High Speed Downlink Packet Access

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2010

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

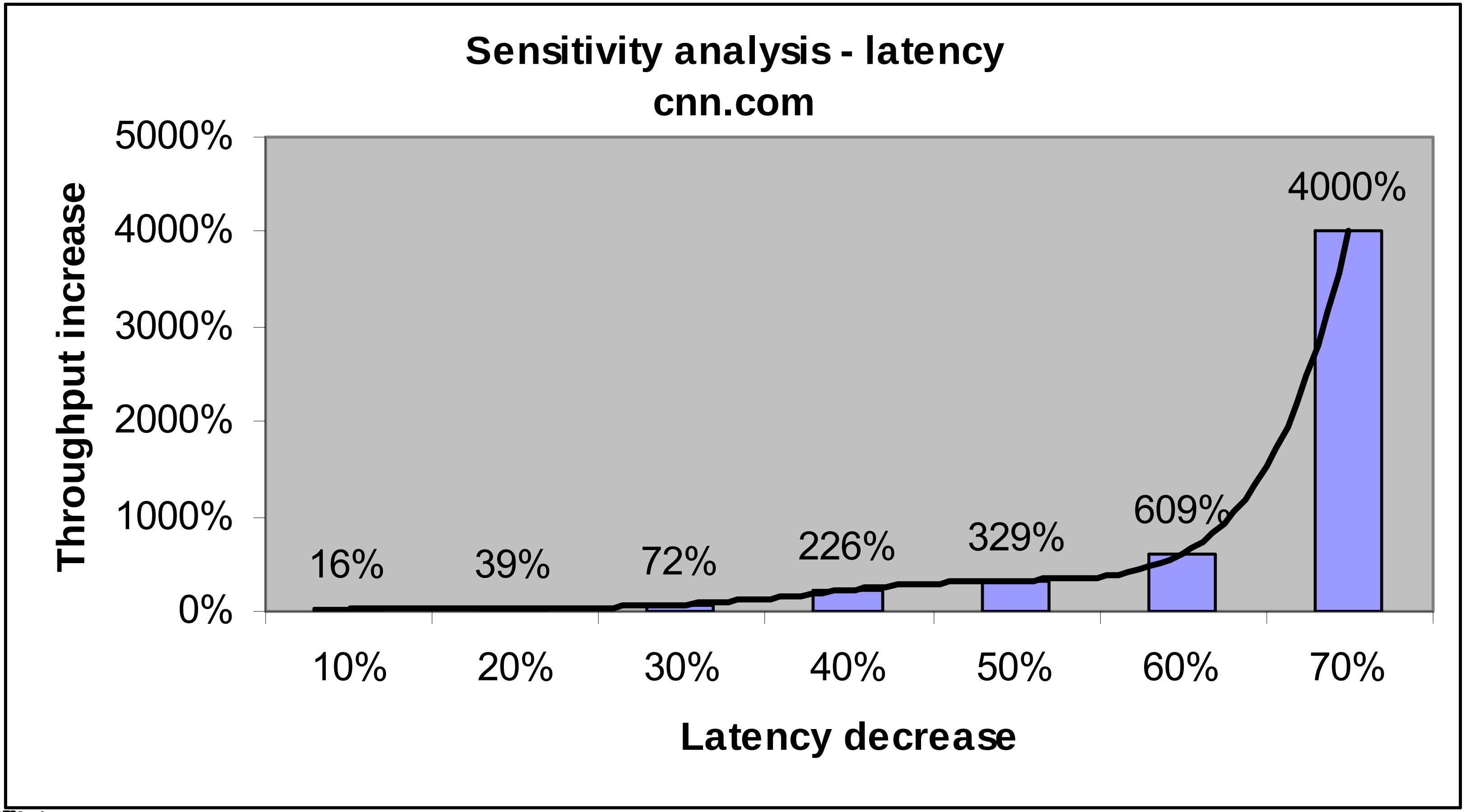
1) L2/L3 issues
2) small effect on L1
3) can be changed in already existing system

Increase throughput

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

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

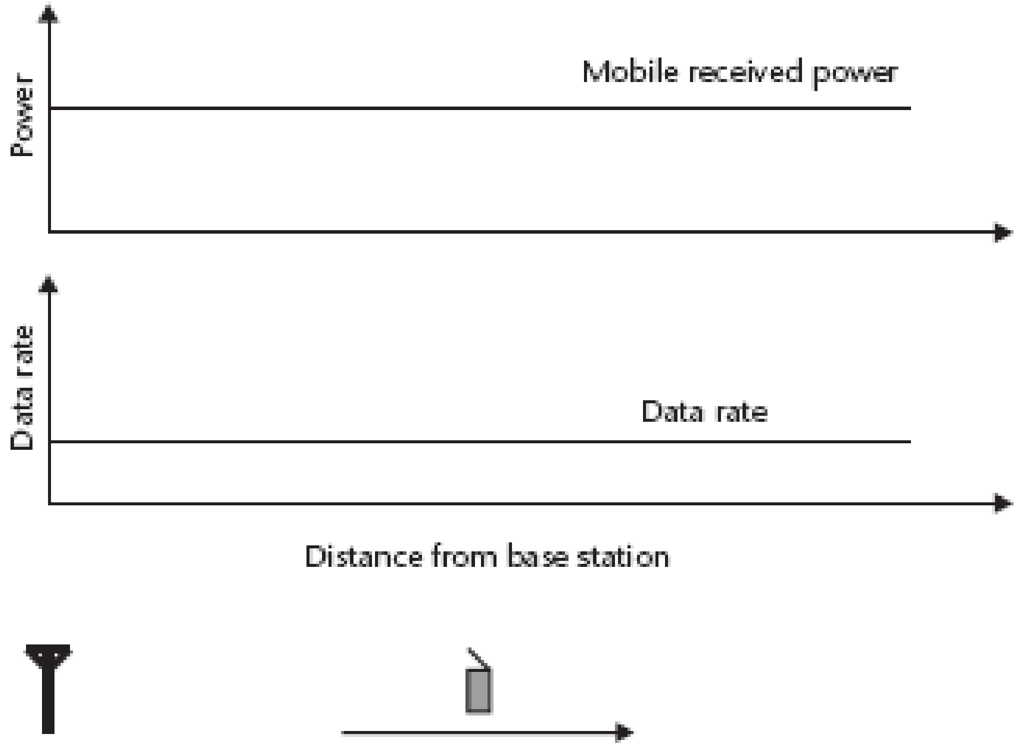
What has bigger impact?

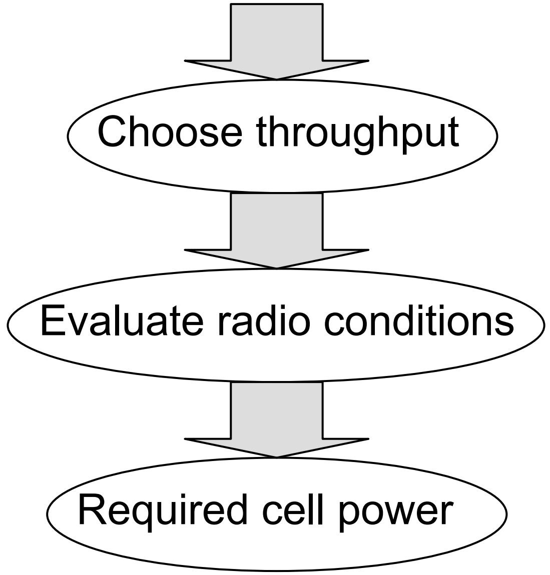


What about UMTS R99?

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

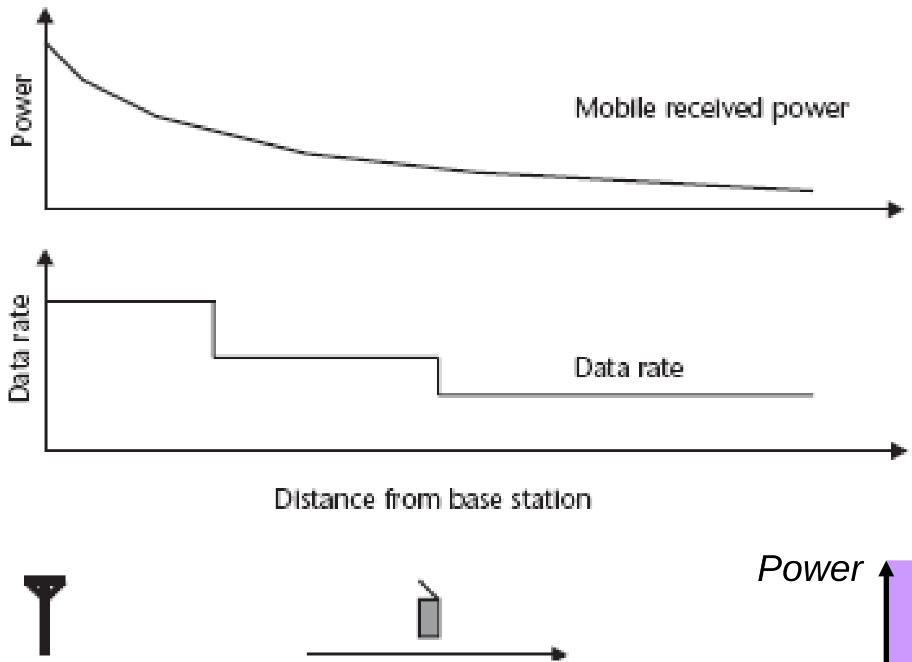
Power control – R99

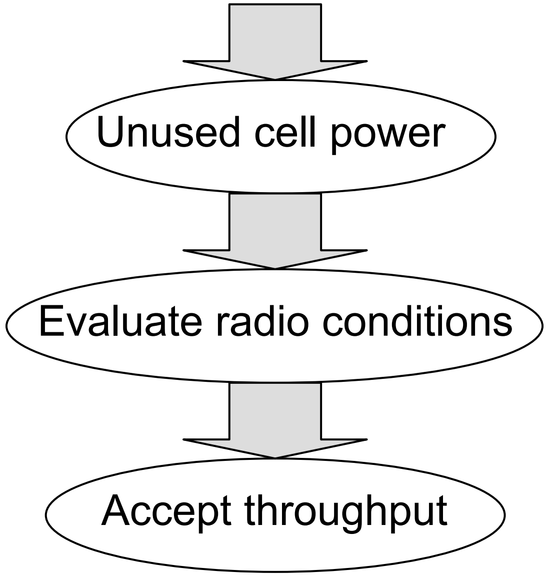




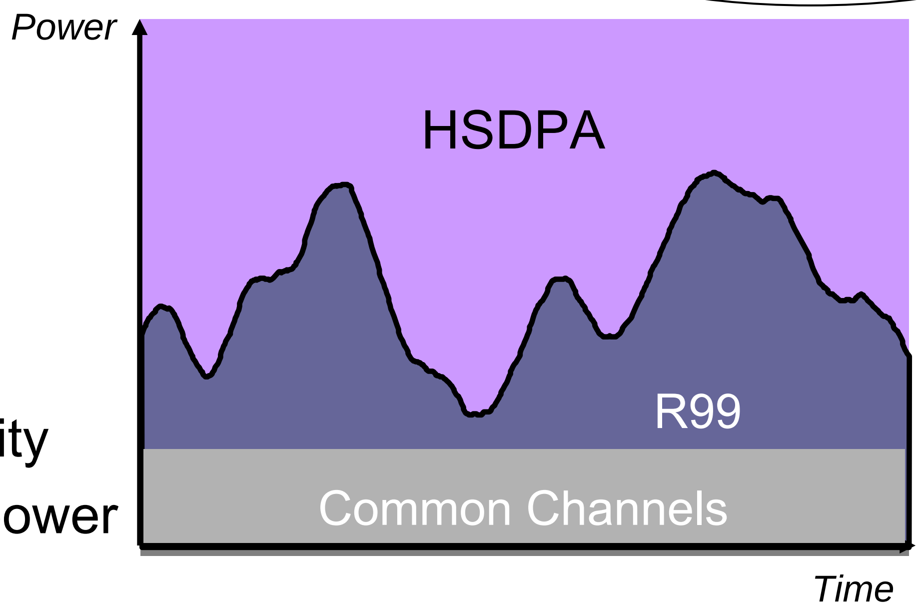
- Circuit switched services are guaranteed
- Packet switched services are best effort

Power control - revised





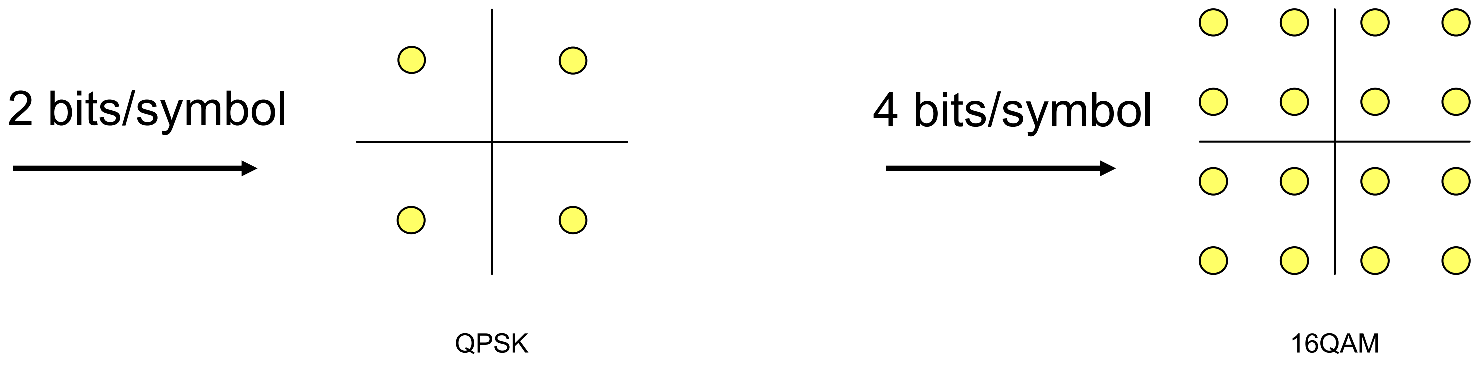
- No guarantee
- Best effort
- Maximize cell capacity
- Utilize all available power



HSDPA – 3GPP Rel.5

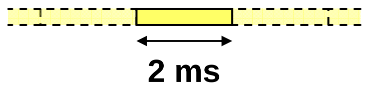
- 2 ms frame format
- 2 ms scheduler ATDMA/CDMA
  - CQI
- 16 QAM or QPSK
- HARQ (Chase, Incremental Redundancy)
  - on L1 (not RLC)
- Fixed SF = 16
- Turbo code only
- Fixed CRC (24 bit)
- No soft handover

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

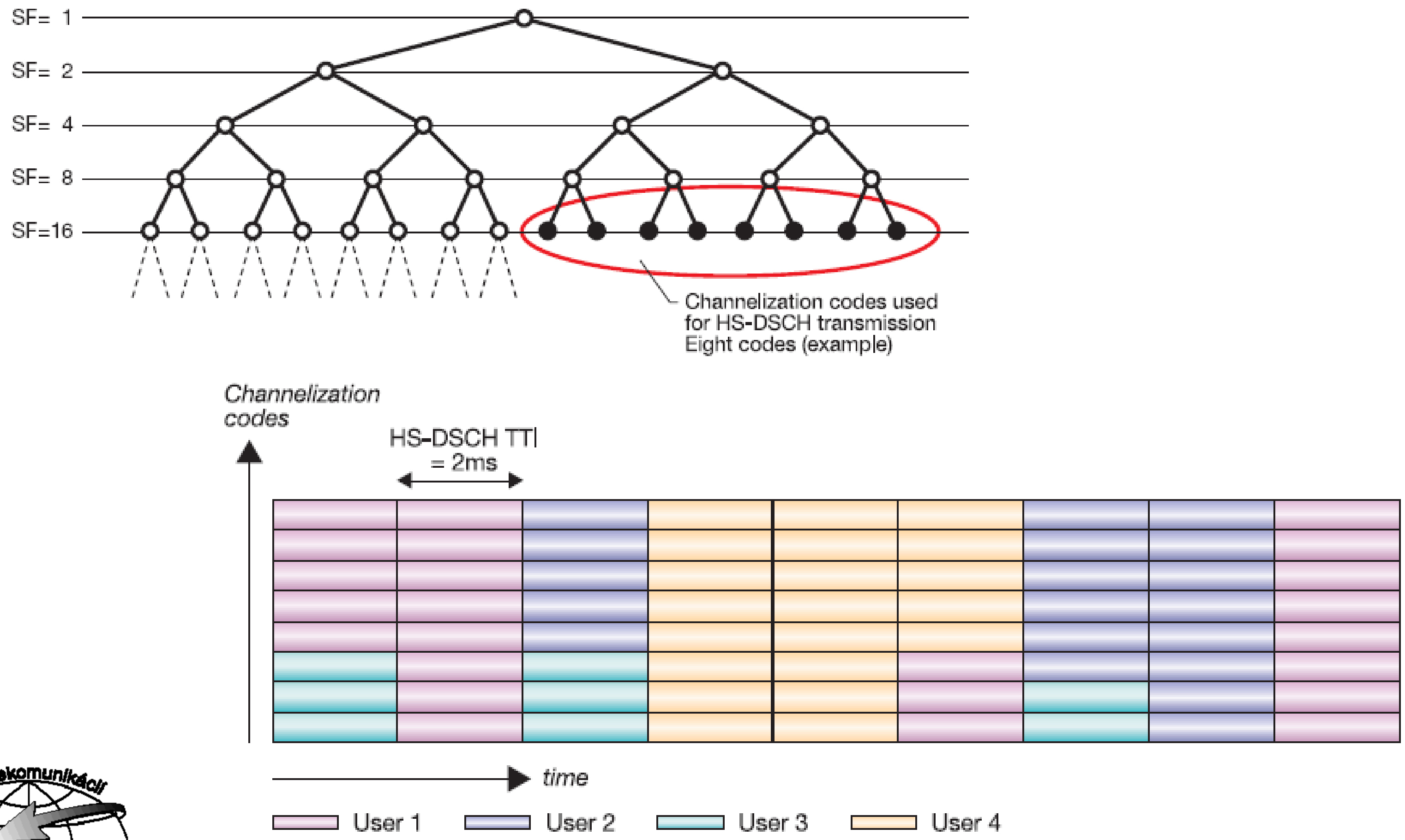
Short TTI
Transmission Time Interval



- 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

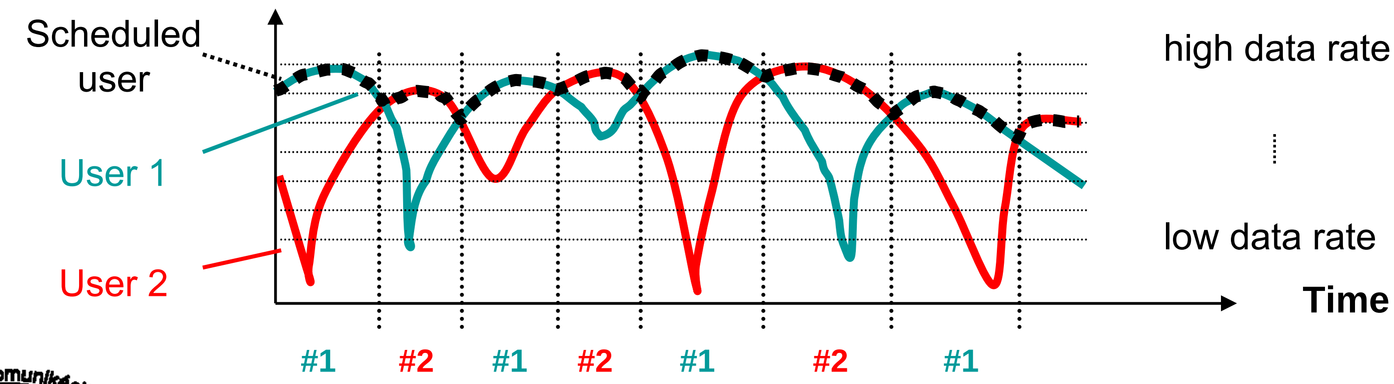
Earlier releases

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

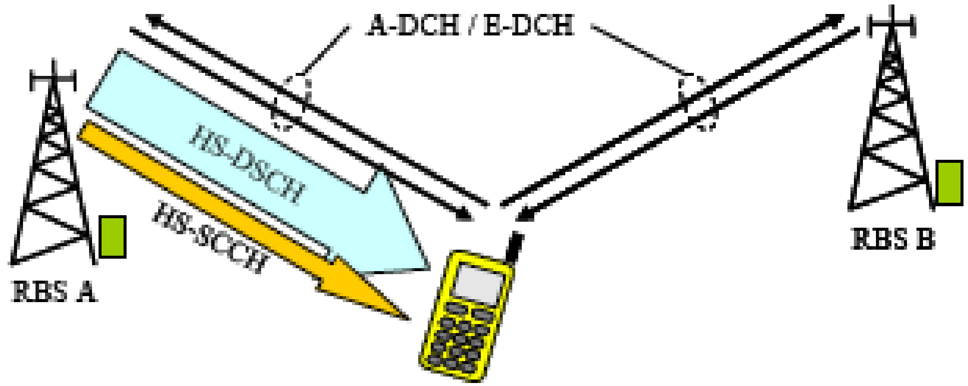


Scheduling

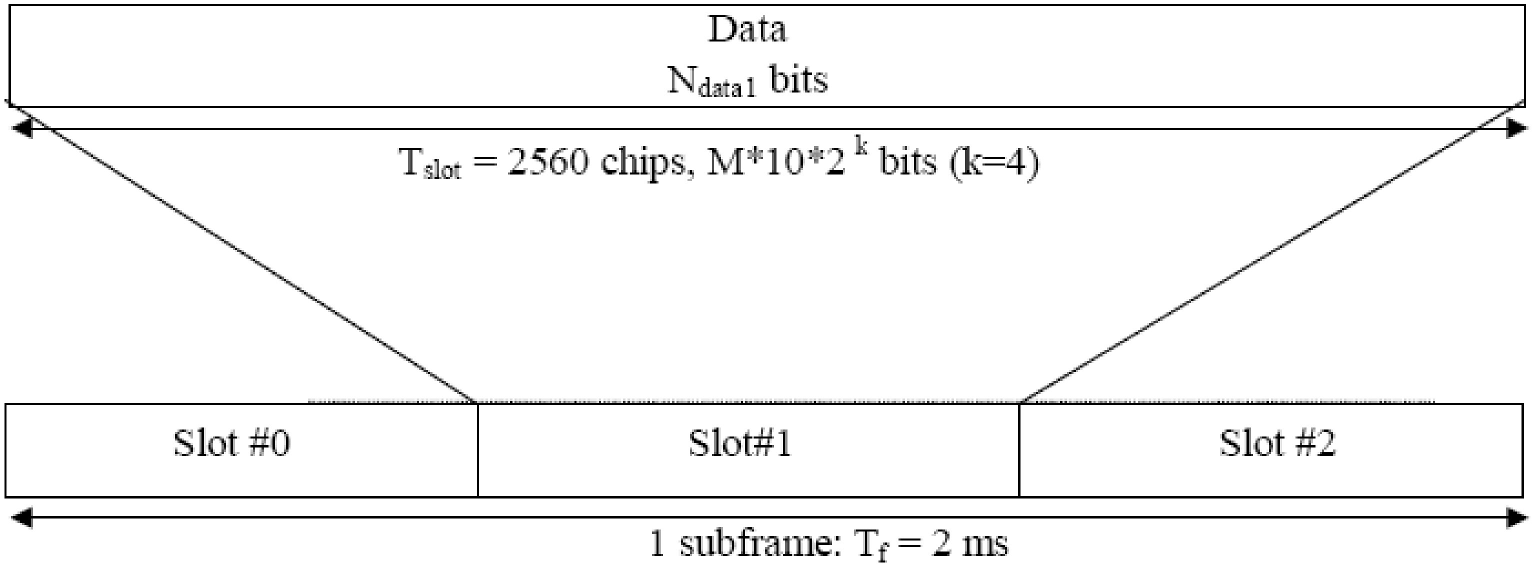
- UEs send reports
- CQI = Channel Quality Indicator (0-30)
- Not explicit quality indicator, but the date rate supported by the UE

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

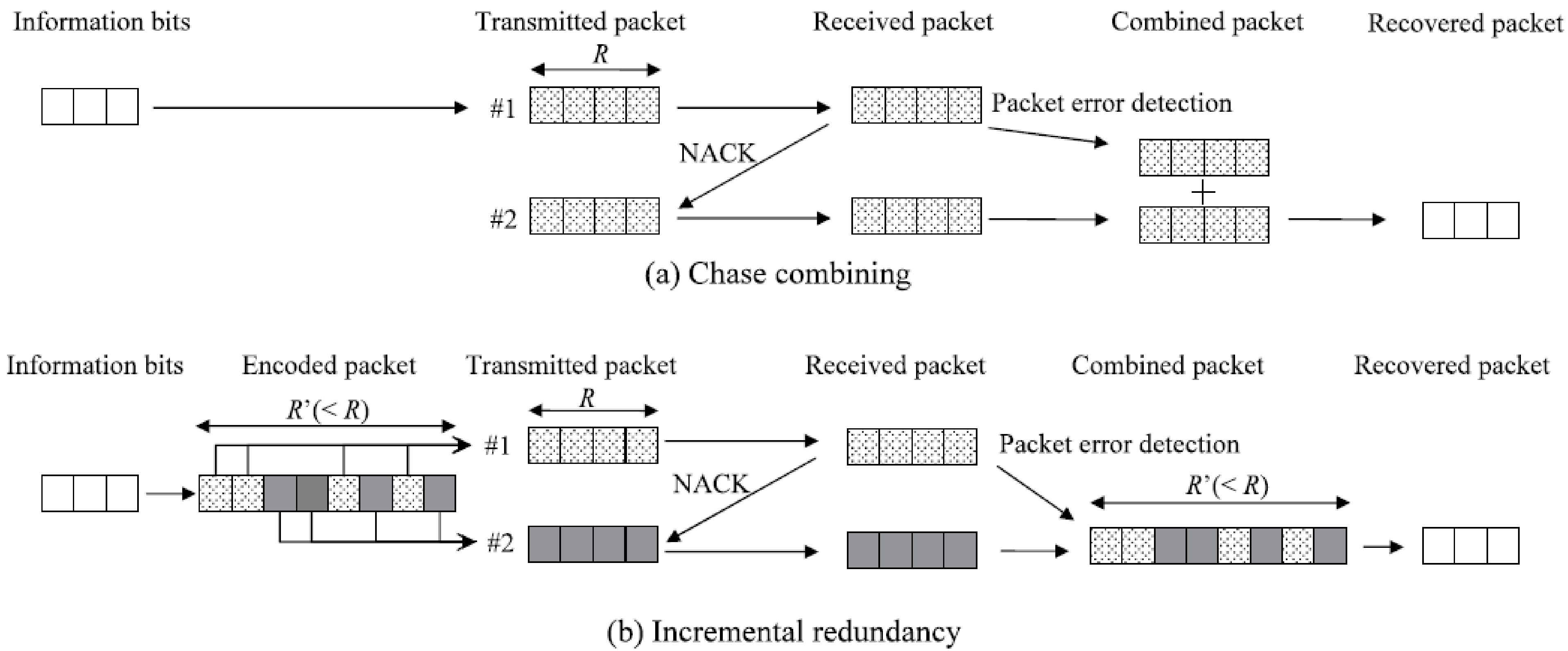


HS-PDSCH



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

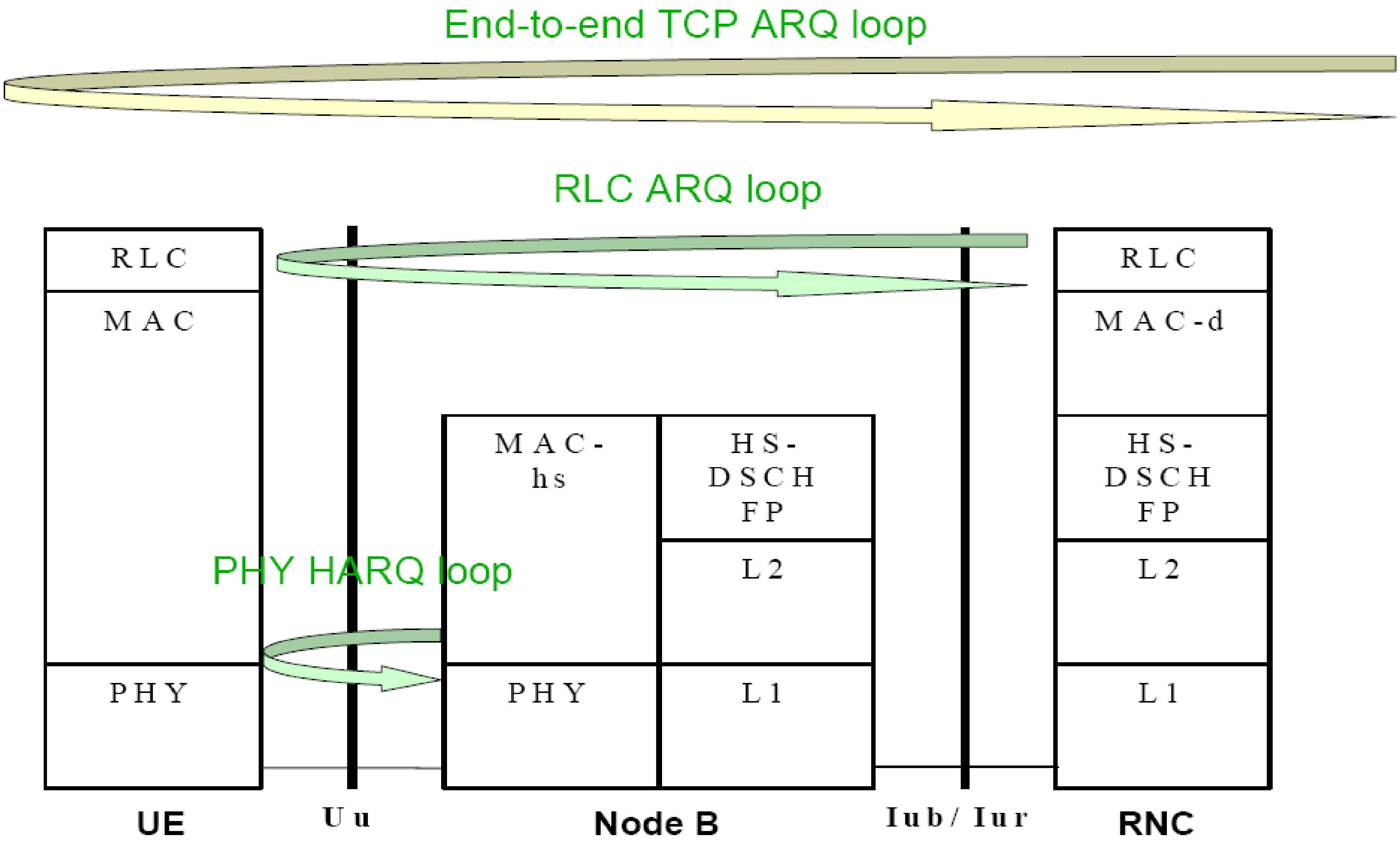
Hybrid ARQ


Information bits
Transmitted packet
Received packet
Combined packet
Recovered packet
R
#1
#2
Packet error detection
NACK
(a) Chase combining
Information bits
Encoded packet
Transmitted packet
Received packet
Combined packet
Recovered packet
R'(< R)
R
#1
#2
Packet error detection
NACK
R'(< R)
(b) Incremental redundancy

Hybrid ARQ

- Send & Wait strategy
  - Long delays
- Up to 12 parallel processes
- Buffer memory in the UE is important

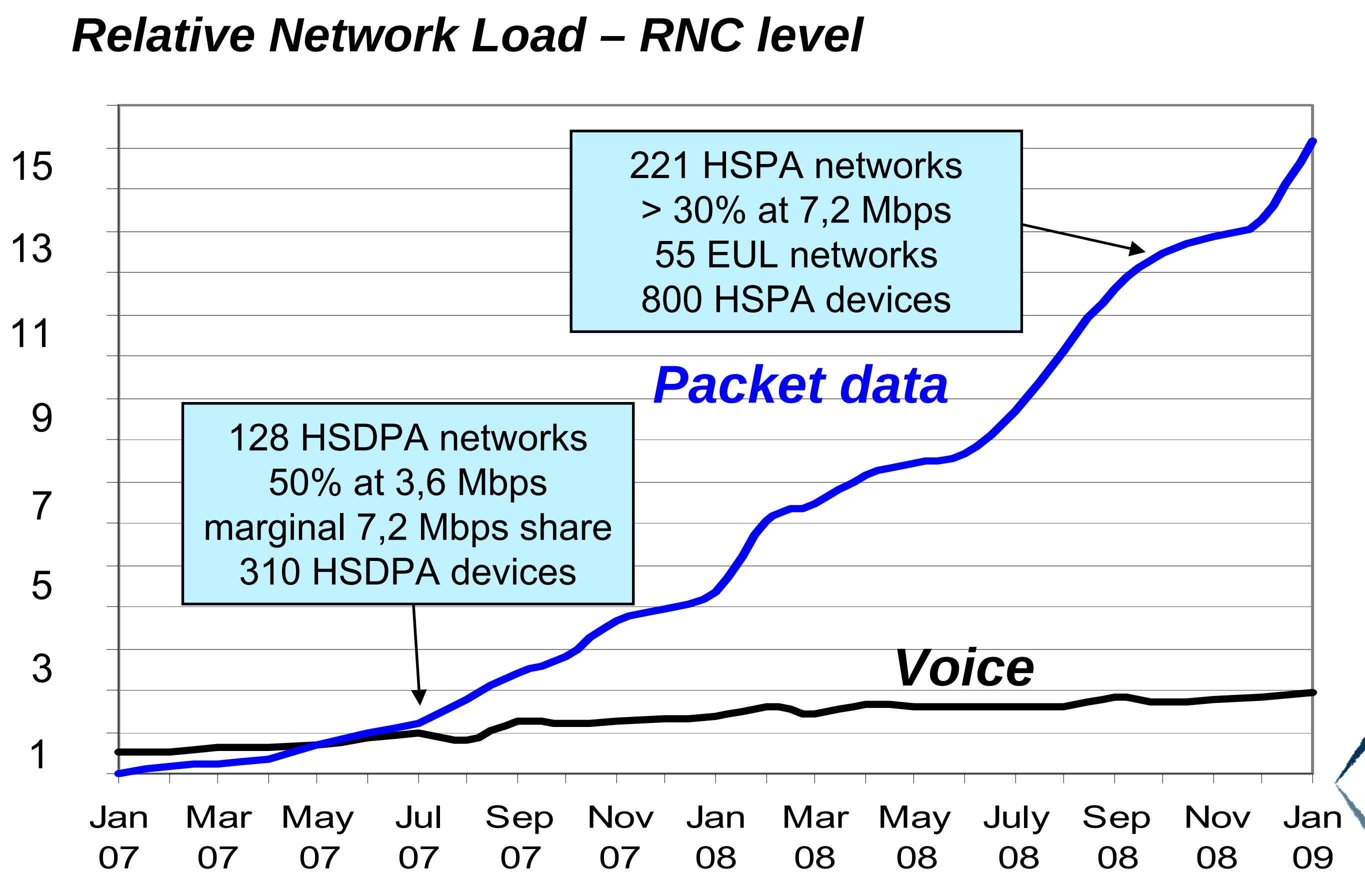
ARQ Loops


End-to-end TCP ARQ loop
RLC ARQ loop
RLC
MAC
PHY
MAC-hs
HS-DSCH FP
L2
L1
PHY HARQ loop
RLC
MAC-d
HS-DSCH FP
L2
L1
UE
Uu
Node B
Iub / Iur
RNC

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

3G – voice or data?



Data is surpassing voice on 3G since 2 years

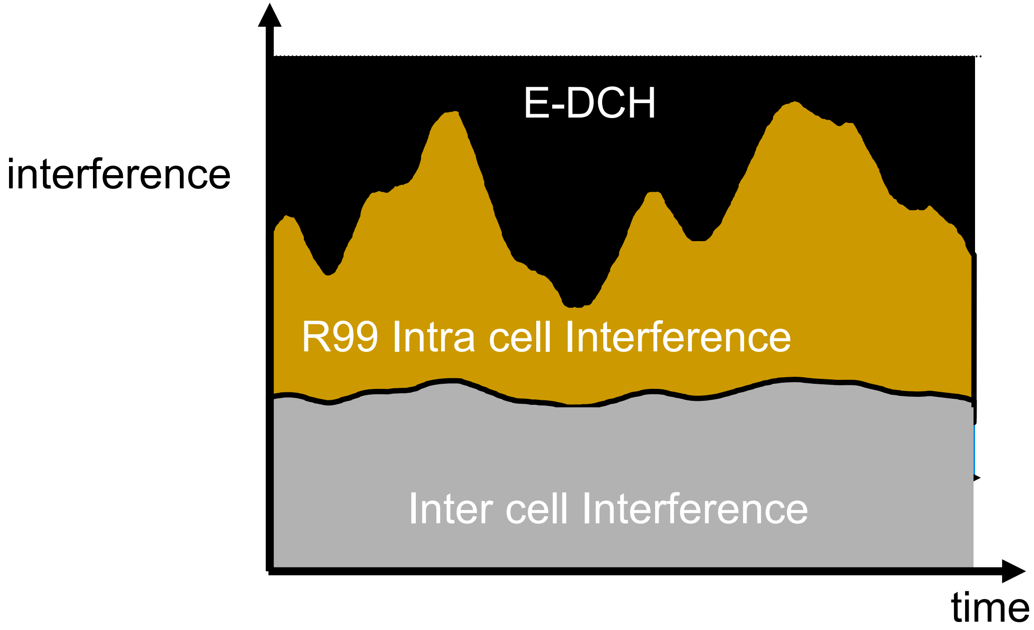
HSPA+

- 64QAM (21 Mbps) alebo 2x2MIMO (28 Mbps)
- 64QAM a Dual-Cell (42 Mbps / 10 MHz)
- 64QAM a MIMO (42 Mbps / 5 MHz)
- MIMO a Dual-Cell (56 Mbps / 10 MHz)
- 64QAM a MIMO a Dual-Cell (84 Mbps / 10 MHz)
- 64QAM a MIMO a Q-Cell (168 Mbps / 10 MHz)
- 64QAM a 4x4MIMO a Q-Cell (336 Mbps / 10 MHz)

Category	Max. number of HS-DSCH codes	Modulation	MIMO - Dual Carrier	code rate required to achieve max. data rate	Max. data rate [Mbit/s]
1	5	QPSK and 16-QAM		.76	1.2
2	5	QPSK and 16-QAM		.76	1.2
3	5	QPSK and 16-QAM		.76	1.8
4	5	QPSK and 16-QAM		.76	1.8
5	5	QPSK and 16-QAM		.76	3.6
6	5	QPSK and 16-QAM		.76	3.6
7	10	QPSK and 16-QAM		.75	7.2
8	10	QPSK and 16-QAM		.76	7.2
9	15	QPSK and 16-QAM		.70	10.1
10	15	QPSK and 16-QAM		.97	14.4
11	5	QPSK only		.76	0.9
12	5	QPSK only		.76	1.8
13	15	QPSK, 16-QAM and 64-QAM		.82	17.6
14	15	QPSK, 16-QAM and 64-QAM		.98	21.1
15	15	QPSK, 16-QAM	MIMO		23.4
16	15	QPSK, 16-QAM	MIMO		27.9
19	15	QPSK, 16-QAM	MIMO		35.3
20	15	QPSK, 16-QAM, 64-QAM	MIMO		42.2
21	15	QPSK, 16-QAM	DC		23.4
22	15	QPSK, 16-QAM	DC		27.9
23	15	QPSK, 16-QAM, 64-QAM	DC		35.3
24	15	QPSK, 16-QAM, 64-QAM	DC		42.2
25	15	QPSK, 16-QAM	DC + MIMO		46.8
26	15	QPSK, 16-QAM	DC + MIMO		55.9
27	15	QPSK, 16-QAM, 64-QAM	DC + MIMO		70.6
28	15	QPSK, 16-QAM, 64-QAM	DC + MIMO		84.4

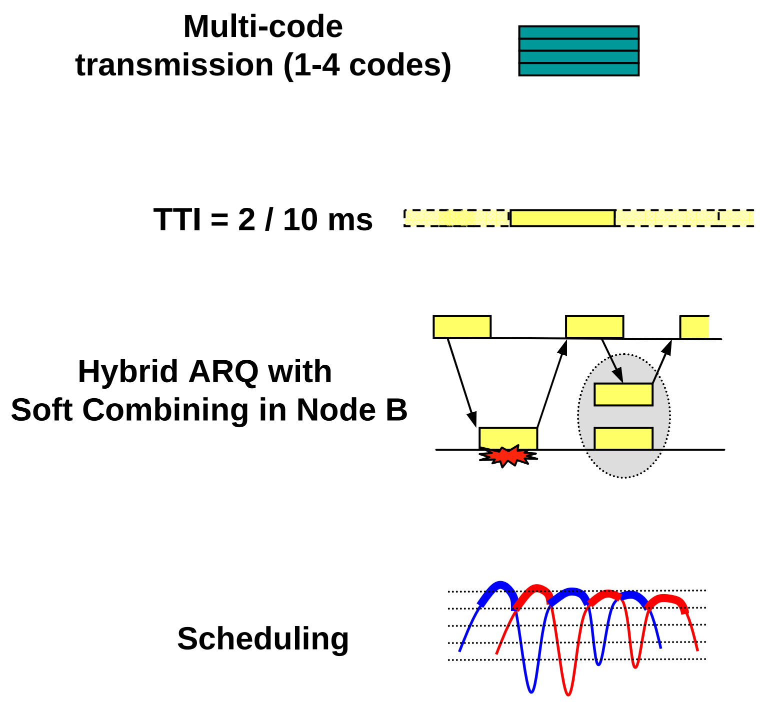
Enhanced Uplink

Resource usage

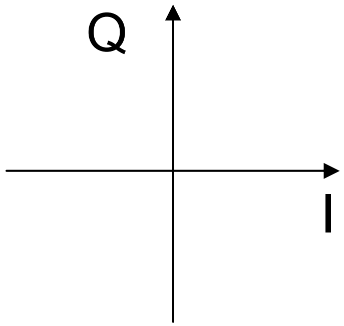


Design principles

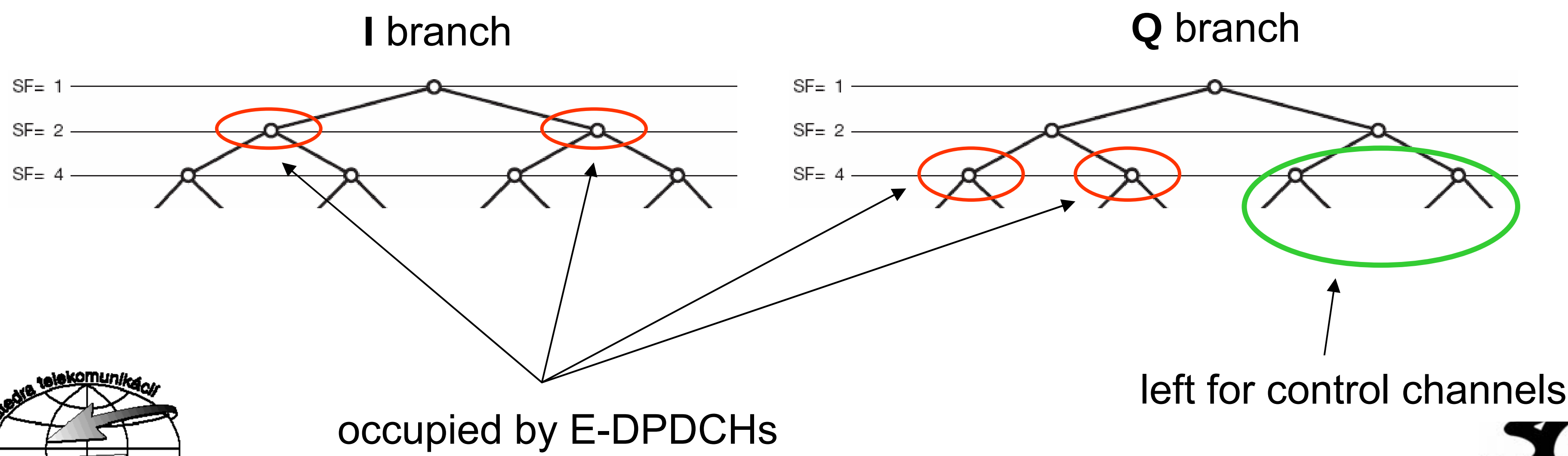
- Multi code transmission
- HARQ
- TTI 2/10 ms
- Scheduling



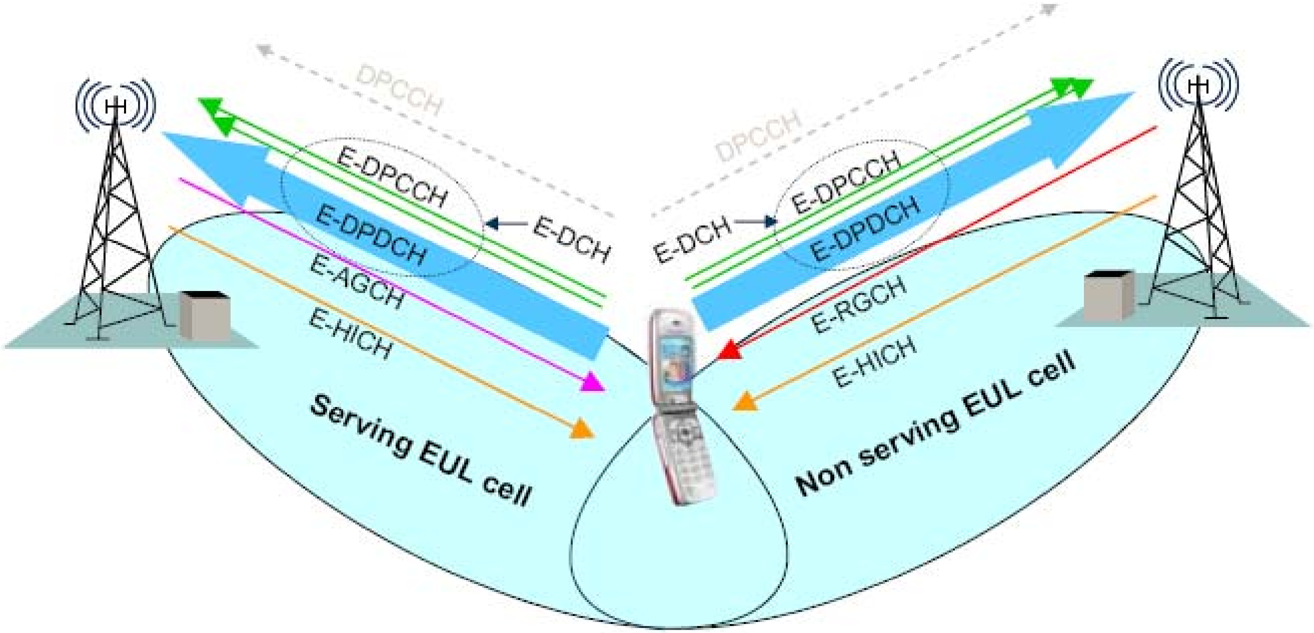
EUL – Physical Layer



- 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

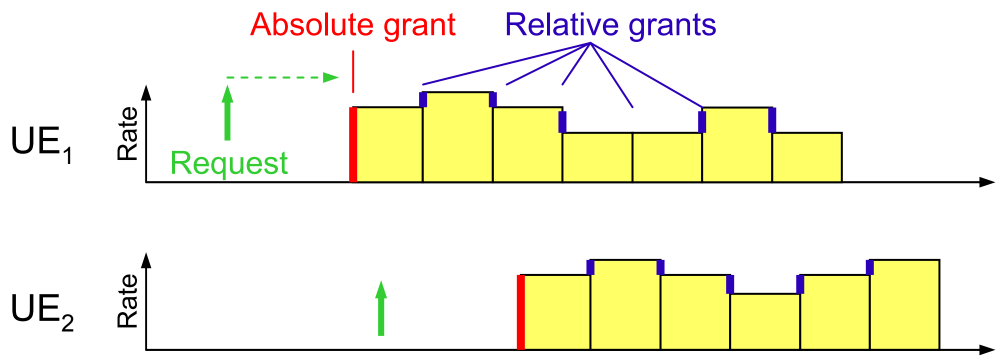
- **E-DCH Dedicated Physical Data Channel (E-DPDCH)**
  - is the data transport channel. The power of the E-DPDCH is set dynamically as an offset to the DPCCH, a so called gain or beta factor, signaled with the grant messages delivered by the scheduler.
- **E-DCH Dedicated Physical Control Channel (E-DPCCH)**
  - 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.

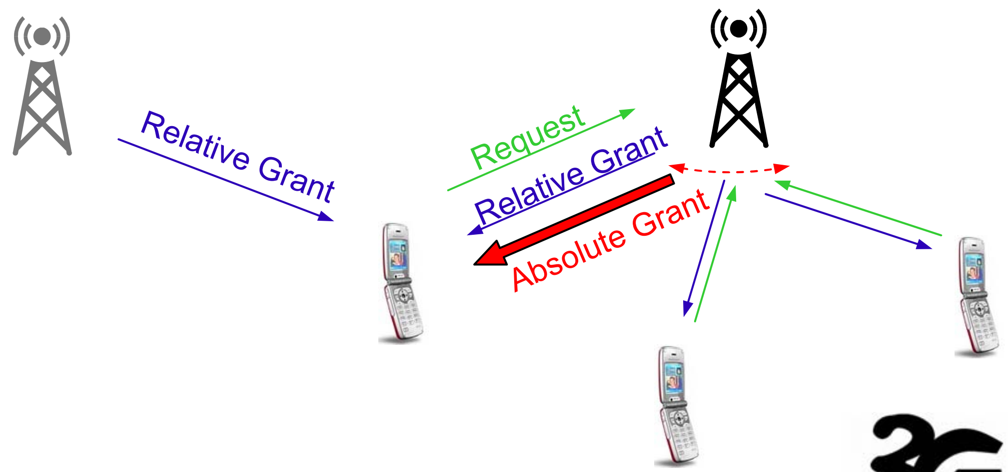
Scheduling

- 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



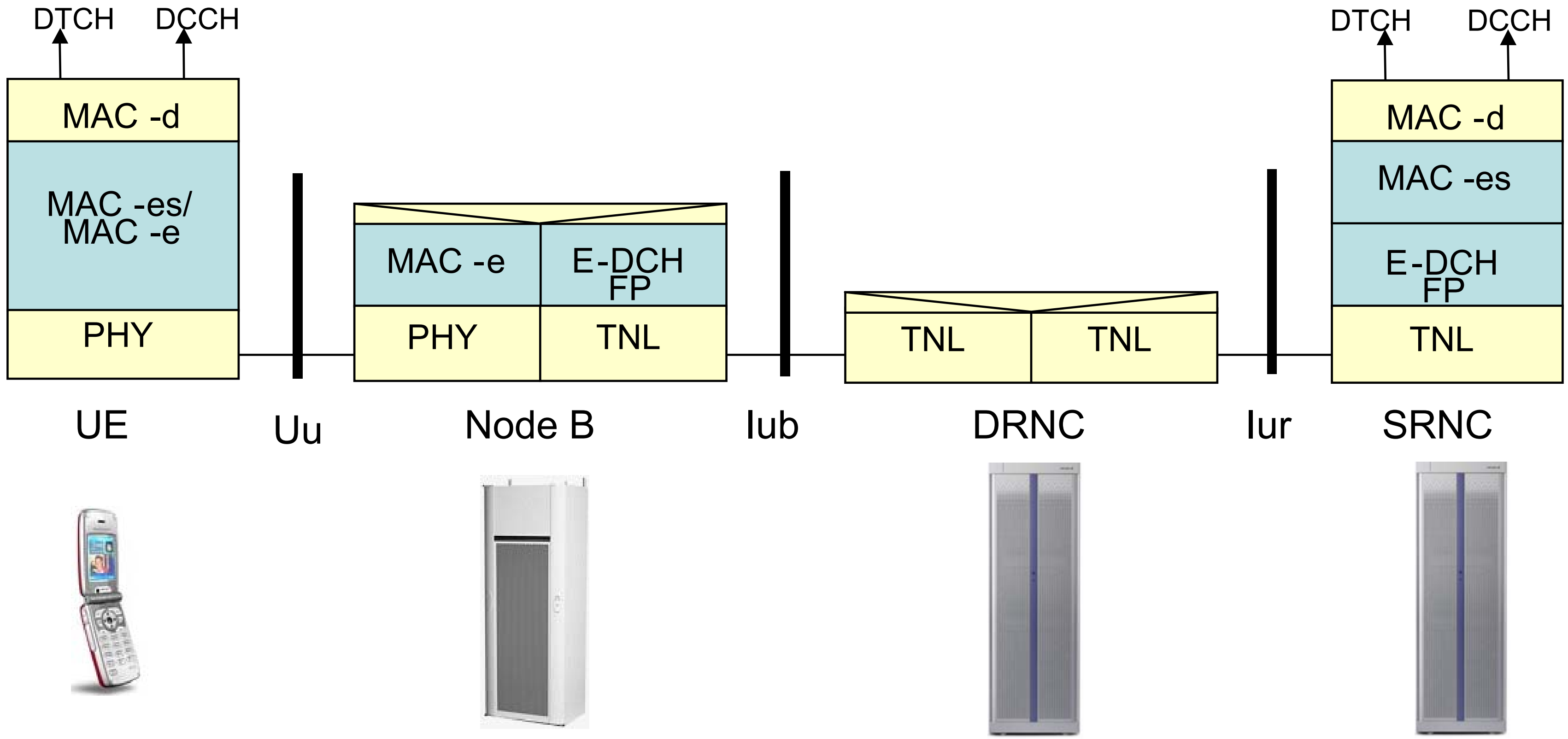


EUL UE classes

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

cat7 – 16QAM = 11,5 Mbps

New Radio interface protocol entities



HSDPA / EUL peak rates

Downlink

2006

3.6 Mbps

15 codes

14 Mbps

64QAM / 2x2 MIMO

21 Mbps / 28 Mbps

2008

Multi-carrier

42 Mbps

4x4 MIMO
Higher Modulation
Combinations

84-336 Mbps

Uplink

20-40 Mbps

Multi-carrier

12 Mbps

16QAM

5.8 Mbps

2008

2 ms TTI

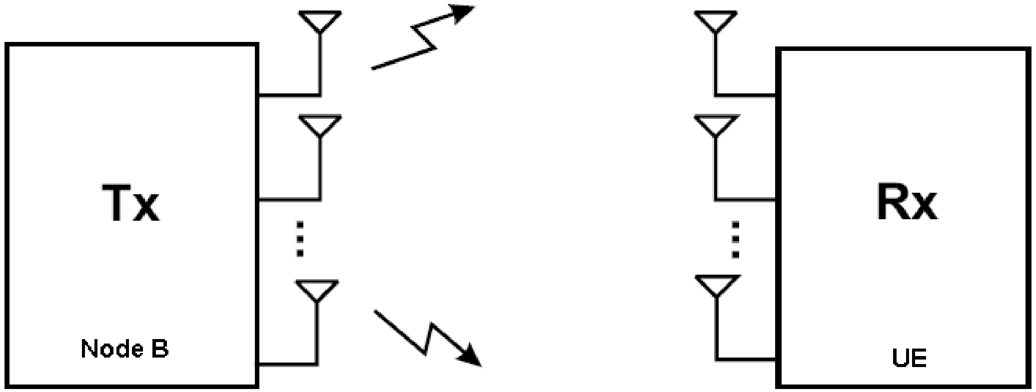
2 Mbps

2006

0.384 Mbps

Multi-antenna systems

MIMO principle



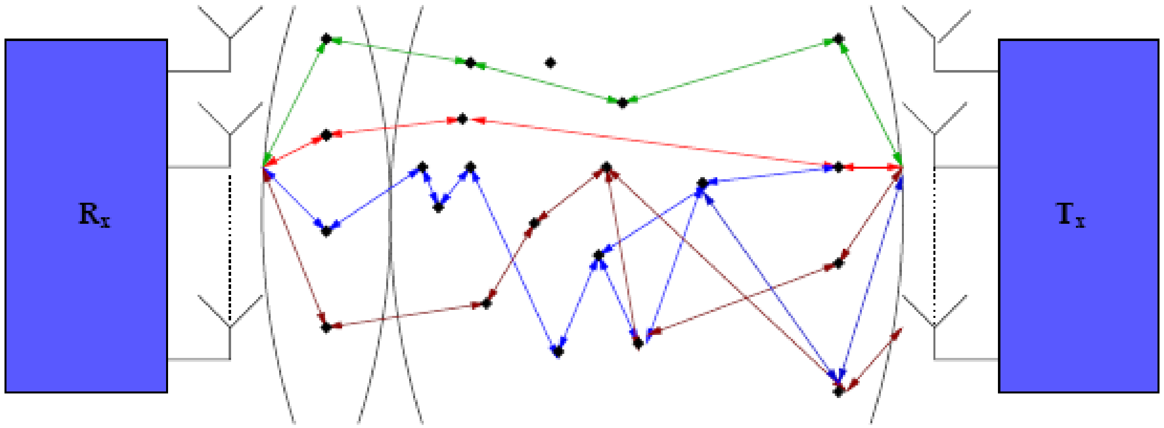
- **Array gain**: Increased coverage.
- **Diversity gain**: Improved quality.
- **Spatial multiplexing**: Increased spectral efficiency.
- **Additional transmission pipe**: Increased data rates.

MIMO principle

MIMO works well, when:

1) conditions are bad:
   - no LOS signal component (or polarization separation)
   - lot of scatteres

2) antennas have sufficient spacing
   - uncorrelated antennas
   - independent CIRs



Capacity

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

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

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

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

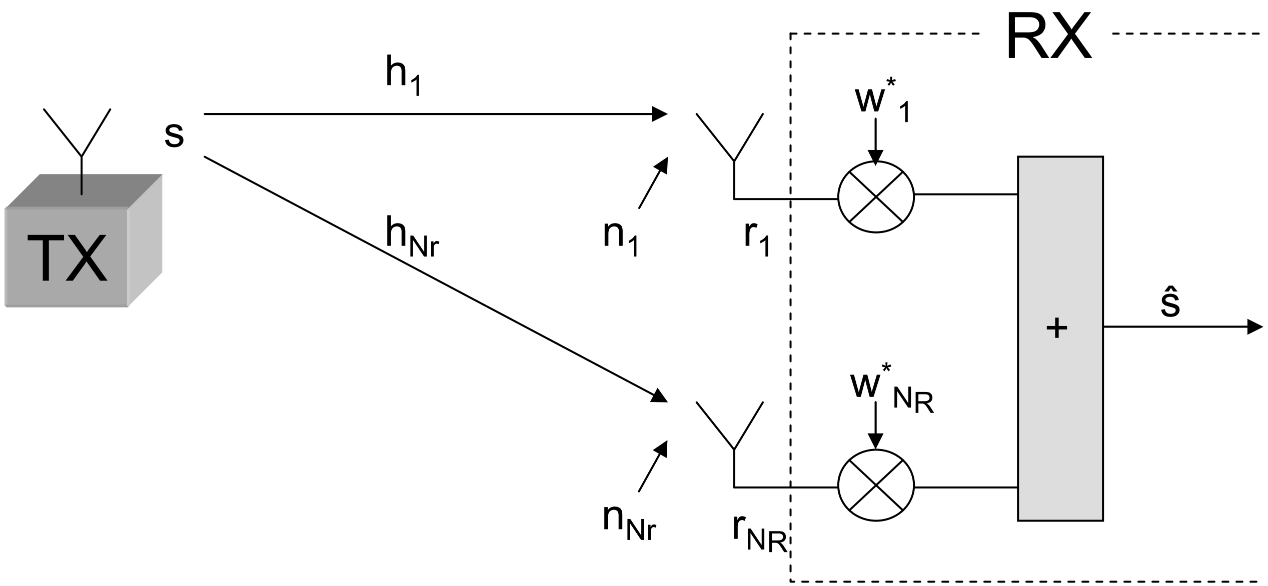
ρ = SNR

h = channel impulse response

H = channel impulse response MxN (input, output antennas) matrix

r = matrix rank

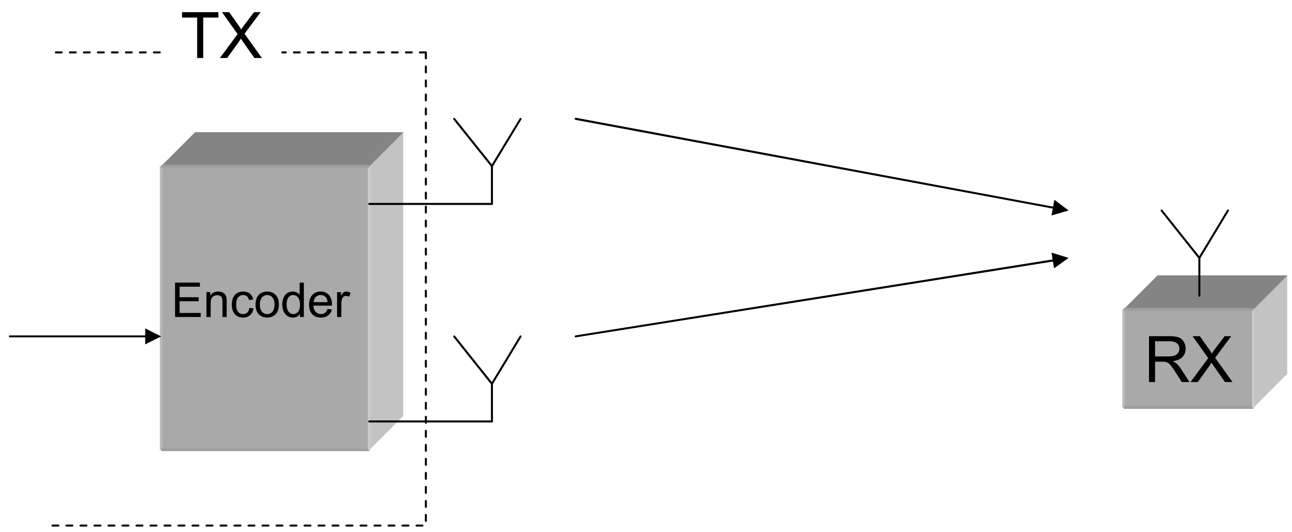
Rx diversity (SIMO)



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

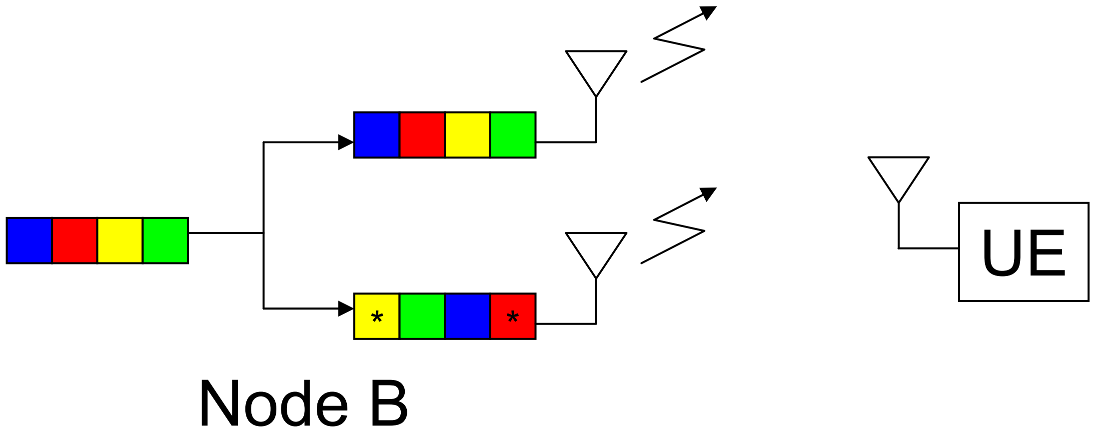
$$\overline{r} = \overline{h} \cdot s + \overline{n}$$

Tx diversity (MISO)



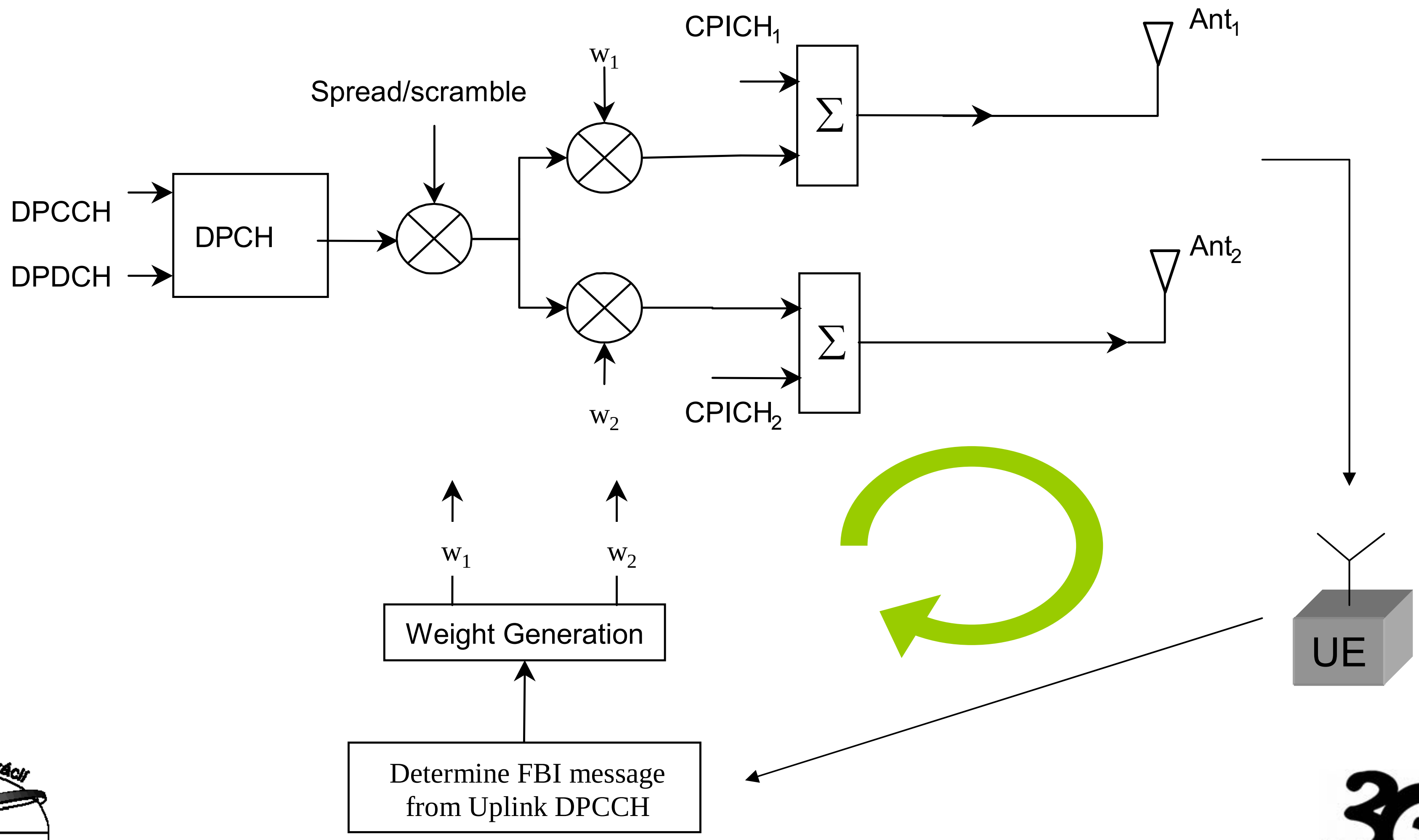
Tx Diversity (open loop), Rel. 6 (MISO)

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

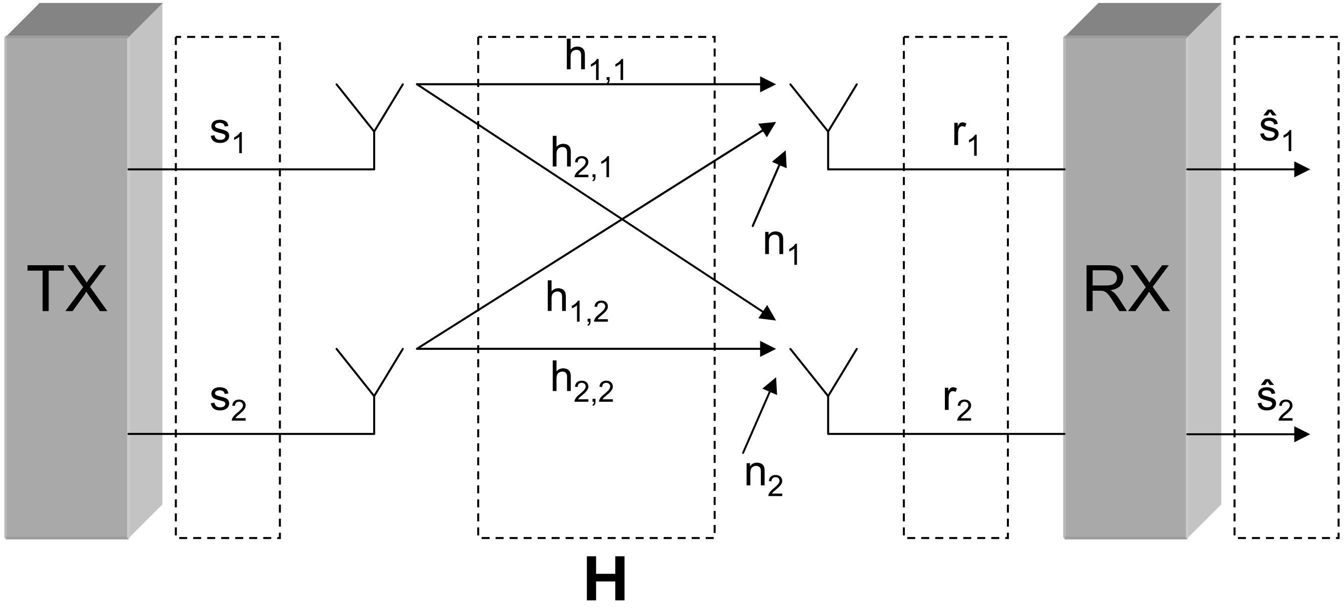


…for QPSK

Closed loop Tx diversity



MIMO



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

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

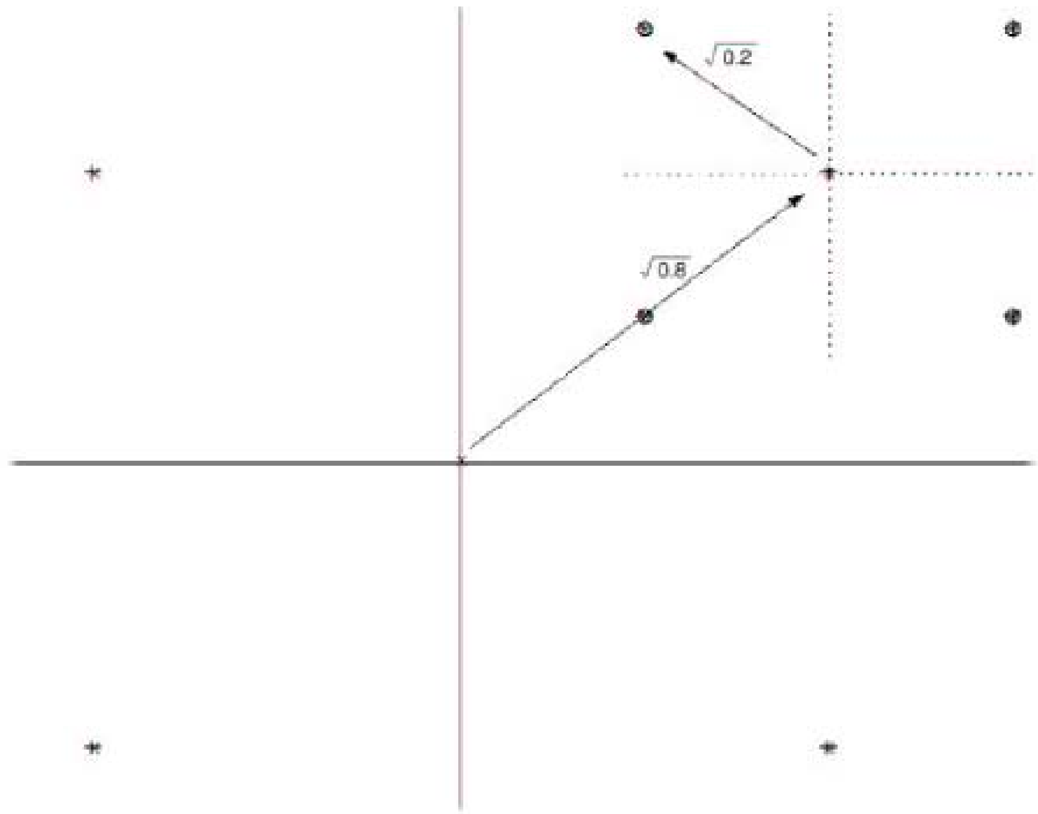
max MIMO capacity

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

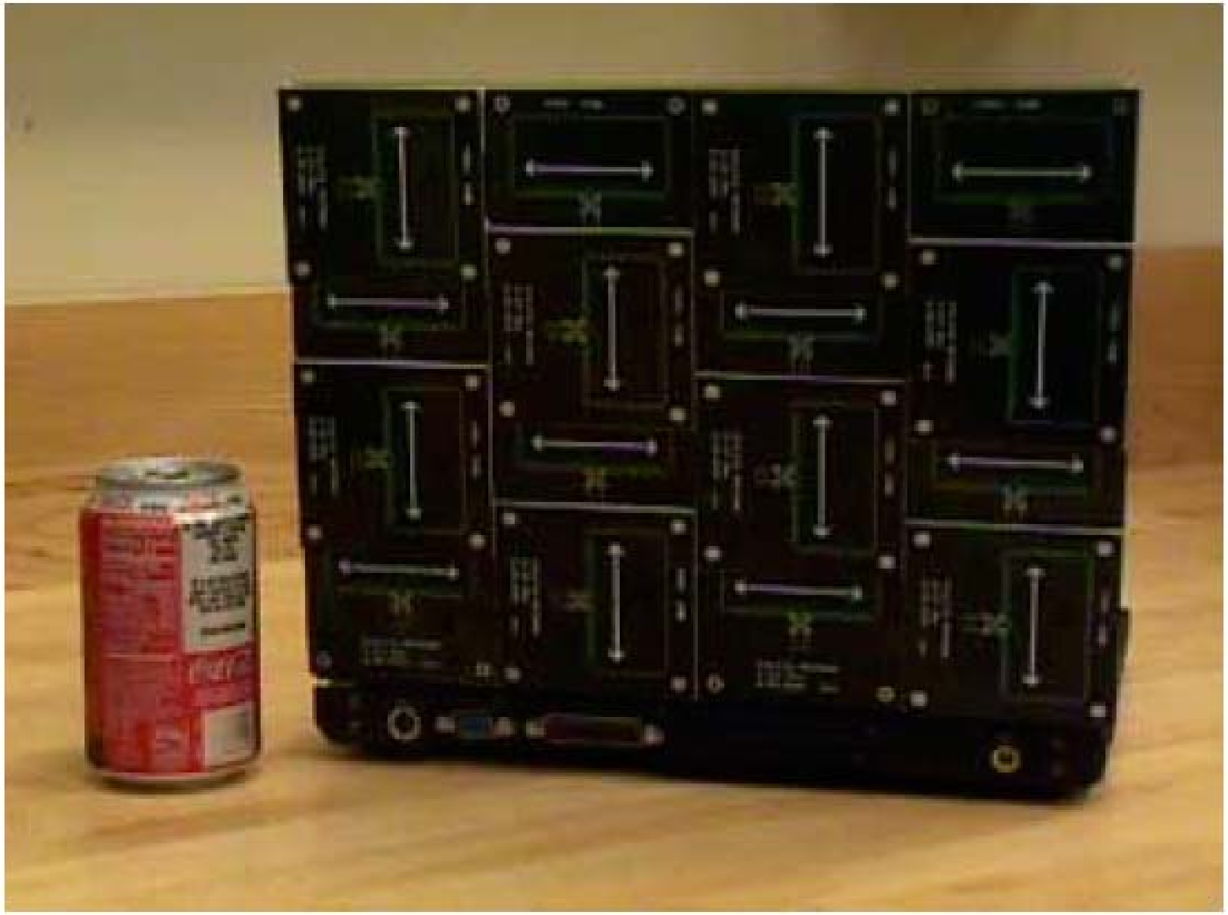
$$C^{D}_{MIMO} = \sum_{i=1}^{r} \log_2\left(1 + \frac{\rho}{M}\lambda_i\right) \text{ bps/Hz}$$

MIMO & HOM relation

- MIMO can be considered as a form of HOM
- 2 streams of 4QAM = 1 stream of 16QAM



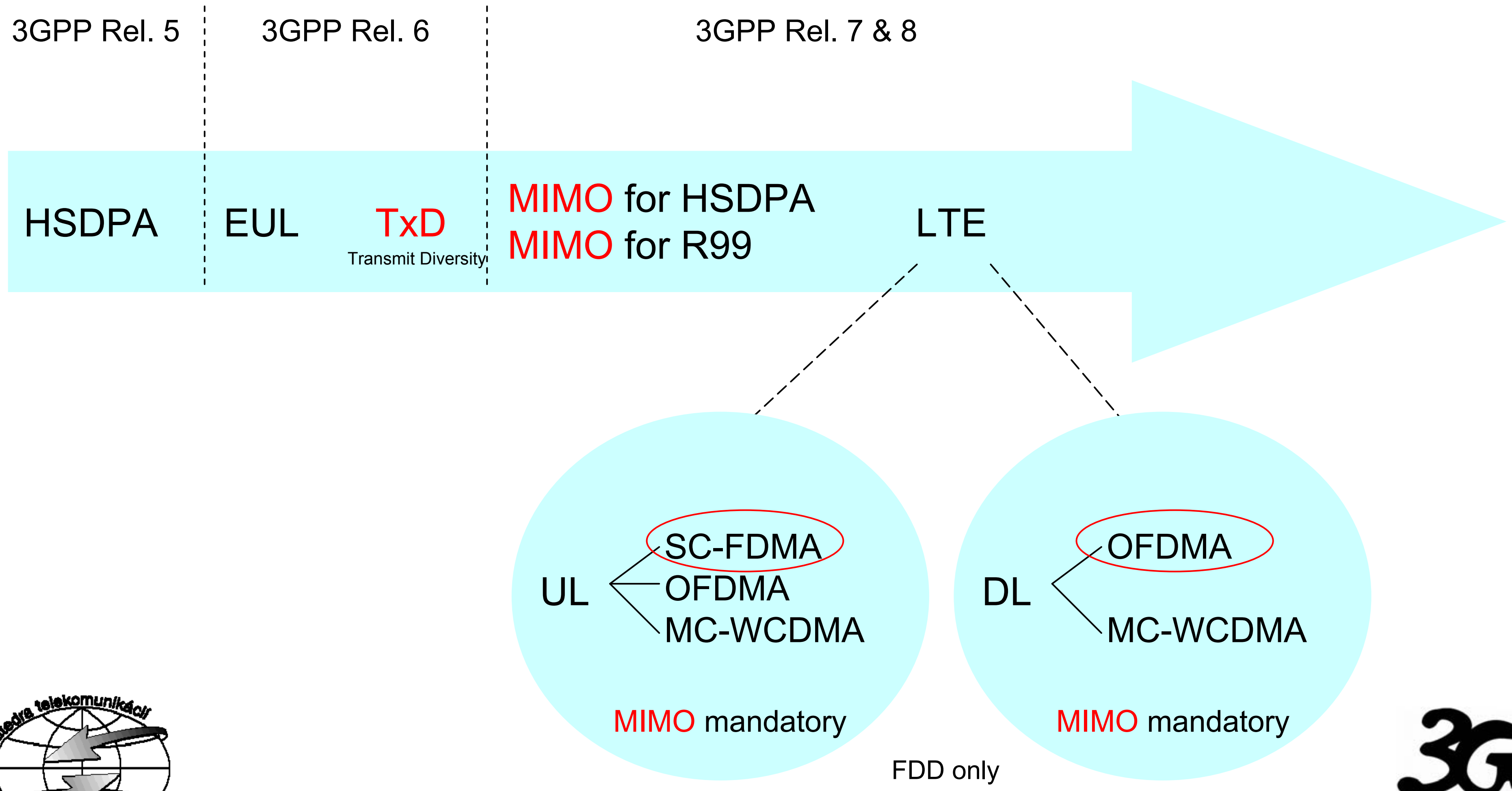
So many antennas…



So many antennas…

So many antennas…

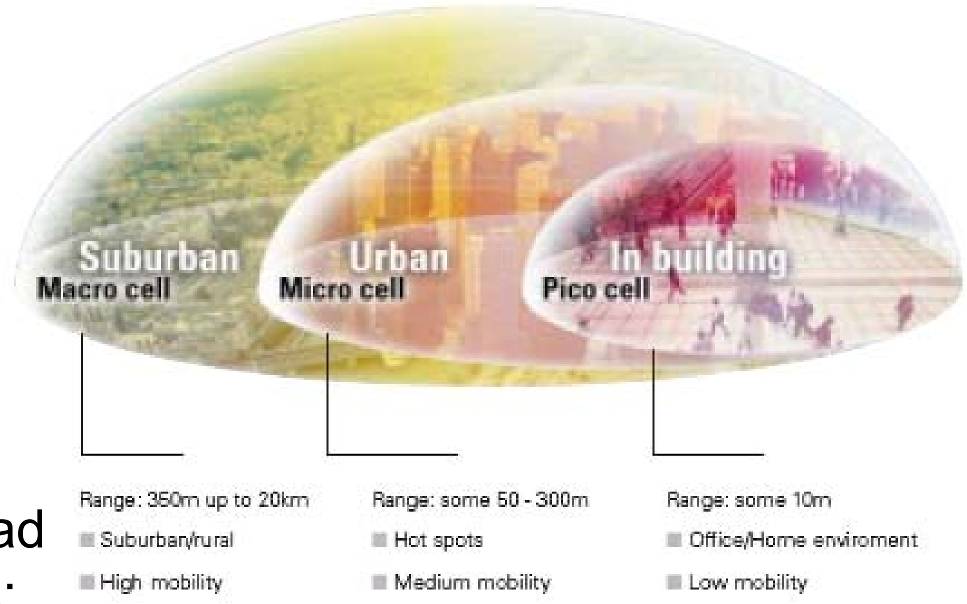
MIMO introduction into 3GPP



HSDPA MIMO

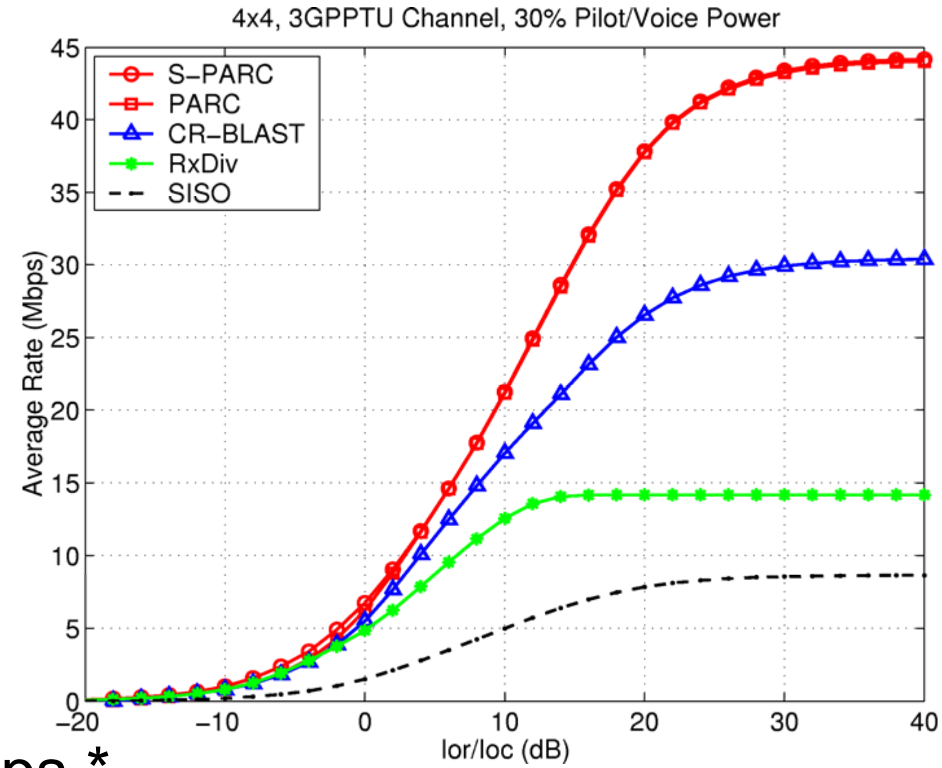
- Where it's hot:
  - higher isolation between cells and/or non-uniform load distribution: **URBAN MICRO**
  - **PICO & INDOOR**

- 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 *)



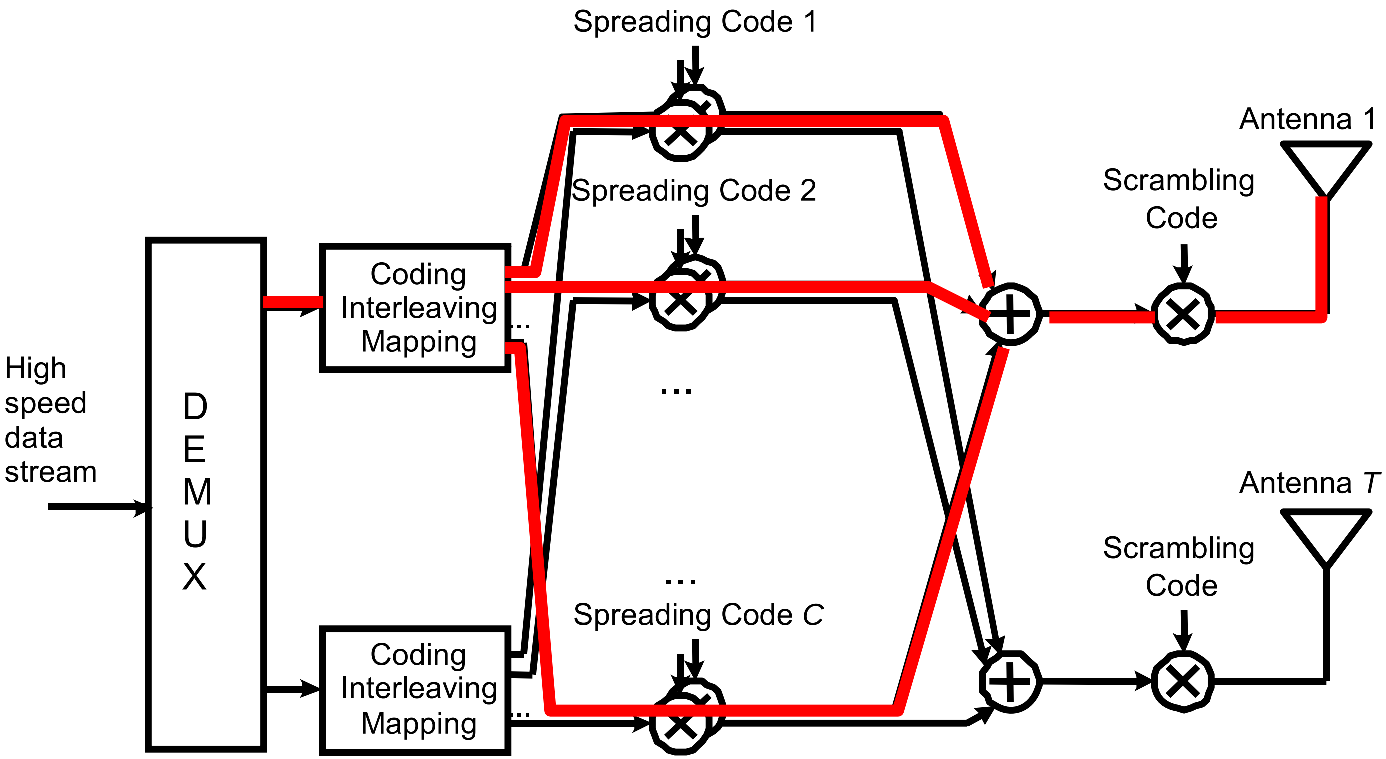
HSDPA + MIMO

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

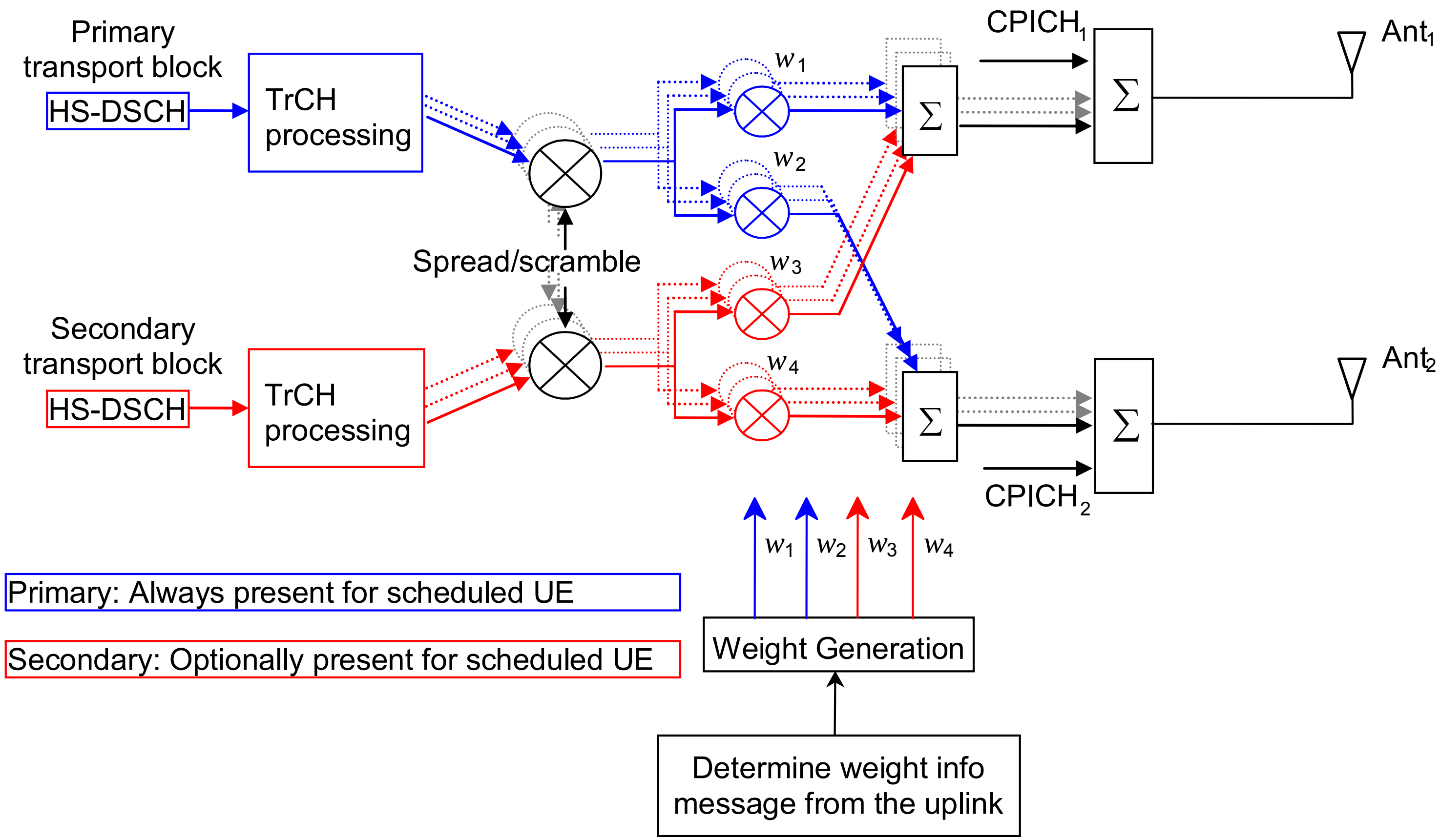
Selective per-antenna rate control (S-PARC)



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…



Double Transmit antenna array (D-TxAA)
LG Electronics