Impact of Synchronization Impairments on CoMP Joint Transmission Performance
Deutsche Telekom @ ITSF2012

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Impact of Synchronization Impairments on LTE-A CoMP Joint Transmission Performance

Agenda

Introduction
- Motivation
- CoMP Joint Processing introduction
- Synchronization need of FDD base stations with CoMP Joint Processing

EASY-C project and Lab test setup
- Project EASY-C
- EASY-C Berlin field setup vs. lab test setup
- Test system and measurement setup

Impairment Test results and Background
1. 1pps phase synchronization ⇒ Symbol Timing Offset (STO)
2. Base Band Unit (BBU) frequency ⇒ Sampling Frequency Offset (SFO)
3. Radio Head (RH) frequency ⇒ Carrier Frequency Offset (CFO)

Summary

List of references

CoMP = Coordinated Multi-Point Transmission and Reception, CPRI = Common Public Radio Interface
EASY-C = Enablers for Ambient Services and sYstems – Part C: Wide Area Coverage
eNB = enhanced NodeB (LTE base station), FDD = Frequency Division Duplex, LTE = Long Term Evolution
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1. Motivation

- Phase synchronization is needed by several mobile LTE-A features:
  - To increase spectral efficiency by base station cooperation with interference cancellation and radio frame alignment.
  - To introduce new services like Multicast, Broadcast or Location based services.

  The features and their related synchronization requirements are often not fully specified by 3GPP yet.

- Deployment of aggregation / mobile backhauling network is ongoing due to traffic growth. Therefore, mobile synchronization performance requirements should be known.

**DT way:**

Own synchronization testing on one of the most challenging phase synchronization requiring features:

- LTE-A CoMP Joint Processing.

  - Existing JP equipment from EASY-C project has been used.
  - Testing has been made jointly by FMED Bremen, T-Labs Darmstadt, Heinrich-Hertz-Institute Berlin and Jacobs University (former IUB = International University Bremen).
  - The results have confirmed synchronization performance requirements from existing 3GPP contributions and own DT assumptions.
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Thanks

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  Deutsche Telekom, T-Labs Darmstadt
- Samip Malla
  Deutsche Telekom, FMED (internship, master thesis), Jacobs University Bremen (now PhD student)
- Helmut Imlau
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- Uwe Habighorst, DT FMED Bremen
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2. CoMP Joint processing introduction

CoMP = Coordinated Multi-Point Transmission and Reception
=> Feature: Coherent Joint Processing (JP), aka “Network MIMO”

CoMP - Joint Processing
- Transmission and/or reception from/to geographically separated antennas.
- Traffic and control data transfer between eNB via X2 interface (logical interface).

Idea of JP is communication between one user equipment and several eNB sectors at the same time.

Synchronization need:
- Phase/time synchronization to synchronize the radio frames to be sent = Symbol timing
- Frequency synchronization for BBU = Sampling frequency, CPRI frequency
- Frequency synchronization for Radio Head = Carrier Frequency
### 3. Synchronization need of FDD base stations with CoMP Joint Processing

<table>
<thead>
<tr>
<th>Type</th>
<th>1 Phase/time synchronization for Base Band Unit (BBU)</th>
<th>2 Frequency synchronization for Base Band Unit (BBU)</th>
<th>3 Frequency synchronization for Radio Head (RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Needed for</strong></td>
<td>To synchronize the radio frames to be sent in time for Joint Processing</td>
<td><strong>Sampling frequency:</strong> samples the OFDM data sent</td>
<td><strong>For air interface frequency</strong> Avoid inter-carrier interference and phase rotations in inter-cell joint channel matrixes</td>
</tr>
<tr>
<td><strong>Synchronization signal</strong></td>
<td>[1] Two-way time transfer protocol (e.g. PTP); [2] GNSS</td>
<td><strong>Sampling frequency:</strong> 38.4 MHz, CPRI= 1,228GHz</td>
<td><strong>Radio Frequency</strong> e.g. 800MHz, 1.8/2.1/2.6GHz</td>
</tr>
<tr>
<td><strong>Synchronization supply options</strong></td>
<td>[1] 1 pulse-per-second (1pps)</td>
<td><strong>Time Interval Error (TIE), Maximum Time Interval Error, Time Deviation (TDEV)</strong></td>
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</tr>
<tr>
<td><strong>ITU-T Impairment/measurement specification</strong></td>
<td>Time Error: [1] Constant [ns] [2] Noise: Max. Time Interval Error, Time Deviation (TDEV)</td>
<td><strong>Packet methods: Result is measured as frequency deviation in ppb (parts-per-billion) + add. metrics</strong></td>
<td><strong>Packet methods: Result is measured as frequency deviation in ppb (parts-per-billion) + add. metrics</strong></td>
</tr>
<tr>
<td><strong>Impairments acc. to 3GPP</strong></td>
<td>Symbol Timing Offset (STO)</td>
<td>Sampling Frequency Offset (SFO)</td>
<td>Carrier Frequency Offset (CFO)</td>
</tr>
</tbody>
</table>

OFDM = Orthogonal Frequency Division Multiplex, SyncE = Ethernet Physical Layer Synchronization acc. to ITU-T G.8261/2/4
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4. Project EASY-C and DT lab activities

**EASY-C** stands for “Enablers for Ambient Services and sYstems – Part C: Wide Area Coverage”
- multi-vendor and multi-operator R&D project, sponsored by the German government
- focus on base station cooperation (i.e. CoMP)
- field trials show LTE-Advanced Joint Processing running

**Project partners:**

- EASY-C has been chaired by Deutsche Telekom Group together with Vodafone.
- Based on EASY-C results DT internal studies on realization including the needed backhaul synchronization support have been performed.

**DT Synchronization impairment lab test with EASY-C test system:**
- Two weeks joint measurement campaign with 4 co-workers
- 7 test scenarios, 50 test cases, (40 á 5 minutes, 10 long-term)
- DT-FMED: Sync impairments / T-Labs: eNB + UE operation / HHI: UE measurements
- For lab testing: 3 of ≈50 real recorded EASY-C fading scenarios were used
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**EASY-C Berlin field setup**

- HHI has modified real base stations for EASY-C
- External synchronization signals derived from GPS + Rb were used: 1 pps, 38.4 MHz, 2.6 GHz

**Lab test setup**

- Fading scenarios were recorded for dedicated UE positions

- Same base stations
- Same user equipment
- Recorded fading scenarios used
- Sync impairment generation: Offset, Wander

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Throughput data
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Detailed lab test setup

- Reference: Cesium
- 10MHz as basis for frequency and 1pps
- 2*ONT503 & Counter to generate synchronous 1pps
- 10MHz frequency offset & wander generation
- Measurement of modified frequency signals for BBU & RH
- PROP Sim8 Fading channel emulator
- Data via Local Monitoring Terminal (average values every 10ms), Throughput, bit error rate, SNR
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Phase/time synchronization: 1pps Offset only => Symbol Timing Offset (STO)

- Offset greater than OFDM cyclic prefix (4.6 μs) can lead to significant throughput drop
- Results differ between master and slave UE
- Results differ between different fading scenarios (not shown) = depending on position of UE related to serving base stations sectors

1pps time offset generated with JDSU ONT-503 #1 for eNB #1 only.

Results: Cumulative Distribution Function (CDF)
Examples only, results differ depending on different fading scenarios
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Phase/time synchronization: 1pps Offset & wander

1pps time offset and wander generated with JDSU ONT-503 #1 for eNB #1 only.

Results:

- 1pps wander amplitude: For offset and current wander amplitude: 4,6µs budget counts
- 1pps wander frequency: Influence seen, physical background not fully understood, further investigations needed.

Effect of 1PPS offset and wander

Cumulative Distribution Function (CDF)

Examples only, results differ depending on different fading scenarios

Throughput (Mbps)
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1. **Phase synchronization budget calculation for CoMP Joint Processing**

   - **4.6 \( \mu s \)**
     - Length of the Cyclic Prefix (maximum budget)

   - **-1.0 \( \mu s \)**
     - Budget for multi path propagation decay time

   - **-1.0 \( \mu s \)**
     - Budget for time error related to ISD 780m ± 500 ns

   With max. time error ±500ns the remaining max. delay difference is 2,6\( \mu s \) => max. ISD for JP is 780m

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**Explanations:**

- **ISD = Inter Site Distance**
- **STO = Symbol Timing Offset**

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*) As presented at WSTS2011, see reference [1]
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Frequency synchronization for Base Band Unit (BBU) => Sampling Frequency Offset (SFO)

Results:

- Same wander frequency, different amplitude

Cumulative Distribution Function (CDF)

Examples only, results differ depending on different fading scenarios
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Frequency synchronization for Base Band Unit (BBU) => Sampling Frequency Offset (SFO)

- Higher wander amplitude => higher system performance degradation
- Figure right shows: Throughput degradation really follows the wander => Sinus wave wander phase ≈ 0 leads to maximum throughput

- Summary for SFO: Less impact compared to 1pps impairment (STO)
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Frequency synchronization for Base Band Unit (BBU) => Sampling Frequency Offset (SFO)

Constellation diagrams showing decision points with:
- 64 sub-carrier and SFO=0/200/600ppm
- 512 sub-carrier and SFO=600ppm

- SFO leads to amplitude and phase distortion of sub-carriers and induces additional Inter-Carrier-Interference (ICI).
- High clock offset leads to high distortion
- Influence depends on number of sub-carriers ↑ => Bit Error Rate ↑

- Very high frequency offset needed to degrade the signal
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Frequency synchronization BBU & Radio Head (RH): Offset only

- More realistic impairment scenario chosen: BBU + RH
- Significant degradation of CoMP performance even at low frequency offset – most significant effects to be identified.
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Results:

- Frequency synchronization BBU & Radio Head (RH): Wander only => Carrier Frequency Offset (CFO)

The sinus wave wander is generated with certain peak-to-peak value and frequency.

- It leads to sinus wave frequency offset ranges, e.g.: $100 \text{ ns} (p-p) \cdot 2 \cdot \pi \cdot 0.01 \text{Hz}$
  
  $= +/\mbox{-}6.3 \text{ ppb}$

which reduces throughput significantly.

Different results for different fading scenarios.

Different results for different fading scenarios.
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Influence of radio frequency (e.g. 800MHz / 1.8GHz / 2.1GHz / 2.6GHz):

- Inter-carrier Interference (ICI) is related to carrier spacing (15 kHz for LTE) and therefore leading to more challenging requirements at higher transmit frequencies.
- Phase rotations within the channel matrix which increases with higher frequency offset relative to transmit frequency.

Effect of CFO can be compensated by channel estimation methods:

- An iterative joint estimation based on Newton-Rhapson method for frequency offset and channel estimation algorithm is proposed.


![Diagram showing channel estimation error for known pilots](chart.png)
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Summary

For performance specification:

- As criteria for max. synchronization impairments => Need to decide for a dedicated throughput degradation or bit error rate value (e.g. 10%)
- Recommendation to specify test fading scenarios for a 3GPP based test bed

1. Phase synchronization impairment for BBU => Symbol Timing Offset (STO)
   - Phase synchronization budget based on CP length 4,6μs with the result: Max. time error < ±500ns for an inter cell distance of 780 m can be used. Related 3GPP contribution [3] can be confirmed.
   - Wander should be considered in addition.

2. Frequency synchronization impairment for BBU => Sampling Frequency Offset (SFO)
   - Less critical for Joint Processing

3. Frequency synchronization impairment for RH => Carrier Frequency Offset (CFO)
   - Critical Joint Processing performance degradation seen
   - Can be reduced via joint channel estimation
   - Max. frequency offset ±5ppb acc. to 3GPP contributions [3] may be sufficient, depending on channel estimation method.
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Thank you for your attention!

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Impact of Synchronization Impairments on LTE-A CoMP Joint Transmission Performance

List of references


[3] 3GPP TSG-RAN WG1 #58bis, R1-094231, (dito. R1-093138, R1-092722, R1-092072), Source Qualcomm Europe: Time synchronization requirements for different LTE-A techniques


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Backup
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**Scenario 1a: Frequency offset for reference of BBU and RH (23u-Slave)**

- **No Impairment**
- 0.2ppb
- 0.5ppb
- 1ppb
- 3ppb

**Results:**

Example: Throughput (in green, right y-axis) follows wander (in blue, green y-axis)
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Time/Phase Synchronization Requirements for LTE-Advanced Wireless Systems including CoMP

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Helmut Imlau, Heinz Droste: Time/Phase Synchronization for LTE-Advanced systems including CoMP, Presentation at WSTS 2011, Broomfield (CO, USA), May 2011.

Time/Phase Synchronization Requirements for LTE Advanced Wireless Systems including CoMP

CoMP time/phase synchronization requirements (4/9)

- In that case the path difference $\Delta_{\text{delay}}$ in the range of the Inter-Site Distance (ISD) and the propagation delay difference $\Delta_{\text{prop}}$ can be calculated with the following formula:

$$
\Delta_{\text{delay}} = \frac{\Delta_{\text{prop}}}{c} = \frac{\text{ISD}}{c}
$$

where $c$ is the speed of light.

- A 3.6 $\mu$s budget leads to maximum Inter-Site Distance (ISD) of 1,300 m.

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Time/Phase Synchronization Requirements for LTE Advanced Wireless Systems including CoMP

CoMP time/phase synchronization requirements (6/9)

- Let us assume a time error up to $\pm 1.5 \mu$s.

<table>
<thead>
<tr>
<th>Time Error</th>
<th>Path Difference</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 $\mu$s</td>
<td>0.1 $\mu$s</td>
<td>1000 m</td>
</tr>
<tr>
<td>0.5 $\mu$s</td>
<td>0.5 $\mu$s</td>
<td>500 m</td>
</tr>
<tr>
<td>1.0 $\mu$s</td>
<td>1.0 $\mu$s</td>
<td>0 m</td>
</tr>
<tr>
<td>1.5 $\mu$s</td>
<td>1.5 $\mu$s</td>
<td>0 m</td>
</tr>
</tbody>
</table>

- The following pages show that 780 m Inter-Site Distance is a good planning guide for efficient CoMP - Joint Processing. Up to $\pm 3.0$ $\mu$s can be used as accuracy requirement for CoMP Joint Processing.

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End