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Power Efficient Dynamic Resource Scheduling Algorithms for LTE

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Outline

- Introduction to Mobile VCE Green Radio programme
- LTE downlink parameters and channel model
- Joint time and frequency resource scheduling algorithms
- Throughput, fairness and energy efficiency performances of different scheduling algorithms
- Conclusions
Mobile VCE Core 5: Green Radio

- MVCE based in the UK and runs a program of research sponsored by industry and government with research conducted by Universities.

- Green Radio consists of researchers from universities of Bristol, Edinburgh, KCL, Southampton and Swansea steered by industrial sponsors.

- Telecommunication industry responsible for substantial CO2 emission.

- Energy costs increase operational expense (OPEX) for network operators.

- MVCE Green Radio Programme (Core 5): Deliver high data rate services with a 100-fold reduction in power consumption.
LTE Downlink Transmission

- LTE next major step in mobile radio communications. Aims to reduce delays, improve spectrum flexibility, reduce cost of operators and end users.
- Adopts OFDMA as the downlink access technology.
- Link Adaptation allows choice of MCS to suit channel quality
- Incorporates various MIMO transmission techniques improve system reliability and performance
- Can operate as a ‘closed loop’ system – CSI available at the transmitter
# System and Channel Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Time Slot/Sub-frame duration</td>
<td>0.5ms/1ms</td>
</tr>
<tr>
<td>Sub-carrier spacing</td>
<td>15kHz</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>30.72MHz (8x3.84MHz)</td>
</tr>
<tr>
<td>FFT size</td>
<td>2048</td>
</tr>
<tr>
<td>Number of occupied sub-carriers</td>
<td>1201</td>
</tr>
<tr>
<td>Number of OFDM symbols per time slot (Short/Long CP)</td>
<td>7/6</td>
</tr>
<tr>
<td>CP length (μs/samples)</td>
<td>Short (4.69/144)x6, (5.21/160)x1</td>
</tr>
<tr>
<td></td>
<td>Long (16.67/512)</td>
</tr>
<tr>
<td>Cell Configuration</td>
<td>Single Cell</td>
</tr>
<tr>
<td>Base Station Transmit Power</td>
<td>43 dBm (20W)</td>
</tr>
<tr>
<td>Packet Arrival</td>
<td>Full Buffer</td>
</tr>
<tr>
<td>Number of users</td>
<td>25</td>
</tr>
<tr>
<td>User Velocity</td>
<td>30Km/h</td>
</tr>
</tbody>
</table>
System and Channel Model

- Spatial Channel Model Extension (SCME) Urban Macro, Cost 231-Hata
- 2x2 MIMO architecture (analysis is readily extendible to higher MIMO orders)
- Low spatially correlated channel for all users
- Error free CQI
- ‘Ideal’ Link Adaptation based on 9 Modulation and Coding Schemes (MCS)
## Modulation and Coding Schemes (MCSs)

<table>
<thead>
<tr>
<th>MCS</th>
<th>Modulation</th>
<th>Cod. Rate</th>
<th>Bit Rate (1x1)</th>
<th>Bit Rate (2x2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QPSK</td>
<td>1/3</td>
<td>10.66 Mbps</td>
<td>20.26 Mbps</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>1/2</td>
<td>16 Mbps</td>
<td>30.4 Mbps</td>
</tr>
<tr>
<td>4</td>
<td>QPSK</td>
<td>3/4</td>
<td>24 Mbps</td>
<td>45.6 Mbps</td>
</tr>
<tr>
<td>3</td>
<td>16 QAM</td>
<td>1/3</td>
<td>21.34 Mbps</td>
<td>40.54 Mbps</td>
</tr>
<tr>
<td>5</td>
<td>16 QAM</td>
<td>1/2</td>
<td>32 Mbps</td>
<td>60.8 Mbps</td>
</tr>
<tr>
<td>6</td>
<td>16 QAM</td>
<td>3/4</td>
<td>48 Mbps</td>
<td>91.2 Mbps</td>
</tr>
<tr>
<td>7</td>
<td>64 QAM</td>
<td>3/5</td>
<td>57.6 Mbps</td>
<td>109.44 Mbps</td>
</tr>
<tr>
<td>8</td>
<td>64 QAM</td>
<td>3/4</td>
<td>72 Mbps</td>
<td>136.8 Mbps</td>
</tr>
<tr>
<td>9</td>
<td>64 QAM</td>
<td>6/7</td>
<td>82.28 Mbps</td>
<td>156.34 Mbps</td>
</tr>
</tbody>
</table>

A link adaptation (LA) target of 10% PER is assumed. 

**Throughput = R(1-PER)**, where R and PER are the bit rate and the residual packet error rate for a specific mode respectively.
Switching Point for SFBC and SM

Throughput (Mbps) vs SNR (dB)

- 2x2 SFBC
- 2x2 SM

Switch over
Joint time and Frequency Scheduler

- Joint time and frequency RRM strategies
- Time domain scheduler:
  - Initial user pre-selection stage
  - Identify users with relatively good channels whilst maintain an overall fairness for all users.

Users’ Requested Rate based on LA → Time Domain Scheduling

Users for FDM → Frequency Domain Scheduling

Scheduling outcome

Time domain updates
Time Domain Scheduler (TD)

- Proportional fair scheduler imposing fairness constraints to users

- Strongest users (60%) are selected for the next frequency domain scheduling stage:

$$k^* = \arg \max_k P_k(t) = \arg \max_k R_k(t)/T_k(t)$$

- $R_k(t)$: current rate chosen from the set of available MCS

$$T_k(t) = \begin{cases} 
(1 - \frac{1}{t_c})T_k(t-1) + \frac{1}{t_c}R_k(t) & k = k^* \\
(1 - \frac{1}{t_c})T_k(t-1) & k \neq k^* 
\end{cases}$$

- $T_k(t)$: user’s average throughput over a window in the past.
  (window length $t_c = 500$)
Frequency Domain Scheduler (FD)

Frequency domain scheduling strategies for the selected users:

- **CSI-independent**
  1. Round-robin

- **CSI-dependent**
  1. Greedy: maximise rate and power efficiency, least fair
  2. Proportional fair algorithm scheme 1 and 2: multi-carrier extension
     - PFA I: scheduler updated after each time interval
     - PFA II: scheduler updated after each PRB
  3. Relative strength scheduling algorithm (RSSA)
  4. Equal gain dynamic allocation (EGDA)
  5. Fair cluster algorithm (FCA)
Metrics for Performance Measurement

- Throughput
- Throughput fairness measured using Jain’s Index
- Power Efficiency is measured by Energy Consumption Rate (ECR) Metric proposed by MVCE Green Radio Programme

\[ ECR = \sum_{k=1}^{K} \frac{P_k}{R_k} \]

- Lower ECR indicates higher energy efficiency.
- And a corresponding Power Fairness Index (PFI) derived from the Jain’s fairness Index:

\[ PFI = \left( \frac{\sum_{k=1}^{K} \frac{P_k}{R_k}}{K \sum_{k=1}^{K} \left( \frac{P_k}{R_k} \right)^2} \right)^2 \]
**Frequency Domain Scheduler Only**

- **All 25 users are allocated resources.**
- **A direct trade-off between throughput and rate fairness.**
- **PF II, FCA, EGDA achieve relatively good performance in terms of both rate fairness and throughput.**
- **PFI and RSSA achieves better throughput but degraded fairness.**
- 60% strongest users are allocated resources.
- PFII, FCA and EGDA algorithms achieve 8% increase in throughput.
- Improved fairness for GA and RSSA while throughput remains the same.
GA achieves best throughput, best energy efficiency but poorest rate fairness.

PFA II, RSSA, FCA, EGDA offers good tradeoff between improving rate fairness, achieving high throughput and power efficiency.
Fairness Performance

Fairness criteria adopted from [2].
- GA badly fails to meet the throughput bound
- PFA I and RSSA just fail the fairness criteria

...and more recently

- Practical systems don’t always operate at full load
- Lower load is an opportunity to save energy
- Need to adapt MIMO, MCS and resource allocation to exploit low load opportunities for energy saving
- Designed a scheduler to do this:
  - Achieves 90% energy saving at 20% load
  - Achieves 80% energy saving at 50% load
  - 50% energy saving across a ‘typical’ daily load cycle

...more on this in future...
Conclusions

- Channel-aware scheduling algorithms can achieve significant improvements of both throughput and ECR over a fixed scheduling strategy such as RR.
- Multi-user diversity gain can be translated into energy saving.
- Joint time and frequency domain scheduler achieves better performance than frequency domain only scheduler.
- PFA, FCA, RSSA and EG-DA provides a good compromise between throughput and rate fairness, whilst also providing good energy efficiency.
- Lower loads can be exploited to save energy with good link adaptation and resource allocation.
The Mobile VCE – Member Companies

Undertaken by some of the UK’s leading comms research Universities
Thank you!