antenna} + a_{rain} + offset + \frac{C}{N+I}$$

- $a_{pathloss} = 10 \cdot \log_{10}\left(\frac{4\pi f_c}{c} \cdot d\right)^2$ **[dB] = line-of-sight path loss,**
  f_c **= carrier frequency,** c **= velocity of light,** d **= distance.**

- a_{rain} **= rain fading (depending on availability, rain zone, frequency)**

- $P_{noise} = F \cdot N_{thermal} = F \cdot KT \cdot B$ **= noise power at receiver input,**
  F **= receiver noise figure,** K **= Boltzman constant,**
  T **= temperature,** B **= bandwidth.**

- ***C/(N+I)*** **depending on modulation and coding and required BER**

- ***G*** **= antenna gains. Typical values @ 26 GHz (+4 dBi @ 42 GHz):**
  G_{BS} **= 17 dBi (8 sectors)**
  G_{TS} **= 28 dBi (planar), 35...41 dBi (30...60 cm parabolic)**

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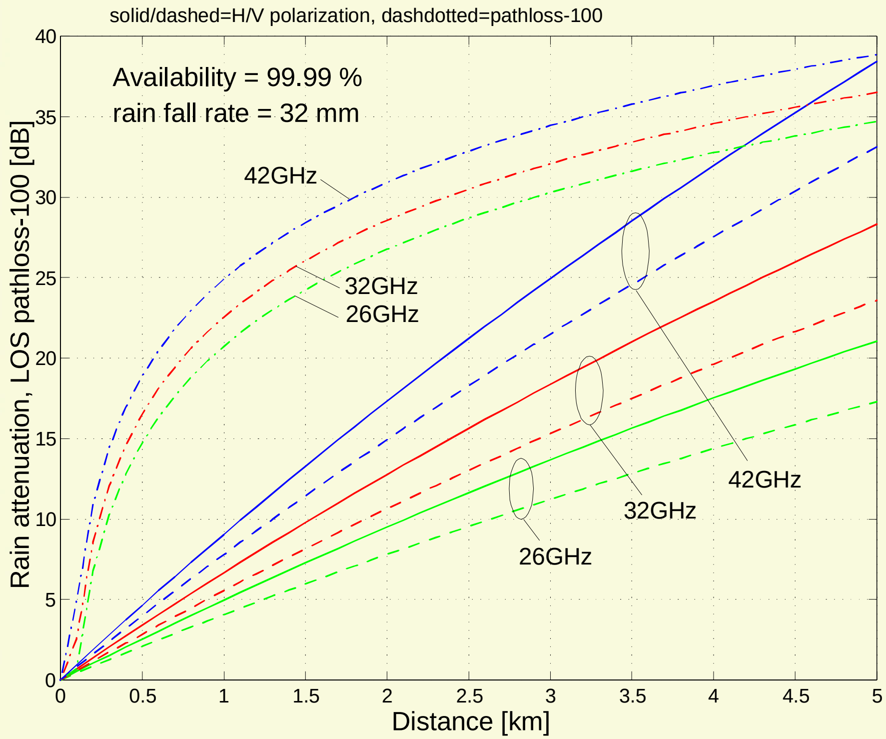
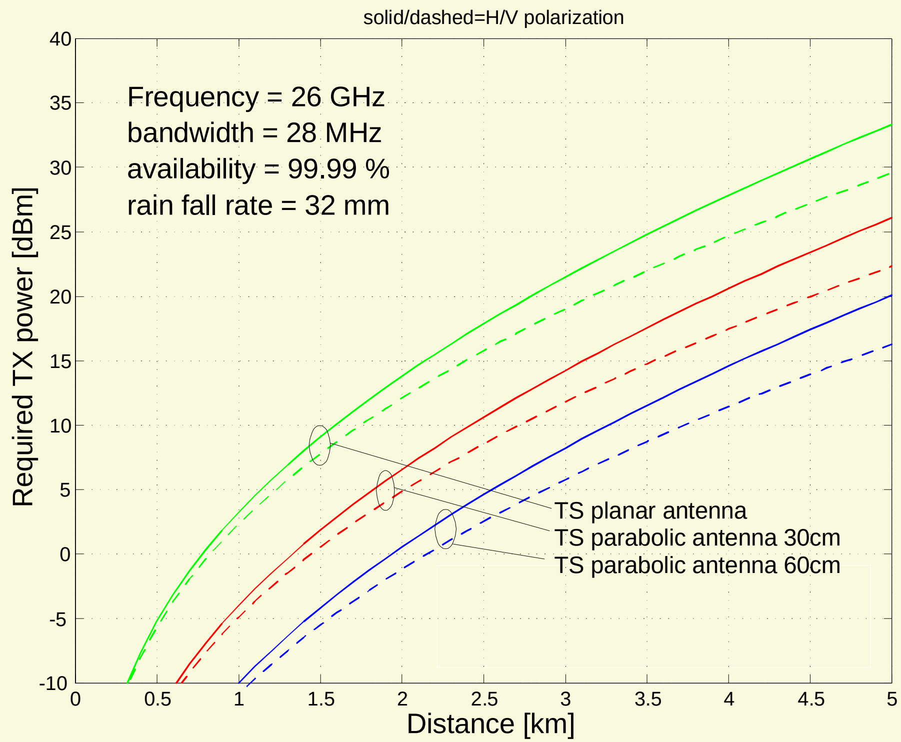
Rain Fading and Link Budget



Rain fading @ availability = 99.99%
and free-space pathloss
(depending on frequency range)



Required transmit power @ 26GHz
(depending on terminal antenna)

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Adaptive Modulation & Coding - Basics

Application

- Adaptation in downlink according to distance, rain fading (C/N) and interference (C/I)
- No adaptation in uplink (lower data rates, more sensitive to interferences, fast C/I-changes)
- 4QAM. . .64QAM; convol. and trellis coded modulation, RS codes

Adaptive modulation requires burst-mode
(e.g. one slot containes one ATM cell)

- TDMA/TDMA instead of TDM/TDMA
- Limited performance of coding (no interleaving, short block codes)
- Each slot requires extra overhead for synchronization

Compare adaptive modulation under real system conditions with best fixed modulation!

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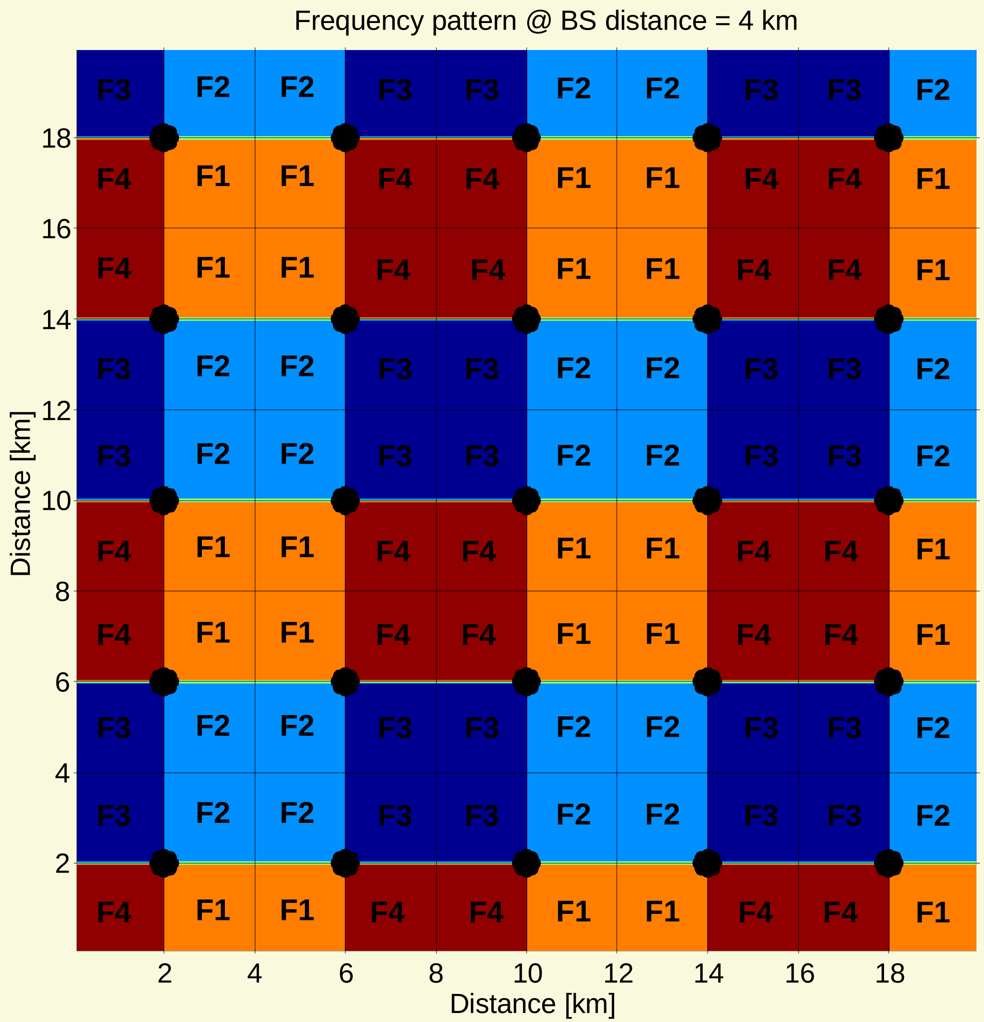
Frequency Plan for a Rectangular Constellation (25 cells, 100 sectors, Re-use Factor = 4)



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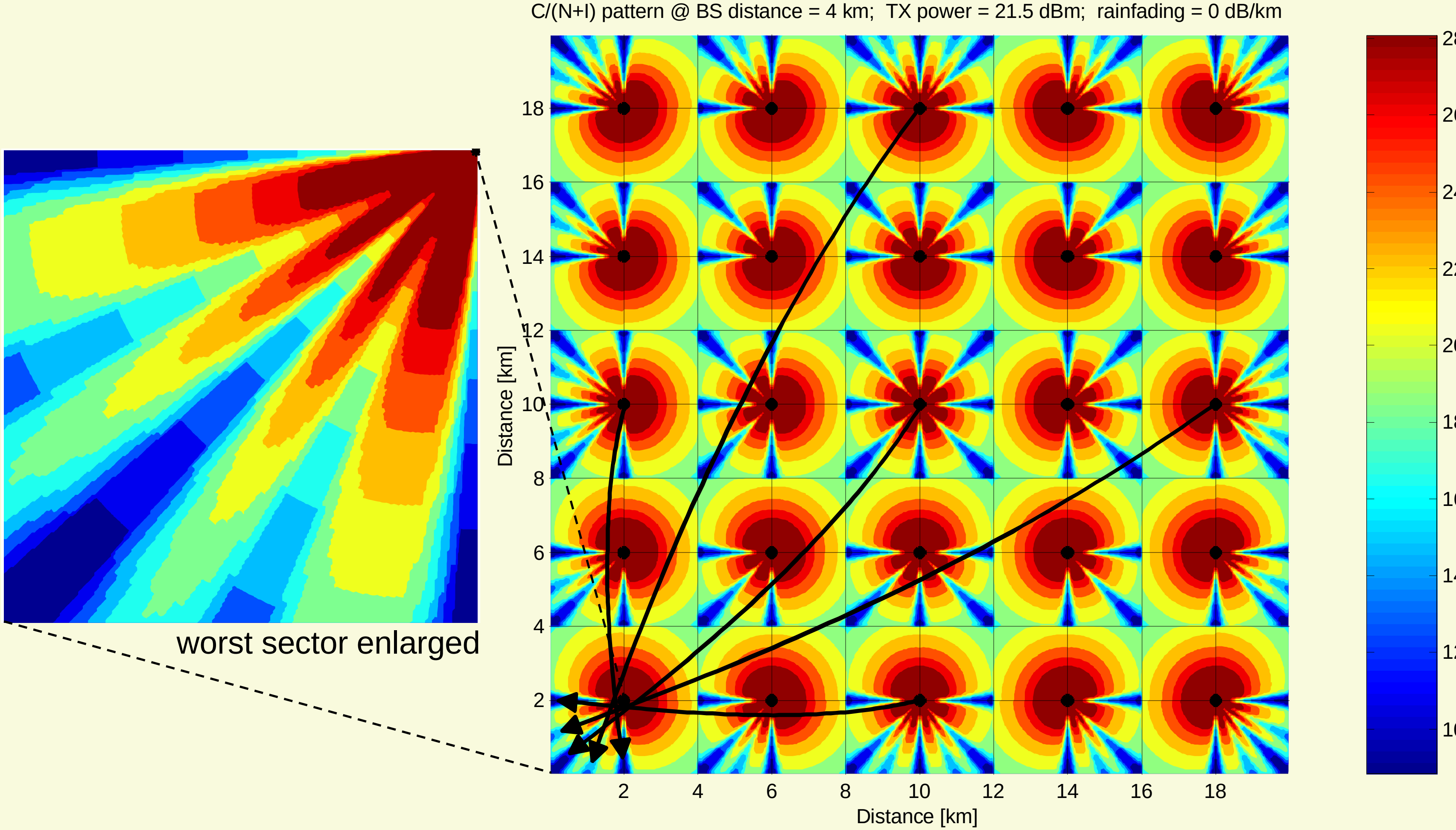
C/(N+I) Distribution in a 5x5 Rectangular Constellation (Re-use Factor = 4)



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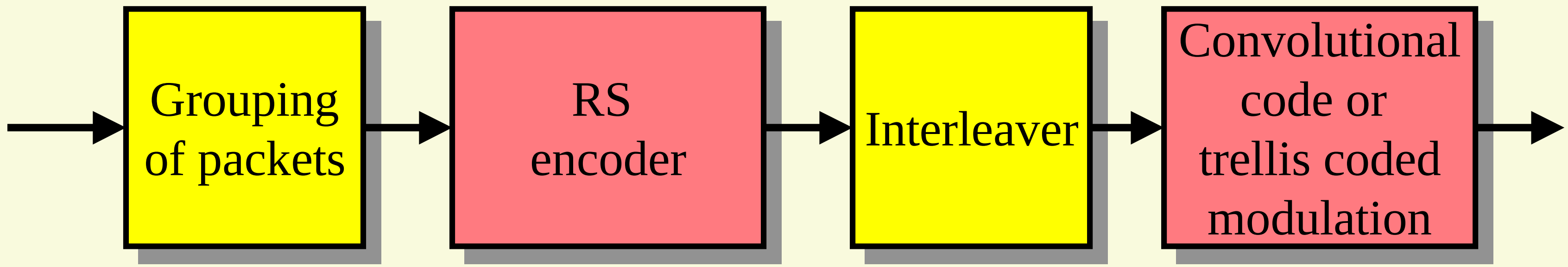
Concatenated Coding for Downlink / Uplink



Downlink	4 ATM-cells	RS(228,212), t=8	2...4 RS-blocks	R=1/2...3/4, QPSK...64QAM-TCM
Uplink	n/a	RS(69,53), t=8	n/a	R=1/2, QPSK

Adaptive Modulation&Coding - Candidates

Modulation and inner coding	Outer coding			
	long RS(228,212) interleaving		short RS(69,53) no interleaving (32 symb sync.)	
	C/N [dB]	Spec.Eff. [bit/symb]	C/N [dB]	Spec.Eff. [bit/symb]
QPSK, R=1/2	3.2	0.93	4.5	0.73
QPSK, R=2/3	4.8	1.24	6.1	0.95
QPSK, R=3/4	6.0	1.39	7.3	1.06
8PSK TCM	8.5	1.86	9.8	1.37
16PSK TCM	14.5	2.79	16.2	1.96
16QAM TCM	12.0	2.79	13.7	1.96
64QAM TCM	19.3	4.65	21.5	2.98

Spectral Efficiency with Adaptive Modulation (Re-use Factor = 4)

	Strategy				
	configurable modulation long RS code interleaving	adaptation terminal groups long RS code interleaving		adaptation slot-by-slot short RS code no interleaving	
	QPSK3/4 8PSK 16PSK	QPSK3/4 8PSK 16PSK	QPSK3/4 16QAM 64QAM	QPSK1/2 8PSK 16PSK	QPSK1/2 16QAM 64QAM
Clear sky					
• worst sector	1.86	2.41	2.86	1.73	1.86
• best sector	2.79	2.65	3.56	1.96	2.28
• average sector	2.01	2.57	3.27	1.89	2.12
Rain condition					
• worst=best sector	1.39	2.25	2.68	1.62	1.72

Spectral efficiency in bit/symbol

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Remarks on Spectral Efficiency Results

- The average spectral efficiency for configurable modulation is disappointing for constellations of 5x5 or larger due to many sectors with small critical areas, but better for smaller constellations.
- 64QAM is never applicable for configurable modulation, QPSK-8PSK-16PSK is better than QPSK-16QAM-64QAM.
- Adaptation of terminal groups requires extra overhead.
- All results for worst/best sectors apply also for larger constellations.
- All results depend on many parameters:
  - distance
  - link budget (TX power, rain fading, rain zone, frequency range)
  - re-use factor, cellular coverage
  - constellation size, particularly irregular constellations

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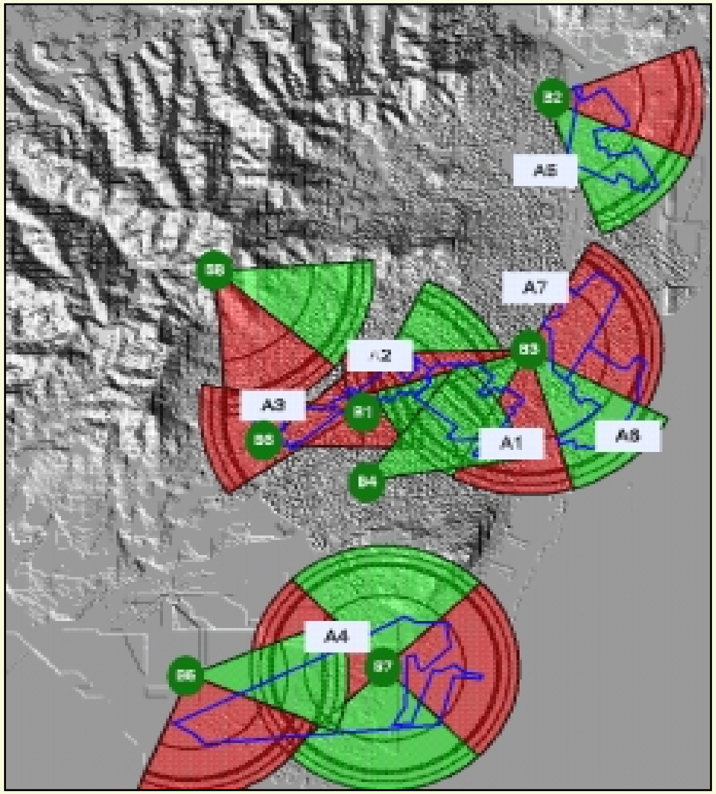
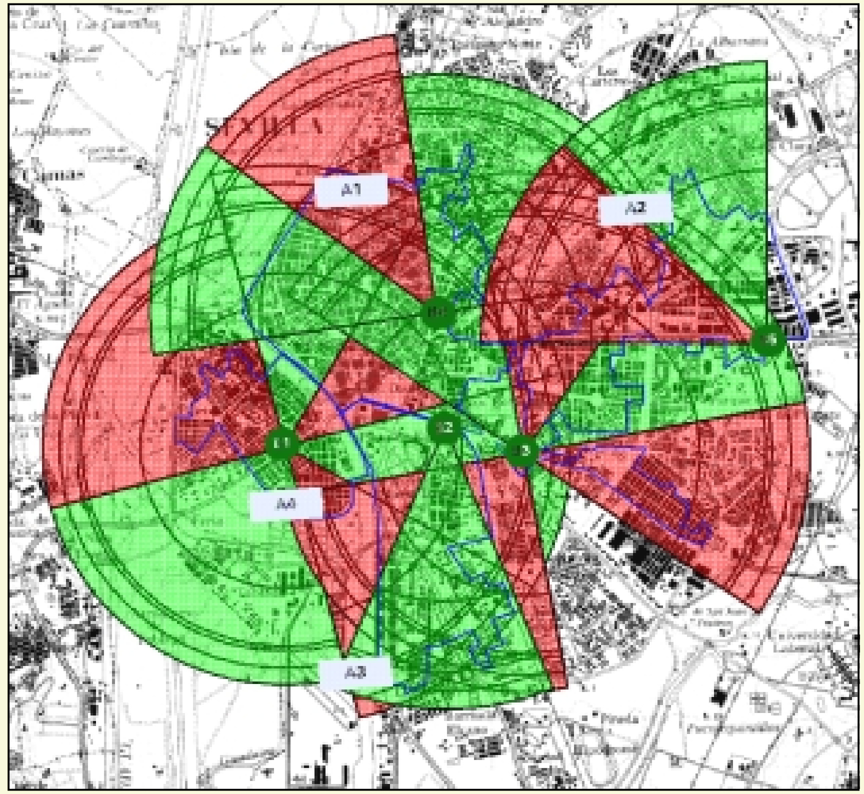
Coverage and Overlapping Sectors

Partly Overlapping Sectors



Decoupling by polarisation
LOS < 50 - 70 %
Reuse 100 %

Fully Overlapping Sectors



Decoupling by polarisation & frequency
LOS nearly 100 %
Reuse nearly 100 %

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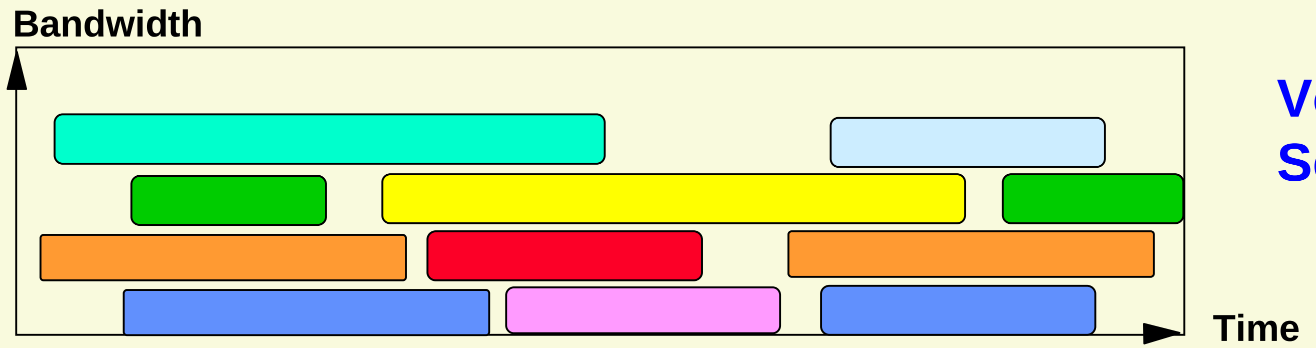
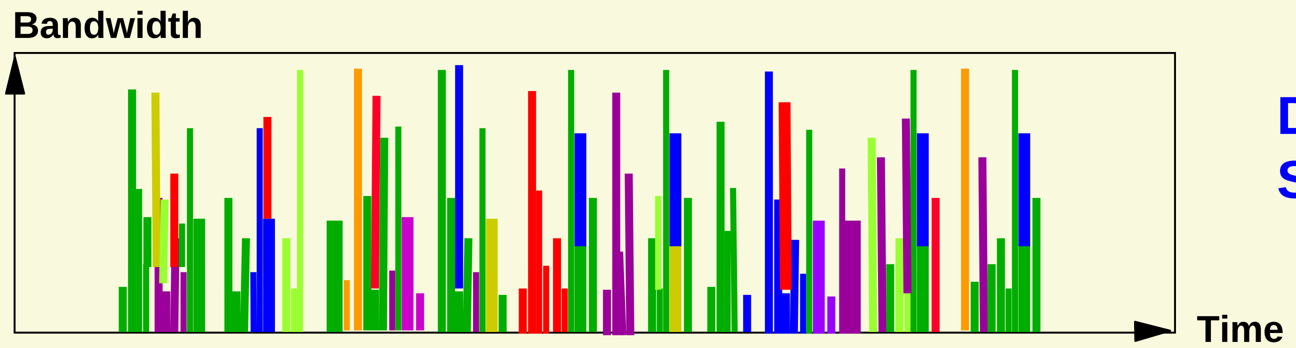
Voice- versus Data-Oriented Services



Voice-Oriented Services

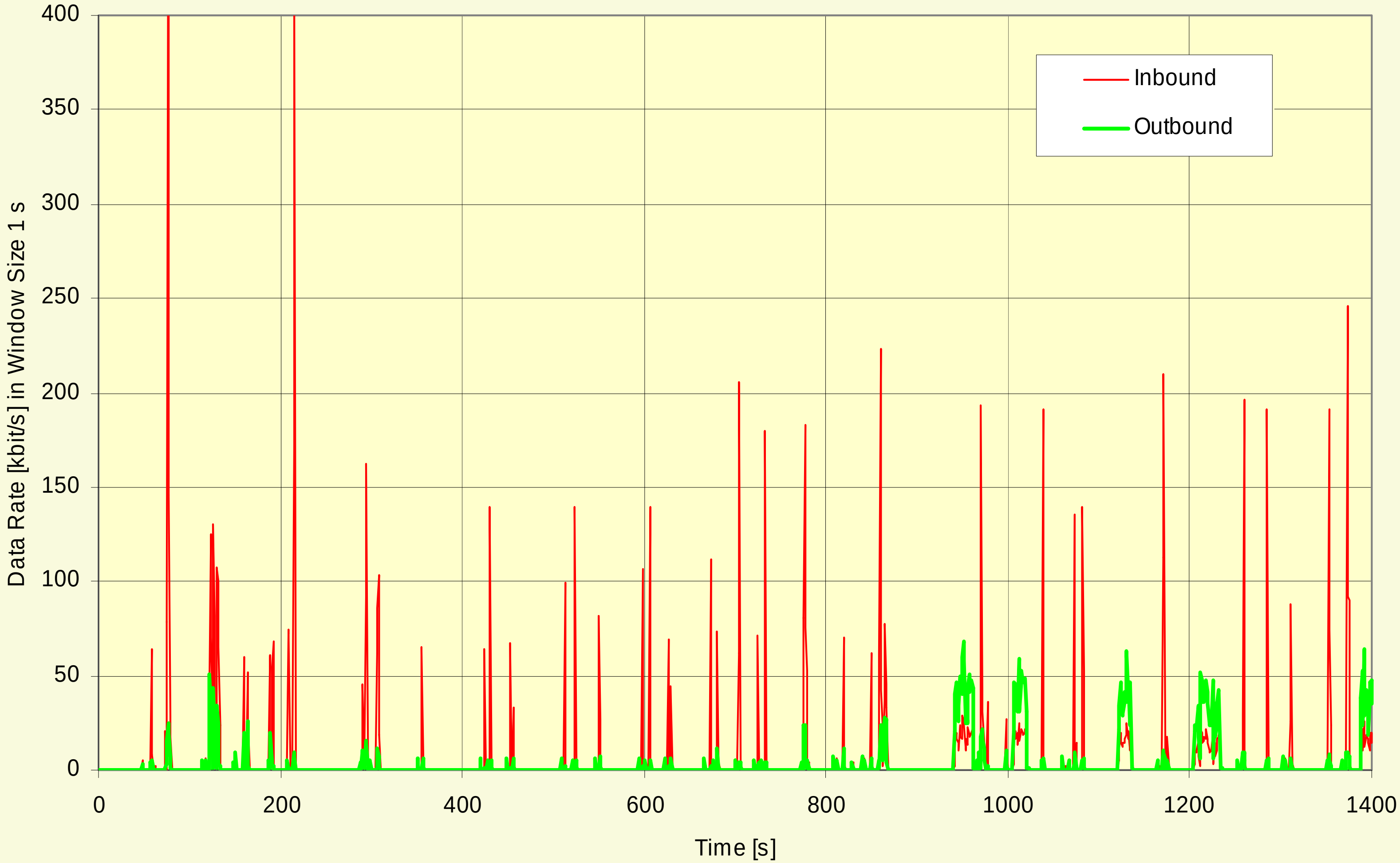
Traffic concentration on a per call/connection basis by dynamic channel allocation
Inherent QoS
Relatively low concentration factor (typically 1: 4...8)



Data-Oriented Services

Traffic concentration by statistical multiplexing
Concentration factor strongly related to required QoS (delay, traffic shaping)
High concentration factor for typical IP traffic (1: 20) given sufficient bandwidth

TCP/IP Internet Traffic Example



DL traffic [kbit/s], mean=7,47; max=568,1; sigma: 31,35
UL traffic [kbit/s], mean=3,43; max= 68,4; sigma: 10,35

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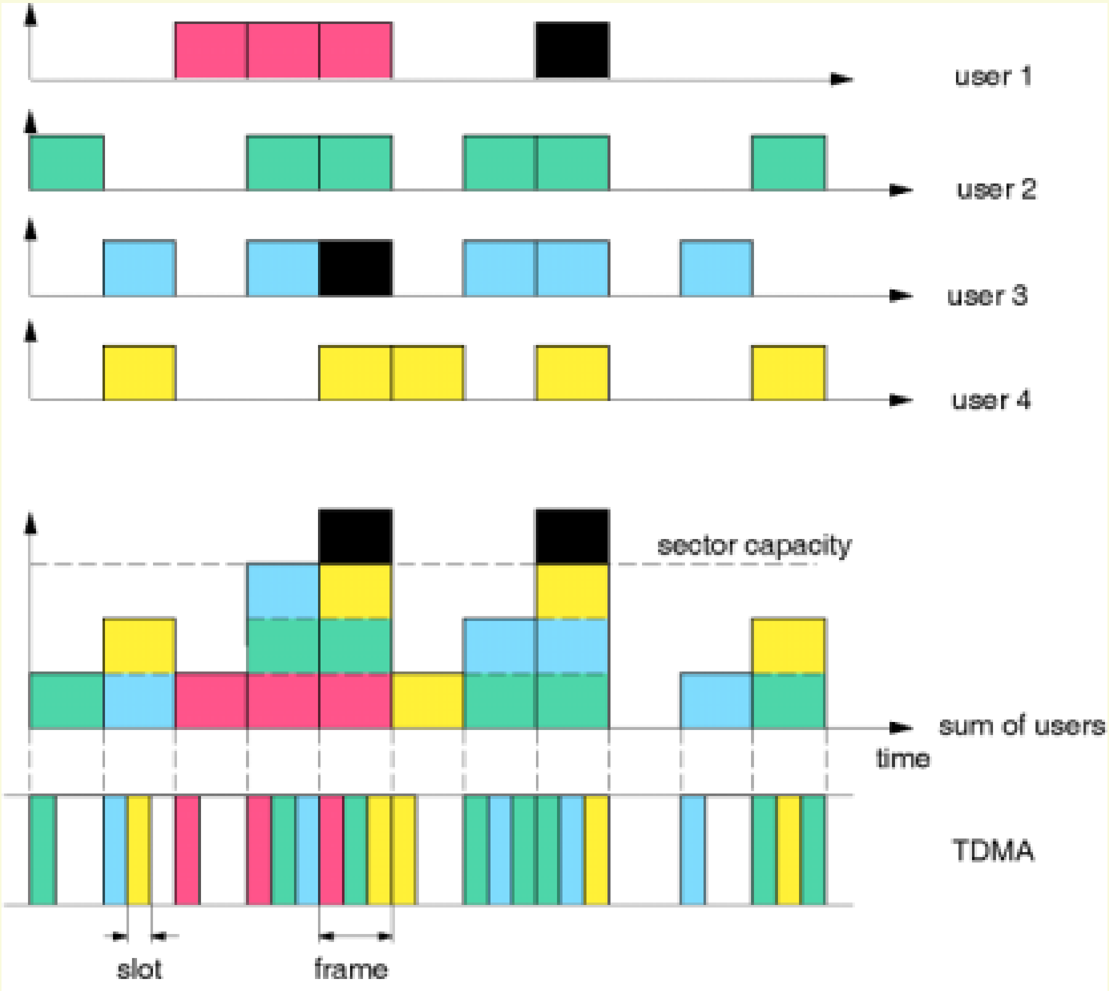
A Simple Traffic Model for Statistical Multiplex Gain Analysis



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Statistical Multiplex Gain - Fundamentals

A PMP system performs as a virtual multiplexer.

Let r_s = total sector rate, r_p = peak data rate per user, r_a = average data rate per user, $b = r_p / r_a$ = burstiness of the data source,

N_{eff} = # users with static collision free multiplex
N_{eff} = # user with statistical multiplex

The statistical multiplex gain G

$$G = \frac{N_{eff}}{N_{cf}} = \frac{\text{max \#users with statistical multiplex}}{\text{max \#users with static collision} - \text{free multiplex}}$$

$$= \frac{N_{eff} \cdot r_p}{r_s} = \frac{\text{required total sector rate with static collision} - \text{free multiplex}}{\text{required total sector rate with statistical multiplex}}$$

and the spectral utilization $U = G/b$ refer to the cell loss rate (CLR)

$$CLR = \frac{\text{average number of lost cells}}{\text{average total number of cells to be transmitted}}$$

$$= 1 - \frac{1}{r_a / r_s \cdot N_{eff}} \cdot \underset{k<N_{cf}}{} (k - N_{cf}) \cdot \binom{N_{eff}}{k} \cdot p^k (1-p)^{N_{eff}-k}.$$

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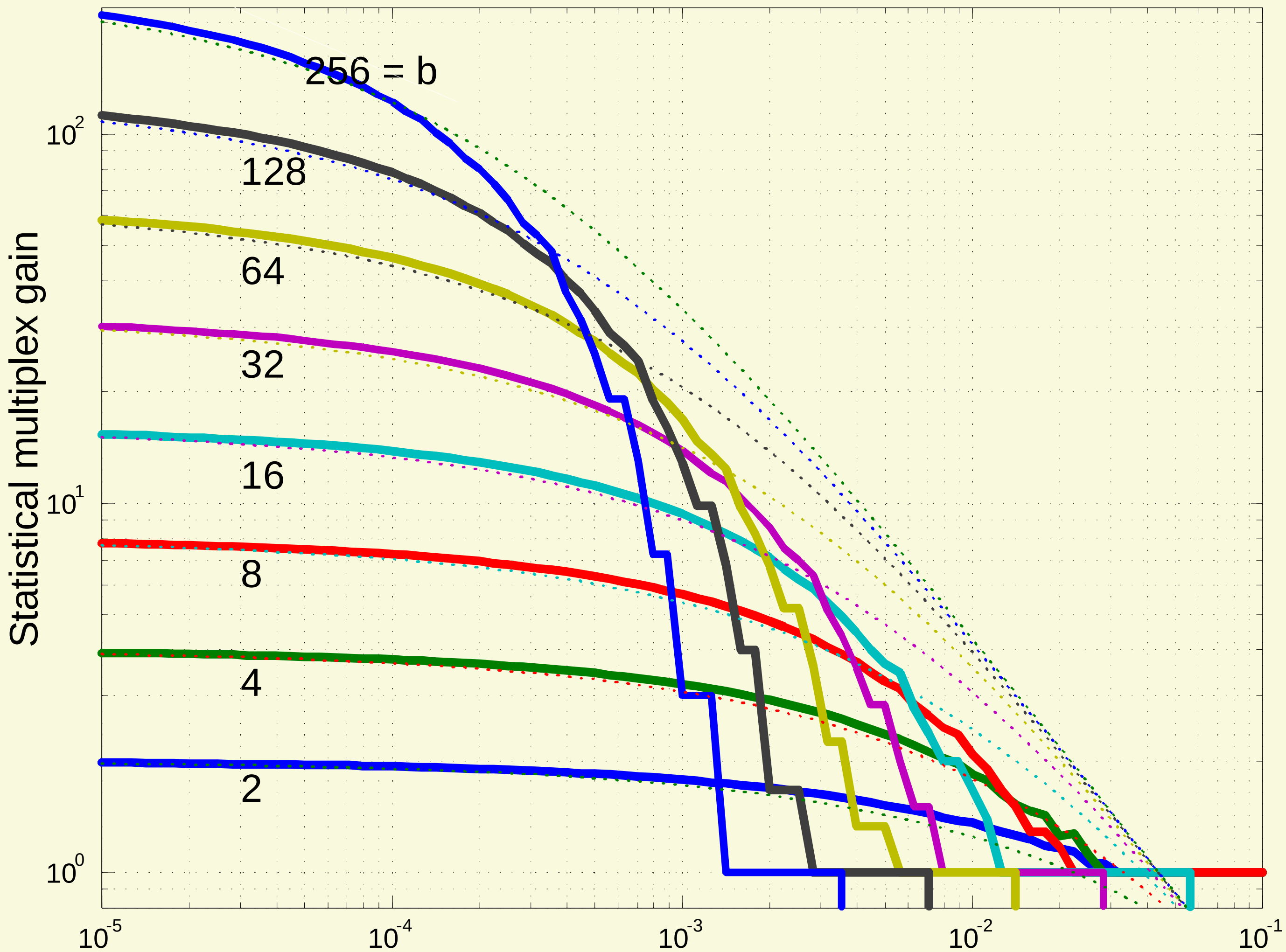
Statistical Multiplex Gain (CLR=10^{-6})



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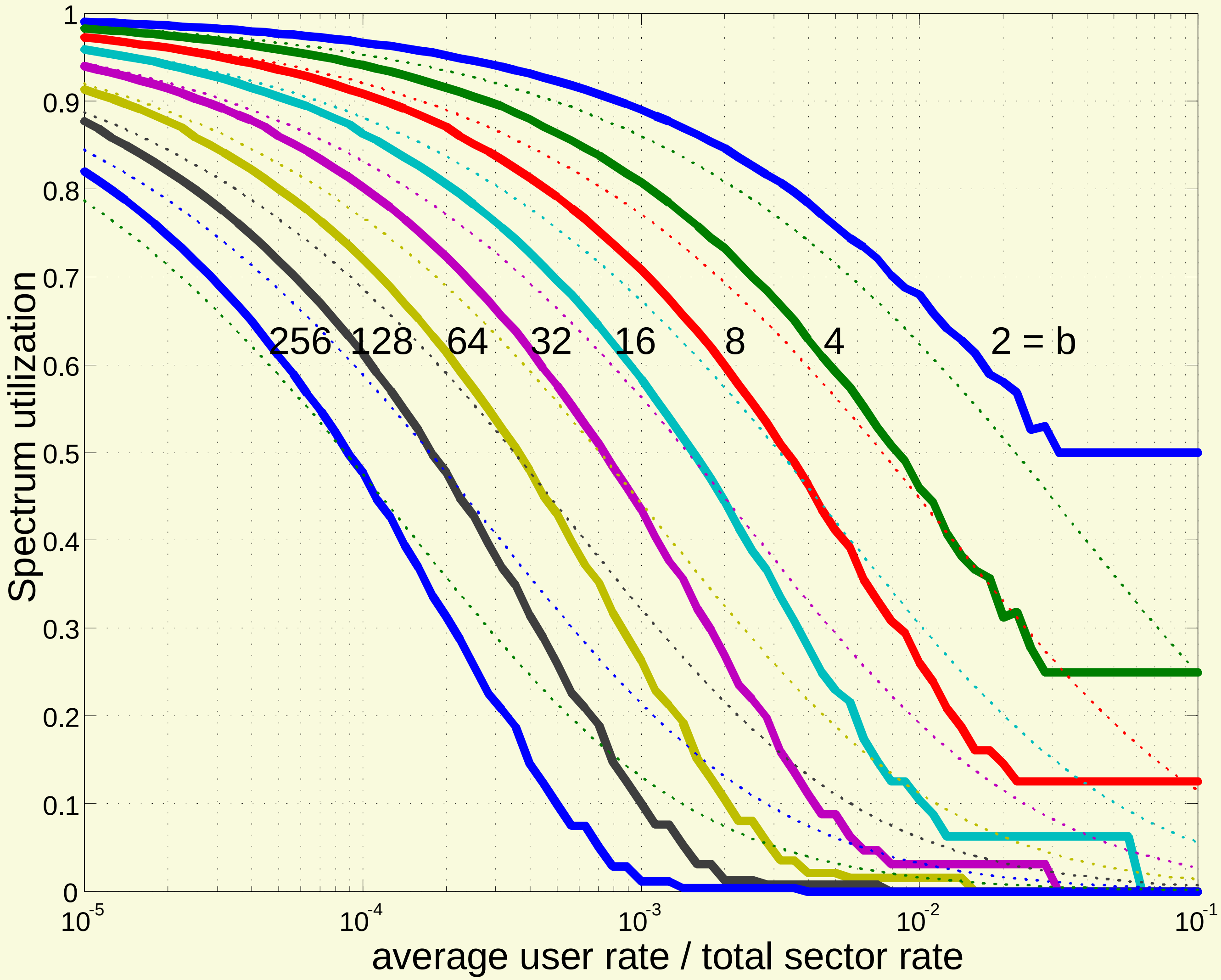
Spectrum Utilization (CLR=10^{-6})



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Conclusion on Reasonable Bandwidth

- **High multiplex gain or high spectrum utilization requires a high number of users, i.e. a high bandwidth per sector and large sectors in order to achieve high user densities per sector. However, both large bandwidth as well as wide range imply an increase of the required transmit power in case of pure TDMA.**

- **The difference between poor and excellent spectrum utilization is approximately a factor of 10 to 100, depending on the burstiness and the -value. Hence a doubling of the bandwidth per carrier has a certain but not overwhelming effect.**

A bandwidth of 28 MHz per TDM/TDMA carrier is a reasonable compromise.

Summary

The design of a flexible (wrt to services and deployment), spectral-efficient and cost-efficient wireless broadband PMP access network is a very complex optimization problem.

Key challenges for R&D include

- digital modem technology,
- multiple access schmes (PHY layer),
- medium access control (DLC layer),
- microwave and antenna technology,
- cell and frequency planning.

Field trials and first deployments prove the applicability.

We as Marconi Communications and as BRAN participants believe in the commercial success of HA.