Interference-Aware Radio Resource Management Framework for the 3GPP LTE Uplink with QoS Constraints

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Agenda

- Introduction
- Uplink Scheduling Design Problem and Constraints
- System Model
- Proposed Framework
- Performance Evaluation
- Conclusions
Introduction

- To offer high data rates LTE exploits OFDM technology in the downlink and SC-FDMA in the uplink

- SC-FDMA is a Discrete Fourier Transform (DFT)-spread version of OFDM
  - Low peak to average power ratio (PAPR) saves the constrained power for the User Equipment (UE)
  - Retains the multipath fading resistance of OFDM and the flexibility in sub-carrier allocation

- LTE uses adaptive coding and modulation and power control to enhance uplink performance

- Uplink scheduling is not comprehensively studied due to complexity arising from the many constraints

- Tradeoff exists between PRB allocation and power allocation
Uplink Scheduling Design Problem and Constraints
SC-FDMA Contiguity Constraint
Uplink Scheduling Constraints

- Each Transmission Time Interval (TTI) the following decisions need to be made:
  - Select UEs to transmit in this TTI
  - Allocation of Physical Resource Blocks (PRBs) to each UE
  - Transport format and maximum power for each UE to transmit

- These decisions are subject to the following constraints
  - Contiguous PRB allocation for each UE
  - Respecting QoS requirements
  - Maximizing throughput
  - Minimizing inter-cell interference
Problem Definition

- Time Domain Scheduler
- Frequency Domain Scheduler
  - AMC
  - Power Control

Inputs:
- QoS parameters
- BSR
- PHR
- CQI
- SINR to CQI mapping
- SINR
- SRS

Outputs:
- Tx BW Allocation
- MCS
- TPC Commands
System Model
System model – closed loop power control

\[ P_{PUSCH} = \min\{P_{\text{max}}, 10 \cdot \log_{10} M + P_0 + \alpha \cdot PL + \delta_{\text{mcs}} + f(\Delta_i)\} \text{ [dBm]} \]

- \[ P_{\text{max}} \] is the maximum allowed transmit power. It depends on the UE power class.
- \[ M \] is the number of physical resource blocks (PRB).
- \[ P_0 \] is cell/UE specific parameter signaled by radio resource control (RRC). (-81 dBm/Hz)
- \[ \alpha \] is the path loss compensation factor. It is a 3-bit cell specific parameter in the range [0 1] signaled by RRC. (0.8)
- \[ PL \] is the downlink path loss estimate. It is calculated in the UE based on the reference symbol received power (RSRP).
- \[ \delta_{\text{mcs}} \] is cell/UE specific modulation and coding scheme defined in the 3GPP specifications for LTE.
- \[ f(\Delta_i) \] is UE specific. \[ \Delta_i \] (TPC) is a closed loop correction value and \( f \) is a function that permits to accumulate or use absolute correction value.
System model - Assumptions

- Perfect channel knowledge is assumed with no delay to calculate Channel Quality Indicator (CQI)
- UE transmission power used in interference calculation is obtained from the reports sent by the UE to the eNB
- Assume 4 different QoS classes
- Each user has only one connection
- State of queues at UE is obtained through Buffer Status Reports (BSR) sent by UE to eNB. We assume perfect knowledge of the queues’ status
Traffic Classes

- VoIP
  - Max Delay 100 msec
  - QoS 1
- Interactive Gaming
  - Max Delay 50 msec
  - QoS 2
- Video Streaming
  - Max Delay 300 msec
  - QoS 3
- FTP (Best Effort)
  - Max Delay 300 msec
  - QoS 4
Proposed Framework
Proposed Framework

Priority Assignment

QoS Parameters
- BSR

Time Domain Scheduler

Users' Priorities

Channel Capacity

Schedulable Users

Frequency Domain Scheduler
- Closed loop power control

PRB assignment
- MCS assignment
- Power Control
Proposed Framework

The framework solves the uplink scheduling problem via three main stages.

- **Time domain scheduling**: selects set of users to be served according to their given priority
- **Frequency domain scheduling**: performs PRB allocation, initial power allocation and MCS selection
- **Closed loop fractional power control**
Time Domain Scheduling

\[ P_i = V_i(S_i(m)) + \frac{QoS_i}{8} \]

\[ V_i(S_i(m)) = \frac{1}{1 + e^{-q_i(S_i(m)-B_i^{\text{max}})}} \]

\[ B_i^{\text{max}} = TrafficSourceRate_i \times D_i^{\text{max}} \]

- \( QoS_i \) is the quality of service class
- Division by 8 is done to have the QoS part comparable to the delay part
- \( D_i^{\text{max}} \) is the maximum allowable delay
- \( S_i(m) \) is the queue length of user \( i \) at frame \( m \)
Frequency Domain Scheduling

- PRB group: set of empty contiguous PRBs
- Search for the PRB group or subset thereof that would meet the user’s requested bytes with the least number of PRBs
- Assuming maximum power is used for transmission the appropriate MCS is selected
- Transmission power is then recalculated from MCS and number of assigned PRBs according to closed-loop power control loop while meeting interference limit (next slide).
- More iterations can be done. However, a stable power typically reached using only one.
Closed Loop Fractional Power Control

- Set limit for interference generated by a cell CIL (Cell Interference Limit)
- Map overall CIL to individual UE interference limits
- Approaches to dividing CIL on users
  - Equal weights
  - Low weight – High path loss (Cell Edge)
  - Low weight – Low path loss (Cell Center)

\[ IL_i = \frac{CIL \cdot w_i}{\sum_k w_k} \]
Performance Evaluation and Results
# System Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Bandwidth</td>
<td>10MHz</td>
</tr>
<tr>
<td>Channel Model</td>
<td>Winner II C1- Suburban Macrocell</td>
</tr>
<tr>
<td>User Speed</td>
<td>60m/sec</td>
</tr>
<tr>
<td>TTI</td>
<td>1 ms</td>
</tr>
<tr>
<td>Number of OFDM symbols per slot</td>
<td>7</td>
</tr>
<tr>
<td>Noise Power</td>
<td>-160 dBm/Hz</td>
</tr>
<tr>
<td>Rx Noise Figure</td>
<td>5 dBm</td>
</tr>
<tr>
<td>Maximum User Power</td>
<td>24 dBm</td>
</tr>
</tbody>
</table>

- Number of users: 100.
- Four traffic classes: VoIP, FTP, Interactive Gaming, Video Streaming
- Proposed scheme compared to the First Maximum Expansion (FME)
  - Delay
  - Throughput
  - Generated interference.
Performance Evaluation – Delay CDF

![Delay CDF Graph]

- ftp
- voip
- gaming
- video
- ftpFME
- voipFME
- gamingFME
- videoFME

Delay [msec]

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Performance Evaluation – Delay vs Load

![Graph showing delay vs load for FTP and VoIP](image)

- Shows the relationship between FTP load (in Kbps) and the 95% delay in milliseconds.
- FTP and VoIP lines are distinctly marked.

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Performance Evaluation – Cell edge Throughput

- Equal Weights
- Low Weights High Pathloss
- Low Weights Low Pathloss

10 percentile Cell Throughput [Kbps]

Cell Interference Limit [dBm]

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Performance Evaluation – Generated Interference

![Graph showing generated cell interference vs. cell interference limit][1]

[1]: graph.png
Conclusions

- Combining channel dependent scheduling, AMC and power control.
- QoS requirements consideration in the scheduling decision.
- Tradeoff between
  - PRB allocation and power allocation
  - Maximizing throughput and minimizing interference.
- Scheme is capable of achieving QoS differentiation and meeting interference limits.
- Better performance in terms of delay, packet drop ratio, and generated interference with the expense of small decrease in throughput.

- **Future work** includes evaluation in mutli-cell environments.
Questions

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