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PERFORMANCE EVALUATION OF HYBRID ARQ SCHEMES OF 3GPP LTE OFDMA SYSTEM
Outline of Presentation

- 3GPP LTE Targets
- System and Channel Model
- Diversity Techniques
  - Subcarrier Rearrangement
  - Constellation Rearrangement
- Performance comparison of enhanced Hybrid ARQ Schemes
- Conclusion
3GPP LTE targets

Develop a framework for the evolution of the 3GPP radio-access technology towards a **high-data-rate, low-latency and packet-optimized** radio-access technology:

- Support of packet switched domain only (including VoIP).
- Significantly increased peak data rate: 100 Mbps (downlink) and 50 Mbps (uplink)
- 2 or 4 times capacity over Release 6 reference scenarios with HSDPA or HSUPA.
- Scalable bandwidth up to 20 MHz (lowest possible BW: 1.25 MHz).
- Radio Network user plane latency below 10 ms (RTT) with 5 MHz or higher spectrum allocation.
- Reduced complexity (of terminals)
- Need for inter-working with WCDMA and GSM based networks.
Parameters for LTE OFDMA Downlink Transmission

<table>
<thead>
<tr>
<th>Transmission BW</th>
<th>1.25 MHz</th>
<th>2.5 MHz</th>
<th>5 MHz</th>
<th>10 MHz</th>
<th>15 MHz</th>
<th>20 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-frame duration</td>
<td></td>
<td></td>
<td>0.5 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-carrier spacing</td>
<td></td>
<td></td>
<td>15 kHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>1.92 MHz</td>
<td>3.84 MHz</td>
<td>7.68 MHz</td>
<td>15.36 MHz</td>
<td>23.04 MHz</td>
<td>30.72 MHz</td>
</tr>
<tr>
<td>(1 / 2 × 3.84 MHz)</td>
<td>(2 × 3.84 MHz)</td>
<td>(4 × 3.84 MHz)</td>
<td>(6 × 3.84 MHz)</td>
<td>(8 × 3.84 MHz)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFT size</td>
<td>128</td>
<td>256</td>
<td>512</td>
<td>1024</td>
<td>1536</td>
<td>2048</td>
</tr>
<tr>
<td>Number of occupied sub-carriers† † †</td>
<td>76</td>
<td>151</td>
<td>301</td>
<td>601</td>
<td>901</td>
<td>1201</td>
</tr>
<tr>
<td>Number of OFDM symbols per sub frame (Short/Long CP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP length (μs/samples)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5.21 /10) × 1*</td>
<td>(5.21 /20) × 1</td>
<td>(5.21 /40) × 1</td>
<td>(5.21 /80) × 1</td>
<td>(5.21 /120) × 1</td>
<td>(5.21 /160) × 1</td>
</tr>
</tbody>
</table>

- Sub-carrier spacing is constant regardless of the transmission bandwidth
- Transmission bandwidth is varied by varying number of OFDM sub carriers to allow for operation in differently size spectrum
- Sub frame duration correspond to the minimum downlink TTI
Generic Frame Structure
Proposed OFDMA System Model
Channel Model

- 3GPP Spatial Channel Model Extended
- SISO/MIMO radio channel models that are commonly accepted and used
- Three environments are specified
  - Suburban Macrocell (approx. 3km distance BS to BS)
  - Urban Macrocell (approx. 3km distance BS to BS)
  - Urban Microcell (approx. 1km distance BS to BS)
- 6 paths tap delay line model
# Tapped Delay-Line Parameters

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Suburban -Macro</th>
<th>Urban Macro</th>
<th>Urban Micro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power - Delay Parameters (relative)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>-2.6682</td>
<td>0.1408</td>
<td>-2.2204</td>
</tr>
<tr>
<td>3</td>
<td>-6.2147</td>
<td>0.0626</td>
<td>-1.7184</td>
</tr>
<tr>
<td>4</td>
<td>-10.4132</td>
<td>0.4015</td>
<td>-5.1896</td>
</tr>
<tr>
<td>5</td>
<td>-16.4735</td>
<td>1.3830</td>
<td>-9.0516</td>
</tr>
<tr>
<td>6</td>
<td>-22.1898</td>
<td>2.8280</td>
<td>-12.5013</td>
</tr>
<tr>
<td>Resulting Total DS (us)</td>
<td>0.231</td>
<td>0.841</td>
<td>0.294</td>
</tr>
</tbody>
</table>
System Simulation parameters

• Several HARQ techniques are considered
  – Simple ARQ (Type I)
  – Chase Combining (Type I with CC)
  – Full IR (Type II)
  – Partial IR (Type III)
• Focused at static environment (channels remain invariant in the retransmissions)
• Retransmission is limited to 4
• 54 bytes packet size
Rate Compatible Punctured Turbo (RCPT)

- Turbo code introduced in 1993
- Concept of RCPT codes introduced in 1995 first used in ARQ protocol in 1997 in literature
- Enable Incremental Redundancy techniques
- Rate 1/3 mother turbo code
- A puncturing period of 6 is used in the simulation to form code rates of 3/4 and 1/2.
Puncturing Pattern

Chase Combining

\[ \begin{array}{c|c|c}
T_n & R_{eff} & \text{Rate} \\
1 & 1/2 & 1/2 \\
2 & 1/2 & 3/4 \\
3 & 1/2 & 3/4 \\
4 & 1/2 & 3/4 \\
\end{array} \]

\[ \begin{array}{c|c|c}
T_n & R_{eff} & \text{Rate} \\
1 & 1/2 & 1/2 \\
2 & 1/2 & 3/4 \\
3 & 1/2 & 3/4 \\
4 & 1/2 & 3/4 \\
\end{array} \]

- Soft bit values from different retransmission(s) are added to obtain the combined value of soft bits
- Obtain soft combining and diversity gain
Puncturing Pattern

Partial Incremental Redundancy

\[
\begin{align*}
T_n & \\
1 & 1/2 \\
2 & 1/3 \\
3 & 1/3 \\
4 & 1/3 \\
\end{align*}
\]

\[
\begin{align*}
R_{\text{eff}} & \\
1 & 3/4 \\
2 & 3/5 \\
3 & 1/2 \\
4 & 3/7 \\
\end{align*}
\]

- Soft bit values from different retransmission(s) are added to obtain the combined value of soft bits
- Obtain soft combining and diversity gain
Puncturing Pattern

Full Incremental Redundancy

- Soft bit values from different retransmission(s) are added to obtain the combined value of soft bits
- Obtain soft combining and diversity gain
Modulation and Coding Schemes Used in the simulation

<table>
<thead>
<tr>
<th>MCS</th>
<th>Modulation</th>
<th>Coding Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QPSK</td>
<td>1/2</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>3/4</td>
</tr>
<tr>
<td>3</td>
<td>16 QAM</td>
<td>1/2</td>
</tr>
<tr>
<td>4</td>
<td>16 QAM</td>
<td>3/4</td>
</tr>
<tr>
<td>5</td>
<td>64 QAM</td>
<td>1/2</td>
</tr>
<tr>
<td>6</td>
<td>64 QAM</td>
<td>3/4</td>
</tr>
</tbody>
</table>
PER Performance of H-ARQ Schemes

Mode 1

Mode 4

PER

Throughput

Type I − Simple ARQ
Type I − with CC
Type II − Full IR
Type III − Partial IR
Diversity Technique I: Subcarrier Rearrangement

- In frequency selective channel, each OFDM subcarrier suffers different distortion and thus different received signal quality
- Assign coded bits to different subcarriers in retransmissions
- Shift the coded bits by suitable step – larger than channel coherent bandwidth
- Generates frequency diversity between retransmissions
PER Performance of H-ARQ Schemes with subcarrier mapping—Mode 1

w/o subcarrier mapping

with subcarrier mapping

PER

Throughput

PER

w/o subcarrier mapping

PER

w/o subcarrier mapping

SNR (dB)

Type I—Simple ARQ
Type I—with CC
Type II—Full IR
Type III—Partial IR

SNR (dB)

Type I—Simple ARQ
Type I—with CC
Type II—Full IR
Type III—Partial IR

Mbps

Type I—Simple ARQ
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PER Performance of H-ARQ Schemes with subcarrier mapping – Mode 6

![Graphs showing PER and Throughput for different H-ARQ schemes with and without subcarrier mapping.](image)
Diversity Technique II: Constellation Rearrangement

<table>
<thead>
<tr>
<th>Constellation version parameter b</th>
<th>Output bit sequence</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>I₁Q₁I₂Q₂</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>I₂Q₂I₁Q₁</td>
<td>Swapping MSBs with LSBs</td>
</tr>
<tr>
<td>2</td>
<td>I₁Q₁I₂Q₂</td>
<td>Inversion of LSBs’ logical values</td>
</tr>
<tr>
<td>3</td>
<td>I₂Q₂I₁Q₁</td>
<td>Both Swapping and inversion</td>
</tr>
</tbody>
</table>

- Different reliabilities exist for four bits which form a 16 QAM symbol
- Average reliabilities through retransmission by different constellation mappings
- Simple operations to rearrange the output bit sequence
- Constellation rearrangement does not require additional User Equipment (UE) buffer
**PER & Throughput Performance for different diversity techniques for Chase Combining (MCS4)**

- Sub-carriers rearrangement can be coupled with Constellation rearrangement to achieve further improvement
**PER & Throughput performance for MCS6 for enhanced Hybrid ARQ schemes (with combined diversity techniques)**

- For highest MCS scheme, Full IR and Partial IR still perform better due to significant decoding gain but only up a margin of approx. 2 dB
Conclusion on Hybrid ARQ Performance

- Different subcarriers and constellation mapping in retransmission(s) achieve diversity effects
- Without diversity strategies, Full and Partial IR achieve best throughput performance
- Chase Combining gets most benefit from diversity strategies, Partial IR gets less than CC and followed by Full IR
- For highest MCS scheme, Full IR and Partial IR still perform better due to significant decoding gain but only up a margin of approx. 2 dB
Thank you