INTERFERENCE MANAGEMENT WITHIN 3GPP LTE ADVANCED

KONSTANTINOS DIMOU, PHD
SENIOR RESEARCH ENGINEER,
WIRELESS ACCESS NETWORKS, ERICSSON RESEARCH
konstantinos.dimou@ericsson.com
OUTLINE

- 3GPP LTE (Advanced)
  - Short Introduction

- Interference Management
  - Goal of interference management in cellular systems
  - Sources of interference within 3GPP LTE Advanced
    - Inter-system Interference
    - Intra-LTE Interference
    - Inter-Cell Interference

- Inter-Cell Interference Coordination (ICIC)
  - Data Channels
    - Cell-autonomous schemes
    - Coordinated Schemes

- Summary
LTE - SPECTRUM FLEXIBILITY

› Operation in differently-sized spectrum allocations
  - From 1.4 MHz to 20 MHz

› Support for paired and unpaired spectrum allocations
TIME-DOMAIN STRUCTURE

### FDD
- Uplink and downlink separated in frequency domain

One radio frame, $T_{\text{frame}} = 10$ ms

One subframe, $T_{\text{subframe}} = 1$ ms

- UL
- DL

Subframe #0 #1 #2 #3 #4 #5 #6 #7 #8 #9

### TDD
- Uplink and downlink separated in time domain ➔ ”special subframe”
- Same numerology etc as FDD ➔ economy of scale

Ul DL

DwPTS GP UpPTS

f_{DL/UL}
TRANSMISSION SCHEME

**Downlink – OFDM**
- Parallel transmission on large number of narrowband subcarriers

**Uplink – DFTS-OFDM**
- DFT-precoded OFDM

**Benefits:**
- Avoid own-cell interference
- Robust to time dispersion

**Main drawback**
- Power-amplifier (PA) efficiency

**Tx signal has single-carrier properties**
- Improved power-amplifier efficiency
  - Improved battery life
  - Reduced PA cost

**Critical for uplink**
- Equalizer needed \(\Rightarrow\) Rx Complexity
  - Not critical for uplink
Downlink – OFDM

- Parallel transmission using a large number of narrowband “sub-carriers”
- “Multi-carrier” transmission
  - Typically implemented with FFT
- Insertion of cyclic prefix prior to transmission
  - Improved robustness in time-dispersive channels – requires CP > delay spread
  - Spectral efficiency loss

<table>
<thead>
<tr>
<th>Configuration, $\Delta f$</th>
<th>CP length</th>
<th>Symbols per slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal 15 kHz</td>
<td>≈4.7 µs</td>
<td>7</td>
</tr>
<tr>
<td>Extended 15 kHz</td>
<td>≈16.7 µs</td>
<td>6</td>
</tr>
<tr>
<td>7.5 kHz</td>
<td>≈33.3 µs</td>
<td>3</td>
</tr>
</tbody>
</table>
PHYSICAL RESOURCES

One subframe (1 ms)

One slot (0.5 ms)

One frame (10 ms)

One resource element

12 sub-carriers

$T_{CP}$

$T_u$
UPLINK – DFT-SPREAD OFDM (‘SC-FDMA’)

- Single-carrier uplink transmission ➔ efficient power-amplifier operation ➔ improved coverage
  - OFDM requires larger back-off than single-carrier
  - DFT-spread OFDM – OFDM with DFT precoder to reduce PAR

- Uplink numerology aligned with downlink numerology

![Diagram showing DFT-spread OFDM process]

- Terminal A: DFT ($M_1$) ➔ IFFT ➔ CP insertion ➔ ...
- Terminal B: DFT ($M_2$) ➔ IFFT ➔ CP insertion ➔ ...

$M_1 > M_2$
UPLINK – DFT-SPREAD OFDM (‘SC-FDMA’)

- Combined TDMA/FDMA ➔ intra-cell orthogonality
  - Scheduled uplink – NodeB scheduler controls resource allocation
  - Orthogonal uplink ➔ no intra-cell interference
  - Orthogonal uplink ➔ relaxed need for fast closed-loop power control

- Why FDMA component?
  - To support small payloads
  - To handle the case of power limitations
ARCHITECTURE

› Core network evolved in parallel to LTE
  – EPC – *Evolved Packet Core*

› Flat architecture, single RAN node, the *eNodeB*
  – Compare HSPA, which has an RNC
HYBRID-ARQ WITH SOFT COMBINING

- Same basic structure as HSPA
  - Parallel stop-and-wait processes
  - 8 processes ➔ 8 ms roundtrip time
INTERACTION WITH RLC

› Why *two* transmission mechanisms, RLC and hybrid-ARQ?
  – Retransmission protocols need feedback

› Hybrid ARQ [with soft combining]
  – Fast retransmission, feedback every 1 ms interval
  – Frequent feedback ➞ need low overhead, single bit
  – Single, uncoded bit ➞ errors in feedback (~10^-3)

› RLC
  – Reliable feedback (sent in same manner as data)
  – Multi-bit feedback ➞ less frequent

› Hybrid-ARQ and RLC *complement* each other
**MULTI-ANTENNA TRANSMISSION TECHNIQUES**

- **Diversity** for improved system performance
- **Beam-forming** for improved coverage (less cells to cover a given area)
- **SDMA** for improved capacity (more users per cell)
- **Multi-layer transmission** ("MIMO") for higher data rates in a given bandwidth

The multi-antenna technique to use depends on what to achieve.
GOAL OF INTERFERENCE MANAGEMENT
INTERFERENCE WITHIN CELLULAR SYSTEMS

Serving enhanced Node B (eNB)  
User Equipment (UE)  
Neighbor eNB

Useful signals  
Interference

\[ \text{SINR} = \frac{S}{I + N} \]

Downlink  
Interference @ the UE  
Interference

Uplink  
Interference @ the eNB  
Useful Signal  
Noise

Reduce interference so as to increase SINR
SOURCES OF INTERFERENCE
SOURCES OF INTERFERENCE WITHIN LTE

› Inter-system interference
  – From other cellular systems
    › E.g. from WCDMA, IS-95 or from bands belonging to other LTE operators
  – From other types of systems
    › E.g. TV or other broadcasting systems, satellite communications, radars

› Intra-LTE Interference
  – Inter-cell Interference
INTER-SYSTEM INTERFERENCE

- Inter-system interference
  - Typically of steady nature
  - Exception: interference created by radars transmitting pulses/signals on certain time instants
  - Either on the same frequency
    - "Co-channel interference" or
  - On adjacent frequencies
    - "Adjacent channel interference"
    - Created by
      - hardware imperfections at the transmitter resulting in:
        - Out of Band/Spurious emissions
        - Adjacent Channel Leakage
      - Non-perfect filter at the receiver
SOLUTIONS TO INTER-SYSTEM INTERFERENCE

➤ Adjacent channel interference
  ➤ Receiver blocking
    ➤ Filtering
  ➤ Guard bands

➤ Co-channel interference
  ➤ Receiver Desensitization
  ➤ Network Planning
  ➤ Inter-system coordination
INTRA LTE INTERFERENCE

Other-cell interference

- Independent scheduler operation may result in collisions
- For data: A collision typically leads to some SINR degradation; it does not necessarily mean information loss
  - Collisions more harmful to cell edge users
HOW CAN A COLLISION BE AVOIDED?

› Radio Resource Management (RRM)
  - Frequency Reuse (FR)

› Coordinated RRM
  - Joint scheduling
ICIC FOR DATA CHANNELS
"COST" TRADE-OFF ANALYSIS

› "Cost" of a "collision"
  - Fewer user data bits can be carried in one PRB, as the link adaptation needs to select lower modulation order and/or lower coding rate to compensate the lower SINR
  - More HARQ retransmissions may be needed for successful data delivery (due to BER degradation)

› "Cost" of avoiding a collision
  - Bandwidth restriction: colliding PRBs may need to be banned from use in the neighbor cell or may be used only with restrictions (e.g., with lower power)
  - Delayed scheduling: the scheduling of some UEs (interfering or interfered UEs) may need to be postponed.
WHAT IS THIS RESULT OF THIS TRADE-OFF?

Downlink: 2X2, Maximum Ratio Combining (MRC)

Uplink: 1X1, Single Input Single Output (SISO)

Avoiding a collision results in higher loss in radio resource usage than the gain in interference reduction.
HOW CAN THE EFFECTS OF A COLLISION BE MINIMIZED? - 1

› Radio Resource Management (RRM)
  - Scheduling
  - Fractional Frequency Reuse (FFR)

  - Fractional Power Control (FPC)

› Coordinated RRM
  - Joint scheduling
  - Joint power control
HOW CAN THE EFFECTS OF A COLLISION BE MINIMIZED? - 2

- Advanced Receivers, e.g.
  - Interference Rejection Combining (IRC)

Weighted signals combined to maximize SINR (reject interference and amplify desired signal)

- Coordinated RRM Combined with Advanced Receivers aka as Coordinated Multipoint Transmission & Reception (COMP)
  - IRC
  - Successive Interference Cancellation (SIC)
“COST” FOR REDUCING THE EFFECTS OF A COLLISION

› Advanced receivers
  – Hardware complexity, higher processing power, cost

› Coordinated schemes
  – Hardware complexity, higher processing power
  – Backhaul cost
    › Requirements on
      - Latency
      - Capacity
REL. 8-9 SUPPORT FOR ICIC
**UPLINK ICIC**

- **Overload Indicator – OI** ("Reactive" mechanism)
  - Bit map per resource block sent over X2 to neighbor cells
  - Signals if cell experiences low, medium, or high interference

- **High Interference Indicator – HII** ("Proactive" mechanism)
  - Bit map per resource block sent over X2 to neighbor cells
  - Indicates intention to schedule cell edge users in specific bands
DOWNLINK ICIC

› Less beneficial compared to uplink
  - Enough power available also for wide bandwidth transmission
  - Cost in DL data rate from power limitation

› Relative Narrow band TX Power Indicator (RNTPI)
  - Own intention to limit DL TX power in e.g red subband (per RB)
  - Soft intention that can be broken in case if needed
ICIC ALGORITHMS
AUTONOMOUS-COORDINATED SCHEMES

› ICIC schemes can be either:
  - cell autonomous or
  - Coordinated between eNBs (aka "X2-based")

› Cell autonomous schemes
  - No coordination between neighbor cells

› Coordination schemes
  - exchanging scheduling information between cells
    - time scale of information exchange depends on the backhaul latency
AUTONOMOUS ICIC

EXAMPLE OF AUTONOMOUS ICIC ALGORITHMS
STARTING OFFSET-BASED

- Offset based allocation order

- Random Start index
  - Starting PRB selected randomly

Well performing schemes @ low loads
ICIC BASED ON FFR

› Cell edge user determined by averaged geometry