Intro To Timing
Synchronization Fundamentals

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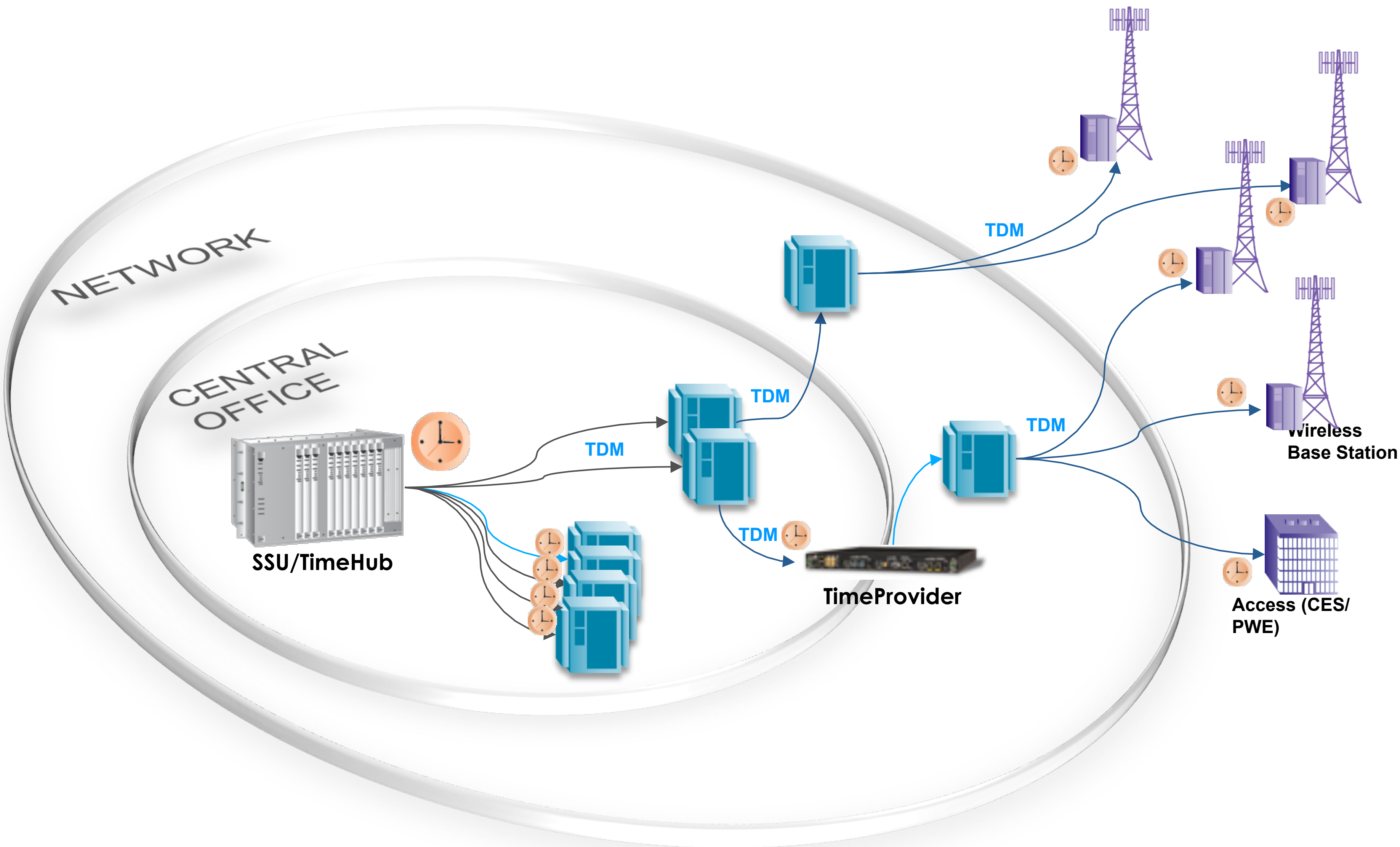
Draft-V3

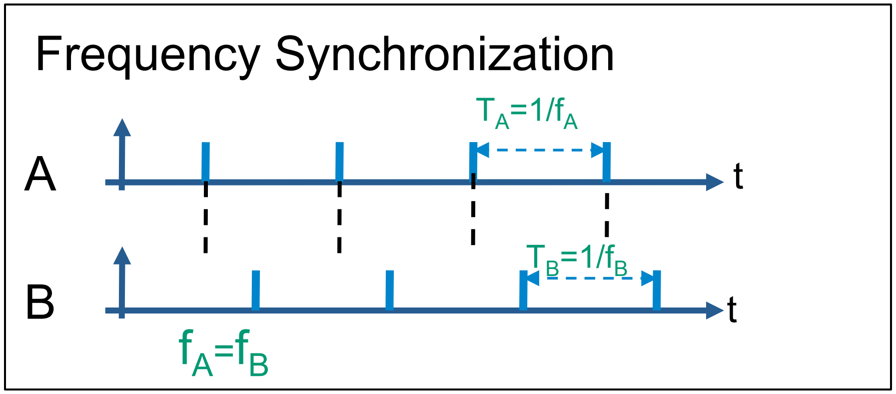
Network Synchronization

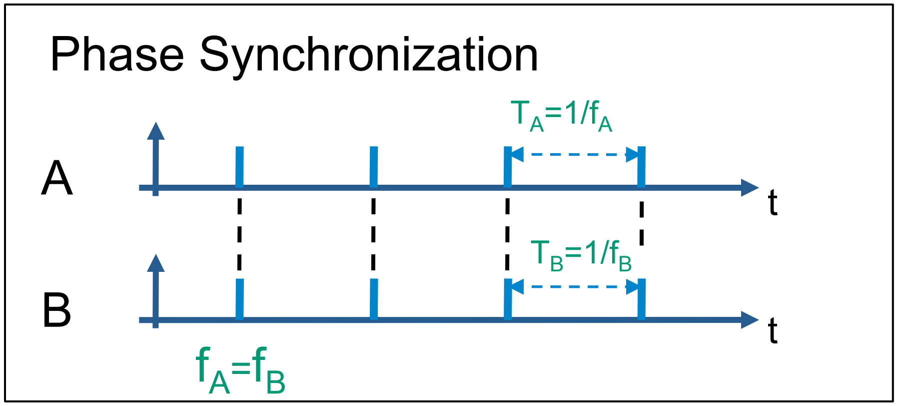


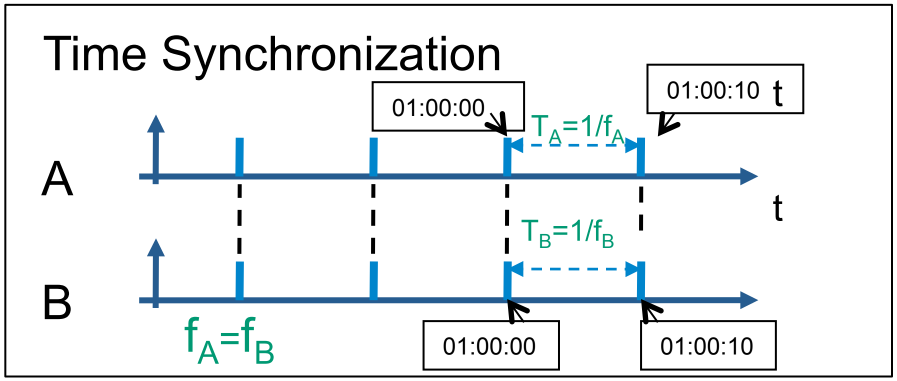
Telecom Synchronization

- Synchronization in telecommunications networks is the process of *aligning the time scales of digital transmission and switching equipment so equipment operations occur at the correct time and in the correct order*
- Synchronization is especially critical for real time services, such as voice and video
- The impacts of poor synchronization are:
  - Call setup, takedown, and management problems
  - Degraded speech quality and audible clicks
  - Degraded data traffic throughput
  - Freeze-frames and audio pops on video transmissions
  - Call disconnects during mobile call hand-off
  - Partial or complete traffic stoppage

Synchronization Requirements







Stratum Levels

- Performance levels, or **stratum**, are specified by ANSI and Telcordia
- Telecom networks should always be traceable to Stratum 1 – the office's Primary Reference Source
- Holdover is the ability of a system to maintain frequency accuracy if its Stratum 1 reference timing has been lost
- A slip, a measure of a synchronization error, it is a frame (193 bits) shift in the time difference between two signals

Stratum	Clock Type	Accuracy	1st HO Slip	Pull-In
1	Cesium/GPS	1 x 10-11		
2	Rubidium	1.6 x 10-8	~ 14 days	1.6 x 10-8
3E	Precision Quartz	1 x 10-6	~ 48 hours	1 x 10-6
3	Transport	1 x 10-6	minutes	1 x 10-6
4	CPE	3.2 x 10-6	N/A	3.2 x 10-6

Clocks

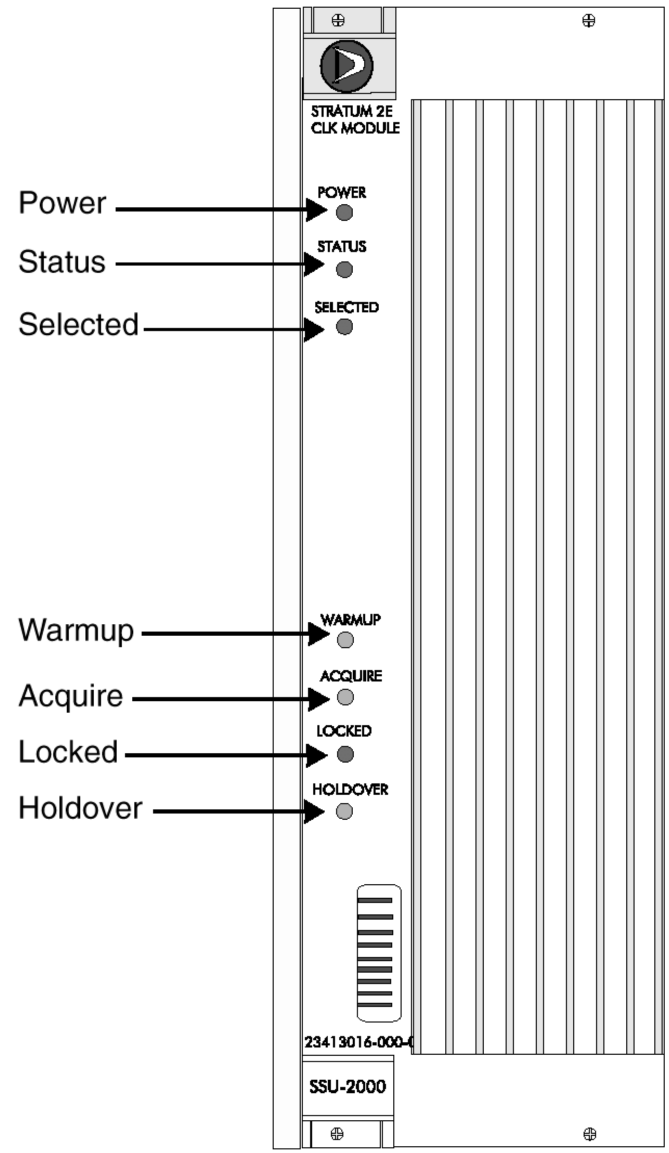
Warm up – initialization/time/no output

Acquire – valid reference

Locked – normal state/time/takes on the quality of input reference

Holdover – output/drift

Free run – time will return to nominal rate of oscillator



Primary Reference Source

Equipment that provides a timing signal whose long-term accuracy is maintained at 1×10^{-11} (stratum 1) or better with verification to coordinated universal time (UTC) and whose timing signal may be used as the basis of reference for the control of other clocks.

- ANSI T1.101

Cesium

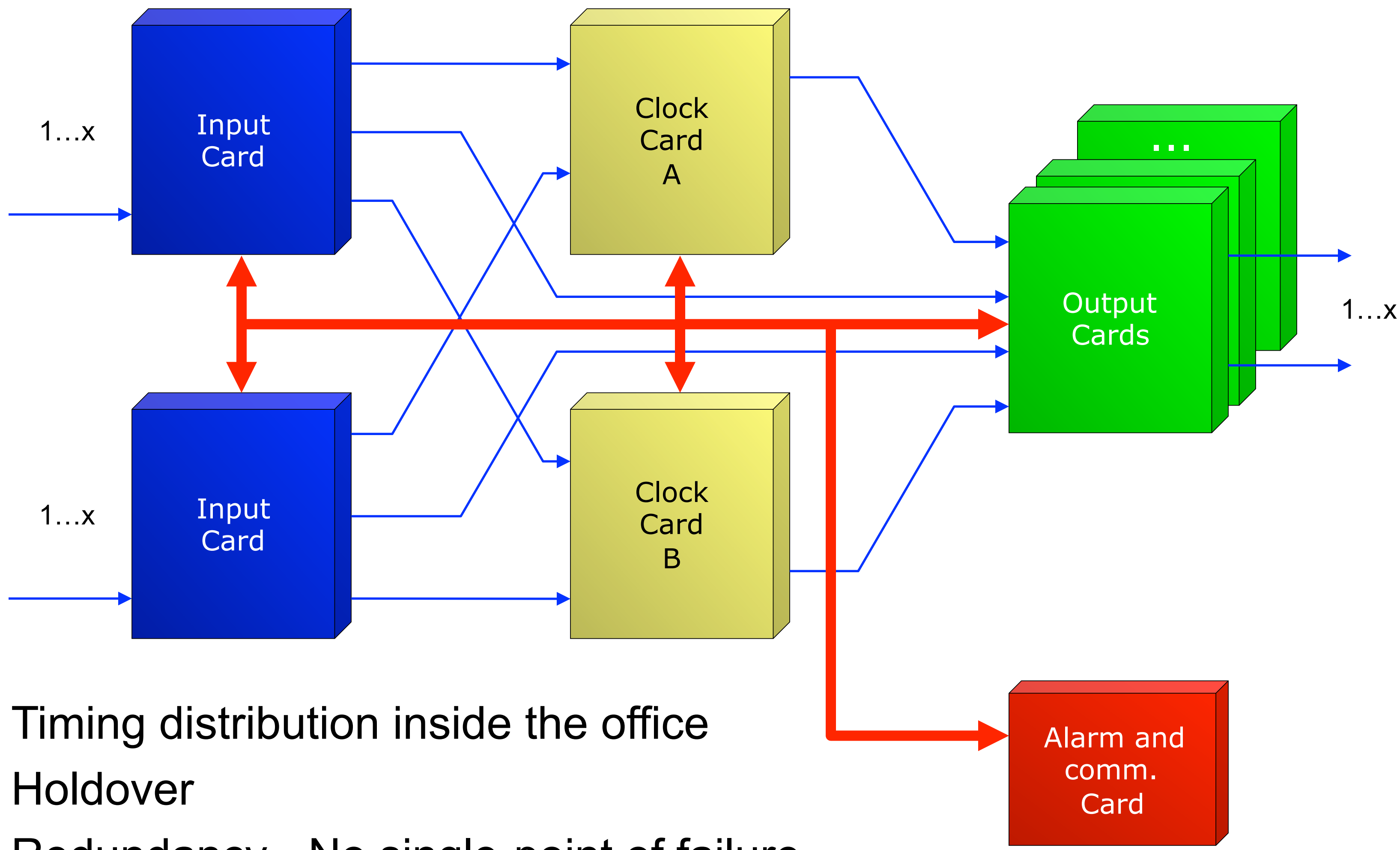
GPS

PacketPRS

Loran-C

CDMA

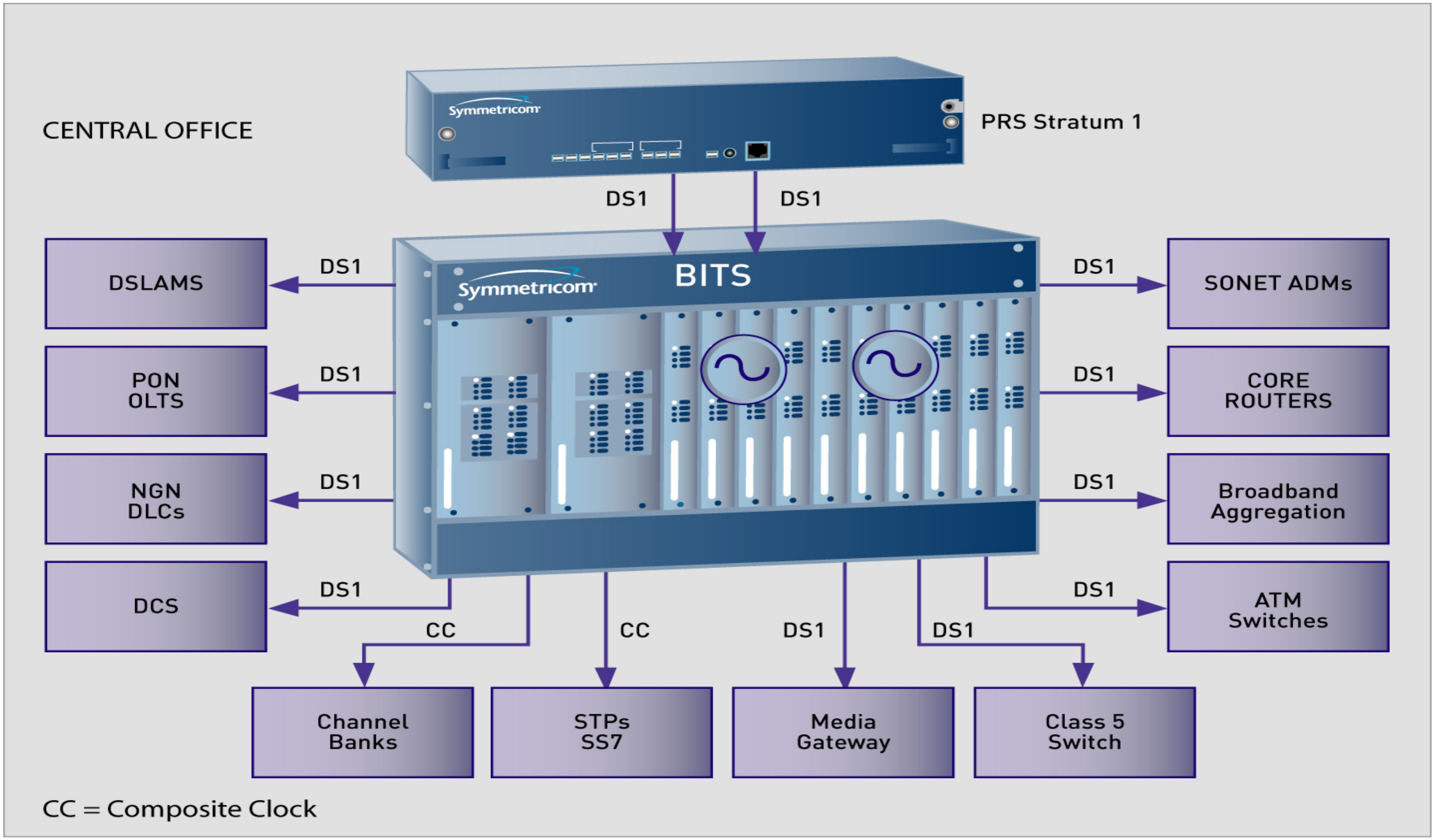
Timing Signal Generator



- Timing distribution inside the office
- Holdover
- Redundancy - No single-point of failure
- Filtering (FLL vs. PLL)

Building Integrated Timing Supply, BITS

The Heartbeat of the Network



Virtually every NE connects to and is dependent on the sync infrastructure

SONET Mapping

Synchronous –

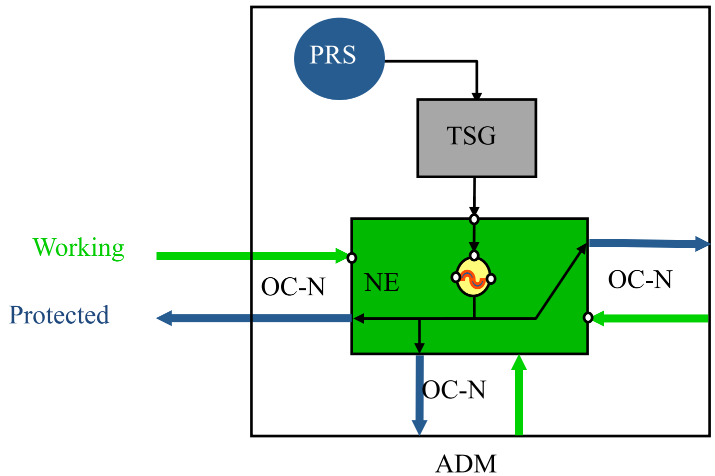
- T1 tributary mapped in has the clock of the SONET network
- Frequency offset results in slips if SONET network and T1 network are not plesiochronous.
- Slip buffers used to compensate for frequency offset
- Loss or corruption of data

Asynchronous –

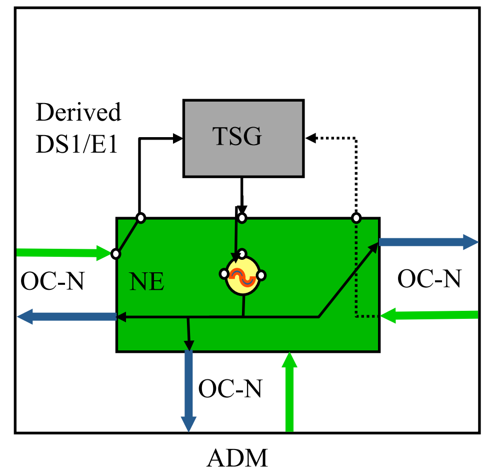
- T1 tributary mapped maintains the source clock of the T1 network
- frequency offset between T1 network and SONET network generates VT1.5 pointer movements but to slips
- Frequency offset justified by bit-stuffing
- VT1.5 pointers = jitter

SONET

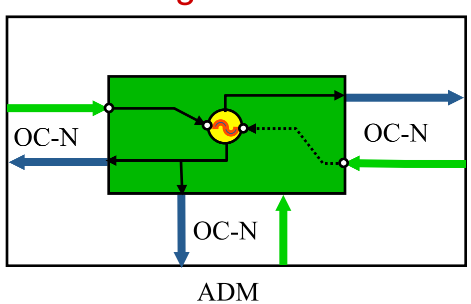
PRS&TSG External Timing



TSG External Timing



Line Timing

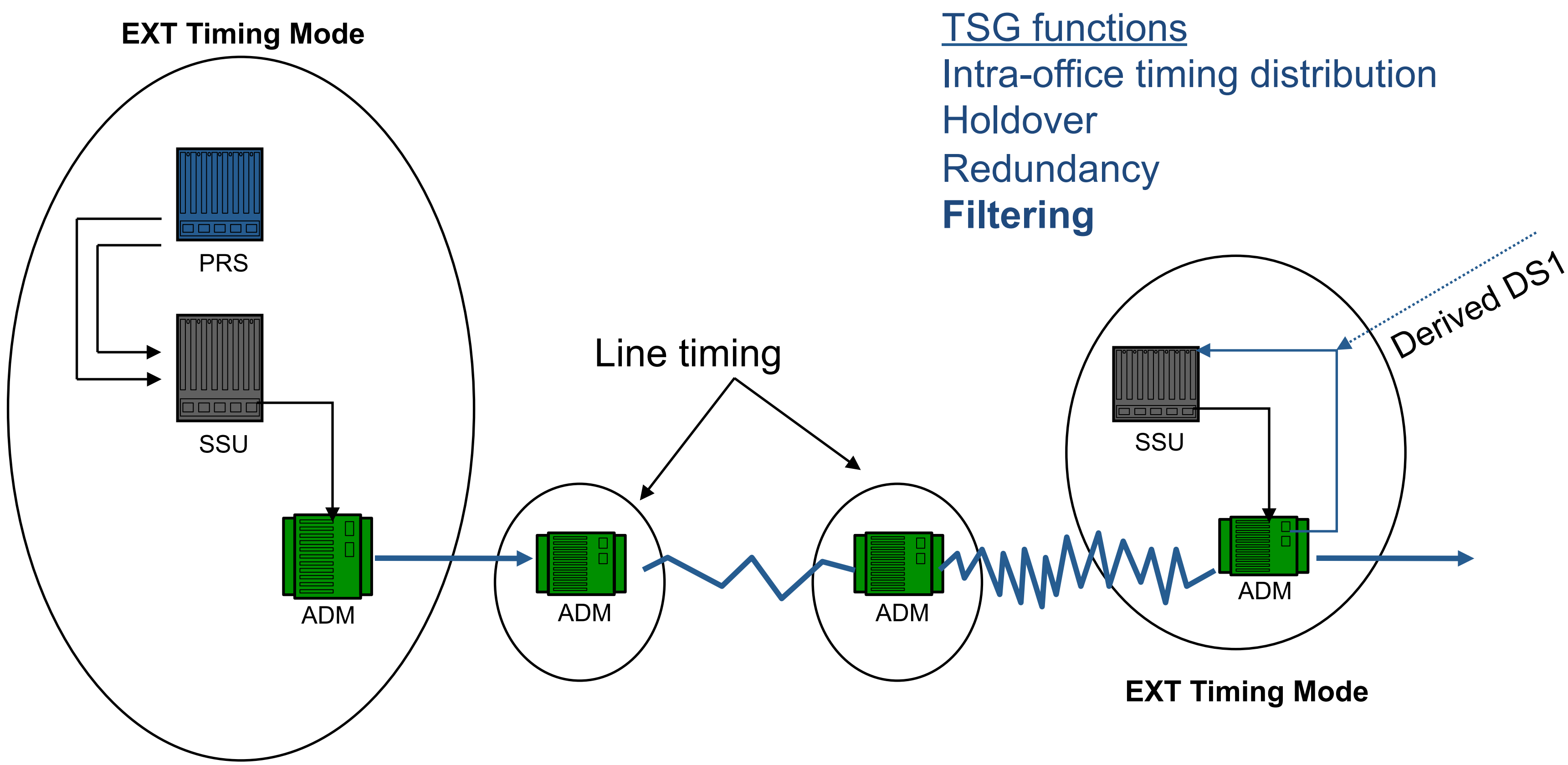


Other Specific Modes

- Loop Timing for SONET Terminals
- Through Timing for Uni-Path Switched Rings/IXC/Regeneration applications
- Internal Timing for Point-To-Point applications

Primary Timing ———
Secondary Timing ·········
Input connection point o o

Timing Degradation



Frequency-lock loop control of direct digital synthesizer in SSU provides mechanism to filter short-term instability on cascaded timing signals.

Most effective with long time constant made possible by Rubidium oscillator because of its exceptional stability.

Synchronization Integrity Impaired

TDM Timing Issues –

- **Short-term instability –**
  - Jitter
  - Wander
  - Phase Transients
  - MTIE & TDEV
- **Long-term accuracy** –
  - Frequency Offset
  - Phase & Frequency
- **What you see** –
  - Bit-errors
  - Slips
  - Pointer activity
  - Holdover & Clock Alarms

Packet Timing Issues –

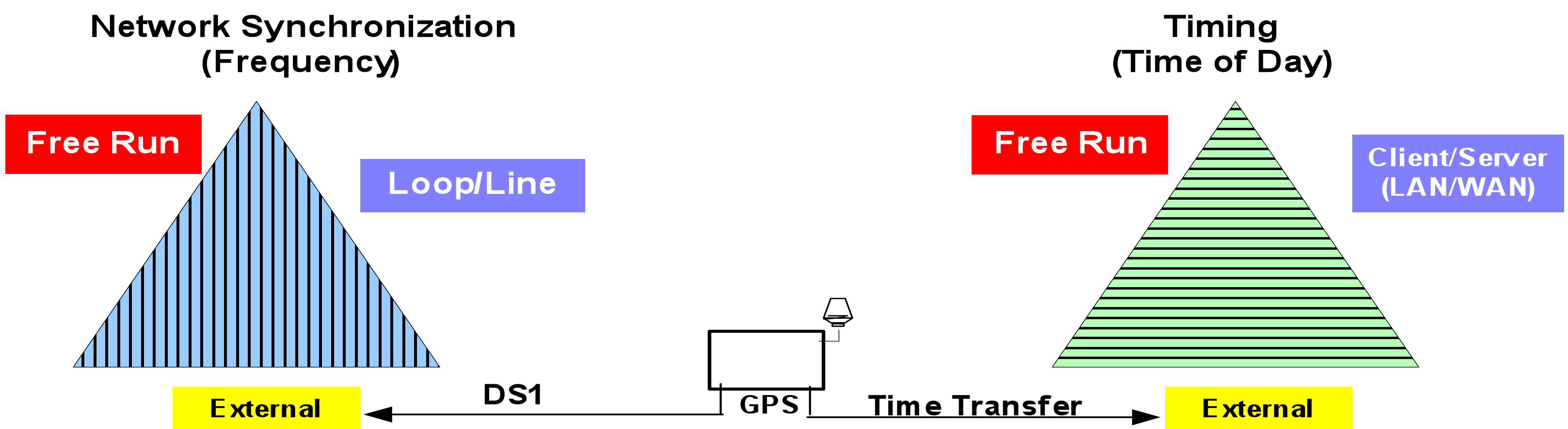
- Packet Jitter (PDV)
- Asymmetry
  - time/phase for time transfer
- Latency or Delay
- Packet Loss
  - MinTDEV
  - MRTIE

Poor synchronization is the most common, <u>non-obvious</u>, cause of service degradation

Network Time Protocol (NTP)

- Internet protocol for synchronizing system clocks, via time stamps, over a packet network
- Uses Universal Coordinated Time (UTC) as reference from GPS constellation
- IP Client/Server architecture
  - Time stamps delivered via LAN/WAN
- Developed in 1985 at U of Delaware
  - Air traffic control was one of first applications
  - Widely employed in information technology domain, e.g. every PC
- *Telecom NEs with NTP clients include softswitches, routers, IP transport, and mobile switching centers*

Network Time Protocol (NTP)



Stratum 1 - G.811
Stratum 2 - G.812
Stratum 3E -G.812
Stratum 3 - G.813
Stratum 4 - G.813

Frequency Accuracy

Most Accurate

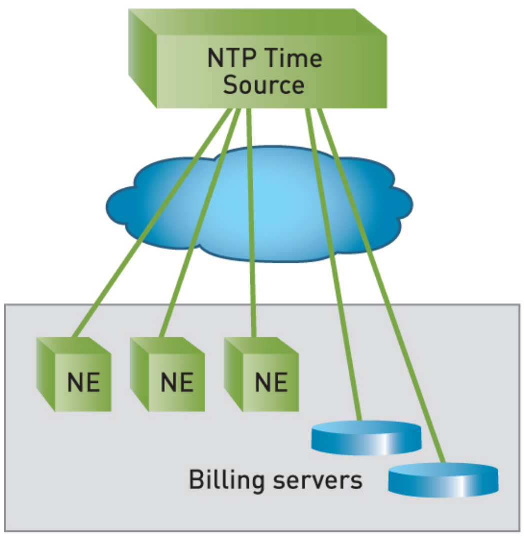
Least Accurate

Stratum 0 (Source that is UTC traceable)
Stratum 1 (Stratum 1 gets time directly from Stratum 0 source)
Stratum 2
Stratum 3
Stratum 4

Distance (number of hops) from Stratum 1

Carrier Class NTP

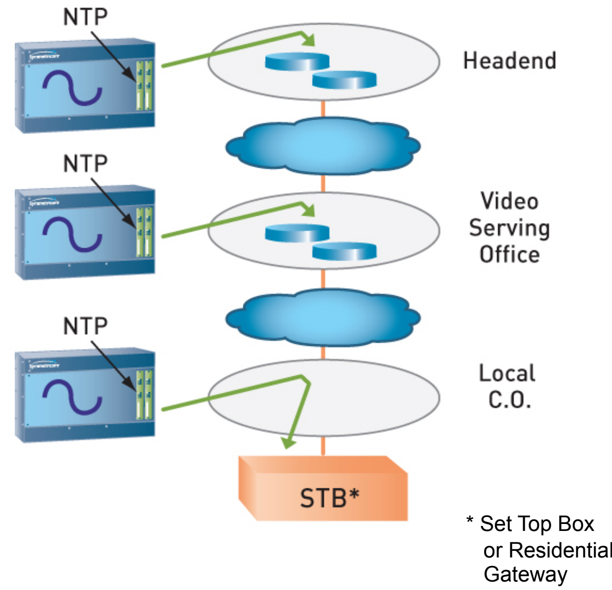
Enterprise NTP



Enterprise/Data Center NTP

- *Best Effort* Delivery
- Accuracy --- 10s of seconds (WAN)
- Enterprise Implementation
- Traceability is Not Assured
- Not secure or authenticated – spoofing
- Not designed for mission critical applications

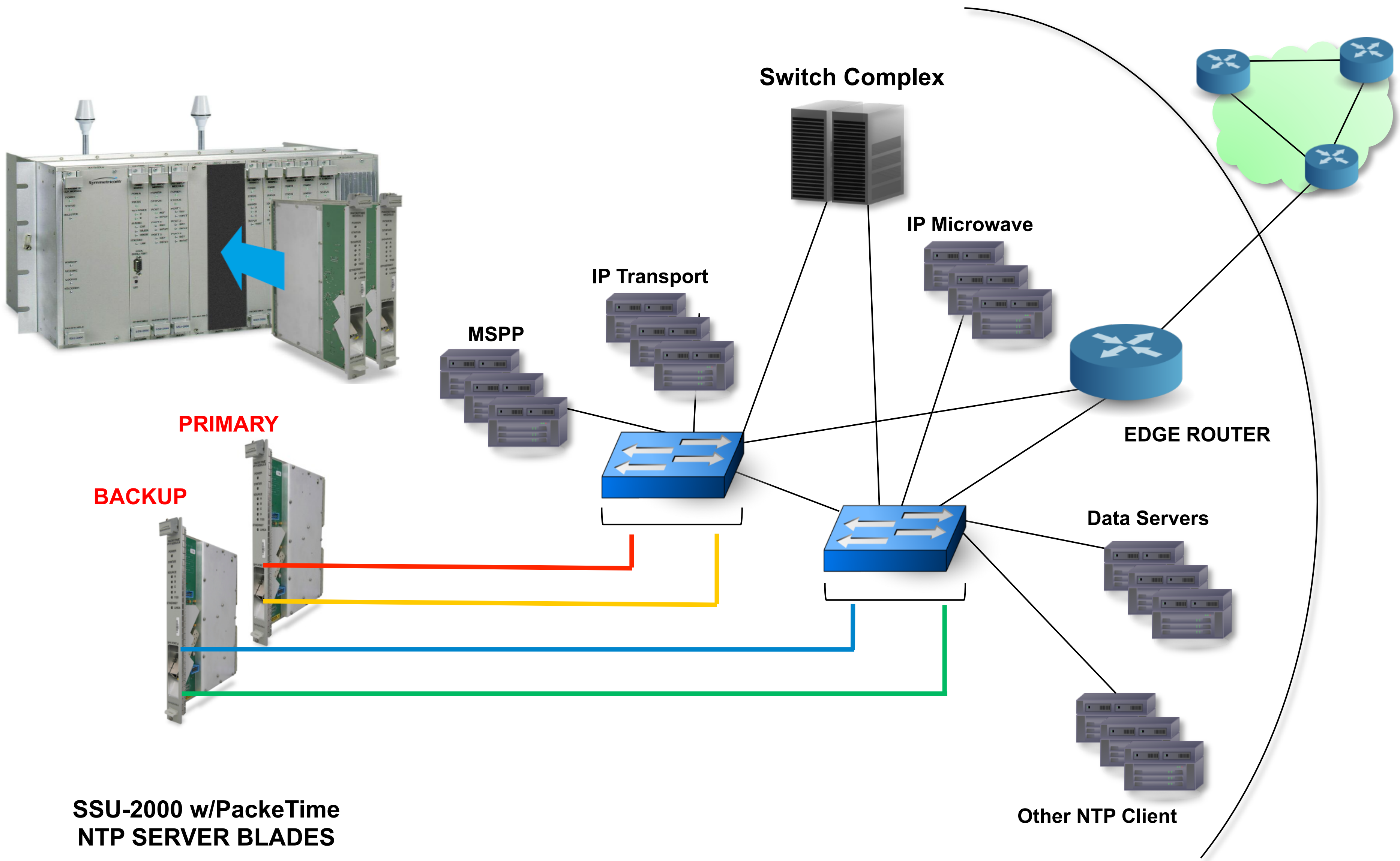
Telecom NTP



Carrier Class NTP

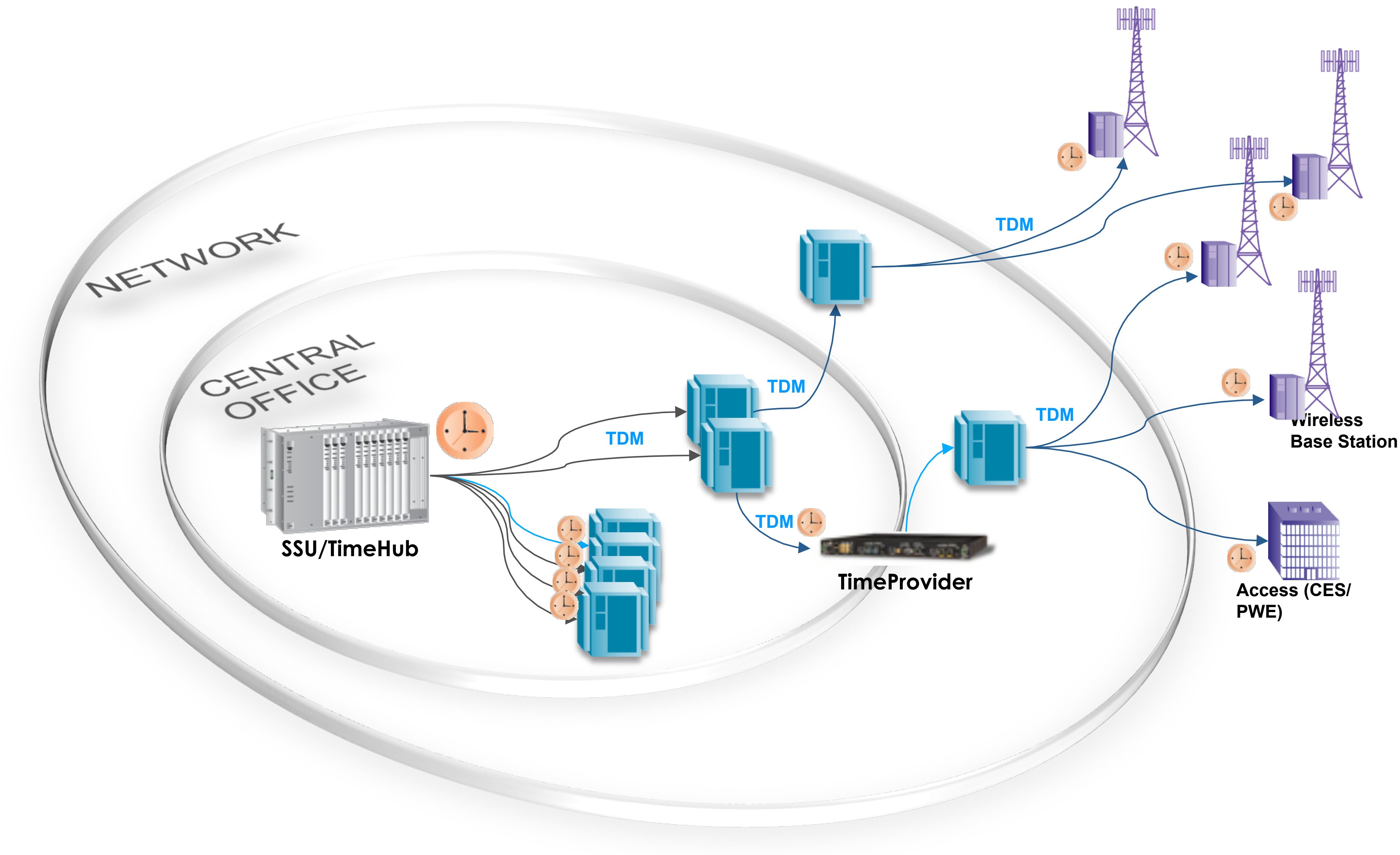
- High Performance, High Accuracy
- UTC Traceable
- Five Nines Availability and Reliability
- Security and Authentication
- Management and Monitoring
- Suitable for mission-critical applications

Carrier-Class Timing Architecture

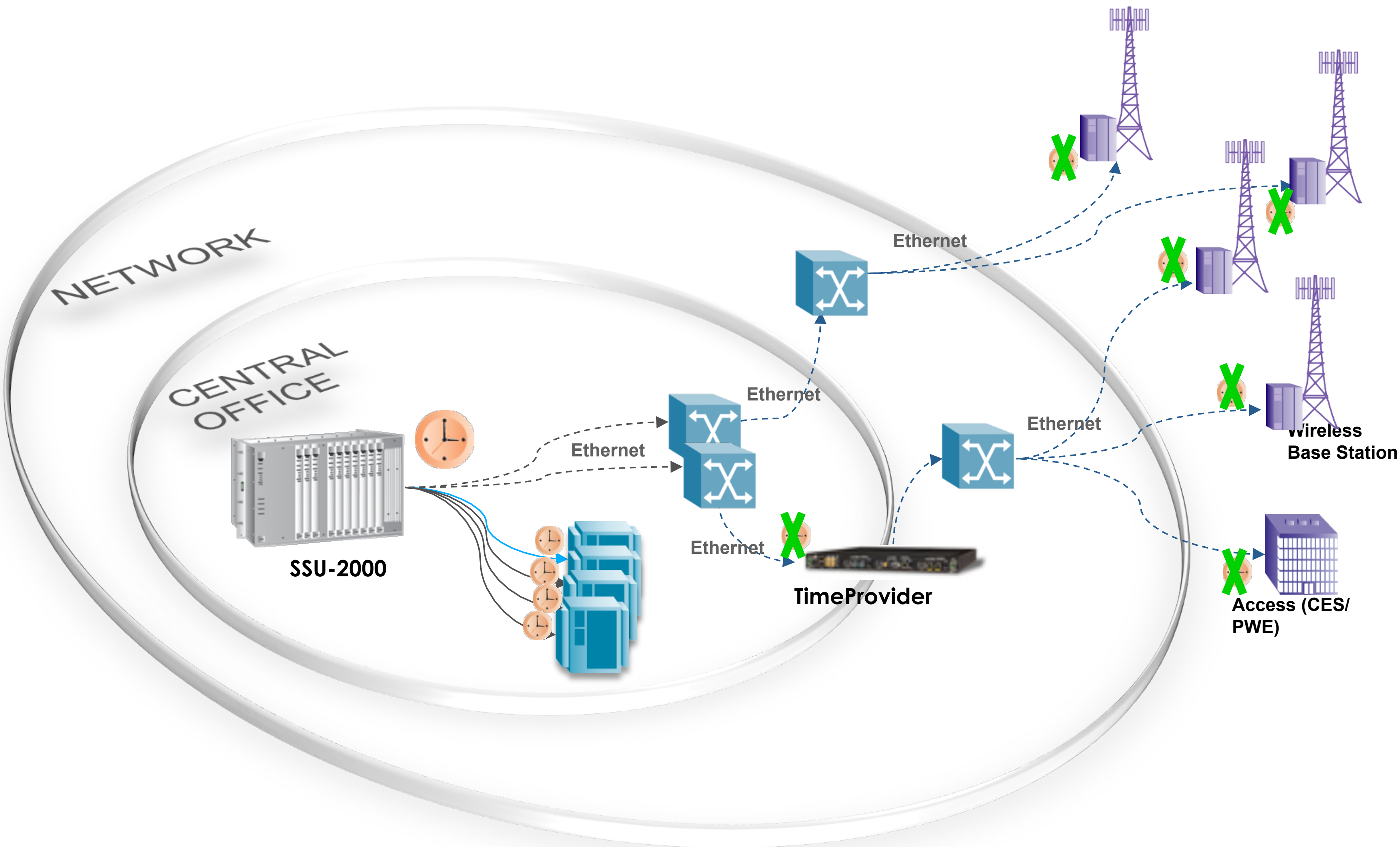


Changing Landscape of Telecommunications

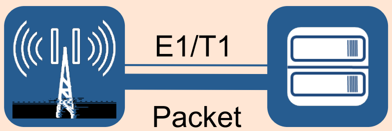
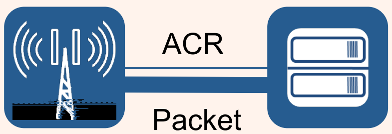
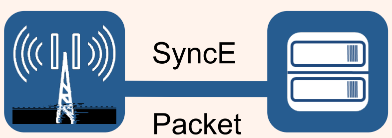
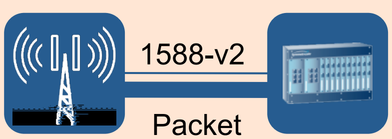
Networks are Transitioning to IP



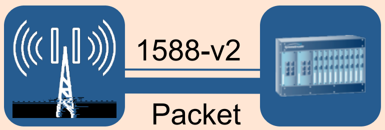
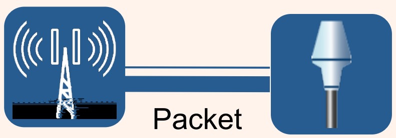
Network Sync Must Transition Too



Frequency Delivery Strategies

Synchronization Strategies	
	**E1/T1 Circuit(s)** Strategy based on use of legacy PDH systems. This method is only applicable to TDM networks.
	**Adaptive Clock Recovery** A vendor specific book-end solution used to support TDMoIP services. ACR methods are not industry standard compliant.
	**GPS Radio** Good performance, supporting wide range of applications. Cost, vulnerability and maintenance issues limit wide scale use.
	**Synchronous Ethernet** An end-to-end solution that mirrors, and is a substitute for, the physical layer frequency distribution schemes of SONET/SDH.
	**IEEE 1588-2008 (PTP)** Layer 2/3 time transfer technology that can deliver frequency and time. Alternative to SyncE for frequency distribution.

Time/Phase Delivery Strategies

Synchronization Strategies	
	**IEEE 1588-2008 (PTP)** Layer 2/3 time transfer technology that can deliver frequency and time. Alternative to SyncE for frequency distribution.
	**GPS Radio** Good performance, supporting wide range of applications. Cost, vulnerability and maintenance issues limit wide scale use.

IEEE 1588-2008 Profiles


IEEE

IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

IEEE Instrumentation and Measurement Society

Sponsored by the
Technical Committee on Sensor Technology (TC-9)

1588™

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

24 July 2008

IEEE Std 1588™-2008
(Revision of
IEEE Std 1588-2002)

IEEE 1588-2008 …

- -2008 defined for **all** applications … barrier to interoperability
- profiles define application related features from the full specification, enabling interoperability

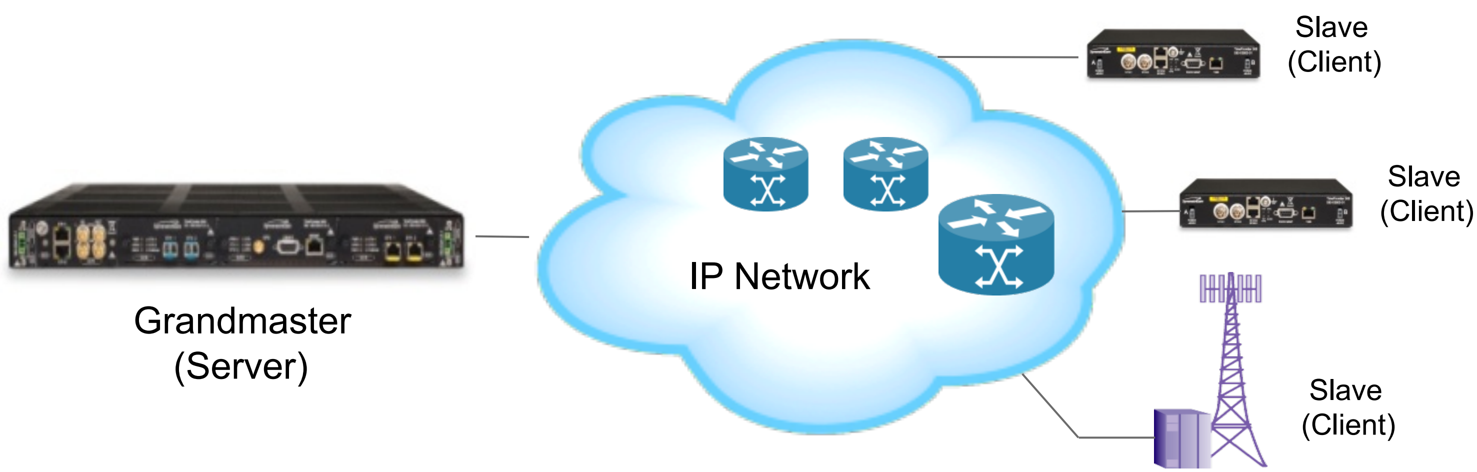
Power Profile
Defined by IEEE PSRC (C37.238)
Substation LAN Applications

Telecom Profile
Defined by ITU-T (G.8265.1)
Telecom WAN Applications

Default Profile
Defined in Annex J. of 1588 specification
LAN/Industrial Automation Application (v1)

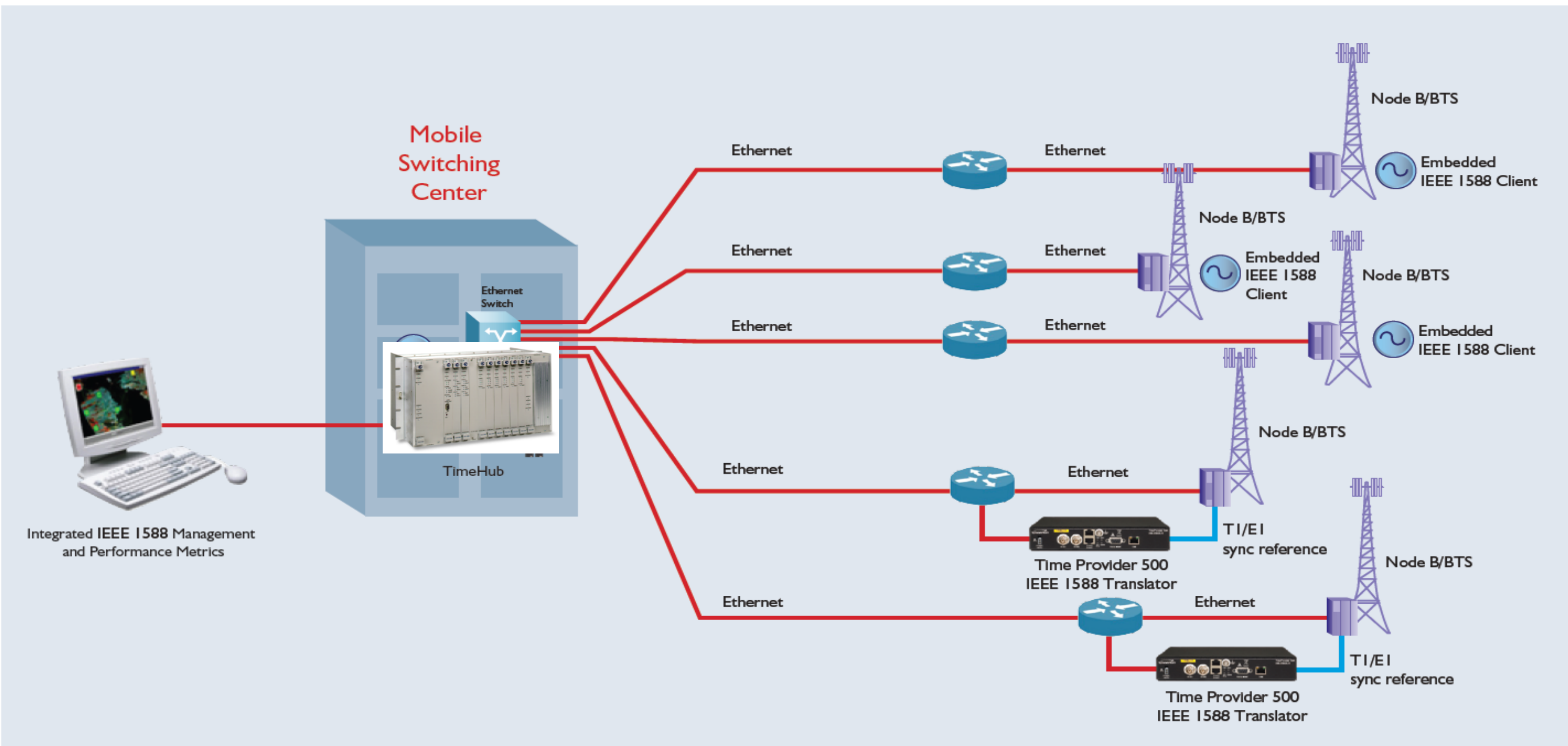
What is IEEE 1588?

- IEEE 1588 is a protocol that enables precise distribution of time and frequency over packet-based networks.
- ► IEEE 1588 was originally for a building/factory, and version-2008 contains enhancements for Telecommunication networks (Telecomm Profile).
- ► The "Server" clock sends a series of messages to slaves to initiate the synchronization process. Clients synchronize themselves to their Server.
- ► *Network equipment manufacturers are building slaves (clients) into their latest equipment, e.g. IP DSLAM, OLT, and eNodeB (LTE base stations).*



IP Sync & Timing with IEEE-1588

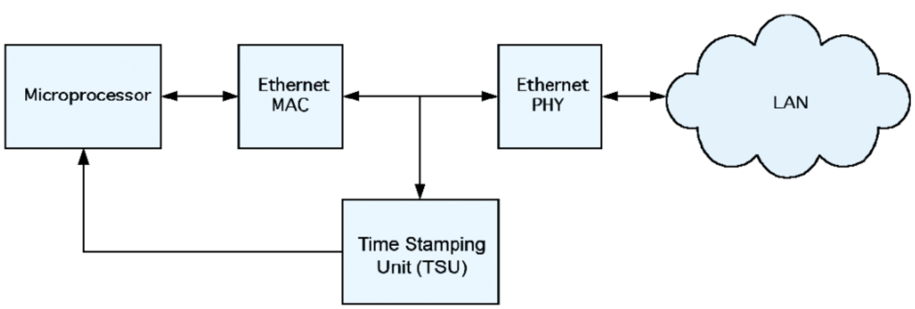
- Any service where synchronization over Ethernet is needed, such as:
  - Wireless Ethernet backhaul (base station synchronization), below
  - Packet PRS - primary reference over IP (IP equivalent of derived OC-N)
  - Enterprise applications requiring synchronization

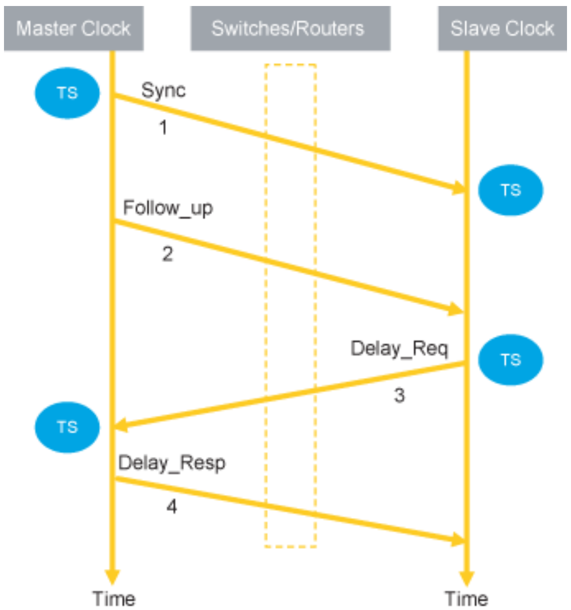


Extra slides that may be of use

How Is Precision Possible?

- Message Exchange Technique
  - Frequent "Sync" messages broadcast between master & slaves, and
  - delay measurement between slaves and master
- Hardware-Assisted Time Stamping
  - Time stamp leading edge of IEEE 1588 message as it passes between the PHY and the MAC
  - Removes O/S and stack processing delays
- Best Master Clock (BMC) Algorithm

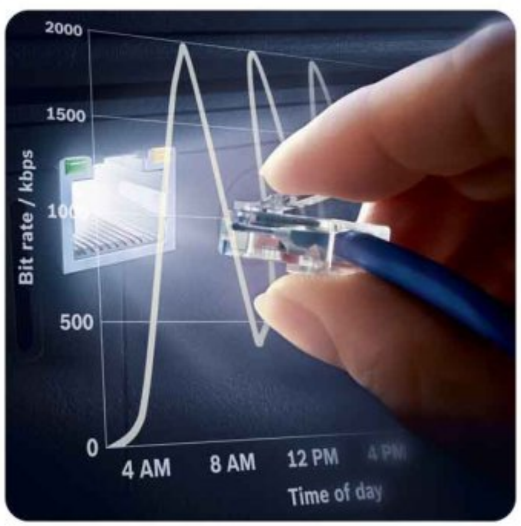




IEEE 1588-2008 Traffic Impact

Message Packet Sizes

• Signaling (request)	96 bytes (54)
• Signaling (ACK/NACK)	98 bytes (56)
• Announce message	106 bytes (64)
• Sync message	86 bytes (44)
• Follow_Up message	86 bytes (44)
• Delay_Resp(onse)	96 bytes (54)
• Delay_Req(uest)	86 bytes (44)



In-band Traffic Rate

Using the following typical values:

• Announce interval	1 per second
• Sync interval	64 per second
• Lease duration	300 seconds
• Delay_Req(uest)	64 per second
• Delay_Resp(onse)	64 per second

Peak traffic transmitted in one second:

(96x3)+(98*3)+106+64x(86+96+86)

= 17840 bytes

= 0.017% of Fast Ethernet (100mbps)

= 0.00166% of GigE

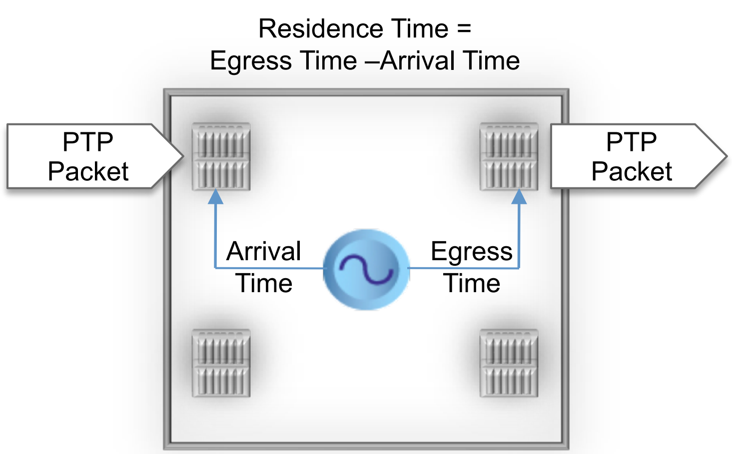
() 1588 only message size in bytes

Introducing IEEE 1588 Elements

- Ordinary Clocks
  Grandmaster & Slave (client)
- Boundary Clock
  Regenerates PTP message, eliminating earlier path delays
  (Switch with a built-in clock)
- Transparent Clock
  Adjusts the *correction field* in the *sync* and *delay_req* event messages
  (Switch with ability to measure packet residence time)
- Management Node
  Human/programmatic interface to PTP management messages

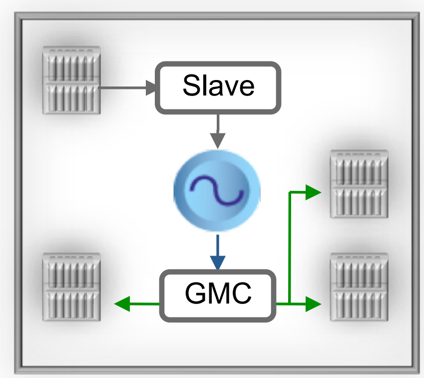
On-Path Support

- **Transparent Clock** , Switch not a Clock
  - Measures 1588 packet delay inside the switch (residence time)
  - Modifies (adds) residence time to the *correction field* in the 1588 message
  - Limited to non-encrypted networks
  - *Correction field* must be accurate



Transparent Clock

- **Boundary Clock**, Switch with built-in clock
  - Internal clock synchronized via 1588 to the upstream master
  - Regenerates 1588 messages
  - Slave on 1 port, master on other ports
  - Interrupts the Sync flow
  - The burden of holdover, reliability and traceability is on the boundary clock



Boundary Clock

IEEE 1588-2008 Message Overview

The Grandmaster (Server) sends the following messages:

- *Signaling* (2 types)
  - Acknowledge TLV (ACK)
  - Negative Acknowledge TLV (NACK)
- *Announce* message
- *Sync* message
- *Follow_Up* message
- *Delay_Resp*(onse)

Message Headers entering the PHY are the “on-time” marker

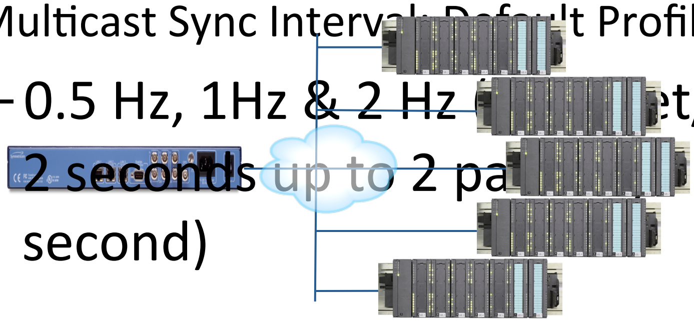
The Slave (Client) sends the following messages:

- *Signaling* (3 types)
  - Request announce
  - Request sync
  - Request delay_resp(onse)
- *Delay_Req*(uest)

IEEE 1588 Routing Options

Multicast

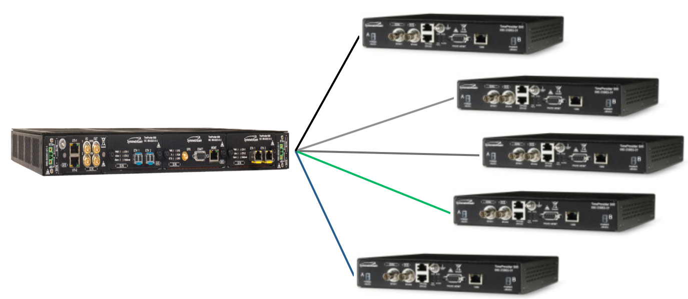
- Grandmaster broadcasts PTP packets to a Multicast IP address
- Switches/Routers…
  - With IGMP snooping, forwards multicast packets to subscribers
  - Else traffic broadcast to all ports
- Multicast Sync Interval; Default Profile:
  - 0.5 Hz, 1Hz & 2 Hz [illegible]et/ 2 seconds up to 2 pa[illegible] second)



Multicast (1:group)

Unicast

- Grandmaster sends PTP packets directly to PTP slaves
- Switches/Routers forward PTP packets directly to slaves
- Unicast Sync Interval; Telecom Profile:
  - User defined Sync interval up to 128Hz
  - Many subscribers supported



Unicast (1:1)

SLA for PTP Flow

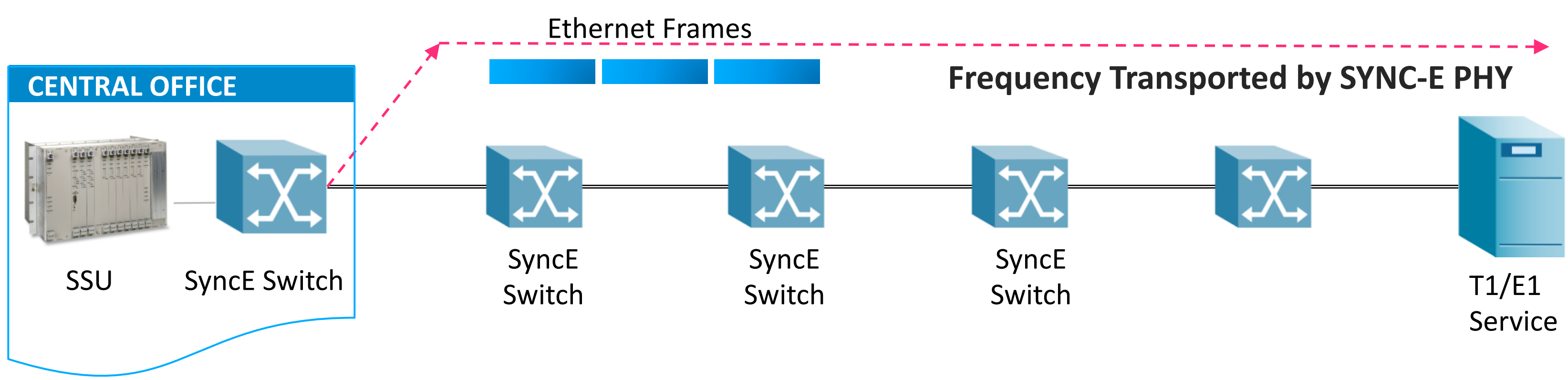
Bandwidth Capacity	Maximum Loading	Intermittent Congestion	QoS	Hop Count	Switch Attributes
Minimum 1GigE (Core)	80% Average	100% load for less than 100s	Highest Priority	Frequency (10 hops) Time (5 hops)	Hardware Forwarding QoS

Jitter (Highest Priority Traffic QoS)
250 us to 10 ms PTP client algorithms use only a fraction of total packets, the ones with the best quality (low PDV). Packets with high PDV are not used. So high jitter can be tolerated if the distribution of the jitter includes sufficient high quality packets.

SyncE Overview

What is Synchronous Ethernet?

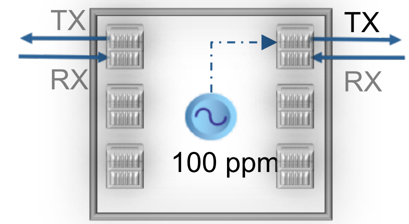
- Schema that transports frequency at the Ethernet physical layer
- Implemented in the IP transport element hardware, i.e. SyncE enabled
- End to End scheme similar to SONET, synch traceable to office PRS
- All switches must be SyncE enabled to transport synchronization
- ITU-T G.8261, G.8262 and G.8264 define Synchronous Ethernet



SyncE Overview

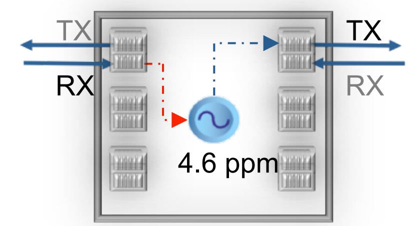
How is SyncE different from normal Ethernet?

Standard Ethernet PHY (Physical Layer)

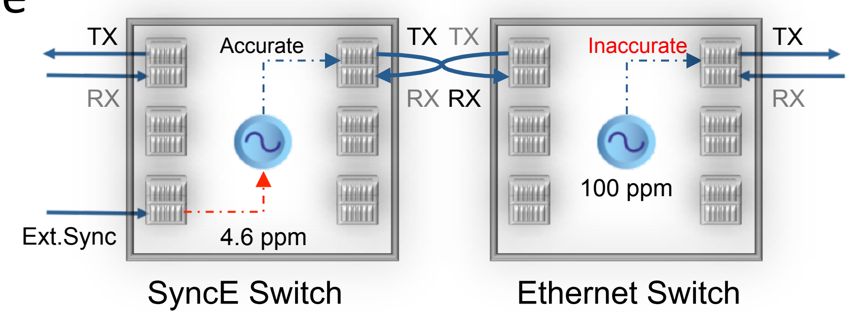


- Rx uses the incoming line time. Tx uses the built-in 100ppm clock
- *No relationship between the Rx & Tx*

SyncE PHY (Physical Layer)



- Rx disciplines the internal oscillator (4.6ppm)
- Tx uses the traceable clock reference, creating end-end scheme
- As with SONET the PRS provides the reference
- SyncE and standard Ethernet switches cannot be mixed



- Extra slides that may be of use.

Commonly Used Terms

Meanings of common terms used in IEEE 1588	
Boundary clock	A boundary clock is a clock with more than a single PTP port, with each PTP port providing access to a separate PTP communication path. Boundary clocks are used to eliminate fluctuations produced by routers and similar network elements.
Clock	A device providing a measurement of the passage of time since a defined epoch. There are two types of clocks in 1588: boundary clocks and ordinary clocks.
Clock timestamp point	1588 requires the generation of a timestamp on transmission or receipt of all 1588 Sync and Delay_Req messages. The point in the outbound and inbound protocol stacks where this timestamp is generated is called the clock timestamp point.
Direct communication	The communication of PTP information between two PTP clocks with no intervening boundary clock is termed a direct communication.
External synchronization	It is often desirable to synchronize a single clock to an external source of time, for example to a GPS system to establish a UTC time base. This synchronization is accomplished by means other than those specified by 1588 and is referred to as external synchronization
Epoch	The reference time defining the origin of a time scale is termed the epoch.
Grandmaster clock	Within a collection of 1588 clocks one clock, the grandmaster clock, will serve as the primary source of time to which all others are ultimately synchronized.
	http://ieee1588.nist.gov/terms.htm

Commonly Used Terms

Meanings of common terms used in IEEE 1588	
Master clock	A system of 1588 clocks may be segmented into regions separated by boundary clocks. Within each region there will be a single clock, the master clock, serving as the primary source of time. These master clocks will in turn synchronize to other master clocks and ultimately to the grandmaster clock.
Message timestamp point	1588 Sync and Delay_Req messages contain a distinguished feature, the message timestamp point, serving as a reference point in these messages. When the message timestamp point passes the clock timestamp point, a timestamp is generated that is used by 1588 to compute the necessary corrections to the local clock
Ordinary clock	A clock that has a single Precision Time Protocol (PTP) port in a domain and maintains the timescale used in the domain. It may serve as a source of time, i.e., be a master clock, or may synchronize to another clock, i.e., be a slave clock.
Preferred master clock set	1588 allows the definition a set of clocks that will be favored over those not so designated in the selection of the grandmaster clock.
PTP	PTP is an acronym for Precision Time Protocol, the name used in the standard for the protocol.
PTP domain	A PTP domain is a collection of one or more PTP sub domains. A sub domain is a logical grouping of 1588 clocks that synchronize to each other using the PTP protocol, but that are not necessarily synchronized to PTP clocks in another PTP sub domain. Sub domains provide a way of implementing disjoint sets of clocks, sharing a common network, but maintaining independent synchronization within each set.
	http://ieee1588.nist.gov/terms.htm

Commonly Used Terms

Meanings of common terms used in IEEE 1588	
PTP message	There are five designated messages types defined by 1588: Sync, Delay_Req, Follow-up, Delay_Resp, and Management
Multicast communication	1588 requires that PTP messages be communicated via a multicast. In this style of communication any node may post a message and all nodes in the same segment of a sub domain will receive this message. Boundary clocks define the segments within a sub domain.
PTP port	A PTP port is the logical access point for 1588 communications to the clock containing the port.
Synchronized clocks	Two clocks are synchronized to a specified uncertainty if they have the same epoch and measurements of any time interval by both clocks differ by no more than the specified uncertainty. The timestamps generated by two synchronized clocks for the same event will differ by no more than the specified uncertainty.
	http://ieee1588.nist.gov/terms.htm

Synchronization Impact

Application	Frequency	Phase	Need for Compliance	Impact of Non-compliance
LTE (FDD)	16 ppb	N/A	Hand-off	Dropped calls
LTE (TDD)	16 ppb	± 1.5 µs Time difference	Time slot alignment	Interference, Bandwidth efficiency
LTE MBSFN	16 ppb	± 32 µs inter-cell Time difference	Coherent video signal from multiple eNodeB	Video service degradation
LTE-A MIMO/CoMP	16 ppb	± 0.5 µs inter-cell Time difference	Coordination of signals from multiple eNodeB	Slower throughput and Poor signal quality at edge of cells, Accuracy of LBS

LTE Synchronization

Application	Frequency (Air Interface)	Time /Phase	Why You Need to Comply	Impact of Non-compliance
LTE (FDD)	50 ppb	N/A	Call Initiation	Call Interference Dropped calls
LTE (TDD)	50 ppb	+/- 1.5 µs Time difference	Time slot alignment	Packet loss/collisions Bandwidth efficiency
LTE MBSFN	50 ppb	+/- 32 µs inter-cell Time difference	Proper time alignment of video signal decoding from multiple BTSs	Video broadcast interruption
LTE-A MIMO/COMP	50 ppb	+/- 500 ns (0.5 µs) inter-cell Time difference	Coordination of signals to/from multiple base stations	Poor signal quality at edge of cells
WiMAX (TDD) includes Femtocell	2 ppm absolute, ~50 ppb between base stations	Typically 1 -8 µs	Time slot alignment	Packet loss/collisions Bandwidth efficiency

Frequency and Time Specifications

Application	Frequency: Transport / Air Interface	Phase
GSM / UMTS / W-CDMA	16 ppb / 50 ppb	N/A
UMTS/ W-CDMA Femtocells	n/a / 200 - 250 ppb	
GSM, UMTS, LTE Network Interface	16 ppb / 50 ppb	
CDMA2000	16 ppb / 50 ppb	+/-3 – 10 µs
TD-SCDMA	16 ppb / 50 ppb	+/- 1.5 µs
LTE (FDD)	16 ppb / 50 ppb	N/A
LTE (TDD)	16 ppb / 50 ppb	+/- 1.5 µs small cell, +/- 5µs large cell
LTE MBSFN	16 ppb / 50 ppb	+/- 1-32 µs, implementation dependent
LTE-A CoMP (Network MIMO)	16 ppb / 50 ppb	+/- 500 ns (0.5 µs), pre-standard
WiMAX (TDD)	16 ppb / 50 ppb	+/-1 - 8 µs, implementation dependent