Backhaul Requirements for Centralized and Distributed Cooperation Techniques

Dr. Stefan Brück
Qualcomm CDMA Technologies

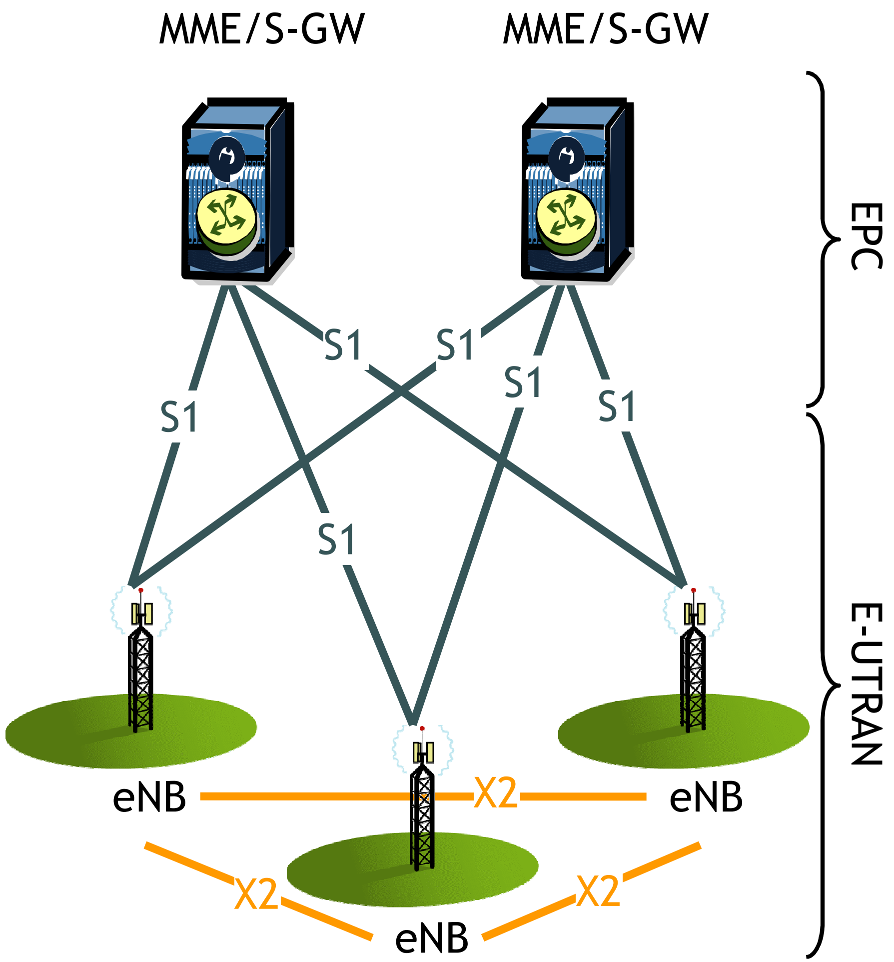
8th July 2010

Overview

- The LTE Architecture
- The X2 Interface in LTE Release 8
  - An introduction to the X2AP protocol
- Categories of Downlink Coordinated Multipoint (CoMP)
- Two Implementation Examples
  - Centralized Joint Transmission
  - Decentralized Coordinated Scheduling/Beamforming
- X2AP Protocol Extensions
  - Examples for the considered CoMP schemes*)
- Bandwidth and Delay Requirement Analysis for Downlink CoMP
- Conclusions

*) S. Brueck, L. Zhao, J. Giese, M. A. Awais, “Centralized Scheduling for Joint-Transmission Coordinated Multi-Point in LTE-Advanced” and J. Giese, M. A. Awais, “Performance Upper Bounds for Coordinated Beam Selection in LTE-Advanced” in Proceedings of the ITG/IEE Workshop on Smart Antennas, Bremen (WSA'10), Germany, 23. – 24. February 2010

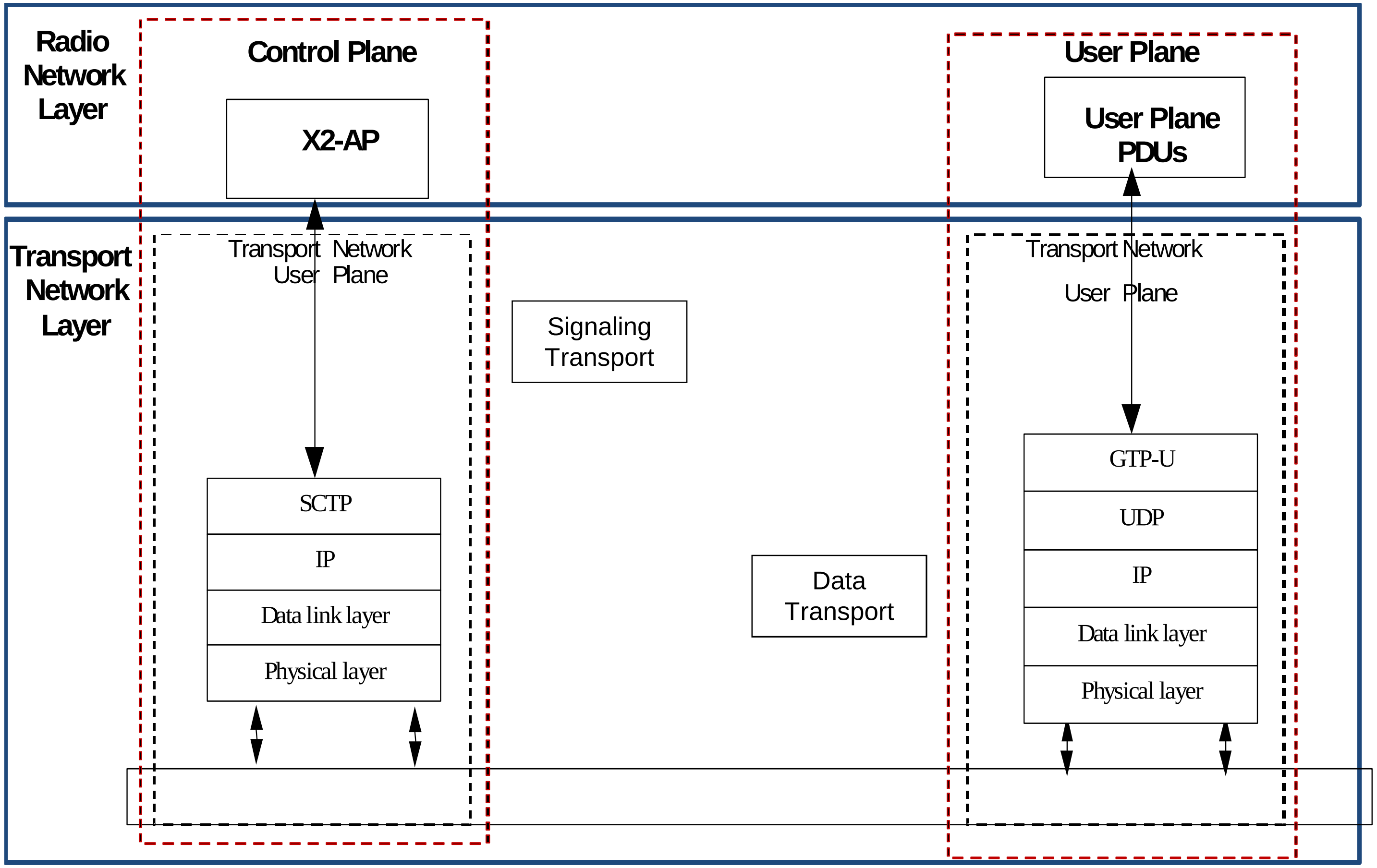
The LTE Architecture



EPC = Evolved Packet Core

- The core network is packet-switched only
- The E-UTRAN consists of one node only
- S1 interface between S-GW/MME and eNB
  - Logical many-to-many interface
  - Supports procedures to establish, maintain and release E-UTRAN Radio Access Bearers
  - Supports transfer of NAS signalling messages between UE and EPC
- X2 interface between eNBs
  - Logical point-to-point interface
  - Seamless mobility
  - Interference management
  - Load management

X2 Protocol Structure



- Clear separation between radio network and transport network layers
  - The radio network layers defines interaction between eNBs
  - The transport network layer provides services for user plane and signaling transport

X2 Application Protocol (X2AP)

- The X2AP is responsible for providing signaling transport between eNBs
  - Specification: 3GPP TS 36.423
- X2AP functions are executed by so called Elementary Procedures
- Release 8 defines eleven EPs related to different X2AP functions
- In Release 9 six additional EPs have been added
- In Release 8/9 limited load management functionality is supported
  - eICIC is currently under specification for Release 10

Function	Elementary Procedure(s)	
Mobility Management	**a) Handover Preparation** **b) SN Status Transfer** **c) UE Context Release** **d) Handover Cancel**	Release 8
Load Management	**a) Load Indication** **b) Resource Status Reporting Initiation** **c) Resource Status Reporting**	Release 8
Reporting of General Error Situations	**Error Indication**	Release 8
Resetting the X2	**Reset**	Release 8
Setting up the X2	**X2 Setup**	Release 8
eNB Configuration Update	**a) eNB Configuration Update** **b) Cell Activation**	Release 8 (a) / Release 9 (b)
Mobility Parameters Management	**Mobility Settings Change**	Release 9
Mobility Robustness Optimisation	**a) Radio Link Failure Indication** **b) Handover Report**	Release 9
Energy Saving	**a) eNB Configuration Update** **b) Cell Activation**	Release 9

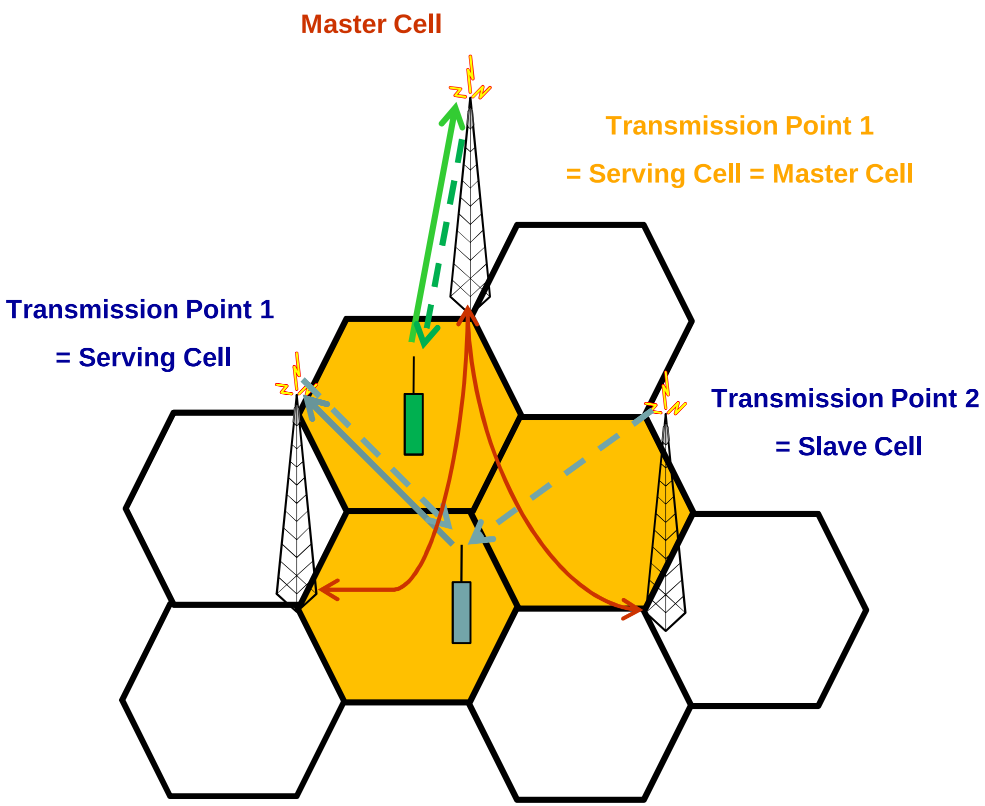
Coordinated Multipoint in 3GPP

- Network coordination became popular by publications of Bell Labs (Network MIMO)
  - M. Karakayali, G. Foschini and R. Valenzuela, “Network Coordination for spectrally efficient Communications in Cellular Systems”, August 2006, IEEE Wireless Communications Magazine

- 3GPP considered coordination techniques under the name Coordinated Multipoint (CoMP) for Release 10
  - 3GPP TR 36.814, v9.0.0, March 2010
  - 3GPP Conclusion: CoMP will not be part of the Release 10 specification

- 3GPP Downlink CoMP terminology
  - **Joint Processing Coordinated Multipoint:** User data to be transmitted to one terminal is available in multiple sectors of the network. A subclass of joint processing is joint transmission, where the data channel to one terminal is simultaneously transmitted from multiple sectors.
  - **Coordinated Scheduling/Beamforming:** User data is only available in one sector, the so-called serving cell, but user scheduling and beamforming decisions are made with coordination among the sectors.

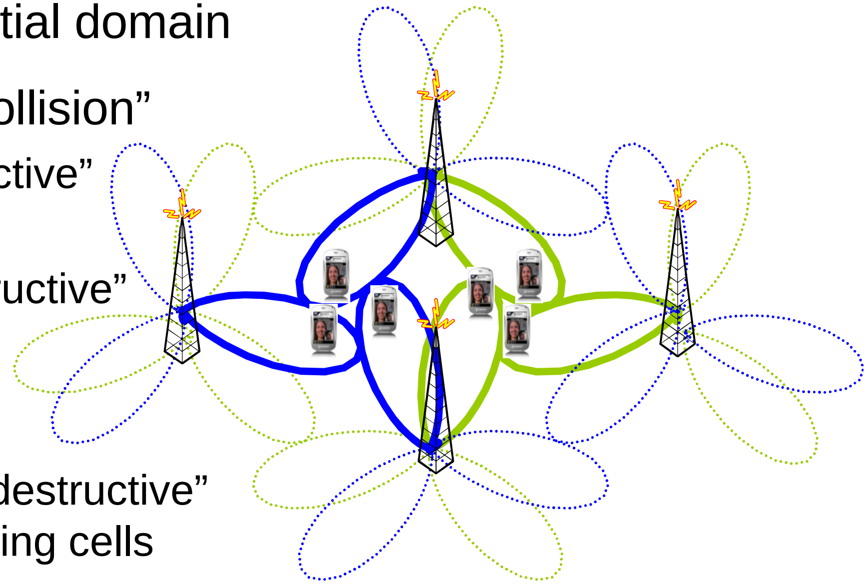
Example 1: Centralized Joint Transmission



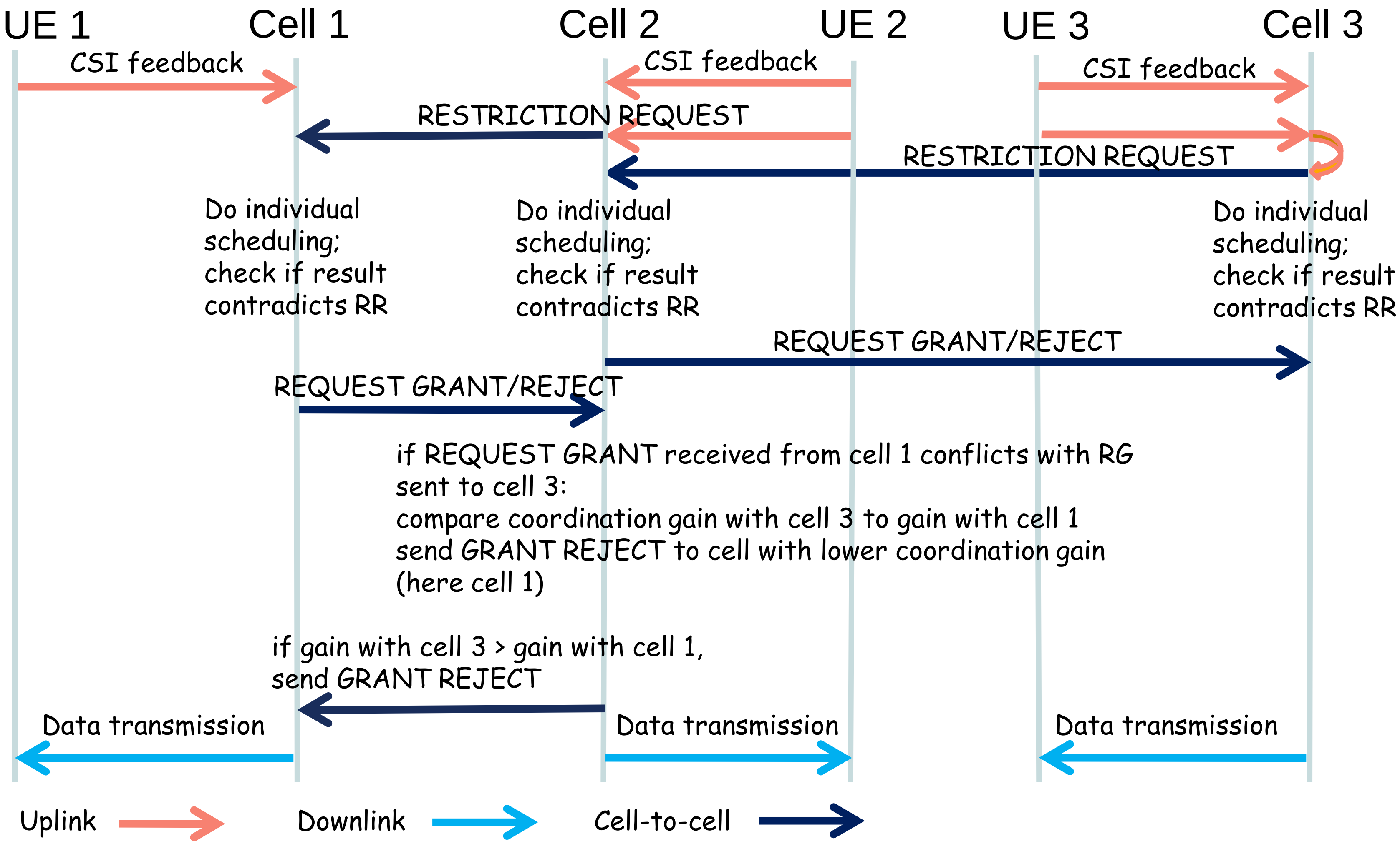
- A central master cell manages all resources of the cooperating cells
- Each UE reports channel state information (CSI) to its serving cell
- The serving cell forwards the CSI to the master over the X2 interface
- The master distributes scheduling decisions to the transmitting cells over X2
- Advantage:
  - Allows optimal scheduling since the master knows the CSI of all UEs
  - Only two X2 usages are required
- Disadvantage
  - CSI needs to be sent over X2 for each <u>active</u> UE

Example 2: Decentralized Coordinated Scheduling

- Goal: Avoidance of interference in the spatial domain
- Idea: Identify worst interferer and avoid “collision”
  - Prevent interferers from using “most destructive” precoding matrices
  - Interfering cell can serve UEs on “non-destructive” beams
- Typical Coordination Approach
  1) Active UEs send information about “most destructive” interfering precoding matrices to their serving cells
     - RESTRICTION REQUEST message in slide 9
  2) The serving cell forwards the received messages to the interfering cells over X2
     - Option: The message is only forwarded if the requesting user is scheduled in order to reduce the number of X2 messages
  3) Optional: Cells negotiate their beams to improve a utility metric
     - REQUEST GRANT/REJECT messages in slide 9



Example of a Coordination Time Line*)



*) Based on J. Giese, M. A. Awais, "Performance Upper Bounds for Coordinated Beam Selection in LTE-Advanced", in Proceedings of the ITG/IEE Workshop on Smart Antennas, Bremen (WSA'10), Germany, 23. – 24. February 2010

X2 Bandwidth Considerations

- Centralized Joint Transmission CoMP

Estimate of Signaling Load per active User (Slave → Master)	
Information Content	**Required Bits**
Two Cell IDs (ECGI)	56 bits
ACK/NACK report	2 x 1 bit (dual stream transmission)
CQI/PMI/RI reports (assuming implicit periodic reporting as in LTE Rel8)	9 bits (subband CQI) ≤ 11 bits (wideband CQI) (per measured radio link)
Σ	≤ 58 bits + 11 bits/measured radio link

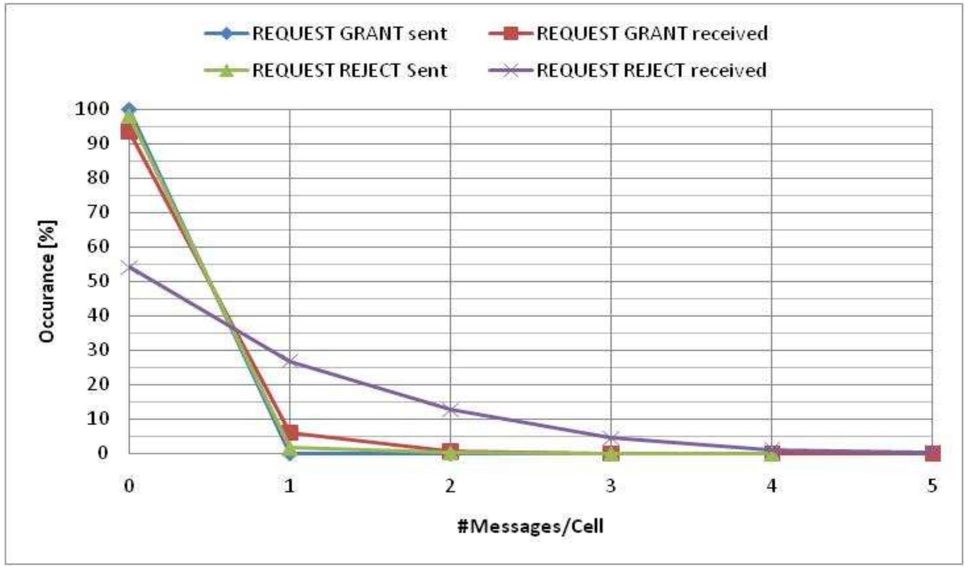
- Decentralized Coordinated Scheduling/Beamforming

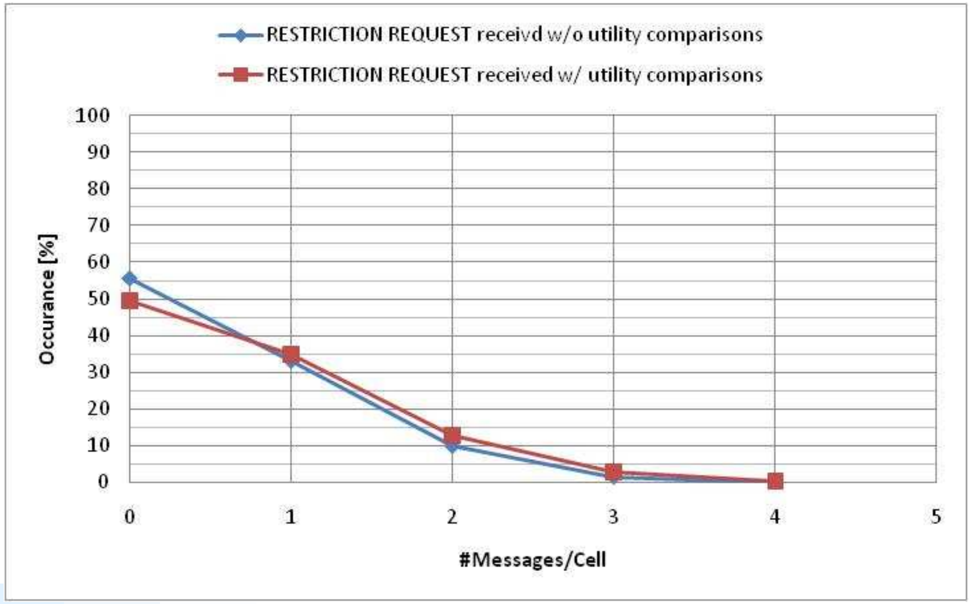
Estimate of Signaling Load for Restriction REQUEST	
Information Content	**Required Bits**
Two Cell IDs (ECGI)	56 bits
UE average throughput	16 bits
SINR Increase by precoding matrix restriction (silencing)	16 bits
Σ	≤ 86 bits

- If coordination takes place each TTI = 1ms, one RESTRICTION REQUEST message requires a bandwidth of 86 kbits/s

10

Frequency of X2 Messages

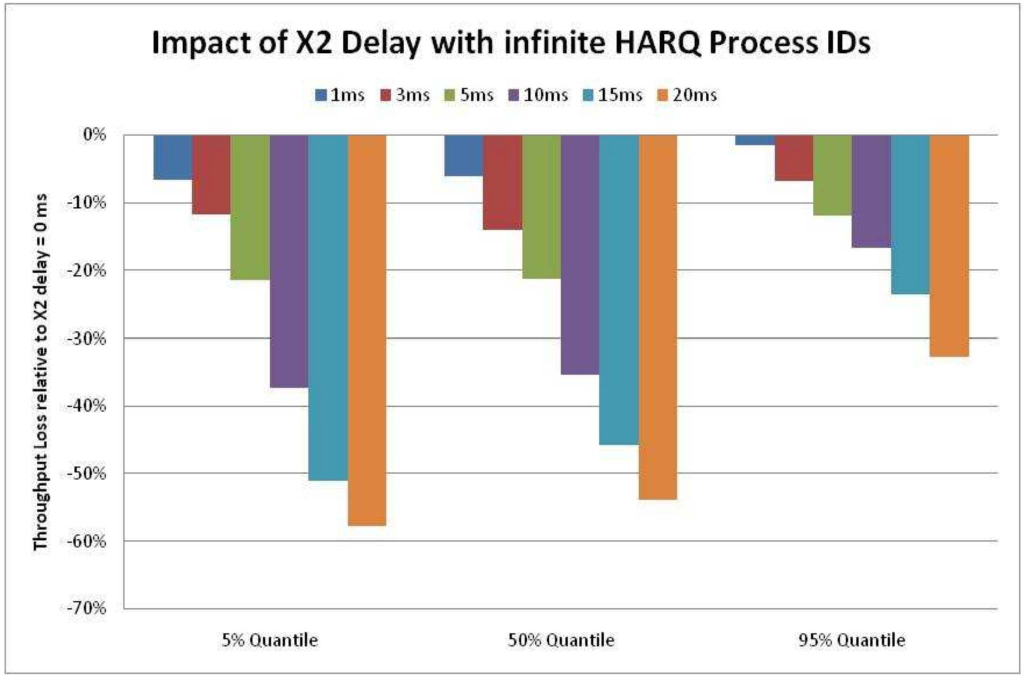




- The figures show the number of sent and received X2 messages/cell for a coordinated scheduling approach*)
- With probability of 95%, less or equal than three messages are received per cell
- The number of received RESTRICTION REQUEST messages scales with the number of scheduled users in this example
- Receiving three messages/cell requires a bandwidth of 3 * 86 kbits/s = 258 kbits/s
- A three sector eNB would therefore require a X2 bandwidth of 3 * 258 kbits/s = 774 kbits/s
  - This assumes 10 UEs/cell and RESTRICTION REQUEST messages targeting 900 kHz and sent at for geometries < - 3dB

*) Based on J. Giese, M. A. Awais, “Performance Upper Bounds for Coordinated Beam Selection in LTE-Advanced”, in Proceedings of the ITG/IEE Workshop on Smart Antennas, Bremen (WSA'10), Germany, 23. – 24. February 2010

Impact of X2 Delay



- The figure shows the throughput loss for a centralized non-coherent JT CoMP approach*)
- The X2 delay increases the time till the CSI/CQI is available in the MAC scheduler
- Consequently, the CSI information alters and the data rates cannot be adapted well to the channel
- The figure shows the impact of the one-way X2 delay
  - V = 3 km/h
  - Release 8 CQI delay = 6ms
- The X2 delay comprises of
  a) Interface propagation delay
  b) eNB Tx/Rx processing delay

*) S. Brueck, L. Zhao, J. Giese, M. A. Awais, “Centralized Scheduling for Joint-Transmission Coordinated Multi-Point in LTE-Advanced”, in Proceedings of the ITG/IEE Workshop on Smart Antennas, Bremen (WSA'10), Germany, 23. – 24. February 2010

Conclusions

- Downlink coordination techniques require extensions of the X2 application protocol (3GPP TS 36.423)
- In case of centralized coordination, the required X2 bandwidth scales with the number of users in RRC_CONNECTED mode
  - This number can be in the order of tens to hundreds
  - The required X2 bandwidth has a large variance
- Decentralized coordination techniques allow for a scaling with the number of scheduled users
  - This allows reducing the X2 bandwidth significantly
  - The drawback is a loss in performance compared to optimal schemes
- Coordination techniques are delay sensitive
  - X2 delay comprises of interface propagation delay and eNB processing delay
  - A X2 delay of 5ms caused a loss in spectral efficiency of 20% for the investigated scheme

Thank you!!

Contact: Dr. Stefan Brück
Tel: 0911 54013270
sbrueck@qualcomm.com