Closed Loop Control Scheduling in Multihop Cellular Networks

VDE/ITG Workshop Contribution

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Outline

- Packet vs. resource scheduling:
- Packet scheduling: QoS, Priorities etc.
- Resource scheduling
  - Fading channel (frequency & time varying)
  - Channel State Information (CSI, CQI)
  - OFDMA scheduling under fading conditions
  - Dynamic Subcarrier Assignment (DSA)
  - Adaptive Modulation & Coding (AMC)
  - Adaptive Power Control (APC)
  - **Closed Loop Control Resource Scheduling**
- The schedulers in OpenWNS
Motivation

Packet scheduling vs. resource scheduling:

- Packet scheduling chooses packets/bits from queue, handles QoS
- Resource scheduling allocates OFDMA subchannel, modulation and coding (PhyMode), transmit power
Packet Scheduling - Scheduler Classes

**head-of-line (static priority) scheduling**
- CBR: priority 1
- VBR
- ABR
- UBR: priority 4

**per-VC queueing**
- CID 1
- CID 2
- CID x
- CID c

**deadline scheduling**
- incoming cell
- sort for deadline
- EDF
- deadline requirements
- PDF
- delay

**rate proportional scheduling**
- "scattered" WRR
- RR
  - weighted max-min fairness
  - line L1
  - line L2
  - 7 5 4 2
Scheduler Performance

Delay: \( \Pr\{d > t\} \)

- **FCFS**: \( \sim a e^{-bt} \)
- **EDF**: \( \sim a e^{-b(t+x)} \)
- **Round Robin**
- **Weighted Round Robin**

Higher rate: \( t \)

Graphs and data points for different rates and throughput.
QoS with prioritisation

- Separation of QoS classes
- High channel utilisation due to unlimited best effort traffic and flow control

Typical load on a controlled channel:

![Graph showing throughput load over time]

Average packet delay [s] with CDMA

Total offered load
• Why is the scheduler so complicated?
• Components of the scheduler:
  - CQI : Channel Quality Indication
  - DSA : Dynamic Subcarrier Assignment
  - AMC : Adaptive Modulation & Coding
  - APC : Adaptive Power Control
  - Multi-Antenna: MIMO/Beamforming
  - Resource Partitioning
  - QoS : Priorities and Substrategies
  - Buffer/Queue management
FDD Multihop Frame Scheduling for LTE Advanced
# Half-Duplex FDD Frame Scheduling

## HalfDuplex Group 1

<table>
<thead>
<tr>
<th>FrameNumber / Time</th>
<th>UT</th>
<th>BS</th>
<th>RN</th>
<th>RemoteUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>DL</td>
<td>DL</td>
<td>DL</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>UL</td>
<td>UL</td>
<td>UL</td>
<td></td>
</tr>
<tr>
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<td>DL</td>
<td>DL</td>
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<td></td>
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<tr>
<td>3</td>
<td>UL</td>
<td>UL</td>
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<td>DL</td>
<td>DL</td>
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<td>UL</td>
<td>UL</td>
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<tr>
<td>6</td>
<td>DL</td>
<td>DL</td>
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</tr>
<tr>
<td>7</td>
<td>UL</td>
<td>UL</td>
<td>UL</td>
<td></td>
</tr>
</tbody>
</table>

### Frame Details

- **UT**: UL, DL
- **BS**: UL, DL
- **RemoteUT**: UL, DL

### Map and Data

- **Map**: Green
- **Data**: Yellow
Multihop Resource Partitioning 
(between BS and RN)

![Diagram of multihop resource partitioning between base station (BS) and remote node (RN)]

- **TaskPhase**: BS, UT
- **UL (Uplink)**: BS1, RN2
- **DL (Downlink)**: BS1, RN2
- **Time/Frequency**: frame 1-5
- **Hop Count**: hop1, hop1

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Half-duplex multihop (uplink) throughput

Using simple stateless scheduler

Using stateful scheduler: ProportionalFair
Using proper Resource Partitioning
Fading: Variable in Frequency and Time

Loss due to Fading (dB)

subchannels  Time samples
Dynamic Subcarrier Assignment

- DSA strategies:
  - LinearFFirst, BestChannel, BestCapacity …

![Diagram showing DSA strategies LinearFFirst and BestChannel]
• AMC: PhyMode choice depends on:
  - SINR
Control loop representation of scheduler


\[
\begin{align*}
\text{desired RxSINR (20dB)} & \quad \rightarrow \quad \text{maxPower} \\
& \quad \rightarrow \quad \text{Adaptive Power Control} \\
& \quad \rightarrow \quad \text{Adaptive Modulation and Coding} \\
& \quad \rightarrow \quad \text{Physical channel (Path loss + fading)} \\
& \quad \rightarrow \quad \text{RxPower} \\
& \quad \rightarrow \quad \text{Interference + Noise} \\
& \quad \rightarrow \quad \text{SINR(f,t)} \\
& \quad \rightarrow \quad \text{measurement noise} \\
& \quad \rightarrow \quad \text{channel quality measurement} \\
& \quad \rightarrow \quad \text{Interpolation} \\
& \quad \rightarrow \quad \text{filtering} \\
& \quad \rightarrow \quad \text{send filtered info back to BS} \\
& \quad \rightarrow \quad \text{special procedures to get downlink channel quality at BS} \\
& \quad \rightarrow \quad \text{Averaging the filtered info} \\
& \quad \rightarrow \quad z^{-1} \\
\end{align*}
\]
Performance of adaptive resource scheduling

Dynamic Subcarrier Assignment

• DSA Strategies Evaluation: (768m)

Resource usage: old method (LinearFFirst) on downlink

Resource usage: new method (BestChannel) on downlink
Performance of adaptive resource scheduling
Adaptive Modulation & Coding

- AMC Strategies Evaluation: (1600m)

PhyMode usage: method 1 (WithoutCQI) on downlink

PhyMode usage: method 2 (WithCQI) on downlink

SINR: method 1 (WithoutCQI) on downlink

SINR: method 2 (WithCQI) on downlink
Performance of adaptive resource scheduling
Adaptive Power Control

- APC Strategies Evaluation: (768m)

**TxPower**
- method 1 (UseNominalTxPower) on downlink
- method 2 (FCFSMaxPhyMode) on downlink

**SINR**
- method 1 (UseNominalTxPower) on downlink
- method 2 (FCFSMaxPhyMode) on downlink
Conclusions

• Packet and resource scheduling can and must be separated
• QoS distinction by priorities is sufficient in the early phase
  – Sub-strategies are important for further QoS differentiation and fairness
• QoS aware scheduling and optimum utilization go hand in hand

• Resource Scheduling and Resource Partitioning happen on different timescales
• The wireless link is a loop (DL+UL). Delay=RTT (round trip time)
• DSA and AMC are straightforward (open loop), but
• APC requires a closed control loop system view
• CQI, DSA, AMC and APC optimally utilize the channel capacity
• All known algorithms are building blocks in the control block diagram
Thank you for your attention!

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Any questions?