Update on High Accuracy Work in IEEE P1588 Working Group

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Outline

- Introduction
- Summary of White Rabbit
- High Accuracy (HA) Subcommittee (SC) requirements
- HA SC use cases
- HA SC expected work between now and April, 2014 F2F meeting
- Current work on Layer 1 (L1) Syntonization
- Current discussions on link calibration (delay/asymmetry)

Introduction and Outline

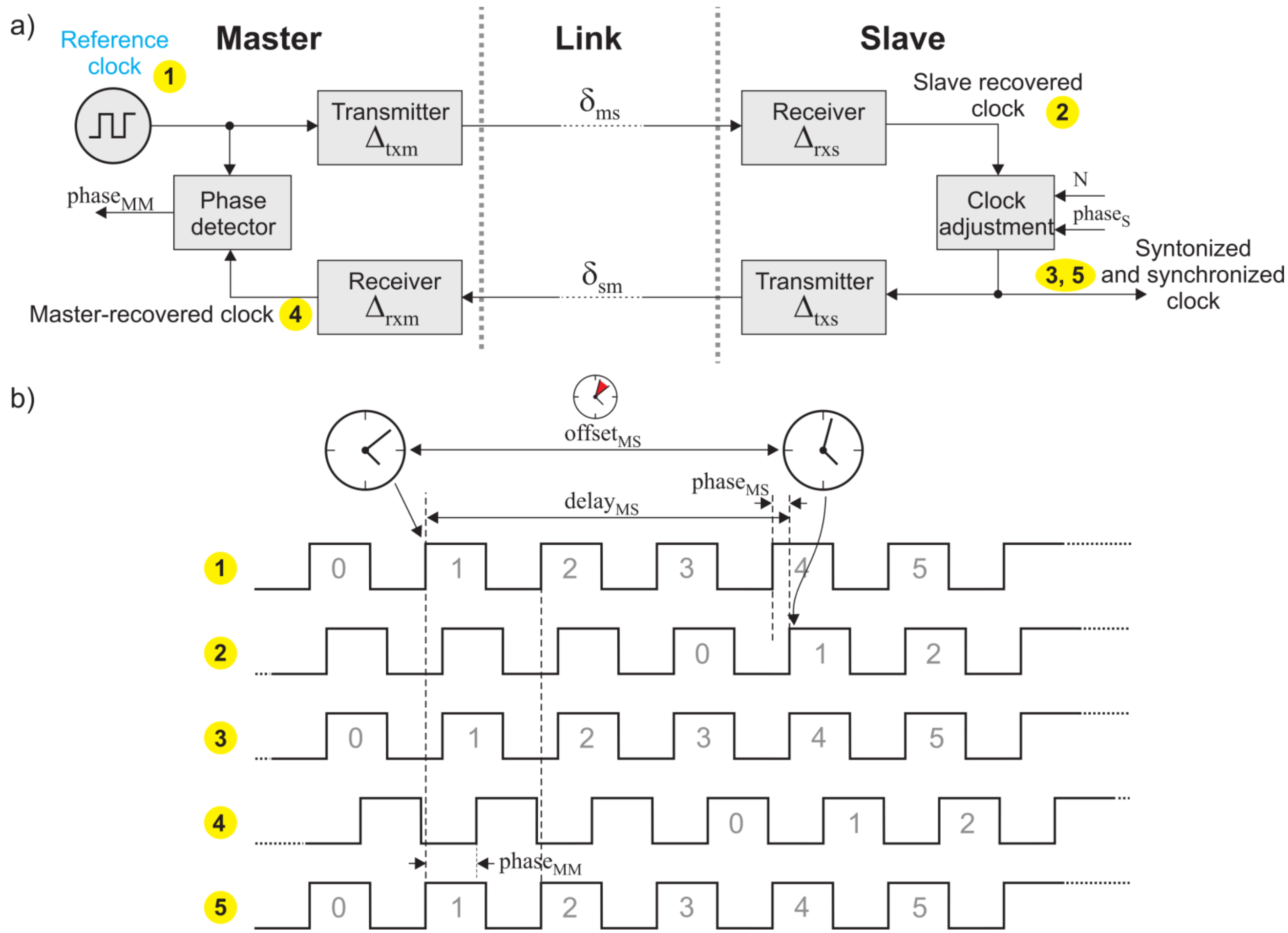
- This presentation gives an update on the High Accuracy work of the IEEE P1588 Working Group (in the High Accuracy Subcommittee)
  - It was requested in the January 15, 2014 TSN call that author give this presentation
- High accuracy will be an optional feature for the next version of IEEE Std 1588 (i.e., next version after the 2008 version)
- The White Rabbit (WR) work at CERN was one main driving force for including this feature
  - The WR work is an input to the HA work; however, the HA feature is expected to be more general
  - Nonetheless, since the WR work is, at present, the most complete description of a way of achieving sub-ns accuracy, we begin here with a summary of the WR work
  - Most of the detailed description in this presentation uses WR as an example, as detailed description for the more general HA mechanisms is not available yet

Summary of White Rabbit - 1

- See [1] and [3] for a detailed description of WR, and [2] for an overview
- WR includes a PTP profile, and adds the following aspects
  - A WR state machine (SM) that is driven by the PTP state machine
  - A link model that includes
    - A digital dual mixer time difference (DDMTD), for obtaining timestamps with sub-ns granularity
    - L1 syntonization (needed for the DDMTD to work)
      - By *L1 syntonization*, we mean syntonization at the physical layer, i.e., the *syntonized oscillators* have the same physical layer frequency (we are not simply measuring a rate ratio, as in 802.1AS)
    - Models for link asymmetry estimation (i.e., link calibration)
  - Note that the DDMTD requires L1 syntonization only at the link level, i.e., between the two ports at the end point of a link
    - However, the actual L1 syntonization in WR is network-wide
    - Some of the discussions in the P1588 HA SC have centered on whether L1 syntonization needs to be network-wide or only on a link-by-link basis

Summary of White Rabbit - 2

- WR link model (taken from Figure 3.12 of [1] and Figure 11 of [3])



Model of a WR link (a) and relations between master and slave clocks (b)♪

Summary of White Rabbit - 3

- On slide 5
  - Δ_{txm}, Δ_{rxs}, Δ_{txs}, Δ_{rxm}, are PHY delays at the master transmitter, slave receiver, slave transmitter, and master receiver, respectively
    - These delays are fixed (except there might be components that change whenever the link is initialized
  - δ_{ms} and δ_{sm} are link delays from master to slave and slave to master, respectively
  - The current link model assumes a fiber link; the transmit and receive messages are assumed to traverse the same fiber, and these delays depend on the group indices of refraction for the transmit and receive wavelengths
  - The reference clock nominal rate is 125 MHz (i.e., 8 ns coarse timestamp granularity)
  - When a PTP event message is sent by the master (i.e., Sync) or by the slave (i.e., Delay_Req; WR uses the Delay Request/Response mechanism), the messages are sent at times aligned with transmit clock edges

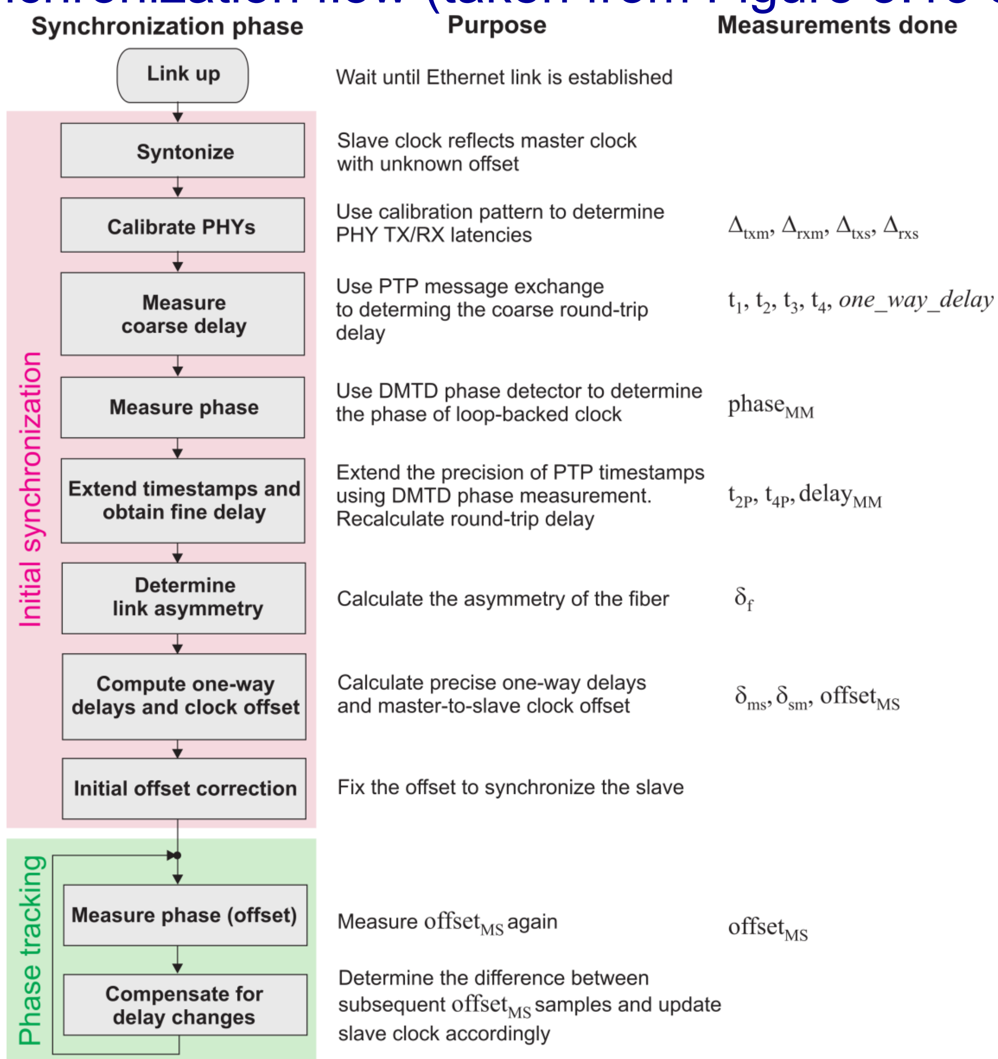
Summary of White Rabbit - 4

❑On slide 5 (cont.)

- Each event message is timestamped with the reference clock on receipt (this is a coarse timestamp, since the granularity is 8 ns)
- The phase detector at the master is the DDMTD; it makes a fine (i.e., sub-ns) measurement of the phase difference ($phase_{MM}$ on slide 5) between the sent and received message
- Based on this measurement and the link delay asymmetry models, the time offset at the slave is obtained, and $phase_{S}$ is adjusted.
- The full process is summarized in more detail on the following slide (taken from Figure 3.13 of [1] and Figure 12 of [3])

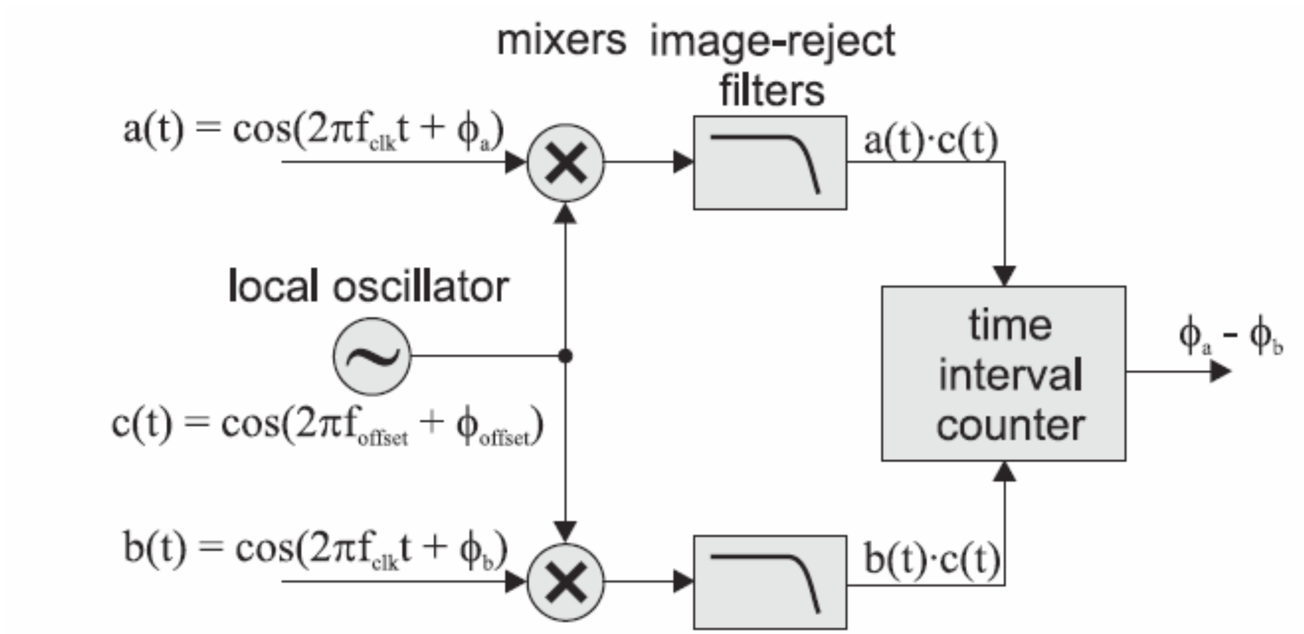
Summary of White Rabbit - 5

- WR synchronization flow (taken from Figure 3.13 of [1] and Figure 12 of [3])



Summary of White Rabbit - 6

❑Analog Dual Mixer Time Difference (taken from Figure 3.18 of [1] and Figure 17 of [3])



Multiplier output:

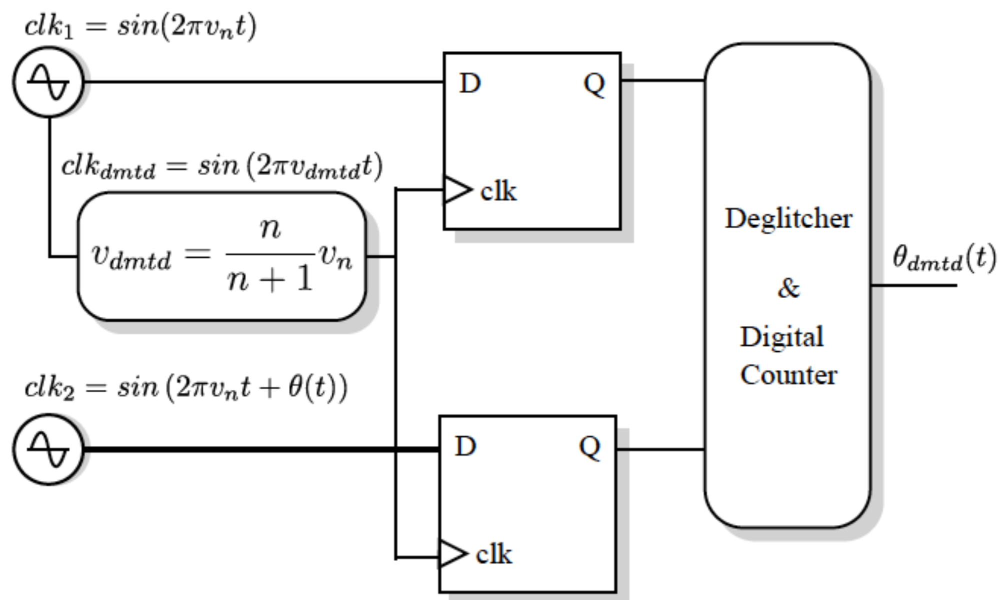
$$a(t)c(t) = \frac{\cos(2\pi(f_{clk} + f_{offset})t + \phi_a + \phi_{offset}) + \cos(2\pi(f_{clk} - f_{offset})t + \phi_a - \phi_{offset})}{2}$$

If f_{clk} and f_{offset} are very close, then the low-pass filters remove the high frequency components, and the resulting signal has much lower frequency, for which time can be measured to much finer granularity

Summary of White Rabbit - 7

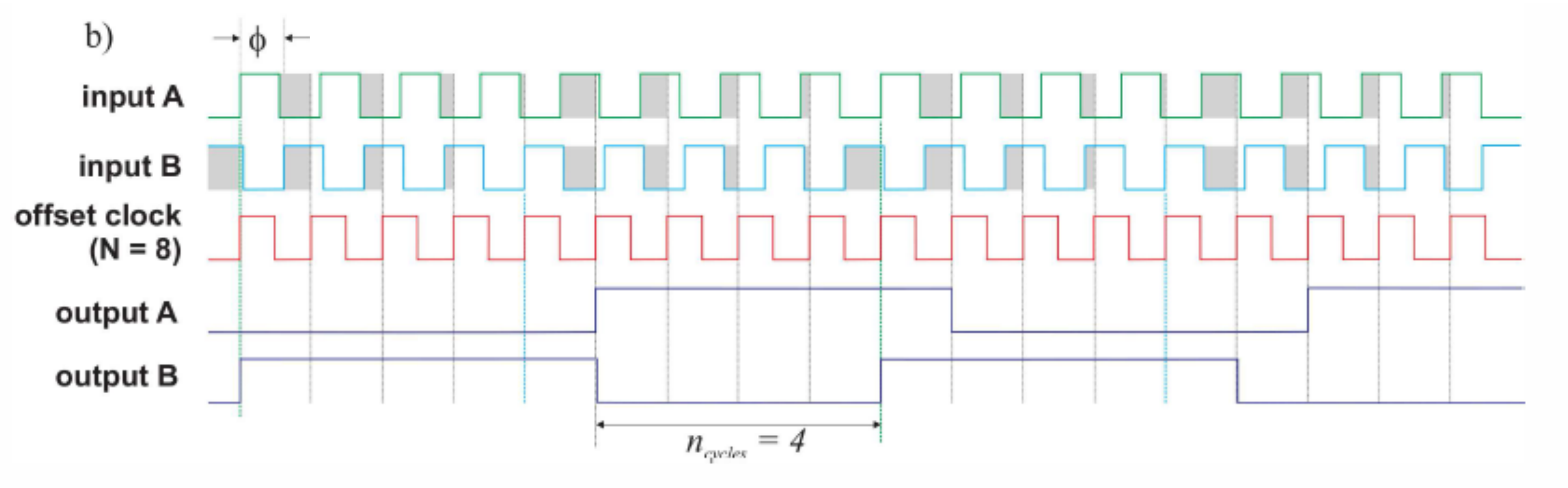
- If f_{clk} and f_{offset} are very close, then the low-pass filters remove the high frequency components, and the resulting signal has much lower frequency, for which time can be measured to much finer granularity
  - For example (see [1] and [3]), if f_{clk} = 125 MHz and f_{offset} = 124.99 MHz, the output signal is 10 kHz
- White Rabbit uses a digital version of the mixer, the Digital Dual Mixer Time Difference (DDMTD) (see [1] and [3], and see [4] for a detailed description of the DDMTD)

DDMTD Schematic (taken from Figure 2 of [4])



Summary of White Rabbit - 8

- Signals generated by the DDMTD (taken from Figure 3.20 (b) of [1] and Figure 19(b) of [3])



Summary of White Rabbit - 9

- Note that for the DDMTD to work, the frequencies of the signals being compared must be the same
- This means that the frequency at the master and the received frequency from the slave must be syntonized
- In principle, this does not require that the entire network be syntonized; however (the following sub-bullets are the current view of the author of this presentation):
  - Timestamping on each port of a clock must be relative to a common clock; this implies that different ports on the same clock will have the same frequency
  - This, plus syntonization of the ports at the ends of a link, seem to imply syntonization of all the nodes in the network
  - In theory, different ports of a clock could timestamp relative to different clocks if we knew the relations among those clocks
  - But, if those clocks were not syntonized, we would have to measure those relations using timestamps, and would need the HA mechanisms for those measurements (i.e., DDMTD and syntonization)

Summary of White Rabbit - 10

- White Rabbit SM (taken from Figure 9 of [3])

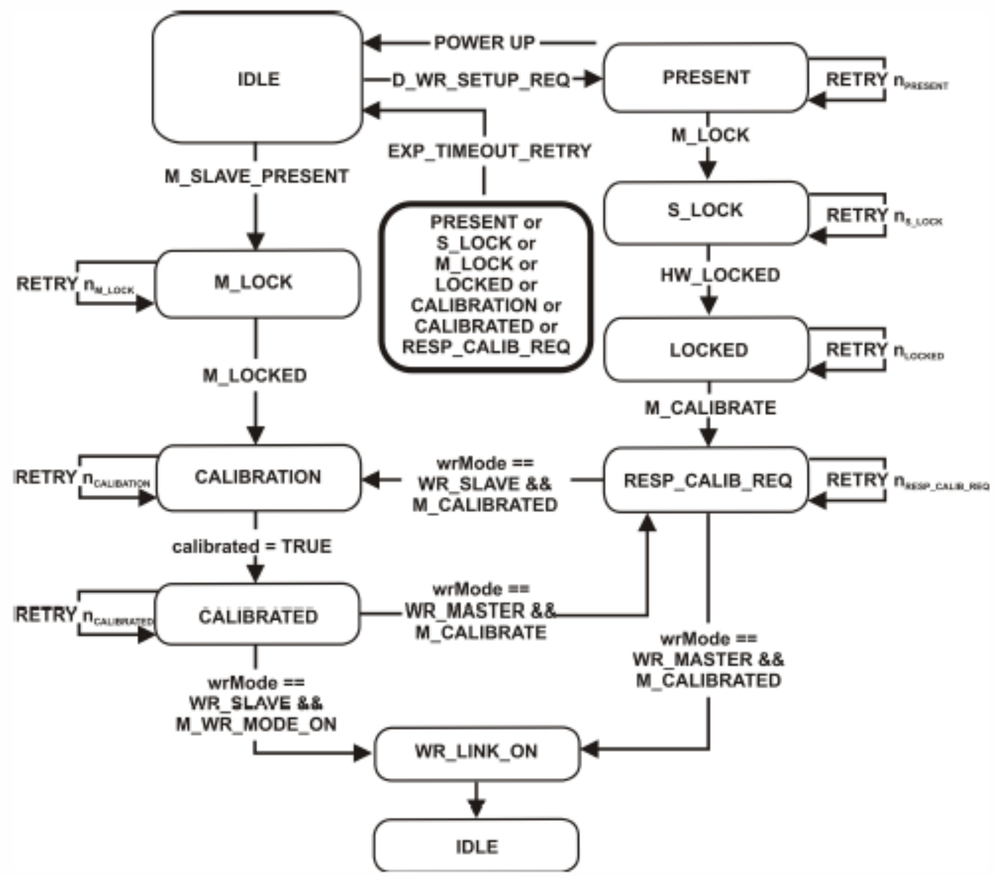


Figure 9: White Rabbit state machine.

This SM is driven by the (modified) PTP state machine, and in turn drives message flows shown on the nex t slide♪

Summary of White Rabbit - 11

- Example of message flows (taken from Figure 3.14 of [1] and Figure 13 of [3]; note that this is not the full set of message flows)

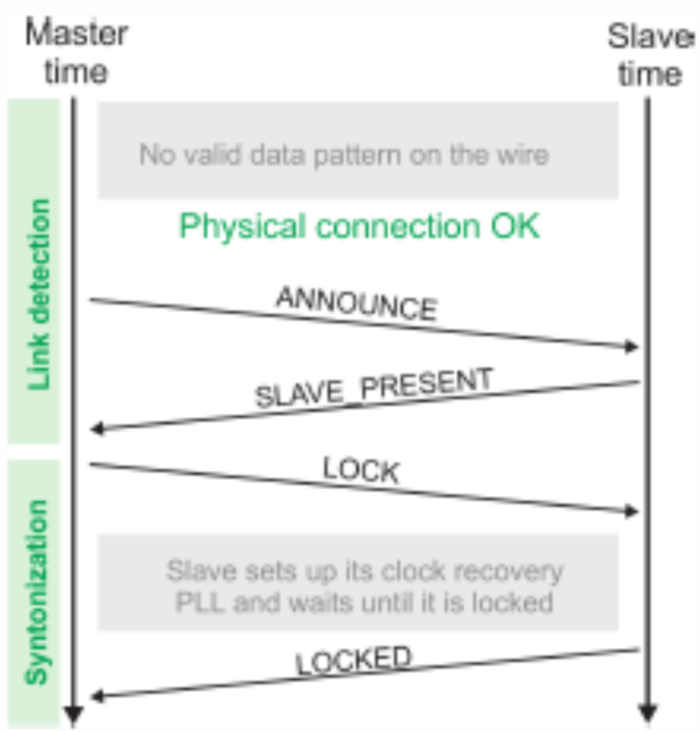


Figure 13: WR Link detection and syntonization

High Accuracy SC Requirements

- The full requirements are in the P1588 Working Group HA SC Central Desktop area
- The requirements are not reproduced verbatim here because it was not clear to the author what permissions, if any, were needed for this
- However, the requirements are, essentially, to consider the optional mechanisms needed for the HA feature, provide a detailed description of each mechanism, provide examples of how to combine the mechanisms to achieve HA (i.e., better than 1 ns), and identify other groups (either in the P1588 WG or elsewhere) to liaise information to
- The main mechanisms discussed so far are
  - physical layer syntonization
  - link delay/asymmetry calibration
  - Means to achieve the necessary timestamp granularity (need not be confined to DDMTD)

HA Use Cases – 1

- This list is a result of a survey within the P1588 WG, plus subsequent discussion in the HA SC
- This is a current list; it could be added to if there are additional suggestions
  - White Rabbit
  - Telecom networks (essentially the current Telecom time profile with full timing support (i.e., all nodes PTP capable) and SyncE support for frequency, and using current method for link calibration
    - Note that discussions are still ongoing concerning what this item will include and how it would differ from the current Telecom time profile with full timing support
  - High accuracy over Telecom (essentially the current Telecom time profile with full timing support and SyncE support, but with DDMTD and other features to obtain high accuracy
    - Note that we must consider whether SyncE as specified in G.8262 would support the use of the DDMTD (it is not clear what the SyncE performance is in White Rabbit; this is being looked at)

HA Use Cases - 2

  - High accuracy over Copper
    - Link calibration of the portion of link delay that could vary each time the link is initialized could likely not be done as in WR

- Note that some of the HA optional mechanisms could be useful by themselves, for example
  - Link calibration is useful even if sub-ns accuracy is not needed
  - Note that management support for automatic calibration of link asymmetry is part of the 802.1ASbt PAR
    - Whatever is done here should be consistent with what is done in the HA SC
  - Also, some application may not need sub-ns accuracy per se, but might need a much larger number of hops than has currently been considered
    - For example, some of the industrial automation use cases in AVB Gen 2 need 64 hops or 128 hops

HA SC Work Expected between now and F2F in April, 2014

- Produce use cases and requirements for Optional L1 Syntonization
- Produce proposal for full P1588 WG for optional L1 Syntonization feature
- Even though L1 Syntonization is the initial mechanism being worked on, there will be some discussion of link calibration prior to and during the April, 2014 F2F meeting
  - It was indicated that, since the meeting will be at CERN, it would be desirable to take advantage of the fact that WR experts will be present and not limit the discussion to only L1 Syntonization
- As of the preparation of this presentation, the requirements for L1 syntonization are being discussed in the HA SC
  - The next call is Thursday, January 23, 2014 at 11 AM EST (8 AM PST)

References - 1

[1] Tomaz Wlostowski, *Precise time and frequency transfer in a White Rabbit Network*, Master of Science Thesis, Warsaw University of Technology, Academic year 2010/2011.

[2] Maciej Lipinski, Tomasz Wlostowski, Javier Serrano, and Pablo Alvarez, *White Rabbit: a PTP Application for Robust Sub-nanosecond Synchronization*, ISPCS 2011.

[3] Emilio G. Cota, Maciej Lipinski, Tomasz Wlostowski, Erik van der Bij, and Javier Serrano, *White Rabbit Specification: Draft for Comments*, version 2.0, 06-07-2011.

[4] Pedro Moreira, Pablo Alvarez, Javier Serrano, and Izzat Darwezeh, *Digital Dual Mixer Time Difference for Sub-Nanosecond Time Synchronization in Ethernet*, 2010 IEEE Frequency Control Symposium.