3GPP Long Term Evolution
Physical Layer

Rohit Budhiraja
Outline of the talk

- Brief overview of the eNodeB MAC-PHY interface
  - Information sent by the MAC to the PHY
    - Data and control information
- Concepts of Adaptive Modulation & Coding, BLER & CQI
- Description of Transceiver chain
  - Discussion of individual sub-blocks
- Concepts of Channel Estimation and Equalization
- Synchronization principles
  - DL Initial access
  - UL RACH
- Initial access example
MAC-PHY Interface

- MAC
  - Control Information
  - Data payload (Transport block)

- PHY
  - Control Information
  - Data payload (Transport block)
Transport block (TB) sizes & Modulation order details

- TB sizes are specified in the standard using a Table
  - Table is indexed using
    - Modulation and Coding Scheme (MCS)
    - Number of PRBS
- MCS indirectly specifies the coding-rate
- MCS and number of PRBS are decided by the Scheduler
  - Based on Channel Quality Information (CQI) feedback from the UE
  - Also a function of fairness and number of active users in the system
Modulation order and TBS Index relationship

<table>
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<tr>
<th>MCS Index $I_{MCS}$</th>
<th>Modulation Order $Q_m$</th>
<th>TBS Index $I_{TBS}$</th>
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Two MCS indices refer to same TBS indices

Reserved for UL HARQ

Ref: (Table 7.1.7.1-1 of 36.213)
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Ref: (Table 7.1.7.2.1-1 of 36.213)

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Adaptive Modulation & Coding
Fundamentals of Adaptive Modulation and Coding (AMC)

- Wireless channel has statistical variations
  - A mobile user channel will vary with its location & speed
- Channel variations can be estimated and fed-back
  - For a slow moving user:
    - (Nearly) exact channel can be fed-back to eNodeB
    - Done by quantizing the channel
      - Done by feeding back the MCS, PMI and RI (Will revisit later)
  - For a fast moving user
    - First (mean) and second order (variance) statistics can be fed

- AMC
  - Achieves capacity
  - Binary (but not practical) way to state:
    - Transmit only when channel is good and don’t when channel is bad
  - Non binary way:
    - Match the code-rate to the channel conditions
Channel Conditions

- Channel condition = SINR seen by a particular user

20% UEs have SINR <= 0 dB

SINR CDF plot
BLER concept

- Turbo codes are capacity achieving
  - Does-not follow water-fall behavior like Convolutional code
  - BER/BLER drops to zero after a particular SNR

Ref: (Figure 10.1 Stefania Sesia et. al, LTE – The UMTS Long Term Evolution)
CQI concept

- UE calculates the **post-processing SNR**
  - Post-processing SNR – Depends on the capability of UE (UE category)
  - A particular category UE has 2 antennas
    - 3 dB extra gain
    - Category indirectly refers to the UE price

- UE maps the post-processing SNR to the MCS

- Different kinds of CQI

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Aperiodic CQI reporting (1/2)

- **Wideband**
  - CQI for the entire system bandwidth

- **Higher layer configured sub-band**
  - UE reports a wideband CQI value for the whole system bandwidth
  - In addition, the UE reports a CQI value for each subband, calculated assuming transmission only in the relevant sub-band
  - Sub-band CQI reports are encoded differentially with respect to the wideband CQI using 2-bits as follows

  \[
  \text{Sub-band differential CQI offset} = \text{Sub-band CQI index} - \text{Wideband CQI index}
  \]

  Possible sub-band differential CQI offsets are \{<-1,0,+1,>+2\}

Ref: (Table 7.2.1-3 of 36.213)
Aperiodic CQI reporting (2/2)

- **UE selected sub-bands**
  - UE selects a set of $M$ preferred sub-bands of size $k$ within the whole system bandwidth
  - UE reports one wideband CQI value and one CQI value reflecting the average quality of the $M$ selected sub-bands
  - UE also reports the positions of the $M$ selected sub-bands
  - Sub-band CQI reports are encoded differentially with respect to the wideband CQI using 2-bits as follows

  **Differential CQI = Index for average of $M$ preferred sub-bands – Wideband CQI index**

- Possible sub-band differential CQI offsets are \{<+1,+2,+3,>+4\}

### Table: System Bandwidth vs. Subband Size and $M$

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<tr>
<th>System Bandwidth $N_{DL}^{DL}$</th>
<th>Subband Size k (RBs)</th>
<th>$M$</th>
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<td>64 – 110</td>
<td>4</td>
<td>6</td>
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</table>

Ref: (Table 7.2.1-5 of 36.213)
Periodic reporting

- RRC connection reconfiguration message configures the reporting modes
  - Only wideband and UE-selected sub-band feedback is possible for periodic CQI reporting
  - Sent using the PUCCH
  - Period = \{2, 5, 10, 16, 20, 32, 40, 64, 80, 160\} ms or Off
  - The UE selected subband reports are based on bandwidth parts and not on subbands as in the aperiodic case

<table>
<thead>
<tr>
<th>System Bandwidth</th>
<th>Subband Size k (RBs)</th>
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Ref: (Table 7.2.2-2 of 36.213)
LTE Transceiver chain
eNodeB PHY Transmit chain

CRC → Segmentation → CRC → Turbo coding → Rate Matching → Code-block Concatenation → Scrambler → Modulation

CRC → Segmentation → CRC → Turbo coding → Rate Matching → Code-block Concatenation → Scrambler → Modulation

Layer Mapping → Pre-coding → Resource Block mapping → OFDM signal generator (IFFT) → CP addition → Antenna 1

Layer Mapping → Pre-coding → Resource Block mapping → OFDM signal generator (IFFT) → CP addition → Antenna n

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CRC

- Performs error detection
  ◦ Does not correct
- Essential for HARQ implementation
- Different CRC for data and control
- 24-bit for data
  ◦ Transport block can be segmented into multiple code blocks
  ◦ CRC is computed for the Transport Block and each segmented code block
    ○ Allows error detection at code-block level
    ○ If a code-block is in error, no need to process remaining code blocks
  ◦ CRC for TB and each code-block
    ○ Duplication of efforts?
    ○ Different polynomials for TB-CRC and code-block CRC
      - Allows detection of any residual errors
- 16-bit for DL control
- 8-bit for UL control (when multiplexed with data)

Ref: (5.1.1 of 36.212)
Segmentation

- Transport block size can be greater than Turbo code block size
  - Maximum Turbo code block size - 6144
  - Maximum Transport block size (for MCS-26 and 110 RBs) - 73376
    - TB should be segmented if TB size > 6144

- BLER performance is limited by the smallest TB size
  - Coding gain is less

- Segmentation block ensures that a TB is divided into equal size code-blocks
  - E.g., TB size of 6224 is segmented into two code block of sizes 3136

- Maximum Turbo code block size in UMTS - 5114
  - Size increased in LTE such that 1500-byte TCP/IP packet is segmented into two code blocks instead of three
    - Increase the coding gain
Forward Error Correction Block

- Turbo block input = K bits
  - Turbo block output - 3 streams of K bits +12 tail bits
    - K Systematic bits, K Parity1 bits, K Parity2 bits
    - 12 tail bits are shared across three stream

- Three streams are rearranged with their own sub-block Interleavers
  - Interleaver handles the block errors by spreading them across the code-block

- Single buffer is formed by placing the rearranged systematic bits

- Systematic bits are followed by interlacing of the two rearranged parity streams
  - Interlacing allows equal protection for each constituent code

Sub-block Interleaver is based on row-column interleaver.
Rate Matching Principles

- Mother code-rate is 1/3
- Coded bits should be pruned to match the allocated resources
- Pruning implies repetition/puncturing
  - E.g., TB size is 256 for MCS-0 (QPSK) and NPRB-10
    - Total number of bits which can be transmitted
      - $10(\text{NPRB}) \times 120(\text{RE}) \times 2(\text{QPSK}) = 2400$
    - Turbo encoder output length – $256 \times 3 = 768$
    - Bits should be repeated as encoded data is less than the resources available
      - code-rate is lower than $1/3^{rd}$
  - E.g., TB size is 1544 for MCS-9 (QPSK) and NPRB-10
    - Total number of bits which can be transmitted
      - $10(\text{NPRB}) \times 120(\text{RE}) \times 2(\text{QPSK}) = 2400$
    - Turbo encoder output length – $1544 \times 3 = 4632$
    - Bits should be punctured as encoded data is more than the resources available
      - code-rate is higher than $1/3^{rd}$
Rate Matcher in LTE

- Circular buffer based rate-matcher

![2-D view of the circular buffer](image)

$N_r \times 96$

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Rate Matcher in LTE

- Redundancy version specifies a starting point in the circular buffer
- Different RVs are specified by defining different starting points
- Usually RV-0 is selected for initial transmission to send as many systematic bits as possible
- Scheduler can choose different RVs to support Chase and IR HARQ
- Systematic bits are also punctured
  - Leads to enhanced performance at high-code rates [1]

HARQ Principles

- Code-rate is decided by eNodeB after getting the CQI feedback from UE

- In spite of this, a received TB could be in error
  - Fast moving user
    - CQI reported may be outdated
  - Slow moving user
    - Erroneous reporting of CQI in interference limited scenario
  - Standard specifies that the UE should specify the MCS
    - such that BLER = 10^{-1}

- HARQ is employed to utilize the time diversity
  - Chase – Same bits are transmitted
    - Allows Maximal ratio combining
  - Incremental redundancy – different RVs are transmitted
    - Coding gain
HARQ details

- Multiple parallel Stop and Wait processes in parallel

- Eight processes in parallel

Ref: (Figure 19.1, Dehlman et. al. 3G EVOLUTION : HSPA AND LTE FOR MOBILE BROADBAND)
HARQ flow-diagram in DL

- ACK/NACK for data packets transmitted in the downlink: UE requests retransmission of incorrectly received data packets
  - ACK/NACK is transmitted in UL, either on PUCCH or mux with PUSCH
  - ACK/NACK transmission refers to the data packet received four sub-frames (= 4 ms) before,

Ref: (Figure 4.4, Freescale white paper, Long Term Evolution Protocol Overview)
HARQ flow-diagram in UL

- eNodeB requests retransmission of incorrectly received data packets
  - ACK/NACK is transmitted in PHICH
  - ACK/NACK transmission refers to the data packet received four sub-frames (= 4 ms) before,

Ref: (Figure 4.6, Freescale white paper, Long Term Evolution Protocol Overview)
Scrambler

- Scrambling is applied to all downlink physical channels
  - Initialized using cell-id
    - Serves the purpose of interference randomization
  - Order-31 Gold code
    - $2^{31}$ sequences
  - Can be generated with very low implementation complexity
    - Modulo-2 addition of two sequences
    - Can be generated from two shift registers

- Reduces correlation between sequence used in adjacent cells
## Modulation - Downlink Alphabet

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<tr>
<th>Channels</th>
<th>Modulation scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBCH</td>
<td>QPSK</td>
</tr>
<tr>
<td>PDCCH</td>
<td>QPSK</td>
</tr>
<tr>
<td>PDSCH</td>
<td>QPSK, 16-QAM, 64-QAM</td>
</tr>
<tr>
<td>PMCH</td>
<td>QPSK, 16-QAM, 64-QAM</td>
</tr>
<tr>
<td>PCFICH</td>
<td>QPSK</td>
</tr>
<tr>
<td>PHICH</td>
<td>BPSK modulated on I and Q with the spreading factor 2 or 4 Walsh codes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Signals</th>
<th>Modulation scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS</td>
<td>Complex I+jQ pseudo random sequence (length-31 Gold sequence) derived from cell ID</td>
</tr>
<tr>
<td>P-SCH</td>
<td>One of three Zadoff-Chu sequences</td>
</tr>
<tr>
<td>S-SCH</td>
<td>Two 31-bit BPSK PN-sequence</td>
</tr>
</tbody>
</table>
# Modulation - Uplink Alphabet

<table>
<thead>
<tr>
<th>Channels</th>
<th>Modulation scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUCCH</td>
<td>BPSK, QPSK</td>
</tr>
<tr>
<td>PUSCH</td>
<td>QPSK, 16-QAM, 64-QAM</td>
</tr>
<tr>
<td>PRACH</td>
<td>Zadoff-Chu</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Signals</th>
<th>Modulation scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demodulation RS</td>
<td>Zadoff-chu</td>
</tr>
<tr>
<td>Sounding RS</td>
<td>Based on Zadoff-Chu</td>
</tr>
</tbody>
</table>
Code-word to Layer Mapping (1/3)

- Mapping of symbols on-to the antenna ports
- Layer mapping depends on the MIMO scheme employed
- Number of layers is equal to the antenna ports used

Concept of Antenna Port

Layer Mapping for single antenna port

\[ x^{(0)}(i) = d^{(0)}(i) \]

(Ref:6.3.3.2 of 36.211)
## Code-word to Layer Mapping (2/3)

- **Layer Mapping for transmit diversity**

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Number of code words</th>
<th>Codeword-to-layer mapping $i = 0, 1, \ldots, M_{\text{symb}}^{\text{layer}} - 1$</th>
</tr>
</thead>
</table>
| 2               | 1                    | $x^{(0)}(i) = d^{(0)}(2i)$  
$x^{(1)}(i) = d^{(0)}(2i + 1)$  
$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} / 2$ |
| 4               | 1                    | $x^{(0)}(i) = d^{(0)}(4i)$  
$x^{(1)}(i) = d^{(0)}(4i + 1)$  
$x^{(2)}(i) = d^{(0)}(4i + 2)$  
$x^{(3)}(i) = d^{(0)}(4i + 3)$  
$M_{\text{symb}}^{\text{layer}} = \begin{cases} 
    M_{\text{symb}}^{(0)} / 4 & \text{if } M_{\text{symb}}^{(0)} \mod 4 = 0 \\
    (M_{\text{symb}}^{(0)} + 2) / 4 & \text{if } M_{\text{symb}}^{(0)} \mod 4 \neq 0
\end{cases}$  
If $M_{\text{symb}}^{(0)} \mod 4 \neq 0$ two null symbols shall be appended to $d^{(0)}(M_{\text{symb}}^{(0)} - 1)$ |

(Ref: 6.3.3.2 of 36.211)
Layer Mapping for spatial multiplexing

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Number of code words</th>
<th>Codeword-to-layer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>$x^{(0)}(i) = d^{(0)}(i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$M_{\text{layer}} = M_{\text{symb}}^{(0)}$</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>$x^{(0)}(i) = d^{(0)}(i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x^{(1)}(i) = d^{(1)}(i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$M_{\text{layer}} = M_{\text{symb}}^{(0)} = M_{\text{symb}}^{(1)}$</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>$x^{(0)}(i) = d^{(0)}(2i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x^{(1)}(i) = d^{(0)}(2i+1)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$M_{\text{layer}} = M_{\text{symb}}^{(0)} / 2$</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>$x^{(0)}(i) = d^{(0)}(i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x^{(1)}(i) = d^{(1)}(2i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x^{(2)}(i) = d^{(1)}(2i+1)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$M_{\text{layer}} = M_{\text{symb}}^{(0)} = M_{\text{symb}}^{(1)} / 2$</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>$x^{(0)}(i) = d^{(0)}(2i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x^{(1)}(i) = d^{(0)}(2i+1)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x^{(2)}(i) = d^{(1)}(2i)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x^{(3)}(i) = d^{(1)}(2i+1)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$M_{\text{layer}} = M_{\text{symb}}^{(0)} / 2 = M_{\text{symb}}^{(1)} / 2$</td>
</tr>
</tbody>
</table>

(Ref: 6.3.3.2 of 36.211)
Rank Indicator (RI)

- A 2 x 2 MIMO system is represented as a set of linear equations

\[ h_{11}x + h_{12}y = c_1 \]
\[ h_{21}x + h_{22}y = c_2 \]

- RI definition in the LTE framework
  - Borrowed from Linear Algebra and is defined as the number of independent columns
  - Number of independent columns = Number of streams
  - For a 2 x 2 MIMO system,
    - Number of independent columns = 1, 2

- UE can decide the Rank using different performance criterion
  - Throughput maximization
    - Calculate the throughput using Rank - 1 and Rank - 2
    - Feedback the rank which gives the maximum throughput
Precoder

- **Open loop precoding**
  - No feedback from UE
  - Transmit diversity

- **Closed loop precoding**
  - Requires feedback from the UE
  - UE calculates the post-processing SNR for different precoding matrices
  - Reports the matrix which results in best SNR (PMI)

- **Post-processing SNR for single stream transmission**

Without PMI

- $h_2$
- $h_1$
- $h_2^2 + h_1^2$

With PMI = 3

- $h_2$
- $h_1$
- $h_3 = jh_2$
- $h_1^2 + h_3^2$
## Precoding Matrix Indicator

- Applicable for transmission modes 4, 5 and 6
- Indicates the precoder weights used for precoding
  - usual objective function is post-SINR maximization
- Feedback bits depends on the number of tx antenna ports
  - \{0, 1\} in case with 2 antenna port
  - \{0, 1, ..., 15\} with 4 antenna ports
- PMI sent on either PUSCH or PUCCH

<table>
<thead>
<tr>
<th>Two transmit antennas</th>
<th>Single stream</th>
<th>Dual stream</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[1 \quad 1]</td>
<td>[[1 \quad 1], [1 \quad -1]]</td>
</tr>
<tr>
<td></td>
<td>[1 \quad -1]</td>
<td>[[1 \quad j], [1 \quad -j]]</td>
</tr>
<tr>
<td></td>
<td>[1 \quad j]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[1 \quad -j]</td>
<td></td>
</tr>
</tbody>
</table>
Resource Block Mapping and Baseband Signal Generation

- Symbols are mapped on-to the 2-D Resource Blocks
- Location of Resource blocks allocated to a user depends on the CQI feedback from the user
  - Decided by the scheduler in the MAC layer

Symbols are mapped on to the 2-D Resource Blocks. The location of the Resource blocks allocated to a user depends on the CQI feedback from the user, which is decided by the scheduler in the MAC layer.

Symbols are mapped on to the 2-D Resource Blocks. The location of the Resource blocks allocated to a user depends on the CQI feedback from the user, which is decided by the scheduler in the MAC layer.
OFDM basics (1/2)

- OFDM is the sum of sinusoids on in-phase and quadrature arms
  \[ I = \sum_i \sin(2\pi f_i t) + j\sum_i \cos(2\pi f_i t) \]
  - Sinusoids are orthogonal over one period of the lowest frequency sinusoid
  - Sinusoids are separated by \( \Delta f = 1/T_s \)
  - Can be easily separated at the receiver by observing one period of the lowest frequency sinusoid

- From ‘Signal and Systems fundamentals’
  - Sinusoids are Eigen functions of an LTI system
    - In case of wireless systems, multipath channel is the LTI system
  - O/P is only a scaled version of the I/P
    - Individual rx subcarriers are scaled version of tx subcarriers
    - Scaling factor (Channel coefficients) can be easily determined using well established signal processing techniques like Least Squares etc

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OFDM basics (2/2)

- CP – Few samples of the sum of sinusoids are taken from the end are appended in the beginning
  - Extends the symbol duration and also phase continuity is maintained
    - Helps in tackling multipath
    - Ensures that timing estimation can have tolerance of few samples

Samples corrupted by Multipath

Window 1

Window 2

Window 3
PHY Receive Chain

TB CRC validation
Concatenation
CRC validation
Turbo decoder
Rate Dematcher
Code-block Segmentation
Descrambler
Demodulation

TB CRC validation
Concatenation
CRC validation
Turbo decoder
Rate Dematcher
Code-block Segmentation
Descrambler
Demodulation

Layer Demapping
Resource Block Demapping
Equalizer
Channel Estimation
OFDM receiver (FFT)
CP deletion
Ant 1

Resource Block Demapping
Equalizer
Channel Estimation
OFDM receiver (FFT)
CP deletion
Ant n
Demodulation (1/2)

- Equalizer output can be processed in two ways
  - Sub-optimum
    - Apply the nearest distance detection rule
      - Threshold the equalized symbols to the nearest transmitted symbol
      - Demap the symbols into bits
    - Results in a penalty of 2-3 dB
Apply the nearest distance detection rule

- Calculate $LLR = \log(b_0/b_1)$
- E.g., if $x = 0.1 - j0.1$,
  - $LLR_{\text{bit0}} \approx 0.1$ & $LLR_{\text{bit1}} \approx -0.1$
De-rate Matching Principles

- Recall
  - Turbo mother code-rate is 1/3
  - Coded bits were pruned to match the allocated resources
    - Pruning implies repetition/puncturing
      - Repetition implies that code-rate is lower than 1/3\(^{rd}\)
      - Puncturing implies that code-rate is higher than 1/3\(^{rd}\)
  - Turbo decoder is designed for code-rate = 1/3
    - Code rate should be made = 1/3
      - LLRs of repeated bits are added
      - Zeros are inserted in place of LLRs of punctured bits
Synchronisation
LTE Initial access

1. Cell Search and Selection
2. Derive System Information
3. Random Access
4. User Data RX/TX

Power-up
Cell search (1/3)

- Cell search: Mobile terminal or user equipment (UE) acquires time and frequency synchronization with a cell and detects the cell ID of that cell
  - Based on BCH (Broadcast Channel) signal and hierarchical SCH (Synchronization Channel) signals

- Cell search procedure:
  1. Step 1: Find Primary SCH sequence
     - Obtain 5ms timing
     - Get cell identity within the cell-identity group (3 nos)
  2. Step 2: Find Secondary SCH sequence
     - Sequence pair to obtain exact frame timing
     - Obtain cell identity group (168 nos)
     - Know also the reference signal sequence
  3. Step 3: Read BCH
     - Obtain basic data as bandwidth, number of antennas etc.
Cell search \((2/3)\)

Synchronization signals in the time domain

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[Src: Telesystem Innov.]
1. **Primary synchronization signal (PSS)**
   - 3 possible sequences to identify the cells physical layer identity (0, 1, 2)

1. **Secondary synchronization signal (SSS)**
   - 168 different sequences to identify physical layer cell identity group

Hierarchical cell search as in 3G; providing PSS and SSS for assistance,
- PSS is carrying physical layer identity $N_{ID}^{(2)}$,
- SSS is carrying physical layer cell identity group $N_{ID}^{(1)}$,
- Cell Identity is computed as $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$, where $N_{ID}^{(1)} = 0, 1, ..., 167$ and $N_{ID}^{(2)} = 0, 1, 2$.
Summary of Cell-search Stages

1. Primary synchronization signal
   - 3 possible sequences to identify the cell’s physical layer identity (0, 1, 2).

2. Secondary synchronization signal
   - 168 different sequences to identify physical layer cell identity group,
   ⇒ Downlink reference signals,

3. Physical Broadcast Channel (PBCH)
   - Carrying broadcast channel with Master Information Block (MIB)
Physical Broadcast Channel (PBCH)

- Carrying broadcast channel (BCH) with Master Information Block (MIB) System bandwidth [4 bit], PHICH configuration [Duration: 1 bit, Resource: 2 bit], System Frame Number [SFN, 8 bit] and indirect about the used Tx antennas,
- QPSK modulated, cell-specific scrambling
- Transmitted on 72 subcarriers around the carrier frequency
PBCH

- PBCH structure
PBCH Generation

<table>
<thead>
<tr>
<th># of TX antennas</th>
<th>PBCH CRC Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0000000000000000bn</td>
</tr>
<tr>
<td>2</td>
<td>1111111111111111bn</td>
</tr>
<tr>
<td>4</td>
<td>0101010101010101bn</td>
</tr>
</tbody>
</table>

System bandwidth, PHICH configuration, System Frame Number (SFN), Logical channel

Master Information Block (MIB) ➔ Transport Block (TB) ➔ PBCH ➔ Scrambling ➔ Modulation ➔ Layer mapping and pre-coding ➔ Mapping to Resource Elements (RE)
Uplink Synchronisation (1/2)

- Three users in a system
- Three of them located at differential distances from the eNodeB

- Different RTDs will lead to interference at the eNodeB
Uplink Synchronisation (2/2)

- Uplink transmission orthogonality between users is maintained by timing advance
  - Set initially during Random Access Procedure
  - Updated as necessary subsequently

- Supports at least 100 km cell range
  - Greater ranges are up to implementation

\[ N_{TA} \times T_S \text{ time units} \]

\[ N_{TA} \text{ can range from 0 to 20512, } T_S = 1/30.72 \, \mu\text{sec} \]
Carries the RACH preamble a UE sends to access the network in non-synchronized mode and used to allow the UE to synchronize timing with the eNodeB.
Subcarrier spacing of 1.25 KHz

Consists of 839 subcarriers = 1.05 MHz
  ▶ 15 KHz guard, either side

FDD LTE -> 4 formats
  ▶ Format 0, good up to 14 Km
    ◦ 1 msec subframe

Position fixed by SIB2
Preamble Formats

Near user
Other users CP Sequence Other users

Far user
Other users CP Sequence Other users

Distant-dependent timing uncertainty

Configuration 0
(1 ms window)
CP \( N_{ZC} \)-point Zadoff-Chu sequence
0.1 ms 0.8 ms 0.1 ms

Configuration 1
(2 ms window)
0.68 ms 0.8 ms 0.52 ms

Configuration 2
(2 ms window)
0.2 ms 1.6 ms 0.2 ms

Configuration 3
(3 ms window)
0.68 ms 1.6 ms 0.72 ms
UL Power Control

- Controls uplink power spectral density
  - Total uplink transmit power scales linearly with transmitted bandwidth
- Fractional power control can compensate for all or part of path loss
  - Allows trade-off between intra-cell fairness and inter-cell interference
- MCS-specific offsets may be applied
- Closed-loop power control commands can fine-tune the power setting
  - Carried on PDCCH
    - Individual commands in UL resource grants
    - Group commands for groups of UEs
- Separate power control for PUCCH and PUSCH
Reference Signal Received Power (RSRP)

- RSRP is defined as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth.

- Reference point for the RSRP shall be the antenna connector of the UE.
Reference Signal Received Quality (RSRQ)

$$\text{RSRQ} = N \times \frac{\text{RSRP}}{\text{Carrier RSSI}}$$

- $N$ is the number of RBs of the carrier RSSI measurement bandwidth.
- Carrier RSSI is the linear average of the
  - Total received power (in [W]) observed only in
    - Reference symbols for antenna port 0 in $N$ RBs
- Measurements in the numerator and denominator shall be made over the same set of resource blocks.
References

- **3GPP Documents**
  - 36.101 Overview
  - 36.211 Physical channels and modulation
  - 36.212 Multiplexing and channel coding
  - 36.213 Physical layer procedures
  - 36.214 Physical layer measurements
  - 36.133 Radio resource management

- **Books**
  - LTE, The UMTS Long Term Evolution: From Theory to Practice (Matthew Baker et. al., Philips)
  - 3G EVOLUTION: HSPA and LTE for Mobile Broadband (Erik Dahlman et. al., Ericsson)
  - LTE for UMTS - OFDMA and SC-FDMA Based Radio Access (Anti Toskala et. al., Nokia / NSN)

- **Whitepapers and tutorials from Rohde Schwarz, Agilent, ...**
Thanks
Back-up Slides
Example procedures
Example: Indicating PDCCH format

Check PCFICH! It will tell you how many symbols (1, 2, 3 (or 4)) in the beginning of each subframe are allocated for PDCCH!

Physical Control Format Indicator Channel (PCFICH)

Physical Downlink Control Channel (PDCCH)

I would like to read the PDCCH but where is it?
1) Several identities are used in LTE to identify UE’s (e.g. C-RNTI), System Information (SI-RNTI), Paging Information (P-RNTI) or during Random Access Procedure (RA-RNTI), for details see 3GPP TS36.321 V8.5.0 MAC Protocol Specification.

[Src: Rohde Schwarz]
Example: Scheduling for uplink data

Check **PDCCH** for your UE ID. As soon as you are addressed, you will find your uplink scheduling grants there.

**Physical Downlink Control Channel (PDCCH)**

**Physical Uplink Shared Channel (PUSCH)**

(QPSK, 16QAM modulated, 64QAM is optional for the UE)

I would like to send **data** on **PUSCH** but I don’t know which resource blocks and transport formats I can use?

[Sr: Rohde Schwarz]
Example: Ack. UL data packets on PHICH

Read the **PHICH**. It carries ACK or NACK for each single packet.

Physical Hybrid ARQ Indicator Channel (PHICH)

Physical Uplink Shared Channel (PUSCH)

I have sent data packets on PUSCH but I don’t know whether they have been received correctly.

[Rohit Budhiraja](mailto:rohit.budhiraja@cewit.org)  © CEWiT 2011
Thanks
Thanks
Concept of Antenna port (1/2)

- RS structure for 1, 2 and 4 antennas in normal CP

RS structure for 1, 2 and 4 antennas in normal CP:

- Antenna Port 0
- Antenna Port 1

Rohit Budhiraja
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- UE specific RS for normal CP
  - Supports non-code book based beam forming
Code-rate calculation

- Code - rate = k/n
  - k = Number of information bits
  - n = Total number of bits transmitted

- TBS = 0 & NPRBS = 10
  - k = 256
  - n = modulation-order * Number of resource elements
    = 2 * (NPRBS * 120)
    = 2 * (10 * 120)
    = 2400
  - Code - rate = 256 / 2400 = .1066