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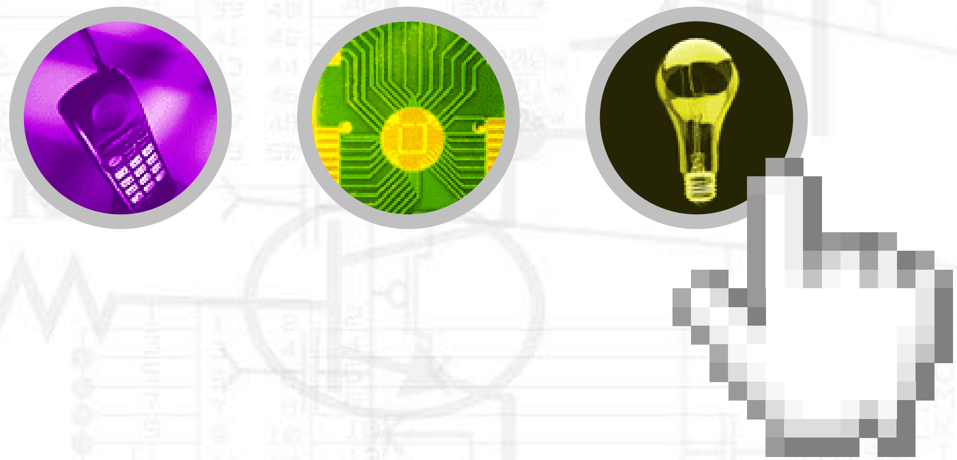

Evolution of 3G Wireless Systems High Speed Downlink Packet Access and Beyond

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Outline

- Motivation for evolution
- Downlink enhancements
- Uplink enhancements
- Impact on terminal design
- Impact on network design
- Summary

Motivation for Evolution

Third generation wireless systems were introduced to extend the data capabilities by providing quality of service (QOS) management and enabling the high data rate required for high speed data

To satisfy predicted future increasing demands on even higher data services additional enhancements are being incorporated into the different 2.5G and 3G standards

- EDGE
- UTRA FDD and TDD (WCDMA, UMTS)
- CDMA 2000 1x EV-DV
- CDMA 2000 1x EV-DO

Downlink Enhancements

- Fast link adaptation (adaptive modulation and coding)
- Hybrid ARQ (HARQ)
- Fast scheduling
- Fast cell selection
- Multiple Input Multiple Output (MIMO) antenna processing

Fast Link adaptation - Motivation

Higher order modulation (16 QAM, 64 QAM) provides higher spectral efficiency in terms of bits/sec/Hz compared to QPSK. Therefore it can be used to increase the peak data rate for a given bandwidth. For example it can enable peak data rates in the order of 10 Mbits/sec within the current 5 MHz WCDMA bandwidth.

However, higher order modulation schemes are significantly less robust to noise, interference and other channel impairments. Hence higher order modulation must be combined with fast link adaptation.

Fast link Adaptation – How does it work?

The coding rate and modulation scheme is rapidly adapted to the instantaneous channel conditions.

Users experiencing favorable channel conditions, e.g., close to the cell site, can be assigned higher order modulation and high code rate thus achieving higher peak rates.

Users with less favorable conditions, e.g., users close to the cell border or users at a deep fade need to use the more robust QPSK modulation and low coding rates.

The downlink user throughput is maximized given the instantaneous channel conditions.

Fast Link Adaptation – an example (1x EV-DO)

Physical Layer Parameters												
Data Rate (kbps)	38.4	76.8	153.6	307.2	307.2	614.4	614.4	921.6	1228.8	1228.8	1843.2	2457.6
Modulation Type	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	8PSK	QPSK	16QAM	8PSK	16QAM
Bits per Encoder Packet	1024	1024	1024	1024	2048	1024	2048	3072	2048	4096	3072	4096
Code rate	1/5	1/5	1/5	1/5	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3
Encoder Packet Duration (ms)	26.67	13.33	6.67	3.33	6.67	1.67	3.33	3.33	1.67	3.33	1.67	1.67
Number of Slots	16	8	4	2	4	1	2	2	1	2	1	2

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Fast Link Adaptation – an example (UMTS TDD)

CQI	SIR low (dB)	SIR high (dB)	TBSS	Code Rate	Modulation Type
0	-inf	-3	TBD	TBD	TBD
1	-3.0	-2.8	6496	0.184	QPSK
2	-2.8	-2.5	6990	0.198	QPSK
3	-2.5	-2.2	7633	0.216	QPSK
4	-2.2	-1.9	8214	0.233	QPSK
5	-1.9	-1.6	8839	0.250	QPSK
6	-1.6	-1.2	9511	0.269	QPSK
7	-1.2	-0.8	10386	0.294	QPSK
8	-0.8	-0.4	11176	0.316	QPSK
9	-0.4	-0.1	12026	0.340	QPSK
10	-0.1	0.4	12941	0.366	QPSK
11	0.4	0.8	14131	0.400	QPSK
12	0.8	1.2	15206	0.430	QPSK
13	1.2	1.8	16362	0.463	QPSK
14	1.8	2.3	17867	0.506	QPSK
15	2.3	2.8	19226	0.544	QPSK
16	2.8	3.3	20689	0.586	QPSK
17	3.3	4.1	22263	0.630	QPSK
18	4.1	4.8	24310	0.688	QPSK
19	4.8	5.5	26159	0.740	QPSK
20	5.5	6.1	28149	0.398	16 QAM
21	6.1	6.7	30738	0.435	16 QAM
22	6.7	7.3	33076	0.468	16 QAM
23	7.3	7.9	35592	0.504	16 QAM
24	7.9	8.7	38299	0.542	16 QAM
25	8.7	9.4	41821	0.592	16 QAM
26	9.4	10.2	45002	0.637	16 QAM
27	10.2	11.0	48426	0.685	16 QAM
28	11.0	12.0	52109	0.738	16 QAM
29	12.0	17.2	56901	0.805	16 QAM
30	17.2	inf	61230	0.867	16 QAM

Far from Basestation

Close to basestation

Link adaptation – who makes the decision?

The mobile terminal performs channel quality measurements and reports to the network using physical layer signaling

The measurements are typically expressed as an index to a packet transmission configuration

- DO – one of 12 configurations
- HSDPA FDD – one of 31 configurations

In EV-DO, the network "obeys" the terminal and transmits the requested configuration

In HSDPA FDD and EV-DV the fast scheduling algorithm in the base station makes the decisions based on the channel quality reports from all active terminals.

- Hundreds of allowed configurations

Hybrid ARQ (Automatic Repeat Request)

In case of packet data services the receiver typically detects and requests a retransmission of erroneously received packets

Until the introduction of Hybrid ARQ (also referred to as physical layer ARQ) the ack/nack signaling was done via higher layer signaling resulting in long delays in the retransmission process

When fast link adaptation is used – a faster ARQ mechanism is needed to add robustness to the link adaptation

Hybrid ARQ – How does it work?

Implicit link adaptation technique that is not based on channel quality measurements

Physical layer acknowledgements are used for re-transmission decisions.

Tightly coupled with fast link adaptations

- Fast link adaptation provides an initial estimates for the redundancy required for reliable transmission
- Hybrid ARQ enables fine tuning of the effective code rate

Also enables additional gains by soft combing of packets from the original and subsequent packets prior to the decoding attempt

Hybrid ARQ schemes

Chase Combining

- The simplest form of Hybrid ARQ
- Number of repeats of each coded data packet are sent.
- The decoder combines multiple received copies of the coded packet weighted by the SNR prior to decoding.
- This method provides time diversity gain and is very simple to implement.

Incremental redundancy

- Instead of sending simple repeats of the entire coded packet, additional redundant information is incrementally transmitted if the decoding fails on the previous attempt.

Both schemes are implemented in UTRA FDD/TDD

Hybrid ARQ protocols

Window based Selective Repeat (SR)

- **Advantage: efficient, repeats only those blocks that have been received in error.**
- **Disadvantages:**
  - The transmitter must employ a sequence number to identify each block it sends. Reliable detection of the sequence number must be guaranteed resulting in undesired signalling overhead
  - Terminal memory requirements are high

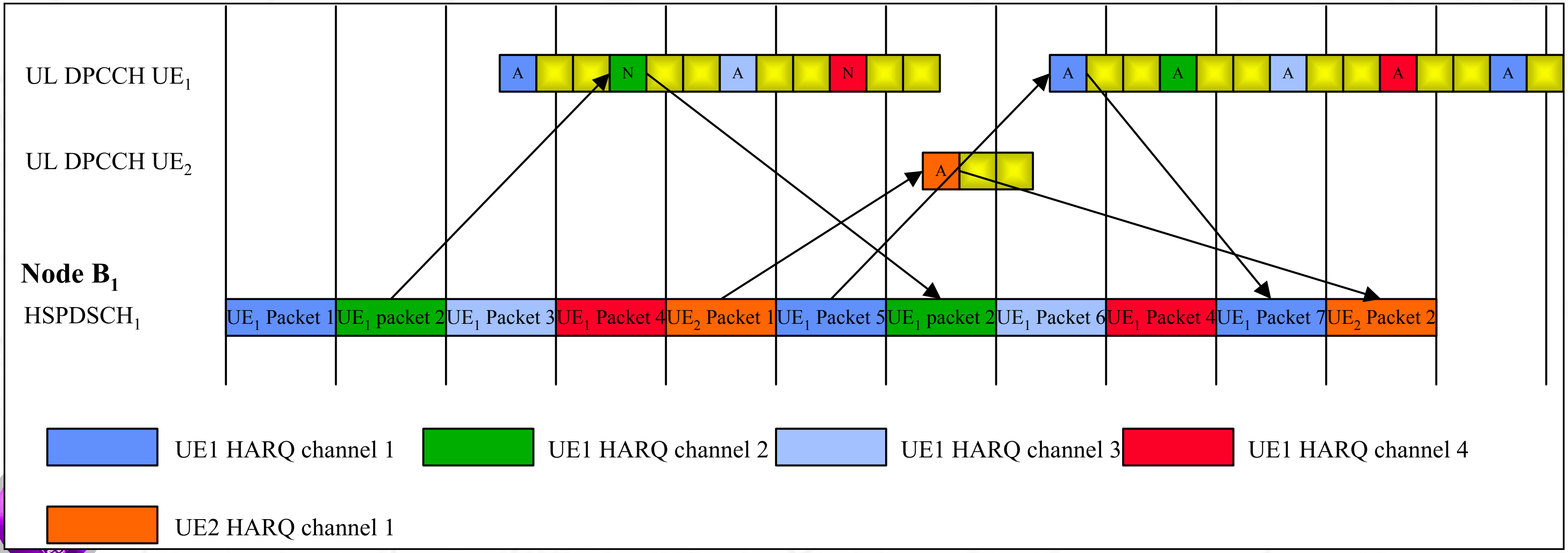
Hybrid ARQ protocols

Stop and Wait

- **Advantages**
  - The transmitter operates on the current block until the block has been received successfully → Minimal signalling overhead
  - Memory requirements are minimized because there is only one block in transit at any time
- **Disadvantages**
  - Acknowledgements are not instantaneous and therefore after every transmission, the transmitter must wait to receive the acknowledgement prior to transmitting the next block.
  - In the interim, the channel remains idle and system capacity goes wasted.

N channel Stop and Wait provides a solution that overcomes the resource utilization problem. Selected for URTA FDD/TDD

Hybrid ARQ – N channel Stop and Wait



N instances of the protocol run in parallel

N is determined to guarantee that the resources are never idle

Fast Scheduling

Fast scheduling is the mechanism determining which user(s) get the cell resources at any given time interval

- In some of the standards the scheduler also decides the data rates (and transmit configurations) of scheduled users

The scheduler is a key element in the design of a packet data system as it determines the overall behavior of the system

To enable fast scheduling the fast scheduler resides in the base station

- Before the introduction of fast scheduling the scheduler has been typically in the Radio Network Controllers (RNC) or the base station controller (BSC)

Scheduling Strategies

Max c/I – Maximizes the cell throughput by allocating all of the cell resources to the user with the best channel conditions

- Unfair scheduler: Users with unfavorable channel conditions will never be served

Round Robin – fair but far from optimal

Practical schedulers - must take in account the channel quality reported by the terminals as well as the time duration since the user has been served

- e.g. – Proportional Fairness schedulers

Proportional Fairness Schedulers

Example is for EV-DO where at any given time a single user gets all cell resources

The scheduler selects for transmission the user with the highest

$$\frac{DRC(n+L)}{\overline{R}(n+L-1)}$$

where

$DRC(n+L)$	The rate requested by the mobile terminal at time n+L
$\overline{R}(n+L-1)$	The average received rate of a suitable selected time interval

Fast Cell Selection

The terminal makes recommendations on the "best" cell for downlink packet transmission and signals this to the network.

Determination of the best cell may not only be based on radio propagation conditions but also available resources such as power and code space for the cells in the active set.

Who makes the decision?

- **EV-DO: The network follows the terminal's recommendation**
- **EV-DV: The network makes the decisions taking in account also available resources**

Multiple Input Multiple Output (MIMO) Antenna Processing

MIMO Techniques Can Be Classified as Evolutionary Versus Revolutionary Techniques

Evolutionary techniques

- Applying standard transmit and receive multiple antenna techniques (e.g. base station transmit diversity and handset receive diversity)
- Do not requires joint transmitter-receiver design

Revolutionary techniques

- Joint Transmit Receive Spatio-Temporal Processing
- Space-time coding
- Code Reuse architecture (e.g. Blast)

On going debate in 3GPP RAN 1 on the relative merits of each approach (evolutionary vs. revolutionary) in the context of Release 6

- To be resolved by simulation studies with common simulation assumptions

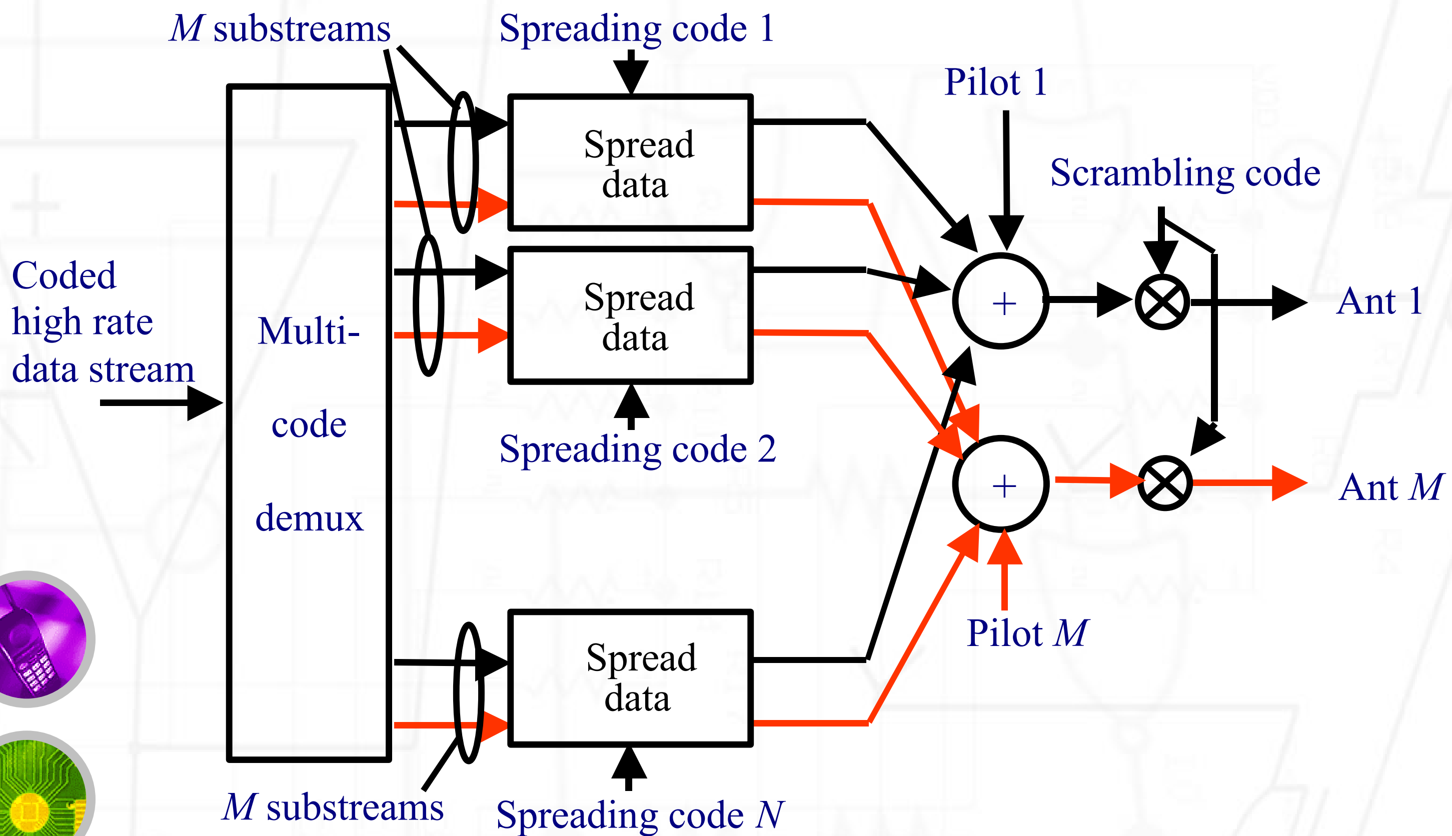
Motivation for Revolutionary Techniques

Significant increases in capacity and data rates are predicted by information theoretic studies.

In an independent Raleigh scattering environment the rates grow linearly with min(M,N) where M is the number of transmitting antennas and N is the number of receiving antennas.

- Diversity based architectures tend to saturate when the number of antennas approaches 3 or 4
- Realistic constrains on beam-width tend to limit beamforming gains

Block Diagram of MIMO Code Reuse Transmitter



Utilizes the spatial dimension by transmitting and detecting a number of independent co-channel data sub-streams, each one transmitted by a different antenna.

Comparison of Implementation is Standards

	EV-DO	EV-DV	HSDPA
Carrier for packet data	Separate carrier	Same carrier for data and voice	Same carrier for data and voice
Data/Control multiplexing	Time multiplexing- The access point transmits at full power serving one user at a time	Code and Time multiplexing	Code and time multiplexing
Link adaptation	Select one of 12 configurations adapting modulation scheme & coding rate	Select one of up to 504 configurations adapting modulation scheme, coding rate, and number of codes.	Select one of up to - 1890 configurations adapting modulation scheme, coding rate, number of codes and power level
Hybrid ARQ	Simplified form of physical layer ARQ	Chase combining and incremental redundancy	Chase combining and incremental redundancy
Fast Cell selection	Yes	Yes	Candidate for future enhancements
Fast scheduling	Yes	Yes	Yes
MIMO	Rx + Tx diversity	Candidate for future enhancements	Candidate for future enhancements

Performance of Downlink Enhancements

UTRA FDD: Ior/Ioc= 10 dB, Ec/Ior=-3 dB

	Panasonic		Eeicsson		Sony Ericssson		NEC		Qualcomm	
	Throughput [kbps]	BLER	Throughput [kbps]	BLER	Throughput [kbps]	BLER	Throughput [kbps]	BLER	Throughput [kbps]	BLER
PA3	1885	0.21	1921	0.2	1571	0.3	1552	0.3	2162	0.13
PB3	1267	0.12	1212	0.14	1099	0.21	1155	0.2	1287	0.12
VA30	1000	0.21	836	0.34	876	0.32	1053	0.23		
VA120			832	0.23						

Results are for UE categories 5,6 with max of 5 codes per transmission interval

Higher UE categories allow up to 15 codes per transmission interval

Performance of Downlink Enhancements

UTRA TDD: Ior/Ioc = 10 dB, Ec/Ior =0 dB

	Throughput [kbps]	BLER
PA3	2200	0.21
PB3	2200	0.06
VA30	2000	0.15
VA120	1750	0.09

Results are for UE category 8 with max of 16 codes Per transmission interval

8 out of the 15 time slots in a frame are allocated to the HSDPA service

Note advantage compared to FDD and better robustness against fading channel conditions (TDD is already using advanced receivers)

Uplink Enhancements

Motivation: Increasing importance of IP based services → an increasing demand to improve capacity, coverage and delay in the uplink

Application that can benefit from uplink enhancements: Video clips, email, gaming, video streaming

Enhancements considered in UTRA FDD (Release 6 Study Items)

- Adaptive modulation and coding
- Hybrid ARQ
- Node B controlled scheduling
- Fast DCH set up
- Shorter frame size and Improved QoS

Node B Controlled Scheduling

Purpose: To enable more efficient use of the uplink power resources of the cell

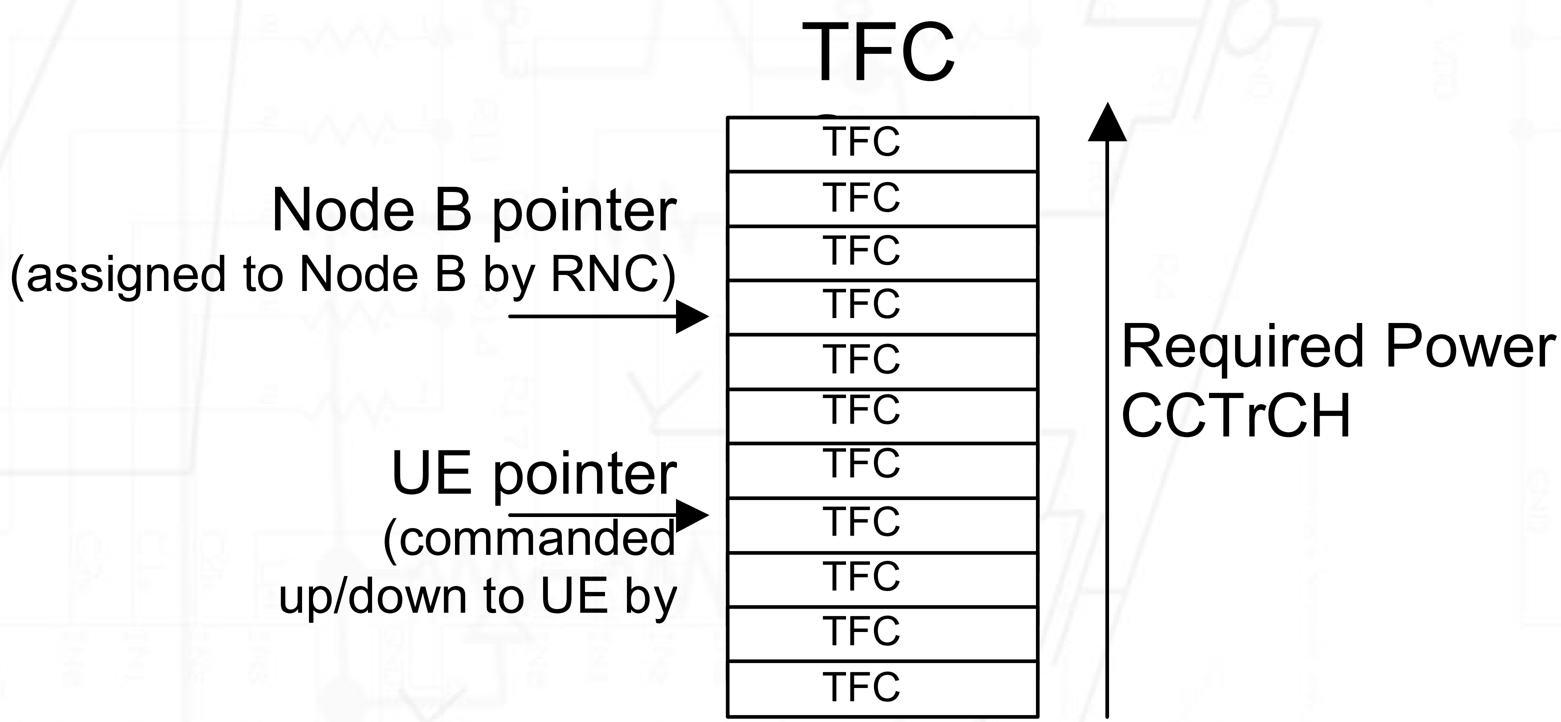
In the existing system the uplink scheduling and data rate control resides in the RNC, which is not able to respond to the changes in the uplink load as fast as a control residing in Node B could.

Proponents claim that Node B control will require less UL noise rise headroom for combating overload conditions.

Proponents also claim that Node B control is capable of smoothing the noise rise variance by allocating higher data rates quickly when the uplink load decreases and respectively by restricting the uplink data rates when the uplink load increases.

Node B Controlled Scheduling – How will it work?

Fast TFCS restriction control



Impact on Terminal Design

Increased memory requirements to support N-channel stop and wait HARQ

Ability to receive simultaneously multicodes

- More processing power and/or more gates

Faster response time is required to satisfy L1 signaling requirements (HARQ ack/nack)

- More processing power and/or more gates

Advanced receiver concepts will be needed to fully achieve HSDPA gains

- Handset diversity
- Replace rake structures by equalization

Mostly driven by downlink enhancements

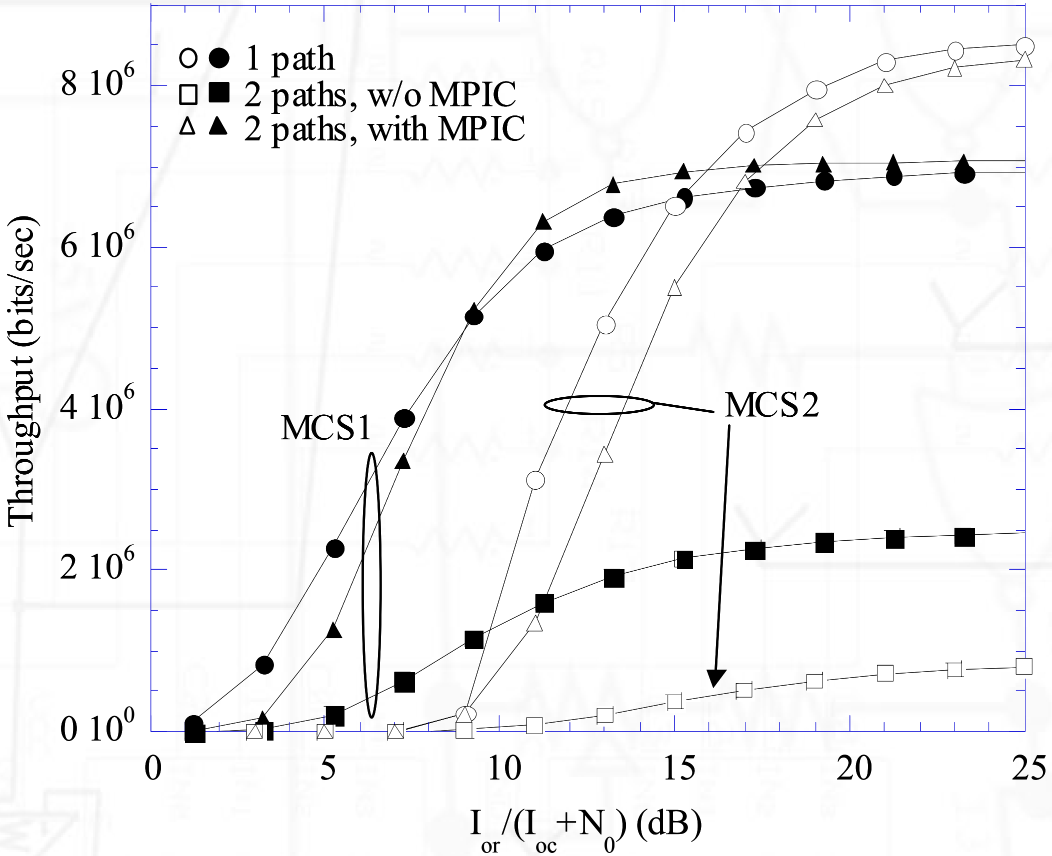
Benefits of Advanced Receivers - Equalization

[Baum et al, “on the system level benefit of equalization for DS-CDMA”, WWC 2002]
Equalizer performance gain depends on the channel model, number of sectors and frequency reuse plan
For the typical omni one cell reuse and moderate to severe delay spread the capacity gain is roughly a factor of two – may reduce the need to introduce FDD micro-cells.
Capacity for omni one cell reuse
This capacity gain can be achieved without any changes to the infrastructure.

	System Capacity [bits/sec/Hz/Cell]	
	Rake	MMSE Equalizer
2 ray equal power	0.65	1.53
2 ray exp. decay	0.72	1.51
5 ray equal power	0.48	1.36
5 ray exp. decay	0.53	1.49
Ricean	0.98	1.97

Benefits of Advanced Receivers –Multipath Interference Cancellation

Enable QAM to achieve higher throughput
MCS1- 16QAM, MCS2 – 64 QAM



Results provided by Panasonic
TR 25.848
(3GPP – UTRA FDD)

Impact on Network Design

Network functionalities are moved closer to the physical layer

- **Example**
  - In UTRA FDD and TDD part of the MAC (MAC-hs) is moved to the NodeB
  - Minimal changes to layers above the MAC
  - MAC-hs functionalities
    - Flow control
    - Scheduling/Priority Handling
    - Hybrid ARQ
    - TFRI (transport format and resource information) selection

Summary

Discussed the motivation for enhancements

Focused on downlink enhancements

- Technical aspects
- Comparison between standards/systems
- Performance

Touched on uplink enhancements

Discussed impact on terminal and network design

Thank you for you attention