Scheduling in LTE

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Outline

LTE Overview

- Network & Signals
- Physical Resources in Time & Frequency
- Radio Protocol Architecture
- Control Information for Scheduling Operation

Scheduling in LTE

- Scheduling Operation
- CQI Reporting for Scheduling
- Schedulers in LTE

Summary & References
LTE Overview

Network & Signals: E-UTRAN, OFDMA/SC-FDMA

Physical Resources: Physical Resources, Resource Unit, Scheduling Unit

Radio Protocol Architecture: L1/L2/L3, Physical/Transport Channels

Control Information for Scheduling Information

- Control & Data Regions
- Control Information for Scheduling
- LTE Network (E-UTRAN)

- OFDMA: Orthogonal Frequency-Division Multiple Access
- SC-FDMA: Single-Carrier-Feed-Forward-Division Multiple Access
- UE: User Equipment
- eNB: evolved Node B
- HeNB: Home eNodeB
- GW: Gateway
- MME: Mobility Management Entity
- S-GW: Serving Gateway
- P-GW: Packet Data Network Gateway
- EPC: Evolved Packet Core
- W-CDMA: Wideband Code Division Multiple Access
- 3G: Third Generation
- 2G: Second Generation
- CDMA2000 1X: Code Division Multiple Access 2000 1X Evansion
- EV-DO: Enhanced Data Rates for Global Evolution-Data Only
- Internet

* EPC: Evolved Packet Core
* UE: User Equipment
* eNB: evolved Node B
LTE Signals

- OFDMA & SC-FDMA(DFTS-OFDMA)

Demands
- Higher Data Rate Reliability

Techniques
- Broadband, Multi-carriers
- CP

Downlink
- OFDMA with CP
  - Good Throughput
  - High PAPR
- SC-FDMA With CP
  - Low PAPR
  - Fair Throughput

Uplink

Used Subcarriers
- QPSK
- 16QAM
- 64QAM

* Except for MBMS (4096)
### Time & Frequency Resources

#### Frequency Resources

<table>
<thead>
<tr>
<th>System BW [MHz]</th>
<th>1.4</th>
<th>3</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>N / Freq. Spacing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2048 / 15 KHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

#### Used Subcarriers $N_u$

<table>
<thead>
<tr>
<th># Used Subcarriers $N_u$</th>
<th>72</th>
<th>180</th>
<th>300</th>
<th>600</th>
<th>900</th>
<th>1200</th>
</tr>
</thead>
</table>

**Parameters** (Except for MBMS : 4096/7.5 KHz, 2*N_u)

- Time
  - Slot: 0.5ms
  - Sub-frame: 1ms
  - Frame: 10ms
- Frequency
  - Frequency (# Sub-carriers)
  - N=2048

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Resource Unit

- Physical Resource Block (PRB)

✓ The Smallest User Assignment Resource Unit

Parameters (Except for MBMS)

<table>
<thead>
<tr>
<th>CP Type</th>
<th># Symbols / Slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal CP</td>
<td>7</td>
</tr>
<tr>
<td>Extended CP</td>
<td>6</td>
</tr>
</tbody>
</table>
Scheduling Unit

- Sub-frame (2 Slots)

✓ Smallest Scheduling Time Interval : TTI (1ms)

Parameters (Except for MBMS)

<table>
<thead>
<tr>
<th>System BW [MHz]</th>
<th>1.4</th>
<th>3</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td># PRBs $N_{RB}$</td>
<td>6 (72)</td>
<td>15 (180)</td>
<td>25 (300)</td>
<td>50 (600)</td>
<td>75 (900)</td>
<td>100 (1200)</td>
</tr>
<tr>
<td>(# Used Subcarriers $N_u$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Radio Protocol Architecture

- **Protocol Architecture around PHY**

  - **Layer 3**: Radio Resource Control (RRC)
    - **Logical Channels**
  - **Layer 2**: Medium Access Control (MAC)
    - **Transport Channels**
  - **Layer 1**: Physical Layer (PHY)

**Logical Channels**: Type of information

**Transport Channels**: How the information is transferred
Physical/Transport Channels

Transport Channels – Physical Channel

Layer 2

Medium Access Control (MAC)

Transport Channels
- BCH
- MCH
- PCH
- DL-SCH

Layer 1

Physical Layer (PHY)

Physical Channels
- PBCH
- PMCH
- PHICH
- PDSCH

Layer 2

Broadcasting

Layer 1

Physical Layer (PHY)

Layer 2

Paging

Layer 1

Physical Layer (PHY)

Layer 2

Multicasting

Layer 1

Physical Layer (PHY)

Layer 2

Data

Layer 1

Physical Layer (PHY)

Layer 2

Random Access

Layer 1

Physical Layer (PHY)

Layer 2

Data

Layer 1

Physical Layer (PHY)

Layer 2

UL-SCH

Layer 1

Physical Layer (PHY)

Layer 2

RACH

Layer 1

Physical Layer (PHY)

Layer 2

PUSCH

Layer 1

Physical Layer (PHY)

Layer 2

PRACH

Layer 1

Physical Layer (PHY)

Layer 2

PUCCH

Layer 1

Physical Layer (PHY)

Layer 2

DCI

Layer 1

Physical Layer (PHY)

Layer 2

PDCCH

Layer 1

Physical Layer (PHY)

Layer 2

DL Control

Layer 1

Physical Layer (PHY)

Layer 2

Scheduling Information

Layer 1

Physical Layer (PHY)

Layer 2

UL Control
Control Information for Scheduling

- Scheduling Information : PDCCH

Information of the length of Control Region

(Slot 2i)  (Slot 2i+1)

PRB $N_{RB} - 1$
...
PCFICH
PDCCH
...
PRB 1
PRB 0

Symbol 0  Symbol 1  Symbol 2  \ldots  $N_{symb} - 1$  Symbol 0  Symbol 1  Symbol 2  \ldots

Control Region  Data Region

(Reference : p. 57 3GPP TS 36.211 V8.9.0 (2009-12))
# Scheduling Information: DCI in PDCCH

## DCI Formats

<table>
<thead>
<tr>
<th>DCI Formats</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UL Scheduling</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Scheduling + TPC for PUSCH</td>
</tr>
<tr>
<td>1</td>
<td>Scheduling for PDSCH, TPC for PUCCH</td>
</tr>
<tr>
<td>1A</td>
<td>Compact Scheduling for PDSCH, TPC for PUCCH</td>
</tr>
<tr>
<td>1B</td>
<td>MIMO Compact Scheduling for PDSCH, TPC for PUCCH</td>
</tr>
<tr>
<td>1C</td>
<td>Very Compact Scheduling for PDSCH</td>
</tr>
<tr>
<td>1D</td>
<td>Compact Scheduling for PDSCH with Power Offset, TPC for PUCCH</td>
</tr>
<tr>
<td>2</td>
<td>Closed Loop MIMO Compact Scheduling for PDSCH, TPC for PUCCH</td>
</tr>
<tr>
<td>2A</td>
<td>Open Loop MIMO Compact Scheduling for PDSCH, TPC for PUCCH</td>
</tr>
<tr>
<td><strong>DL Scheduling</strong></td>
<td></td>
</tr>
<tr>
<td><strong>UL Power Control</strong></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>TPC for PUCCH, PUSCH 2bit Power Adjustment</td>
</tr>
<tr>
<td>3A</td>
<td>TPC for PUCCH, PUSCH 1bit Power Adjustment</td>
</tr>
</tbody>
</table>
User Identification – C-RNTI

- **User Identification**

  ✓ With **C-RNTI** (Cell specific Radio Network Temporary Identifier)

  ![Diagram of User Identification with C-RNTI]

  - DCI
  - CRC Attachment
  - DCI + 16 bit CRC scrambled with RNTI

  \[(DCI + \text{RNTI}) \mod 2\]

  (Reference: p. 56 3GPP TS 36.212 V8.8.0 (2009-12))
Scheduling in LTE

Basic Scheduling Operations
Resource Assignment
CQI Reporting for Schedulers
Schedulers in LTE
Example: DL Scheduling
Basic Scheduling Operation

- **Purpose**
  - Efficient SCH(Data) Resources Assignments

- **Consideration**
  - Traffic Volume, QoS (Buffer Status, Priority…)
  - Channel Condition

- **Scheduling Interval**
  - Dynamic Scheduling by MAC: One TTI (1ms : One Sub-frame)
  - Semi-Persistent for VoIP: Multiple TTIs by RRC

- **Resource Assignment**: PRBs & Associated MCS
Resource Assignment

- **Per UE # PRBs Assignment**
  - Channel Dependent Resource Allocation
    - User Assignment based on Channel Quality

- **CQI / MCS / TBS**
CQI Reporting for Scheduling

- **Reporting modes**

- **In time**: Periodic (PUCCH/PUSCH) & Aperiodic (PUSCH)

- **In Frequency**
  - Wide-band CQI: 4 bit
  - Differential Sub-band CQI: 2 bit (Sub-band CQI – Wideband CQI)
  - Differential Spatial CQI: 3 bit for MIMO
Schedulers in LTE

- MAC Schedulers

Layer 3 RRC

Layer 2

Layer 1 PHY

PDCP : Packet Data Convergence Protocol
ARQ : Automatic Repeat Request

ROHC : Robust Header Compression
HARQ : Hybrid ARQ
DL Scheduling

- DL MAC Scheduler

- CQI
- ACK/NACK
- HARQ
- Retransmission
- Modulation Scheme
- Resource Assignment
- Power Assignment
- Antenna Mapping

User N

- N Transport Blocks (Dynamic Size for N Users)
- Redundancy for Error Detection
- Redundancy for Data Detection
- QPSK, 16QAM, 64QAM

- Multi-Antenna Processing
Conclusion & References
Summary

• LTE Overview
  ✓ LTE Network, Physical Resources
  ✓ Signaling Scheduling Information in PHY

• Scheduling in LTE
  ✓ PRB & MCS Assignment
  ✓ CQI Reporting Process for Schedulers
  ✓ MAC Schedulers in LTE
  ✓ DL Scheduling Process
References

- **LTE Web**
  www.3gpp.org

- **LTE L1(PHY) Standards**
  TS 36201 : LTE PHY Overview
  TS 36211 : LTE PHY Modulation
  TS 36212 : LTE Multiplexing and Channel Coding
  TS 36213 : LTE PHY related Procedures
  TS 36214 : LTE Measurements

- **LTE L2/L3(MAC/RRC) Standards**
  TS 36300 : LTE L2/L3 Overview
  TS 36321 : LTE MAC
  TS 36331 : LTE RRC