Statistical Multiplex Gain in Cellular Communication Systems

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Overview

Broadband wireless communication systems

- **with PMP topology (Point-to-MultiPoint)**
- **maximum data rate?**

Stochastic models must be

- **simple enough to allow analysis**
- **detailed enough to accurately represent key system properties**

Stochastic influences

- **Gaussian Noise**
- **Interference**
- **Weather (rain)**
- **Terminal distribution**
- **Properties of data source (ATM service classses)**

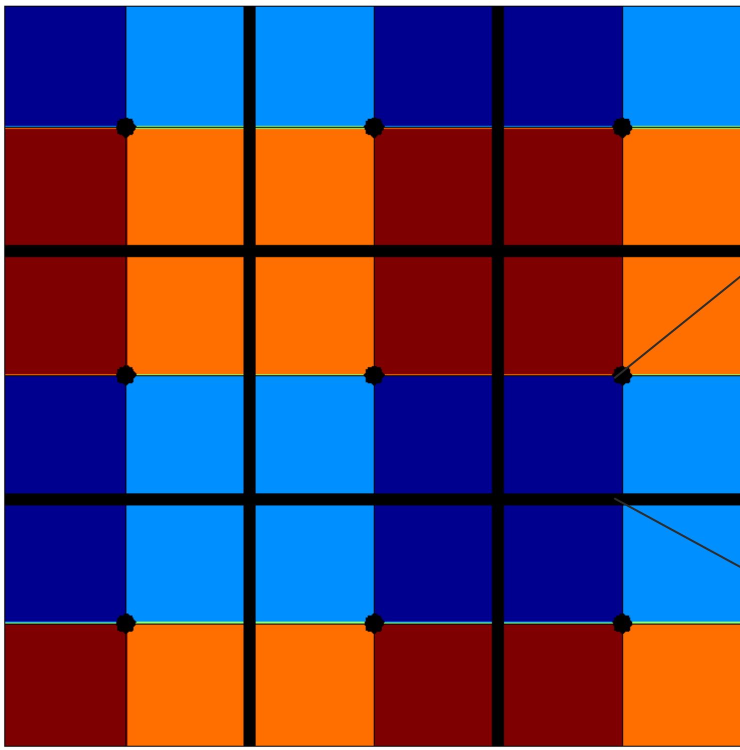
Statistical Multiplex Gain

About ETSI BRAN HiperAccess standardization

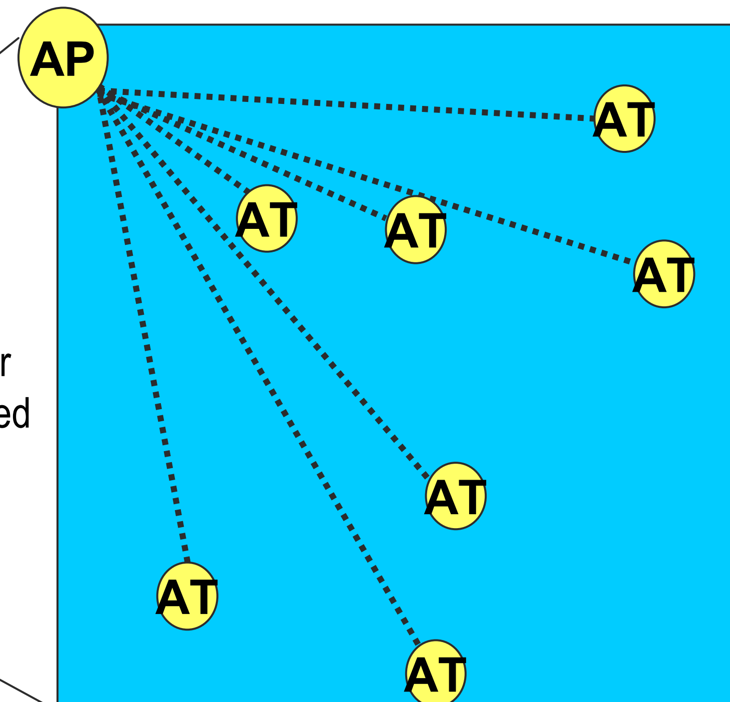
Cellular Communication Systems with Point-to-Multipoint (PMP) Architcture

Example of a cellular constellation
(9 Base Stations, 36 sectors, 4 sectors per cell
different colours indicate different frequencies)

AP = Access Point (Base station)
AT = Access Terminal
One AP serves many ATs per sector,
using capacity sharing methods (multiplex gain)

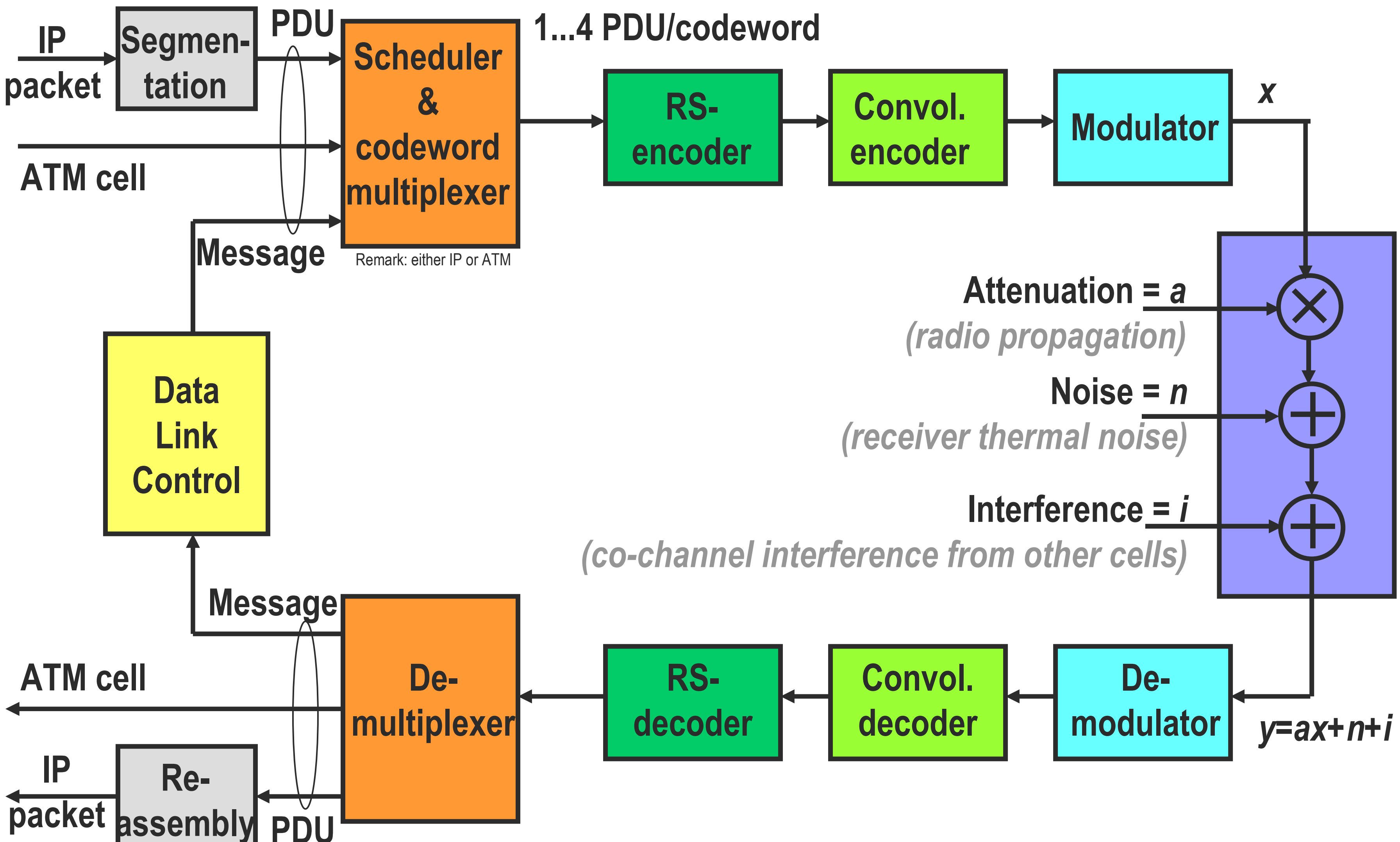


sector
enlarged



access radio: AT fixed, LOS propagation
mobile radio: AT mobile, non-LOS propagation

Radio Link Model (1 of 6)
Simplified Transceiver Block Diagram



Radio Link Model (2 of 6)
Basic Transmission Model

$$y = a \cdot x + n + i$$

- y: received signal
- a: attenuation (time-variant)
- x: transmit signal
- n: thermal noise, exactly Gaussian
- i: interference, approx. Gaussian (time-variant)

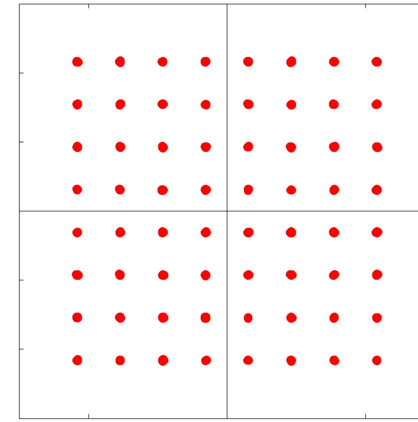


Figure: Amplitude plot of x (64-QAM)

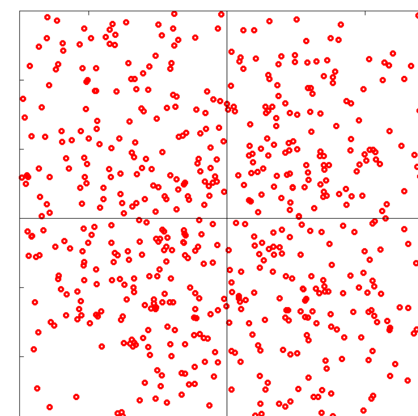


Figure: Amplitude plot of *y*

Energy / Power

$$\underbrace{E(|y|^2)}_{P_{Rx}} = \underbrace{a^2 E(|x|^2)}_{C = a^2 P_{Tx}} + \underbrace{E(|n|^2)}_{N} + \underbrace{E(|i|^2)}_{I}$$

Channel quality determined by $\dfrac{C}{N+I} = \dfrac{\text{Carrier}}{\text{Noise} + \text{Interference}}$

Radio Link Model (3 of 6)
Gaussian Noise

Thermal noise is exactly Gaussian-distributed, even for extremely small probabilities such as 10^{-15}

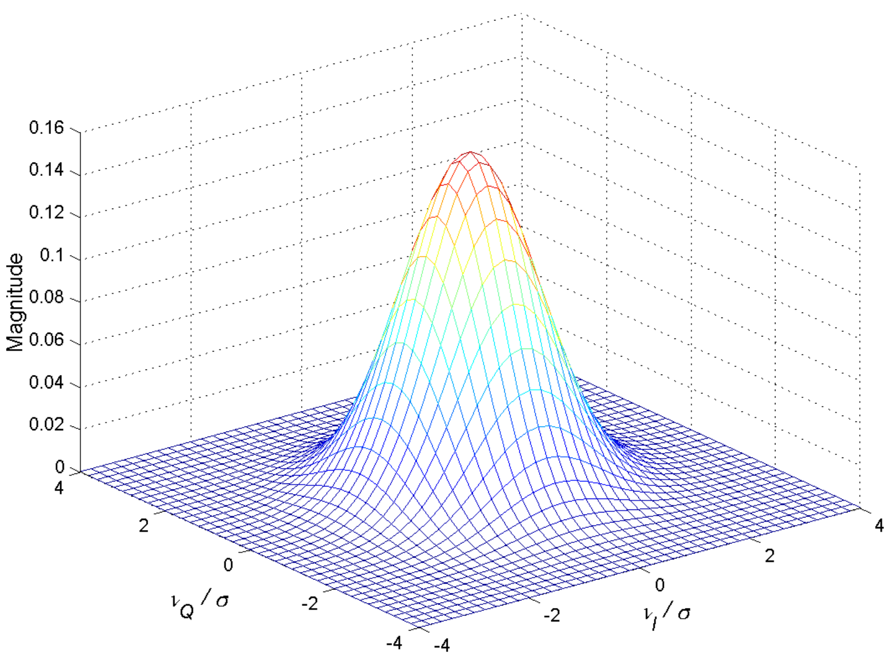


Figure: 2-dim. Gaussian PDF

Complementary Gaussian error function:

$$Q(\alpha) = P\left(\frac{n_i}{D(n_i)} > \alpha\right) = \frac{1}{2\pi}\int_{\alpha}^{\infty} \exp(-\nu^2/2)\, d\nu$$

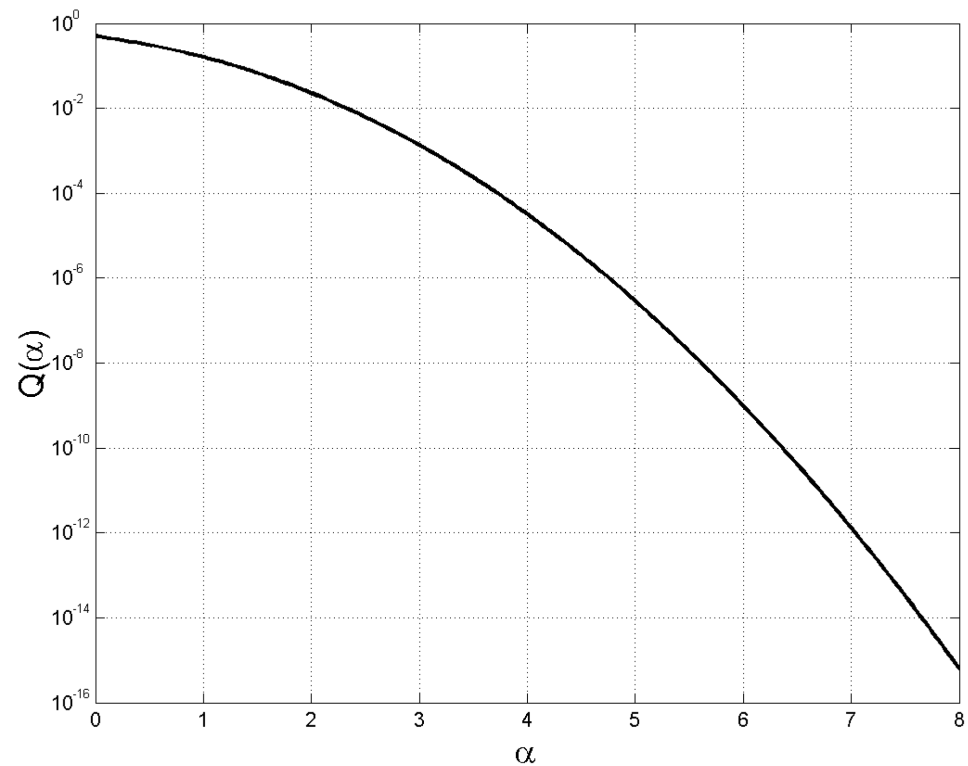


Figure: Complementary Gaussian error function

Radio Link Model (4 of 6)
Link Budget (C/N = Carrier-to-Noise)

$$\frac{C}{N} = \frac{a^2 P_{Tx}}{N} = \frac{P_{TX} \cdot G_{TX} \cdot G_{RX}}{N \cdot L_{free} \cdot L_{rain} \cdot L_0} \approx \text{const} \cdot \frac{P_{Tx}}{d^2 \cdot B \cdot f_c^2}$$

(doubling of distance or carrier frequency causes loss of 6 dB)

where

$$L_{free} = \left(\frac{4\pi f_c}{c} \cdot d \right)^2 = \text{free-space path loss, where} \begin{cases} d = \text{distance} \\ f_c = \text{carrier frequency} \\ c = \text{velocity of light} \end{cases}$$

$$L_0 = \text{offset}$$

(linear and nonlinear distortions, sync and implementation losses)

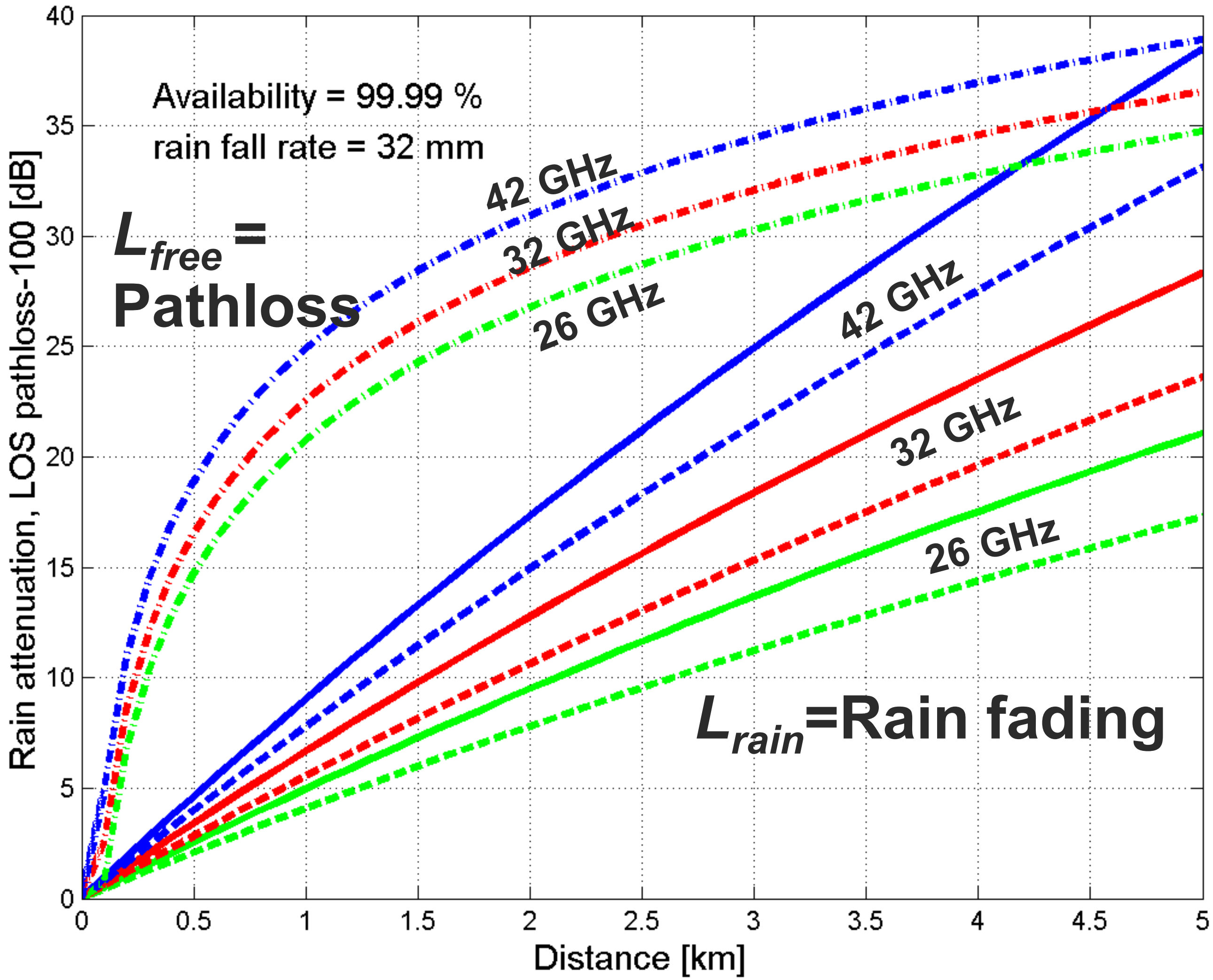
$$L_{rain} = \text{function}\left(d, p_{\text{availability}}, \Phi_{\text{rain fall rate}}, \Phi_{\text{polarization}}\right)$$
$$\approx \exp(\text{const} \cdot d) \quad \text{for small } d$$

(according to complex model ITU-R P.530-7, e.g. 4 dB/km)

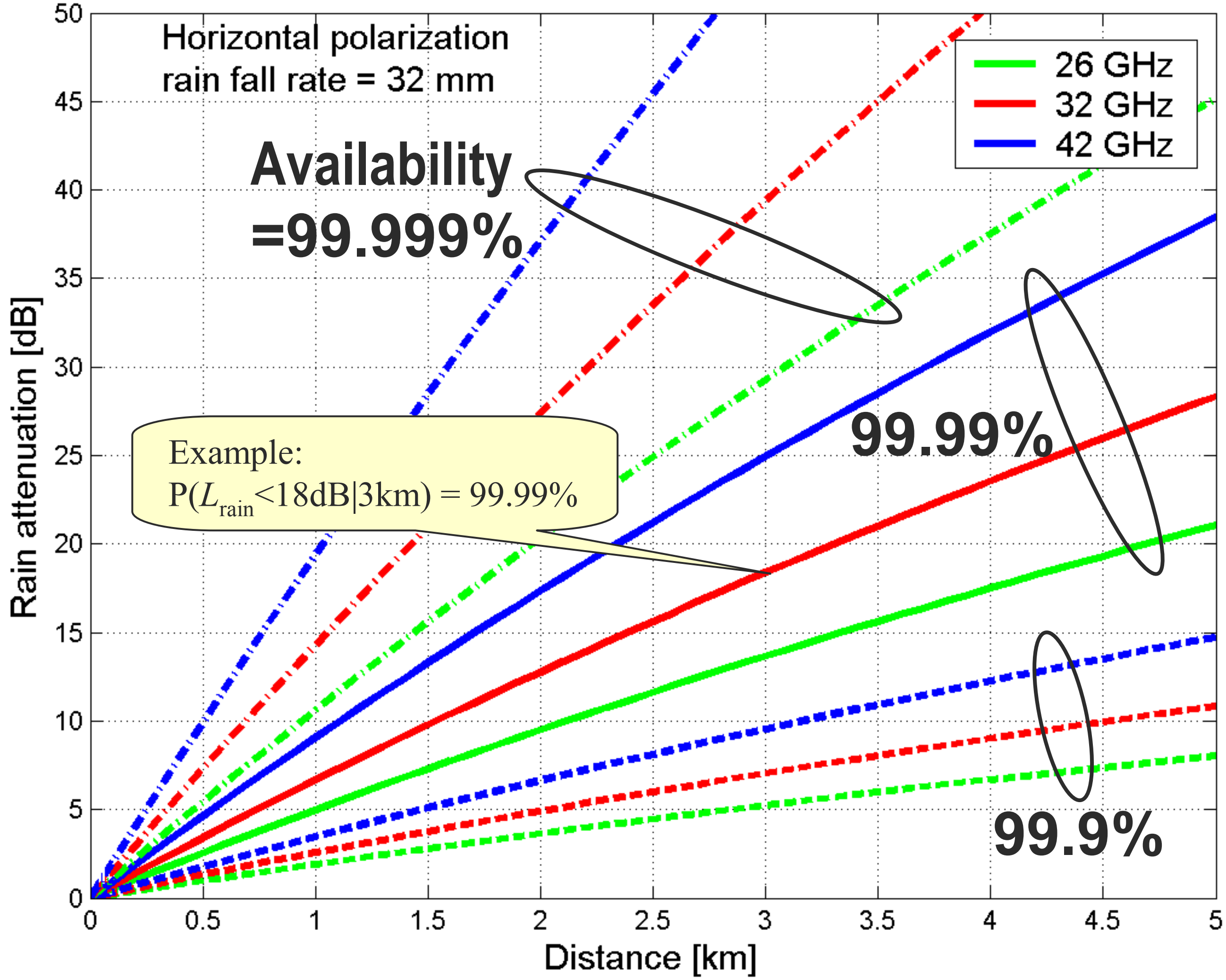
$$N = F \cdot K \cdot T \cdot B = \text{noise power, where} \begin{cases} F = \text{noise figure} \\ K = \text{Boltzman constant} \\ T = \text{temperature} \\ B = \text{bandwidth} \end{cases}$$

$$G = \frac{4\pi \cdot A}{\lambda^2} = \text{antenna gain, where} \begin{cases} \lambda = c / f_c = \text{wavelength} \\ A = \pi \cdot D^2 \cdot \eta / 4 \\ D = \text{diameter} \\ \eta = \text{antenna efficiency} \end{cases} \begin{cases} \text{typical values:} \\ G_{AP} = 17 \text{ dBi for } 45^\circ \text{ sectors,} \\ G_{AT} = 28 \text{ dBi for } 5^\circ \text{ planar antenna} \end{cases}$$

Radio Link Model (5 of 6)
Free-Space Pathloss and Rain Fading



Radio Link Model (6 of 6)
Rain Fading Depending on Availability



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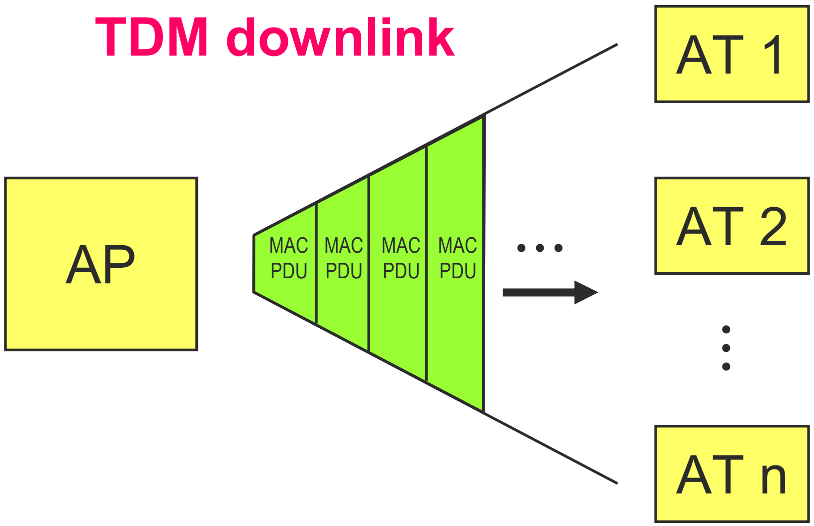
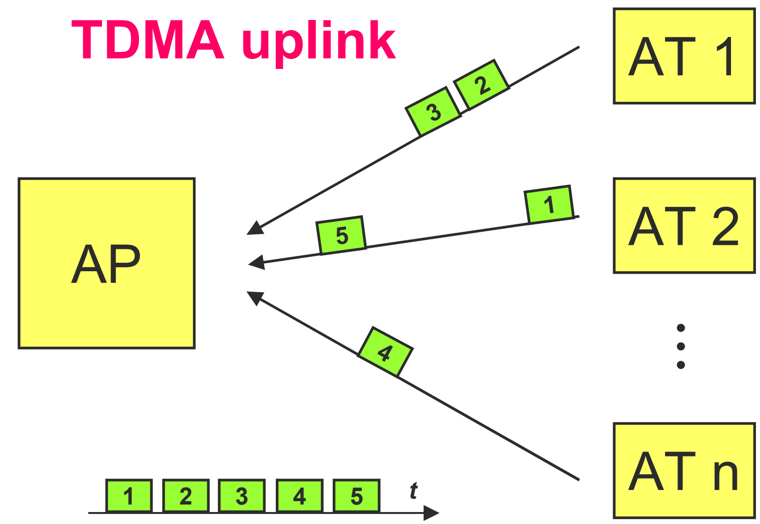
Time Division Multiplex (TDM) in Downlink, Time Division Multiplex Access (TDMA) in Uplink

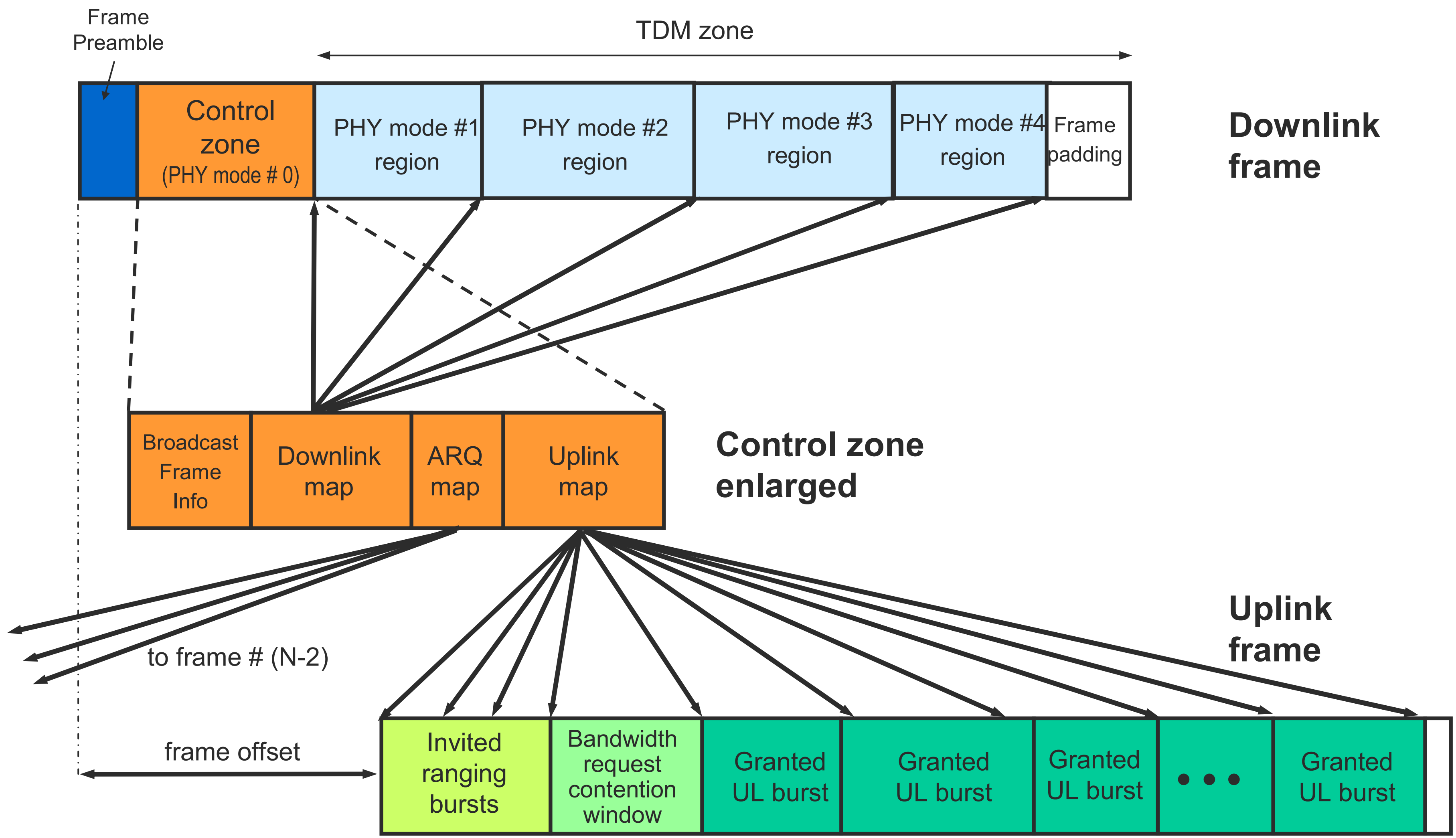




Further important properties of downlink and uplink

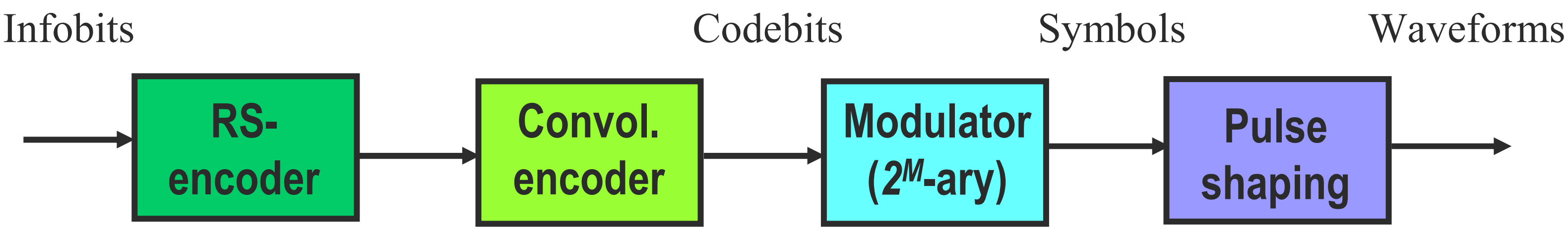
	Downlink	Uplink
Link budget & rain fading & multipath propagation	approx. identical	
Co-channel interference	time-invariant from other APs	time-variant from other ATs
Transmit power (same bandwidth)	constant for all ATs	individual per AT (distance, modulation, fading) for constant RX power

Frame Structure (from HiperAccess)



Order of ranging burst and
contention window is just an example

PHY Modes (1 of 7)
Definition, Robustness vs. Efficiency



$$R_{outer} = \frac{l \cdot n}{l \cdot n + 2t}$$

($l = 1...4$ PDU/codeword,
$n = 54...55$ length of PDU
$t = 8$ correctable errors)

$$R_{inner} \in [1/2, 1]$$

r_s = symbol rate

(M codebits/symbol)

$B = r_s(1+\alpha)$ = bandwidth

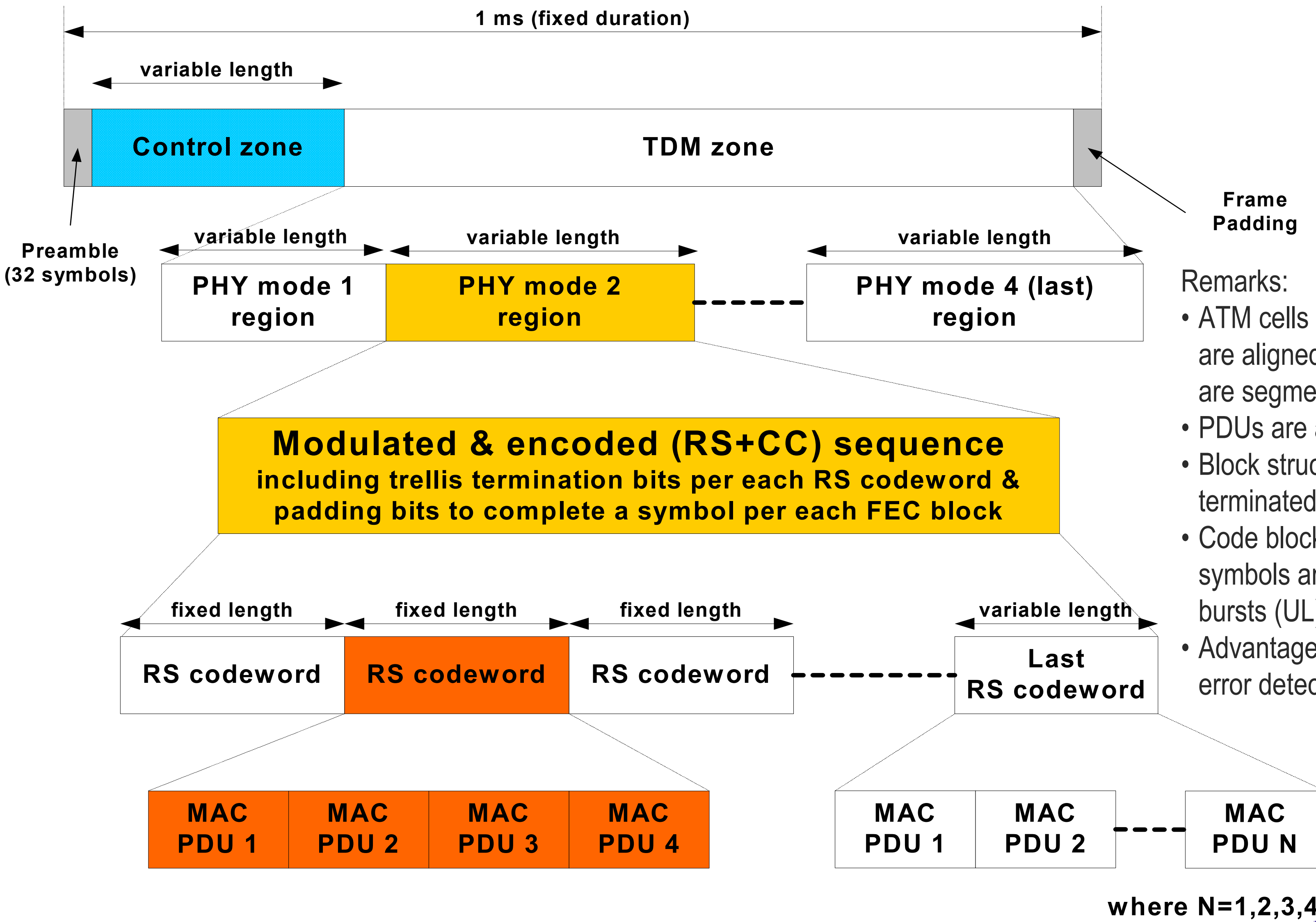
($\alpha = 0.25$)

$$\text{Spectral efficiency} = \frac{\text{infobit data rate}}{\text{bandwidth}} = \frac{r_s \cdot R_{outer} \cdot R_{outer} \cdot M}{B} = \frac{R_{outer} \cdot R_{outer} \cdot M}{1+\alpha}$$

PHY mode defined by
- concatenated coding and
- modulation
(where „PHY“ refers to the physical layer of OSI model)

PHY Mode	R_{outer}	R_{inner}	M	Spectral efficiency (for l=4)	$C/(N+I)_{required}$
0 (CZ)	0.65	1/2	2	0.52	7 dB
1	0.93	2/3	2	0.99	8 dB
2	0.93	1	2	1.49	12 dB
3	0.93	7/8	4	2.60	18 dB
4	0.93	5/6	6	3.72	25 dB

PHY Modes (2 of 7)
Concatenated Coding



Remarks:

- ATM cells and DLC messages are aligned to PDUs, IP packets are segmented to PDUs
- PDUs are aligned to RS blocks
- Block structure preserved by terminated convolutional coding
- Code blocks are aligned to symbols and regions (DL) and bursts (UL)
- Advantages:
  error detection and ARQ

PHY Modes (3 of 7)
Maximum Range per Mode

Maximum d, P_{Tx} and $p_{availability}$ are related as

$$P\left(P_{Tx} \geq \left(\frac{C}{N+I}\right)_{required} \cdot \underbrace{\left(1+\frac{I}{N}\right)}_{>1} \cdot \underbrace{\frac{N L_{free} L_{rain} L_0}{G_{TX} G_{RX}}}_{\text{mainly dependent on } d,\, f_c,\, B,\, p_{availability},\, \Phi_{\text{rain fall rate}}} \right) \geq p_{availability}$$

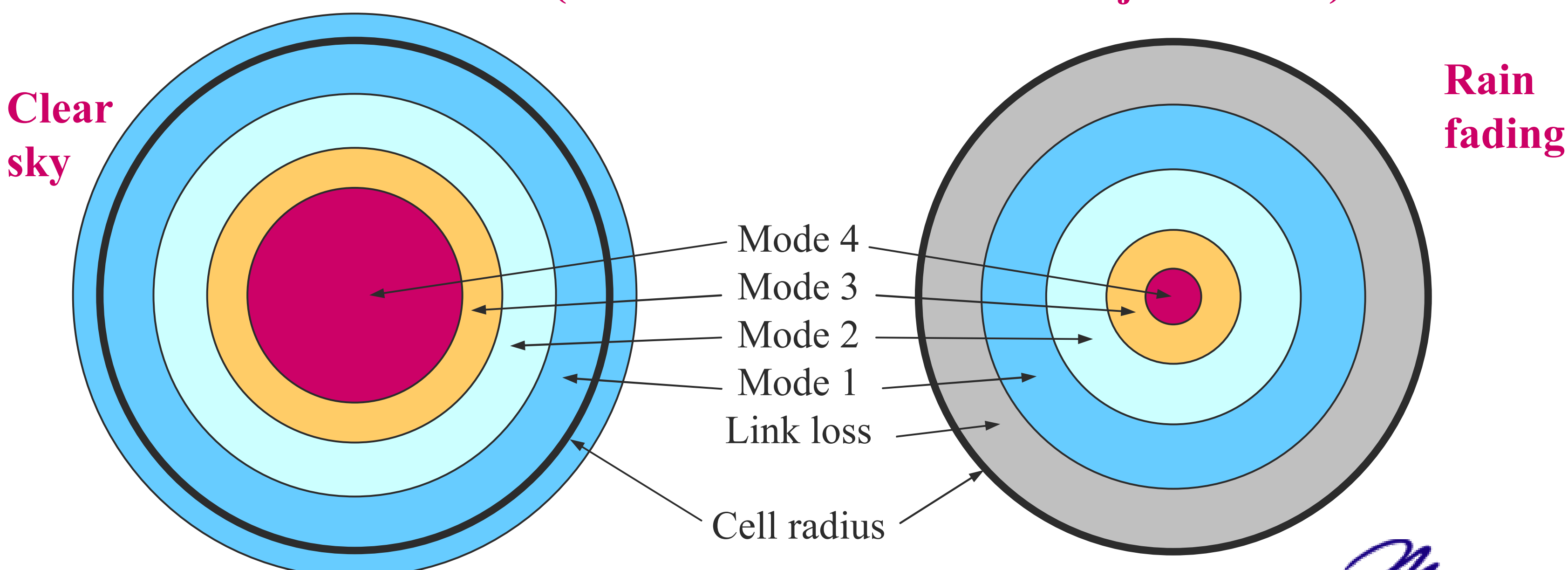
>1

I is time-variant

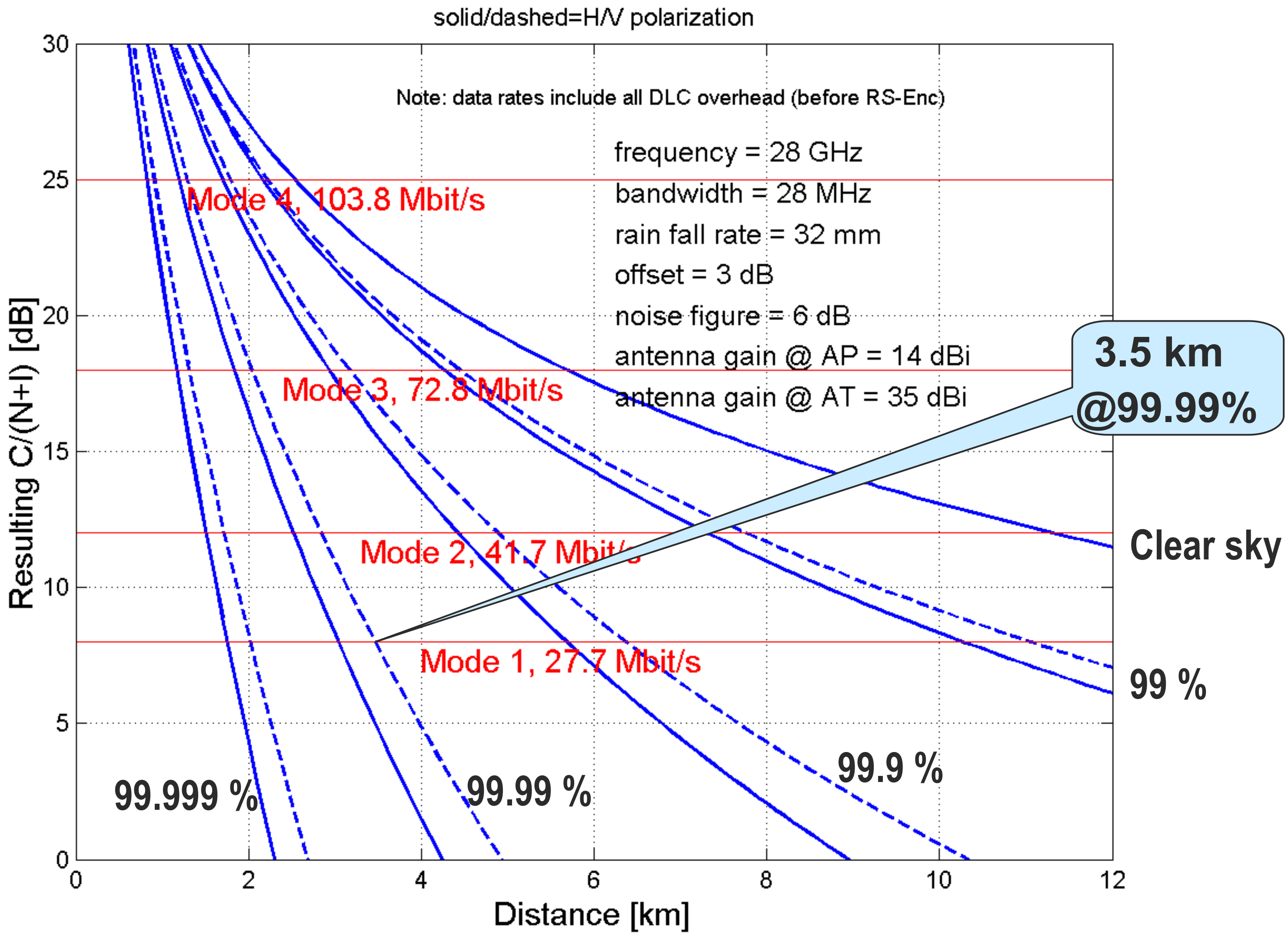
mainly dependent on $d, f_c, B, p_{availability}, \Phi_{\text{rain fall rate}}$

L_{rain} is time-variant

Stand-alone cells (without interference from adjacent cells)

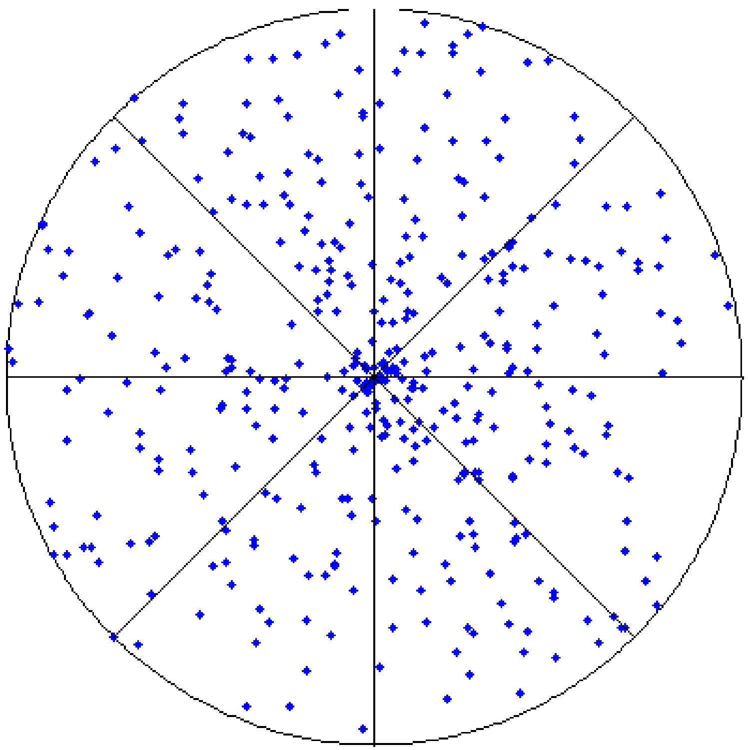


PHY Modes (4 of 7)
Throughput, Range vs. availability

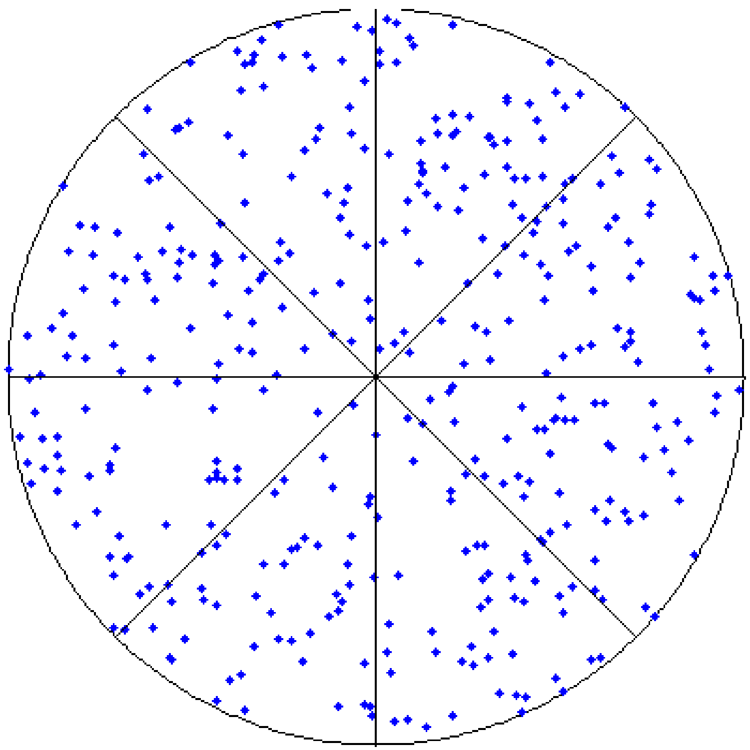


PHY Modes (5 of 7)
Terminal Distributions

Uniform distribution over distance



Uniform distribution over area



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PHY Modes (6 of 7)
Calculation of Throughput

Let r_k be the data rate (throughput) for PHY mode k

Let $(C/N)_{required,k}$ be the required C/N for mode k, applicable in the interval $[0, d_k]$

Let $d_{AT} \in [0, d_{max}]$ be a r.v. describing the distance AT-AP for a cell radius of d_{max}

For the probability that an AT can use mode k,

$$p_k(d_{\max}) = P(d_{k+1} \le d_{AT} < d_k) = \begin{cases} \dfrac{d_k - d_{k+1}}{d_{\max}} & \text{uniform distance} \\[2ex] \dfrac{d_k^2 - d_{k+1}^2}{d_{\max}^2} & \text{uniform area} \end{cases}$$

Hence, for the total data rate (throughput) per sector,

$$r(d_{\max}) = \sum_k r_k \cdot p_k(d_{\max})$$

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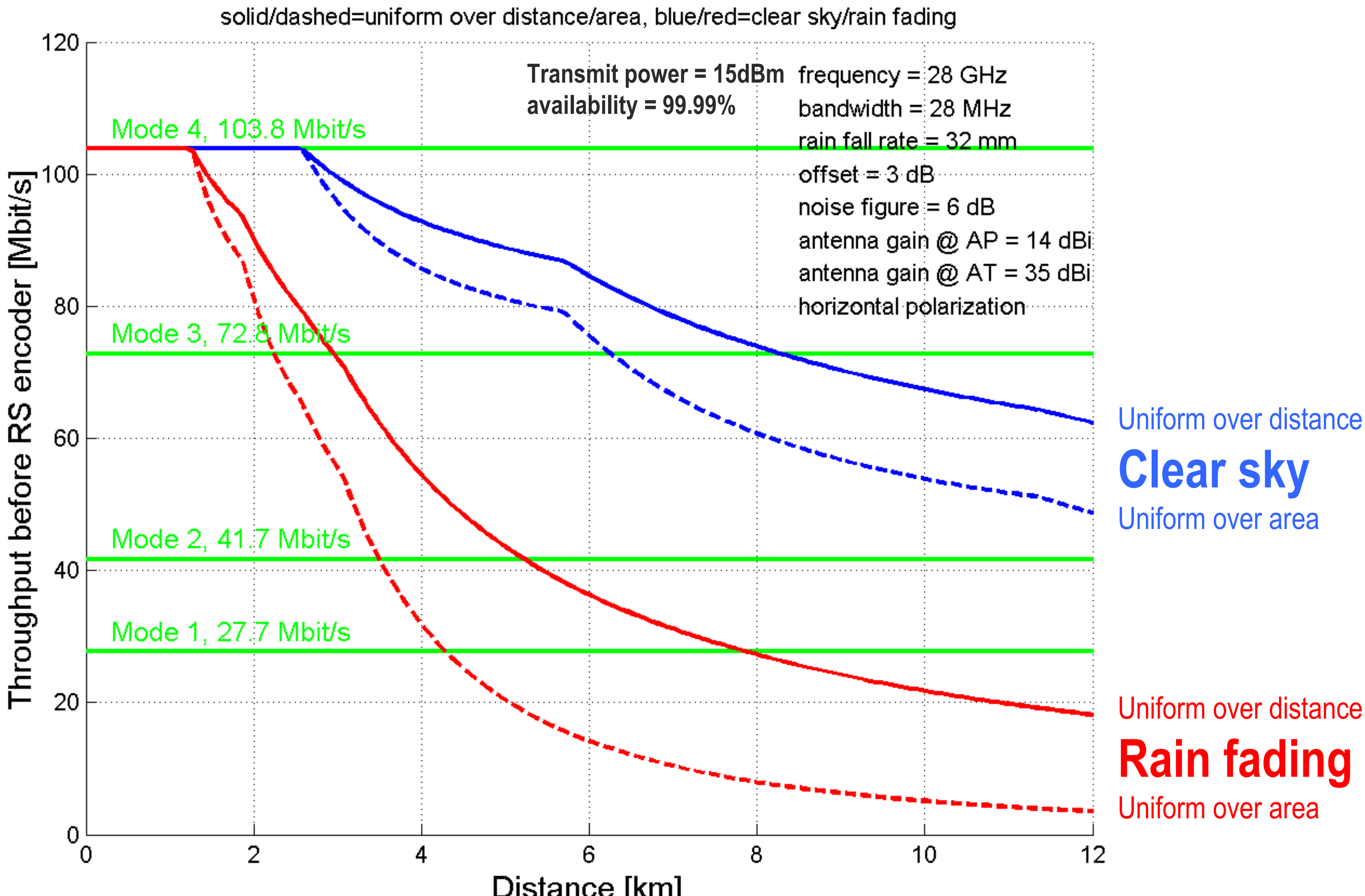
PHY modes (7 of 7)
Throughput Depending on Terminal Distribution



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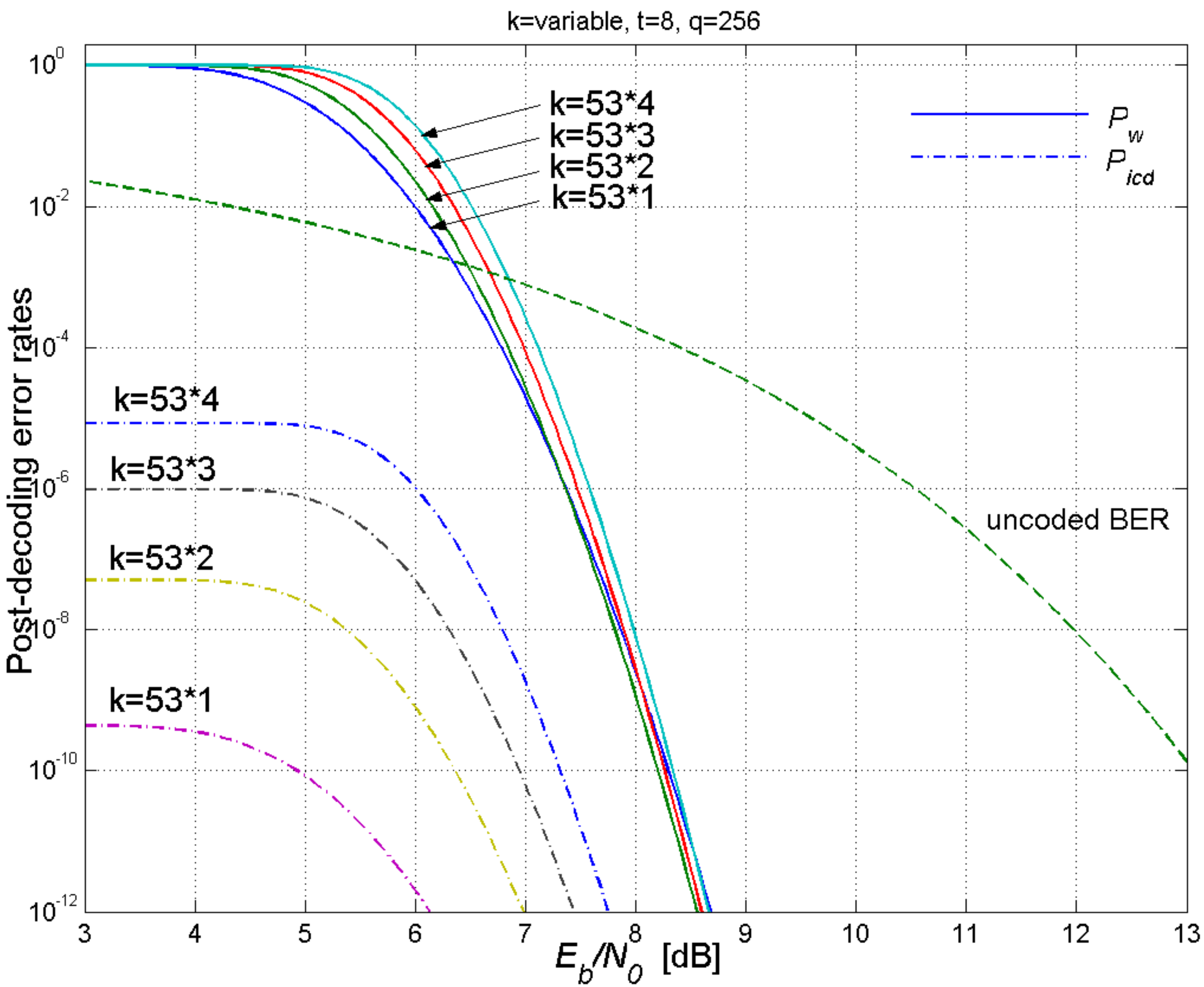
Error Control Coding (1 of 3)
RS Code Performance



$$
\begin{aligned}
P_w &= P(\text{decoding error}) \\
&= P(w_H(\mathbf{e}) > t) \\
&= 10^{-10} \quad \text{for} \quad (C/N)_{required}
\end{aligned}
$$

$$
\begin{aligned}
P_{icd} &= P(\text{incorrect decoding}) \\
&= P\left(\mathbf{e} \in \bigcup_{\mathbf{b} \in C \setminus \{\mathbf{0}\}} K_t(\mathbf{b}) \right) \\
&< 10^{-20} \quad \text{at same} \quad E_b / N_0
\end{aligned}
$$

Notes:

a) 1 dB difference in E_b/N_0 corresponds to several magnitudes in P_w

b) graphs are steeper for concatenated coding

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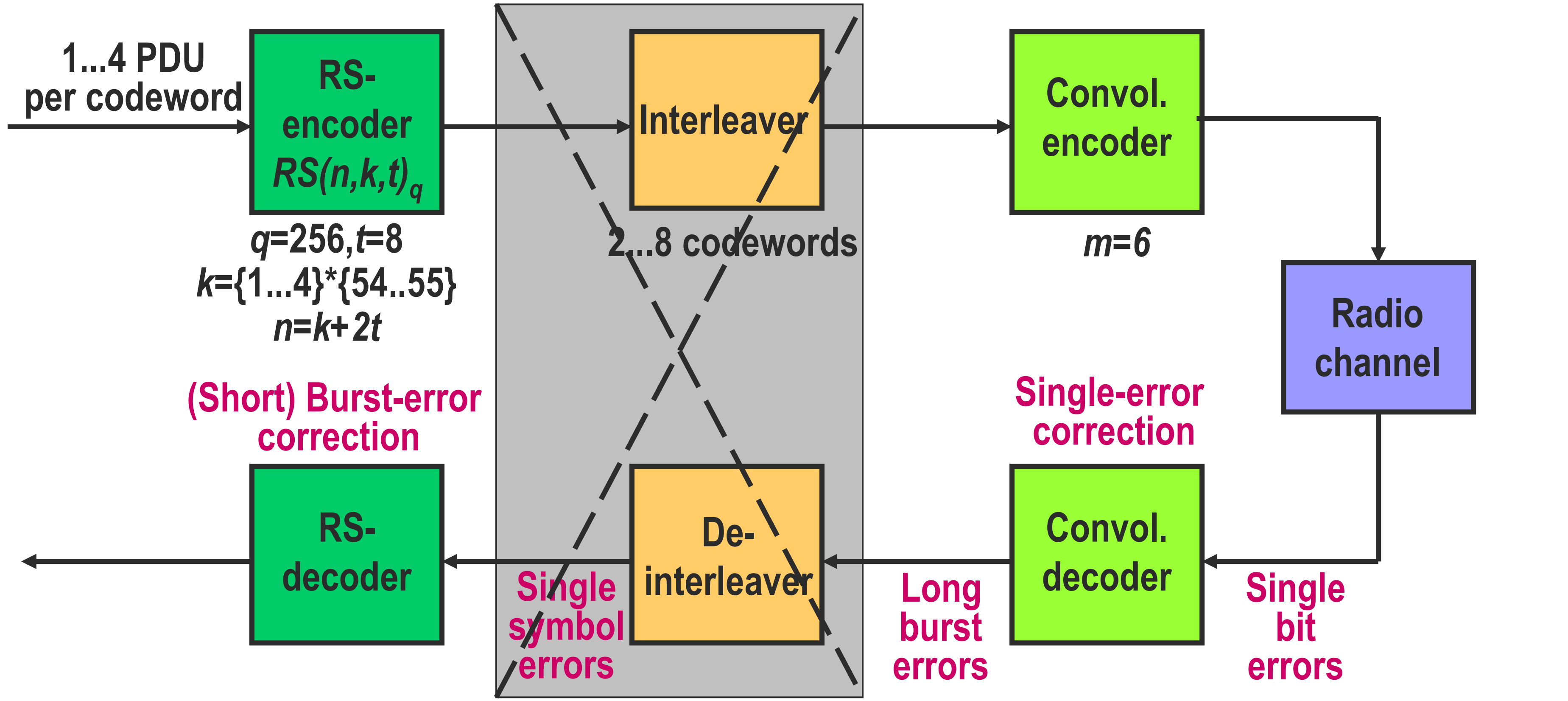
Error Control Coding (2 of 3)
Concatenated RS*CC - Interleaving not Possible!



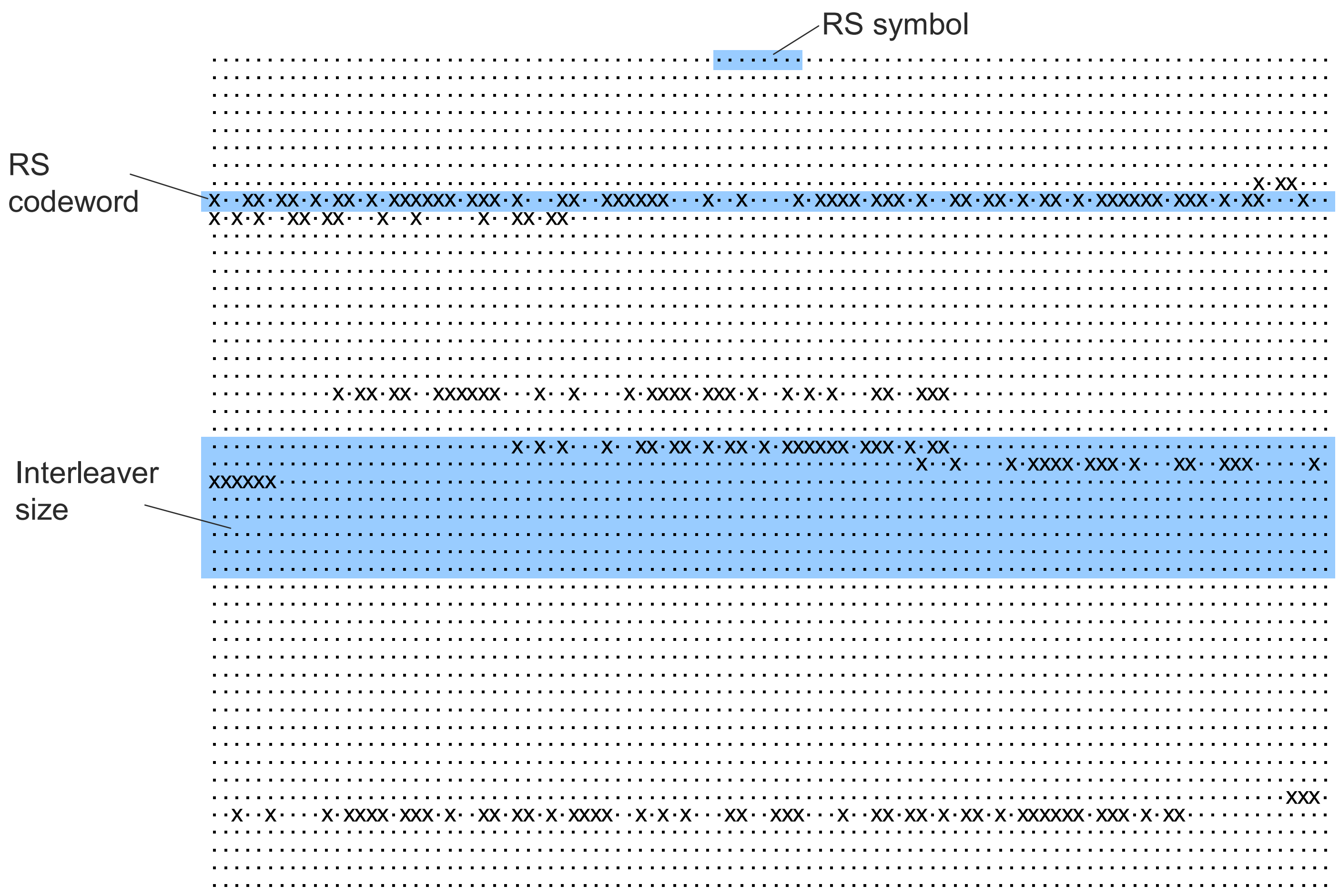
Interleaving improves link budget by several dB, but is not applicable for TDM / TDMA

- DL: partly possible within PHY mode region, but regions can be short
- UL: not possible (a burst could consist only of a single PDU or even less), same for Turbo codes

DL improvement only does not help (UL is more critical in terms of TX power and interference)

Error Control Coding (3 of 3)
Burst Error Statistics

Measured error pattern @ output of convolutional decoder = input of RS decoder



Remarks: RS codeword and interleaver size are shown symbolically, the true length is larger
Results from punctured convolutional code with rate-7/8 and m=6 at E_b/N_0=3.5 dB (mode#3)

Adaptive Operation - PHY Mode Change

Adaptation according to

- *d* = distance (fixed)
- *I* = interference (slow in DL, fast in UL)
- *N* = noise (representing link budget *C/N*)
- L_{rain} = rain fading (fast, 20 dB/s)

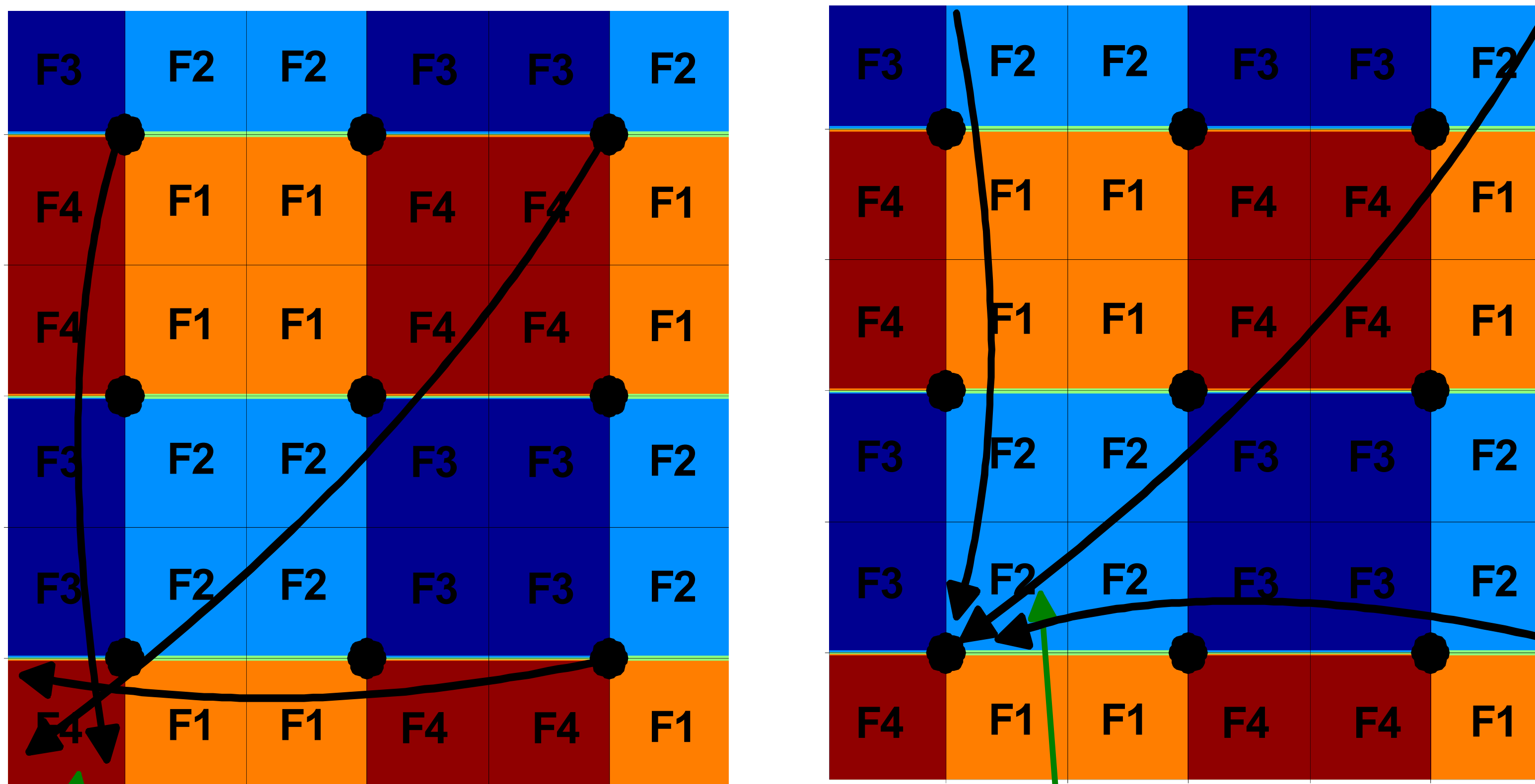
Mechanisms

- PHY mode change per terminal
- PHY mode change per frame
- combined with ATPC (Adaptive Transmit Power Control)

Control loop

- decided centrally by AP
- based on
  - measurement reports from AT
  - received signal in AP
- commanded as
  - announcement in DL map for DL,
  - granted per UL map for UL

Interference in Downlink and Uplink



DL worst sector

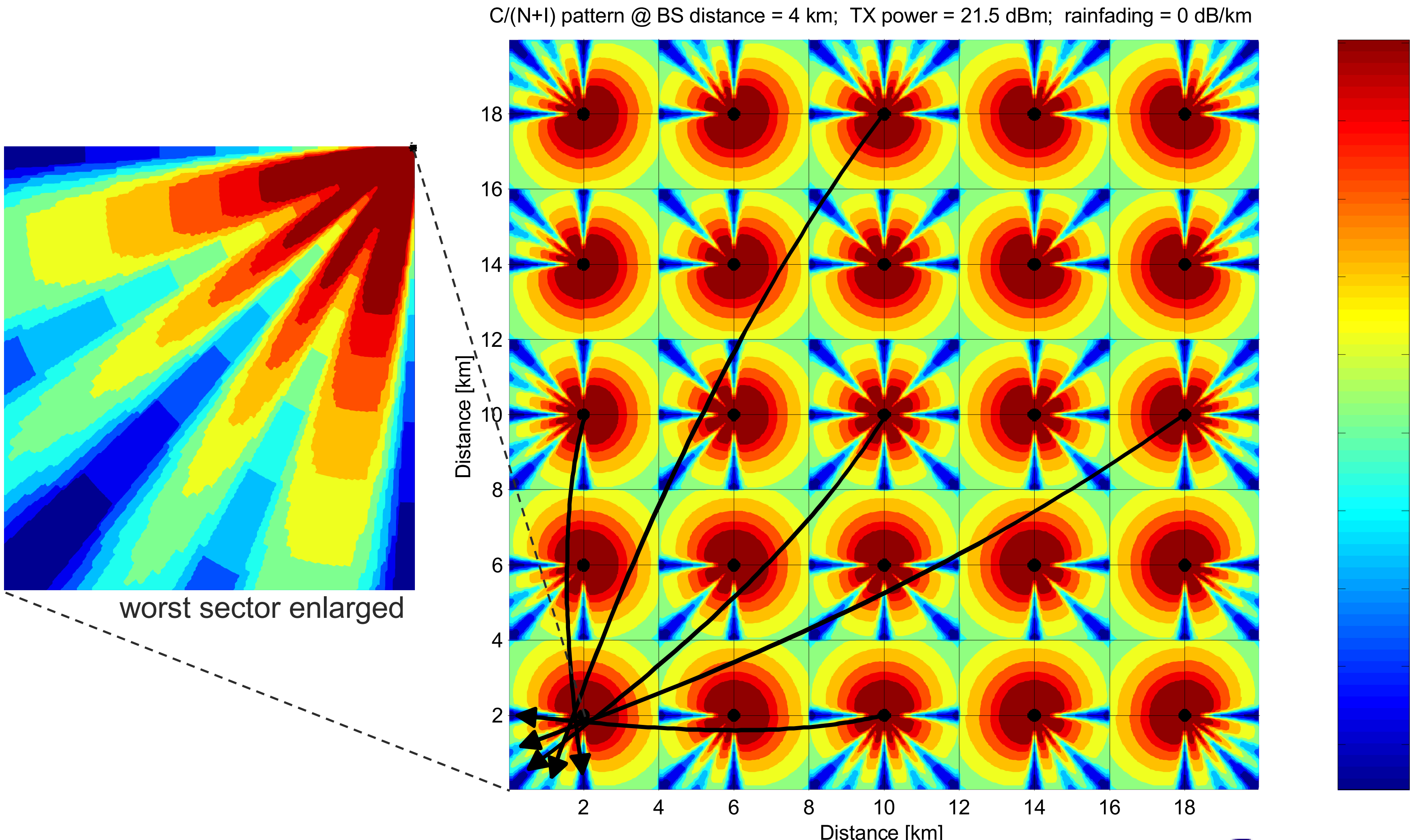
$(C/I)_{min}$ = 20*log(5) = 14.0 dB

UL worst sector

Interference degradation typically depends on direction

- **a sector may have poor properties for DL but good properties for UL**
- **interference is time-invariant for DL and time-variant for UL**

C/(N+I) Pattern for 5x5 Rectangular Constellation (Downlink, ClearSky, ReUseFactor =4)



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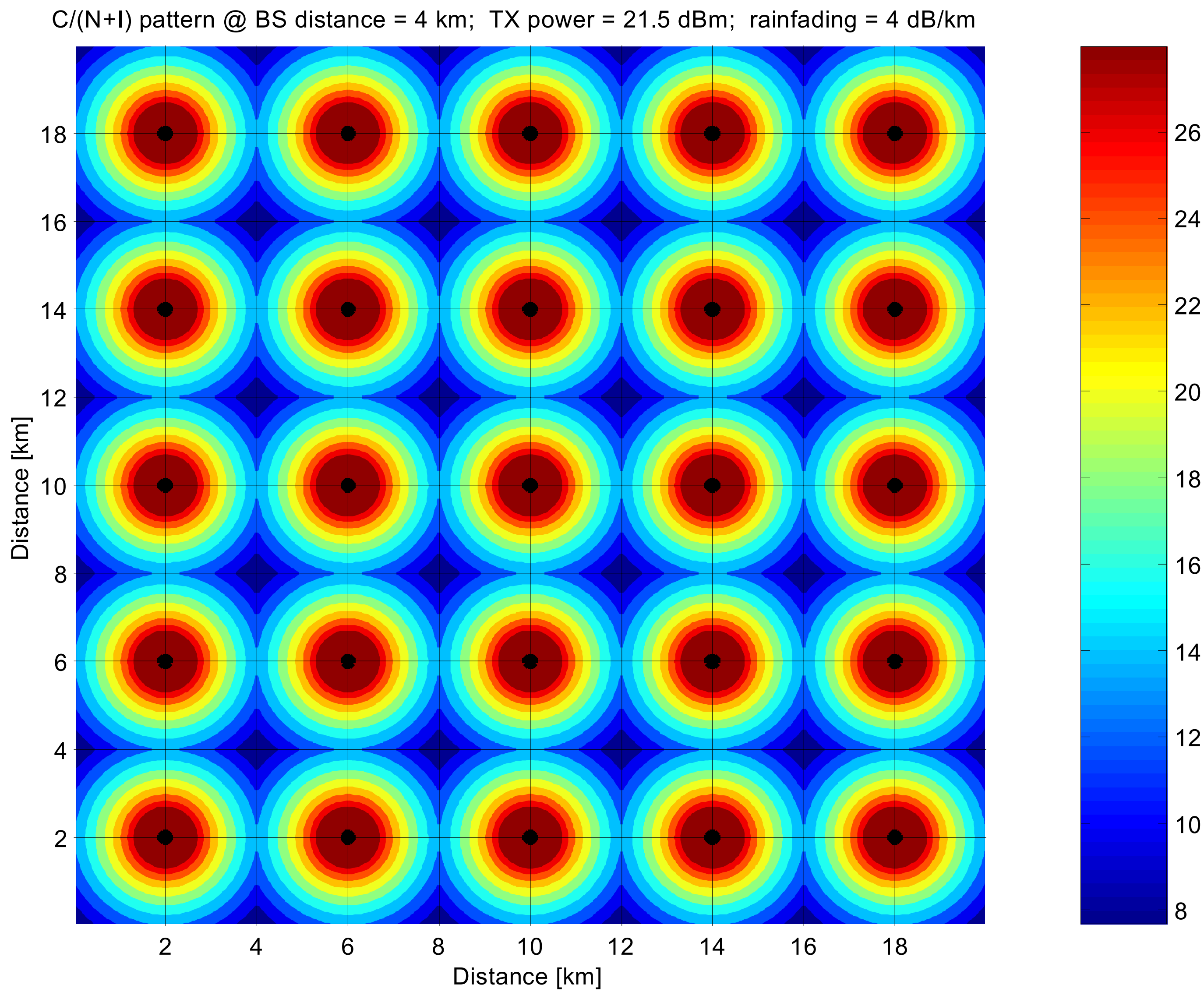
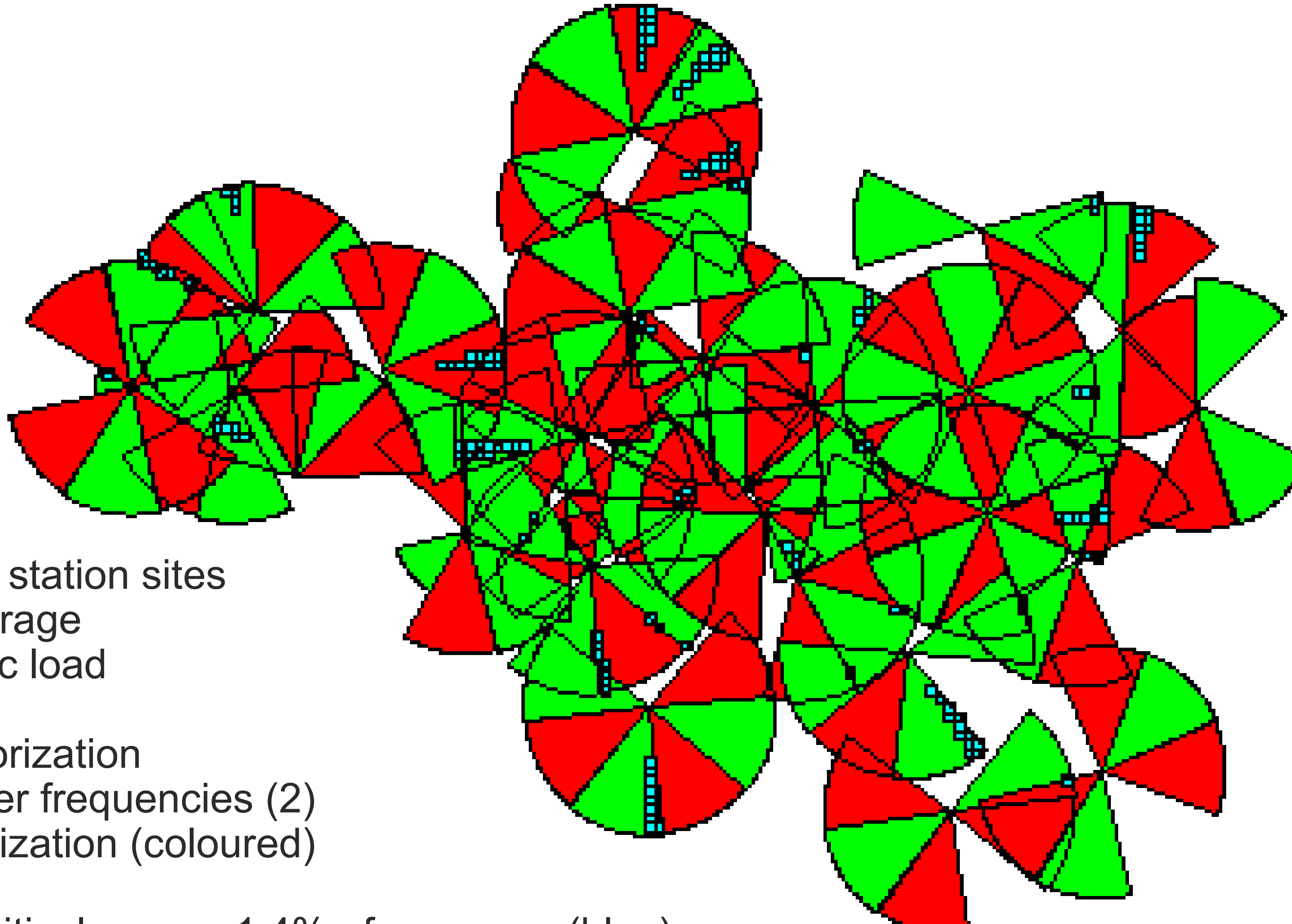
C/(N+I) Pattern for 5x5 Rectangular Constellation (Downlink, RainFading, ReUseFactor =4)



Marconi's Radio Network Planning Tool (Realistic Constellation with 142 Sectors)



Input: Base station sites
Coverage
Traffic load

Output: Sectorization
Carrier frequencies (2)
Polarization (coloured)

Interference critical zone = 1.4% of coverage (blue)

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Intermediate Summary

Throughput (= total data rate = capacity) per sector

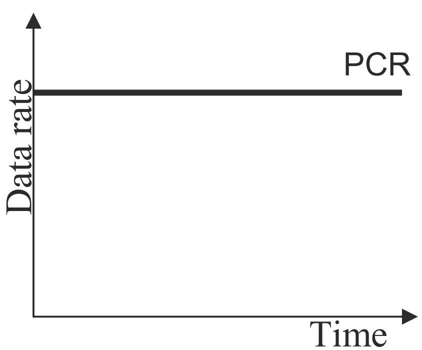
- Combine *C/(N+I)*-pattern and terminal distribution to calculate a more „realistic“ throughput

- However, this still ignores the statistical and QoS-parameters (Quality of Service) of different traffic types...

ATM Service Classes

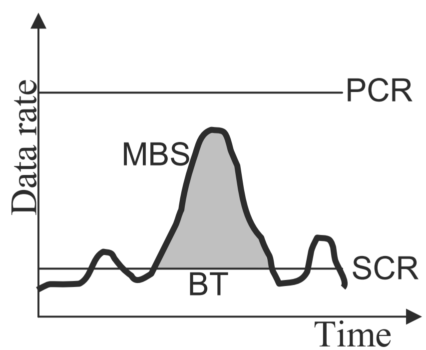
	Traffic parameter				QoS Parameter		
ATM service category	**PCR** (peak cell rate)	**SCR** (sustainable cell rate)	**MBS** (maximum burst size)	**MCR** (minimum cell rate)	**CDV** (cell delay variation)	**CTD** (cell transfer delay)	**CLR** (cell loss rate)
CBR (constant bit rate)	m				m	m	m
rt-VBR (realtime variable bit rate)	m	m	m		m	m	m
nrt-VBR (non-realtime variable bit rate)	m	m	m				m
ABR (available bit rate	m			m			o
UBR (unspecified bit rate)	o						

m=mandatory, o=optional



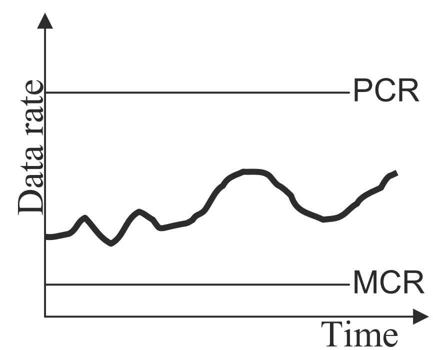
CBR

Guarantee of constant bit rate



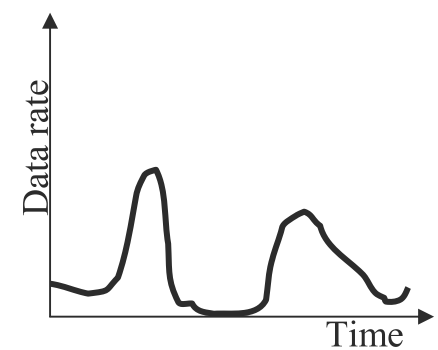
VBR

Guarantee of average and peak data rate



ABR

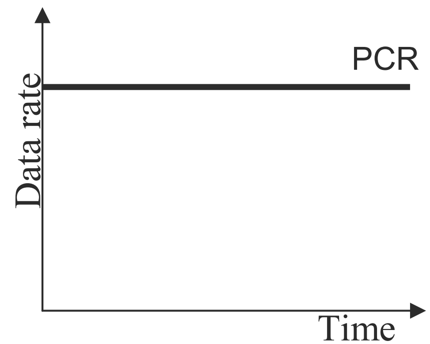
Guarantee of minimum data rate, burst-type, delay-independent



UBR

No guaranteed date rate, low-priority, best effort

Sector Capacity for CBR (Constant Bit Rate)



The data rate per AT

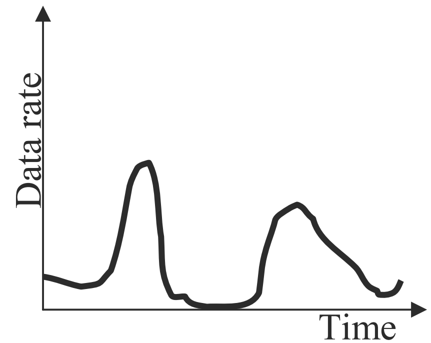
- **is constant: PCR = SCR = MCR**
- **shall be possible under worst-case conditions (rain fading, interference terminal distributions, signalling overhead, etc.)**

The sum of the data rates of all ATs must be smaller than the sector capacity

- **the sector capacity is determined by the worst-case conditions**

If there is only CBR traffic (and no mix with other traffic types), then adaptive operation is useless.

Sector Capacity for UBR (Unspecified Bit Rate)



The data rate

- **can be adapted to the actual channel conditions**
- **buffering of data before transmitting possible**

The sum of the data rates of all ATs must be smaller than the sector capacity

- **the sector capacity is defined by typical conditions (clear sky)**
- **capacity reductions by rain fading are almost negligible**
- **link loss by heavy rain fading occurs with small probability** $1\text{-}p_{availibility}$

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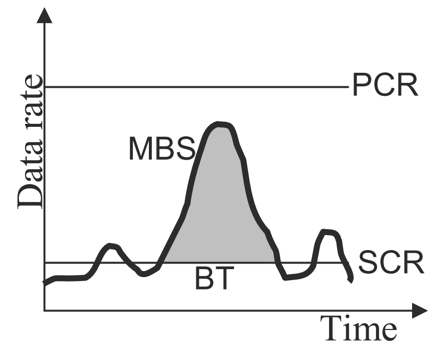
Sector Capacity for VBR (Variable Bit Rate)



The data rate is variable, varies around SCR

MBS (Maximum Burst Size) is maximum number of consecutive cells that a source can send at PCR

BT (Burst Tolerance) is approx. the time span allowed for PCR

$$\mathrm{BT} = \mathrm{MBS} \cdot \left(\frac{1}{\mathrm{SCR}} - \frac{1}{\mathrm{PCR}} \right)$$

average cell transmit interval

cell arrival interval

very difficult for analysis in contrast to CBR or UBR

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Statistical Multiplex Gain - Introduction

Due to the bursty nature of traffic (especially in case of VBR), not all ATs transmit at the same time with their peak data rates.

- Peaks of different ATs will coincide only with small probability.
- A PMP system performs like a virtual multiplexer:

Statistical multiplexing with a small CLR (cell loss rate) allows higher total data rates than fixed allocation guaranteeing peak data rates. Formally,

$$G = \frac{\text{throughput with statistical multiplex}}{\text{throughput with static collision-free multiplex}}$$

The multiplex gain of a PMP system increases with

- larger bandwidth
- larger number of ATs
- higher burstiness (measured by PCR/SCR)
- tighter delay constraints (measured by CDV, CTD)

Statistical Multiplex Gain - Definitions

Let

$r_s = r_s(t)$ = max. data rate per sector (throughput, capacity), may depend on time

N = number of ATs (users)

X_i = r.v. describing the time-variant requested data rate (DL or UL)

$$S_N = \sum_{i=1}^{N} X_i = \text{total data rate requested by all ATs}$$

Average data rates (SCR): $E(X_i) = r_a, \quad E(S_N) = N \cdot r_a$,

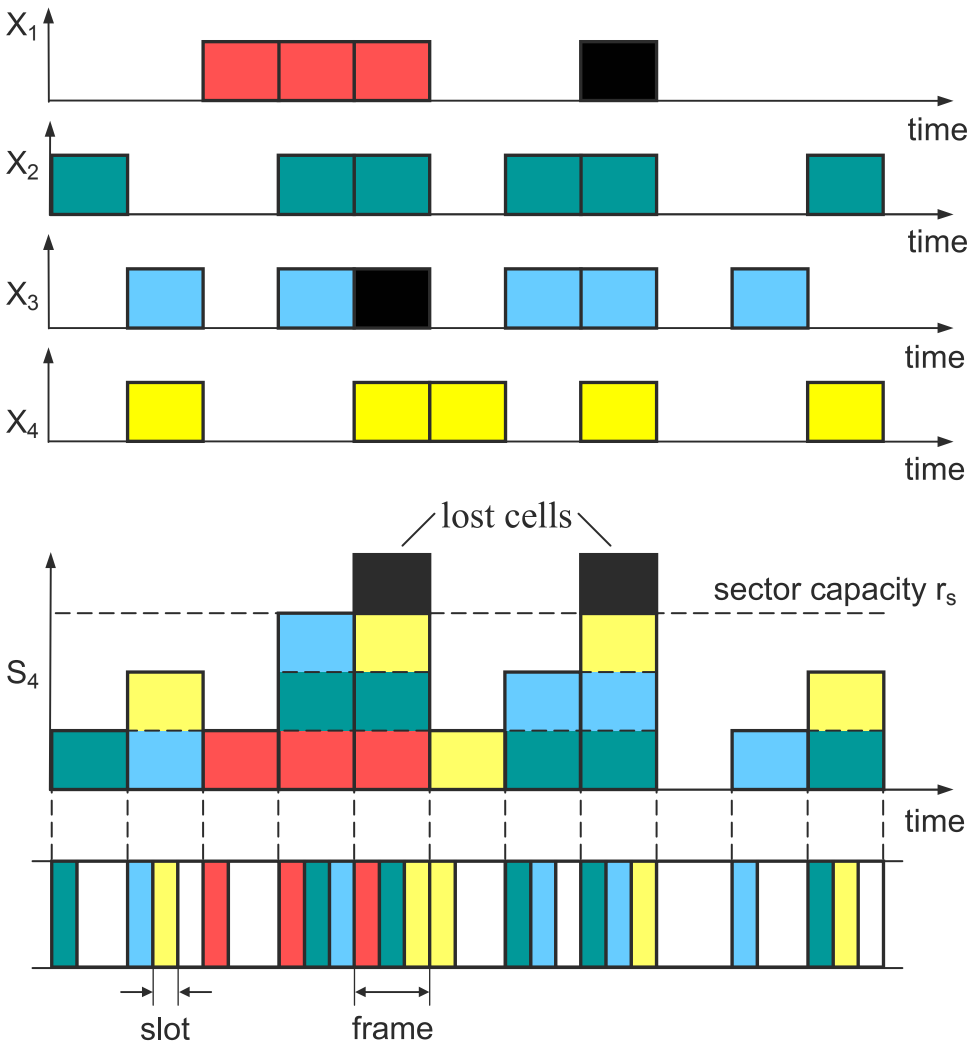
Peak data rates (PCR): $\max X_i = r_p, \quad \max S_N = N \cdot r_p$

Standard deviations: $D(S_N) = \sqrt{N} \cdot D(X_i)$

Define

$$b = \frac{r_p}{r_a} = \frac{\text{PCR}}{\text{SCR}} = \text{burstiness}$$

Simple On-Off Model



Model:

- zero or one cell per AT per frame
- number of cells = number of active ATs
- a cell is considered as lost if an immediate transmission is not possible

$$P(\text{AT active}) = P(X_i = r_p) = \frac{1}{b}$$

$$P(\text{AT passive}) = P(X_i = 0) = 1 - \frac{1}{b}$$

Hence,

$$r_a = E(X_i) = \frac{r_p}{b}, \quad D(X_i) = \sqrt{1 - \frac{1}{b}} \cdot r_p$$

$$b = \frac{r_p}{r_a} = \text{burstiness}$$

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Statistical Multiplex Gain Theory (1 of 2)

For a static collision-free allocation of resources, $\max S_N = N \cdot r_p \le r_s$ must be guaranteed.

Hence

$$N_{cf} = \frac{r_s}{r_p} = \text{number of cells that can be transmitted without any losses}$$

Let

$$N_{eff} = \text{number of cells that can be transmitted with a certain CLR}$$

and this bounded as $N_{cf} \le N_{eff} \le \frac{r_s}{r_a} = b \cdot N_{cf}$

The **statistical multiplex gain** G with respect to a specific CLR is defined as

$$G = \frac{N_{eff}}{N_{cf}} = \frac{\max \#\text{users with statistical multiplex}}{\max \#\text{users with static collision} - \text{free multiplex}} \in [1, b]$$

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

Another important parameter is the **spectrum utilization** U, defined as

$$U = \frac{\text{average total data rate in sector with statistical multiplex}}{\text{total sector rate}} = \frac{N_{eff} \cdot r_a}{r_s} = \frac{G}{b} \in [0,1].$$

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Statistical Multiplex Gain Theory (2 of 2)

A perfect DLC layer is assumed: so it is always guaranteed to transmit up to the maximum number of N_{cf} cells and only the exceeding cells are declared as lost:

$$CLR = \frac{\text{average number of lost cells}}{\text{average total number of cells to be transmitted}} = \frac{E(L)}{E(S_{Neff})},$$

where

S_{Neff} = total number of cells to be transmitted and

$L = \max(0, S_{Neff} - N_{cf})$ = number of lost cells.

Obviously, S_{Neff} has a binomial distribution, hence, the exact expression for CLR is

$$CLR = \frac{\sum_{k>N_{cf}}^{N_{eff}} (k - N_{cf}) \cdot \binom{N_{eff}}{k} \cdot \left(\frac{1}{b}\right)^{k} \left(1 - \frac{1}{b}\right)^{N_{eff}-k}}{N_{eff} \cdot / b}$$

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

For given parameters r_a/r_s and b and CLR, N_{eff} is the maximum integer such that the ratio above is less or equal to *CLR*.

Statistical Multiplex Gain Numerical Evaluation (1 of 2)

The evaluation of the binomial terms is not a trivial for large N_{eff} (e.g. >1000...10000), several approximations can be found in the literature.

Approximation 1.

CLR is (i) replaced by the probability of collisions and (ii) S_{Neff} is approximated as Gaussian:

$$CLR \approx P(S_{Neff} > N_{cf}) \approx Q\left(\frac{N_{cf} - N_{eff}\frac{1}{b}}{\sqrt{N_{eff}\frac{1}{b}\left(1-\frac{1}{b}\right)}} \right)$$

This equation can be solved for G analytically by some simple manipulations:

$$G = \frac{b \cdot r_a / r_s}{4} \cdot \left(\sqrt{\frac{4}{r_a / r_s} + \alpha^2 (b-1)} - \alpha\sqrt{b-1} \right)^2 \quad \text{where } \alpha = Q^{-1}(\text{CLR})$$

Approximation 2.

Using Lindberger's equations (let $l = -2\log_{10}(CLR)$ and $a = 1 + l/100$):

$$\frac{1}{U} = \frac{b}{G} = \begin{cases} a(1+3z(1-1/b) & \text{for } z \le \min(1, b/3) \\ a(1+3z^2(1-1/b)) & \text{for } 1 \le z \le \sqrt{b/3} \\ a \cdot b & \text{otherwise} \end{cases} \quad \text{where } z = l \cdot b \cdot r_a / r_s$$

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Statistical Multiplex Gain Numerical Evaluation (2 of 2)

Exact calculation.

Combination:

(i) exact computation of the binomial terms (for N_{eff} <1000),

(ii) for larger values of N_{eff} use exact evaluation of a Gaussian approximation as follows:

$$CLR \approx \frac{E(\max(0, N_{Neff,Gaussian} - N_{cf}))}{E(N_{eff})} \quad \text{(approximation for large } N_{eff} \text{ only)}$$

$$= \frac{(\mu - N_{cf})Q\left(\frac{N_{cf}-\mu}{\sigma}\right) + \frac{\sigma}{\sqrt{2\pi}}\exp\left(-\frac{(N_{cf}-\mu)^2}{2\sigma^2}\right)}{\mu} \quad \text{(exact)}$$

$$\text{where } \mu = E(S_{Neff}) = \frac{N_{eff}}{b}, \quad \sigma^2 = N_{eff}\frac{1}{b}\left(1-\frac{1}{b}\right)$$

Statistical Multiplex Gain
Numerical Results (1 of 4) - Overview

The following three Figures show *G* and *U*

- for various values of *b* = burstiness
- for CLR = 10^{-6}
- Solid lines show exact results
- Dotted lines show results using approximation 1

Overview

- *G* over SCR/Sector rate
- *G* over PCR/Sector rate
- *U* over SCR/Sector rate

Remark: high *G* or *U* requires high sector rate (bandwidth) compared to

- SCR (approx. factor of 1000...10000)
- PCR (approx. factor of 10...100)

This is exactly the range, where exact calculation of *G* is important

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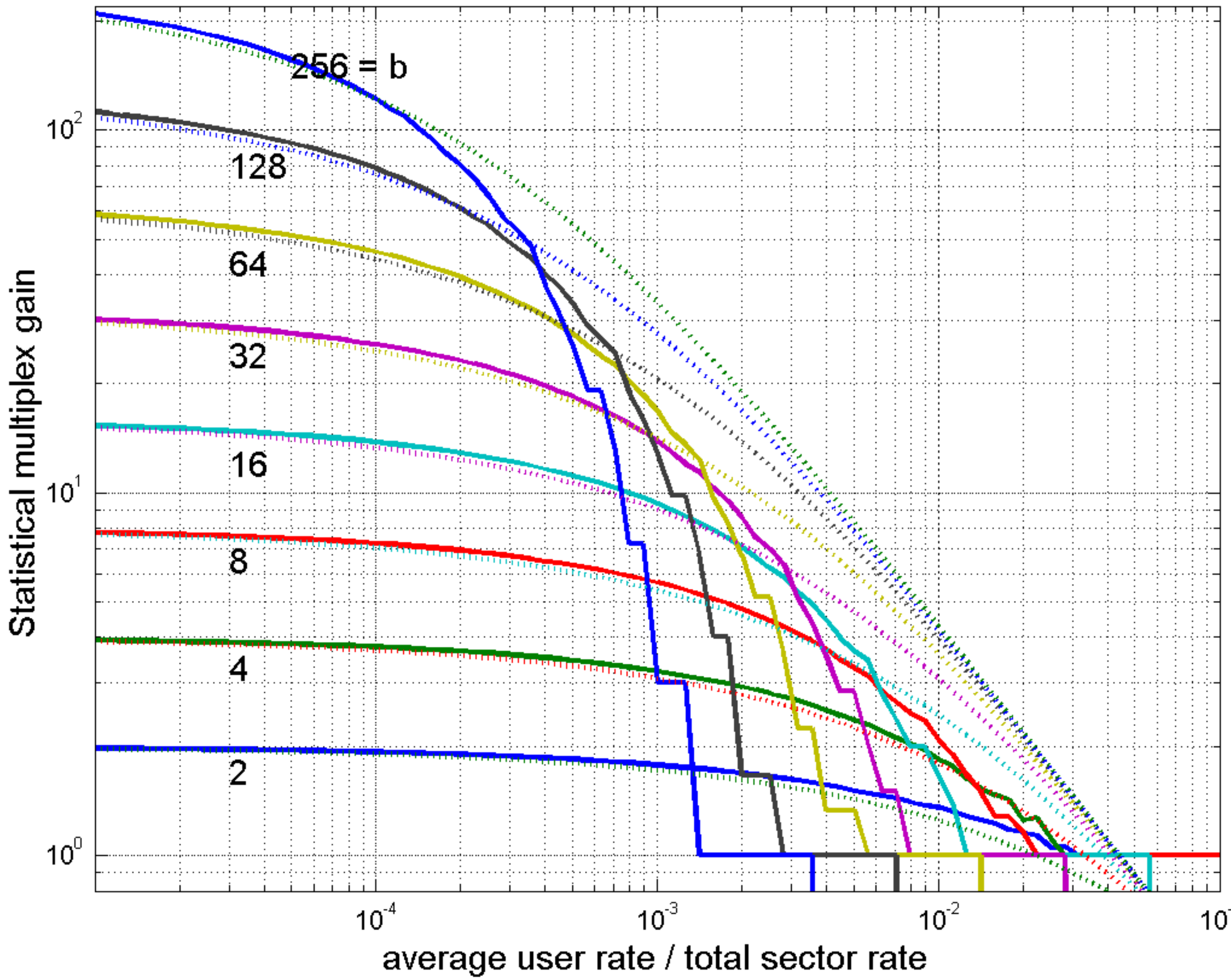
Statistical Multiplex Gain
Numerical Results (2 of 4) - *G* over r_a/r_s



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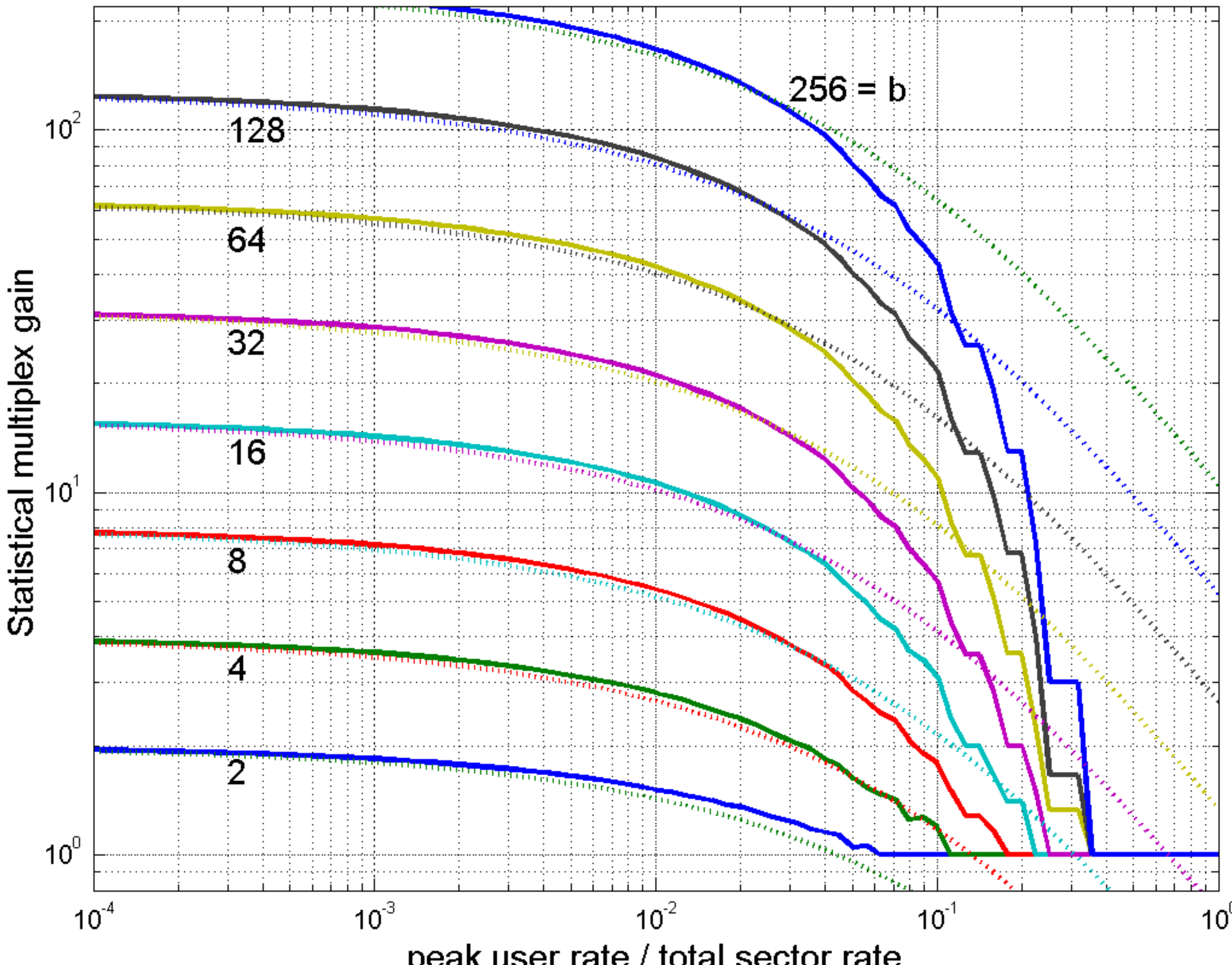
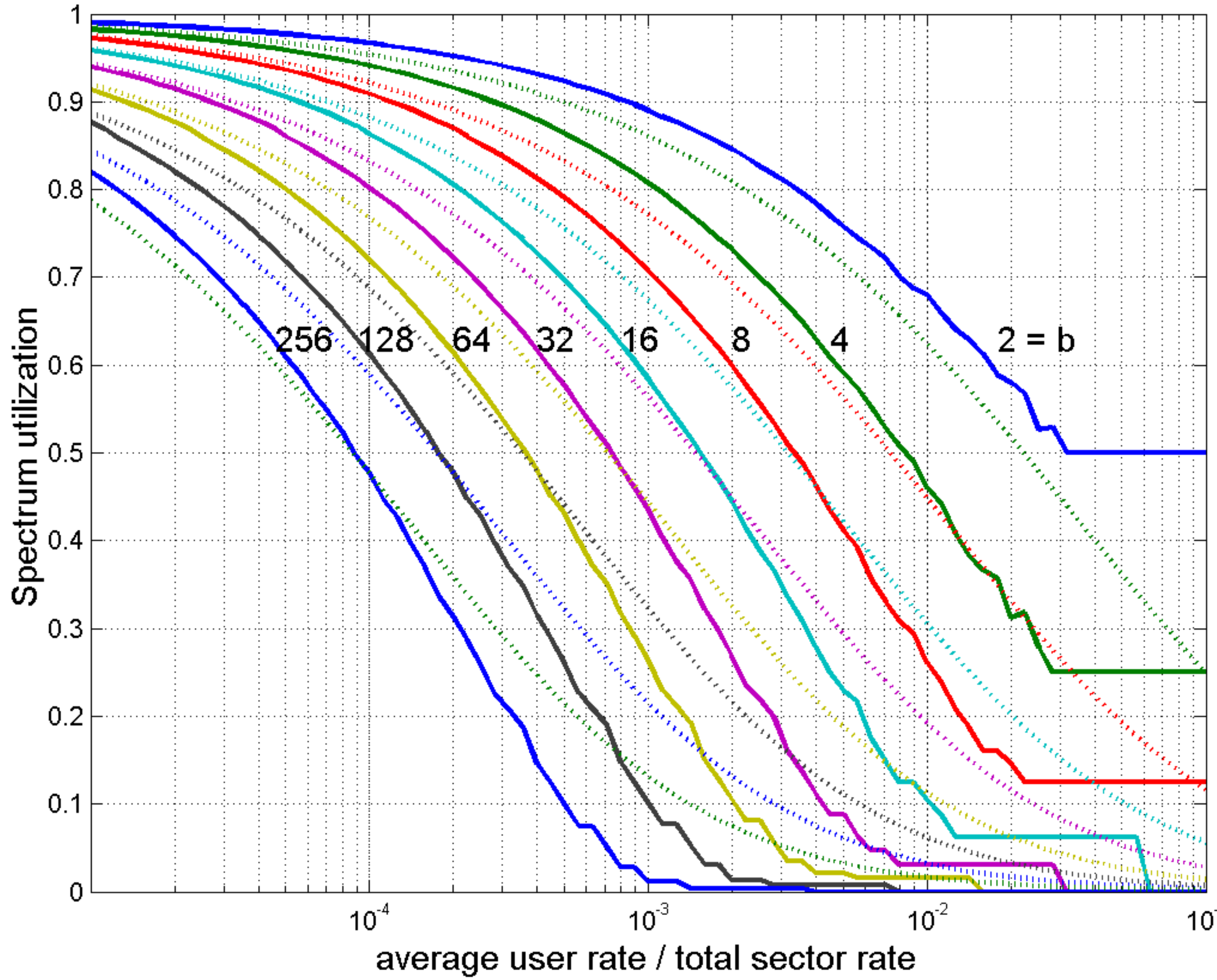
Statistical Multiplex Gain
Numerical Results (3 of 4) - G over r_p/r_s



Statistical Multiplex Gain
Numerical Results (4 of 4) - U over r_a/r_s



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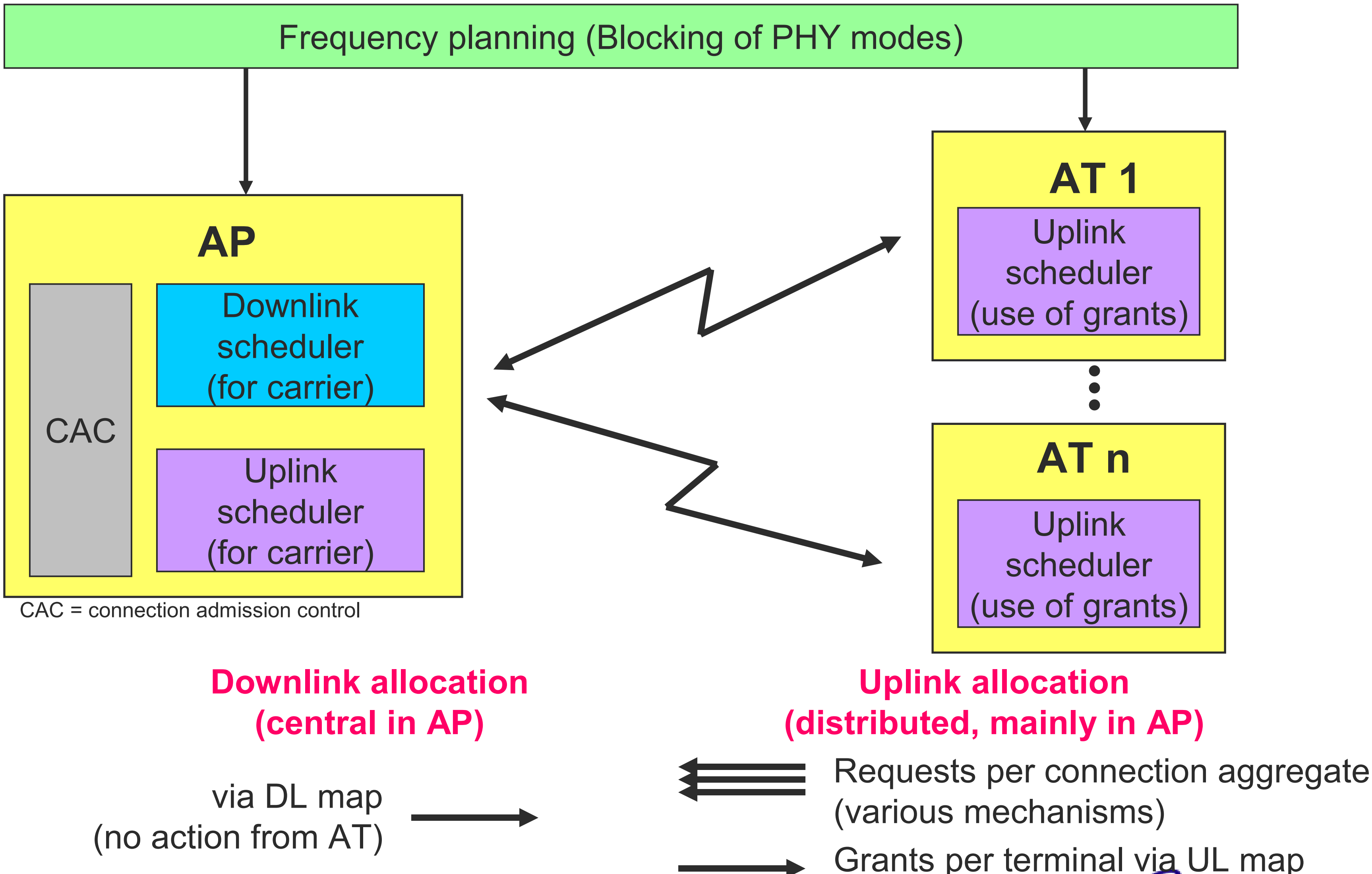
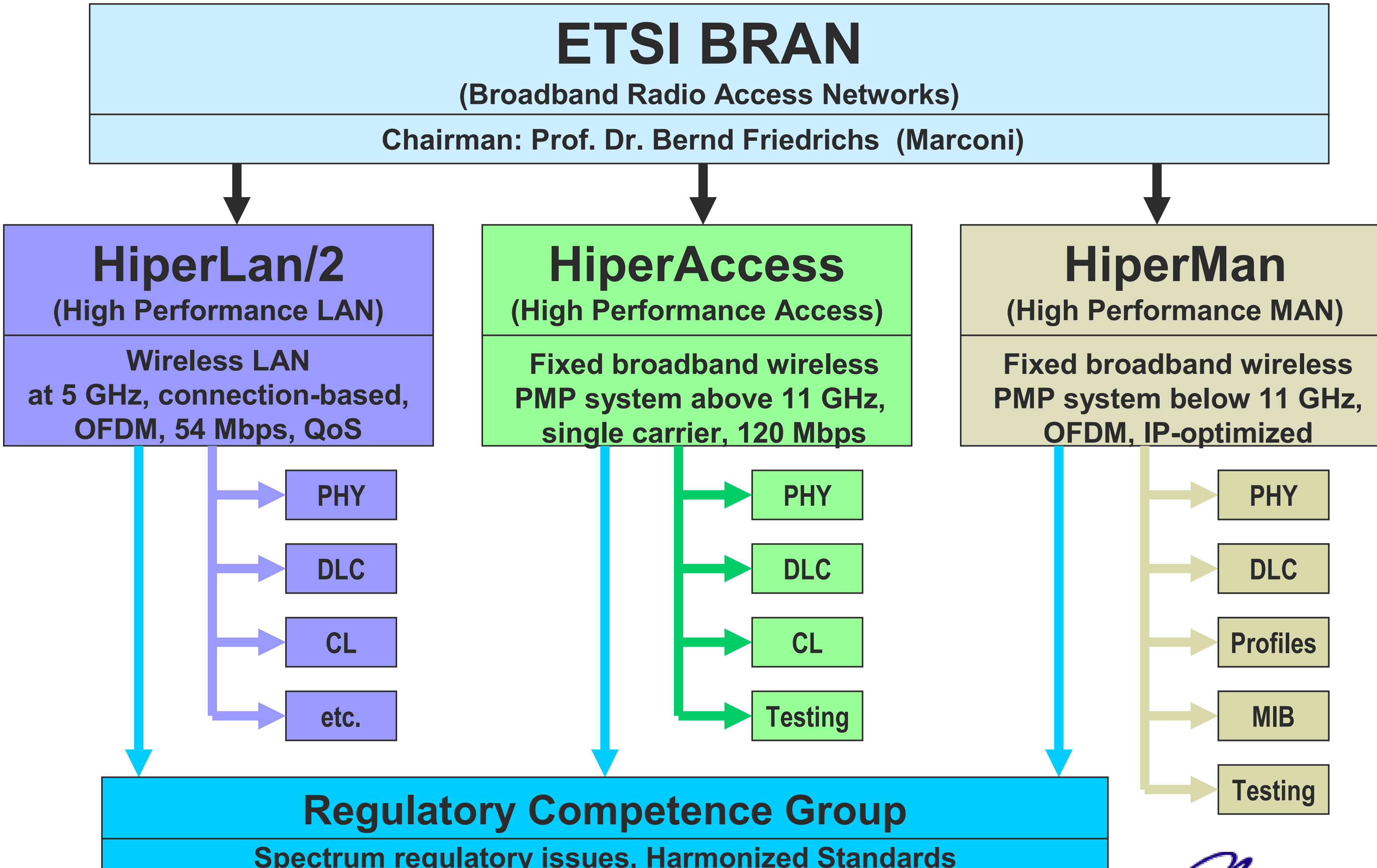
Realization of high Multiplex Gain requires efficient and fast Bandwidth Allocation Schemes



ETSI BRAN Interoperable Standards



Conclusions

System capacity depends on a huge number of parameters

Very simple approximation of VBR traffic

- what about more delay tolerance?
- traffic mix?

Real system performance mainly depends on

- algorithms for adaptive operation
- scheduling mechanisms
- frequency planning

Standardization focus on

- PHY layer - to ensure efficiency and avoid harmful interference
- DLC layer - messaging
- Testing - for interoperability and certification
- Spectrum - to influence allocations and regulations

For more information ...

- **http://portal.etsi.org/bran**

- **bernd.friedrichs@marconi.com**
  (ETSI BRAN Chairman)

Appendix

BRAN Relationship with Other Bodies and Forums

- IEEE 802.xx
  - IEEE 802.11a ~ BRAN HL (same PHY layer)
  - IEEE 802.16+ ~ BRAN HA (harmonization under discusion)
  - IEEE 802.16a ~ BRAN HM (close co-operation)
- HiperLAN2 Gobal Forum
- ATM Forum
- CEPT
- 3GPP
- IETF (Internet Engineering Task Force)
- MMAC-PC (Multimedia Mobile Access Communication Systems - Promotion Council)
- ITU-R, ITU-T
- ETSI OCG, ETSI TM4, ETSI ERM

Why Do We Need Standards ?

- Active participation of many operators
  ➔ Optimized for important applications
  (Cellular backhaul, SME, SOHO, ...)

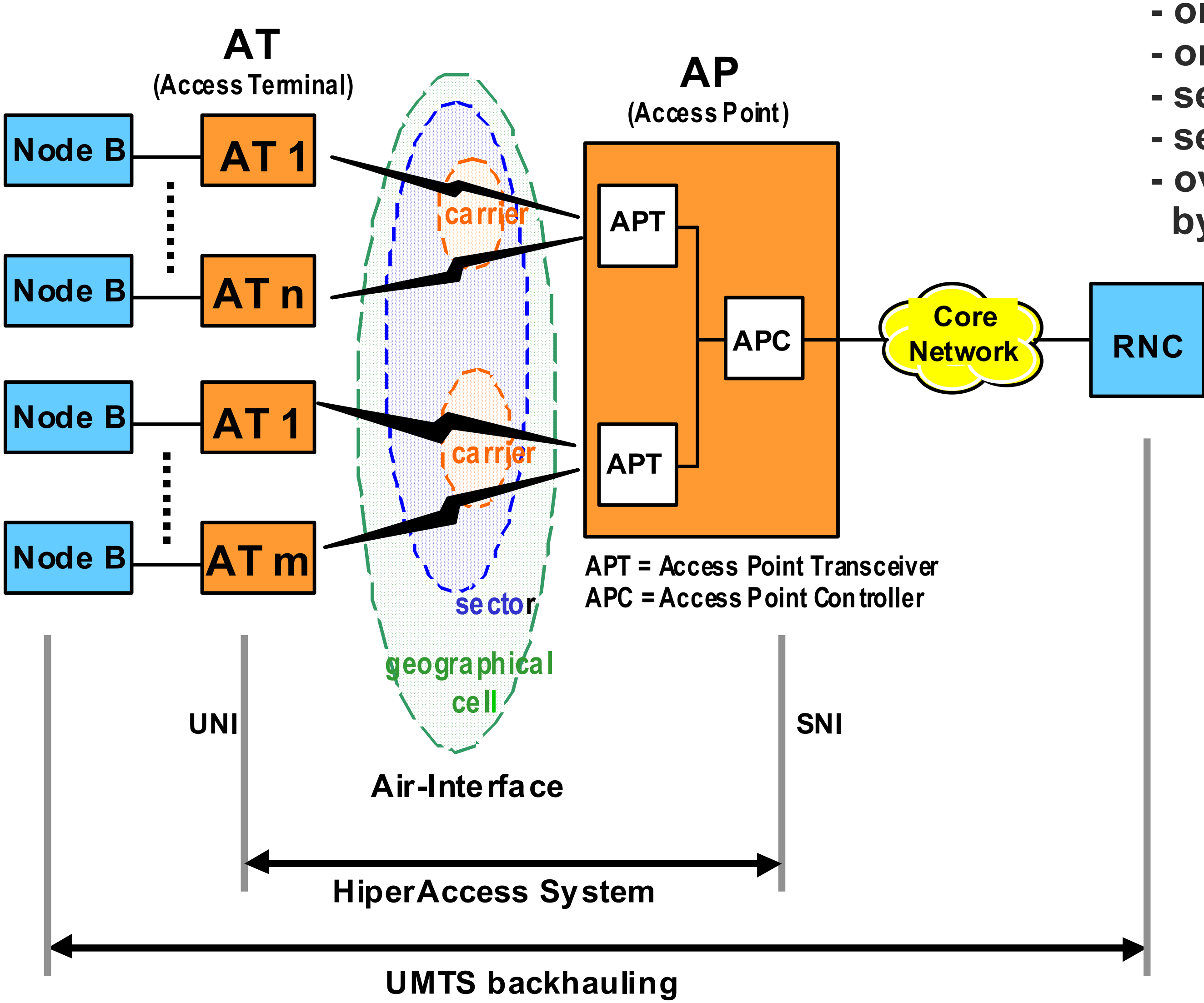
- Active participation of many manufacturers
  ➔ Low-cost and high performance
  (both for IP and ATM core networks)

- Low cost is critical for competiton with wireline access

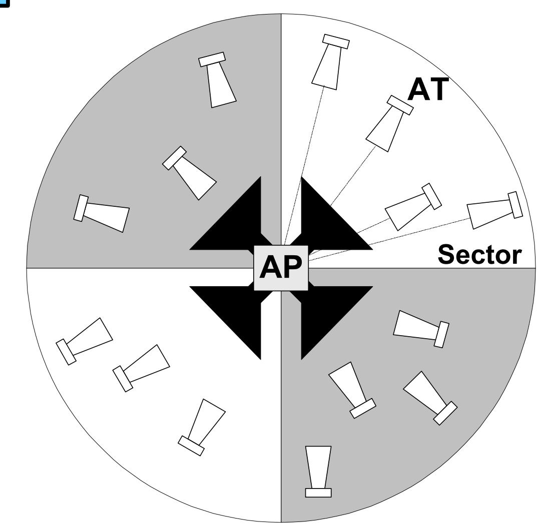
- Interoperable standard ➔ large volume ➔ low cost

- Other advantages of an interoperable standard
  - easy for customers to compare
  - flexibility for customers
  - increased competition ➔ low cost

HiperAccess: Network Topology Model

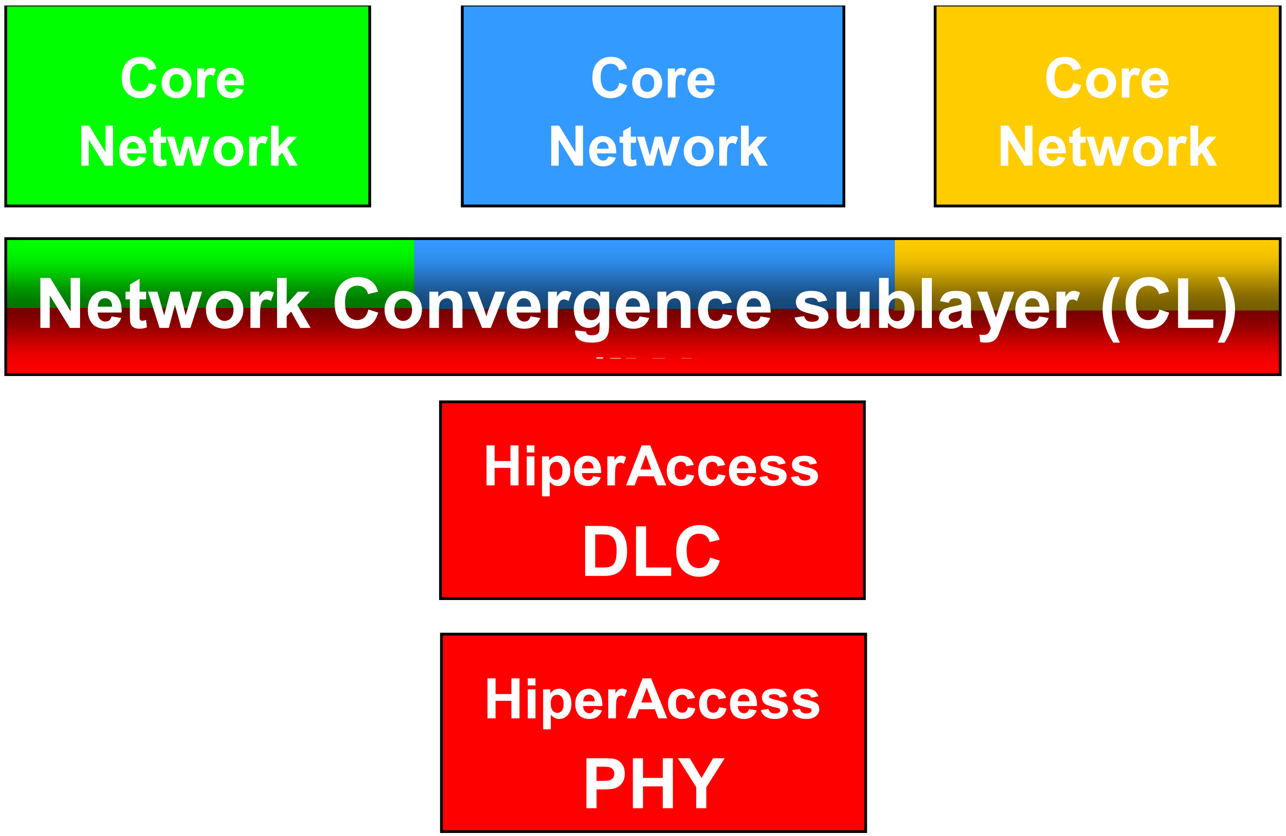


- one APT per carrier
- one APC per cell
- several sectors per cell
- several carriers per sector
- overlapping cells (separated by frequency or polarization)



Cell with four sectors

Interworking Approach



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

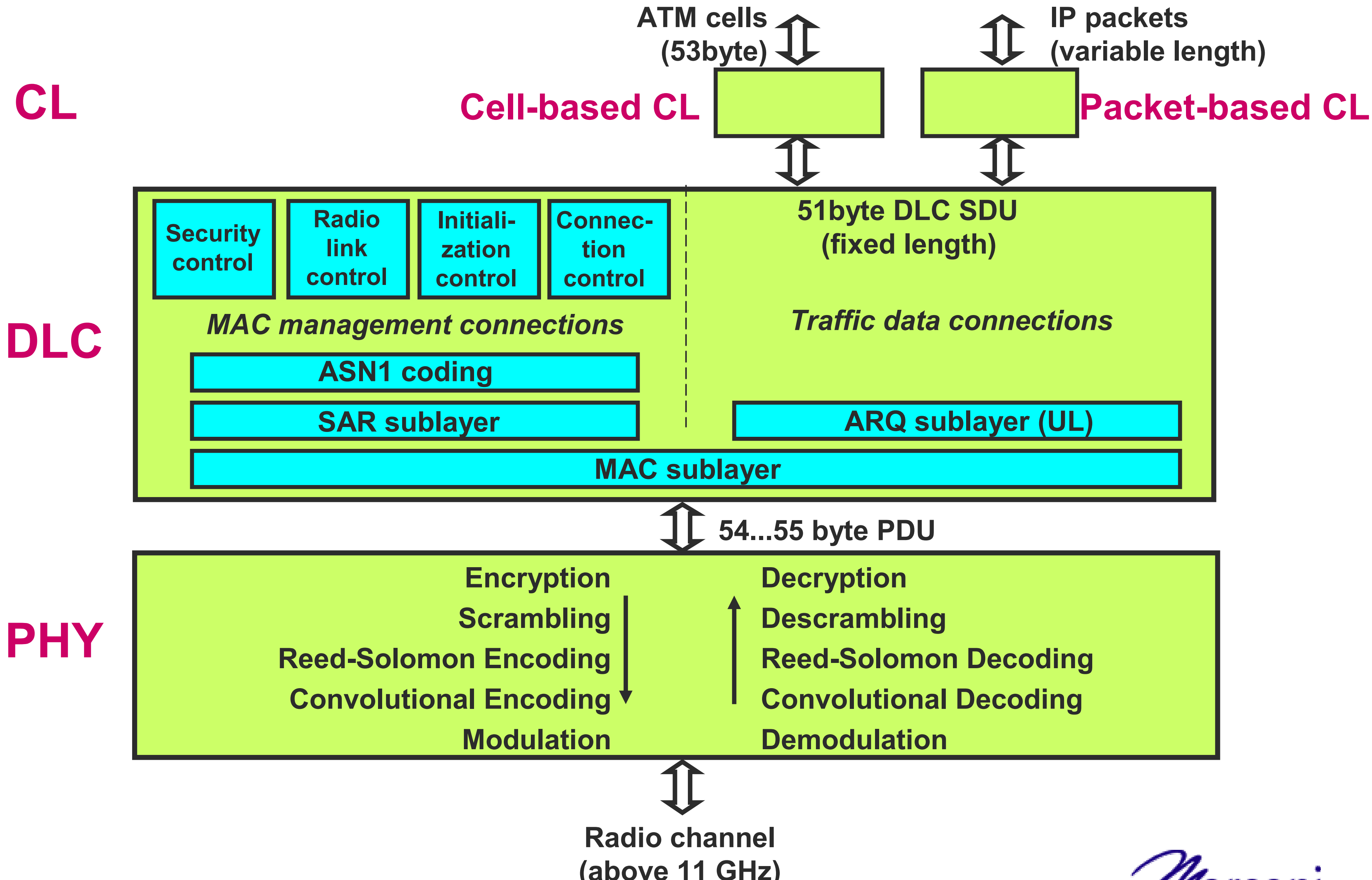
Removes differences between core networks

Matched to the requirements for supporting ATM and IP

Ensure cost-effective implementation and spectral efficiency

DLC and PHY layers are independent of the core network

HiperAccess: Detailed Layer Structure



HiperAccess: Basic Features

Focus on frequency bands

- 40.5 - 43.5 GHz
- 31.8 - 33.4 GHz
- 27.5 - 29.5 GHz
- 24.5 - 26.5 GHz
- other lower frequencies

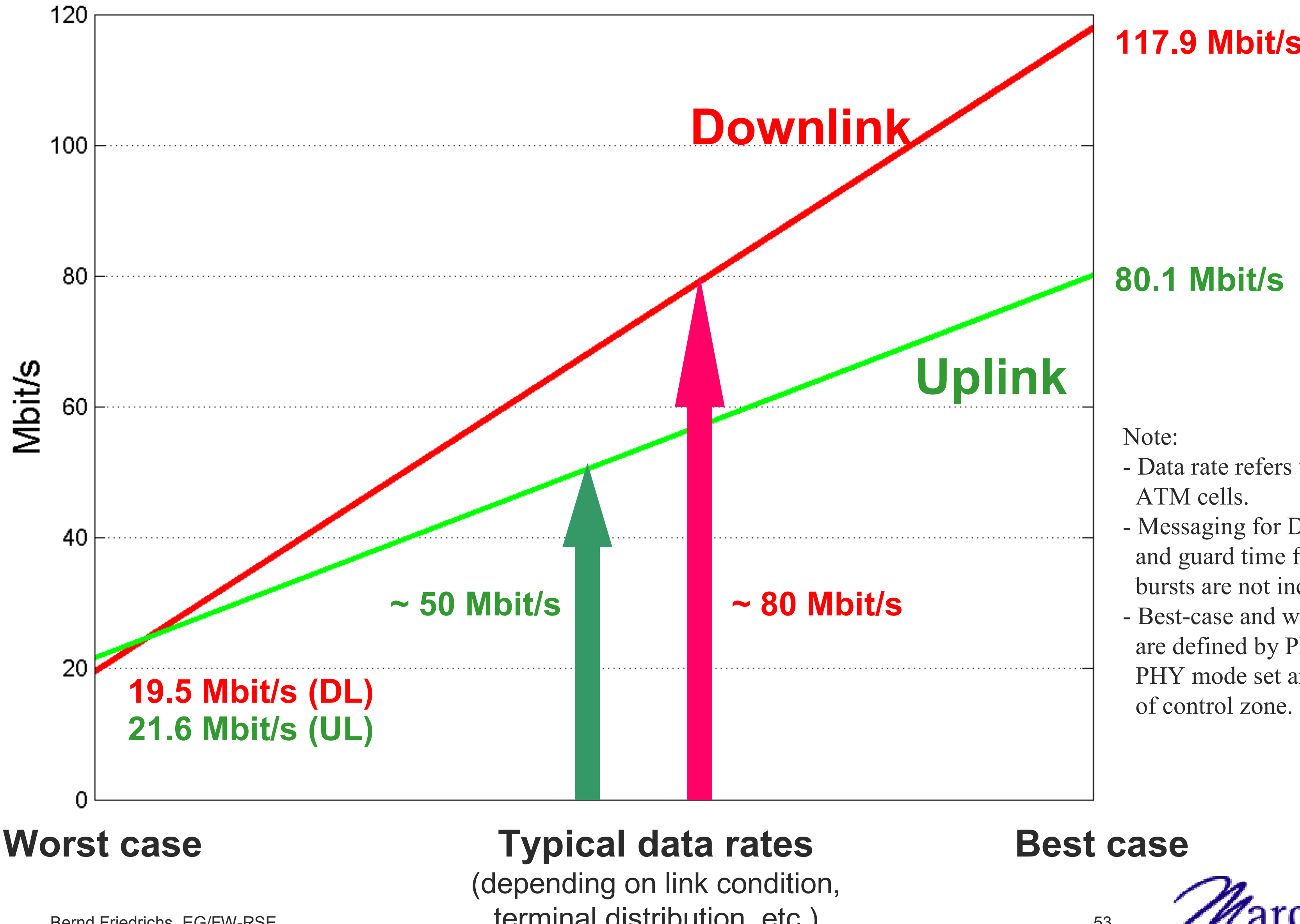
Channel size = 28 MHz, Baudrate = 22.4 MBaud

- Paired bands (FDD mode, fixed asymmetric rates)
- Unpaired bands (TDD mode, adaptive asymmetric rates)
- Optimum trade-off between costs, peak data rate and statistical multiplex gain

Important parameters

	Downlink (AP $\rightarrow$ AT)	Uplink (AT $\rightarrow$ AP)
Data rates (Mbit/s)	20...120 (typically 80)	20...80 (typically 50)
Transmit power	15 dBm	14 dBm
Range	up to 12 km (hard limit from ranging, effectively depending on availability and rain zone)	

Throughput: Best-, Typical-, and Worst Case



Note:
- Data rate refers to 53-byte ATM cells.
- Messaging for DL and UL and guard time for UL bursts are not included.
- Best-case and worst-case are defined by PHY mode, PHY mode set and length of control zone.

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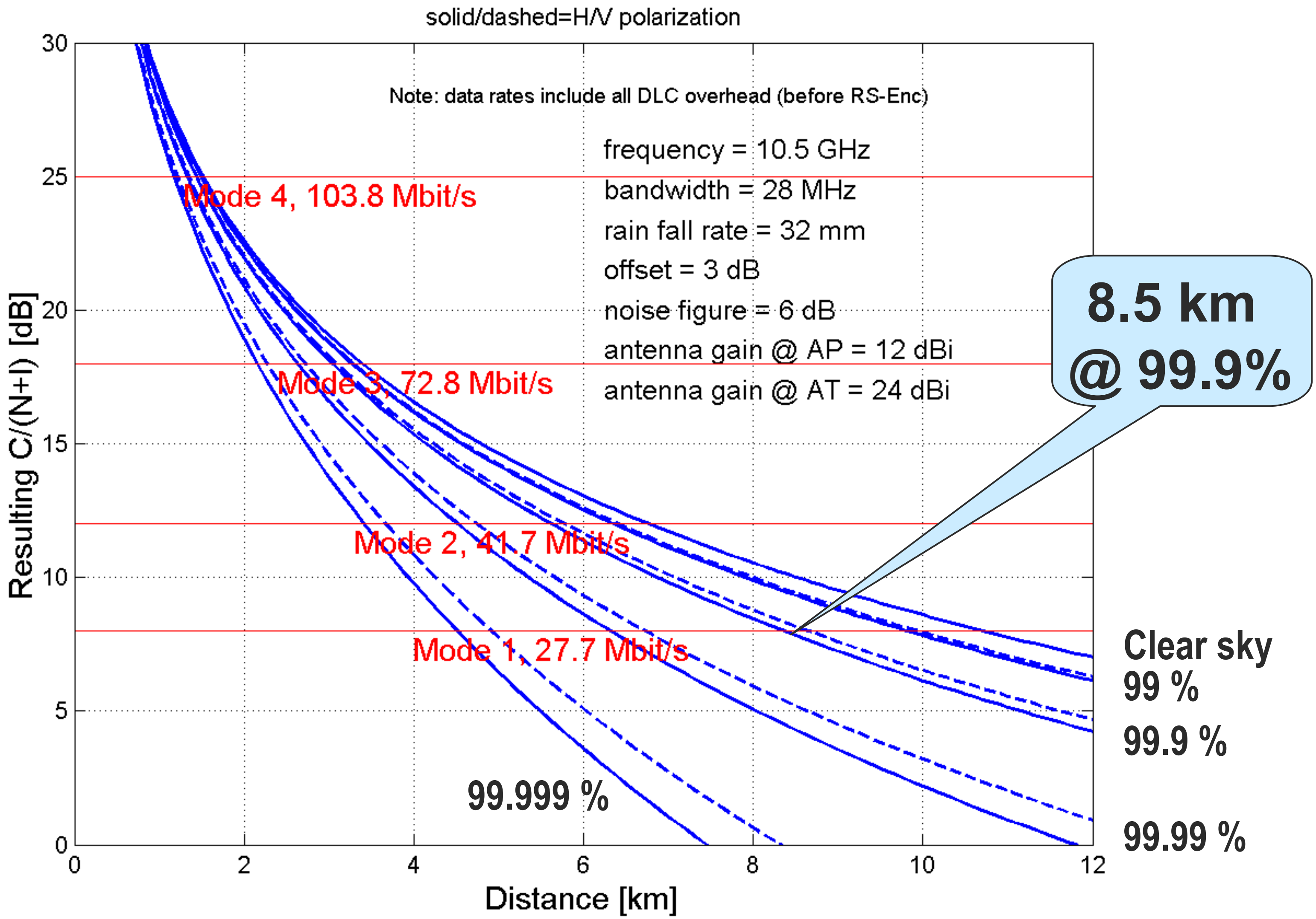
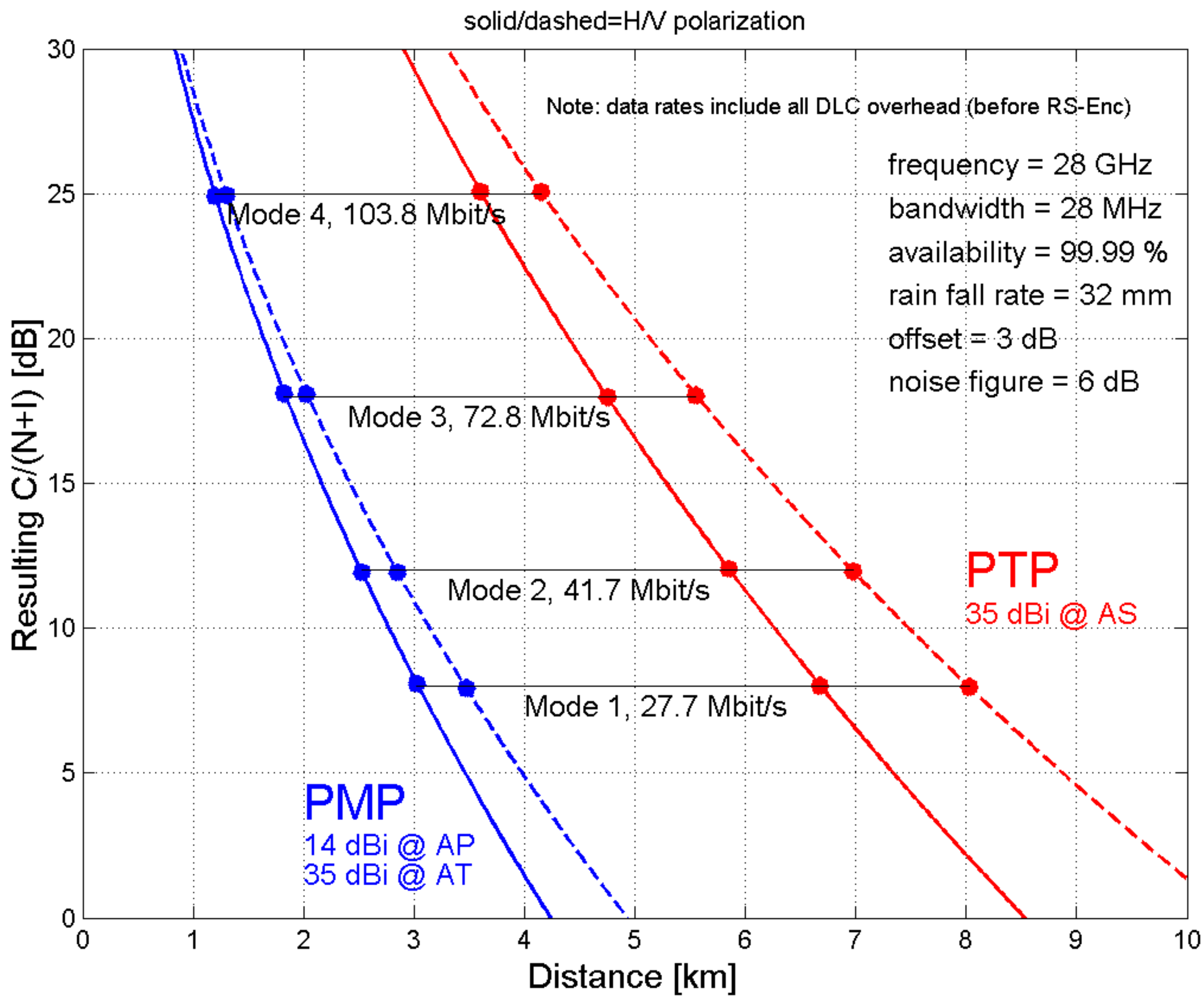
Range and Throughput for PMP @ 10.5 GHz for various availabilities



Range and Throughput: PMP versus PTP
@ 28 GHz, 15 dBm, 99.99%, rain zone H



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HiperAccess: Security (Privacy, Authentication)

Phased approach

- Phase 1: Fixed keys (to relax management requirements)
- Phase 2: Authentication and frequent key exchanges for high-level security
- Phase 3: Privacy for multicast

Algorithms

- Block ciphers: DES, 3DES, AES, CBC mode
- Hash functions: SHA-1
- Certificates: X.509
- Asymmetric keys: RSA (PKCS)

ETSI Approach for Normative Testing ➔ Interoperable Standard

Basic protocol standard development

- **<u>Abstract Syntax Notation</u> (ASN.1) message structure specification, ITU-T X.680**
- **<u>Packed encoding rules</u> (PER) for transfer encoding, ITU-T X.691**
- **<u>Message Sequence Charts</u> (MSC) for message flow description, ITU-T Z.120,**
- **<u>Specification and Description Language</u> (SDL) specification, ITU-T Z.100**
  - SDL models used to precisely define the protocol behaviour.
  - Simulations and validations to early remove ambiguities and erroneous protocol behaviour.

Protocol test specifications (ITU-T X.291...296, ISO/IEC 9646)

- **PICS** **Protocol Implementation Conformance Statement**
- **TSS & TP** **Test Suite Structure and Test Purposes**
- **ATS** **Abstract Test Suite (TTCN)**
  - Significant effort was spent (30 man month of funded expert work plus voluntary contribution by member companies and ETSI PTCC work)

Radio test specifications

- **RCT** **Radio Conformance Test**
- **EN** **Harmonized Standard (European Norm)**, covering the essential requirements of article 3.2 of the EC R&TTE Directives