Holdover – Who needs it?

ITSF 2014
What is holdover?

- **Normal sync operation**
  - Device locks to a clock from an external source
    - In-band with data (T1/E1, SONET, SyncE)
    - Separate source (GPS)
  - Can also pass clock downstream
    - After necessary filtering

- **But what if something goes wrong**
  - No external clock sources available
  - We’re on our own
  - Only option is keep doing the best we can …
  - … for as long as we can
  - Might be able to operate with reduced performance

- **Principle of holdover**
  - Acquire data about the reference while locked to it
  - Use that data in conjunction with local oscillator to maintain output
  - Holdover quality depends on local oscillator stability and “holdover data”
Frequency Holdover

- Traditionally applications only required frequency
  - Holdover meant maintaining frequency error below a certain level
  - Typically specified directly or by an MTIE mask

- These limits are fairly lenient
  - 24 or 72 hour frequency holdover really isn’t a problem
Time Holdover

- Now, time is needed everywhere
  - Cellular backhaul is a big driver
    - TDD
    - CoMP
    - eICIC

- Benchmark phase error target is 1 µs
- That’s not much ...
  - Remember that time is the integral of frequency error
  - Errors add up very quickly

- 1.5 µs over 24 hours:
  - Fractional frequency error = $1.5 \times 10^{-6} / (24 \times 60 \times 60)$
  - $= 17.4$ ppt
    - That’s part per trillion – not million .. not billion … trillion

- Time holdover puts massive requirements on local oscillator
Oscillator Options

- Factors determining holdover performance:
  1) Oscillator selection,
  2) Oscillator selection
  3) And … Oscillator selection

- There’s only really two options …
  - Quartz-based
    • TCXO
    • OCXO
    • TCOCXO
  - Atomic-based
    • Caesium beam
    • Rubidium
    • CSAC (Chip-scale atomic clock)
Accuracy vs Stability

- **Important not to confuse terms**
  - **Accuracy**
    - How close to marked frequency the oscillator is initially
  - **Stability**
    - How the frequency changes over a period of time

- **Holdover only cares about stability**
  - Accuracy is compensated for by comparing frequency to reference while locked
  - Stability over holdover period is key
    - No additional reference to compare to
Quartz Oscillator Options - TCXO

- TCXO – Temperature Compensated Crystal Oscillator
  - Simple AT-cut crystal
  - Operates at ambient temperature
  - Measures temperature and compensates for it
    - 3\textsuperscript{rd} order or higher polynomial
    - Adjust frequency by varying load capacitance

- Cost – Low ($5 +)

- Size – Can be tiny (5 x 3.2 mm or smaller)

- Power – Low (no heating element)

- Stability – Okay (0.1 – 1 ppm after 24 hours)
Quartz Oscillator Options - OCXO

- **OCXO** – Oven Controlled Crystal Oscillator
  - Often an SC cut crystal
  - Uses heating element to maintain stable temperature
    - Above worst case ambient and optimised for SC crystal stability

- **Cost** – Higher ($25 +)

- **Size** – Larger (often 1” x 1”)

- **Power** – Higher (Heating element)

- **Stability** – Good (1 – 10 ppb after 24 hours)

- **TCOCXO** is hybrid of TCXO and OCXO
  - Temperature compensation and stabilisation
  - Between TCXO and OCXO in all parameters
Atomic Oscillator Options

- Combines “physics cell” with crystal oscillator
- Tune RF excitation to match atomic transition of caesium or rubidium
- Quartz oscillator then locked to RF frequency

- Cost – Very high ($500 ++)

- Size – Rb / Cs beam – very large
  CSAC comparable to OCXO

- Power – Rb / Cs beam – high
  CSAC – low (can be battery operated)

- Stability – Good to excellent
# Oscillator Summary

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<tr>
<th>Technology</th>
<th>Oscillator Type</th>
<th>Stability</th>
<th>Cost</th>
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Compensating a Quartz Oscillator

- All holdover functions compensate for accuracy
- What about trying to compensate for stability too?
  - Affected by
    - Temperature
    - Voltage
    - Aging
    - Lessor factors such as output load
- Oscillator technology already handles temperature
  - Compensation (TCXO)
  - Stabilization (OCXO)
- Voltage and other factors should be stable in a good design
- Just leaves aging
  - Can we compensate for this?
Aging Compensation

- Track oscillator frequency against reference while locked
  - Just as for normal holdover
  - But now, try to determine second-order effects

- It’s not trivial … But it can be done
  - Biggest issue is aging swamped by temperature

![Graph showing 1.25 µs over 24 hours]
What Have we Learnt?

- **Time holdover is tough**

- **Atomic oscillators provide a good solution**
  - At a price

- **Quartz can provide a good solution**
  - Especially with aging compensation
  - But again, quality OCXOs are expensive

- **Perhaps the same everywhere doesn’t work**

- **Can we get smart?**
  - Limit holdover to certain locations?
  - Limit holdover time?
  - Eliminate it altogether?
Where Do You Put Holdover?

- Holdover is expensive
  - Financial cost of oscillator
  - Potential for increased real estate
  - Potential for increased power

- The better the holdover the more expensive it is
  - Money, size and power

- Cellular networks are moving to HetNet architectures
  - Macrocells
  - Smallcells

- Small cell aggregation point often associated with a macrocell
The Role of Small Cells

- Increased bandwidth
  - Especially good for high user density areas

- Improve in-building coverage
  - Energy efficient building are not good for RF

- Urban canyons
  - Fill-in for areas with poor macro coverage

- Temporary cell sites
  - Sporting events etc.

- Typically a small cell has a single data link to the aggregator
  - Traffic + Sync

- Does a small cell need holdover?
  - If the link goes down data connectivity is lost

- Why not limit holdover to macrocells
  - And aggregators
Do we need 24 hours?

- One day is a long time
- **How long does it really take to:**
  - Identify a failure has occurred
  - Locate the failure
  - Roll a truck
  - Fix the problem
  - Return the equipment to operational state?

- **Time will depend on equipment and location**
  - Less for an in-building small-cell
  - More for a rural macrocell

- **How about we get smart?**
  - Provide minimal holdover function appropriate to equipment type
  - Dynamically manage network for longer outages
    - Reconfigure adjacent cells to work around outage
Do we Even Need Holdover?

- Why not just provide multiple sync paths?
- Automatically select GNSS if available
- Back up GNSS with Backhaul using PTP
  - Support 2x PTP Grand Master simultaneously
  - 3-way majority vote detects GNSS or PTP GM issues
- Embedded PTP Grand Master
  - Distributes time to local indoor cells
- Indoor Cells Prioritise Local Master
  - Back up with a network G.M.
  - Indoor Cells automatically cancel asymmetry on failover to networked G.M.

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= primary PTP reference

= secondary PTP reference
How About an Overlay Sync Network?

- Build a local network to distribute sync using ISM radio
  - Low cost
  - Ideal for urban areas

Predictions are that 7 concentrators will cover all of lower Manhattan.

A conservative 1 mile radius allows for some in-building penetration even at the edges.
Making it Work

- Multi-sync sources sound good in theory

- But need to be managed well to work correctly

- Can’t have time jumps
  - Need hitless switching

- Equipment designs need to be smart
  - Lock to multiple sources simultaneously
  - Switch between them with phase and frequency buildout
Summary

- The move to “time everywhere” poses a big problem for holdover

- Holdover is expensive ...  
  - Money
  - Space
  - Power

- We should get smart  
  - Can we use multiple sync sources instead?  
  - Can we restrict holdover to specific locations?  
  - Can we reduce the holdover period?  
  - What holdover performance do we really need?
Thank You!
Questions?