Improving Mobile Backhaul Network Reliability with Carrier-Class IEEE 1588 (PTP)

Grandmaster Hardware Redundancy Protects Slave Clock Performance

The Use of PTP for Synchronization over Ethernet

Telecommunications networks are rapidly shifting from circuit switched to packet switched technologies to meet exploding demand for bandwidth in both core and access networks. Traditional circuit switched TDM networks were engineered to carry precise frequency synchronization throughout the network. Access platforms, such as wireless base stations, rely on synchronization delivered over the network backhaul connection to assure high QoS for end user applications. A key dependency in the evolution to Ethernet backhaul in telecom networks is the ability to deliver carrier grade synchronization over Ethernet to remote wireless base stations and access platforms.

IEEE 1588 (Precision Time Protocol or PTP) is rapidly gaining traction as the technology of choice to deliver synchronization to remote telecom elements over Ethernet backhaul connections. Figure 1 shows a typical example of PTP synchronization for wireless networks. All GSM and UMTS base stations must be frequency synchronized to +/- 50 ppb (parts per billion) to support handover as mobiles transition from one base station to another. Failure to meet the 50 ppb synchronization requirement will result in dropped calls.

Base stations have traditionally met this requirement by locking their internal oscillators to a recovered clock from the T1/E1 TDM backhaul connection. When the backhaul transitions to Ethernet, the base station becomes isolated from its traditional network sync feed. New base station designs are incorporating IEEE 1588 PTP slave clocks to meet the 50 ppb requirement. PTP slaves in the base stations rely on access to a carrier-class PTP grandmaster clock deployed in the mobile switching center (MSC) or radio node controller (RNC).

Grandmaster Redundancy Considerations

Network deployment and reference network test models have been established to assist carrier engineering staffs to develop specific deployment rules for IEEE 1588 synchronization solutions in their networks. A key consideration is slave clock performance during a grandmaster clock failure scenario. There are two main options to consider:

- **Built-in grandmaster hardware redundancy.** The grandmaster employs an active and a standby card. The standby master shadows the active master with all settings including the IP address, but remains dormant until the active master fails.
- **Network-based redundancy.** Two entirely separate grandmasters are deployed, possibly at different geographical locations within the network.

Both techniques can be employed together to form a comprehensive and well-protected synchronization infrastructure. This paper discusses the advantages and disadvantages of each technique, and describes the features built into Symmetricom hardware to provide carrier-class reliability and performance.

![Image](image.png)

**FIG 1:** Delivery of synchronization to next generation UMTS base stations will rely on PTP grandmaster clocks deployed in the MSC/RNC. Sync packets flow from the grandmaster clock to the slave clocks in the base stations.

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1 Refer to the white paper “Deployment of Precision Time Protocol for Synchronization of GSM and UMTS Base Stations”. See http://www.symmetricom.com/resources/downloads/white-papers/
PTP Slave Locking Considerations

Firstly, it is necessary to understand how PTP slave clocks synchronize to a grandmaster. The slave clock establishes communication with the grandmaster by requesting a reservation for a synchronization flow, specifying parameters such as message rate and reservation duration. Once the synchronization flow is established with the grandmaster, the slave clock goes through the stages outlined in Table 1 to “lock” to the master.

Figure 2 shows how the process works. Initially the slave free-runs at an indeterminate frequency while the acquisition and qualification processes take place. During this period, both the output frequency and time offset may be well outside of the specification required by the given application. The process of aligning the frequency and time to the master takes place in the tracking stage. By the time the locked stage is reached, the slave is well within the application limits, and able to maintain the target level of performance over the long term.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
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<tbody>
<tr>
<td>Acquisition</td>
<td>Establishes sync flow and determines initial offset</td>
</tr>
<tr>
<td>Qualification</td>
<td>Monitors sync packet stability to qualify the master clock for tracking</td>
</tr>
<tr>
<td>Tracking</td>
<td>Begins reference oscillator alignment process to “tune” the slave oscillator to the grandmaster</td>
</tr>
<tr>
<td>Lock</td>
<td>Slave oscillator is now locked to the grandmaster and will begin long-term tracking to hold the frequency stability inside the application limits</td>
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**TABLE 1:** IEEE 1588 PTP slave clock acquisition and locking process.

**FIG 2:** Illustration of IEEE 1588 PTP slave clock acquisition and locking process.
Network-Based Redundancy

In network-based redundancy, two entirely separate grandmasters are employed. These may be co-located, but preferably are located at different geographic locations in order to provide maximum protection against failure, as shown in Figure 3. The PTP slave clock maintains a list of acceptable masters to use (called the Acceptable Master Table) and establishes communication with at least one of these masters. If the first master fails for some reason, the slave may then attempt to lock to the second master on the list.

Network-based redundancy has the property that it protects against network failure in the vicinity of the grandmaster as well as failure of the grandmaster itself, since the second grandmaster is normally connected via a separate access link into a different part of the network. However, there are some significant issues created by switching between two different grandmasters.

Firstly, typical PTP slave clocks for stringent telecom applications can take more than an hour to achieve fully locked status. This is because the variation in message delay through the packet network is several orders of magnitude larger than the accuracy requirements for telecom applications, and the slave has to build its filter history in order to compensate for the network path behavior. When switching to a new master, the network path between the slave and the new master is different, and the slave has to re-build its filter history to match the new path. While the slave goes through the acquiring, qualifying and tracking process with the new master, the output may drift outside the application limits.

Secondly, the path delay to the new master may be significantly different, which may result in a large phase or time offset between the two. The slave has to identify this offset and compensate for it correctly to avoid building a phase shift into the output clock. It should be noted that a test that compares switching between different network paths has been constructed by ITU-T [G.8261 Appendix VI, Test Case 17], and qualified slaves should pass such a test with an acceptable performance degradation.

Thirdly, there may be a significant phase or time offset between the two master clocks, due to being locked to different primary reference sources. For example, the time difference between the outputs of two GPS receivers can exceed 100ns over the long term. This time difference may cause the slave to skew its output frequency outside the application limits during the switchover process in order to align its phase and time to the new master.

There are some techniques within the slave that can be used to mitigate these issues. For example, since the frequencies of the two grandmasters can be expected to be almost identical (within 1 part in 10^{11}), the process of acquiring the new frequency should not take as long as if starting completely from scratch. It may also be possible, given sufficient processing resources in the slave and capacity at the grandmasters, to have the slave track two different masters simultaneously, such that when a switchover is required the slave has already acquired the filter history and offset between the two masters.

The “Telecom Profile” for PTP currently under development by the ITU-T is still defining how network redundancy will work. For multicast operation, the Best Master Clock Algorithm described in IEEE 1588-2008 is employed, but for unicast operation the switchover process is still being defined. The time to fail over from one master to another is not defined, and will be a property of the PTP slaves and their lock time which means the behavior during the switchover is somewhat unknown.

FIG 3: Network-Based Redundancy
Built-in Grandmaster Hardware Redundancy

A simpler method of providing grandmaster redundancy is to implement a carrier-class IEEE 1588 grandmaster clock with built-in hardware redundancy, similar to that provided in today’s SSU and BITS shelves. A fully redundant grandmaster clock employs an active and standby clock, synchronized to redundant primary reference sources (e.g. GPS or T1/E1), as shown in Figure 4. The active clock connects through the network switching fabric to service all the PTP slave synchronization flows in its timing domain.

The standby master shadows the active master with all settings including the IP address, but remains passive until either the active master fails, or the link to the switch goes down. At that point, the standby grandmaster goes active and takes over the IP address with a gratuitous ARP to the switch. All PTP sync flows are then serviced by the standby master with no impact to the PTP slave community.

The big advantage of this configuration is that since the active and standby clocks share a common reference and common network location, the PTP slave devices see no synchronization offset during a failover switching scenario. The slave clocks will all remain locked to the redundantly protected grandmaster, and will not be forced to acquire, qualify and track to a new grandmaster clock with an unknown offset, or connected through a different network path.

Figure 5 illustrates the benefits of hardware-based grandmaster redundancy. The PTP slave clock in scenario 1 remains locked throughout the switchover process, and in practice may not even

![FIG 4: Built-in Hardware Redundancy](image)

![FIG 5: IEEE 1588 PTP grandmaster clocks that employ hardware redundancy protect slave clocks from potential service impact during failover scenarios](image)
know that the event has taken place. On the other hand, the PTP slave clock shown in scenario 2 goes out of lock as it switches to its backup master clock, and initializes the acquisition, qualification, tracking, and locking process with the new grandmaster clock. The re-locking duration and resulting phase and frequency offsets are functions of the slave clock design, grandmaster performance, and network path and delay differences, much of which can be avoided by deploying a carrier-class IEEE 1588 grandmaster clock with hardware redundancy.

While built-in redundancy doesn’t protect against the failure of the local network (for example, the access link or edge switch/router), this may not be an issue in service terms. For example, if a grandmaster is co-located with the MSC or RNC of a cellular network, and if the access link or edge switch/router fails, the cellular network may lose connection to all of its base stations, and hence the loss of synchronization is merely academic. For important sites such as an RNC or MSC, redundant access links may be used to protect against link failure.

**General Redundancy Issues**

Some reliability issues affect both redundancy methods. The failure of a PRS is an important issue in the design of a grandmaster, particularly if accurate time is required as well as frequency. For example, while the GPS system as a whole is extremely reliable, local components such as an outdoor antenna may be less reliable, since they can be exposed to harsh environmental conditions.

For frequency applications, backup may be provided using a T1 or E1 frequency reference. However, for time applications, other backup sources of time such as NTP may not be sufficiently accurate. In this case, it may be necessary to put the grandmaster into “time holdover”, while synchronizing the timebase using the frequency reference. A primary frequency reference is accurate to within 1 part in 10^11, which means it will drift by less than 1μs a day.

Both methods are vulnerable to the failure of the slave or its access link. However, this affects a much smaller part of the overall system than failure of the grandmaster or its local network. It is not common practice to provide redundant links or clocks to the base station in cellular networks due to the cost of such protection.

**Summary**

As advanced network elements begin to see deployment with IEEE 1588 (PTP) slave clocks, consideration must be given to how synchronization is protected during failover events. Deployment of carrier-class grandmaster clocks with built-in hardware redundancy assures that all slave clocks remained locked and fully protected during clock failover events.

Symmetricom PTP Grandmaster devices, such as the TimeProvider® 5000 and the PTP server blades for the TimeHub and SSU 2000 synchronization systems, provide built-in hardware redundancy to assure maximum performance from the PTP synchronization network. They can also lock to several different primary reference sources, providing failover protection in the event of a reference failure. Symmetricom PTP slaves also enable network-based redundancy by being able to switch between two grandmasters in the event of a failure.