Time Synchronization Aspects in Mobile Backhaul Networks

- 802.3 Time Synchronization Study Group (TSSG)

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Outline

- Definitions Applicable to Telecom & Mobile
- Technology Options for Distributing Phase/Time
- Mobile Application Requirements
- Impairment Budget Allocation
- Summary

Definitions Applicable to Telecom & Mobile

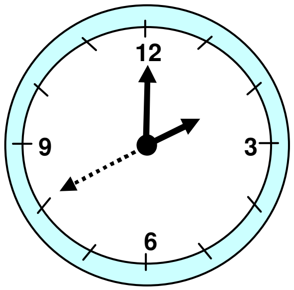
- **Two clock signals are said to be:**

	Frequency Offset Requirement	**Initial Phase Offset Requirement**	**Comment**
Frequency Lock	Frequency is nominally the same and bounded $\leqslant$ 1x10^{-11} (eg., Stratum 1)	Irrelevant	Clock signals that are frequency locked have no timescales associated with them
Phase Lock	Zero long-term average and phase error might be bounded	Important to some extent	Clocks have arbitraty timesscale, with constant and variable offset (eg., equal to propagation delay between a master and slave)
Phase Aligned	Zero long-term average and phase error is bounded	Important	Clocks have arbitraty timesscale, and have a small or zero offset between them (eg., propagation delay has been calculated and compensated for)
Time Aligned	Zero long-term average and phase error is bounded	Important and related to a common timescale (UTC, GPS, TAI)	Clocks are phase aligned and have defined timescale, traceable to some international reference

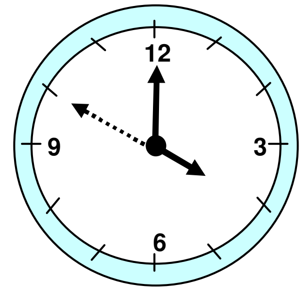
Various mobile systems require some form or frequency, phase <u>or</u> time alignment (GSM, UMTS, CDMA, WiMAX, LTE, LTE-Advanced…)

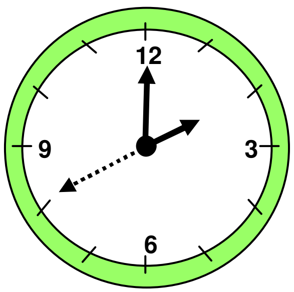
Definitions Applicable to Telecom & Mobile

CLOCK A | **CLOCK B**

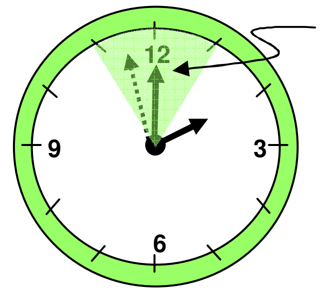


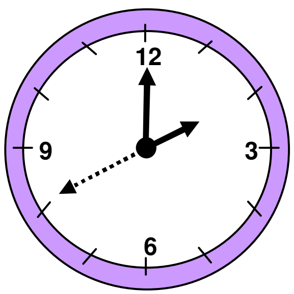
Frequency Locked
- Minute hand move at same rate
- Timescales are irrelevant
- Clocks have different time



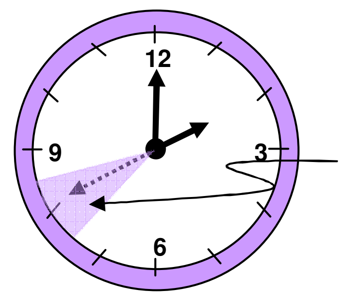


Phase Locked
- Minute hand move at same rate
- Timescales might be the same or can be arbitrary
- Clocks might have different time, but difference in time is bounded based on application





Time Alignment
- Minute hand move at same rate
- Timescales are the same, traceable to international standard
- Clocks show same time, albeit small offset



Frequency is a prerequisite to Phase/Time Alignment
Frequency and Phase/Time Distribution require accurate timestamping

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Technology Options* for Distributing Phase/Time

- **GPS Receiver based (satellite-based distribution)**
  - Accurate, traceable, dependable and robust
  - Mostly used in North American deployments
  - Cost and deployments difficulties for many other wireline/wireless operators
  - Requires additional antenna and cabling, leasing & installation
  - Limited indoor coverage, holdover required during GPS failure event
- **IEEE1588v2** <u>without</u> support from network nodes (network-based distribution)**
  - Typically used for frequency distribution between a Master and Slave → ITU-T developing 1588 PTP profile for frequency distribution
  - Difficult to distribute phase/time due to unknown latency characteristics at all layers
  - Timestamping done in end network elements only, no support from network
- **IEEE1588v2** <u>with</u> support from network nodes (network-based distribution)**
  - Accuracy primarily dependent only on physical layer characteristics
  - Timestamping done in every network element, implemented via boundary and/or transparent clocks which removes unwanted latency impairments
- **IEEE 802.1AS is an example that uses 1588/timestamps & support from network**
  - ITU-T Phase Synchronous Ethernet proposal is another example which does not use 1588 support from network but requires timestamps

***The list is not exhaustive, many other possibilities exist**
**** Two-way time transfer protocol (TWTT) uses set of timestamps to align phase/time**

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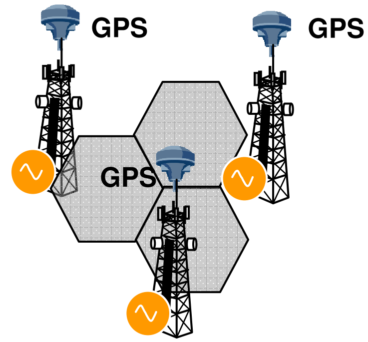
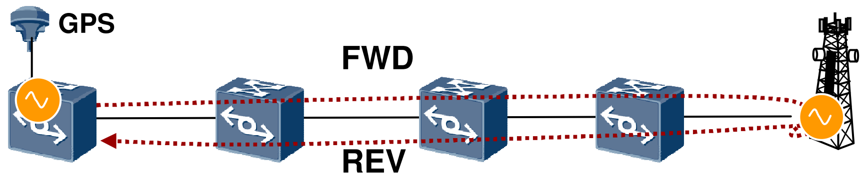
Technology Options* for Distributing Phase/Time

1. GPS



- Delivers accurate time
- Some operators rely on, others don't

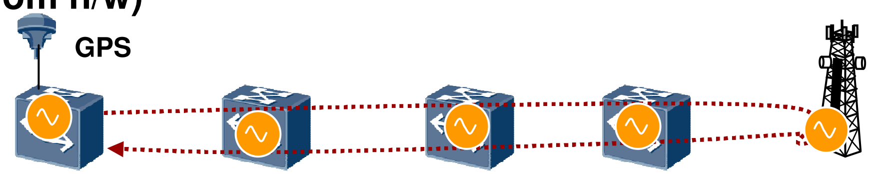
2. end2end Time Distribution
(without support from n/w)



- Accuracy dependent on symmetry of the whole network
- Impacted by route delay, switches/routers queuing delay, physical components, etc.

Time accuracy ~ ½ (FWD route – REV route)

3. Hop-by-Hop Time Distribution
(with support from n/w)



- Accuracy dependent on asymmetry (differential delay) of physical layer
- Eg., 1588 Transparent Clock corrects for latency through nodes

Time accuracy ~ ½ (physical link asymmetry)

Time Distribution relies typically on Two-Way Time Transfer (TWTT)
Latency symmetry is assumed in both directions else time error is produced

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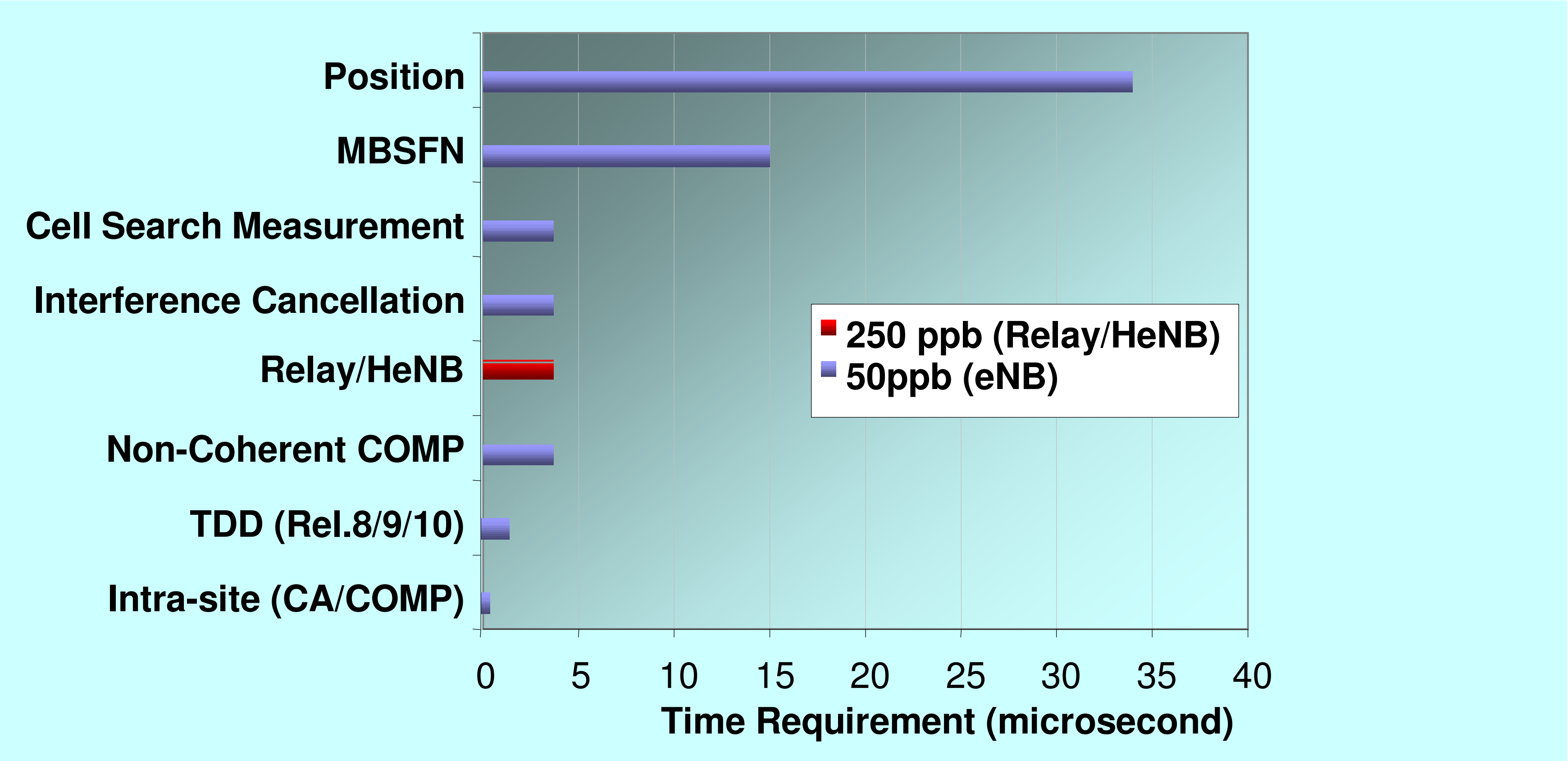
Desired Accuracy for LTE-Advanced
- illustrative example*



Requirements are in the µsec range
Error due to timestamping must be << requirement

* numbers are presented for illustrative purpose, subject to change based on various factors

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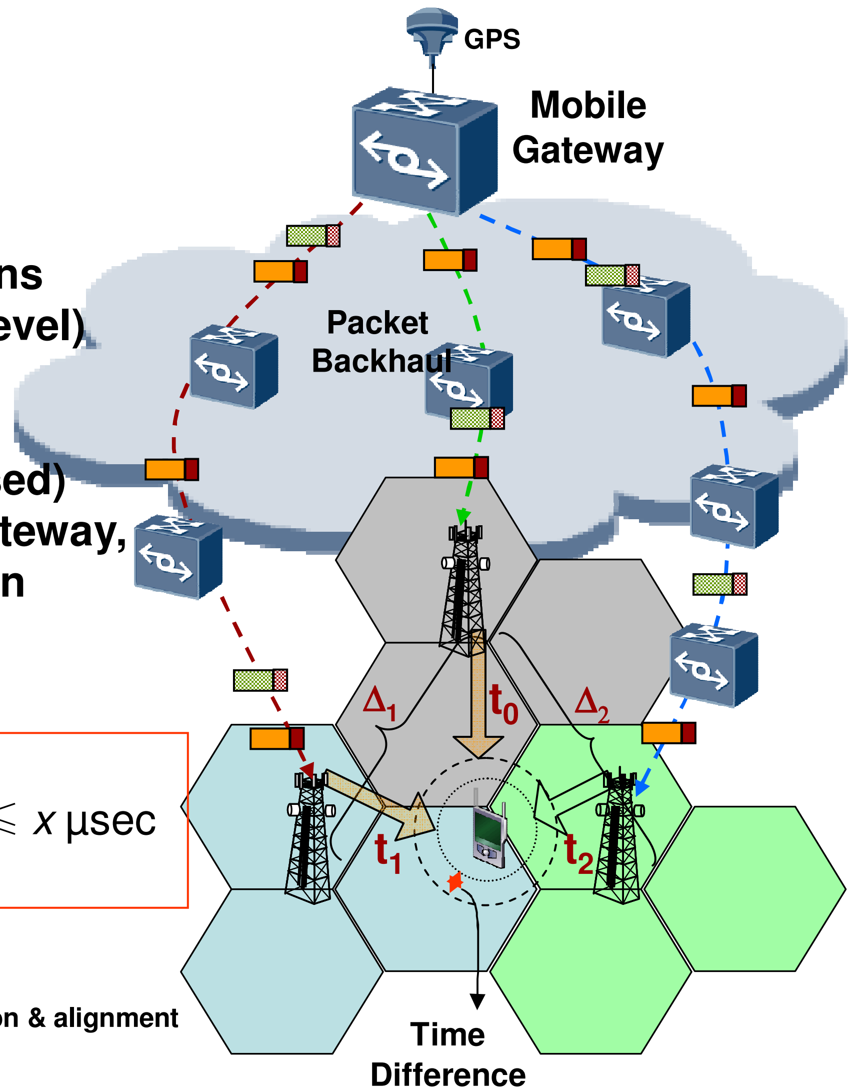
LTE-A Coordinated Multi Point Transmissions
- illustrative example



- **Transmissions from multiple base stations radiate/transmit at the same time (µsec level)**
- **Broadcast service on the air interface**
- **Accurate time delivered to base stations through backhaul network (if GPS not used)**
- **Accurate timestamping required from gateway, through network nodes up to base station**

$$\textit{Time difference} = \textit{max}\{ t_0-(\Delta_1+t_1)\ ,\ t_0-(\Delta_2+t_2) \} \leqslant x\ \mu\text{sec}$$

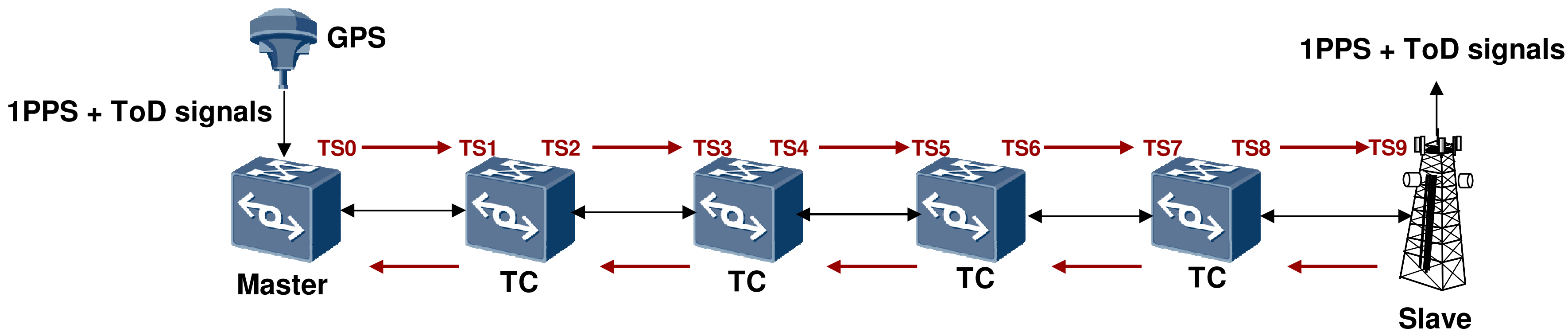
Frame carrying timestamps used for phase/time distribution & alignment

Frame carrying content

Timestamping with support from network

- illustrative example using IEEE1588 Transparent Clock

- Transparent clock does not recover time, but measures the residence time and corrects the 1588 PTP packet. Each node needs to accurately timestamp on the way-in and the way-out



Route delay (Master to Slave) = TS9 – TS0 – (TS2 - TS1) – (TS4 - TS3) – (TS6 - TS5) – (TS8 - TS7)

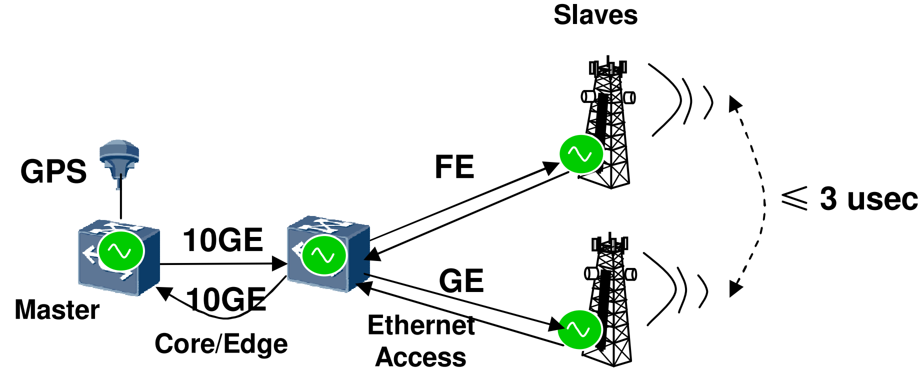
- Timestamping will contribute to the total time error accumulation along the chain of elements
- Let's say requirement = ± 3usec time error, then each node should not generate more than ± 3usec/6 = ± 500nsec of time error per node
- ± 500nsec has to be distributed across various impairments – budget allocation

The function of timestamping is one impairment in the budget allocation

A similar example could be constructed using Boundary Clocks

Impairment Budget Allocation
- Illustrative Example

- To achieve time distribution, total time error budget ⩽ ± x µsec
- System consists of links & network elements. These contribute to the time error accumulation and budget
- Microsecond level… every nanosecond counts



Impairment Allocation	GPS				Total (µsec)
		M-to-S direction	S-to-M direction		
	Core/Edge	Access	Access	End-Device	± 3
Antenna cable length					
Backplane					
PHY Transmit Timestamp error					
PHY Receive Timestamp error					
PHY read-to-transmit wait time					
Physical layer (protection paths, fiber dispersion, differential group delay, fiber splices, patch panels)					
Internal node delay					
PHY latency					
Serialization speed (FE, GE, 10GE)					
Clock synthesis & clock ratios					
Thermal variations					
…					

TSSG Scope* (PHY Transmit Timestamp error; PHY Receive Timestamp error; PHY read-to-transmit wait time)

TSSG Scope* (PHY latency; Serialization speed (FE, GE, 10GE))

illustrative example

*Items that could be considered and under study within IEEE TSSG. Requires further discussion.

Summary of Mobile Backhaul Aspects
- Initial discussion items for TSSG and PAR definition

- **Time sync in mobile networks driven by requirement of radio interfaces (eg., LTE system)**
  - Interfaces that require timestamping are FE/GE/10GE and those that might are 40GE/100GE
- **Various impairments contribute to time error - careful impairment budget allocation necessary**
- **Various measurement points - must be taken as close to the physical layer as possible**
  - MII used today as meas. point in IEEE1588, applicable for FE/GE interfaces, difficult for integrated MAC/PHY
  - MAC level: latency performance might not be deterministic
  - PCS: read/write timestamps triggered based on using/defining unused special codegroups
  - PCS/PMA layer: replace nearest idle ordered set with a “timing” ordered set, NTT/Nihon published paper, demonstrated 2.5nsec accuracy over 5km fiber
- **TSSG could work towards specifying for instance**
  - Timestamping based on distinct and easily recognizable patterns
  - TX/RX timestamping function error (resolution)
  - Delay and delay variation such PHY latency, PHY clock jitter, etc.
  - Wait times, read-to-transmit process
  - etc.
- **IEEE 802.3 TSSG work is relevant to other standards development**
  - ITU-T: starting to study network phase/time distribution and performance
  - IETF TICTOC: accurate time & frequency distribution over packet switched networks
- **Other challenges**
  - Passing timestamps to upper layers, security of timestamps
  - Higher speed interfaces: xMII, multi-lane distribution, deskew mechanism, oscillator frequency
  - Network architecture: underlying OTN structure, ETH interfaces mapped into SDH/SONET
  - …

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