

# High Speed Downlink Packet Access

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2007



# Data traffic characteristics

- Asymmetrical
- Bursty
- > 384 kbps needed
- Low latency

# How to...

## Reduce latency

- fast scheduling
- adaptive scheduling
- HARQ
- avoid protocol translation
- reduce signaling
- simple core architecture
- increase L1/L2 granularity

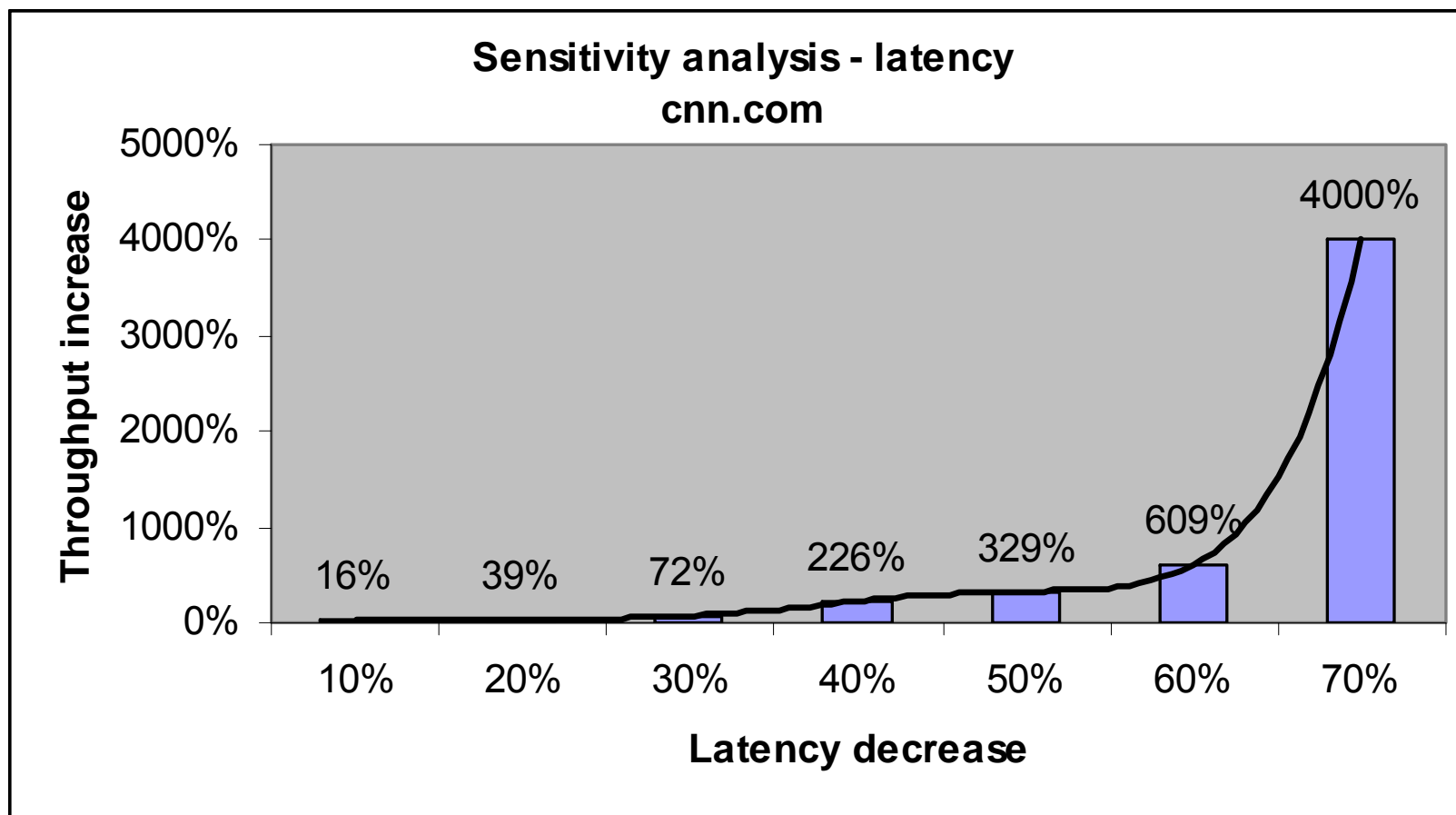
- 1) L2/L3 issues
- 2) small effect on L1
- 3) can be changed in already existing system

## Increase throughput

- more bandwidth
- higher order modulation
- less FEC
- more power

- 1) mostly L1 properties
- 2) set by the system design/regulation
- 3) harder to change in already existing system

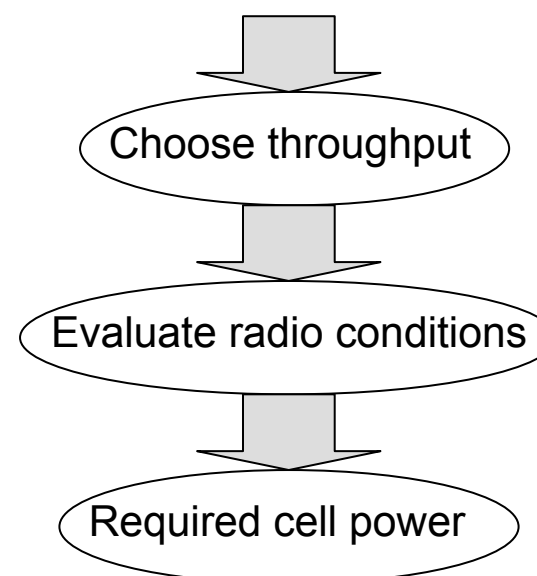
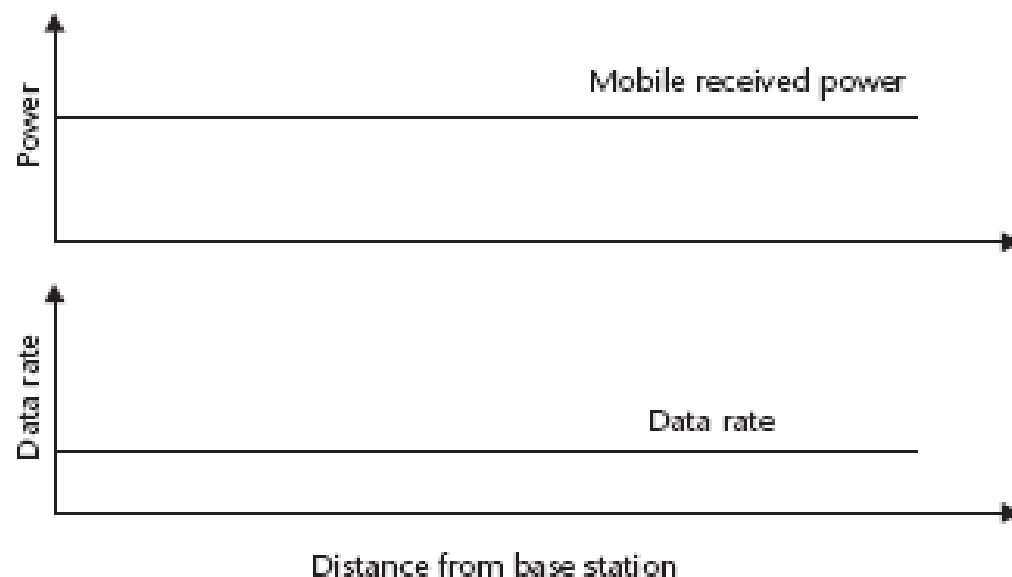
# What has bigger impact?



# What about UMTS R99?

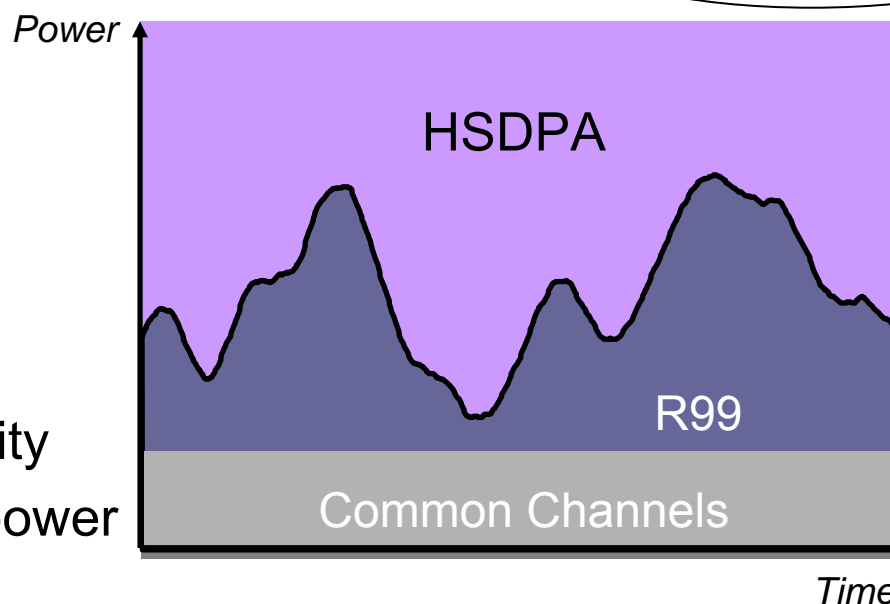
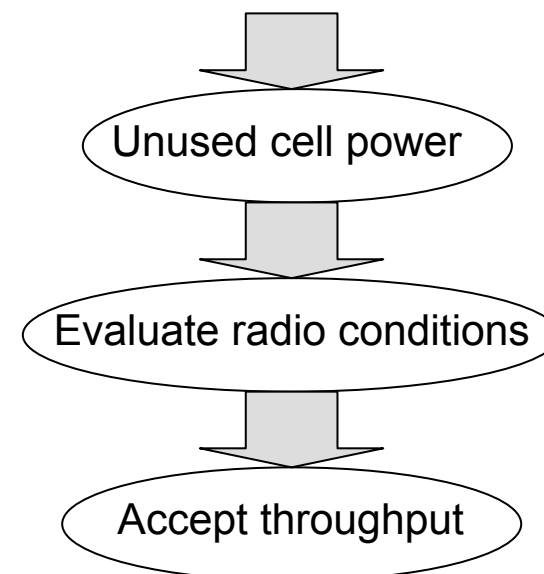
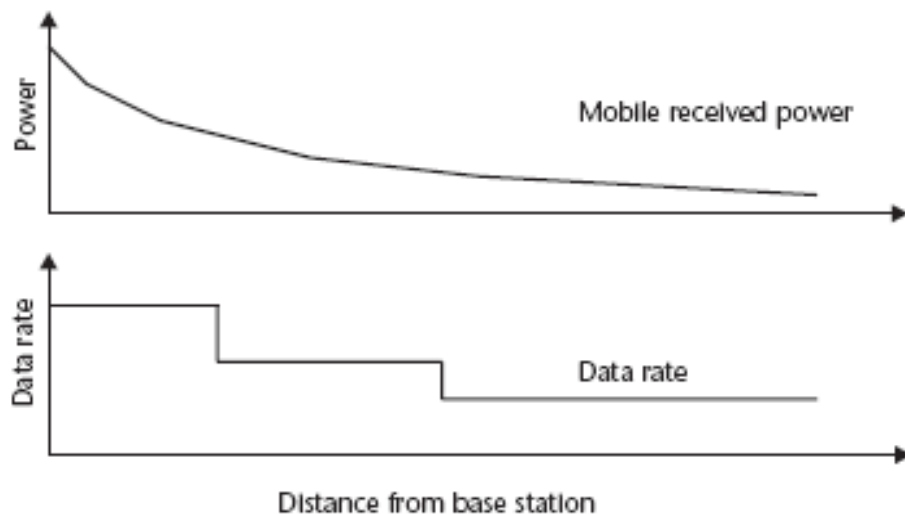
- Design changes
  - Channel
    - transport
    - physical
  - Scheduler
  - Frame format
  - Modulation
  - HARQ
  - Functionality move towards the RBS
  - Power control

# Power control



- Circuit switched services are guaranteed
- Packet switched services are best effort

# Power control - revised



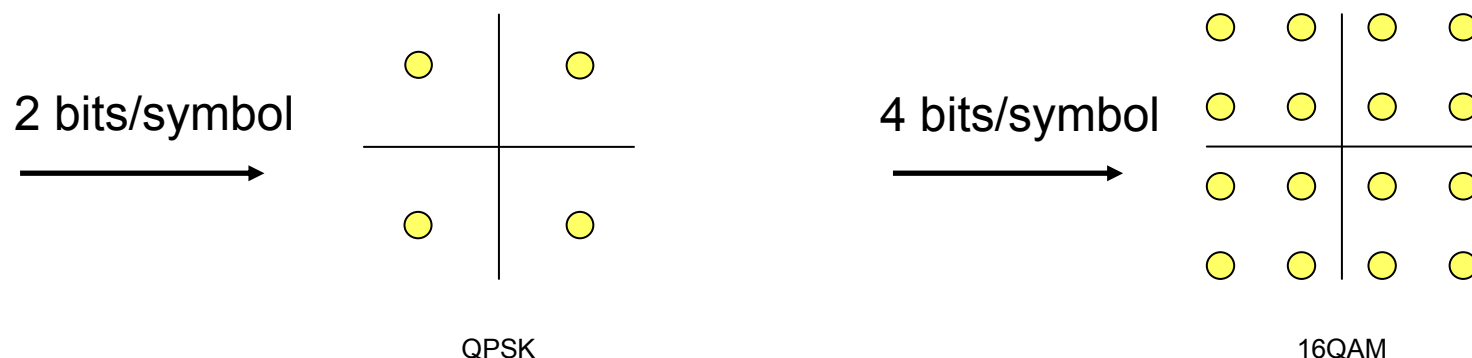
- No guarantee
- Best effort
- Maximize cell capacity
- Utilize all available power

# HSDPA – 3GPP Rel.5

- 2 ms frame format
- 2 ms scheduler ATDMA/CDMA
  - CQI
- 16 QAM or QPSK
- HARQ (Chase, Incremental Redundancy)
  - on L1 (not RLC)
- Fixed SF = 16
- Turbo code only
- Fixed CRC (24 bit)
- No soft handover



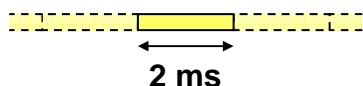
# Higher Order Modulation



- 16QAM
  - Twice the data rate compared to QPSK (used in R99)
- Making optimal use of good channel conditions (high C/I)
  - Close to cell site
  - Low speed
  - Little or no dispersion

# Short TTI

## Transmission Time Interval

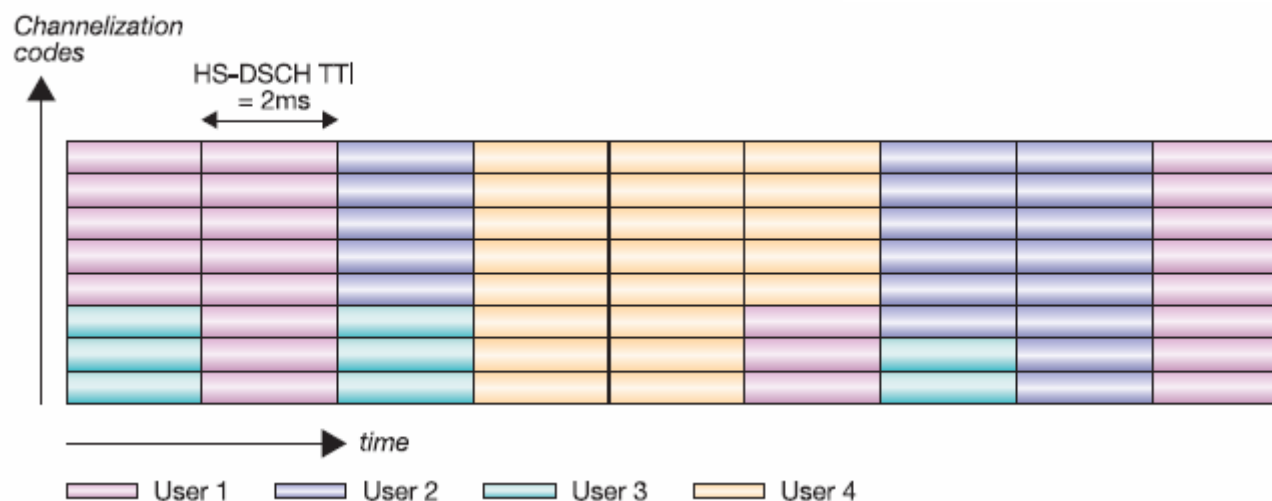
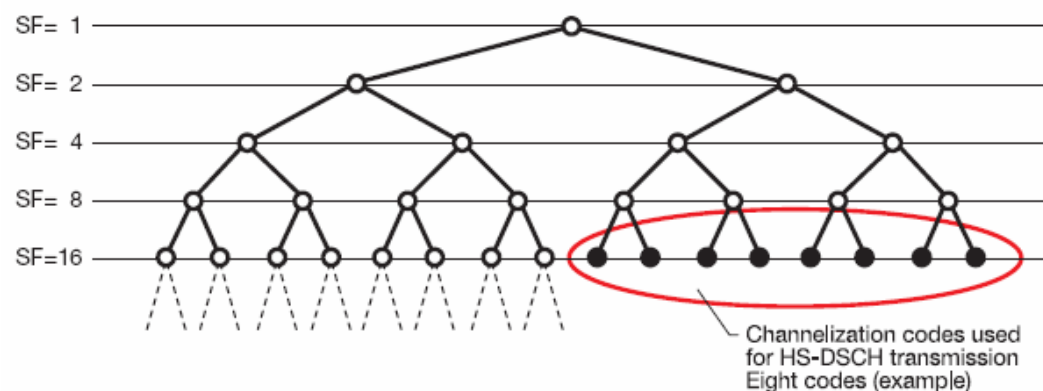


- Reduced air-interface delay
  - Improved end-user performance
- HSDPA features operate at 500 times per second
  - Fast Link Adaptation
  - Fast hybrid Automatic Repeat Request (ARQ) with soft combining
  - Fast Channel-dependent Scheduling

### Earlier releases

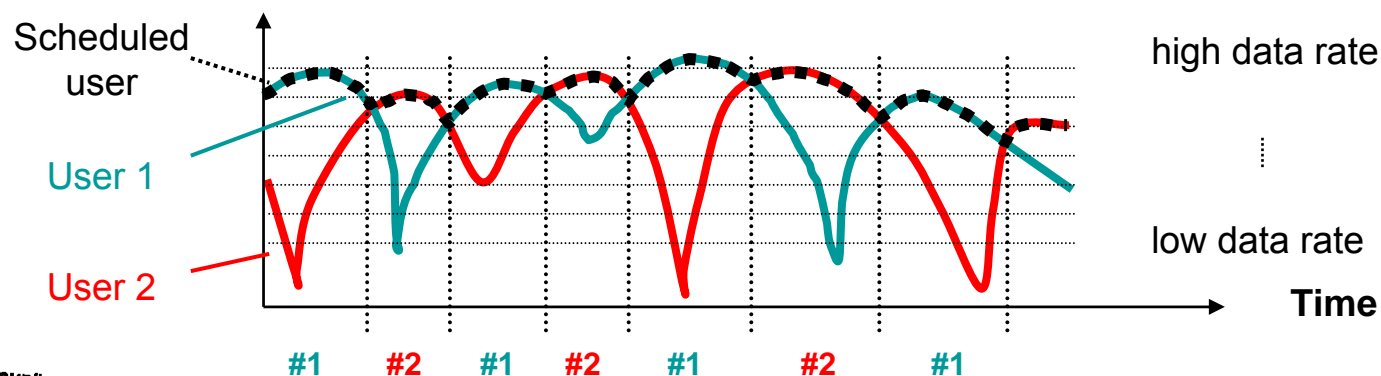


# Code multiplexing



# Fast Channel-dependent Scheduling

- Scheduling = which UE to transmit to at a given moment
- Basic idea: transmit at fading peaks
  - May lead to large variations in data rate between users
  - Tradeoff: fairness vs. cell throughput

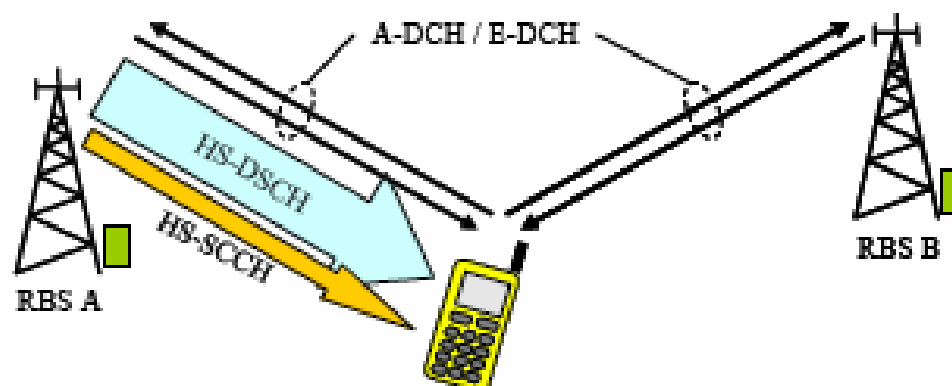


# Scheduling

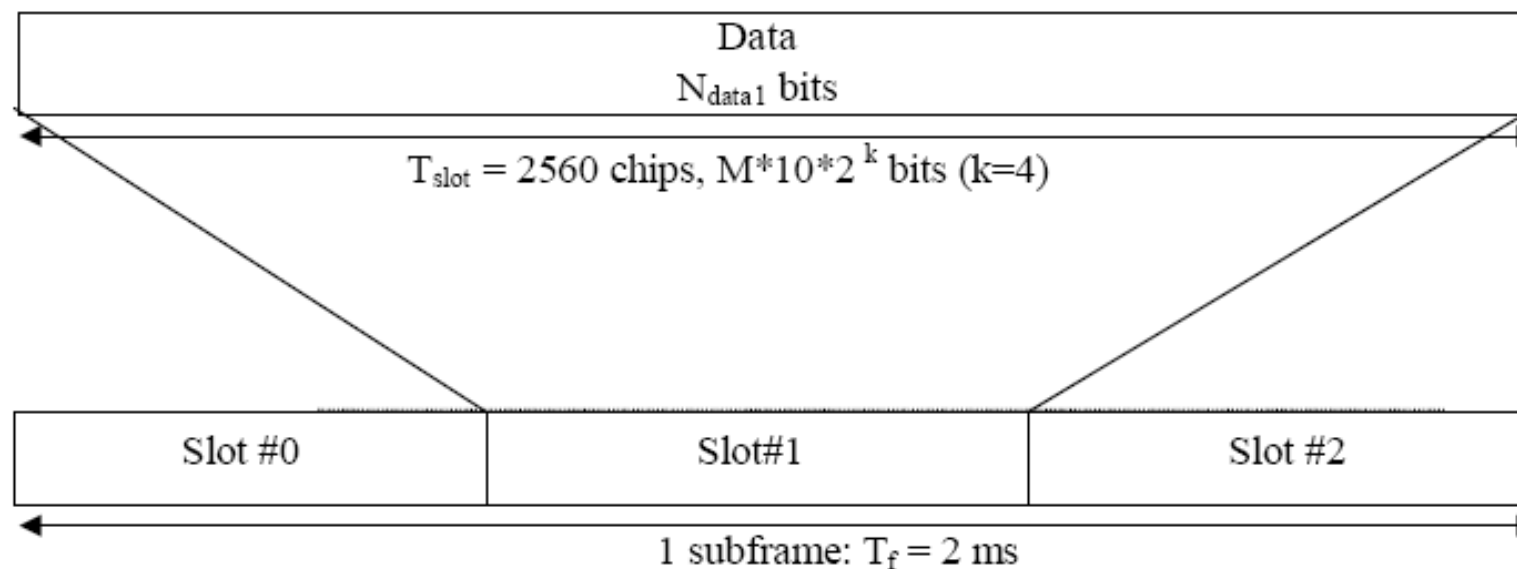
- UEs send reports
- CQI = Channel Quality Indicator (0-31)
- Not explicit quality indicator, but the data rate supported by the UE

# HSDPA Transport Channels

- one High-Speed Downlink Shared Channel (HS-DSCH), used for downlink data transmission, mapped to up to **15 HS-PDSCH**, and is dynamically allocated every 2 msec
- up to **four** High-Speed Shared Control Channels (HS-SCCH), used for downlink control signaling, (e.g. - UE ID, HARQ, TFRC)
- one Associated Dedicated Channel (A-DCH) pair (UL & DL) per HSDPA user in connected state used for controlled signaling and uplink data transmission

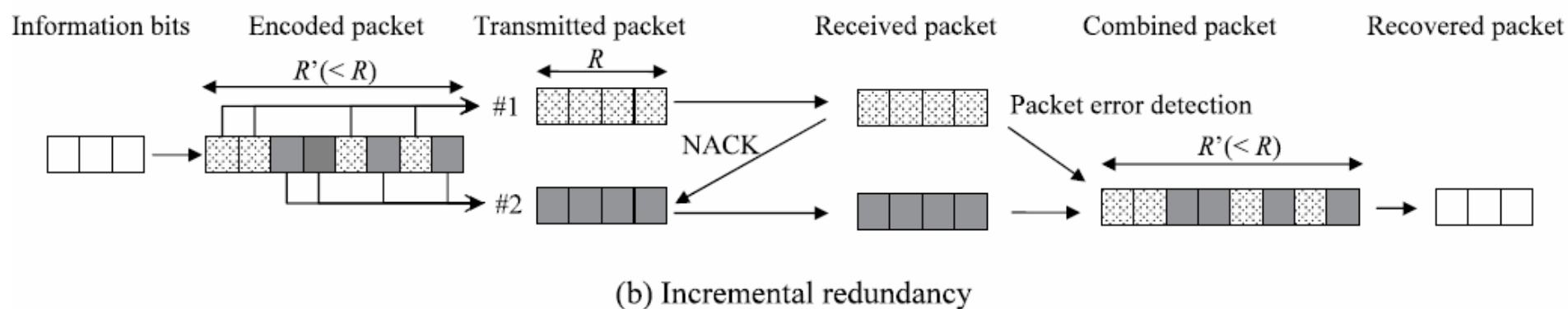
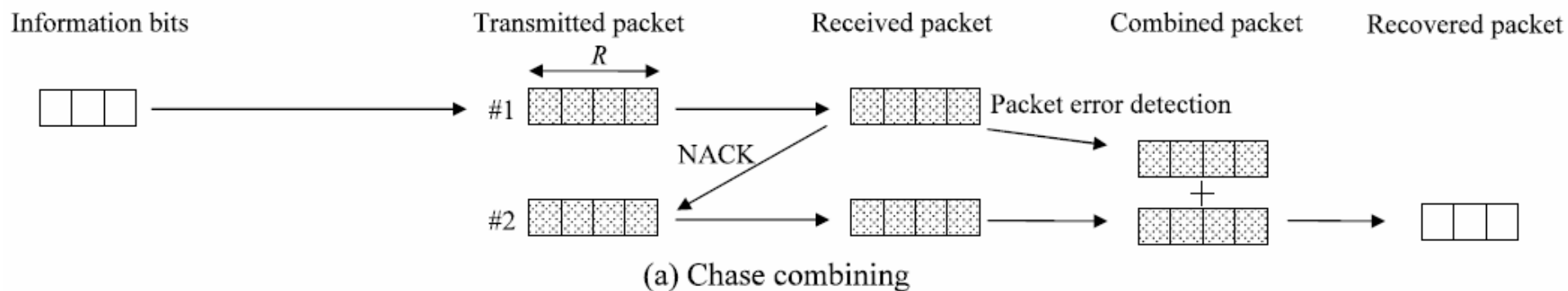


# HS-PDSCH



Slot format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ HS-DSCH subframe	Bits/ Slot	Ndata
0(QPSK)	480	240	16	960	320	320
1(16QAM)	960	240	16	1920	640	640

# Hybrid ARQ





# Hybrid ARQ

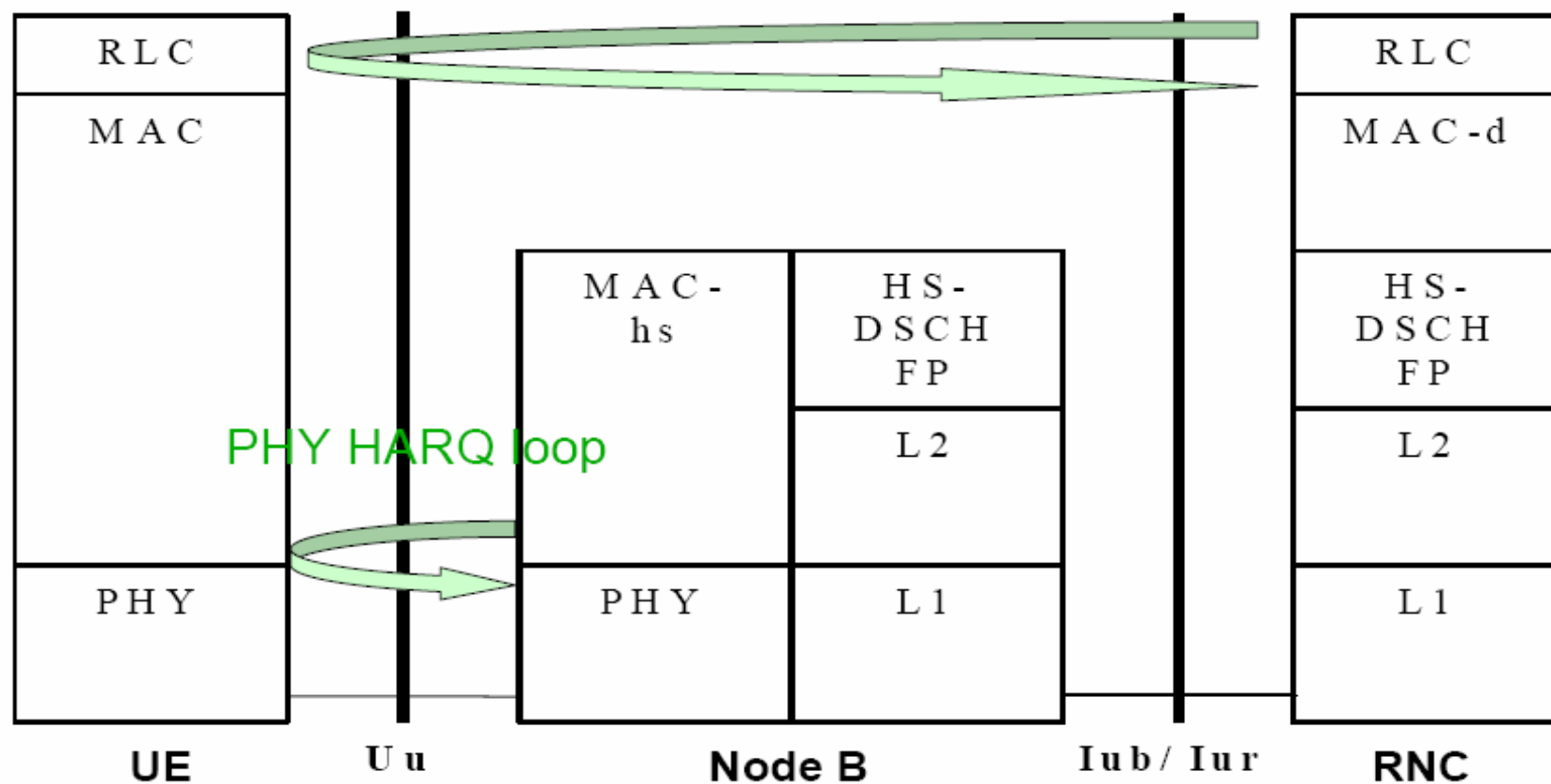
- Send & Wait strategy
  - Long delays
- Up to 8 parallel processes
- Buffer memory in the UE is important

# ARQ Loops

End-to-end TCP ARQ loop



RLC ARQ loop

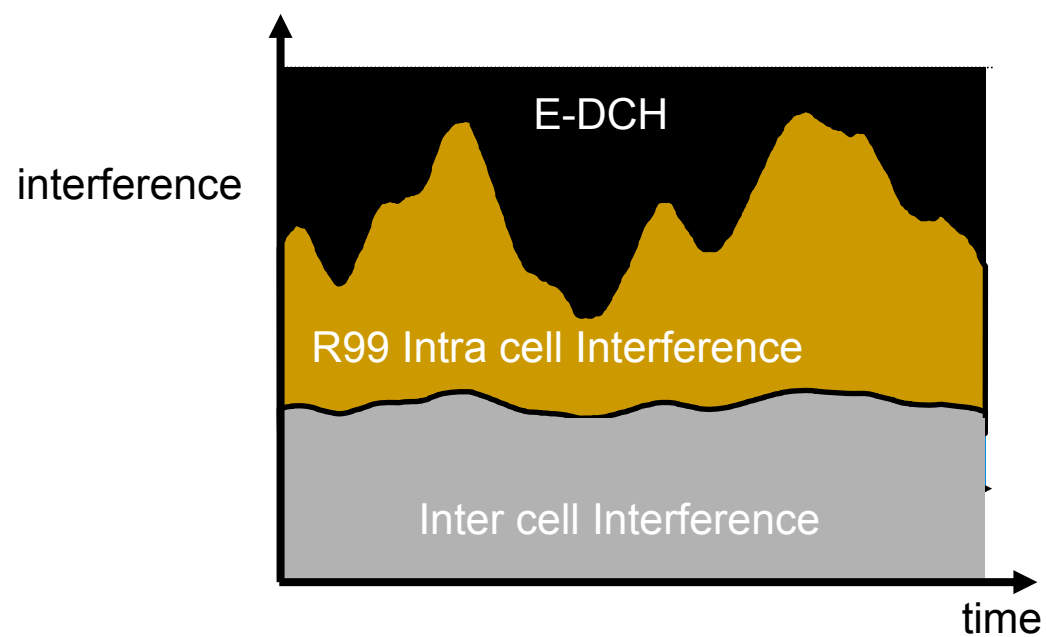


# UE classes

HS-DSCH category	Maximum number of HS-DSCH codes received	Maximum L1 data rate (Mbps)	Maximum RLC data rate (Mbps)	QPSK / 16 QAM
Category 1	5	1.2	1.12	Both
Category 2	5	1.2	1.12	Both
Category 3	5	1.8	1.68	Both
Category 4	5	1.8	1.68	Both
Category 5	5	3.6	3.36	Both
Category 6	5	3.6	3.36	Both
Category 7	10	7.3	6.72	Both
Category 8	10	7.3	6.72	Both
Category 9	15	10.2	9.6	Both
Category 10	15	14.0	13.44	Both
Category 11	5	0.9	0.8	QPSK only
Category 12	5	1.8	1.6	QPSK only


# Enhanced Uplink

# Resource usage



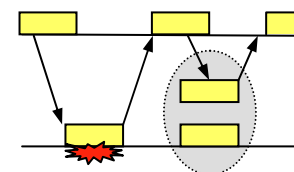
# Design principles

- Multi code transmission
- HARQ
- TTI 2/10 ms
- Scheduling

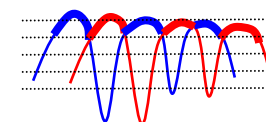
Multi-code  
transmission (1-4 codes) 

TTI = 2 / 10 ms 

Hybrid ARQ with  
Soft Combining in RBS

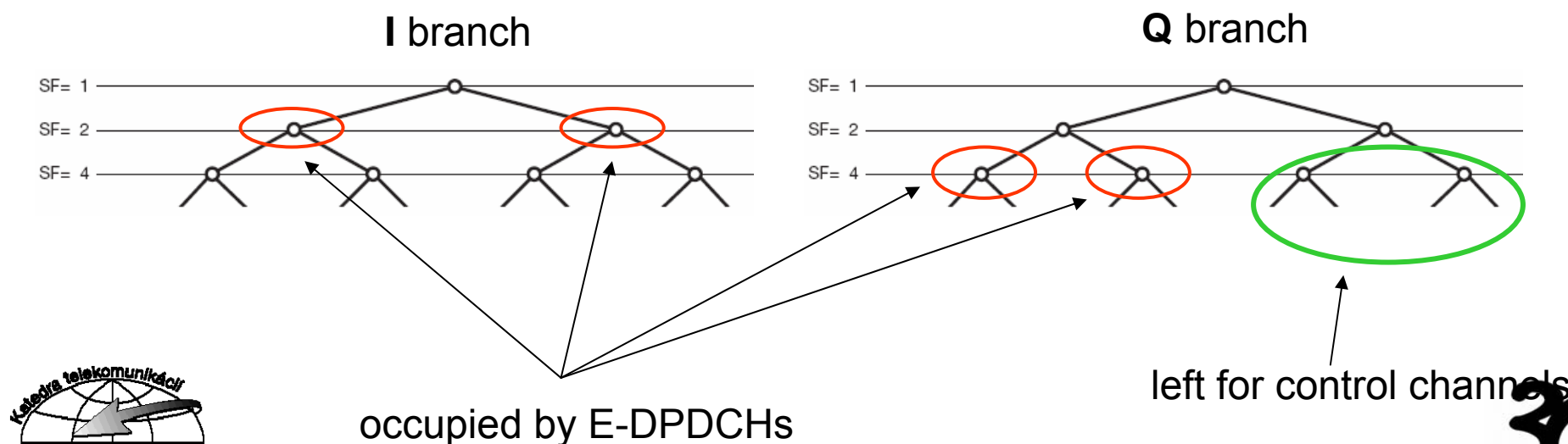
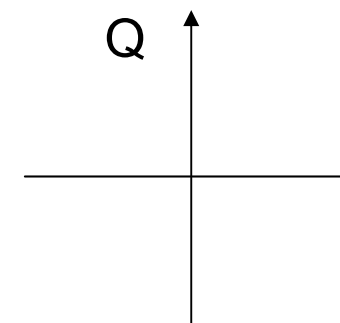


Scheduling

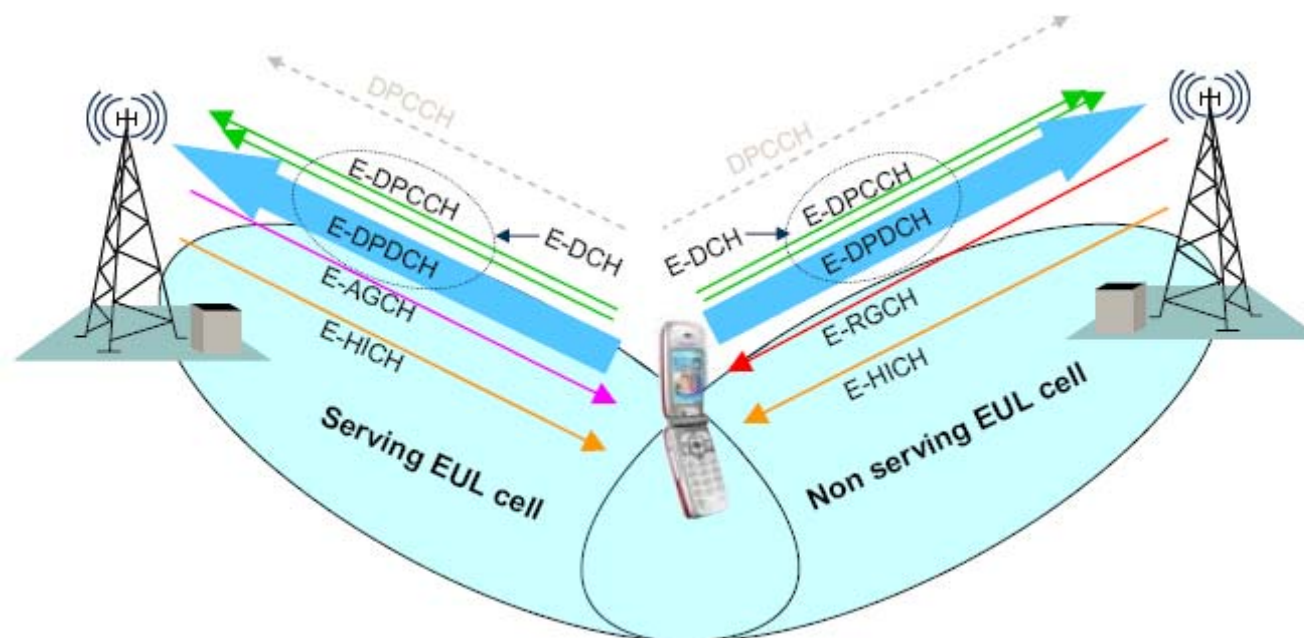


# EUL – Physical Layer

- QPSK is used both in DL & UL, but:
- in DL, QPSK for each data channel
- in UL, every data channel is BPSK modulated
  - UL uses 2 separate OVSF code trees!
  - so EUL can use for example 2x SF2 & 2x SF4



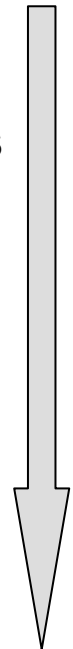
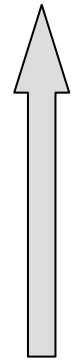
# EUL channels





# Enhanced Uplink Channels

- **E-DCH Dedicated Physical Data Channel (E-DPDCH)**
  - is the data transport channel. The power of the E-DPDCH is set dynamically as an offset to the DPCCH, a so called gain or beta factor, signaled with the grant messages delivered by the scheduler.
- **E-DCH Dedicated Physical Control Channel (E-DPCCH)**
  - is used to transmit to the scheduler information about the channel conditions as seen from the UE.
- **E-DCH Absolute Grant Channel E-AGCH**
  - a shared downlink channel that carries absolute grants. The absolute grant is sent by the scheduler to the UE giving it the information it needs to select a rate and the transmission power.
- **E-DCH Relative Grant Channel E-RGCH**
  - is the channel carrying relative grants. Relative grants are transmitted from non-serving cells only, at the rate of one relative grant per 10 ms from each cell in the active set.
- **E-DCH HARQ Acknowledgement Indicator Channel E-HICH**
  - a dedicated channel, carrying the binary hybrid ARQ (HARQ) acknowledgements. One E-HICH is set up to each EUL user from each cell in its active set.

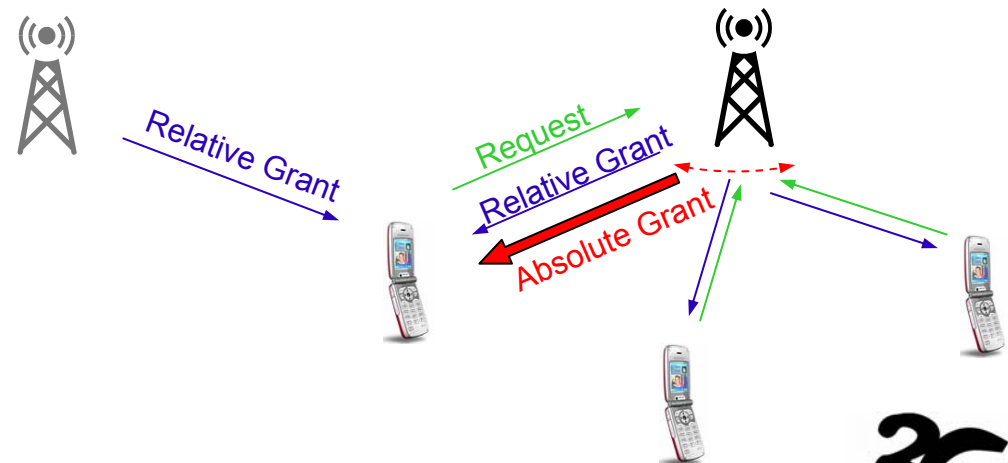
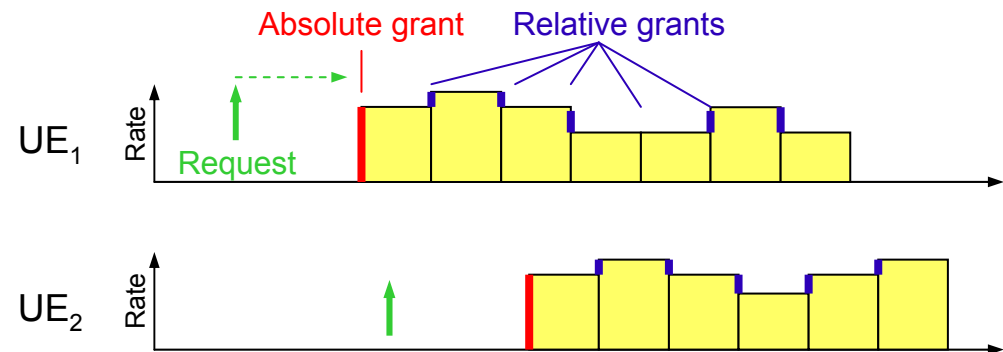


# Scheduling

- Node B decides at which power UE can transmit
- Absolute Grant – from serving cell
- Relative Grant – both from serving/non-serving cell(s)
  - Serving cell (UP, DOWN, HOLD) – dedicated to 1 UE
  - Non-serving cell(s) (DTX, DOWN) – to all UEs (overload indicator)

# Scheduling

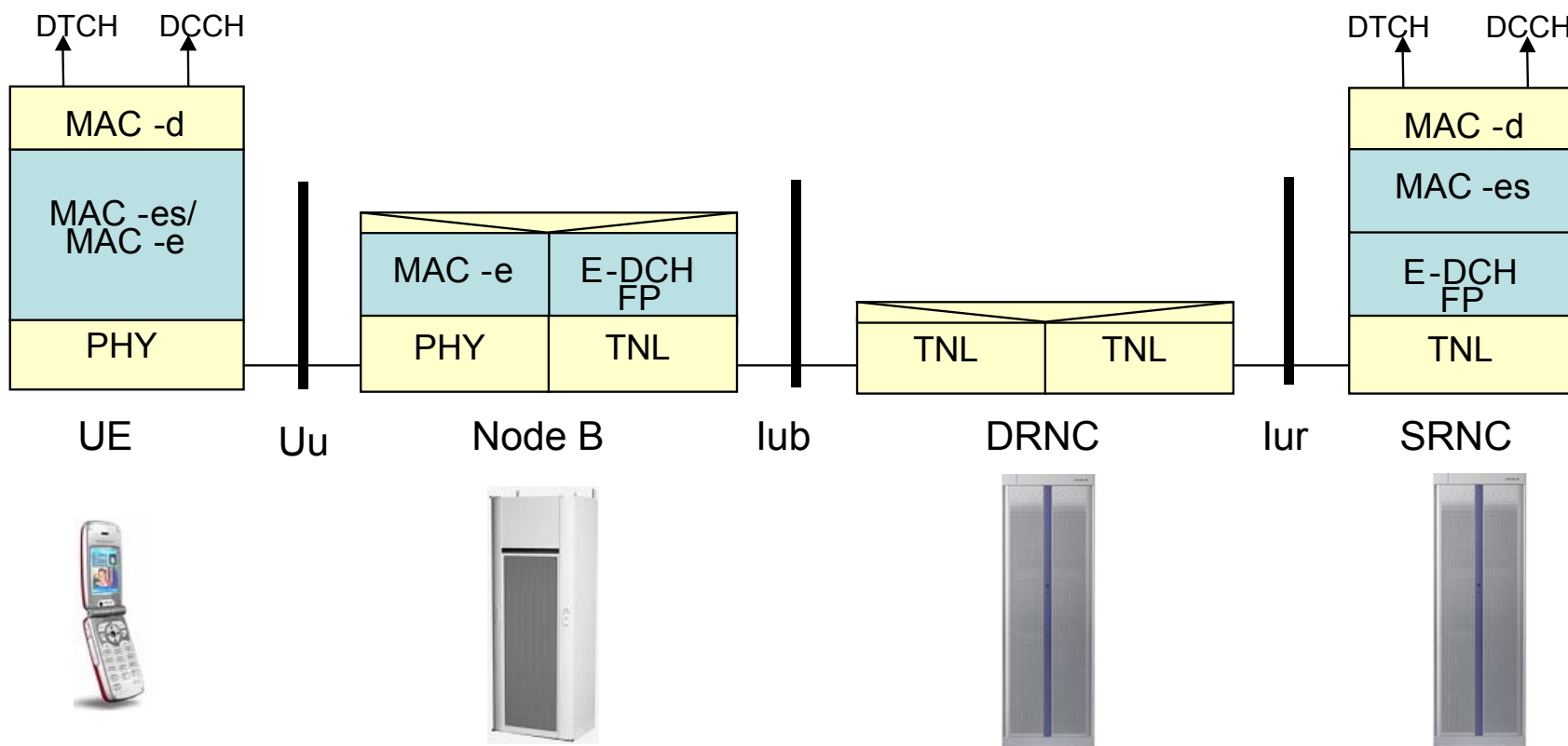
- Scheduling request (UL)
  - Used by the UE to request more resources
- Absolute grant (DL)
  - Used for large absolute changes of the data rate
- Relative grant (DL)
  - UP/HOLD/DOWN



# EUL UE classes

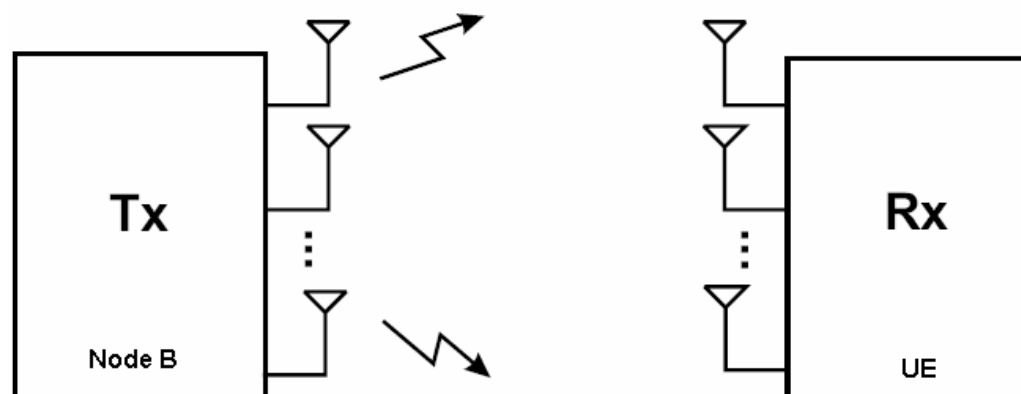
Category	Max codes	Min spreading factor	Support for 2 ms TTI	Max L1 data rate
1	1	1 x SF4	No	0.74 Mbps
2	2	2 x SF4	Yes	1.46 Mbps
3	2	2 x SF4	No	1.46 Mbps
4	2	2 x SF2	Yes	2.92 Mbps
5	2	2 x SF2	No	2.00 Mbps
6	4	2 x SF4 + 2 x SF2	Yes	5.76 Mbps

# New Radio interface protocol entities



# Multi-antenna systems

# MIMO principle



- **Array gain:** Increased coverage.
- **Diversity gain:** Improved quality.
- **Spatial multiplexing:** Increased spectral efficiency.
- **Additional transmission pipe:** Increased data rates.

# MIMO principle

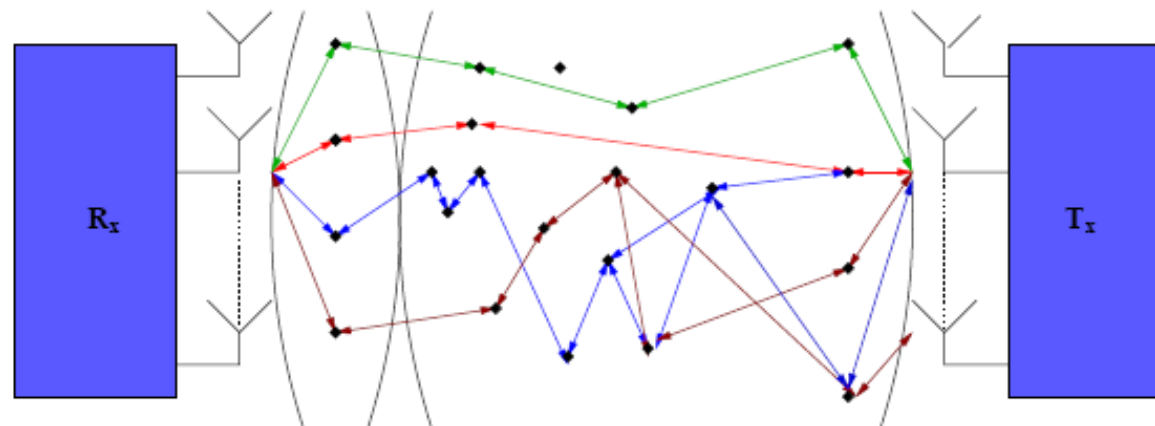
MIMO works well, when:

1) conditions are bad:

- no LOS signal component
- lot of scatterers

2) antennas have sufficient spacing

- uncorrelated antennas
- independent CIRs





# Capacity

$$C_{SISO}^D = \log_2(1 + \rho h^2) \text{ bps/Hz}$$

$$C_{MISO}^D = \log_2\left(1 + \frac{\rho}{M} \sum_{i=1}^M h_i^2\right) \text{ bps/Hz}$$

$$C_{SIMO}^D = \log_2\left(1 + \rho \sum_{i=1}^N h_i^2\right) \text{ bps/Hz}$$

$$C_{MIMO}^D = \sum_{i=1}^r \log_2\left(1 + \frac{\rho}{M} \lambda_i\right) \text{ bps/Hz}$$

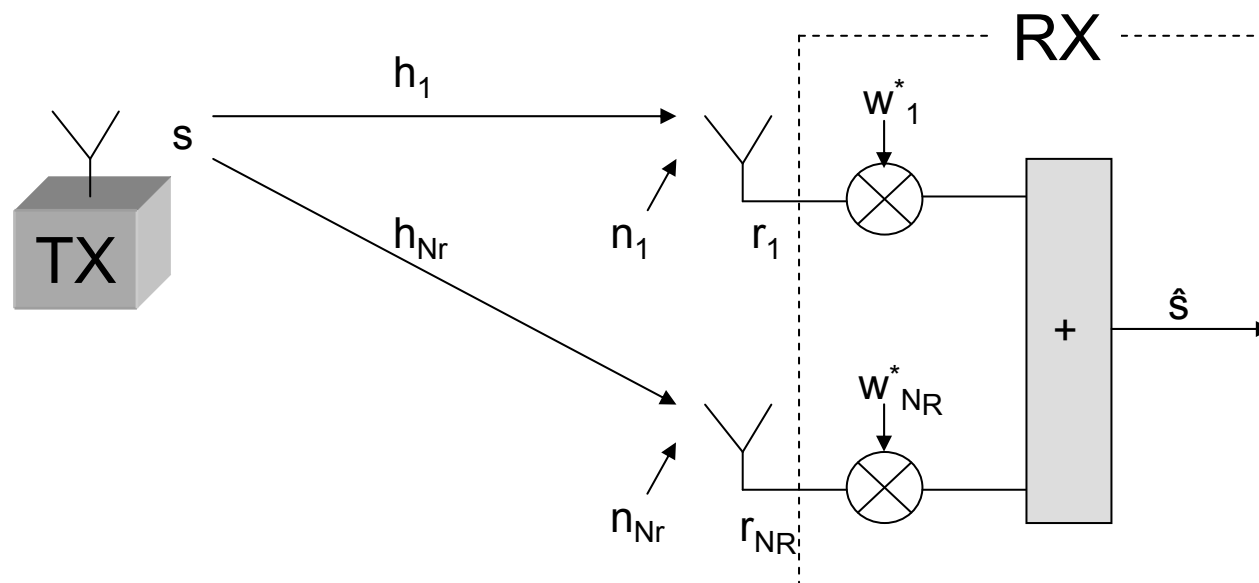
$\rho$  = SNR

$h$  = channel impulse response

$H$  = channel impulse response  $M \times N$  (input, output antennas) matrix

$r$  = matrix rank

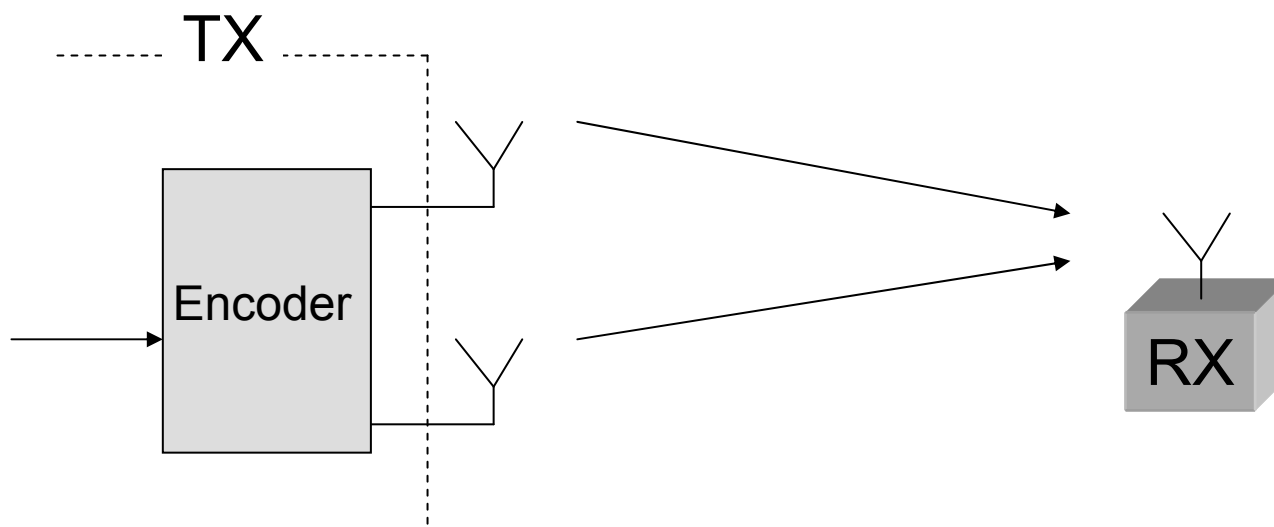
# Rx diversity (SIMO)



$$\hat{s} = \begin{bmatrix} w_1^* & \dots & w_{Nr}^* \end{bmatrix} \cdot \begin{bmatrix} r_1 \\ \vdots \\ r_{Nr} \end{bmatrix} = \bar{w}^T \cdot \bar{r}$$

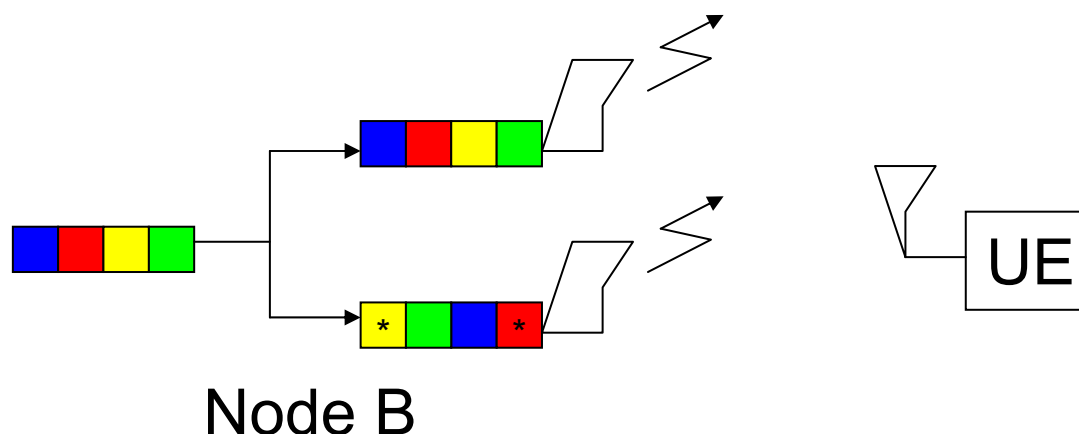
$$\bar{r} = \bar{h} \cdot s + \bar{n}$$

# Tx diversity (MISO)



# Tx Diversity (open loop), Rel. 6 (MISO)

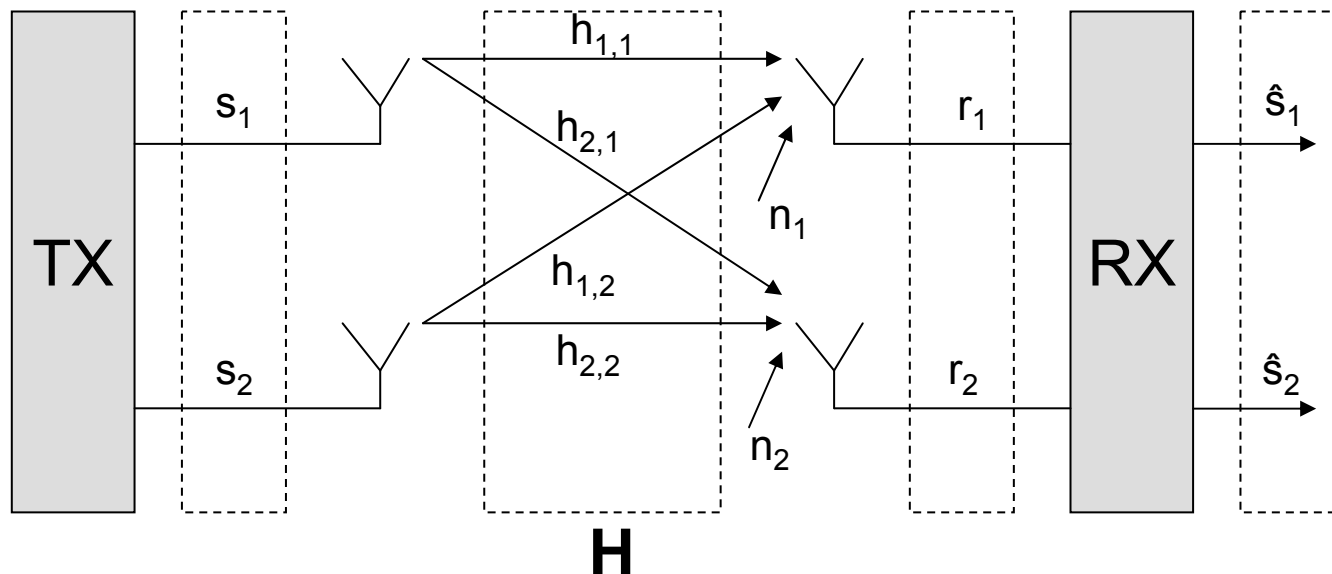
- 2 Tx antennas
- improved quality & coverage
- support is mandatory for all Rel.6 compliant UEs



\*for QPSK

- closed loop TxD requires feedback from the UE

# MIMO



$$\begin{bmatrix} \hat{s}_1 \\ \hat{s}_2 \end{bmatrix} = H^{-1} \cdot \bar{r} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + H^{-1} \cdot \bar{n}$$

$$\bar{r} = \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \cdot \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

# max MIMO capacity

$$\frac{C}{W} = \min\{N_T, N_R\} \cdot \log_2 \left( 1 + \frac{N_R}{\min\{N_T, N_R\}} \cdot \frac{S}{N} \right)$$

# So many antennas...



# So many antennas...

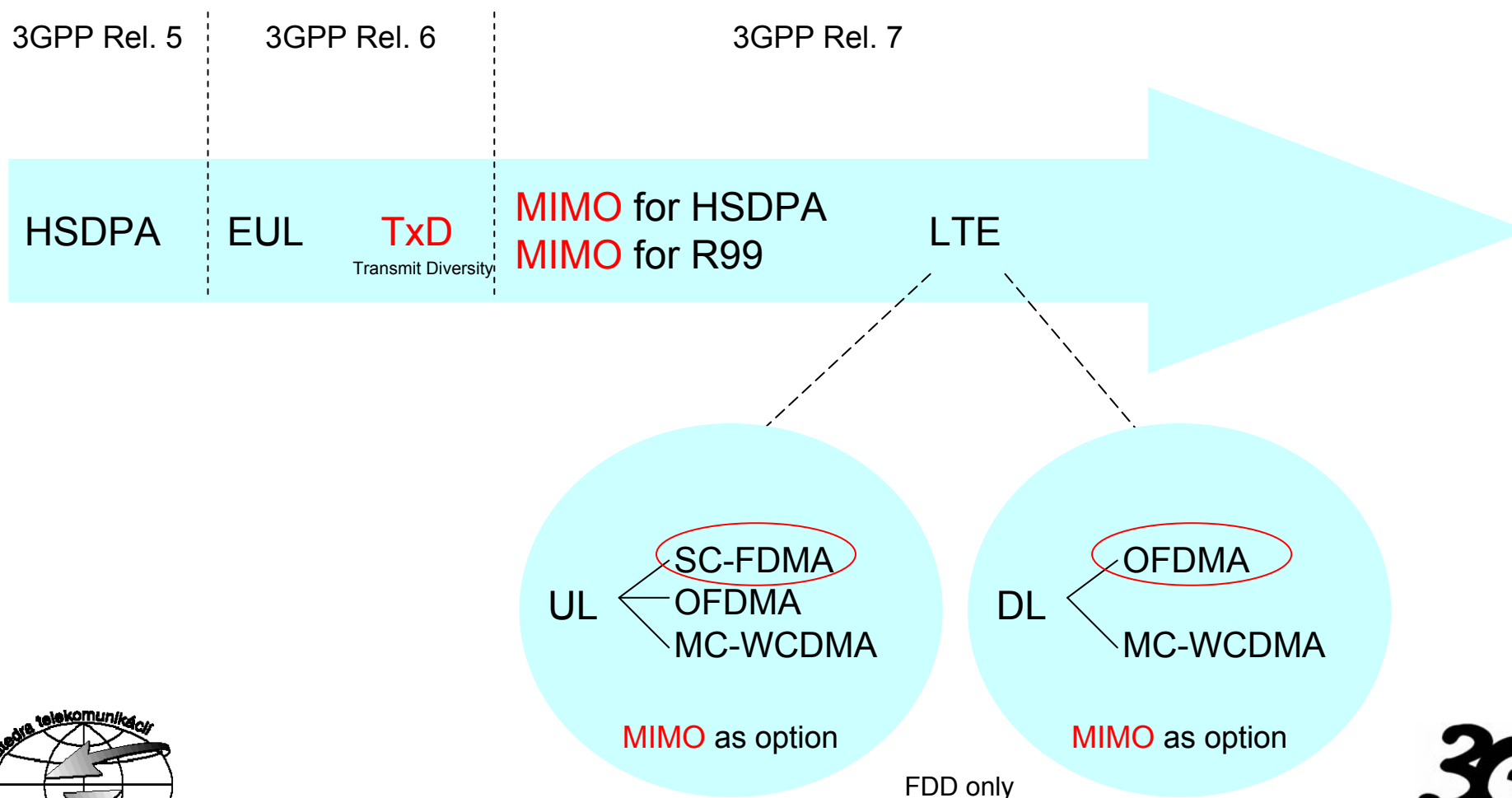




# So many antennas...

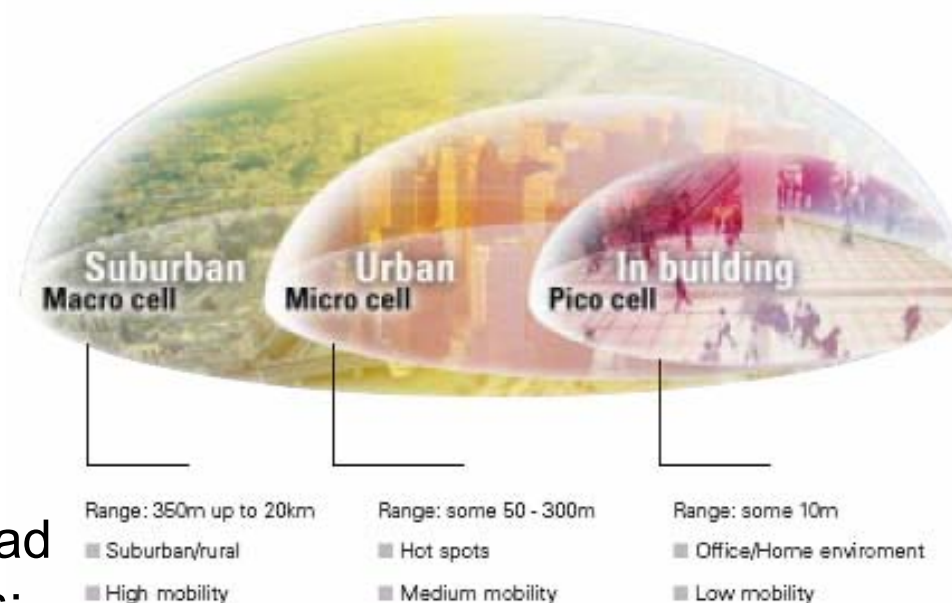


# MIMO introduction into 3GPP



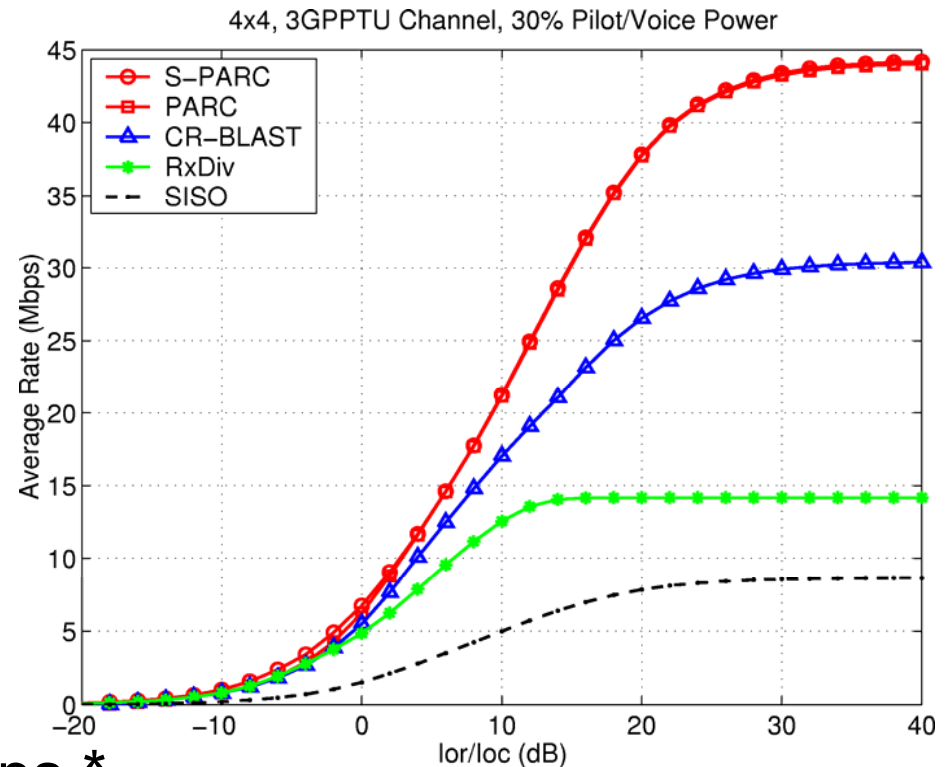
# HSDPA MIMO

- Where it's hot:
  - higher isolation between cells and/or non-uniform load distribution: **URBAN MICRO**
  - **PICO & INDOOR**
- Where it's not:
  - uniform load distribution, frequency reuse of one, high load and little isolation between cells: **URBAN MACRO**



# HSDPA + MIMO

- 3GPP Release 7 – still open (LTE is also part of Rel. 7)
- 11 proposals
- MIMO up to 4x4
- achievable data rate < 45 Mbps \*  
(channel capacity < 80 Mbps \*)



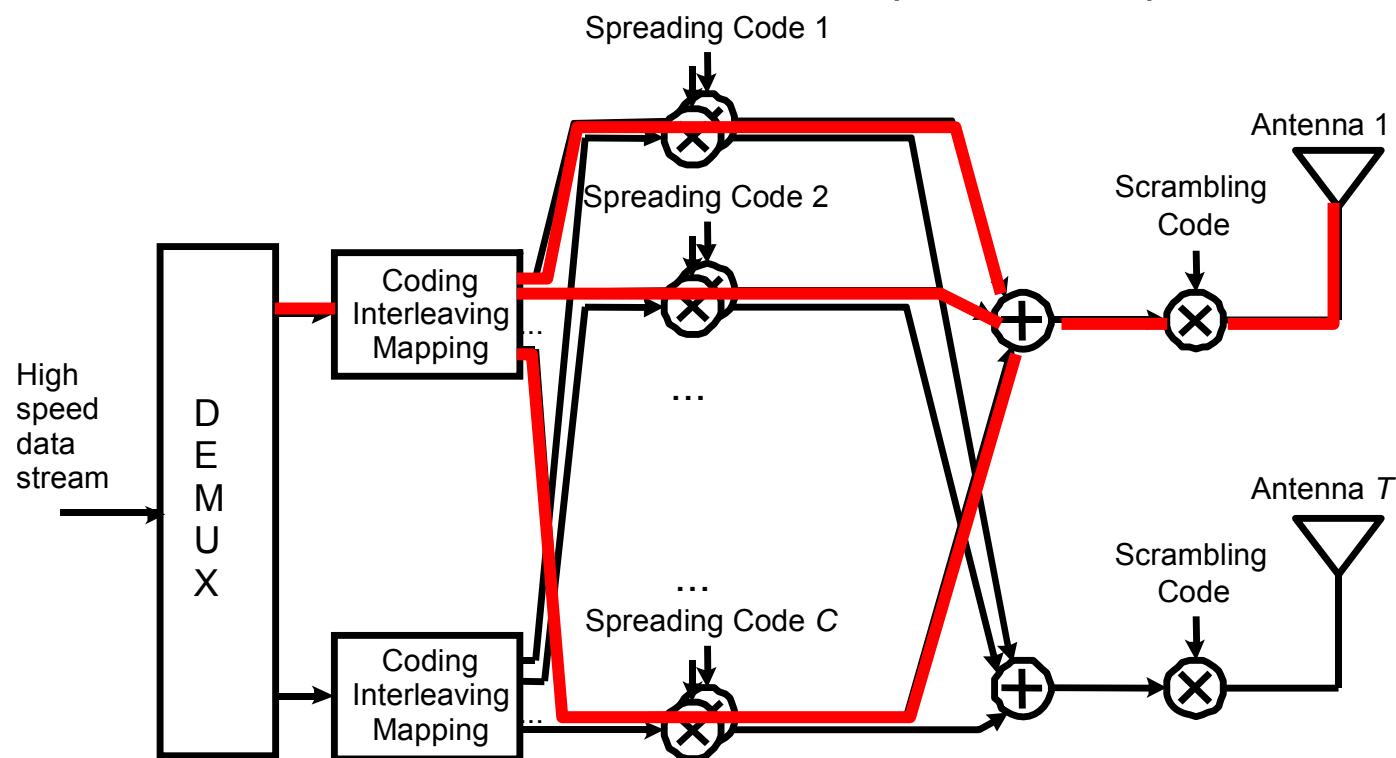
# HSDPA + MIMO

3GPP TR 25.876

1. Per-antenna rate control
2. Rate-Control Multi-Paths diversity
3. Double Space Time Transmit Diversity with Sub-Group Rate Control
4. Single Stream Closed loop MIMO with 4 Tx and L Rx antennas
5. Per-User Unitary Rate Control
6. TPRC for CD-SIC MIMO
7. Selective Per Antenna Rate Control
8. Double Transmit antenna array (D-TxAA)
9. Spatial Temporal Turbo Channel Coding
10. Double Adaptive Space Time Transmit Diversity with Sub-Group Rate Control
11. Single & Multiple Code Word MIMO with Virtual Antenna mapping

# Ericsson MIMO Proposal

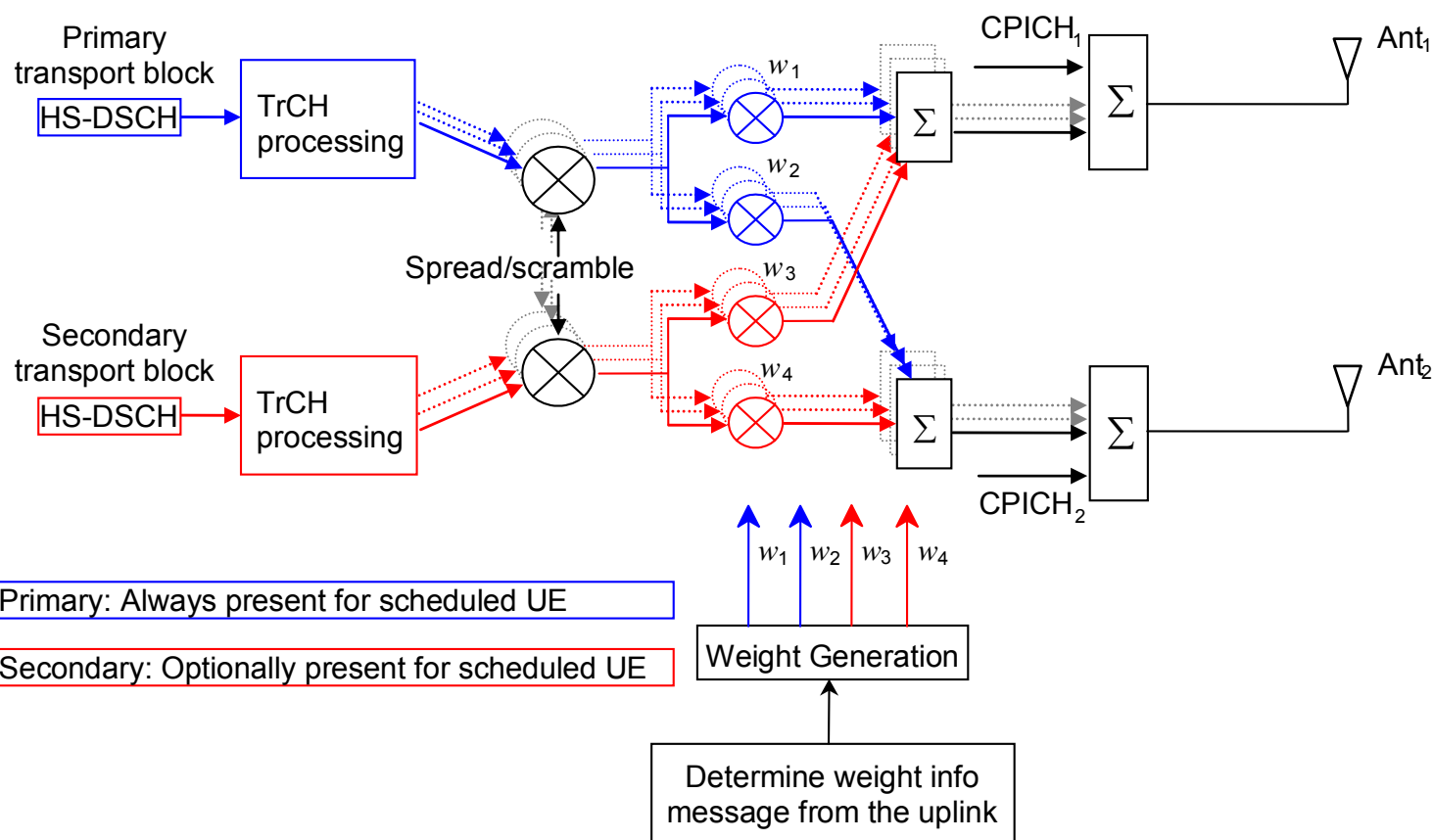
Selective per-antenna rate control (S-PARC)



separately encoded data streams are transmitted from each antenna with equal power but with different data rates

adaptively selects the number of antennas

# And the winner is...



# HSPA Evolution

For 5 MHz carrier

## Downlink

3.6 Mbps



15 codes

14 Mbps

64QAM



21 Mbps

2x2 MIMO



28 Mbps



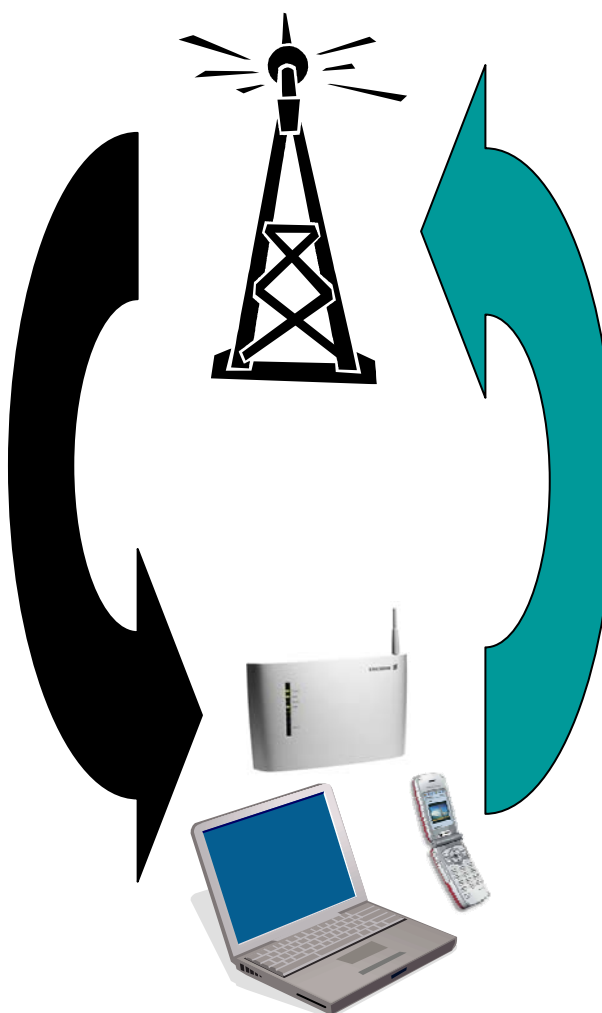
Both

**42 Mbps**



4x4 MIMO

80 Mbps



## Uplink

0.384 Mbps



HSPA  
on the uplink

1.4 Mbps



2 ms TTI

5.8 Mbps



16QAM

**12 Mbps**



2x2 MIMO

23 Mbps

