Telecom Requirements for Time and Frequency Synchronization

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Outline

- Evolution of Sync
  - SONET/SDH
  - Packet-based networks
- Mobile Standards and Sync
- LTE-Advanced
- E911
- Conclusions

Excerpts from WSTS

- The NIST-ATIS-Telcordia Workshop on Synchronization in Telecom Systems
  - Occurs annually since 1992
  - Much of the content here is directly reproduced from WSTS talks given by experts in their field
- WSTS and its European sister ITSF represent a global alliance of pre-eminent experts in synchronization for telecom and related applications. Many of these experts act as steering group members for both conferences, as well as sit on various standards bodies including ITU, ATIS and IETF.

Evolution of Telecom Sync

- Formerly, the network was “synchronous” (really syntonous!)
  - Data transport required same frequency distributed through different quality of clocks call strata
  - The same bandwidth was used for data transport between nodes, independent of traffic
- The network has evolved to have an asynchronous, or packet, core, with access technologies such as wireless cell networks at the edge
  - Packet data does not require syntonization, and uses scalable bandwidth
  - Syntonization and now true synchronization is now required for services and apps at the edge of the network and for users

Telecom Receivers are Generally Stationary, Used for Time and Frequency Only

Example of NIST receiver is similar

SONET/SDH Systems

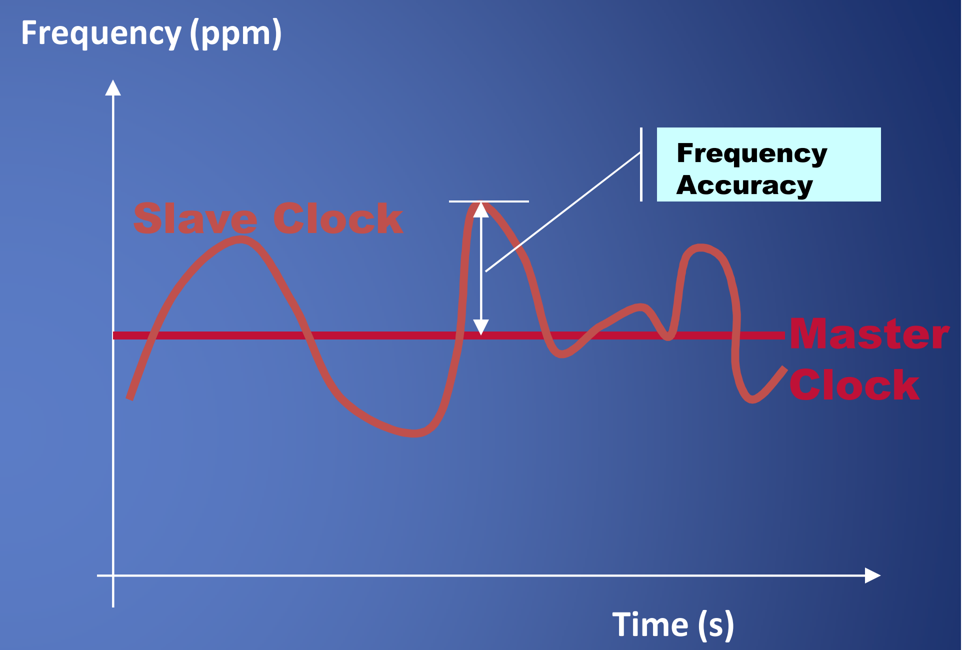
- Synchronous Optical NETwork developed and deployed in the US and Canada in the 80's and 90's
- Synchronous Digital Hierarchy generalizes SONET in that it is the form in ITU-T and used throughout the world besides N. America
- SONET/SDH are transport systems still in use that require frequency synchronization
  - Data and voice can be carried over SONET/SDH
  - Packet data can be carried over SONET/SDH

Packet-Based Networks

- The physical layer can be Ethernet, or other system that does not require sync
  - This allows variable bandwidth and more scalable systems
  - However services still require various kinds of sync and the network requires special transport systems to deliver that
- Many network elements obtain sync from GPS and other GNSS
  - These signals are vulnerable to interference
  - ITU-T and other standards bodies have on-going work to standardize sync transport over packet

Timing Technology: Frequency Accuracy

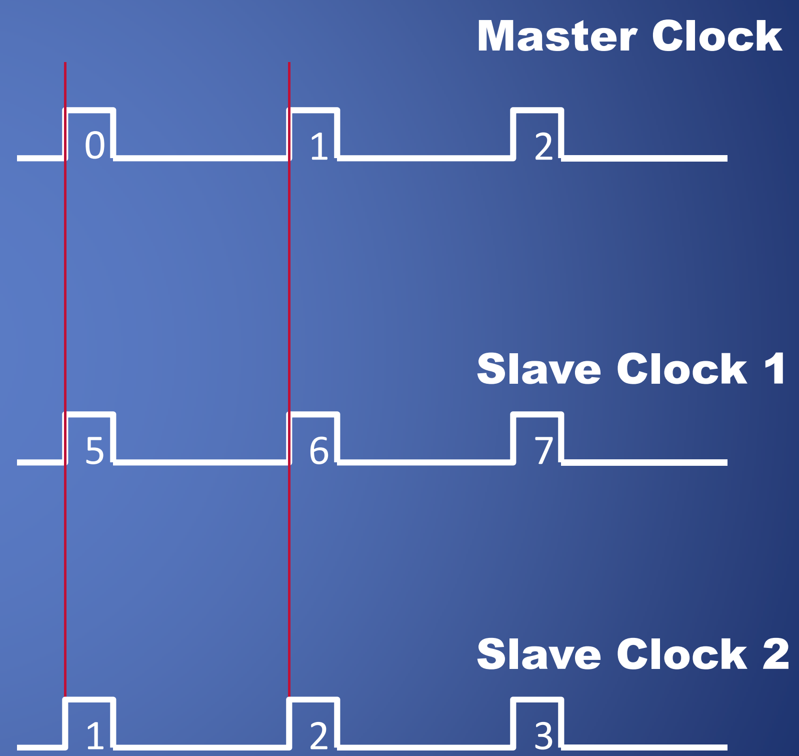
- Frequency accuracy (FFO) is the difference in frequency between the server clock and the recovered client clock over a time interval
- Frequency targets
  - ± 32 ppm for Stratum 4 & 4E
  - ± 4.6 ppm for Stratum 3 & 3E
  - ± 50 ppb for GSM & WCDMA-FDD
  - ± 100 ppb for Home NodeB



Thanks to Adam Wertheimer, Microsemi Co. for the use of this slide.

Timing Technology: Phase

- Alignment and PPS
- Phase alignment is in addition to phase lock. Phase alignment also referred to as Latency Correction.
- Phase alignment has
  - Bounded phase offset between server clock and recovered client clock
  - Bounded phase offset between different recovered client clocks
- Phase alignment requires bi-directional mechanism
- Phase alignment targets
  - ± 1.25 µs for WCDMA-TDD
  - ± 3 µs for CDMA2000, CDMAone
  - ± 1 µs for WiMAX



Thanks to Adam Wertheimer, Microsemi Co. for the use of this slide.

SONET/SDH Frequency Sync
Strata 4 and 4E support 32 ppm

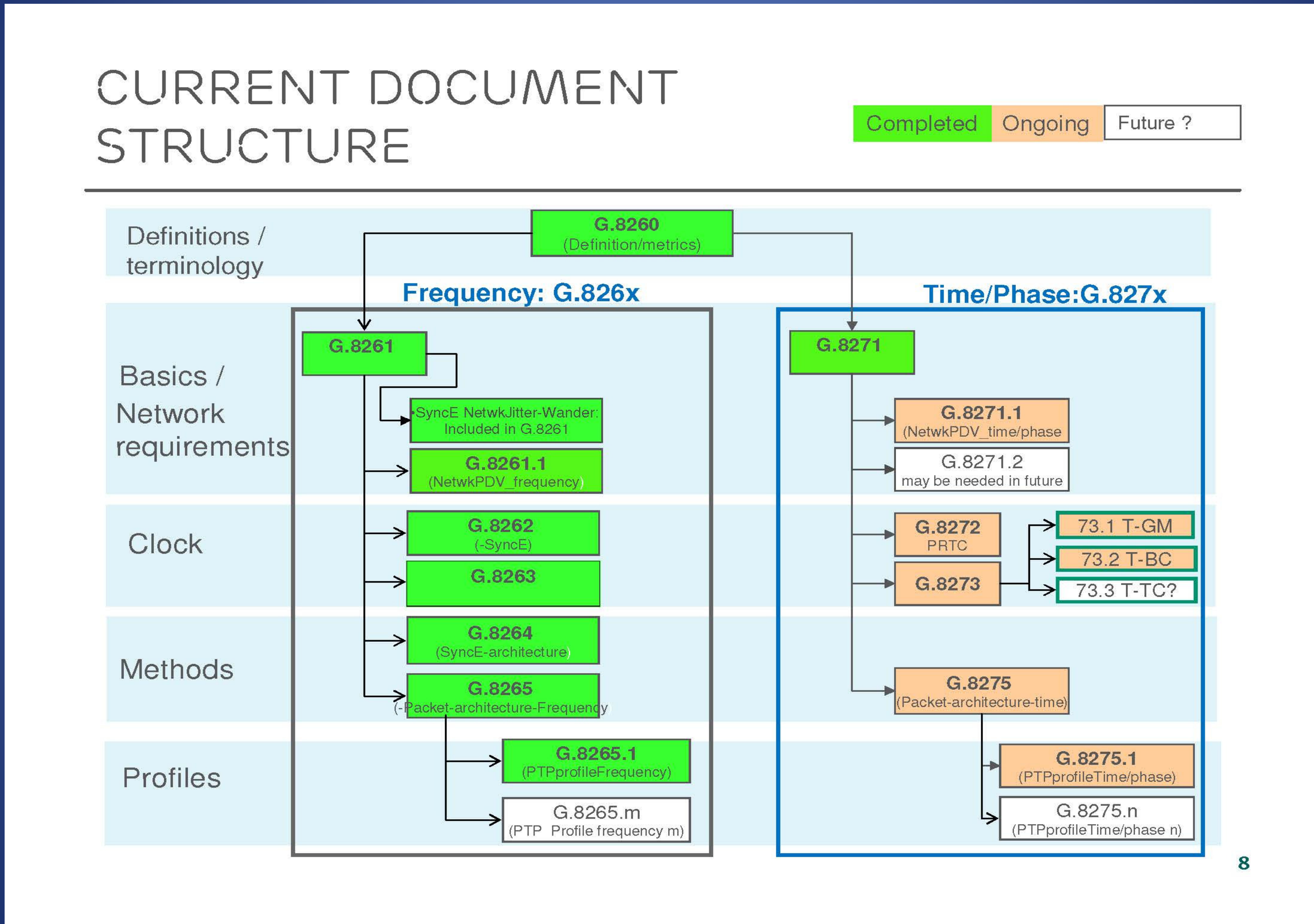
Clock Designation	Long Term Accuracy (± PPM)	Holdover Stability (± PPM)	Free-Run STS Pointer Generation	Holdover STS Pointer Generation
Stratum 1	.00001	N/A	1 every 4.3 hours	N/A
Stratum 2	.016	.0001	1 every 9.6 sec	1 every 25.72 min
Stratum 3E	4.6	0.012	29.81 /sec	1 every 12.86 sec
Stratum 3	4.6	0.37	29.81/sec	2.39 /sec
SMC	20	4.6	129.60 /sec	29.81 /sec
Stratum 4E	32	N/A	207.36 /sec	N/A
Stratum 4	32	N/A	207.36 /sec	N/A

Note:
1. STS pointer generation relative to 0 ppm.
2. 1 STS pointer is equivalent to a one-way phase movement of 154 ns.
3. Pointer generation reflects the maximum frequency offset per clock type.
4. Long-term accuracy is also known as free-run accuracy.
5. SONET payload integrity guaranteed to +/- 4.6 ppm (bold red)

GPS/GNSS meets Stratum 1 Requirements with a Good Local Oscillator

- Stratum 1 requires 10^{-11} frequency accuracy
  - 10 ns at 15 minutes, 100 ns at 3 hours
  - This is 0.01 ppb
- Maybe beyond a Qu, achievable with a CSAC or Rb Oscillator
- Holdover is an important consideration

Current status of ITU-T Standards for Packet Timing in Telecom

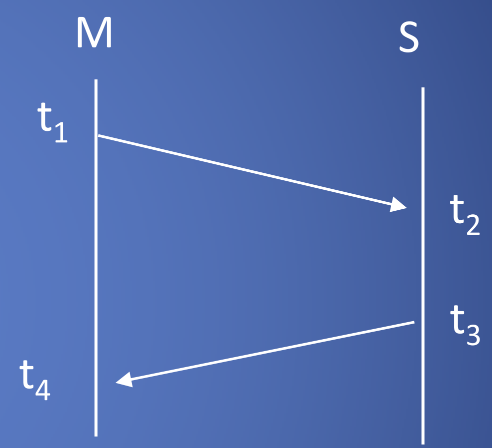


Thanks to Jean-Loup Ferrant, Calnex, Q13/15 Rapporteur, and Stefano Ruffini, Ericsson, Q13/15 Associate Rapporteur

Time Synchronization via PTP

- The basic principle is to distribute Time sync reference by means of two-way time stamps exchange

Time Offset= $t_2 - t_1$ – Mean path delay
Mean path delay = $((t_2 - t_1) + (t_4 - t_3)) / 2$

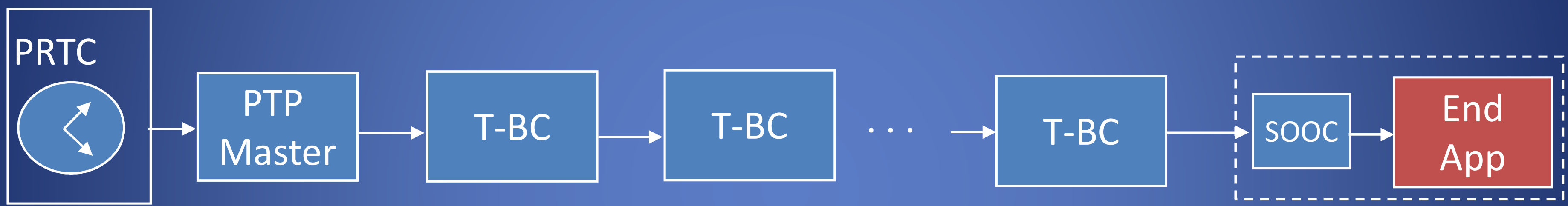


- As for NTP, also in case of PTP Symmetric paths are required:
  - Basic assumption: $t_2 - t_1 = t_4 - t_3$
  - Any asymmetry will contribute with half of that to the error in the time offset calculation (e.g. 3 µs asymmetry would exceed the target requirement of 1.5 µs)

Slide thanks to WSTS – 2011, Stefano Ruffini, Ericsson , Q13/15 Associate Rapporteur

Is “full IEEE 1588 support” good enough ?

- Removal of PDV and asymmetry in the nodes by means of IEEE1588 support (e.g. Boundary Clock in every node).



PRTC : Primary Reference Time Clock
T-BC: Telecom - Boundary Clock
SOOC: Slave Only Ordinary Clock

› Ideally the full support can provide very accurate timing, however several sources of errors still remains

Slide thanks to WSTS – 2011, Stefano Ruffini, Ericsson , Q13/15 Associate Rapporteur

Current Frequency Sync Requirements from ATIS TR on Intra-Office Networks

Frequency Applications and use cases (based on G.8261 appendix IV)

- Existing network where a free-run accuracy of +/-32 ppm is needed for end-equipment. Slips may become a problem. These slips may interfere with voice-band modem communications.
- If the system also supports SONET, then an accuracy of better than +/- 4.6 ppm is needed.
- Wireless technologies.
  - +/-50 ppb for GSM (and other related technology) base stations
  - +/-16ppb In some cases, this requirement is tightened
  - Based on 3GPP TS25.105 and TS36.101, frequency requirements that may apply in addition to the phase requirements :
    - ±50 ppb for wide-area base stations
    - 100 ppb for local-area base stations
    - 250 ppb for home base stations

Thanks to Adam Wertheimer, Microsemi Co. for this information.

Current and Evolving Time Sync Requirements from ATIS TR on Intra-Office Networks

- Phase Applications and use cases (based on G.8271 appendix II)
  - 1 ms to 500 ms for billing and alarm collection systems. It is common to use NTP for this application.
  - For IP delay monitoring, an accuracy of up to 5 microseconds is needed.
  - LTE-TDD and CDMA-based wireless systems need an accuracy of 1.5 – 5 microseconds.
  - UTRA-TDD and LTE-TDD (small cell) need an accuracy of 1 – 1.5 microseconds.
  - In some configurations, WiMAX-TDD and LTE-A have additional requirements below 1 microsecond.
  - A feature in LTE-A may require time sync below 1 microsecond (discussed later)

Thanks to Adam Wertheimer, Microsemi Co. for this information.

Requirements from ITU-T Q13/15 Current Status

Table 1/G.8271 – Time and Phase requirement classes

Level of Accuracy	Range of requirements (Note 2)	Typical Applications
1	1 ms – 500 ms	Billing, Alarms
2	5 µs – 100 µs (Note 1)	IP Delay monitoring
3	1.5 µs -5 µs	LTE TDD (large cell) Wimax-TDD (some configurations)
4	1 µs - 1.5 µs	UTRA-TDD, LTE-TDD (small cell)
5	x ns - 1 µs (x ffs)	Wimax-TDD (some configurations)
6	< x ns (x ffs)	Some LTE-A features (Note 3)

Meeting Sync Requirements in Telecom

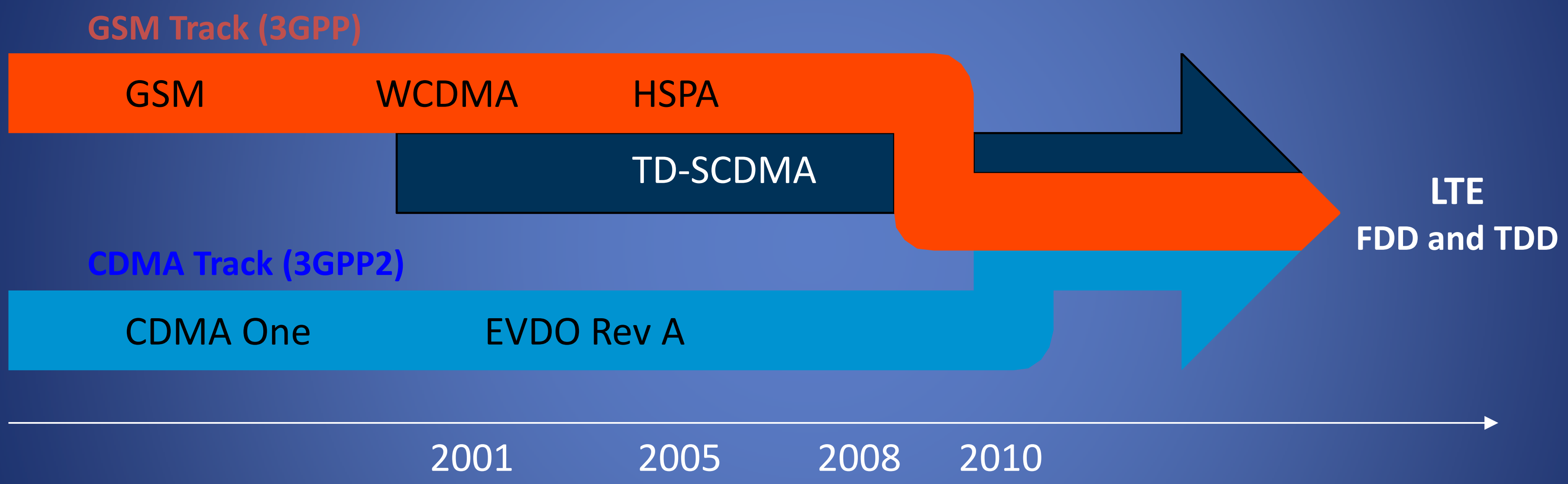
- UTC accuracy and stability brought into network generally with GNSS and local oscillator
  - Short term stability depends on local oscillator
  - Hold-over also depends on local oscillator
  - E.g. holding 1 microsecond for a day cannot be done with a Qu oscillator
- GNSS requires an antenna and sky view. Vulnerability is an issue
- Time and frequency sync is often spread from the receiver through the network
  - Network elements add noise and errors in various forms
  - Passing 1 microsecond time sync is hard, limited by distance

Excerpts from: Mobile standards & synchronization: 3GPP, etc.

WSTS - 2012

Stefano Ruffini, Ericsson

Evolution of mobile technologies



Mobile applications and Synchronization

- The needs of Transport and switching networks have been the main drivers for sync standardization in the 90s
  - Mobile applications only as side users (e.g. Synchronous PDH signals are used to synchronize the GSM network in frequency)
- The needs of Mobile networks are now the main drivers of the sync standardization activities in ITU-T:
  - Several bodies where synchronization is a key topic (3GPP, MEF, BBF, NGMN)
- Discussions between ITU-T and 3GPP on the sync aspects not always easy:
  - Use of different terminologies
  - Different focus

3GPP: 3rd Generation Partnership Project

- 3GPP was created in December 1998. Currently 6 Partners.
- "The purpose of 3GPP is to prepare, approve and maintain globally applicable Technical Specifications and Technical Reports for:
  - an evolved 3rd Generation and beyond Mobile System based on the evolved 3GPP core networks, and the radio access technologies supported by the Partners (i.e., UTRA both FDD and TDD modes), to be transposed by the Organizational Partners into appropriate deliverables (e.g., standards).
  - the Global System for Mobile communication (GSM) including GSM evolved radio access technologies (e.g. General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE)).
  - an evolved IMS developed in an access independent manner."

  (From "**3GPP Scope and Objectives Approved by 3GPP Organizational Partners by correspondence 31 August 2007")**

CDMA 2000 Synchronization Requirements

3GPP2 C.S0010-B: *Recommended Minimum Performance Standards for cdma2000 Spread Spectrum Base Stations*
3GPP2 C.S0002-C: *Physical layer standard for cdma2000 Spread Spectrum Systems*

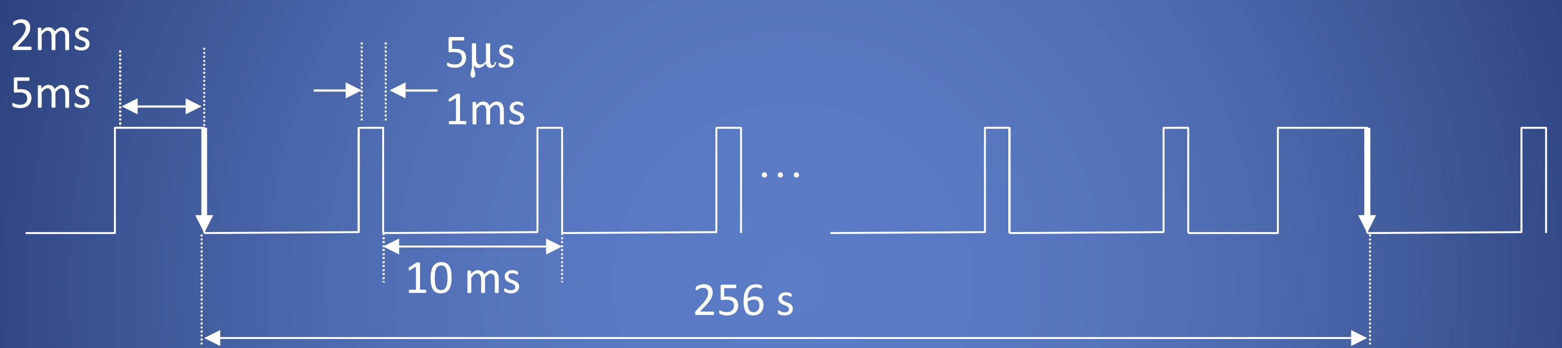
- Time Synchronization Requirements
  - ± 3 μs with respect to CDMA System Time
    (which is traceable and synchronous to UTC)
  - ± 10 μs with respect to CDMA System Time for a period not less than 8 hours
    (when the external source of CDMA system time is disconnected)

[GPS Receiver is typically deployed at every Base Station]

Additional sync requirements for TDD mode

Phase Synchronization (Radio Interface) requirements are defined in TS 25.402

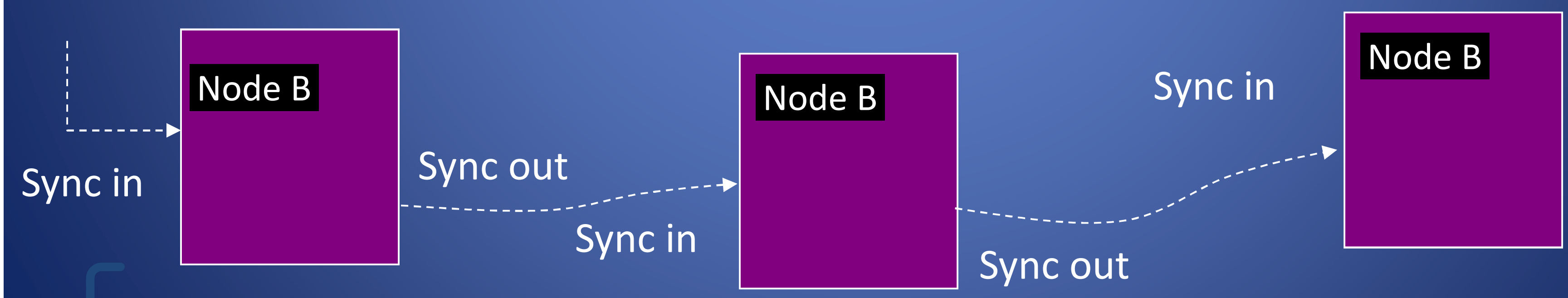
These apply to UTRA-TDD systems (e.g. TD-CDMA, TD-SCDMA)



The relative phase difference of the synchronization

Signal shall not exceed 2.5 µs (3 µs is mentioned for TD-SCDMA)

External sync Source (e.g. GPS)



The Requirements is +/-1.25 µs for independent inputs to the NodeBs

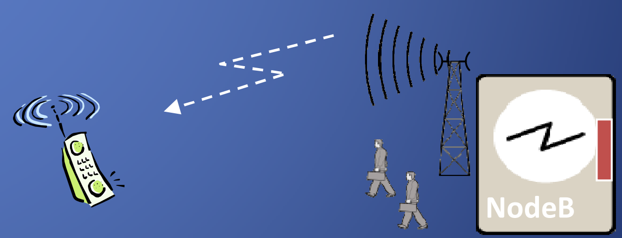
WCDMA Base Station TX Frequency Error

TS 25.104/5:
"Base Station (BS) radio transmission and reception (FDD/TDD)"

- Frequency Synchronization requirements (on the Radio Interface)
- are specified in 3GPP TS 25.104 (FDD), and TS 25.105 (TDD)
- The Base Station shall use the same frequency source for both RF frequency Generation and the chip clock .
- The modulated carrier frequency is observed over a period of one timeslot for RF frequency generation

BS class	Accuracy
Wide Area BS	±0.05 ppm
Medium Range BS	±0.1 ppm
Local Area BS	±0.1 ppm
Home BS	±0.25 ppm

Y < 0.05-0.1 ppm



The requirement applies on the radio interface

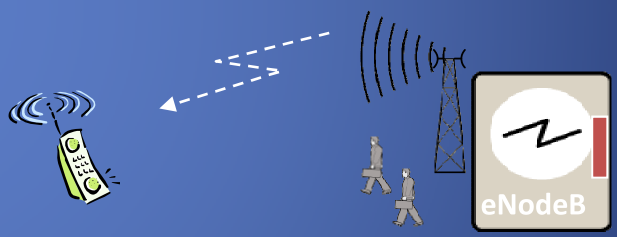
LTE Base Station TX Frequency Error

***TS 36.104:** "Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception*

- Frequency Synchronization (Radio Interface) requirements:
  - The same source shall be used for RF frequency and data clock generation.
  - The modulated carrier frequency of the BS observed over a period of one subframe (1ms) shall be accurate to within

BS class	Accuracy
Wide Area BS	±0.05 ppm
Local Area BS	±0.1 ppm
Home BS	±0.25 ppm

Y < 0.05-0.25 ppm



Requirements at the input of the eNodeB depends on the actual implementation (for instance network limits are defined in case the frequency reference is distributed over the physical layer, TDM or Synchronous Ethernet)

The requirement applies on the radio interface

LTE-TDD Phase Synchronization Requirements

TS 36.133: *"Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management*

TS 36.922: *"Evolved Universal Terrestrial Radio Access (E-UTRA); TDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis"*

	Maximum absolute deviation in frame start timing between any pair of cells on the same frequency that have overlapping coverage areas
LTE-TDD (Wide-Area Base station	- **3usec** for small cell (< 3km radius), - **10usec** for large cell (> 3km radius)
LTE-TDD (Home-Area Base station)	- **3 usec** for small cell (< 500m radius). - **1.33 + *Tpropagation* μs**, for large cell (> 500m radius), *Tpropagation:* propagation delay between the Home BS and the cell selected as the network listening synchronization source
LTE-TDD to CDMA handovers (Synchronized E-UTRAN)	- eNodeB shall be synchronized to GPS time. - With external source of CDMA system time disconnected, the eNodeB shall maintain the timing accuracy within ± 10usec of CDMA system time for a period of not less than 8 hours

Excerpts from: Deutsche Telekom Time/Phase Synchronization Requirements for LTE-Advanced Wireless Systems including CoMP

Deutsche Telekom at WSTS 2011
Helmut Imlau, Heinz Droste

CoMP introduction (1/2)

CoMP = Coordinated Multi-Point Transmission and Reception, with two categories:

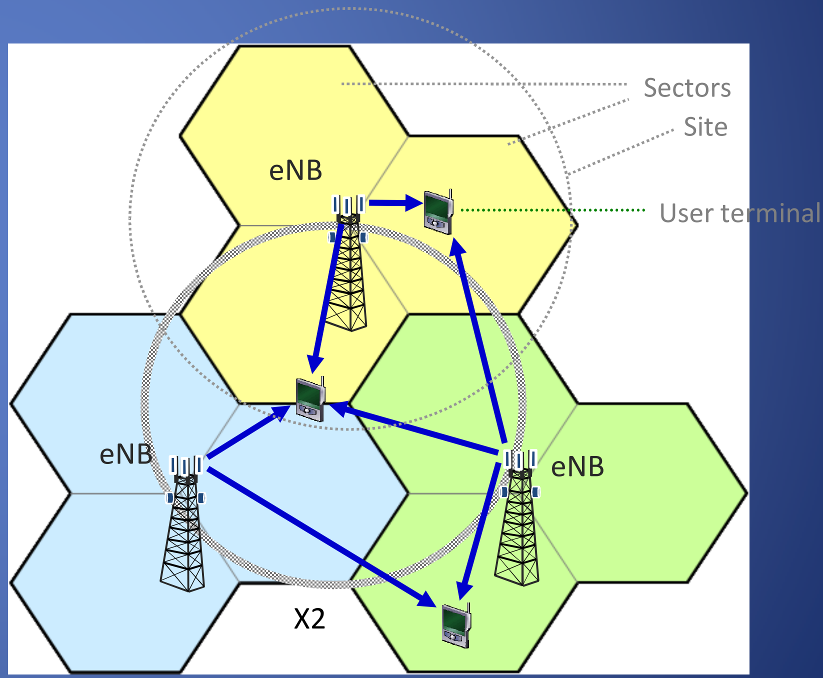
(1) Coherent Joint Processing (JP), aka “Network MIMO” and

(2) Coordinated Scheduling (CS).

<u>CoMP - Joint Processing</u>

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

See Figure:
Idea of JP is communication between one user terminal
and several eNB sectors at the same time.



CoMP introduction (2/2)

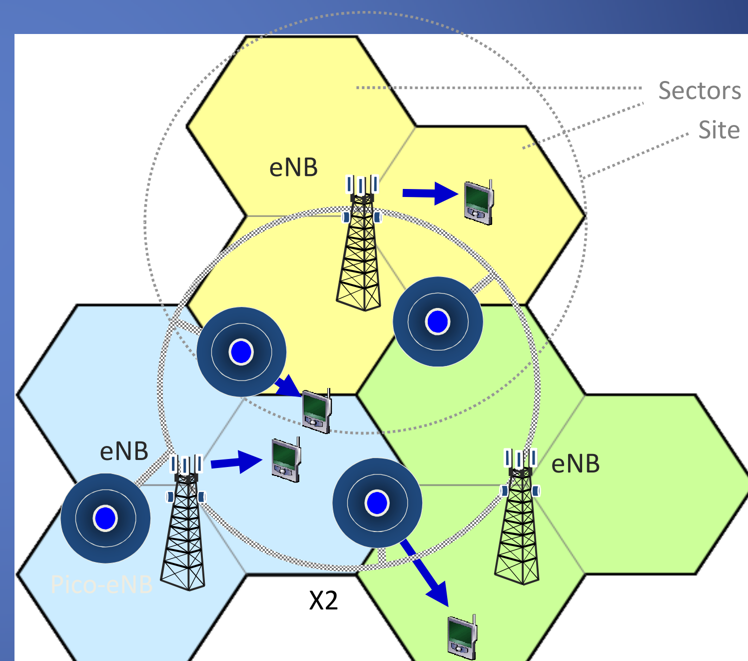
CoMP = Coordinated Multi-Point Transmission and Reception, with two categories:

(1) Coherent Joint Processing (JP), aka “Network MIMO” and

(2) Coordinated Scheduling (CS)

<u>CoMP - Coordinated Scheduling (CS)</u>

- Dynamic allocation of air interface resources in overlapping cells.
- Control data exchange between eNB (incl. Pico-eNB) via X2 interface (X2 for control data only).



- The decision must be made right in time, which eNB / which resource is going to serve which user terminal, depending on user terminal location, bandwidth requirement and speed.

- Coordinated Scheduling options:
  => decentralized per cooperation cluster or
  => centralized (per super cell => fixed number of cells that cooperate
  including several cooperation clusters).

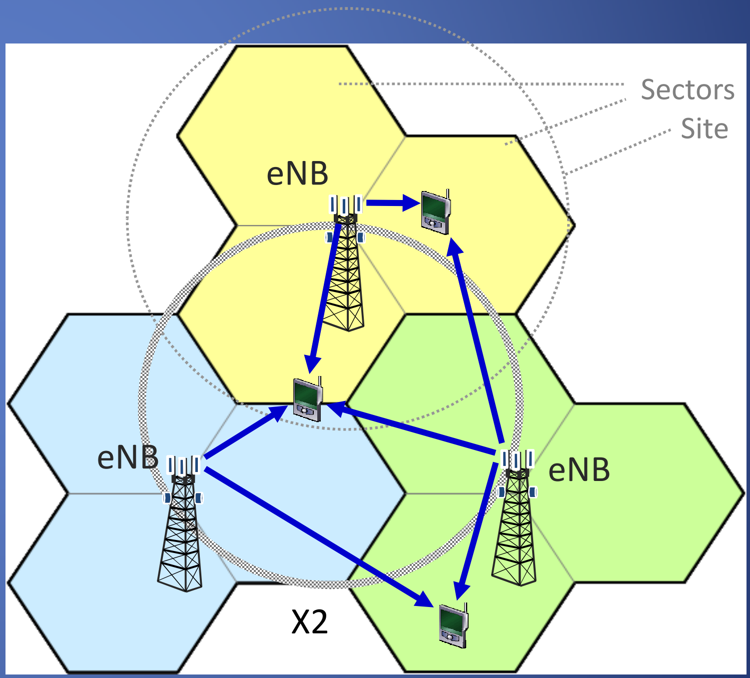
Every user is served by its "Serving Cell" only.

CoMP-JP time/phase synchronization requirements (1/8)

This talk explains the challenging time/phase synchronization requirements for CoMP Joint Processing (CoMP-JP) as an example for LTE-Advanced.

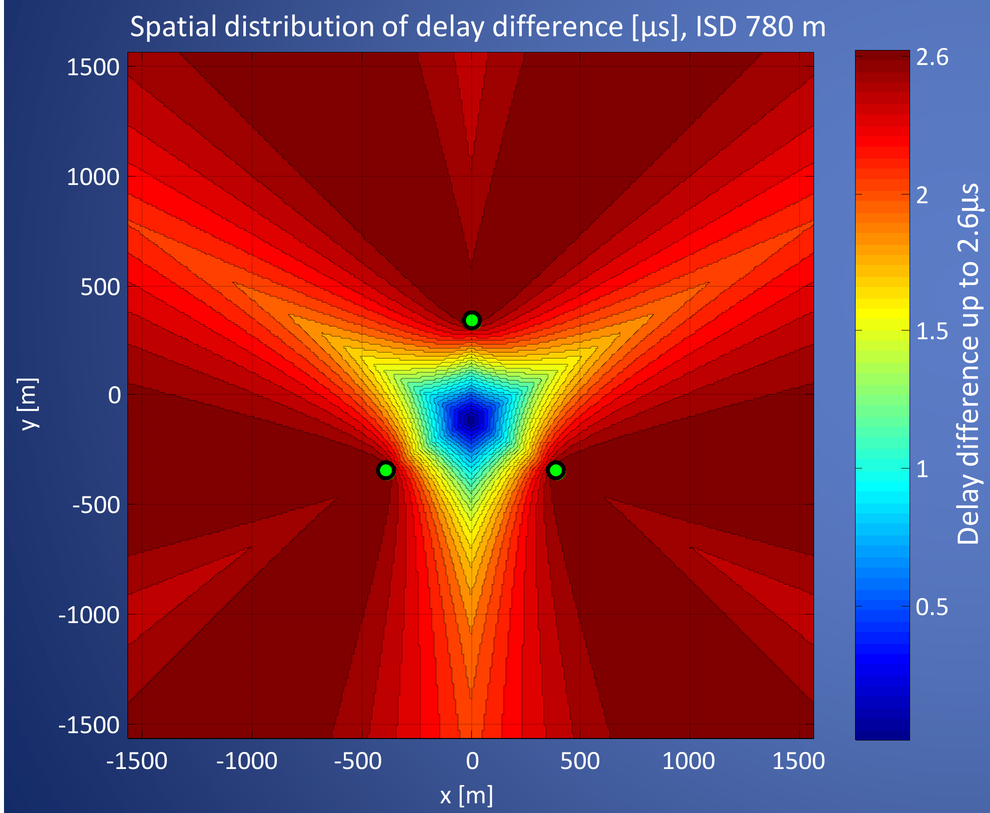
Accuracy calculation for time and phase is made with a very few input parameters only:

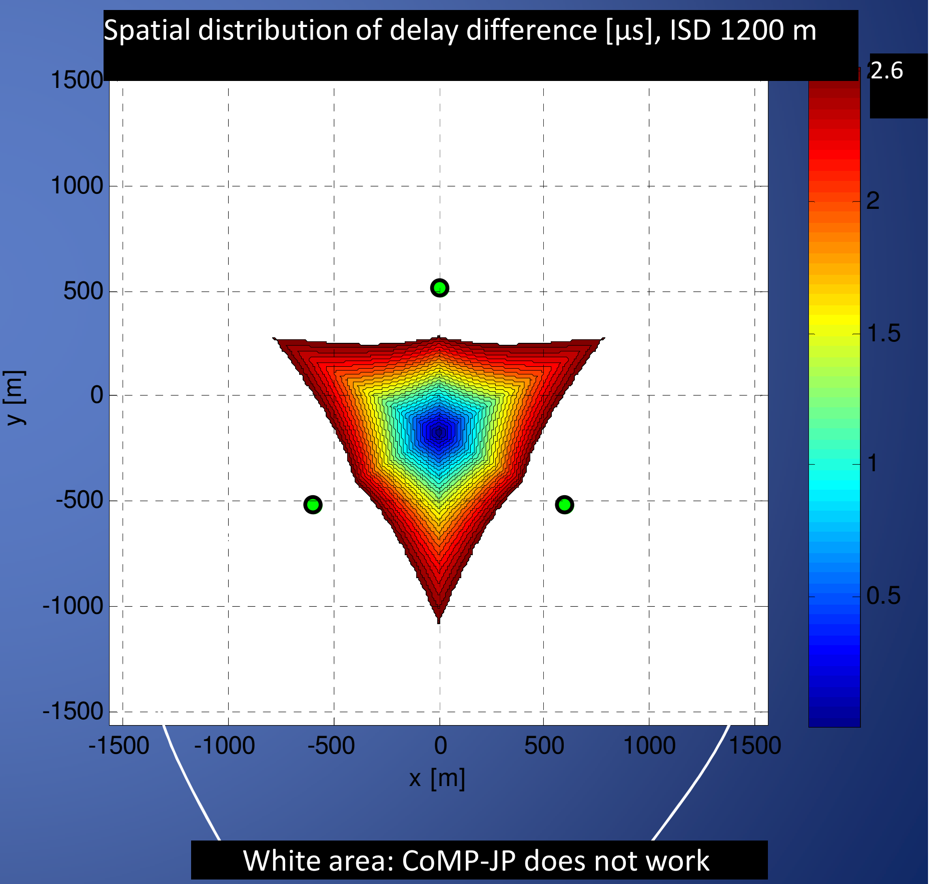
- Already specified signal structure for LTE/LTE-A
- Typical multi-path propagation signal decay time
- Inter-Site-Distance (ISD) and
- Speed of light.



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

Same calculation for 3 mobile cells:





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

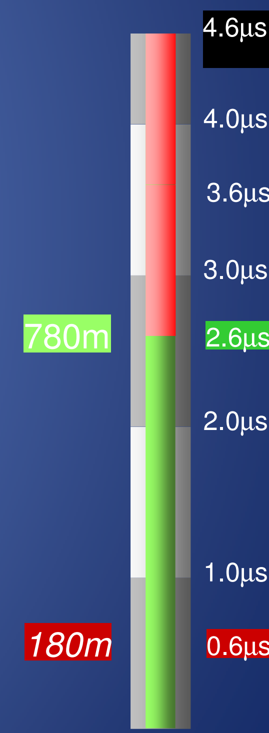
- 1.0 μs = Budget for time error ± 500 ns

=2.6 μs

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

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

Budget



Enhanced 9-1-1 Wireless Services

- FCC requirements have a Phase I and Phase II
- Under Phase II, the FCC requires wireless carriers, within six months of a valid request by a Public Safety Answering Point (PSAP), to begin providing the latitude and longitude of the caller.
- Accuracy standards are generally to within 50 to 300 meters, depending on the type of technology used.
- 50 m = 150 ns for positioning. With a PDOP of 1.5 (as an example), this means 100 ns per range
- For a caller within a building or where GPS is unavailable, the base stations require this appropriate level of time synchronization

Sync from GNSS at ~100 ns

- At a few ~100 ns, calibration of receivers becomes very important
  - Absolute calibration must typically last for the lifetime of the equipment
- Impedance matching in antenna cables is also required
  - Poor matching can cause 10's of ns variation in the code lock point over time
- These requirements might be relaxed if systems can accomplish common-view time transfer
  - Systems really need differential calibration
  - This effectively performs a differential calibration in real time

Summary and Conclusions

- GPS and GNSS meets frequency sync requirements for SONET/SDH with a good oscillator
  - Stratum 1 requires 10^{-11} frequency accuracy
  - 10 ns at 15 minutes, 100 ns at 3 hours
- Wireless telecom is driving new sync requirements
  - Frequency sync requirements up to 50 ppb
  - Time sync requirements up to 0.5 microsecond or perhaps more
- E911 may require sync at the 100 ns level