Scheduling and capacity estimation in LTE

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Agenda

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Introduction

LTE is the new, (following up of HSPA) mobile access technology specified by 3GPP:

- Flat all-IP architecture
- Flexible in frequency bands (700 MHz-2.6 GHz)
- Flexible carrier bandwidths (1.4, 3, 5, 10, 15 and 20 MHz)
- Increased spectrum efficiency based on OFDMA for uplink, SC-FDMA for downlink
  - Typical cell capacity (20 MHz bandwidth), 20 – 40 Mbps for downlink link and 5 – 15 Mbps for uplink
- Momentum in the industry, building on current investments in the GSM/UMTS
Obtainable bitrate as function of SINR

Bitrate function $B = B(SINR)$

- Upper bound Shannon: $B/f = \log_2(1 + SINR)$
- Discrete; $B/f$ based on CQI-table (3GPP TS 36.213) and Linear relation between SINR[dB] and CQI-index
- Approximate/Truncated modified version of Shannon's formula:
  $B/f = \text{MIN}[T, C \log_2(1 + \gamma \cdot SINR)]$

<table>
<thead>
<tr>
<th>CQI index</th>
<th>modulation</th>
<th>code rate x 1024</th>
<th>efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>out of range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>QPSK</td>
<td>78</td>
<td>0.1523</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>120</td>
<td>0.2344</td>
</tr>
<tr>
<td>3</td>
<td>QPSK</td>
<td>193</td>
<td>0.3770</td>
</tr>
<tr>
<td>4</td>
<td>QPSK</td>
<td>308</td>
<td>0.6016</td>
</tr>
<tr>
<td>5</td>
<td>QPSK</td>
<td>449</td>
<td>0.8770</td>
</tr>
<tr>
<td>6</td>
<td>QPSK</td>
<td>602</td>
<td>1.1758</td>
</tr>
<tr>
<td>7</td>
<td>16QAM</td>
<td>378</td>
<td>1.4766</td>
</tr>
<tr>
<td>8</td>
<td>16QAM</td>
<td>490</td>
<td>1.9141</td>
</tr>
<tr>
<td>9</td>
<td>16QAM</td>
<td>616</td>
<td>2.4063</td>
</tr>
<tr>
<td>10</td>
<td>64QAM</td>
<td>466</td>
<td>2.7305</td>
</tr>
<tr>
<td>11</td>
<td>64QAM</td>
<td>567</td>
<td>3.3223</td>
</tr>
<tr>
<td>12</td>
<td>64QAM</td>
<td>666</td>
<td>3.9023</td>
</tr>
<tr>
<td>13</td>
<td>64QAM</td>
<td>772</td>
<td>4.5234</td>
</tr>
<tr>
<td>14</td>
<td>64QAM</td>
<td>873</td>
<td>5.1152</td>
</tr>
<tr>
<td>15</td>
<td>64QAM</td>
<td>948</td>
<td>5.5547</td>
</tr>
</tbody>
</table>
Radio channel propagation model

Signal-to-noise ratio: \[ \text{SINR} = \frac{P_w G}{N} \]

- \( P_w \) sending power

Path loss (model): \[ G = 10^{L/10} \quad L = C - A \log_{10}(r) + X_t \]

- \( C \) and \( A \) constants, \( X_t \) shadowing usually assumed to be normal distributed with zero mean and given standard deviation

Noise \( N = N_{\text{int}} + N_{\text{ext}} \) sum the internal (or own-cell) noise power and is the external (or other-cell) interference.
Radio signal fading model

SINR on the form: \( S_t / r^\alpha h(\lambda) \)

Stochastic part of SINR: \( S_t = X_{\text{ln}} X_e \)

Slow fading (shadowing): Lognormal \( X_{\text{ln}} \)

Fast fading: Rayleigh, i.e. neg. exp. distributed \( X_e \)

\( S_t \): Suzuki distributed with CDF

\[
\tilde{S}_{su}(x) = \int_0^\infty e^{-xt} s_{\text{ln}}(t) dt = \frac{1}{\sqrt{2\pi \sigma}} \int_0^\infty e^{\frac{-t^2}{2\sigma^2}} dt
\]

Truncated version:

\[
\tilde{S}_{su}(x,T) = \frac{1}{\sqrt{2\pi \sigma}} \int_0^T e^{\frac{-t^2}{2\sigma^2}} dt = \frac{1}{2} \sum_{k=0}^{\infty} \frac{(-1)^k}{k!} x^k e^{-\frac{k^2\sigma^2}{2}} \text{erfc}\left(\frac{k\sigma}{\sqrt{2}} + \frac{\ln(x/T)}{\sigma\sqrt{2}}\right)
\]
Analytical models for LTE radio network performance

- Spectrum efficiency through the bit-rate distribution per Recourse Block (RB) for users that are either randomly or located at a particular distance in a cell.

- Cell throughput/capacity and fairness by taking the scheduling into account.
  - Scheduling based on metrics which depends (only) on own SINR and distance
  - Specific models for the common (basic) scheduling algorithms, Round Robin, Proportional Fair and Max-SINR.

- Estimation of the capacity usage for GBR sources in LTE
  - Non-persistent allocation, i.e. allocation every TTI to obtain GBR rate

- Cell throughput/capacity for a mix of GBR and Non-GBR (greedy) users
### Input parameters to numerical examples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Numerical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth per Resource Block</td>
<td>180 kHz=12x 15 kHz</td>
</tr>
<tr>
<td>Total Numbers of Resource Blocks</td>
<td>100 RBs</td>
</tr>
<tr>
<td>Distance-dependent path loss. (Taken from a 3GPP document)</td>
<td>( L = C + 37.6 \log_{10}(r) ), ( r ) in kilometers and ( C = 28.1 \text{ dB for 2GHz} )</td>
</tr>
<tr>
<td>Lognormal Shadowing with standard deviation</td>
<td>8 dB (in most of the cases)</td>
</tr>
<tr>
<td>Rayleigh fast fading</td>
<td></td>
</tr>
<tr>
<td>Noise power at the receiver</td>
<td>-101 dBm</td>
</tr>
<tr>
<td>Total send power</td>
<td>46.0 dBm=(40W)</td>
</tr>
<tr>
<td>Radio signaling overhead</td>
<td>3/14</td>
</tr>
</tbody>
</table>

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Mean throughput per RB as function of cell radius

Suzuki distributed fading, 2GHz frequency and $\sigma=0$dB, 2dB, 5dB, 8dB, 12dB from below.

Located at cell edge

Random location

Throughput per RB drops for large cells. Approx 0.2 Mbit/s for 2km cell and 0.05 Mbit/s at cell edge with 8dB shadowing.
Multiuser gain as function of cell radius

2GHz frequency, 100 RBs, fading Susuki distributed with shadowing $\sigma=8$ dB, number of users $=1, 2, 3, 5, 10, 25, 100$ from below.

Multiuser gain very large for Max-SINR. PF doubles cell throughput compare to RR for cell of 2 km and 25 users.
Mean Bitrate for a user located at cell edge as function of cell radius.

Max-SINR shows very poor cell edge performance

Scheduling: RR, PF and Max-SINR scheduling algorithm, 2GHz frequency and 100 RBs
Mean cell throughput for 10 users scheduled according to PF and a GBR user

GBR rates of less than 1 Mbit/s does not reduce the overall throughput very much. GBR rates larger than 1 Mbit/s is not recommended.

GBR of 3.0, 1.0, 0.3, 0.1 Mbit/s using non-persistent scheduling, for 2 GHz and 100 RB and Suzuki distributed fading with std. $\sigma=8$dB.
Conclusions

• The two most important factors for the radio performance in LTE are fading and attenuation due to distance.

• Numerical examples for LTE downlink shows results which are reasonable;
  - In the range 25-50 Mbit/s for 1 km cell radius at 2GHz with 100 RBs.
  - Multiuser gain is large for the Max-SINR algorithm but also the PF algorithm gives relative large gain relative to plain RR.
  - The Max-SINR has the weakness that it is highly unfair in its behaviour. (Not recommended to use in real operation.)

• The usage of GBR with high rates may cause problems in LTE due to the high demand for radio resources if users have low SINR i.e. at cell edge.
  - GBR rate limited to at most 1 Mbit/s per user?