Drahtlose breitbandige IP/ATM - gestützte Zugangsnetze; Stand bei ETSI BRAN HiperAccess

Bernd Friedrichs, Khaled Fazel

Marconi Communications GmbH
D-71522 Backnang

mailto:bernd.friedrichs@marconicomms.com

The Digital Point-to-Multipoint System

Bernd Friedrichs

Marconi

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

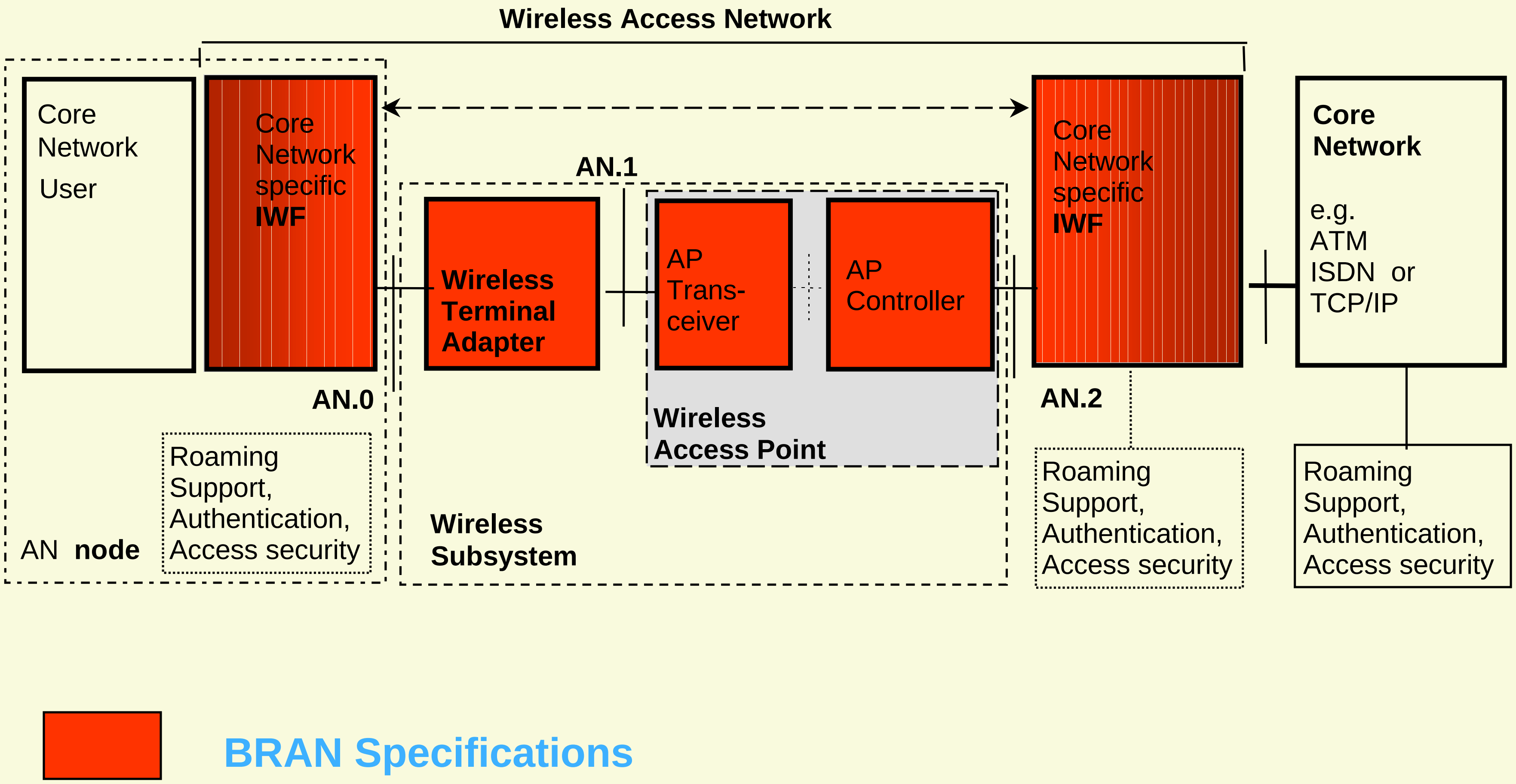
PHY layer

- 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)

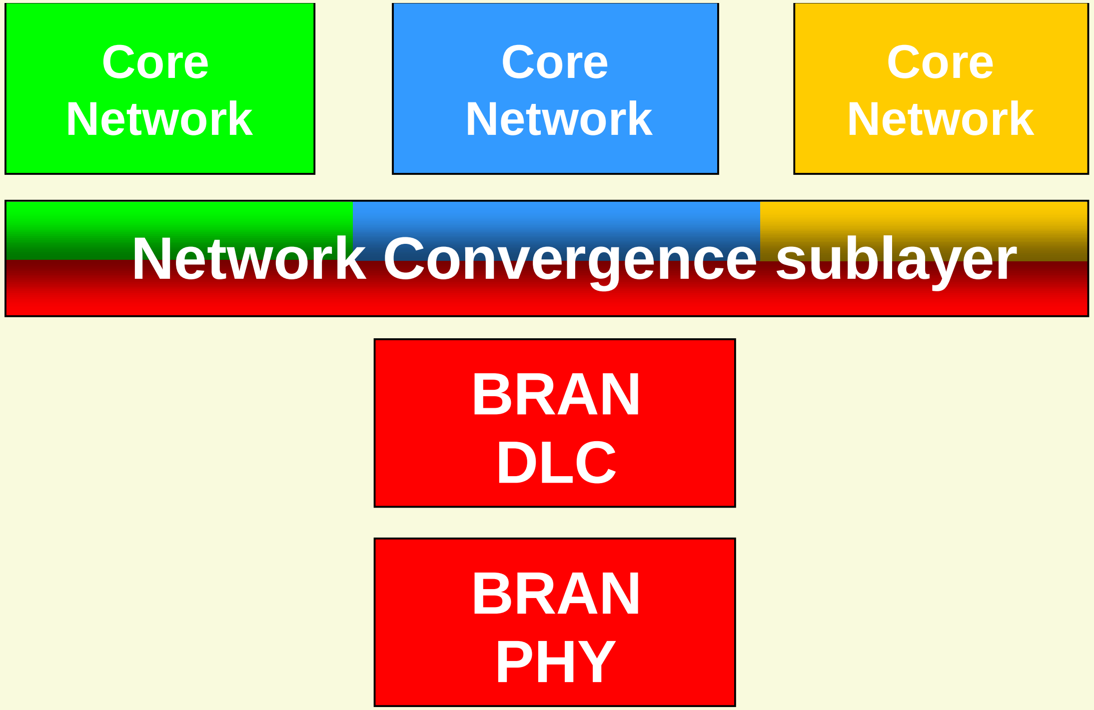
DLC layer

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

Reference Model in BRAN



Basic Interworking Approach in BRAN



Core Networks:
ATM, IP, ISDN, PSTN,...

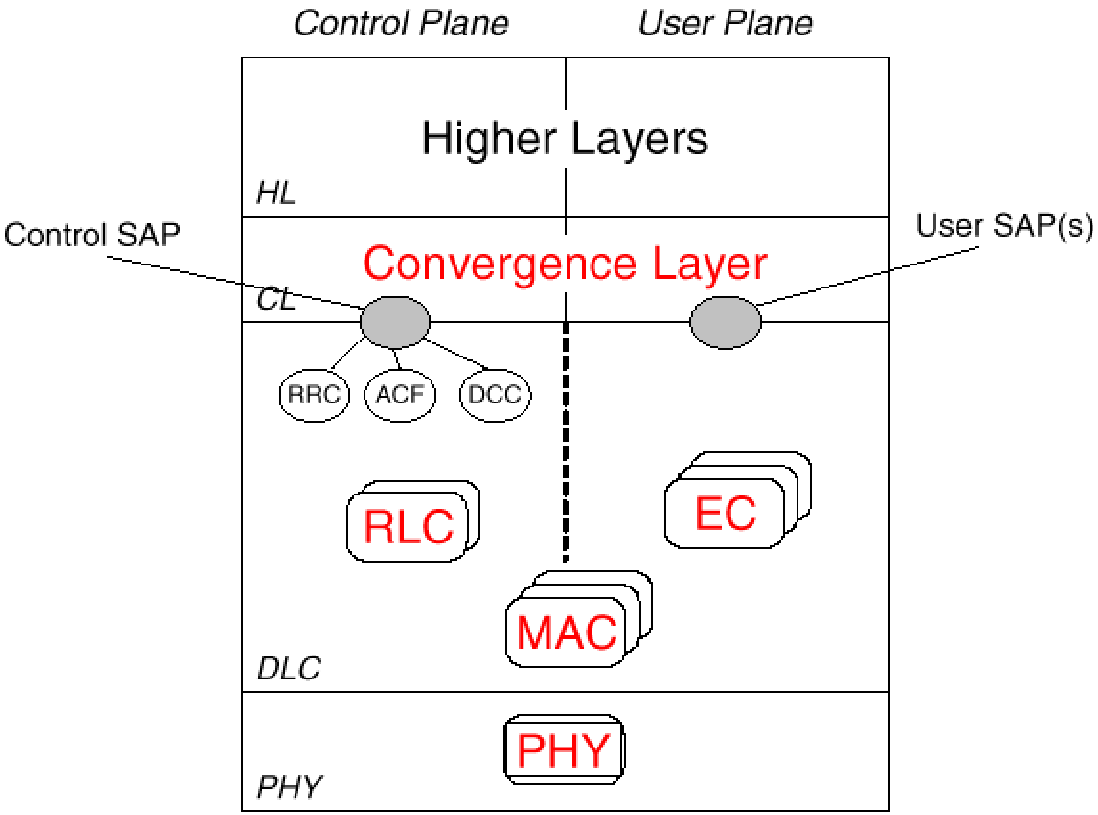
Removes differences between core networks, cooperate with other forums

Matched to the requirements for supporting ATM and IP

Ensure cost-effective implementation and spectral efficiency

Bernd Friedrichs

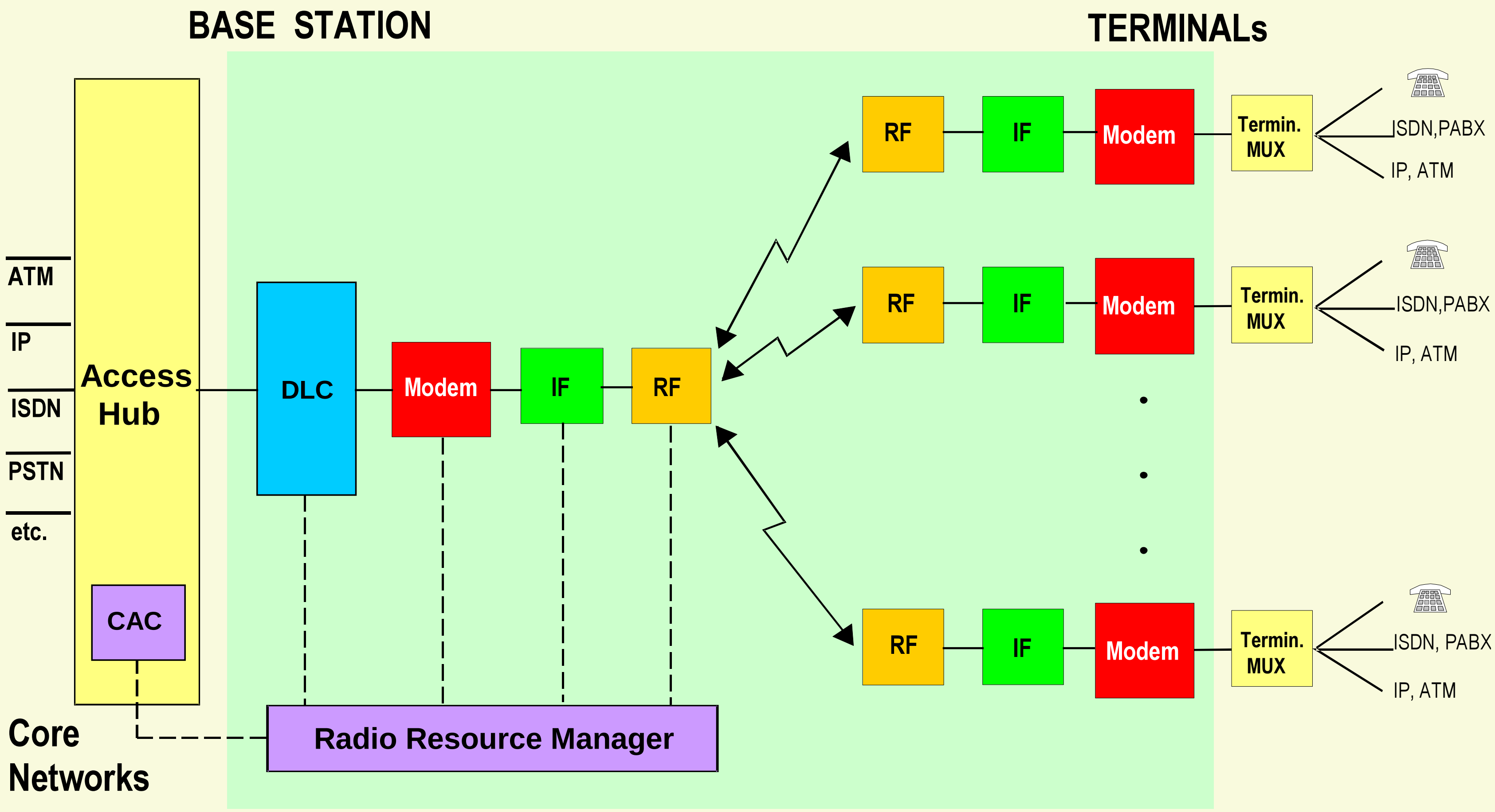
Protocol Stack and Functions (BRAN)



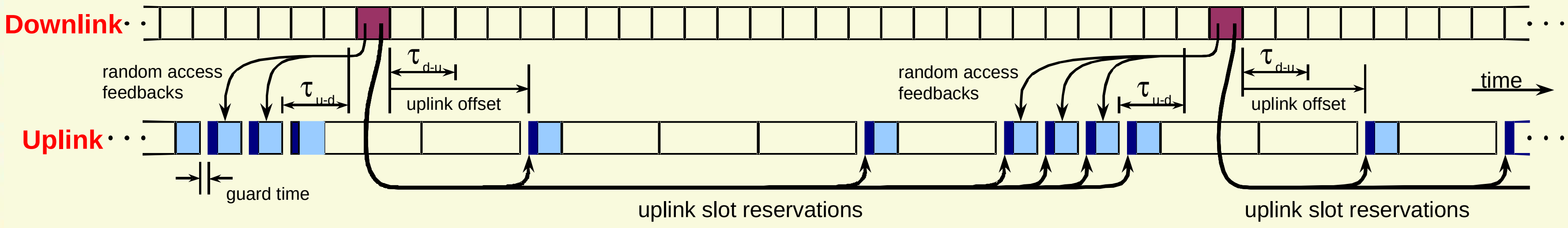
HL	Higher Layers
CL	Convergence Sublayer
DLC	Data Link Control
PHY	Physical Layer
SAP	Service Access Point
EC	Error Control
MAC	Medium Access Control
RLC	Radio Link Control
RRC	Radio Resource Control
ACF	Association Control Function
DCC	DLC Connection Control

Bernd Friedrichs

Point-to-Multipoint (PMP) Architecture



Medium Access Protocol (MAC) Example



downlink PDUs	uplink LLC PDUs	uplink MAC PDUs (bursts)
ATM cell	MAC header	1 ATM cell in reserved slot
Period-Control-PDU	ATM cell	2 ATM cells in reserved slot
	uplink capacity request	capacity request in poll slot or random access

τ_{u-d} [τ_{d-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

Bernd Friedrichs

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

Bernd Friedrichs

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)

Bernd Friedrichs

Marconi

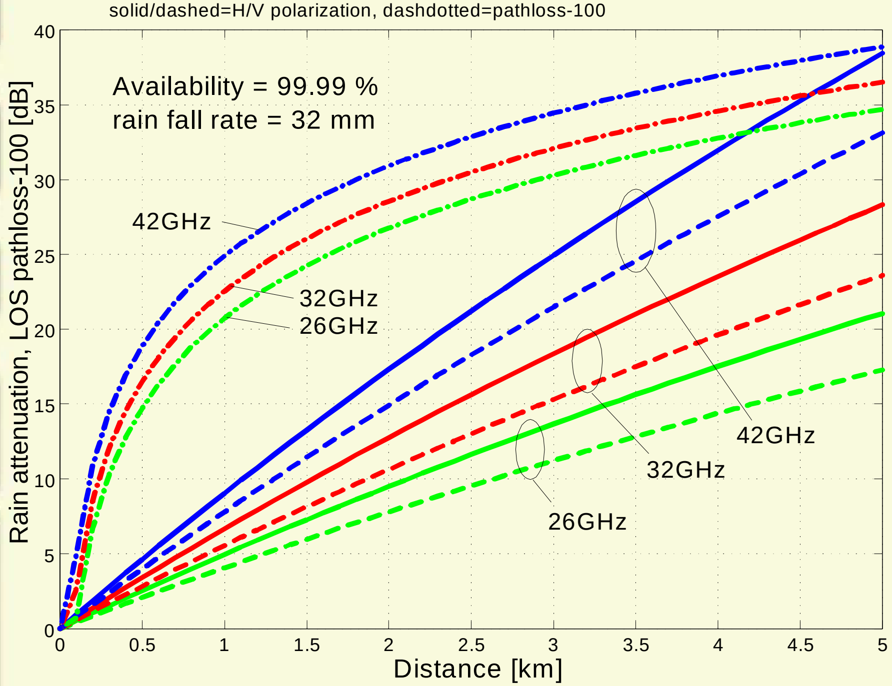
Calculation of Required Transmit Power

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

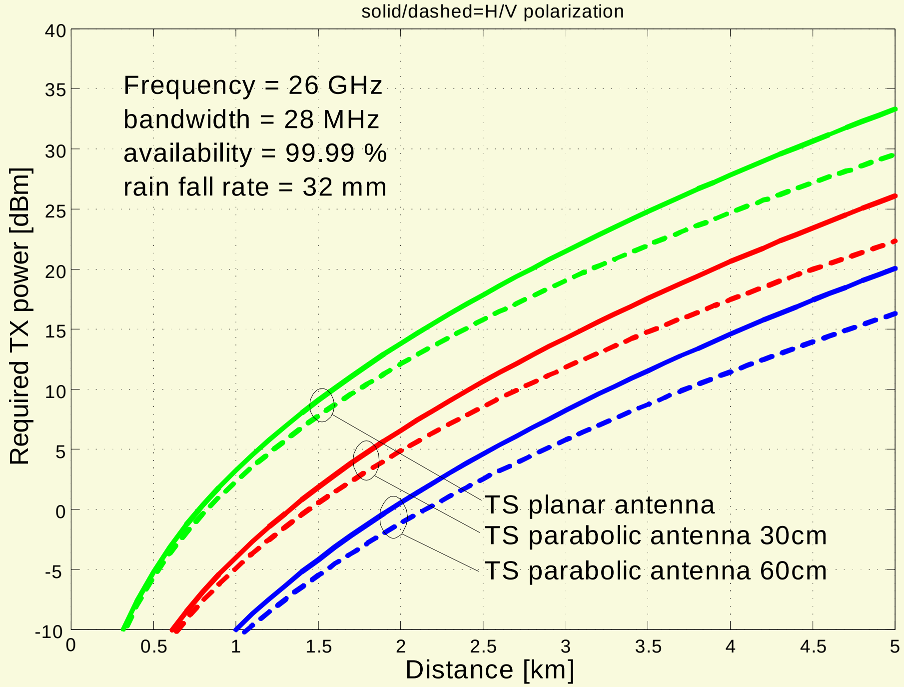
- $a_{pathloss} = 10 \cdot \log_{10}\left(\frac{4\pi f_c}{c} \cdot d\right)^2$ **[dB] = line-of-sight path loss,**
  f_c **= carrier frequency, c = velocity of light, d = distance.**
- a_{rain} **= rain fading (depending on availability, rain zone, frequency)**
- $P_{noise} = F \cdot N_{thermal} = F \cdot KT \cdot B$ **= 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)**

Bernd Friedrichs

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)

Bernd Friedrichs

Adaptive Modulation & Coding - Basics

Application

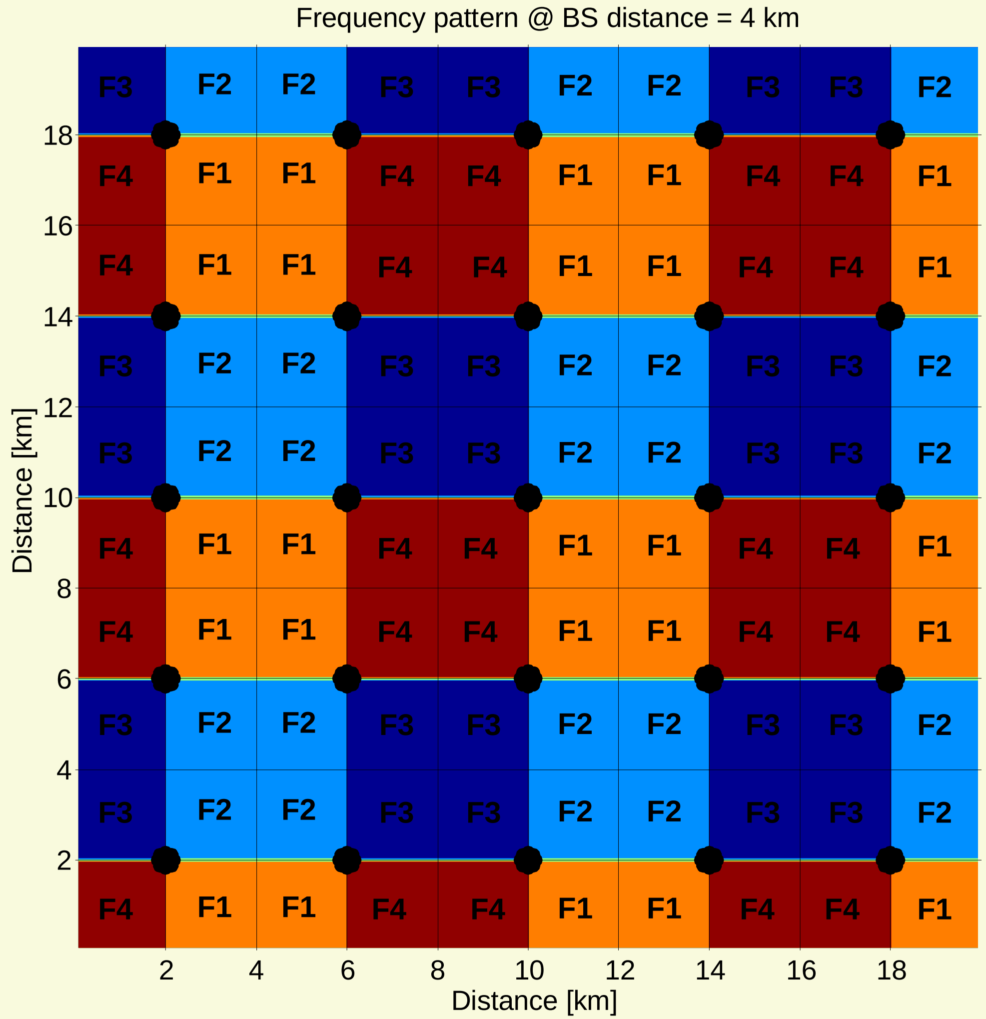
- Adaptation in downlink according to distance, rain fading (C/N) and interference (C/I)
- No adaptation in uplink (lower data rates, more sensitive to interferences, fast C/I-changes)
- 4QAM. . .64QAM; convol. and trellis coded modulation, RS codes

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!

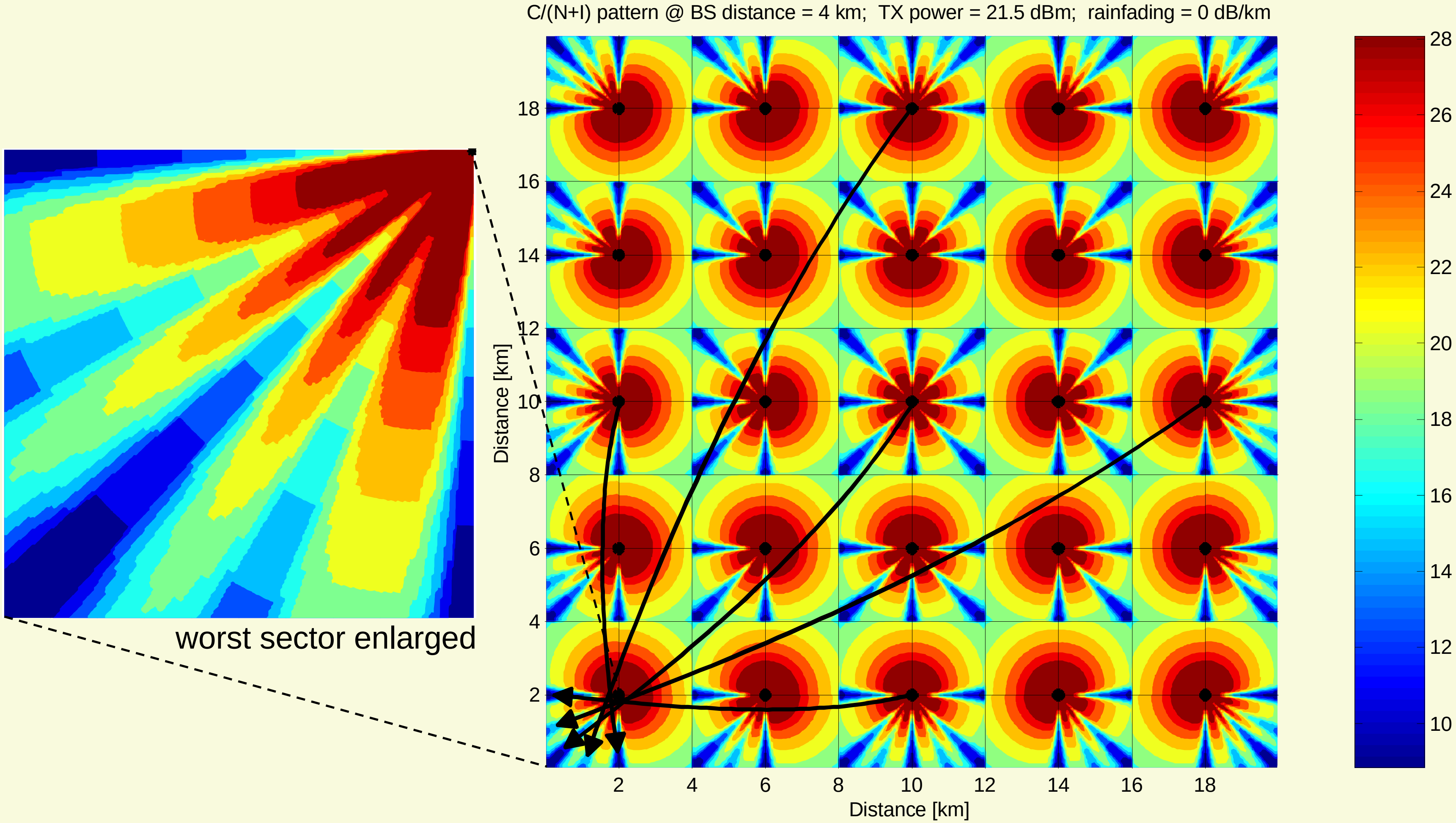
Frequency Plan for a Rectangular Constellation (25 cells, 100 sectors, Re-use Factor = 4)



Bernd Friedrichs

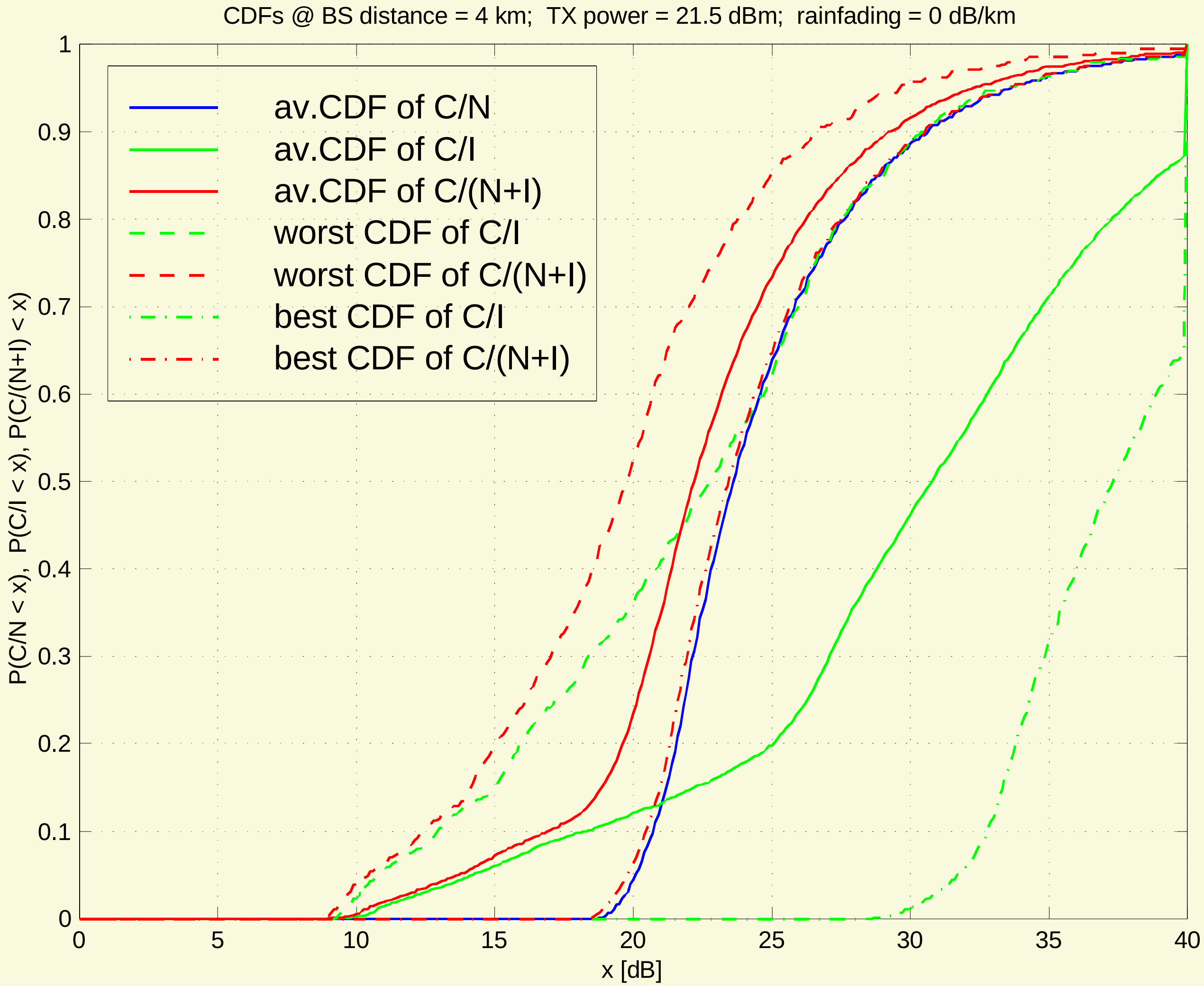
Marconi

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



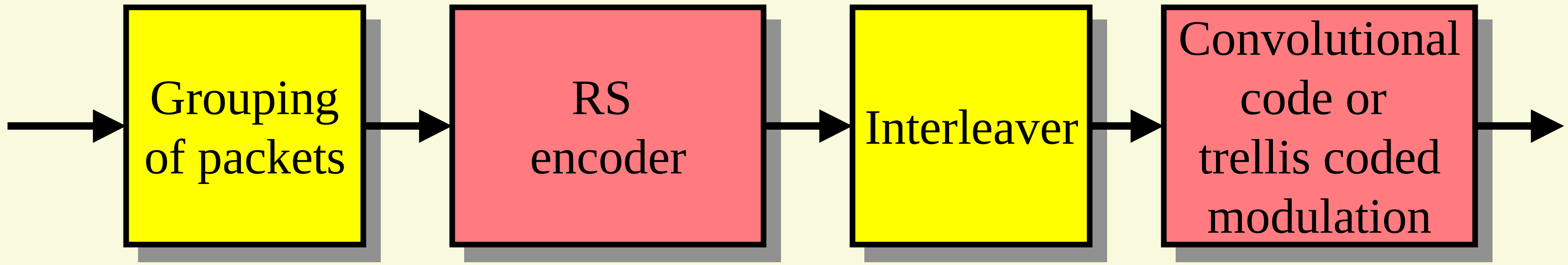
Bernd Friedrichs

Cumulative Distribution Functions for Rectangular 5x5 Constell. (Re-use=4)



Bernd Friedrichs

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

Bernd Friedrichs

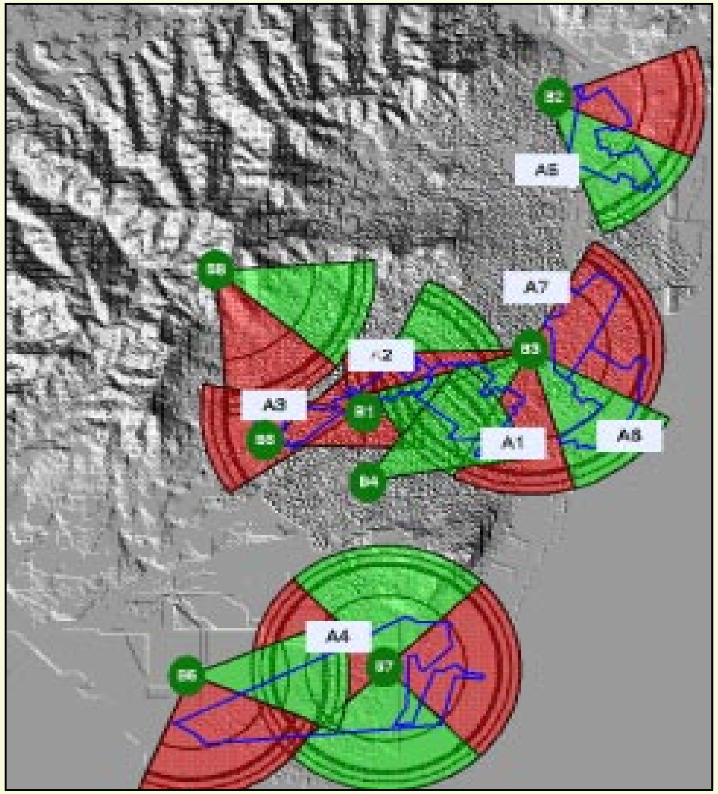
Marconi

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**

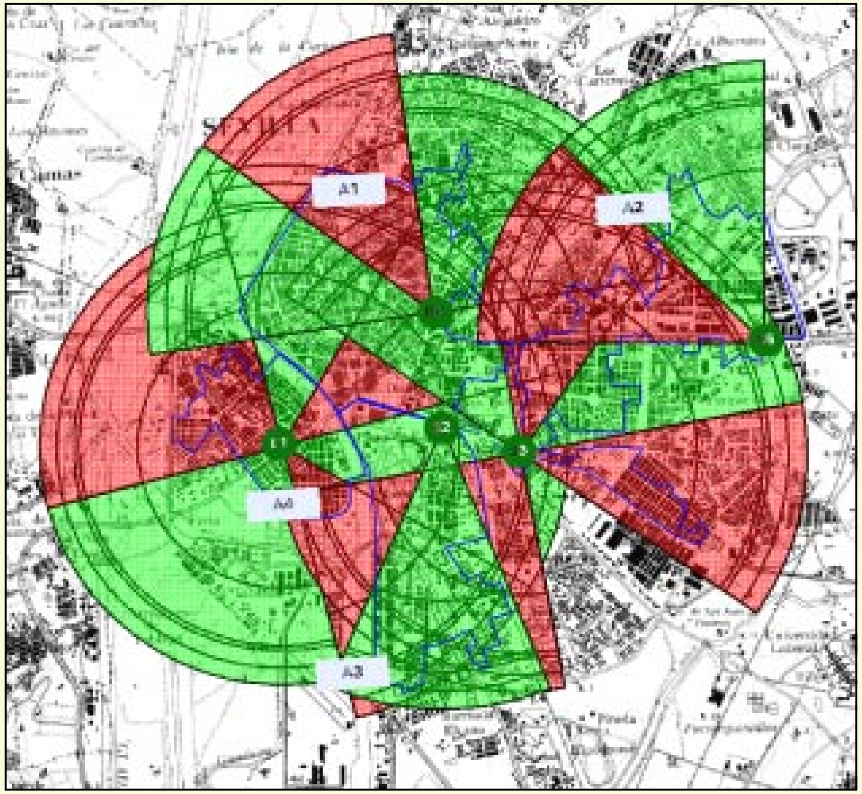
Coverage and Overlapping Sectors

Partly Overlapping Sectors



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

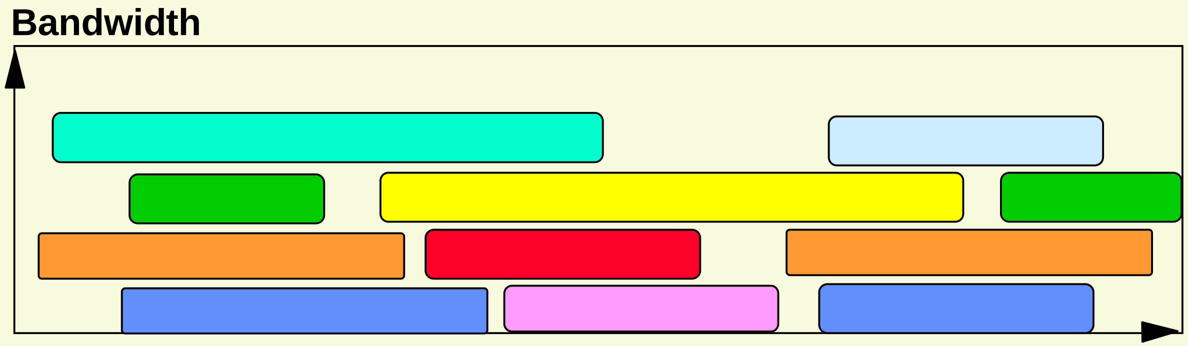
Fully Overlapping Sectors



- ➔ **Decoupling by polarisation & frequency**
- ➔ **LOS nearly 100 %**
- ➔ **Reuse nearly 100 %**

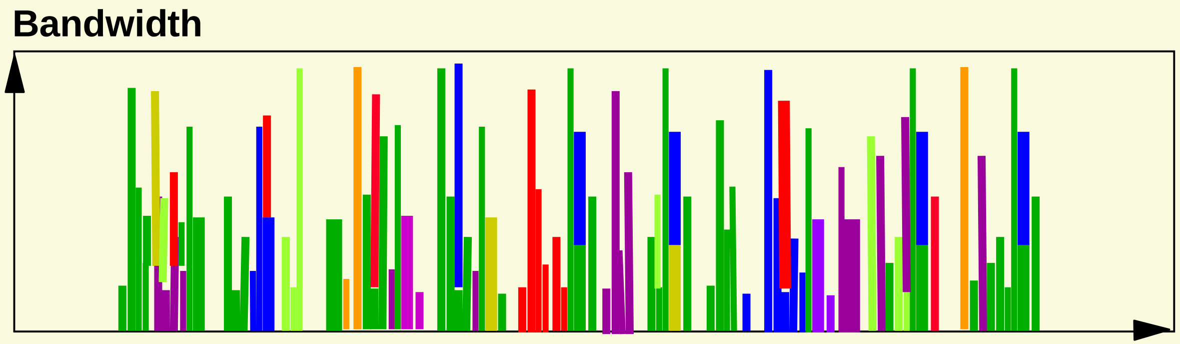
Bernd Friedrichs

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)**

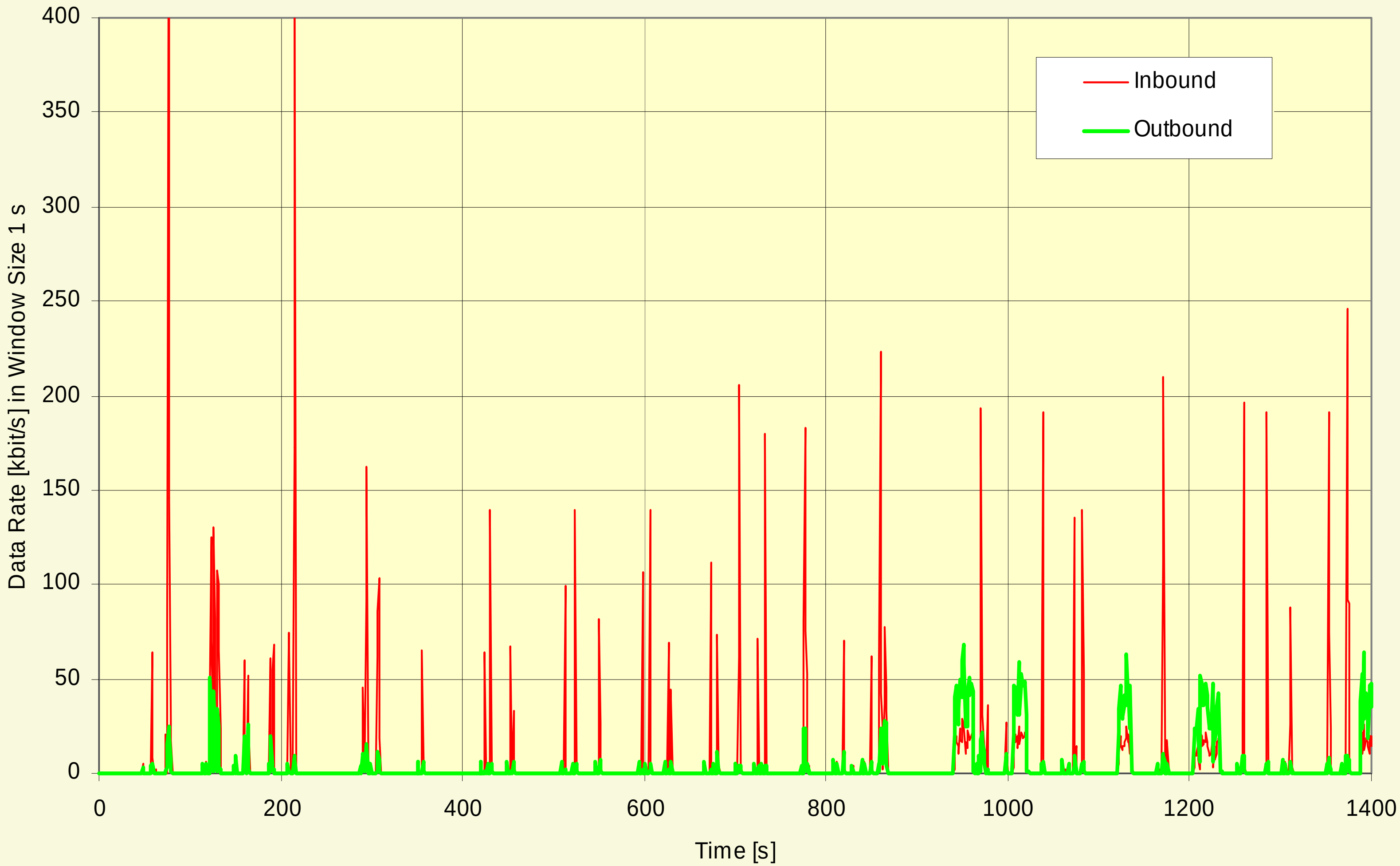


Data-Oriented Services

- ➔ **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**

Marconi

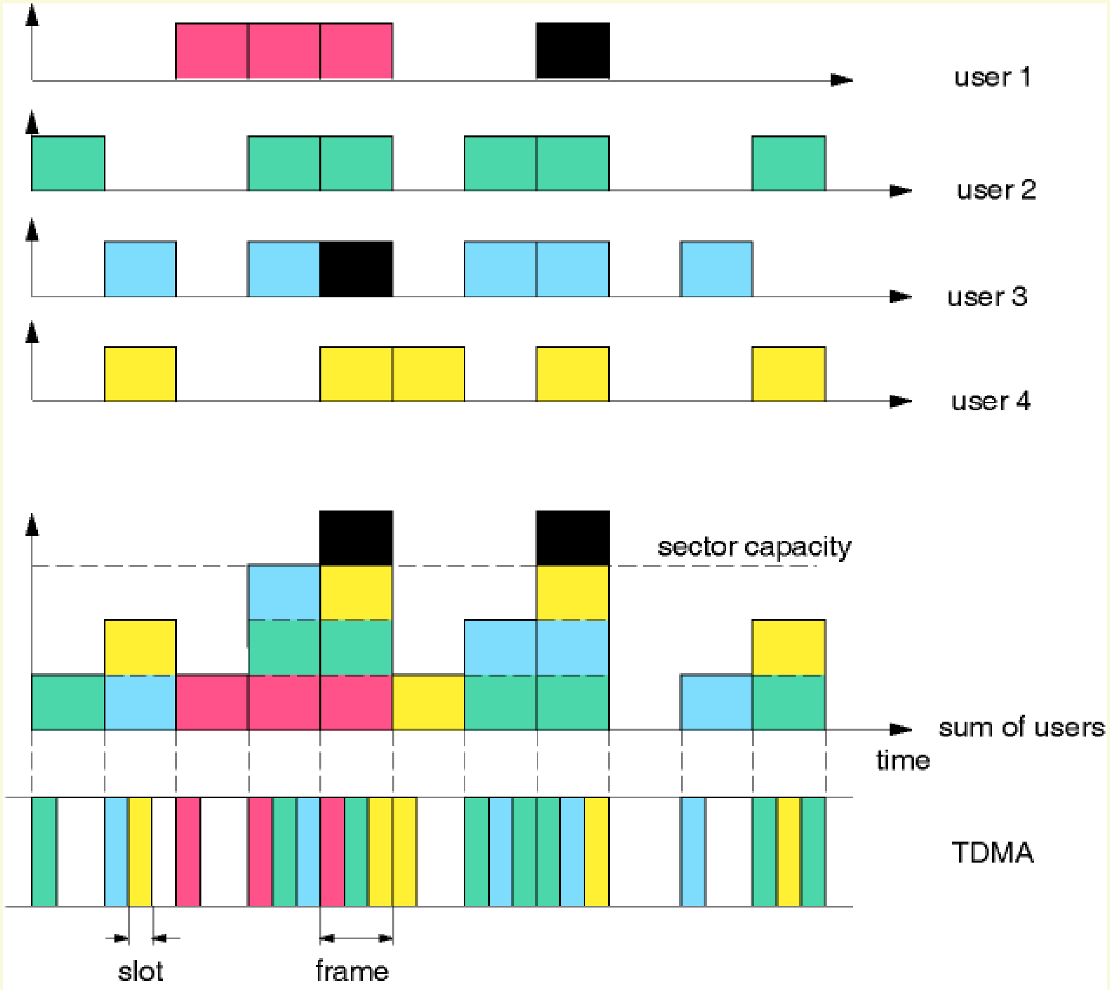
TCP/IP Internet Traffic Example



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

Bernd Friedrichs

A Simple Traffic Model for Statistical Multiplex Gain Analysis



Bernd Friedrichs

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

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

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

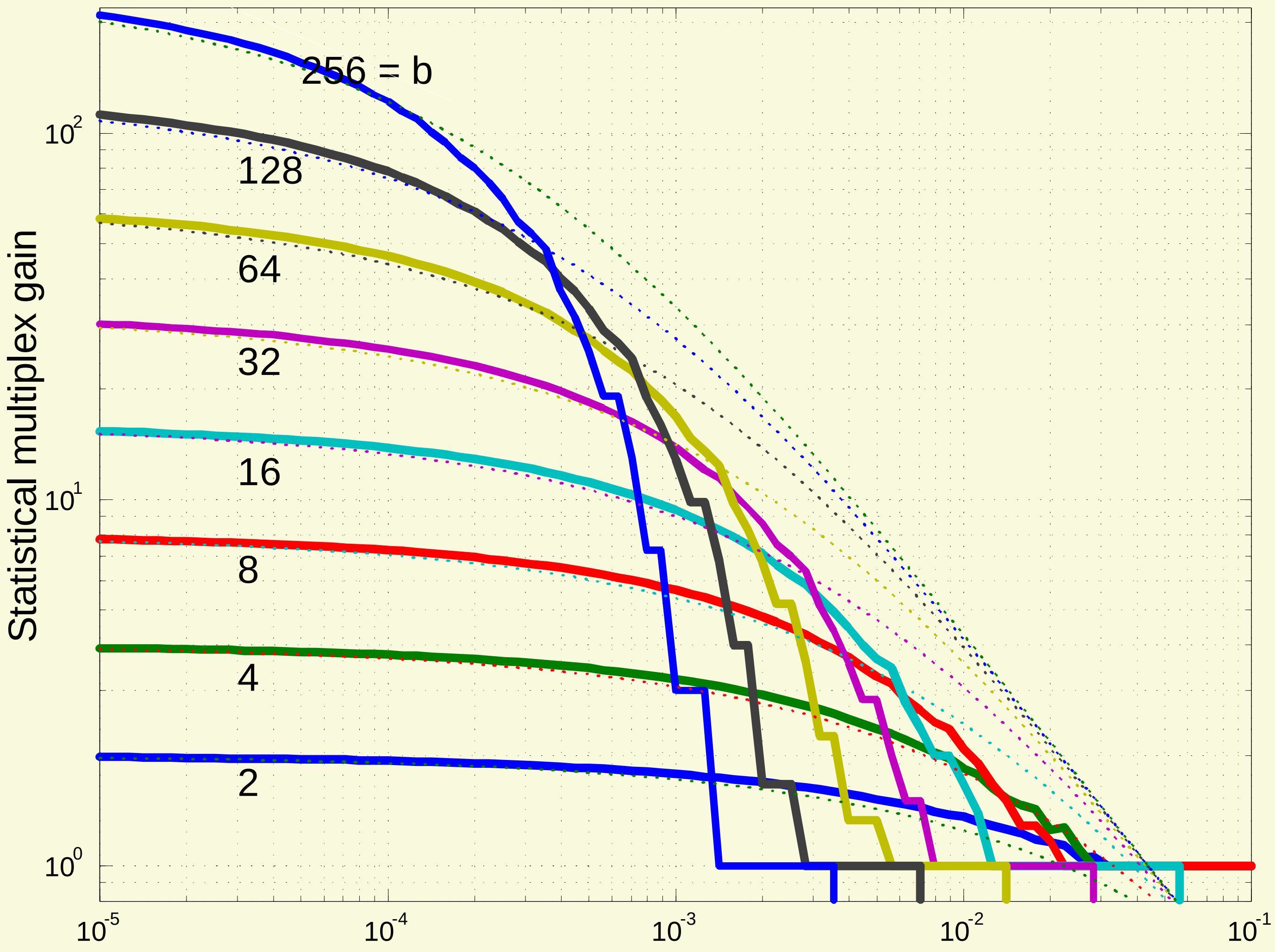
and the spectral utilization $U = G/b$ refer to the cell loss rate (CLR)

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

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

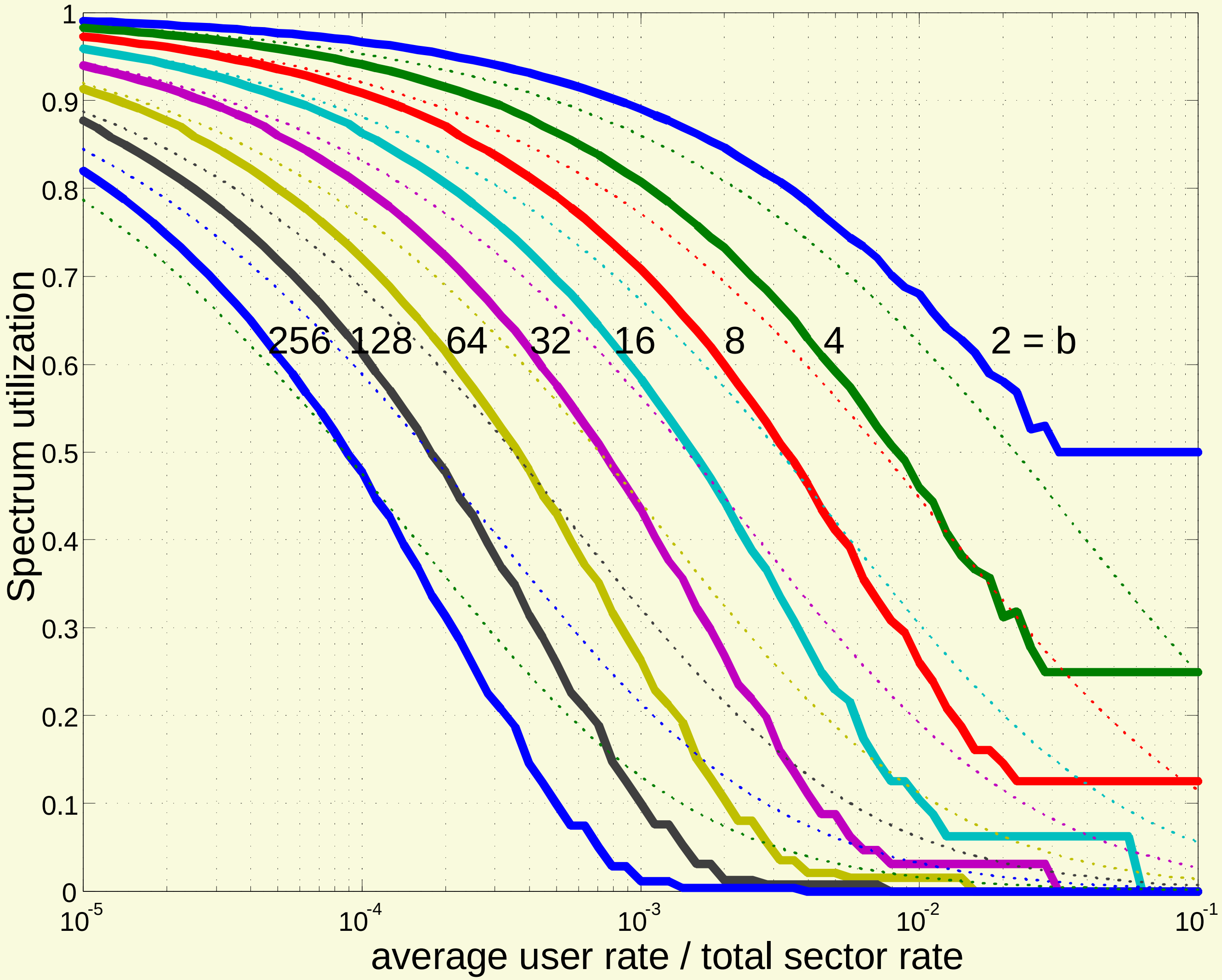
Bernd Friedrichs

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



Bernd Friedrichs

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



Bernd Friedrichs

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 CLR-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.