Impact of Synchronization Impairments on CoMP Joint Transmission Performance

Deutsche Telekom @ ITSF2012

Helmut Imlau DT, FMED
Heinz Droste DT, T-Labs
Samip Malla DT, FMED /Jacobs Uni Bremen

Life's for Sharing

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

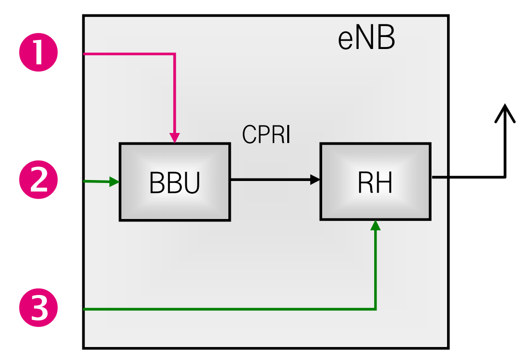
Agenda

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)



Simplified base station model with external synchronization supply

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

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

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.

<u>DT way:</u>

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

This presentation is made jointly by

- Heinz Droste
  Deutsche Telekom, T-Labs Darmstadt
- Samip Malla
  Deutsche Telekom, FMED (internship, master thesis), Jacobs University Bremen (now PhD student)
- Helmut Imlau
  Deutsche Telekom, FMED

Our special thanks go to:

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- Dr. Jon Wallace, Jacobs University Bremen
- Wolfgang Kreher and Jürgen Mueller, DT T-Labs Darmstadt
- 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"

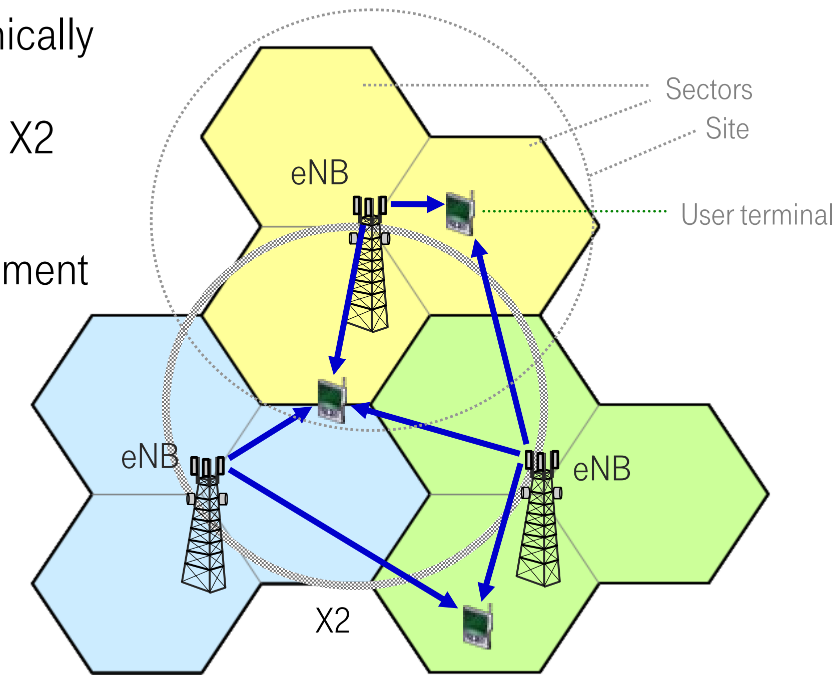
CoMP - Joint Processing

- 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



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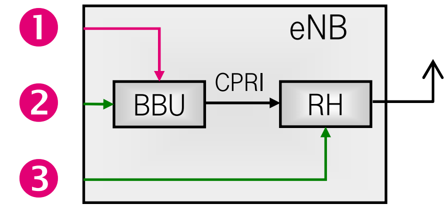
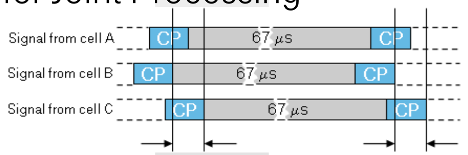
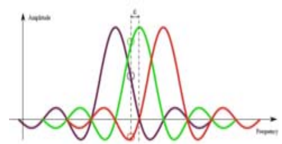


3. Synchronization need of FDD base stations with CoMP Joint Processing

Type	1 Phase/time synchronization for Base Band Unit (BBU)	2 Frequency synchronization for Base Band Unit (BBU)	3 Frequency synchronization for Radio Head (RH)
Needed for	To synchronize the radio frames to be sent in time for Joint Processing 	▪ Sampling frequency: samples the OFDM data sent ▪ Basis for CPRI interface clock ▪ Chip rate	For air interface frequency Avoid inter-carrier interference and phase rotations in inter-cell joint channel matrixes 
Synchronization signal	1 pulse-per-second (1pps)	Sampling frequency: 38,4 MHz, CPRI= 1,228GHz	Radio Frequency e.g. 800MHz, 1,8/2,1/2,6GHz
Synchronization supply options	[1] Two-way time transfer protocol (e. g. PTP); [2] GNSS	2048kHz or 10MHz via [1] Physical layer sync: SyncE, E1, SDH; [2] Packet layer: ITU-T Frequency profile for PTP; [3] GNSS	
ITU-T Impairment/ measurement specification	Time Error: [1] Constant [ns] [2] Noise: Max. Time Interval Error, Time Deviation (TDEV)	Time Interval Error (TIE), Maximum Time Interval Error, Time Deviation (TDEV); Packet methods: Result is measured as frequency deviation in ppb (parts-per-billion) + add. metrics	
Impairments acc. to 3GPP	Symbol Timing Offset (STO)	Sampling Frequency Offset (SFO)	Carrier Frequency Offset (CFO)

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

UE = User Equipment

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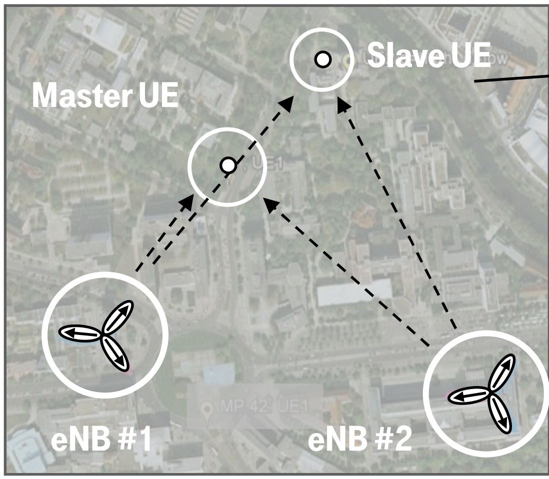
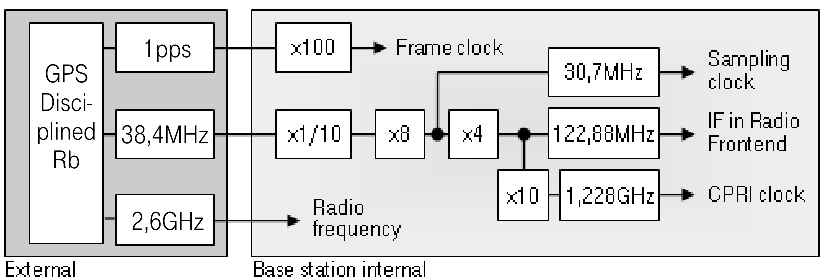
EASY-C Berlin field setup



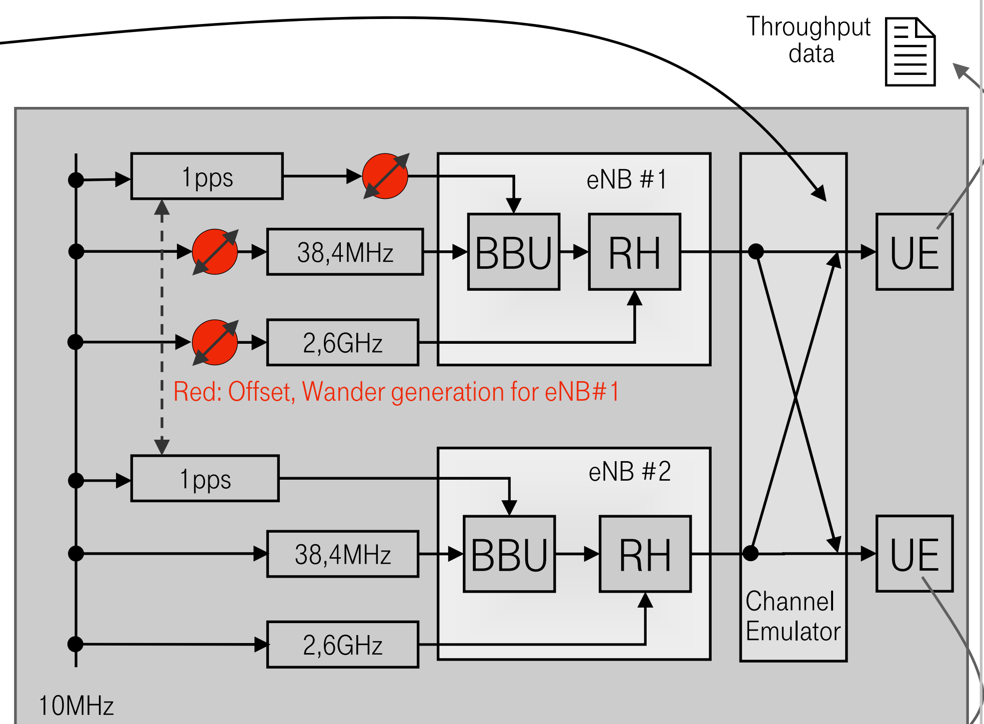
Fading Scenarios

- Fading scenarios were recorded for dedicated UE positions



- HHI has modified real base stations for EASY-C
- External synchronization signals derived from GPS + Rb were used: 1pps, 38,4MHz, 2,6GHz

Lab test setup



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

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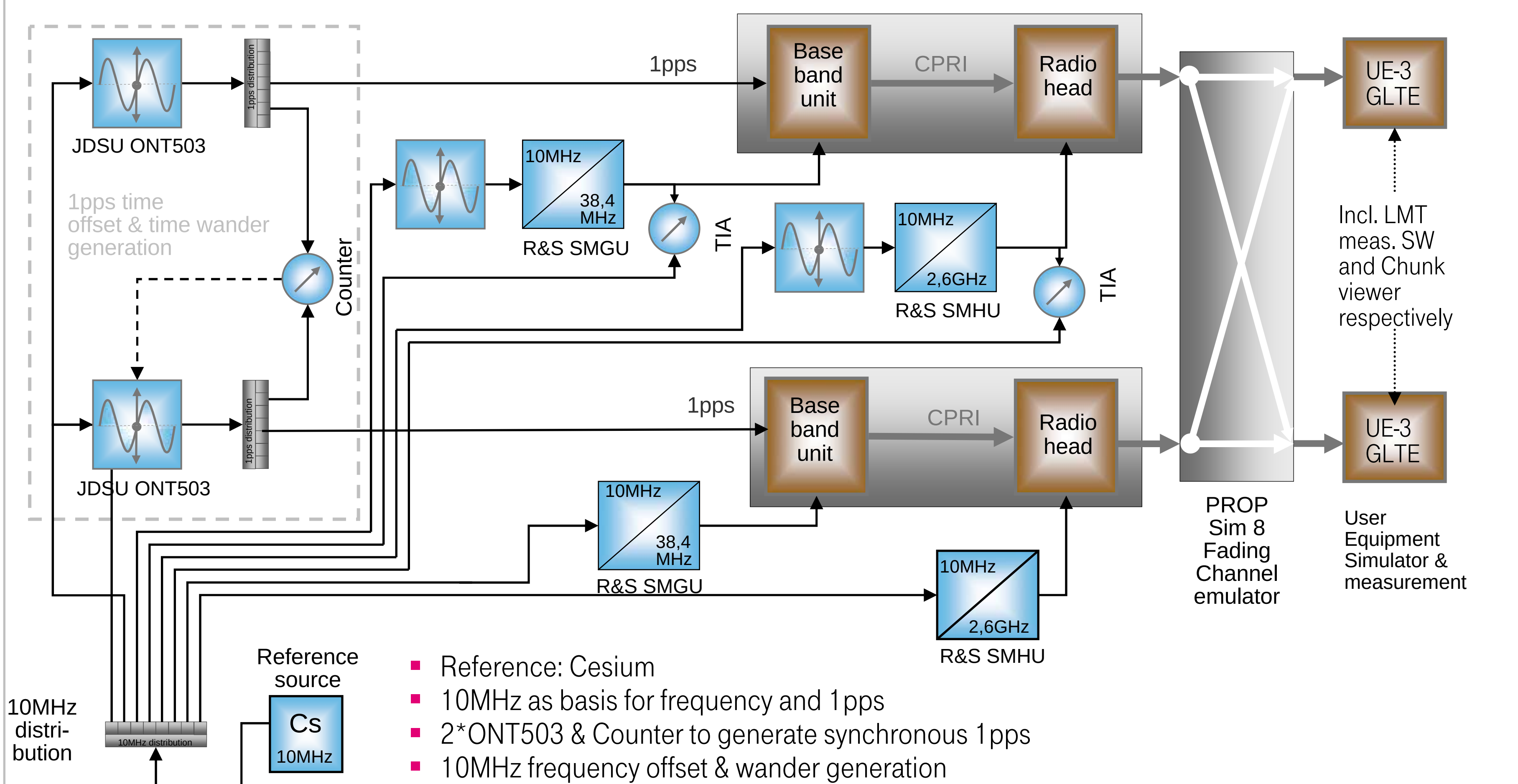
Detailed lab test setup



- 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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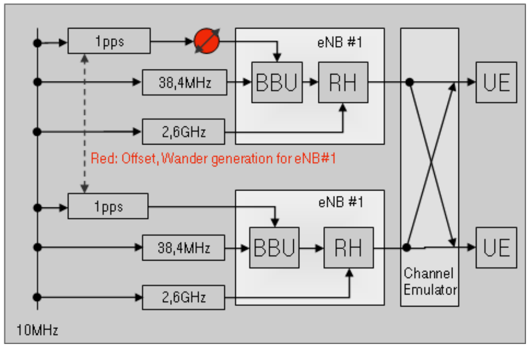
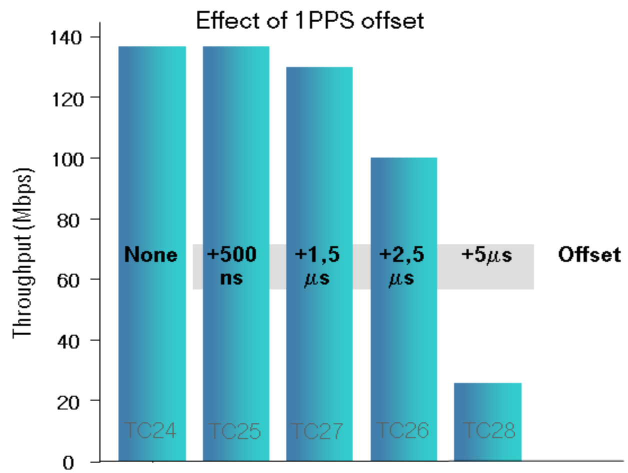
❶ Phase/time synchronization: 1pps Offset only => Symbol Timing Offset (STO)

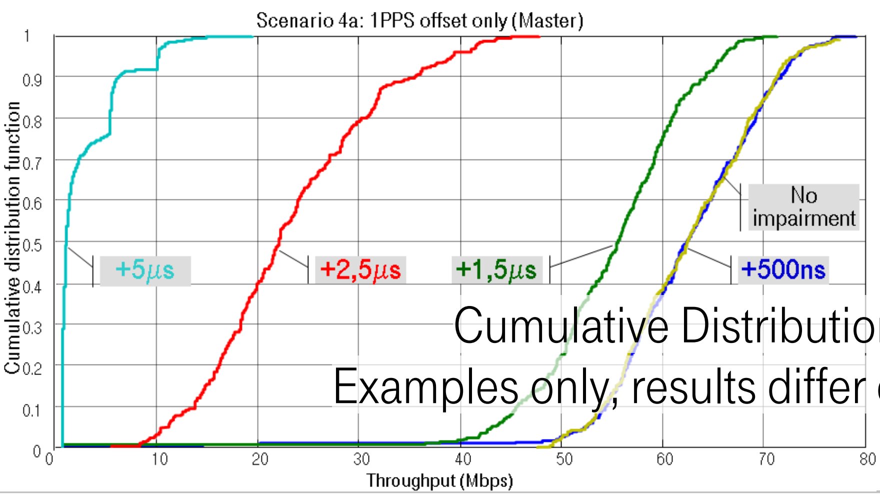
Results:

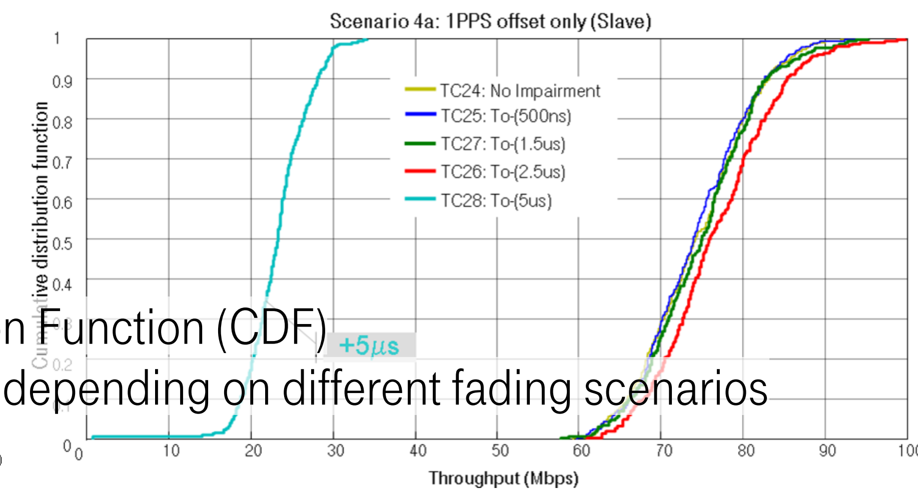


1pps time offset generated with JDSU ONT-503 #1 for eNB #1 only.



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





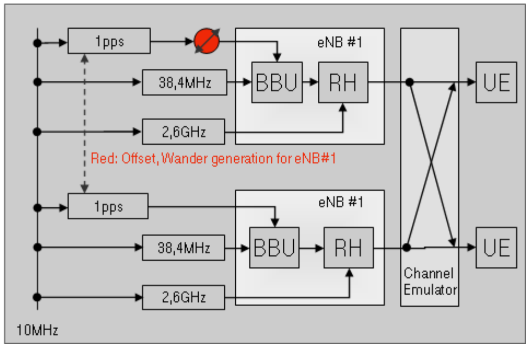
Cumulative Distribution Function (CDF)

Examples only, results differ depending on different fading scenarios

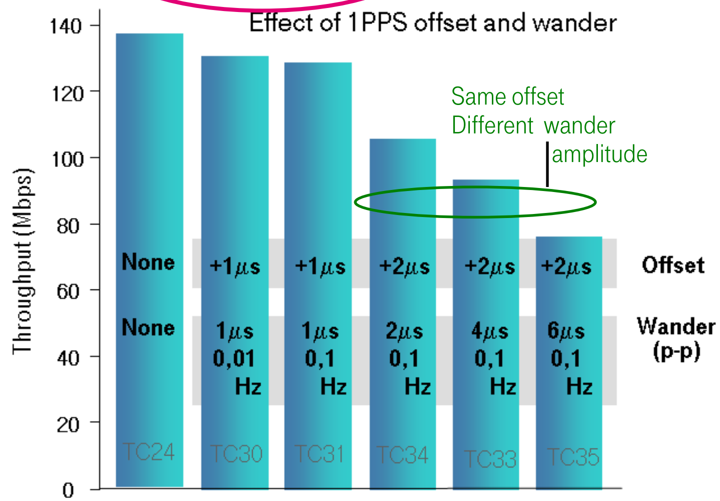
Impact of Synchronization Impairments on LTE-A CoMP Joint Transmission Performance

Results:

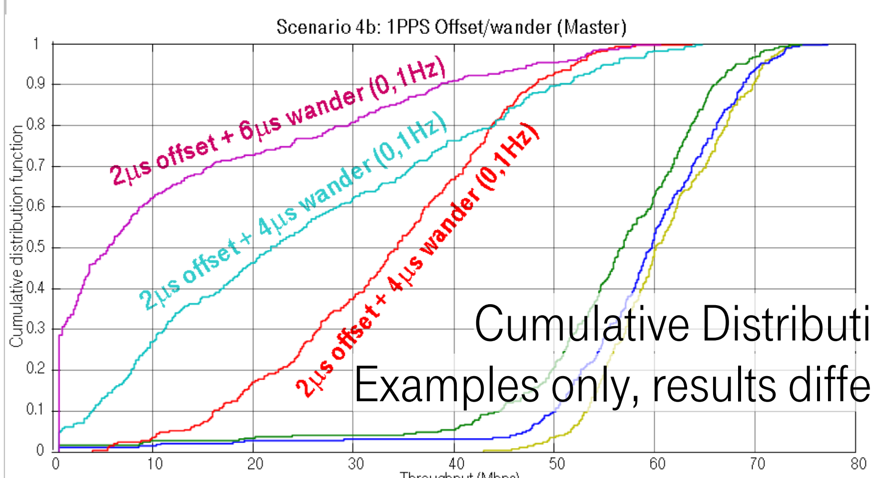
➊ Phase/time synchronization: 1pps Offset & wander => Symbol Timing Offset (STO)

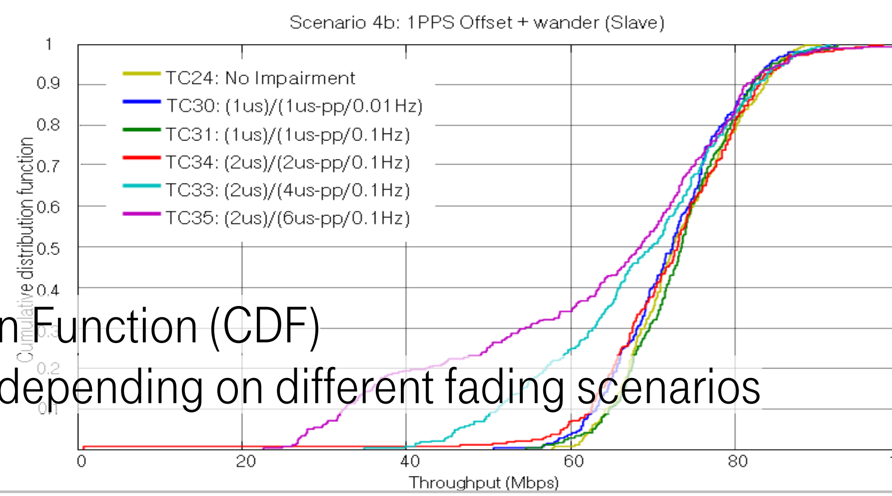


1pps time offset and wander generated with JDSU ONT-503 #1 for eNB #1 only.



- 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.





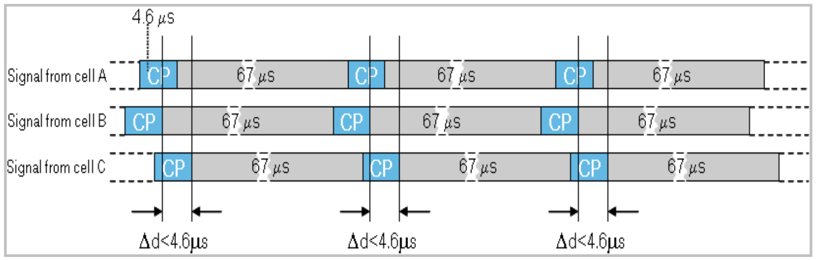
Cumulative Distribution Function (CDF)

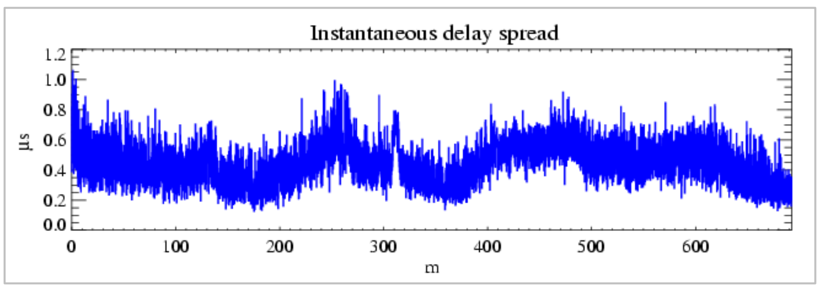
Examples only, results differ depending on different fading scenarios

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

➊ Phase synchronization budget calculation for CoMP Joint Processing*) => Symbol Timing Offset (STO)

Explanations:





Frame time error	Remaining budget	Max. Inter-site-distance for CoMP	Inter-site distance decrease
± 0 µs	3.6µs	1080 m	0 %
± 0.2µs	3.2µs	960 m	-11%
± 0.5µs	2.6µs	780 m	-28%
± 1.0µs	1.6µs	480 m	-56%
± 1.5µs	0.6µs	180 m	-83%

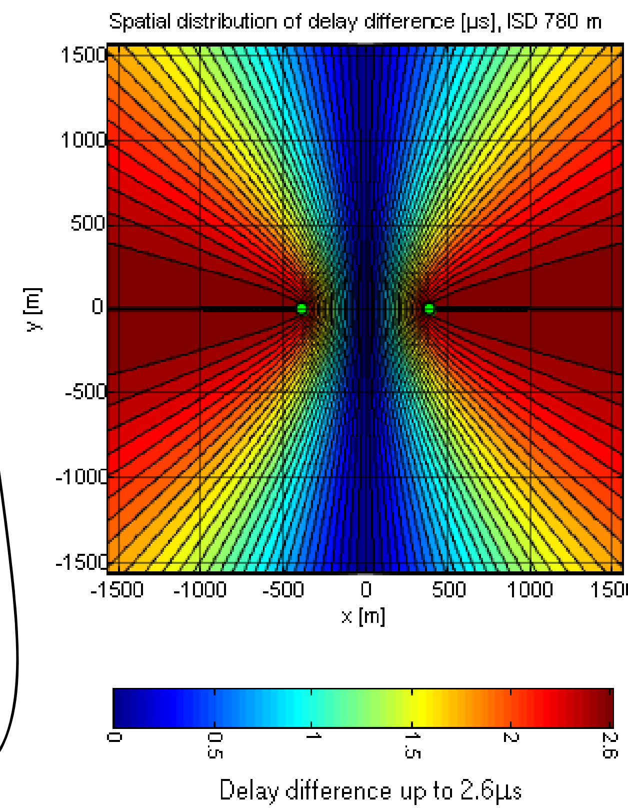
4.6 µs
= Length of the Cyclic Prefix (maximum budget)

- 1.0 µs
= Budget for multi path propagation decay time

– 1.0 µs
= Budget for time error related to ISD 780m ± 500 ns

=2.6 µs

With max. time error ±500ns the remaining max. delay difference is 2,6µs => max. ISD for JP is 780m

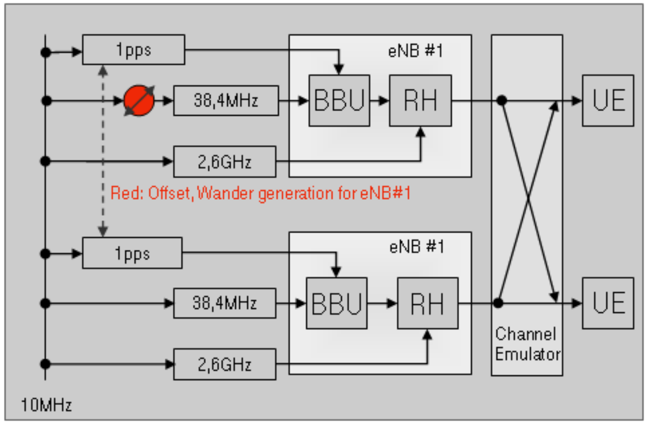


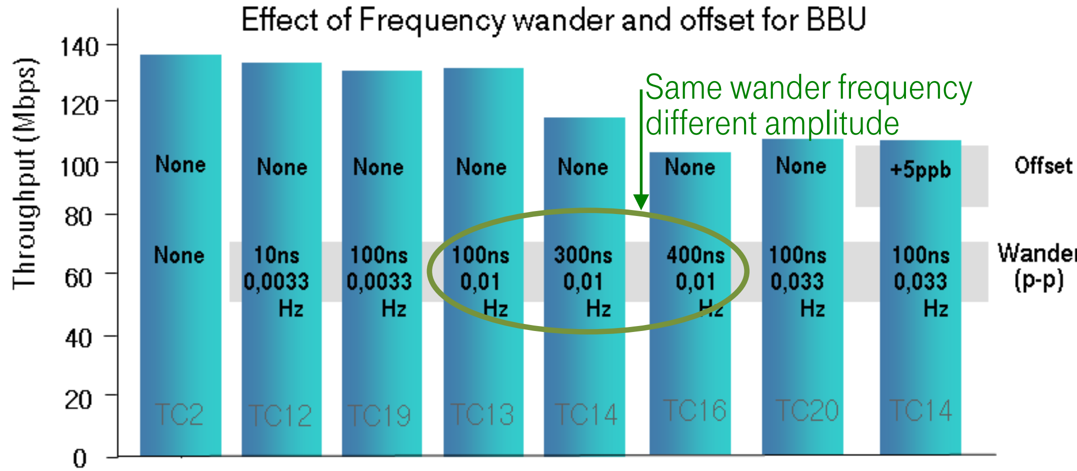
*) As presented at WSTS2011, see reference [1]   ISD = Inter Site Distance

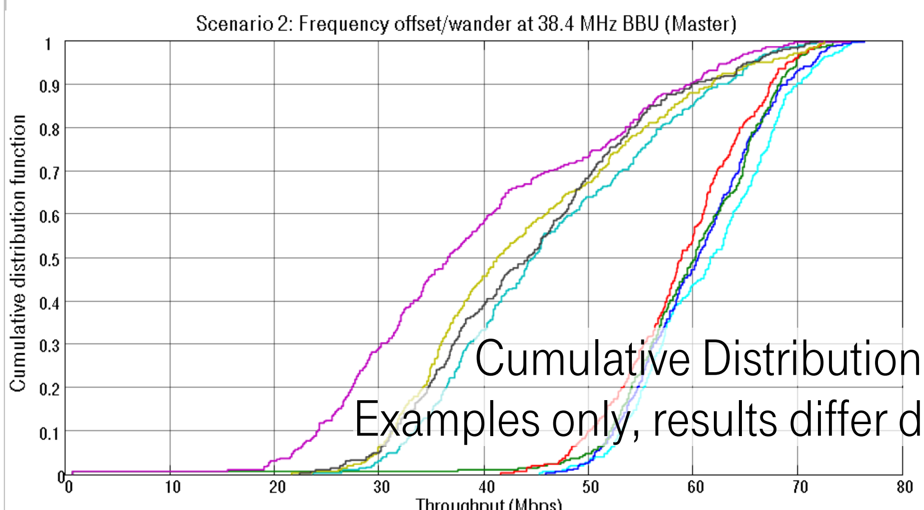
Impact of Synchronization Impairments on LTE-A CoMP Joint Transmission Performance

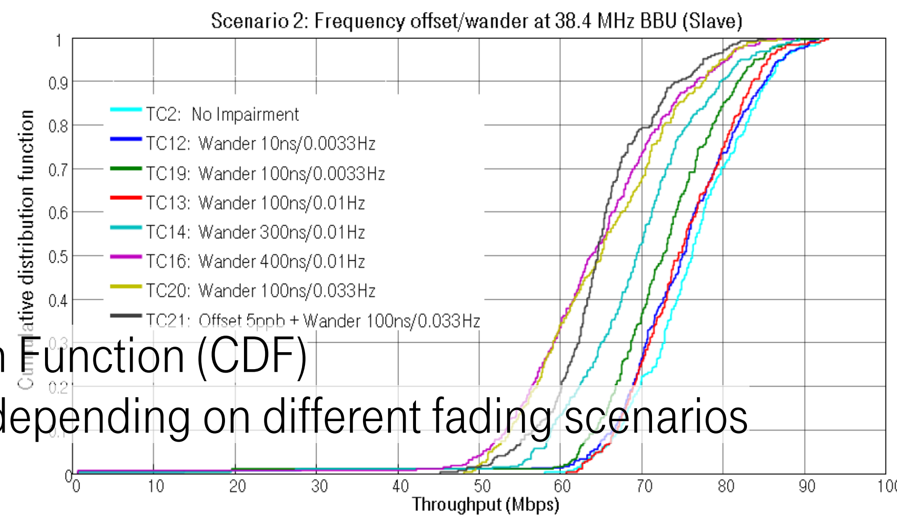
Results:

❷ Frequency synchronization for Base Band Unit (BBU) => Sampling Frequency Offset (SFO)









Cumulative Distribution Function (CDF)

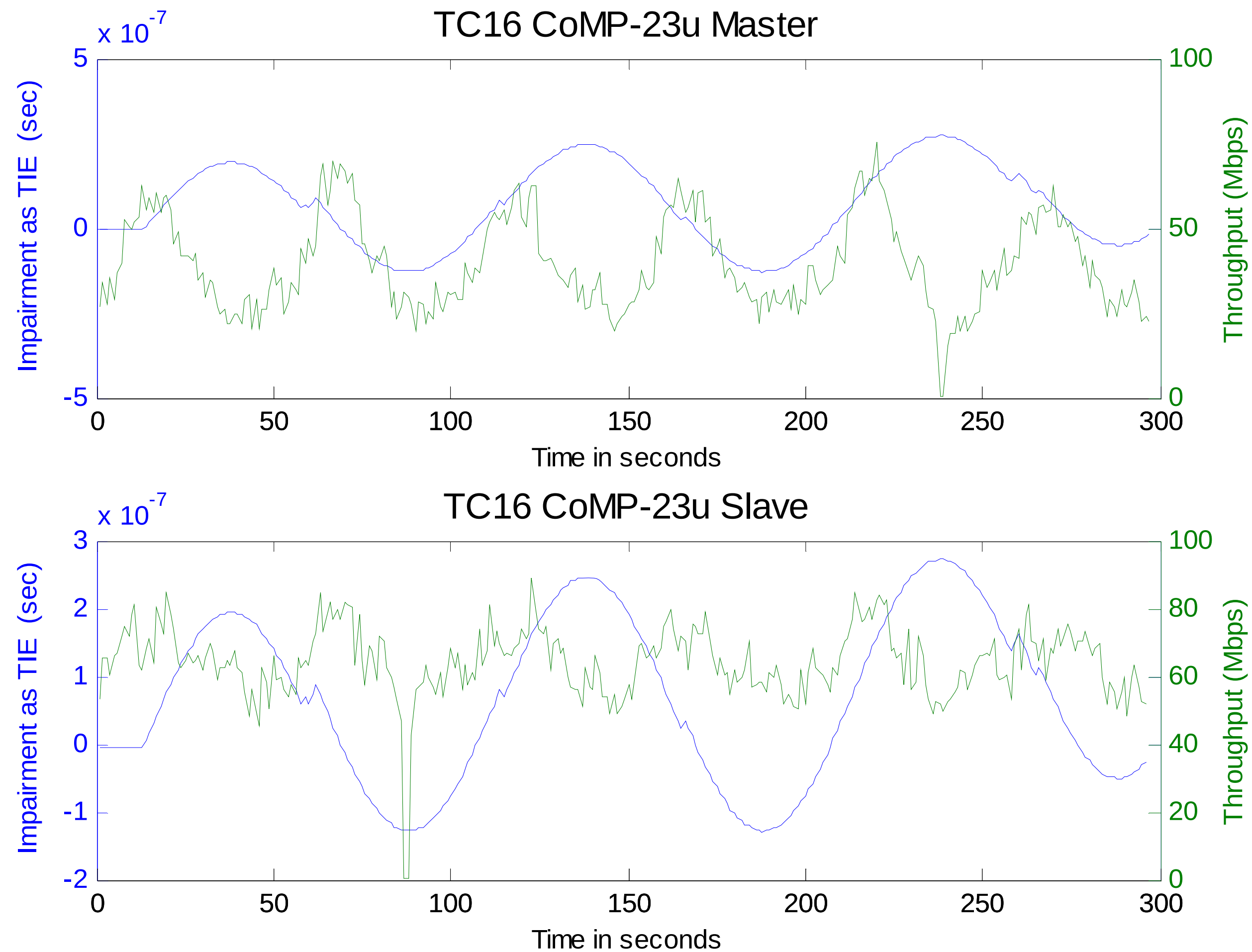
Examples only, results differ depending on different fading scenarios

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

❷ Frequency synchronization for Base Band Unit (BBU) => Sampling Frequency Offset (SFO)

Results:

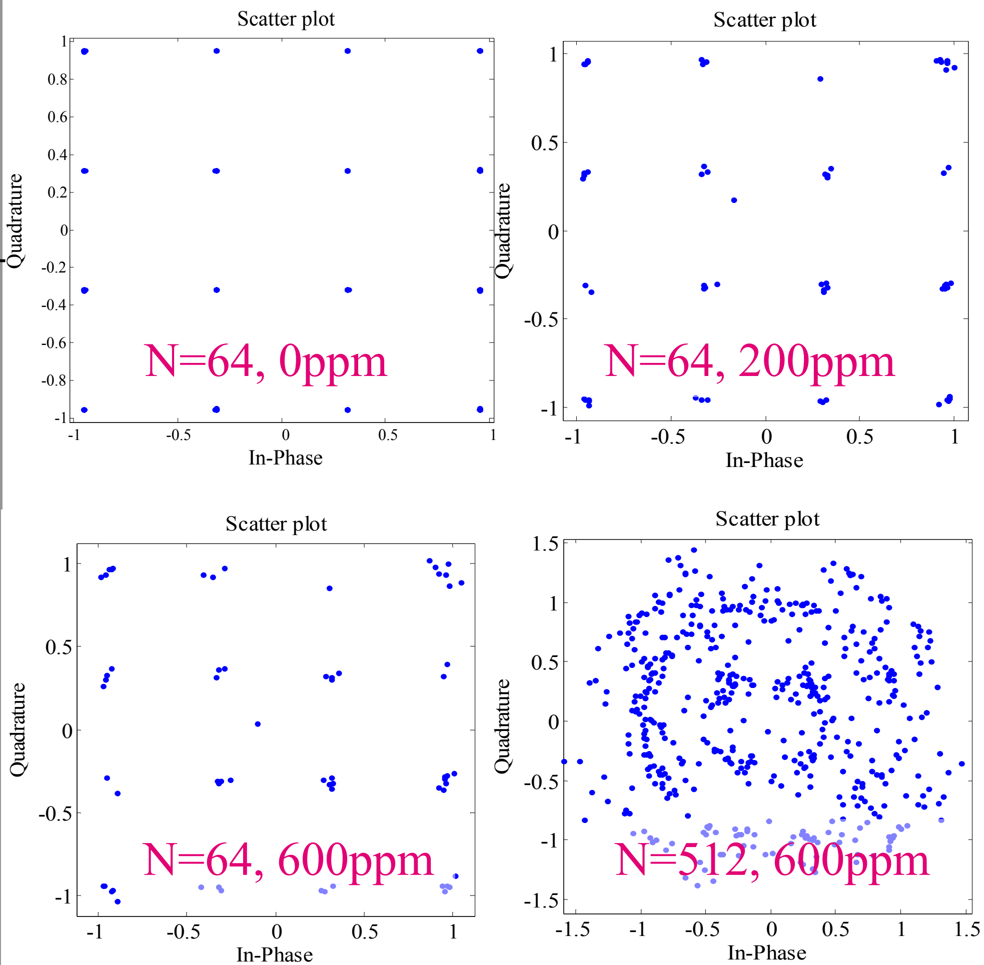
- Higher wander amplitude => higher system performance degradation
- Figure right shows: Throughput degradation really follows the wander => Sinus wave wander phase ≈0 leads to maximum throughput
- <u>Summary for SFO:</u> Less impact compared to 1pps impairment (STO)



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

❷ Frequency synchronization for Base Band Unit (BBU) => Sampling Frequency Offset (SFO)

Explanations:



Constellation diagrams showing decision points with

- 64 sub carrier and SFO=0/200/600ppm
- 512 subcarrier and SFO =600ppm

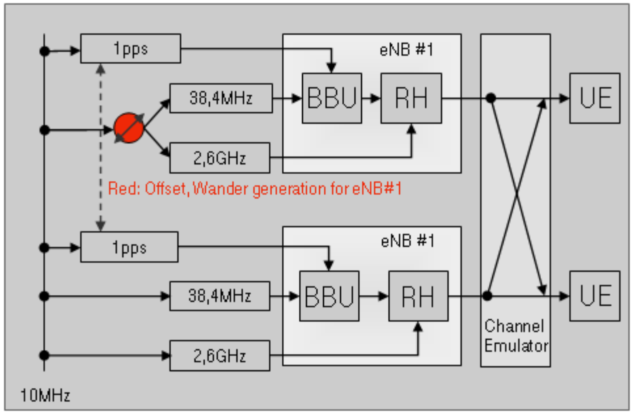
- SFO leads to amplitude and phase distortion of sub-carriers and induces additional Inter-Carrier-Interference (ICI).
- High clock offset leads to high distortion
- Influence depends on number of sub-carriers ↑ => Bit Error Rate ↑

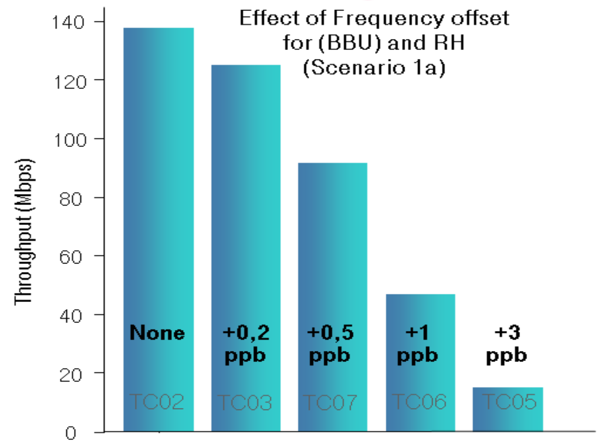
- Very high frequency offset needed to degrade the signal

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

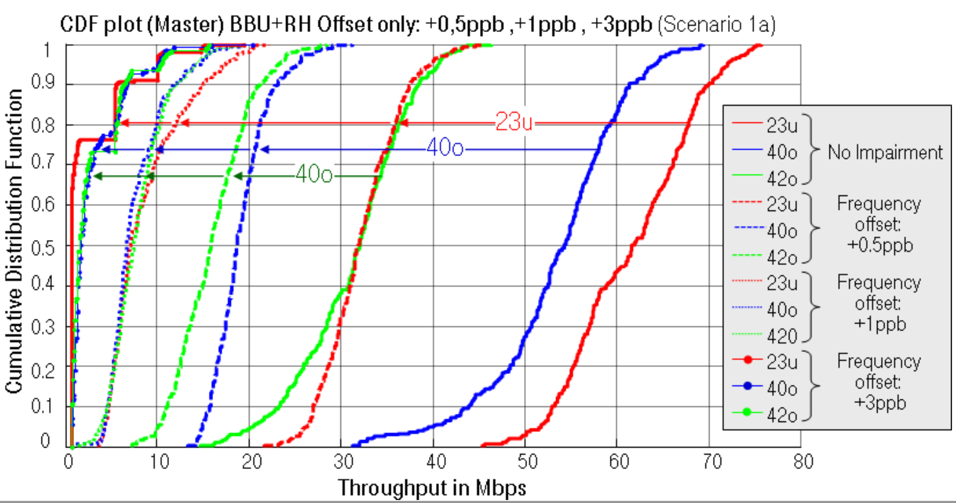
❸ Frequency synchronization BBU & Radio Head (RH): Offset only => Carrier Frequency Offset (CFO)

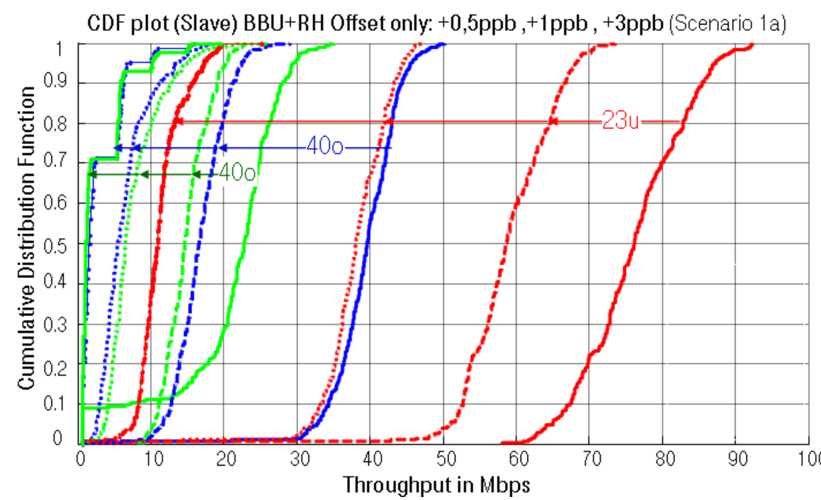
Results:





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

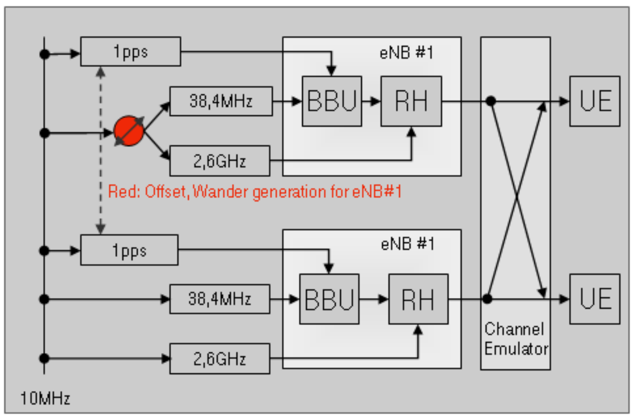


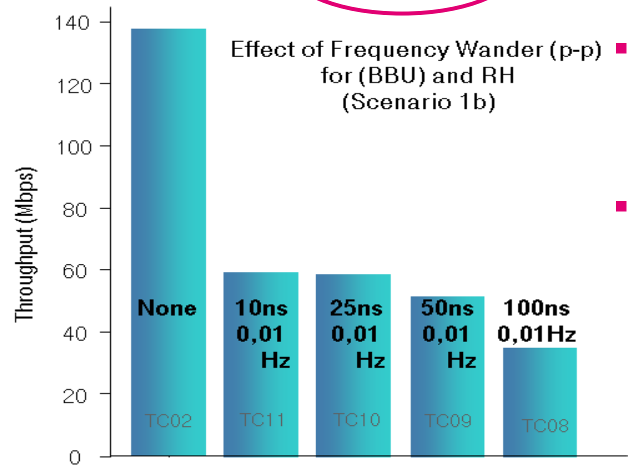


Impact of Synchronization Impairments on LTE-A CoMP Joint Transmission Performance

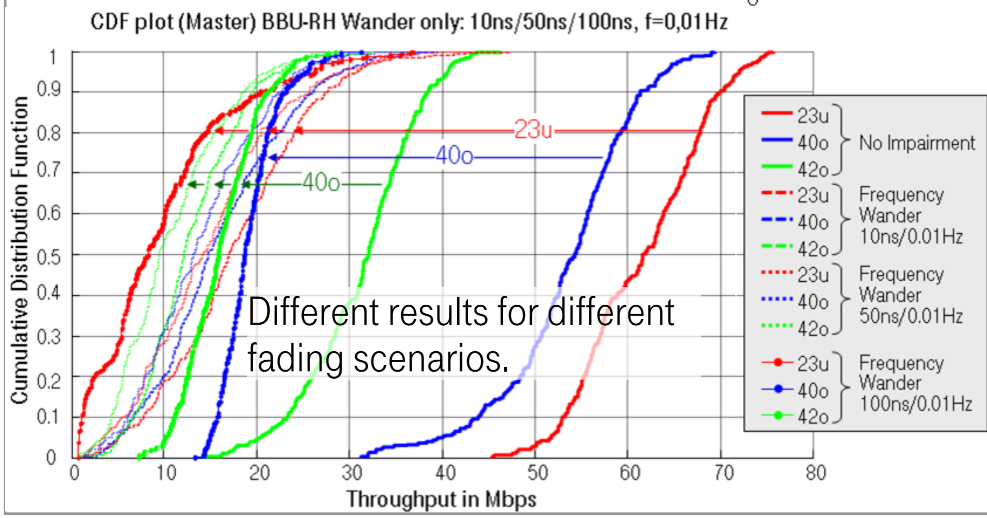
❸ Frequency synchronization BBU & Radio Head (RH): Wander only => Carrier Frequency Offset (CFO)

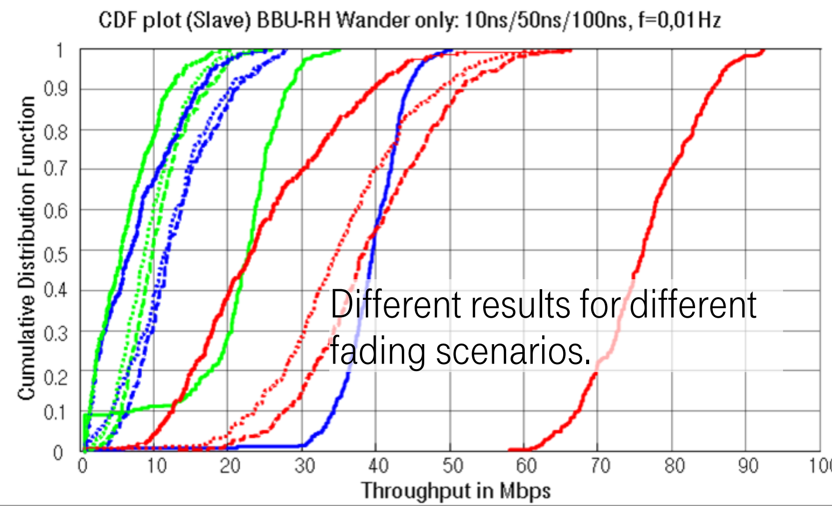
Results:





- 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 ns(p-p) · 2·π·0.01Hz = +/-6,3 ppb which reduces throughput significantly.





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

❸ Frequency synchronization BBU & Radio Head (RH) => Carrier Frequency Offset (CFO)

Explanations:

Influence of radio frequency (e. g. 800MHz / 1,8GHz / 2,1GHz / 2,6GHz):

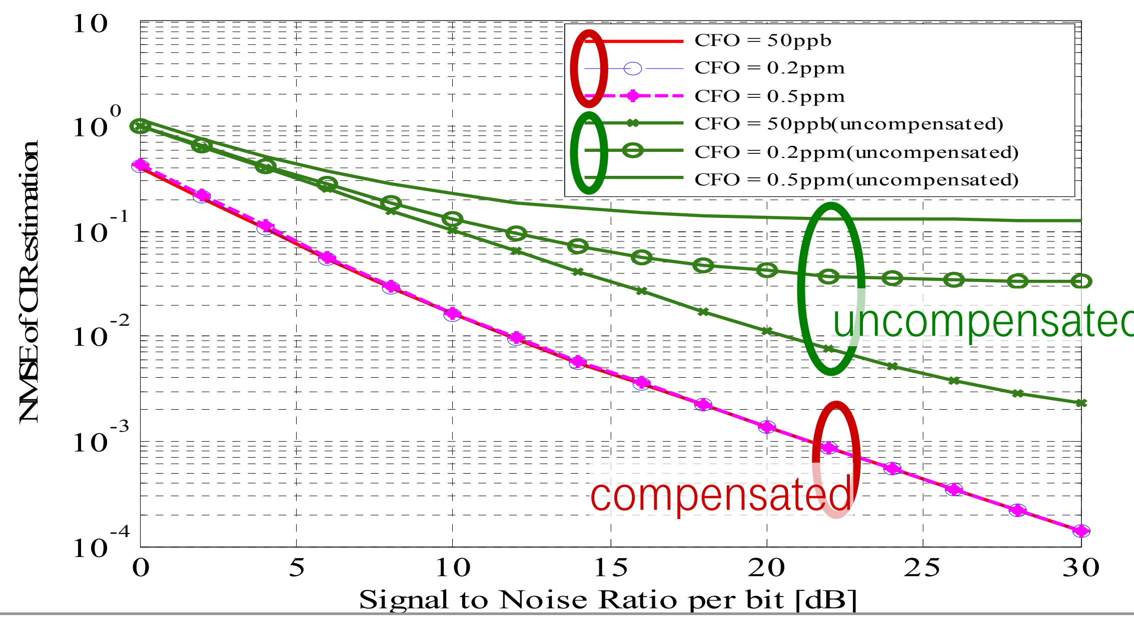
- Inter-carrier Interference (ICI) is related to carrier spacing (15 kHz for LTE) and therefore leading to more challenging requirements at higher transmit frequencies
- Phase rotations within the channel matrix which increases with higher frequency offset relative to transmit frequency.

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.

Samip Malla, Jacobs University Bremen, Master thesis with Deutsche Telekom: OFDM Synchronization in Single-Antenna, MIMO and Multi-User Wireless Systems, Bremen 08-2012 [2]

Channel estimation error for known pilots



NMSE= Normalized Mean Squared Error , CIR= Channel Impulse Response

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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

❶ 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 a inter cell distance of 780 m can be used. Related 3GPP contribution [3] can be confirmed.
- Wander should be considered in addition.

❷ Frequency synchronization impairment for BBU => Sampling Frequency Offset (SFO)

- Less critical for Joint Processing

❸ 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!

Helmut Imlau	Heinrich Droste	Samip Malla
mailto: helmut.imlau@telekom.de	mailto: heinz.droste@telekom.de	mailto: samipmalla@hotmail.com

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List of references

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Backup

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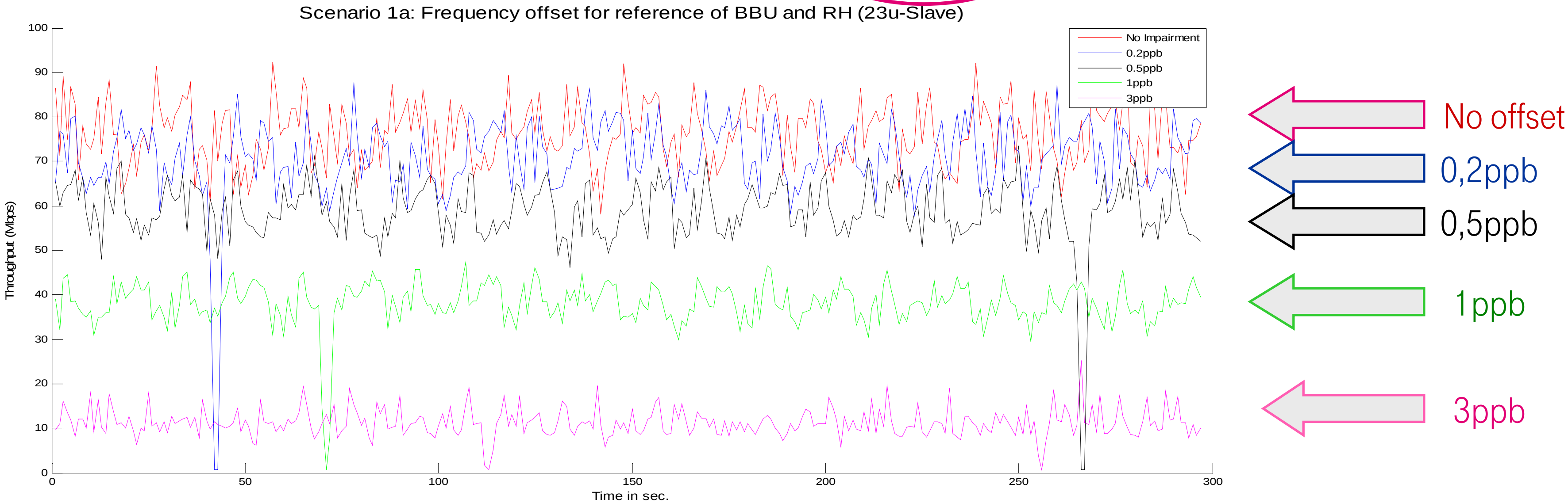
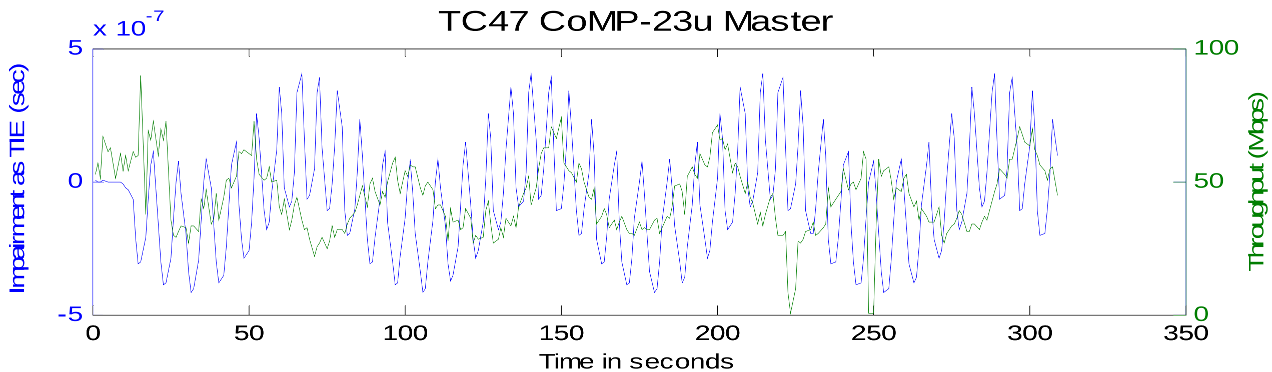
❸ Frequency synchronization BBU & Radio Head (RH): Examples => Carrier Frequency Offset (CFO)

Results:

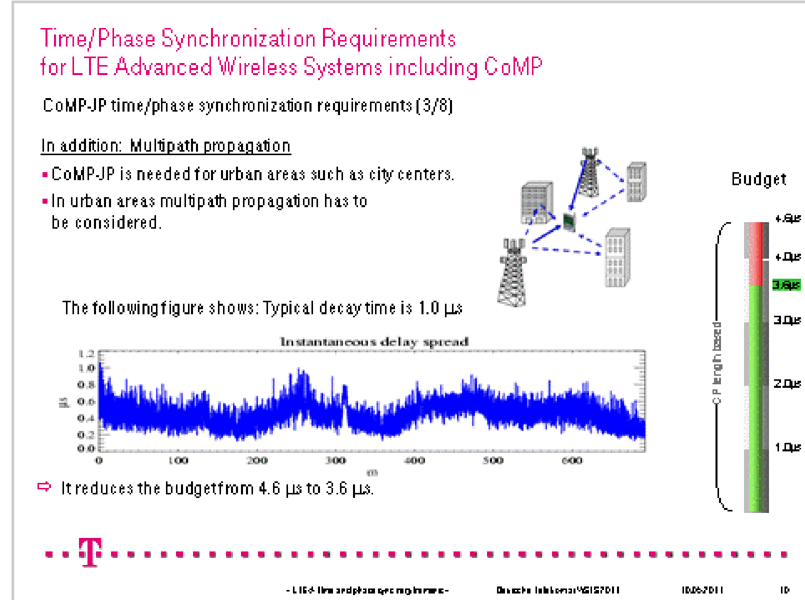


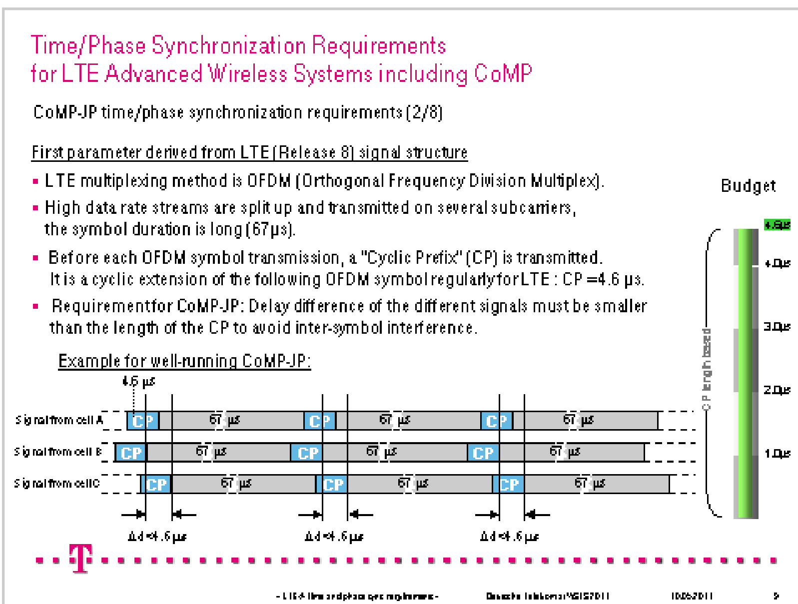
Frequency wander

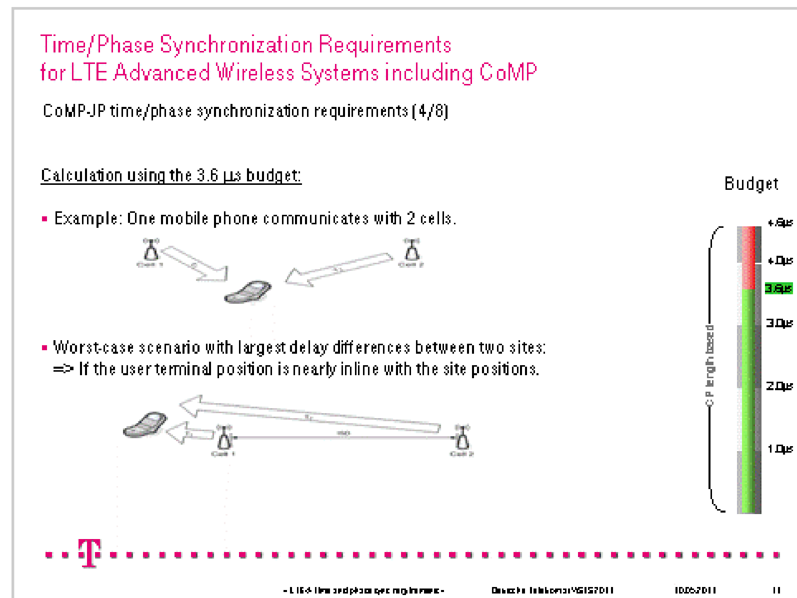


Example: Throughput (in green, right y-axis) follows wander (in blue, green y-axis)

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







[1] 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-JP time/phase synchronization requirements (5/8)

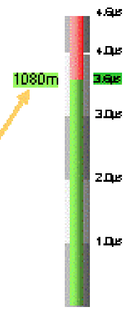
- In that case the path difference Δs_{max} is in the range of the Inter-Site Distance (ISD) and the propagation delay difference $\Delta\tau_{max}$ can be calculated with the following formula:

$$\Delta\tau_{max} = \frac{\Delta s_{max}}{c} \approx \frac{ISD}{c}$$

where c is speed of light

- A 3.6 µs budget leads to maximum Inter-Site-Distance (ISD) of 1080 m.

$$ISD_{max} = \Delta\tau_{max} * c$$
$$ISD_{max} = 3.6\mu s * 300000\frac{km}{s}$$
$$ISD_{max} = 1080m$$



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

Summary

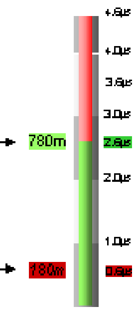
To operate CoMP Joint Processing the following time budget calculation can be used:

4.6 µs = Length of the Cyclic Prefix = maximum budget
- 1.0 µs = Budget for multi path propagation decay time
- 1.0 µs = Budget for time error ± 500 ns

=2.6 µs

2.6 µs is related to maximum Inter-Site Distance of 780 m. → 780m

For comparison: With a time error of ± 1.5 µs (TDD requirement) the maximum ISD for CoMP JP would be 180 m. → 180m



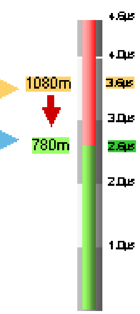
Time/Phase Synchronization Requirements for LTE Advanced Wireless Systems including CoMP

CoMP-JP time/phase synchronization requirements (6/8)

But, all calculations up to now where based on perfect time synchronization, no time error at all.

- Let us assume a frame time error up to ± 1.5 µs

Frame time error	Remaining budget	Max. Inter-site-distance for CoMP	Inter-site distance decrease
±0 µs	3.6µs	1080 m	0 %
±0.2 µs	3.2µs	960 m	-11%
±0.5 µs	2.6µs	780 m	-28%
±1.0 µs	1.6µs	480 m	-56%
±1.5 µs	0.6µs	180 m	-83%



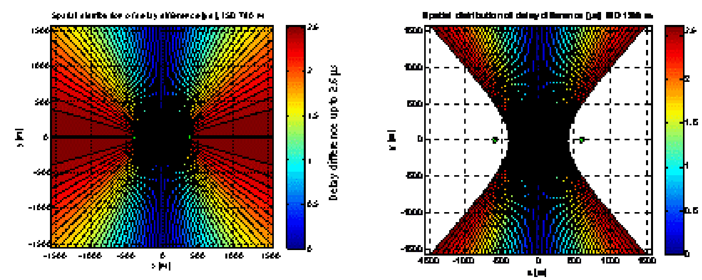
- The following pages show, that 780 m Inter-Site Distance is a good planning value for potential CoMP – Joint Processing areas, so ± 500 ns can be used as accuracy requirement for CoMP Joint Processing.

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

Impact of cooperation cluster size on propagation delay differences (1/2)

Impact of cooperation cluster size on propagation delay differences of direct path components.

- Maximum delay differences arising at any geographical locations near 2 base station sites.
- At 780 m no violations of the effective cyclic prefix occurs.
- At 1200 m inter-site distance cyclic prefix violations can only be avoided in the colored region.



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