The Path Towards Accurate, Reliable Timing for TD-LTE & LTE-A

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WSTS 2013
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CTO, Vitesse Semiconductor

Agenda

TD-LTE & LTE-A Mobile Access

- Status of LTE rollouts
- The role of small cells
- Why IEEE 1588 network timing is required

State-of-the-Art in IEEE 1588

- Impairments impacting IEEE 1588 accuracy
- The expanded mitigation toolbox
- What is possible using all these technologies

What We Still Need To Do

- Not all IEEE 1588 equipment is created equal
- The case for timing equipment classes
- How to upgrade existing networks?

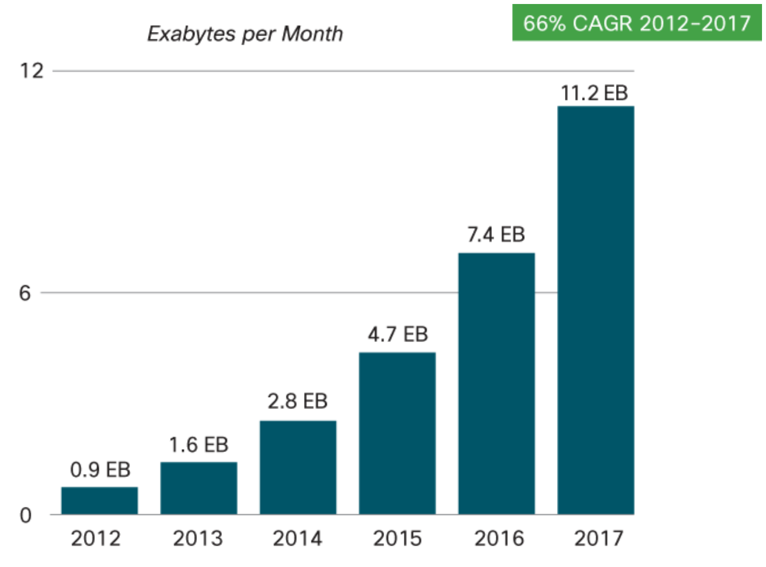
Tremendous Explosion of Mobile Data Traffic

Historically…and in the future

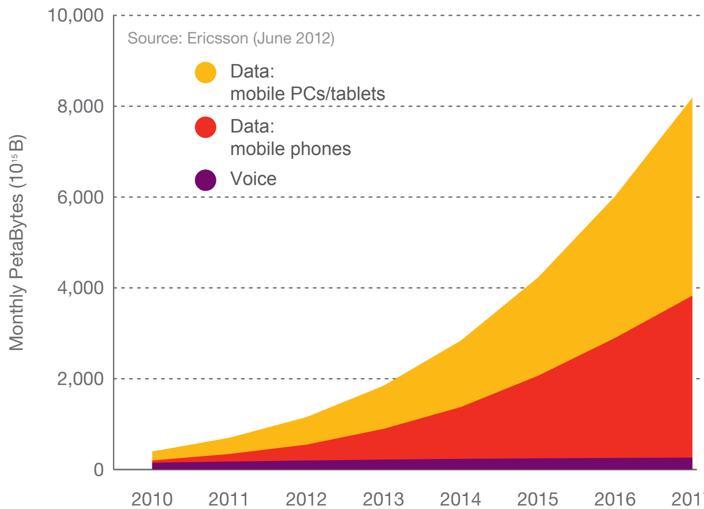
Global mobile data traffic grew 70 % in 2012

Mobile video traffic exceeded 50% for the first time in 2012

Although 4G connections represent only 0.9% of mobile connections today, they already account for 14% of mobile data traffic



Source: Cisco VNI Mobile Forecast, 2013



Service Provider LTE Investment Timeline

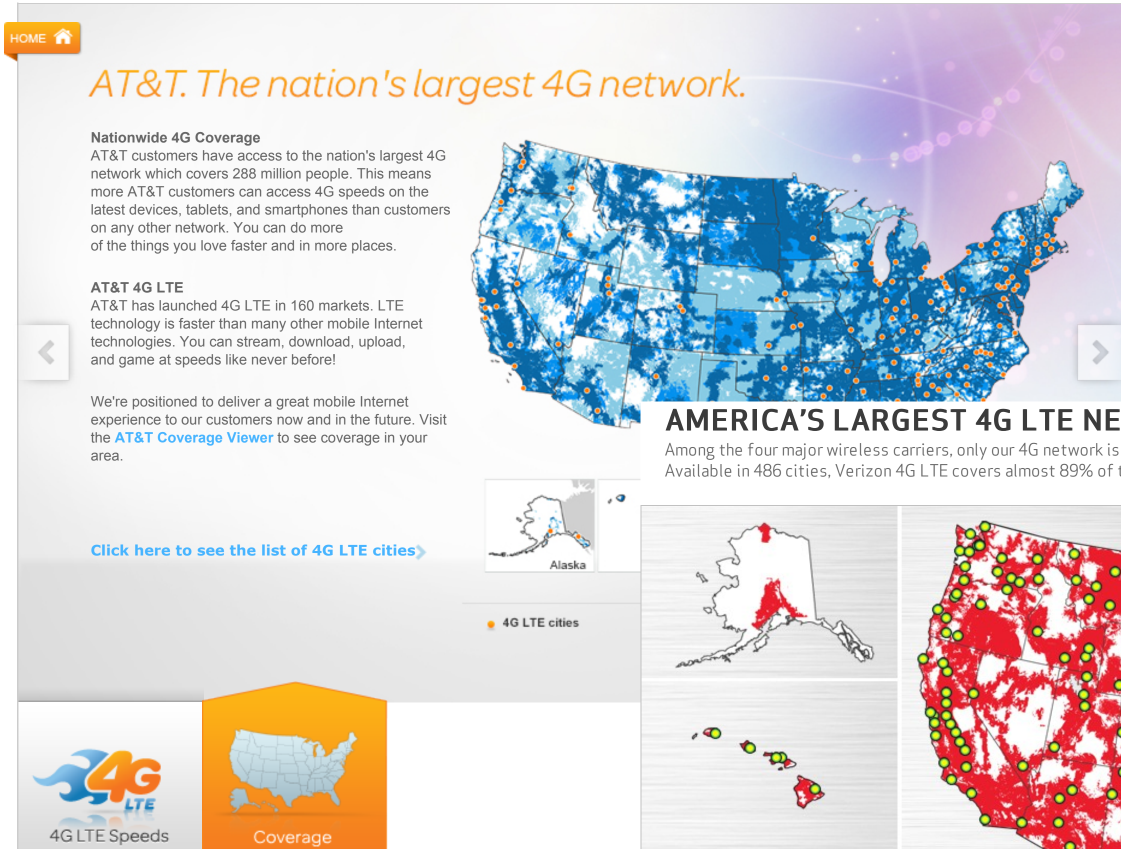
Macro Consolidation
(Software-defined Radios)

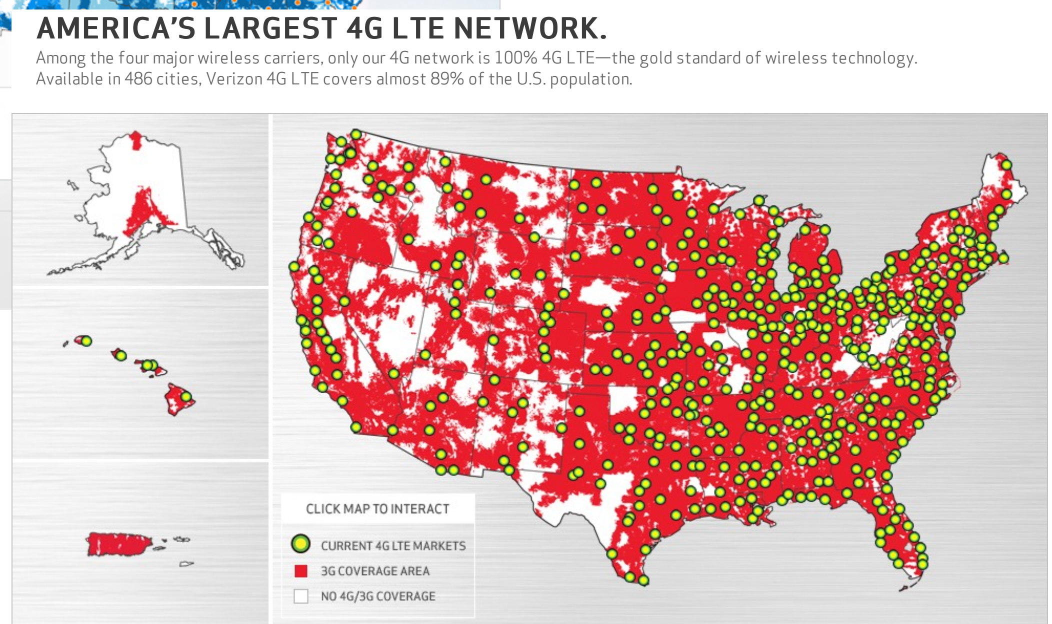
LTE Rollouts:
Backhaul Transition to IP/Ethernet

TD-LTE & LTE-Advanced

Latest investment cycle started in 2009 and will last through 2015/2016 (Infonetics)

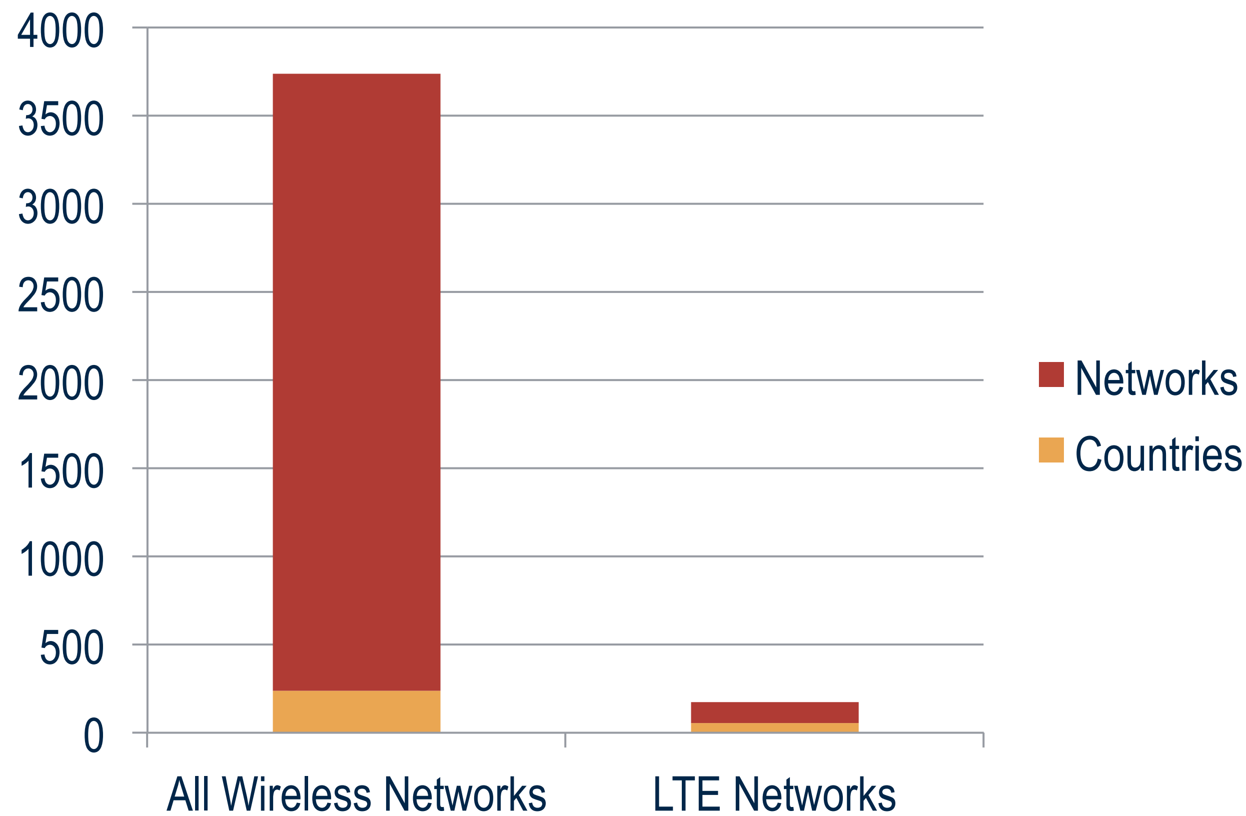
Current 4G/LTE Focus Is Still Only On Coverage





What happens when many people have LTE handsets and tablets?

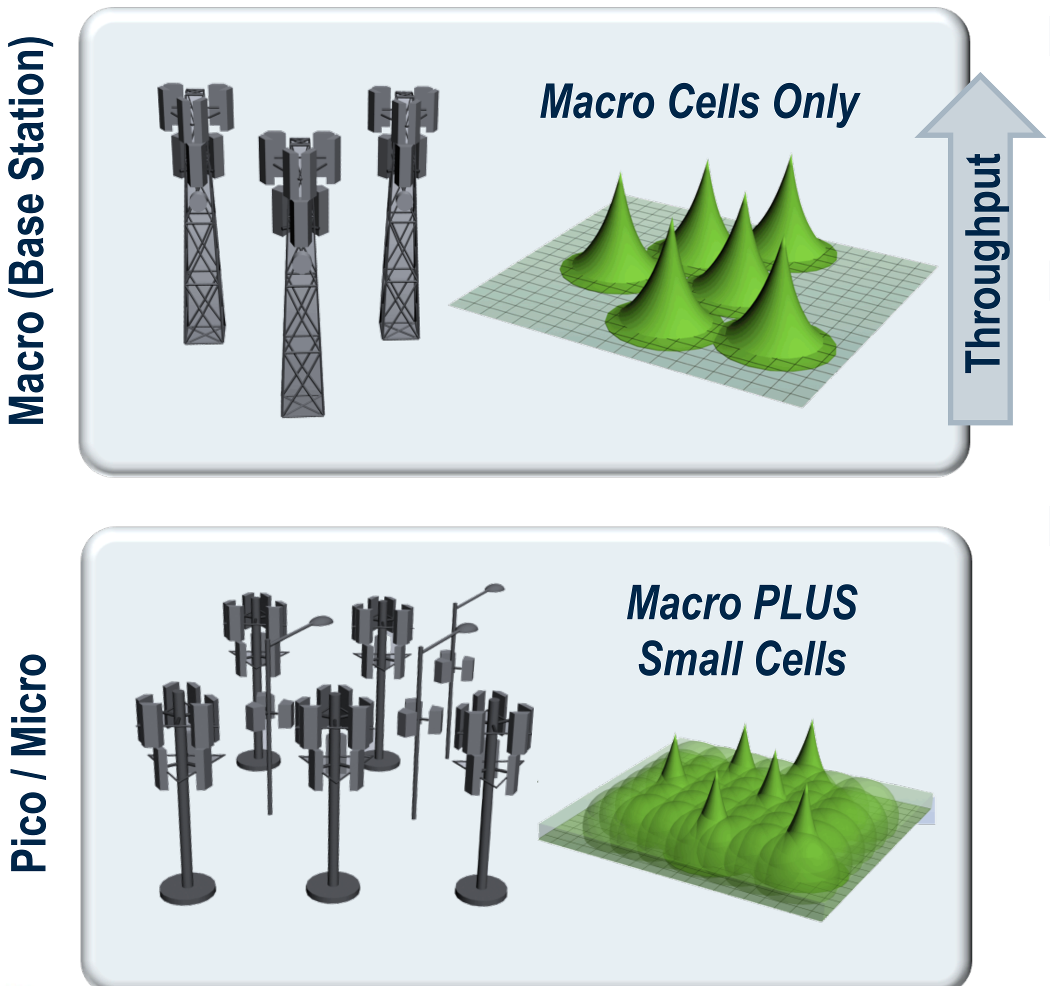
Real Data On LTE Rollouts



Even in the US, only 4% (27M) of all 345M wireless connections are LTE

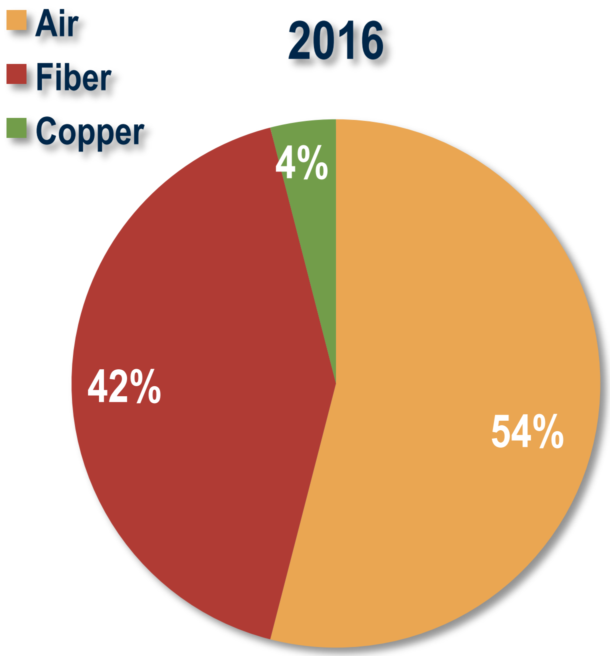
Source: Wireless Intelligence 2013

Small Cells Required To Deliver LTE Capacity



- Today's LTE rollouts focused on coverage, not capacity
- Small (Pico) Cells required when more LTE device deployed
- Small Cells allow spatial re-use of the same spectrum

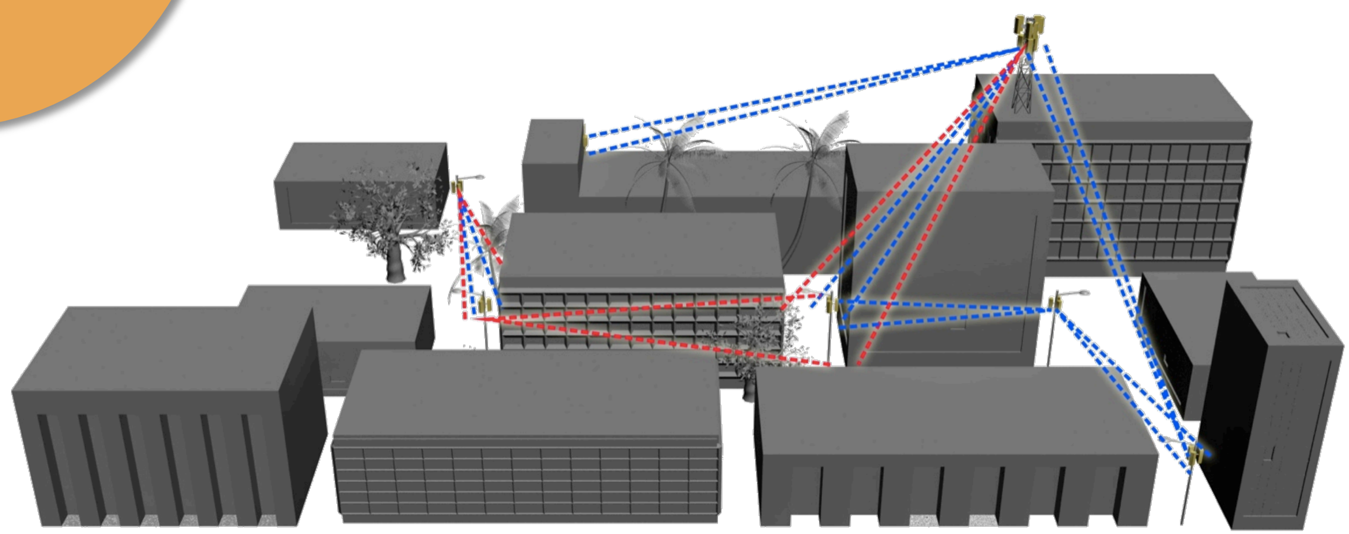
Diverse Backhaul Technologies For Small Cells



Source: Infonetics

- Backhaul can be fiber, microwave, or copper
- >85% of Small Cells will be connected by Micro- or Millimeter-wave (Infonetics)

Network Timing over Microwave more difficult than over Fiber



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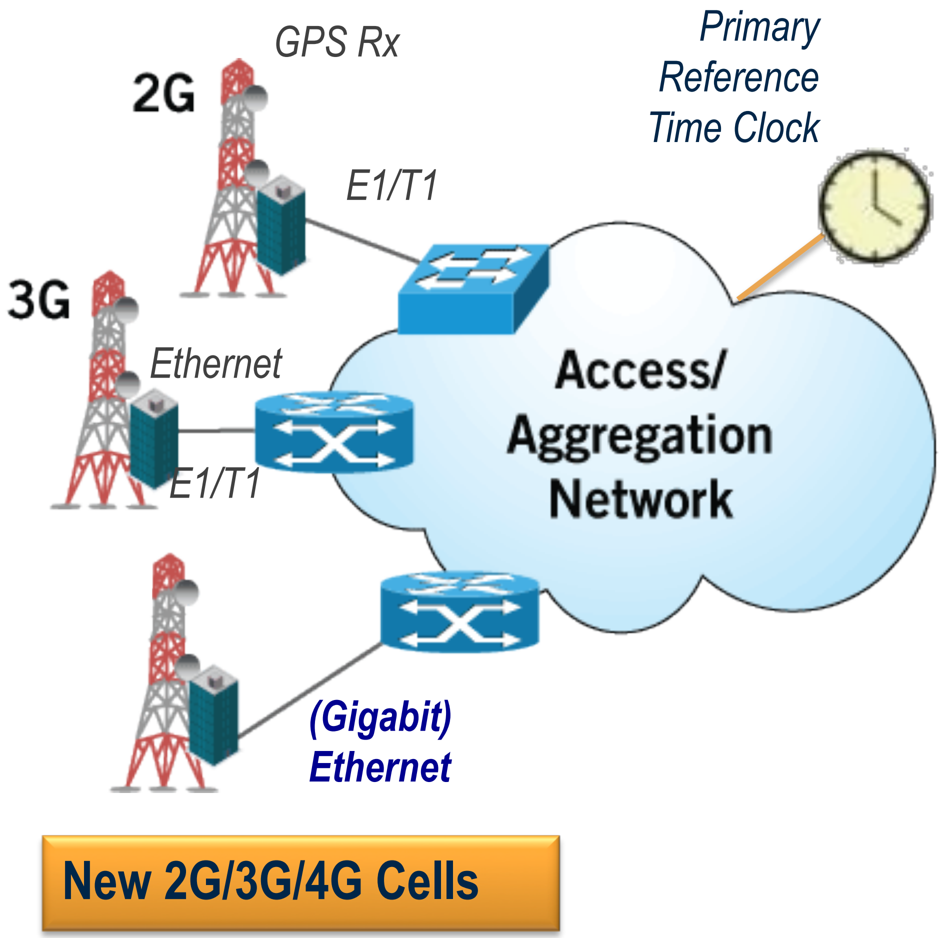
Small Cell Backhaul
With New Footprint & Functionality

INTEGRATED NETWORKING & LOWER POWER

- **Not enough space/power for separate cell-site gateway**
- **Integrated network functions for daisy chain and partial mesh**
  - MEF CE2.0 Service Awareness and Manageability
  - Q-in-Q or MPLS EVCs
  - H-QoS Flow Control & Congestion Avoidance
  - Multi-operator OAM
  - Per-EVC Protection
  - Packet Network Timing
- **10W -15W power envelope requires low power networking silicon**

Photo courtesy of BridgeWave Communications

New Base Stations Require New Timing Models



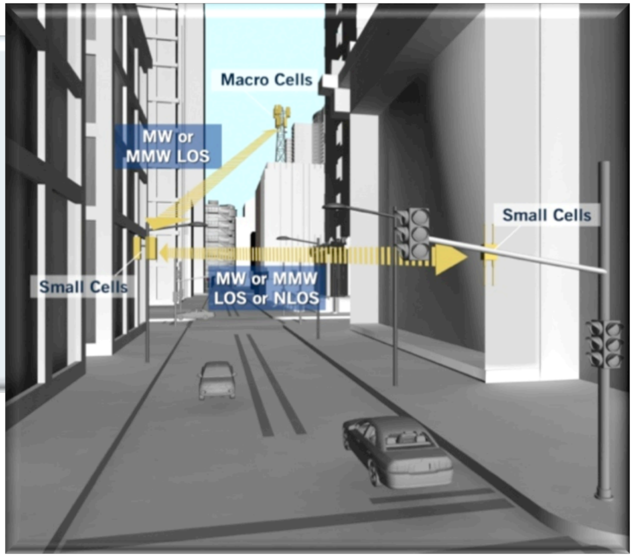
- For 2G/3G, E1/T1 backhaul also provided (frequency) synchronization

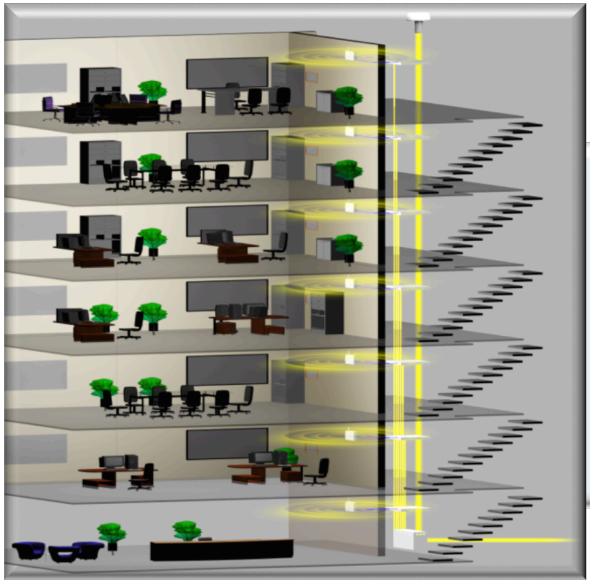
- New base stations use Gigabit Ethernet for backhaul
- TD-LTE and LTE-A need phase in addition to frequency synch

GPS Not Viable In Many New LTE Deployments

Outdoor Small Cells

- Small Cells to deliver LTE capacity
- Often no line of sight to GPS satellites
- More vulnerable to attacks at street level





Indoor Picocells

- Picocells or Enterprise Femtocells for LTE indoor coverage & capacity
- Can't get timing to Femtocells using GPS

GNSS/GPS Outages Are Quite Common

Antenna Failures/Damages

Widely Available GPS Jammers

Lightning Storms

TD-LTE and LTE-A Require Phase and Time

Application	Frequency *Transport / Air Interface*	Phase / Time *Air Interface*
	ITU-T G.8261 Network Target / 3GPP Max Error	
GSM / UMTS / W-CDMA	16 ppb / 50 ppb	None
UMTS / W-CDMA Femtocells	n/a / 250 ppb	
	ITU-T G.8261 Network Target / 3GPP Max Error	Suggested Network Target / 3GPP Max Error
CDMA2000	16 ppb / 50 ppb	± 3 to 10 µs
TD-SCDMA	16 ppb / 50 ppb	± 1.5 µs
	ITU-T G.8261 Network Target / 3GPP Max Error	Suggested Network Target / 3GPP Max Error
LTE (FDD)	16 ppb / 50 ppb	None
LTE (TDD)	16 ppb / 50 ppb	± 1.5 µs
LTE-A MBSFN	16 ppb / 50 ppb	± 1 to 32 µs
LTE-A Hetnet Co-ordination	16 ppb / 50 ppb	± 5 µs
LTE-A CoMP (Network MIMO)	16 ppb / 50 ppb	± 500ns

Consequences of Not Meeting Timing Specs

- Dropped calls
- Packet loss and collisions
- Poor coverage at cell boundaries
- Reduced data throughput
- Video broadcast interruption

Critical to meet Timing Specifications to maximize Investment Returns

Air Interface Phase Accuracy Specs

CDMA2000	3-10 µs
TD-SCDMA	1.5 µs
LTE Hetnet	5 µs
TD-LTE	1.5 µs
LTE-A	500 ns

IEEE 1588-2008
State of the Art

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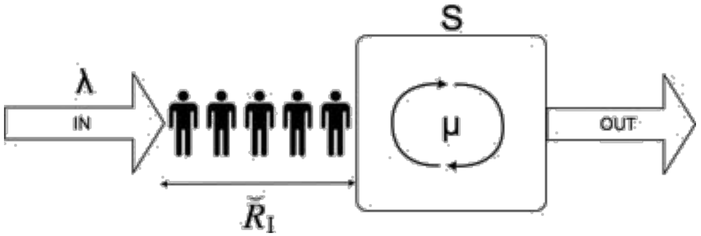
Factors That Impair PTP Time & Phase Accuracy

Upstream/downstream packet delay asymmetries translate directly into time & phase errors

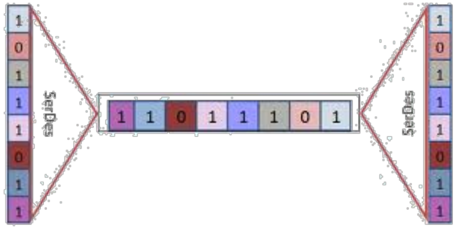
- Packet queuing and forwarding
- Modem latency variations
- OTN/FEC & Encryption
- Link asymmetries & I/O serialization delay variations

Link Asymmetries (10-100ns)

Queuing & Forwarding (10-100µs)

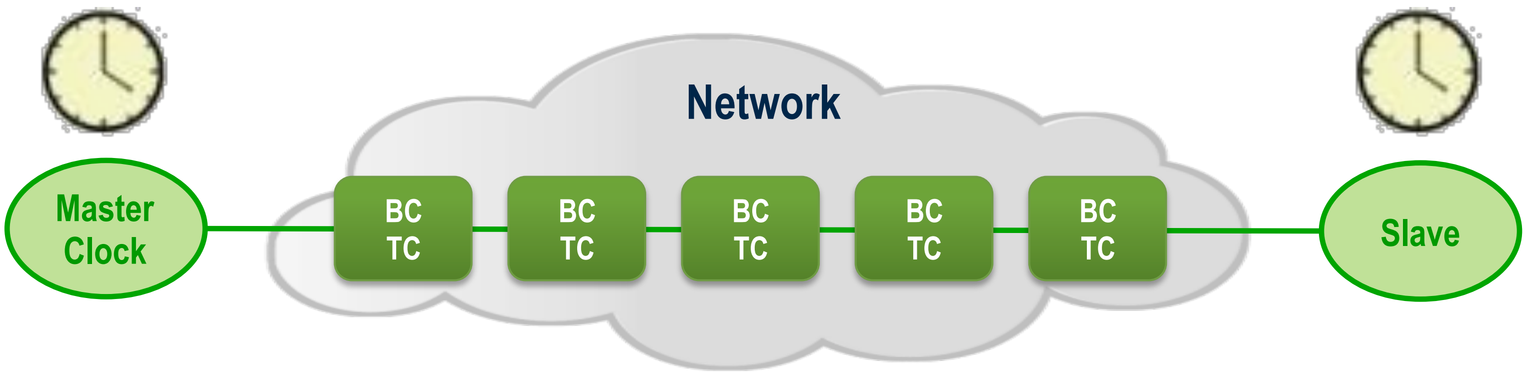


I/O Serialization (10-100ns)



Queuing and forwarding delay asymmetries alone can be >100µs, blowing LTE phase accuracy requirements by 2 orders of magnitude

Boundary And Transparent Clocks To The Rescue



Boundary Clock (BC)

- Recovers clock from the master, and regenerates clock towards next node
- Can be combined with Time Stamping at the PHY level to eliminate I/O serialization PDV

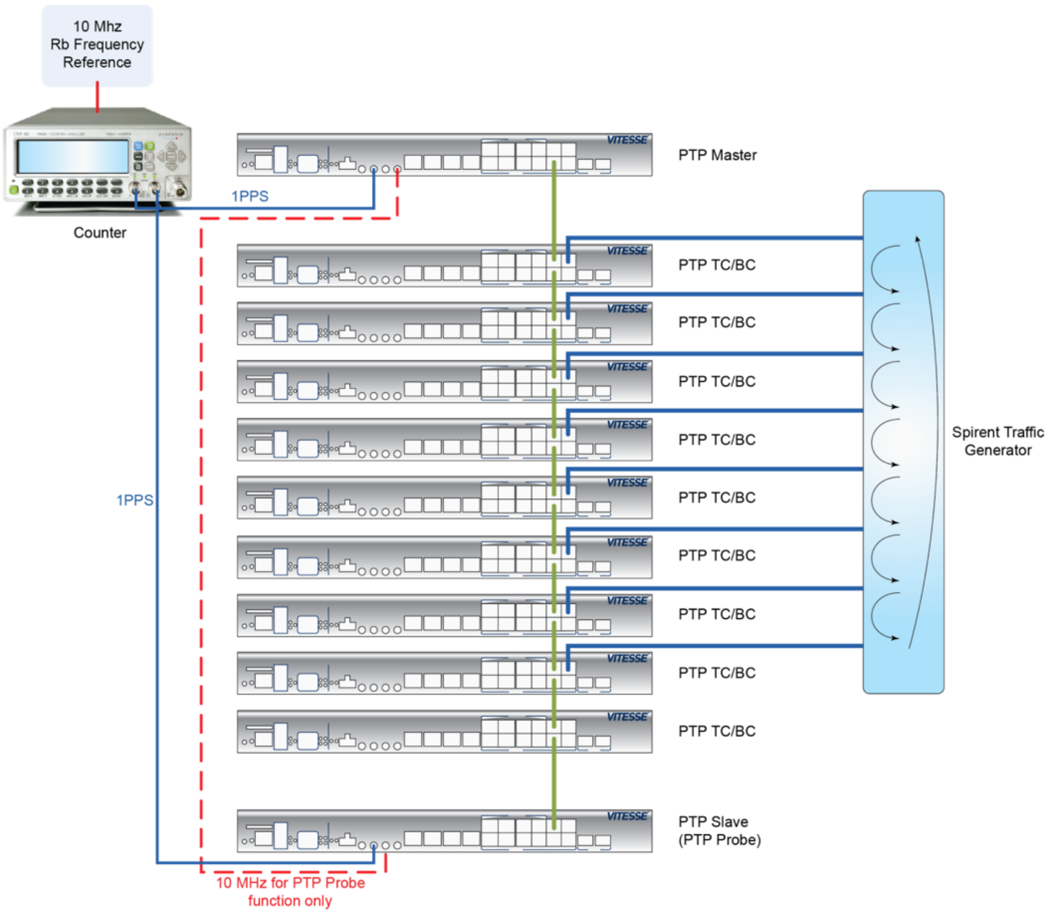
Transparent Clock (TC)

- Simply corrects the Sync packet time stamp for residence time in the node
- Can be implemented solely at the PHY level if desired

The expanded IEEE 1588 Toolbox for Accuracy

- **Very sophisticated Hardware Timestamping Engine (VeriTime™)**
  - Nanosecond Accuracy and Stability
  - Low-wander timing architecture
  - Multi-protocol classification engine even for Timing PHYs (SynchroPHY™)
- **Distributed BC/TC Clocks**
  - E.g. Timestamping on Line Cards and central Timing & Control Complex
  - Solving specific implementation issues like T3 timestamp collection
  - Distributed Transparent Clocks across a Link (for example across a MW link)
- **Predictor Algorithms**
  - Predict packet-by-packet delay when time stamping occurs before PDV
  - Correct for PDV using the offset field in the PHYs (packet-by-packet)
  - Examples: 1588 over OTN/FEC and 1588 with MACsec Encryption (Intellisec™)

BC vs. TC Systems Testing
Using Vitesse VeriTime™ 1588 Technology



Configuration Details

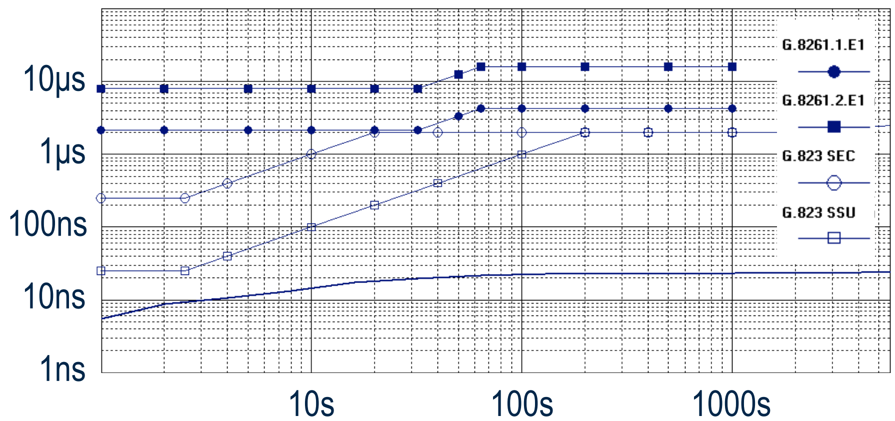
PTP Network Equipment:
VSC5619EV Carrier Ethernet NID Reference Design

- All Interfaces are 1G SFP
- 1-step PTP using Ethernet Encapsulation
- TCs running E2E without Syntonization
- Sync frame rate: 16 FPS
- Background traffic:
  - Forward traffic: 80% load, random frame size
  - Reverse traffic: 50% load, random frame size

Serval™ Switch-based Carrier Ethernet NID Reference Design

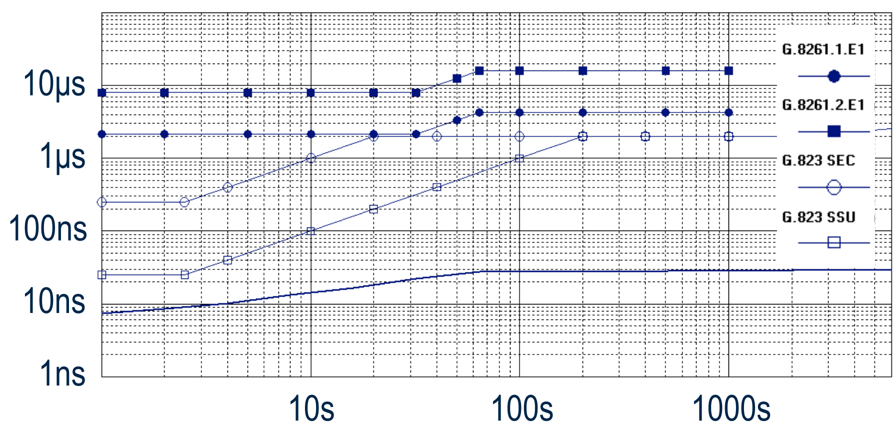
1PPS MTIE Plots

Chain of 9 TCs with Vitesse VeriTime™ 1588 on-path support



- 5ks MTIE below 24ns; down to 17ns w/ SyncE support
- TDEV below 2ns at all times

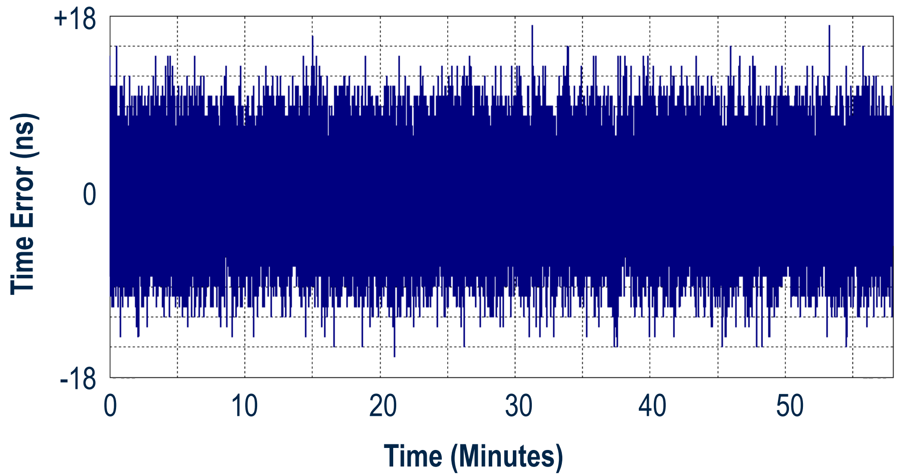
Chain of 9 BCs with Vitesse VeriTime™ 1588 on-path support



- 5ks MTIE below 30ns w/ SyncE support, but goes up to 75ns without SyncE
- TDEV below 3ns at all times, but goes up to 10ns w/o SyncE support

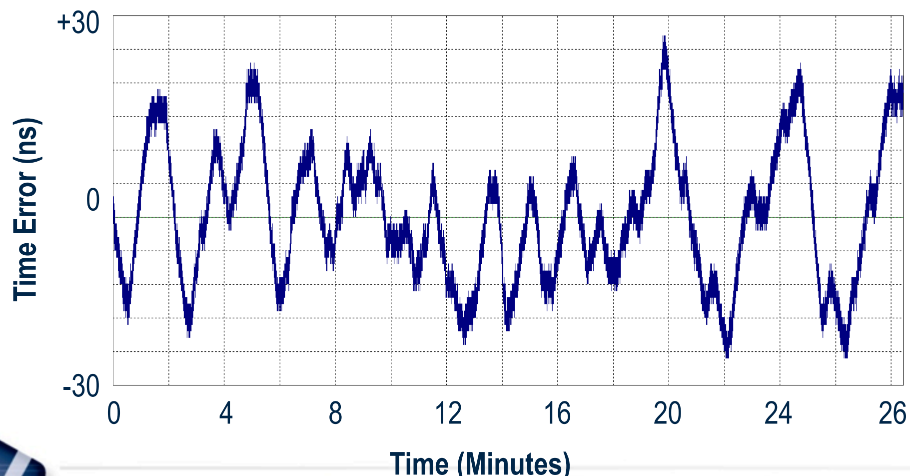
BC and TC Time Errors Behave Very Differently

Chain of 9 TCs with Vitesse VeriTime™ 1588 on-path support



- Very low peak-to-peak time error
- High-frequency error can be filtered out easily with low-cost oscillator

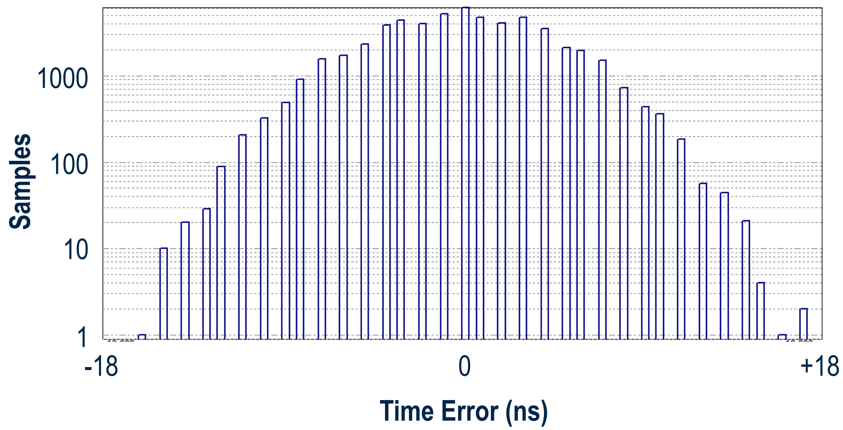
Chain of 9 BCs with Vitesse VeriTime™ 1588 on-path support



- Larger peak-to-peak time error
- Much slower time error evolution since clock recovered at each BC
- Very stable/expensive oscillator required at the slave Small Cell to filter out time error

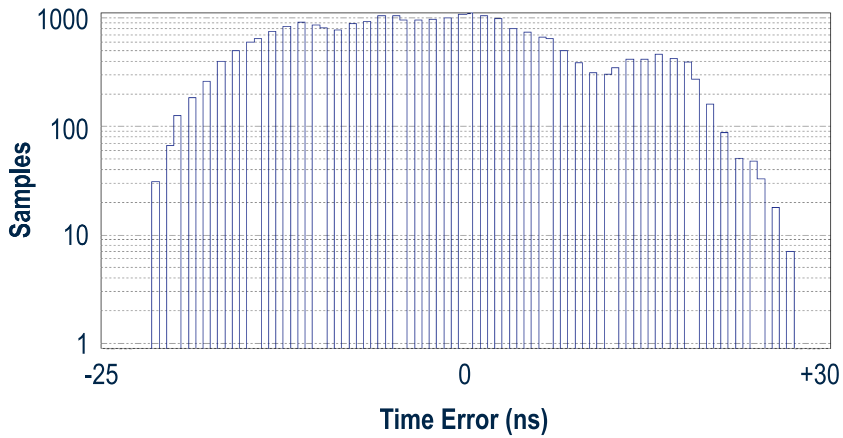
Difference In Time Error Distributions

Chain of 9 TCs with Vitesse VeriTime™ 1588 on-path support



- Gaussian Time Error Distribution
- Primarily dictated by TS accuracy
- Can be filtered out easily with low-cost oscillator

Chain of 9 BCs with Vitesse VeriTime™ 1588 on-path support



- Asymmetric, wide distribution of time errors
- Filtering may lead to TE offset relative to true time, and long-term wander

Performance Summary Of A BC/TC Network
Using Vitesse VeriTime™ 1588 Technology

Configuration	Frequency Support	1PPS MTIE (5000 s)	1 PPS Max TE
Master - 9 x TC - Slave	PTP	24 ns	25 ns
	SyncE	17 ns	11 ns
Master - 9 x T-BC - Slave	PTP	75 ns	51 ns
	SyncE	30 ns	17 ns

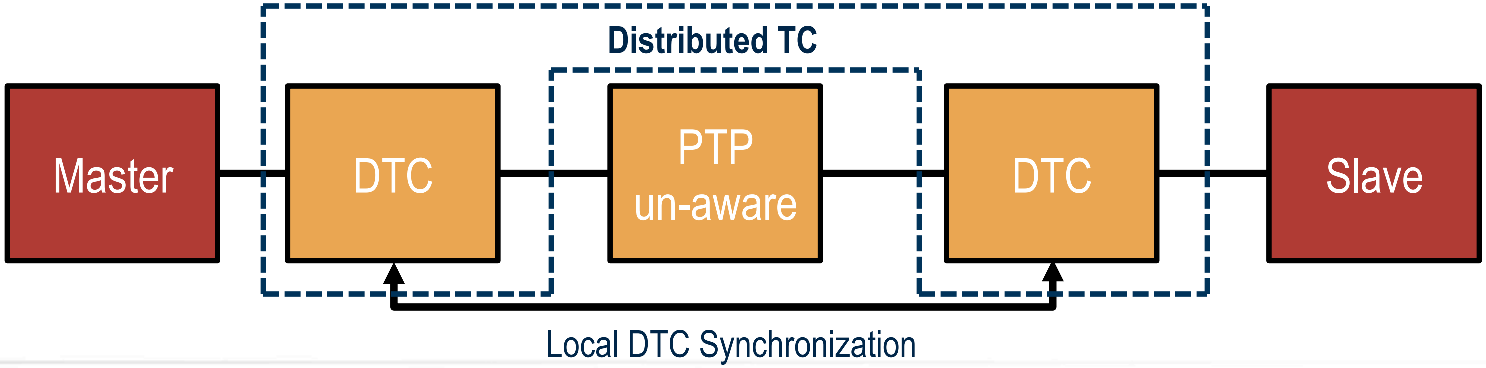
- Nanosecond-level MTIE and Max Time Errors for both BC and TC
- No dependence on traffic load
- PHY-based time stamping removes queuing as well as I/O serialization PDV
- Predictor logic can compensate for OTN/FEC & Encryption DVs

For Fiber or 1000Base-T connected nodes, sub-10ns maximum time errors can easily be achieved

Source: Select ITU-T G.8261.1 test cases; for details see WD17, June 2012 ITU-T SG15 Meeting

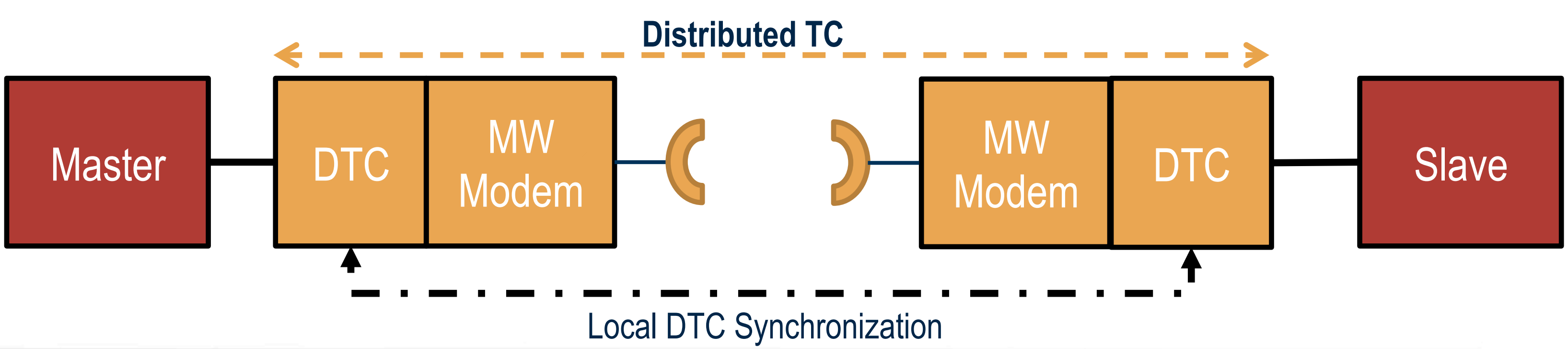
Distributed TC – What Is That?

- **A TC is a network device that measures the residence time of PTP frames inside the equipment**
- **A Distributed TC (DTC) consist of two physical devices placed around other network equipment, making the connection through the network act as one TC unit**
  - The equipment placed between the two DTC is PTP-unaware
  - This requires that the two DTC units can be synchronized in time somehow
    - The method of synchronization can be proprietary and might depend on the equipment placed between the two DTCs

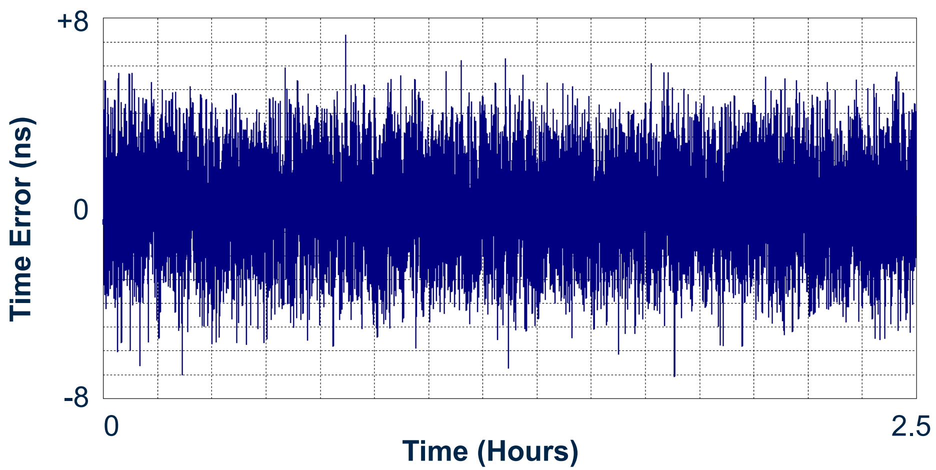


Distributed TC Over Microwave

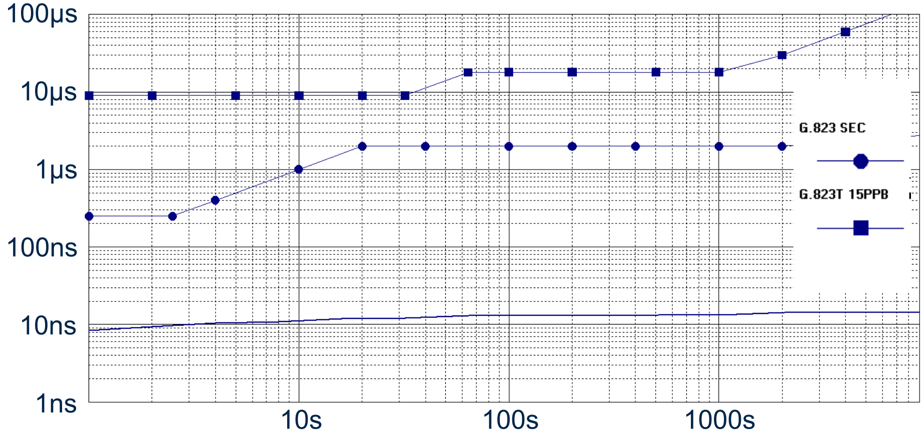
- **Microwave systems are known to introduce large packet delay variation and this is problematic for PTP traffic**
  - Bitrate changes on the wireless link
  - Modulation scheme change as well as FEC used
  - Delay asymmetries due to different up/downlink speeds
  - Packet buffering in modems
- **Distributed TC over MW solves this problem by “wrapping” the microwave link into a Distributed TC**
  - **BUT**: The two DTC ends of the MW link must still be phase synchronized



Performance Results for Distributed TC Over MW

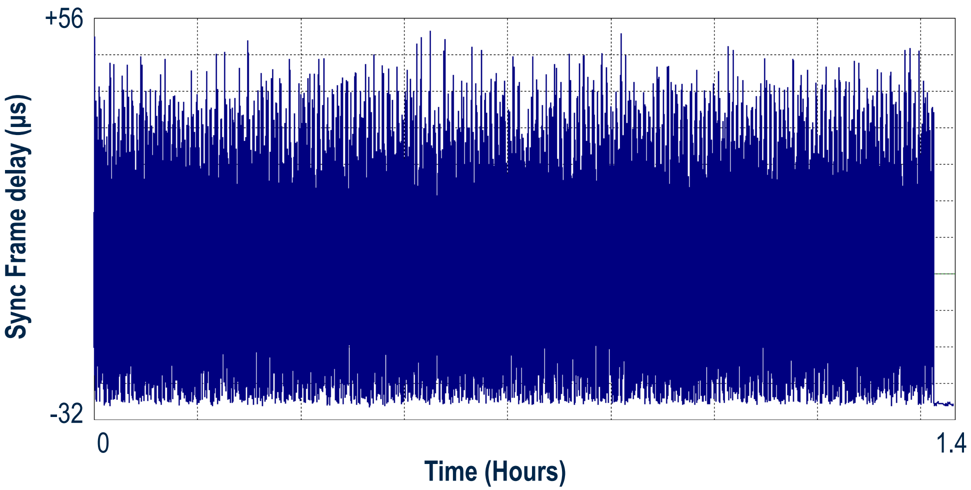


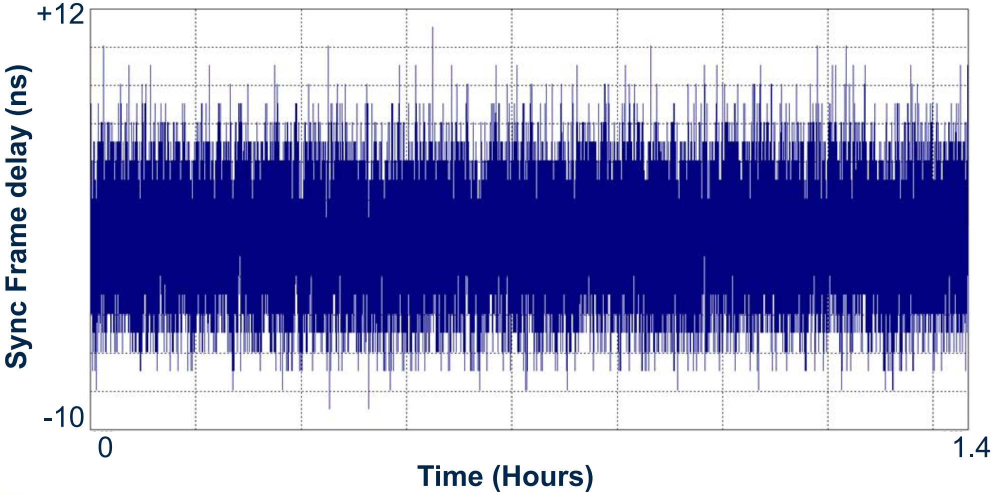
- Setup consist of GM→DTC→ T-TSC and the time error of the slave is measured over time
- Shows very accurate time transfer over the DTC
- < 20 ns(pp) including error caused by GM and T-TSC



- MTIE plot for the 1PPS output of the slave shows very stable output

Forward Sync Frame Delay (with and without CF)





- When measuring with a PTP probe at the output of the DTC pair we can measure the PDV of the Sync frames caused by the DTC link (T2-T1)
- Peak-Peak PDV > 70µs

- Including the CF value in the calculations shows how the DTC corrects for the PDV inside the DTC
- Peak-peak PDV < 20ns

Network Timing Solutions Comparison

Cost / Complexity

Frequency

PDV Filtering "Servo"

- Low implementation cost (software + stable OCXO)
- Asymmetries cannot be filtered out, leading to phase errors

Time/Phase

Boundary Clocks

- Time Stamping on Ingress and Egress
- Needs PLL, OCXO & 1588 Protocol in every node

Transparent Clocks

- Time Stamping on Ingress and Egress
- No PLL, no OCXO, no 1588 protocol processing

Switches and Routers typically implement both BC and TC, but liberal use of TC can lower clock recovery cost for Small Cells

So When to Use BCs and TCs?

- **TCs should be used**
  - Where “low-cost inter-connectivity” is needed
    - Micro and Pico Cells chain/ring/mesh networks
    - Aggregation network close to the end nodes
  - If PTP support for multiple PTP domains are needed
  - If fast failover is needed in ring topologies
  - As an upgrade path for partial PTP-aware networks

- **BCs should be used**
  - Where management of the PTP connection is required
  - When they are needed to provide scale

So…. Have We Solved All Problems?

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No!

The Biggest Misconceptions and Problems

Timing Error Budget is ±1µs

- "So it's ok if my equipment is only 100ns accurate…"
- Base Stations, Routers, Gateways, Microwave Equipment – all say that

Every Hop has the same TE Budget

- This won't be true in real networks
- Base Stations, Routers, Gateways can be much higher accuracy
- MW and MMW Backhaul will need more slack

And the Biggest Problem?

- Right now, no operator can figure out if they will meet the timing budget before the network is installed and can be tested!

The Case for Equipment Timing Classes

- **Most Switches and Routers today only achieve 100ns accuracy**
- **MW/MMW links can only achieve around 100ns accuracy**
- **10-20ns accuracy can easily be achieved with PHY-based timestamping for both Boundary and Transparent Clocks**
- **And then there is of course equipment without any 1588 support**

Why not define different equipment classes by their ability to "keep accurate time?"

- Equipment vendors can continue selling older equipment
- Operators can mix and match older and new equipment, and will always know what time accuracy they will achieve

How That Would Look Mathematically…

500ns LTE-A MIMO Time Error Budget

A) 5 hops Class B (100ns)

B) 25 hops Class A (20ns)

C) 10 hops Class A & 3 hops Class B

…and in a Real Network Example

- Operators need an easy way to calculate maximum time error
- Equipment vendors need to be able to sell equipment with various 1588 capabilities
- Not all hops are equal in a networks, but…..

Equipment	Max Time Error	Hop Count
Small Cell	20 ns	3
MW/MMW Link	100 ns	2
Cell-site Gateway	20 ns	1
Pre-Aggregation Router/Switch	20 ns	1
"Legacy 1588" Aggr. Router	100ns	1
Aggregation Router	20 ns	5
Total Network Time Error		**500 ns**

with 1588 equipment classes, network timing will be possible even with diverse equipment and transport technologies

Summary and Conclusions

- TD-LTE & LTE-A require tight control of timing errors per link to meet timing requirements
- Many tools are available in the 1588 tool chest to meet these requirements
- New base stations and fiber or copper connected switches and routers can easily meet 10ns time error per hop
- Older 1588-aware equipment and MW link time errors can meet 100ns time error per hop
- Operators need an easy way to know if their (heterogeneous) networks will meet timing (before finishing the build-out!)

Thank You

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