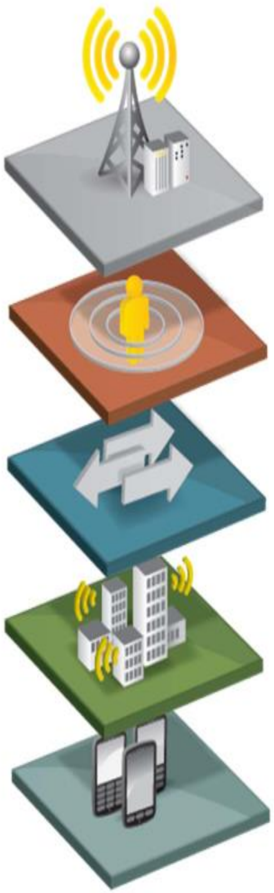

PTP Frequency/Phase Proof-of-Concept & Service Providers' Challenges for Concatenated Networks

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April 10, 2013

NIST-ATIS WSTS - 2013 – San Jose, CA

Sprint Background

- HQ in Overland Park, KS
- FORTUNE 100 company
- Serves 93% of FORTUNE 500 companies
- 2012 Annual Revenues – $35.3B
- Serves more than 56 million
  - 32 million postpaid
  - 16 million prepaid
  - 8 million wholesale/affiliate

- Network Vision Deployment
  - 4G LTE in 58 cities
  - Over 170 more sites expected in 1Q13
  - Construction started in over 450 cities
  - Over 19,500 sites ready for construction
  - Nearly 8,000 sites on air
- One of the world's largest retailers
- Widely recognized for pioneering advanced networks

Participation in Sprint's 2Q12 PTP PoC

- Tommy Cook (Calnex)
- Troy Bergstrom (Calnex)
- Eric Craig (Calnex)
- Rami Yaron (DragonWave)
- Tony Wong (DragonWave)
- Dane Perryman (Juniper)
- Tim Pearson (Sprint)
- Steve Guthrie (Sprint)
- Dave Polson (Sprint)

Note: Companies Listed Alphabetically

PTP PoC Overview

Sprint

Proof-of-Concept (PoC) testing was conducted as a technology review of Precision Timing Protocol (PTP) to support Frequency and Phase for LTE-A.

In general, Sprint determined the following:

- PTP is an excellent candidate for GPS backup and as a redundant synchronization source for CDMA/LTE Macro-cells and in-building Pico-cell synchronization.
- The mature PTP technology allows for setting/maintaining Frequency and acquiring/locking Time/Phase necessary for synchronization of RANs such as CDMA, LTE (eHRPD/eCSFB) and LTE-A (CoMP & eICIC).
- This PoC evaluated the accuracy of recent PTP industry claims that it's capable of supporting distributed synchronization over telecom packet based networks by using the Calnex Paragon-X for a simulated 10 node configuration and G.8261.1 test cases 13/14.

While these tests were extensive, no inferences should be made concerning the use of non On-Path Supported over Concatenated networks. This is because North American carriers have not implemented the ITU-T G.826x or G.827x standards in their access backhaul. Also, G.8271.1 “Network PDV_Time/Phase” has not been finalized.

eHRPD (Enhanced High Rate Packet Data) – Enable hand-off from LTE to EVDO

eCSFB (Enhanced Circuit Switched Fall Back) – Enable hand-off (ring ONLY) from LTE to 3G voice

CoMP (Coordinated Multipoint Transmission) – Enable multi-cell communication to a single device

eICIC (Enhanced Inter-cell Interference Coordination) – Deals with the Orthogonal Frequency-Division Multiple Access interference

PoC ITU-T G.8261 Tests

ITU-T G.8261 tests were used to evaluate PTP distribution performance by simulated networks outlined by G.8261. These lab tests did not evaluate the support of PTP over Concatenated networks such as Alternative Access Vendors (AAVs). Also, while these tests are designed for Frequency ONLY, acquired/locking Phase was also considered.

- A series of test cases were developed to match Sprint's LTE deployment scenarios such as a simulated AAV router/switch networks, Sprint Microwave donor sites and multiple radio links.
- The most stringent of the ITU-T G.8261 tests, the accepted standard for Grand-Master to PTP slave Frequency profile testing, were used to test PTP's robustness through separate networks with varying traffic loads and conditions that best mimic backhaul traffic.
- The PoC tests showed that the PTP client successfully set/maintain Frequency and acquired/locked Time/Phase in each test case.
- The microwave donor sites were also successfully tested using Automatic Adaptive Modulation (AAM) schemes. This is significant since many microwave vendors have had difficulty supporting PTP frames during AAM fade.

Objectives of the PTP PoC Tests

The objectives of the PoC was to evaluate PTP technology by performing PoC testing in the Sprint Lenexa laboratory environment.

PTP promises to provide significant capital and expense cost savings over traditional synchronization methods (i.e. GPS) for in-building Pico-cell applications or localized in-building PTP distribution. As with any new technology, risks must be minimized. By conducting standard ITU-T G.8261 tests, risks are mitigated in this PoC.

Time/Phase and Time of Day standard tests are yet to be defined/approved in ITU-T G.8275.1; therefore, these tests will need to be conducted in another PoC or FIT (Field Integration Test).

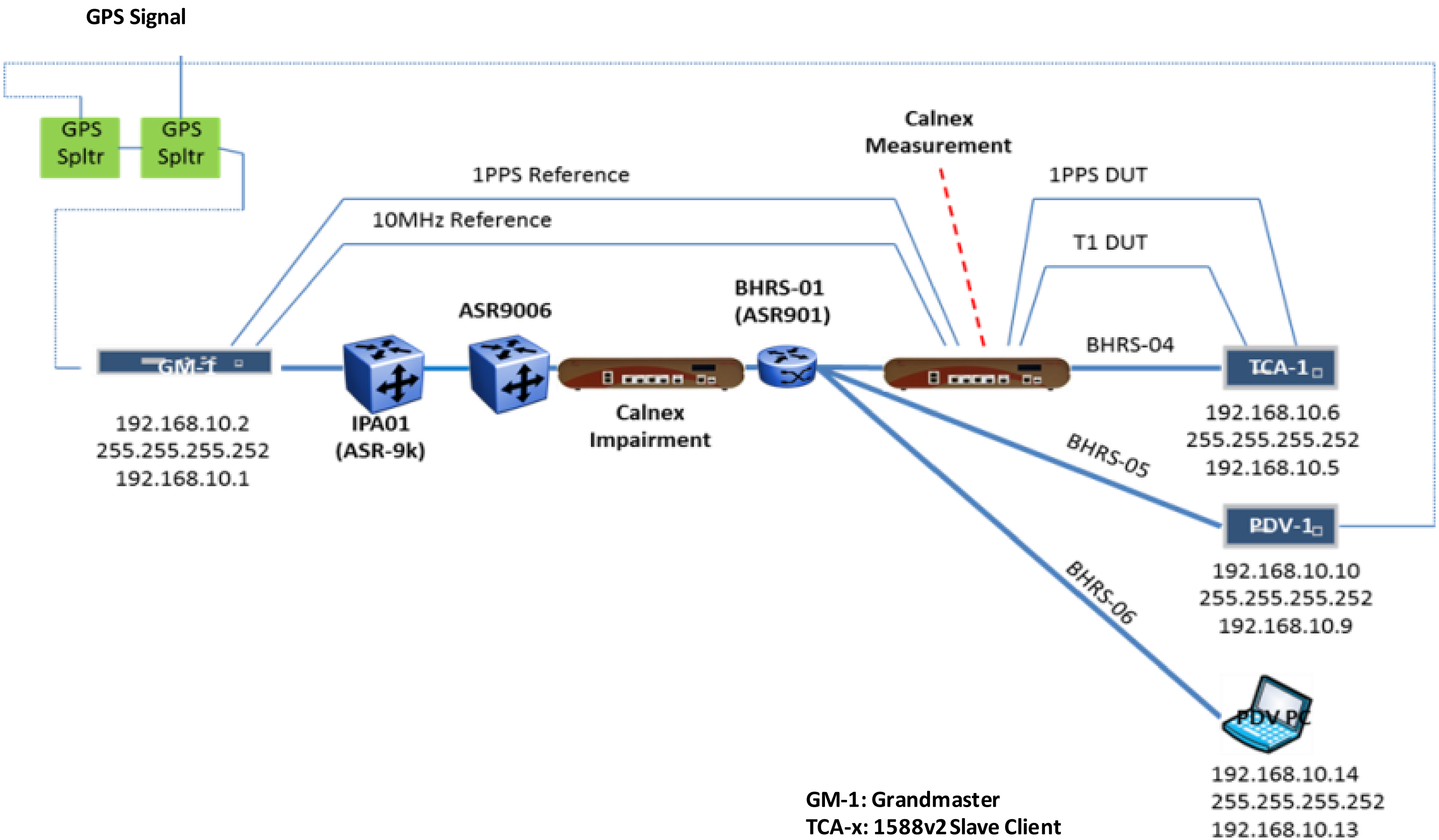
PTP PoC Test Networks & Test Cases

The PoC test was performed over two Sprint architectures using an industry standard PTP synchronization Impairment Generator developed by Calnex. This Impairment Generator has the advantage of scaling from 10-100% loading factor which allows for the implementation of ITU-T G.8261. The two networks used were the ILEC Configuration and Donor Microwave Configuration as seen in Figures 1 and 2 respectively.

- Test Case 13 models sudden large and persistent changes in network load, as seen in bursty traffic. It demonstrates stability on sudden, large changes in network conditions and “wander” performance in the presence of low frequency PDV.
- Test Case 14 changes the network load over an extremely long timescale demonstrating stability with very slow changes in network conditions and “wander” performance in the presence of extremely low frequency PDV.

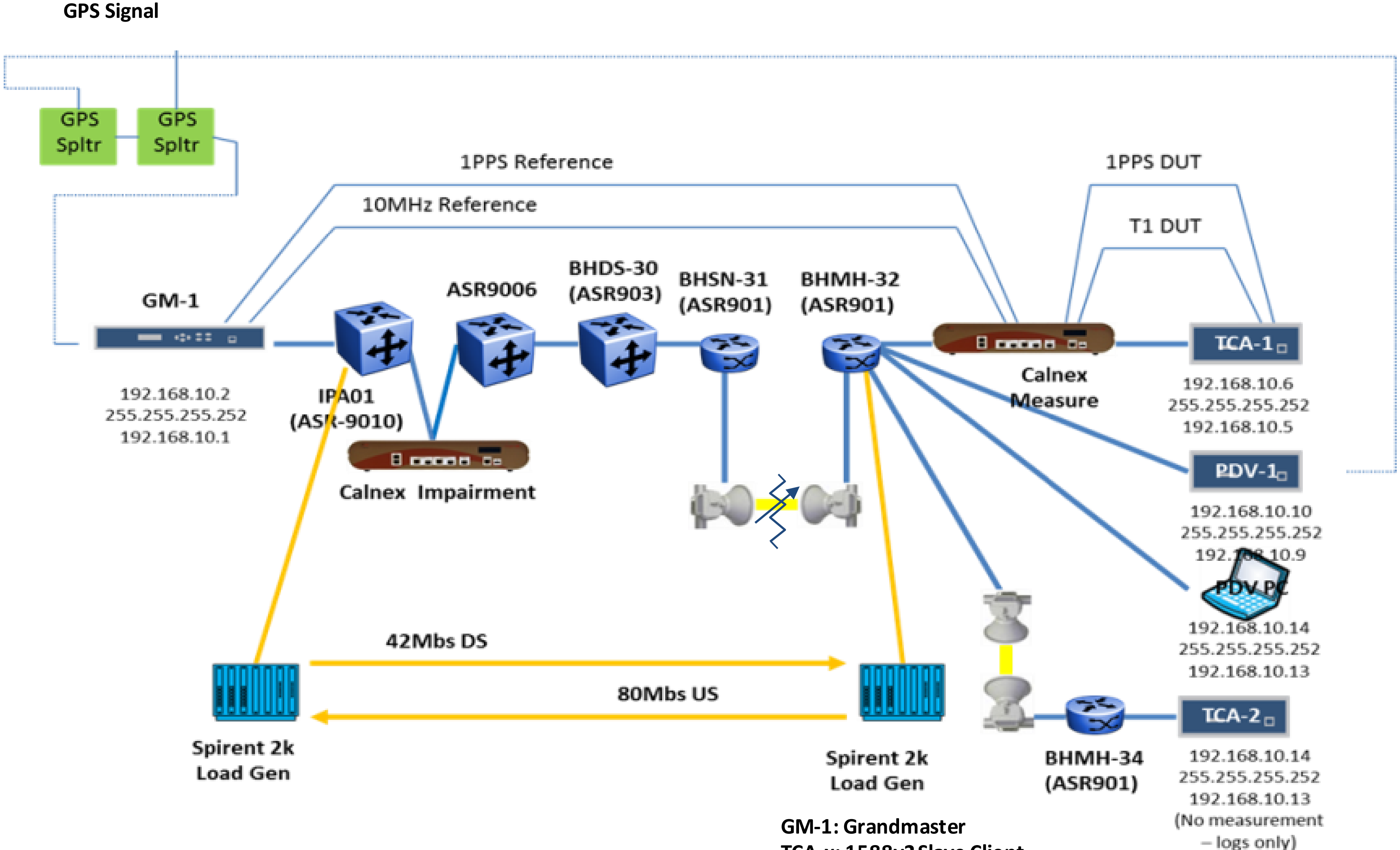
The Donor configuration also was used to test the Automatic Adaptive Modulation (AAM) test case, PDV TIE per Packet Response for: QAM256 to QAM128 to QAM256 to QPSK to QAM256 Test case 13.

PTP PoC Sprint Lab AAV Configuration



GM-1: Grandmaster
TCA-x: 1588v2 Slave Client
PDV-x: PDV Recording Client
ASRs: Cisco Series

PTP PoC Sprint Lab MW Donor Lab



GM-1: Grandmaster
TCA-x: 1588v2 Slave Client
PDV-x: PDV Recording Client
ASRs: Cisco Series

PTP PoC Test Results

The DUT exceeded Sprint's expectations for setting/maintaining Frequency & acquiring/locking Time/Phase over both the ILEC and Donor network configurations.

ILEC Configuration	Long Term Freq. Stability of ITU-T G.824 with a MTIE 16ppb Mask	Freq. Accuracy ITU-T G.824 MTIE-TDEV for the T1 Mask	Time/Phase Accuracy Target: 1.5uSec off-set
ITU-T G.8261 13 (6.25hrs)	Passed	Passed	992nS/Passed
ITU-T G.8261 14 (17.7hrs)*	Passed	Passed	897nS/Passed

Chart 1: PTP Slave Response over the ILEC Configuration

Donor Configuration	Long Term Freq. Stability of G.824 with a MTIE 16ppb Mask	Freq. Accuracy G.824 MTIE-TDEV for the T1 Mask	Time/Phase Accuracy Target: 1.5uSec off-set
ITU-T G.8261 13 (6.25hrs)	Passed	Passed	710nS/Passed
ITU-T G.8261 14 (24hrs)	Passed	Passed	712nS/Passed

Chart 2: PTP Slave Response over the Donor Configuration

DUT: Device –Under-Test

* Test inadvertently interrupted

- G.824 MTIE-TDEV for T1 Mask: included the 1.54Mb/s reference interface from clause 6.2.2. (nearly 0.02ppb over 24 hours)

PTP PoC Test Networks MW Test & Results

The Donor configuration also was used to test the Automatic Adaptive Modulation (AAM) test case, PDV TIE per Packet Response for: QAM256 to QAM128 to QAM256 to QPSK to QAM256 Test case 13.

- Output data for the Automatic Adaptive Modulation (AAM) test case, PDV TIE per Packet Response for: QAM256 to QAM128 to QAM256 to QPSK to QAM256.
- Test case 13 was run for 10 minute intervals for each Automatic Adaptive Modulation band – with 82Mb/50Mb traffic. In this test, we introduced 82Mb of traffic into the network with the microwave configured with Hitless Adaptive Modulation at the highest available modulation - 256QAM. Due to the switch's traffic policy, one direction (Port 1 to Port 2) was limited to 50Mb. On the reverse direction, no policy was enforced.
- After 10 minutes of stabilization, we increased the attenuation and, after a brief transition, the modulation changed from 256QAM to 128QAM. From the Figure 3, the new modulation increased the delay approximately 49ns. After 10 minutes, we decreased the attenuation and the modulation changed from 128QAM to 256QAM. We saw a slight decrease in delay.
- After 10 minutes, we increased the attenuation to cause modulation change from 256QAM to QPSK. The new modulation caused an increase in the delay by 700ns. After 10 minutes, we increased the modulation to 256QAM and delay was returned to its original state.

PTP PoC Test Results continued …

DragonWave supported PTP over a Congested QPSK span.

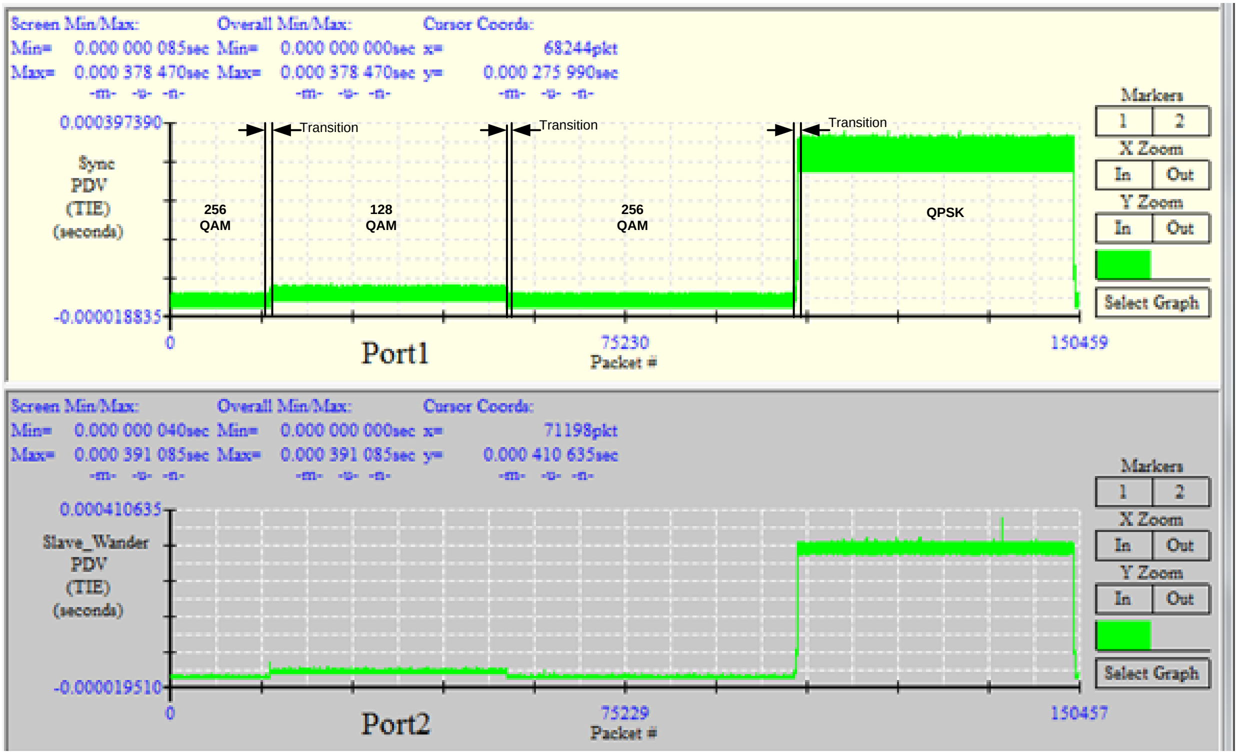


Figure 3: PDV TIE per Packet Response for: QAM256 to QAM128 to QAM256 to QPSK to QAM256

Modulation	Available BW (Ave Mbps)	% of 80Mbps	PTP Result
256QAM	364	22%	Passed
128QAM	271	30%	Passed
QPSK	67	Congestion	Passed

Chart 3: Donor/Automatic Adaptive Modulation (AAM) Response

Interpretation of Data

1. The results of these tests indicate PTP technology maturity:
   a) **PTP is ready for deployment under certain conditions.** PTP distribution using Sprint provided backhaul (wireless) or dedicated Grand-Master located in the in-building Pico cell location.
   b) In the future when PTP on-Path support is available, in order to ensure carrier class stability and accuracy, SLA agreements must define the acceptable PDV as well as a measure of the distribution of the delay variation, such as FPP (Floor Packet Percentage). **This will require ITU-T development in G.8271.1/G8275.1**.

2. Recovering Frequency is easier than acquiring and locking Time/Phase:
   a) **Time/Phase stability can be affected by the rate of change of PDV, asymmetry in the network and dropped packets.**
   b) ITU-T G.8260 Standards have completed Frequency recovery, for the most part, but Time/Phase standards require further development.

3. PTP over a loaded Automatic Adaptive Modulation (AAM) microwave span:
   a) If AAM is designed properly, PTP can continue to provide both Freq./Phase over a microwave span which utilizes AAM even during a extremely high fade.
   b) Not all microwave vendors can make this claim as AAM is a proprietary solution.

Interpretation of Data continued …

4. The performance of the **PTP slave device is critical**:
   a) The slave's control algorithm and the Oscillator are the key factors in the slave's performance. **A poor PTP slave design will result in a greater dependency on a Full on-Path Support.**
      I. Higher quality oscillators improve the recovery of Frequency and Time/Phase, but cost is increased.
      II. Oven Controlled Crystal Oscillators (OCXO) can provide an advantage in stability at a reasonable price.
      III. Eliminating variations in Oscillator production is challenging and care must be taken in the manufacturing process.

   b) The **slave's algorithm control and approach for tracking the Master's Time base is different for every vendor.**
      I. Vendors do not provide a detailed explanation as this is their secret sauce and competitive edge.
      II. There are several approaches for PTP Master to slave alignment.
      III. No standards for rating slaves.

   c) The **PTP slave performance cannot be determined by a single feature or function and should be qualified for performance for given network conditions.**
      I. Metrics will be available to accurately measure the networks ability to support PTP for a given slave. FPP (floor packet percentage) is a metric that is available today and can accurately determine the network's ability to support PTP.
      II. Currently this approach is used for Frequency but it can also be used for Time/Phase.

Conclusions and Key Points

- PTP technology and its potential application have been verified in the Sprint Laboratory environment. However, using PTP across the AAV network to support In-door Pico cell synchronization is NOT verified at this time because of the lack of AAV's on-Path support of PTP.
- Service Providers can't make a decision on a potential GPS backup using PTP until ITU-T standards are approved for Phase Telecom profiles and performance monitoring tests suites.
- There are no classifications for slaves. Therefore, using traditional budget-based planning and engineering is not supported.
- Distributed PTP is NOT able to consistently support the 3GPP Time/Phase LTE/LTE-A requirements for eHRPD, eCSFB, CoMP or eICIC over various types of networks:
  - AAV Networks without on-Path Support
  - Asymmetrical networks (EPON, DSL, ADSL, DOCSx)
  - ALL Public IP networks

Recommendations & Next Steps

ITU-T standard work for Partial on-Path Support (PoPS):

- No attributes have been agreed for PTP slaves. With a form of Frequency & Phase slave attributes, we could classify various types of PTP slaves (including T-BCs). As a theoretical example, classifications might look something like this:
  - Class A: Slaves targeted for Use-Case for Full on-Path support.

  These slaves may have the least restrictive attribute tolerances.
  - Class B: Slaves targeted for Use-Case a single PTP hop from a aggregated edge point.

  These salves may have more restrictive attribute tighter tolerances than Class A.
  - Class C: Slaves targeted for Use-Case for Partial on-Path Support.

  These slaves may have more restrictive attribute tighter tolerances than Class B.
- Slave attributes could establish the required end-point-anchor requirements, which in turn, permit the use path-based-practices for engineering synchronization paths.
- Any PoPS must be measurable using verifiable performance monitoring.
- We need to be realistic when Q13 develops a Hypothetical Reference Model (HRM) for PoPS. Unlike FoPS, the PoPS profile will have various challenges such as nearly limitless permutations which are produced by:
  - associated combinations of "Use-Cases" for varying the numbers of nodes either with clocking or without clocking, (T-TCs and/or T-BCs)
  - the various engineering techniques for scheduling, policing and shaping used by the different router/switch vendors (often within vendor(s) product lines)
  - the allowable percentage loading at each non-clocked node

  All of which makes the task of producing a HRM for PoPS HIGHLY problematic.

Challenges of a Service Provider

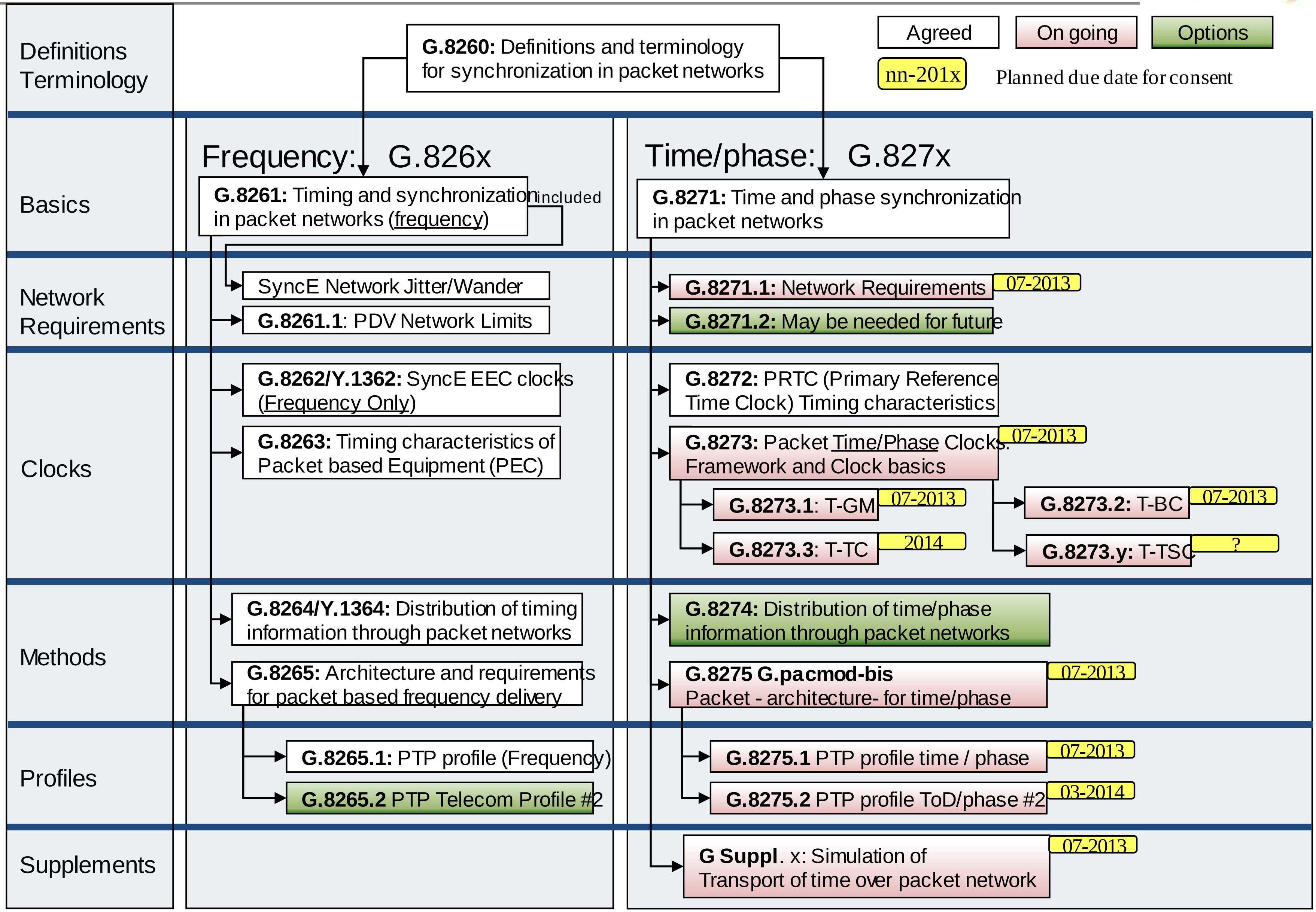
- ANY synchronization strategy must include in-building Pico/eFemto requirements:
  1. E911 Location … If cross-reference location databases are employed, both Static & Dynamic IP addresses are required
  2. Frequency/Phase synchronization are needed
  3. Asset Management "plug-n-play"

- The need for Frequency/Phase synchronization is NOW. However, long lead-times are required for the introduction of approved standards work.

- For Sprint, the number of Access Providers which are under contract makes it HIGHLY challenging for managing Ethernet Backhaul. Now, introduce further constraints such as on-Path Support, types of transport technology, performance objectives … this gets REALLY challenging.

- Sprint's model for leasing Backhaul is to employ Service Level Agreements (SLAs) over Concatenated networks. Without our AAV providers offering some form of on-Path Support, it is HIGHLY doubtful that Sprint or ANY Service Provider would attempt to use existing Ethernet transport, absent of SLA guaranties, to provide distributed PTP.
  - Given the multiple AAVs within a single market Sprint manages, using a Synchronization "Services" maybe problematic to isolate phase Phase off-set issues from Macro to Pico cells.
  - Further study for Synchronization "Services" are needed (very few providers are considering) – British Telecom provides the Synchronization "Services" at no additional charge.

ITU-T (SG15/Q13) NGN Sync.



Glossary of Terms

AAM: Automatic Adaptive Modulation
AAV: Alternative Access Vendor
ATIS/COAST: Alliance of Telecommunication Industry Solutions / Copper/Optical Access, Synchronization and Transport Committee
CDMA: Code Division Multiple Access
CoMP: Coordinated Multipoint Transmission
CoS: Class of Service
DUT: Device-Under-Test
eCSFB: Enhanced Circuit Switched Fall Back
eHRPD: Enhanced High Rate Packet Data
eICIC: Enhanced Inter-cell Interference Coordination
FIT: Field Integrated Testing
FoPS: Full on-Path Support
GPS: Global Positioning System
IEEE: Institute of Electrical and Electronics Engineers
ILEC: Incumbent Local Exchange Carrier
IPv4: Internet Protocol version 4
IPv6: Internet Protocol version 6
ITU-T: International Telecommunication Union - Telecommunication Standardization Sector
LTE: Long Term Evolution (4G – Fourth Generation Mobile)
LTE-Advance: Long Term Evolution – Advance (calls for additional features above LTE)
MEF: Metro Ethernet Forum
MPLS: Multiprotocol Label Switching
MTIE: Measurement of Maximum Time Interval Error for Telecommunications
OCXO: Oven Controlled Crystal Oscillator
PoPS: Partial on-Path Support
PDV: Packet Delay Variation
PTP: Precision Timing Protocol
PoC: Proof-of-Concept
ppb: Parts Per Billion
QPSK: Quadrature Phase Shift Keyed
TDEV: Time Deviation - is the square root of Time Variance (TVAR)
TD&S: Technology Development and Strategy
VLAN: Virtual Local Area Network