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SWATCH GROUP ELECTRONIC SYSTEMS

Synchronization Principles for Packet Networks

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Outline

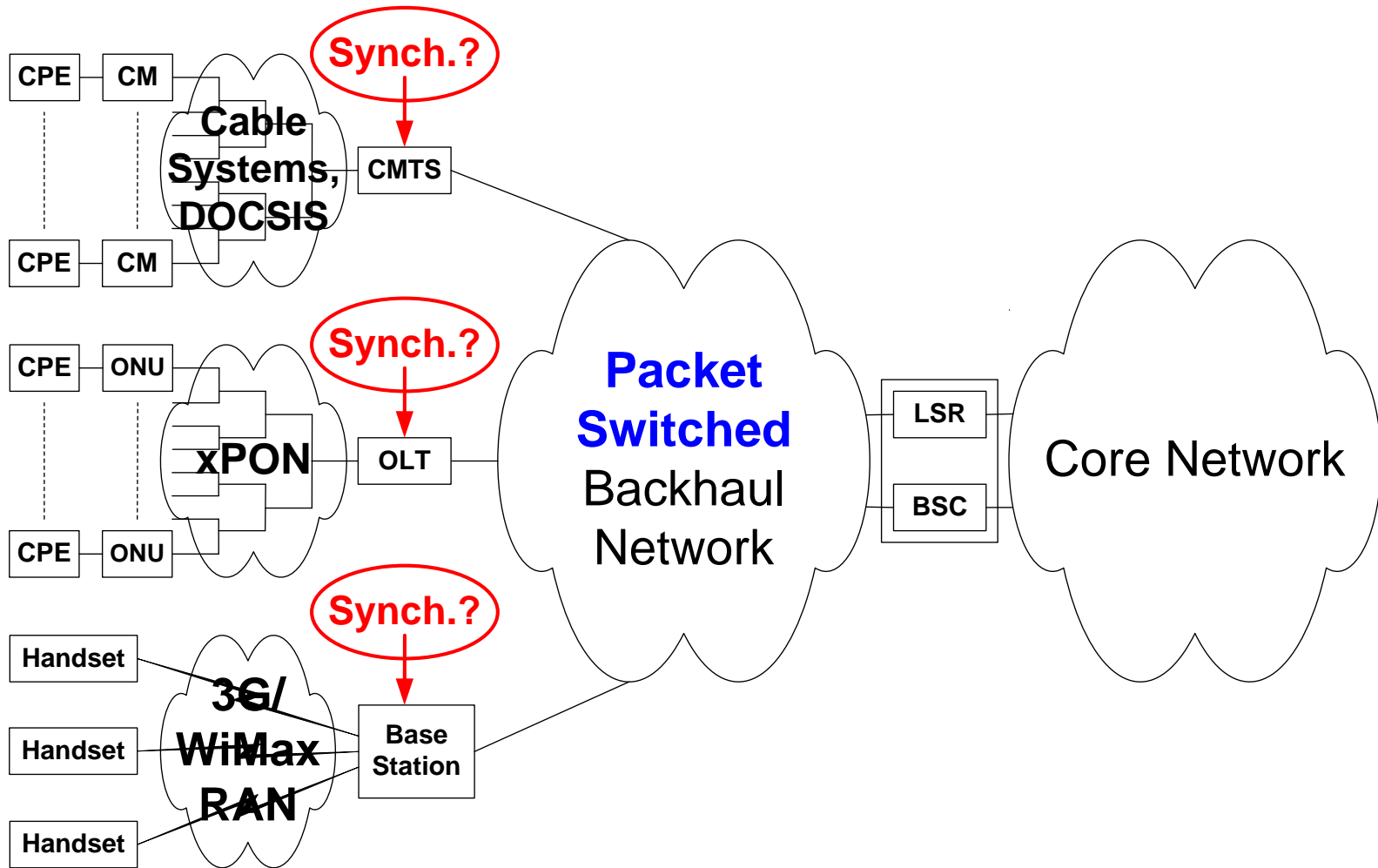
1. Introduction
2. Network Synchronization Techniques
 - 2.1. Free-running Oscillators
 - 2.2. Off-the-air (GNSS)
 - 2.3. From the (Packet) Network
 - 2.3.1. Over the Physical Layer
 - 2.3.1. Over Higher Protocol Layers
 - 2.4. Combinations
4. Conclusions



1.Introduction



Network Synchronization

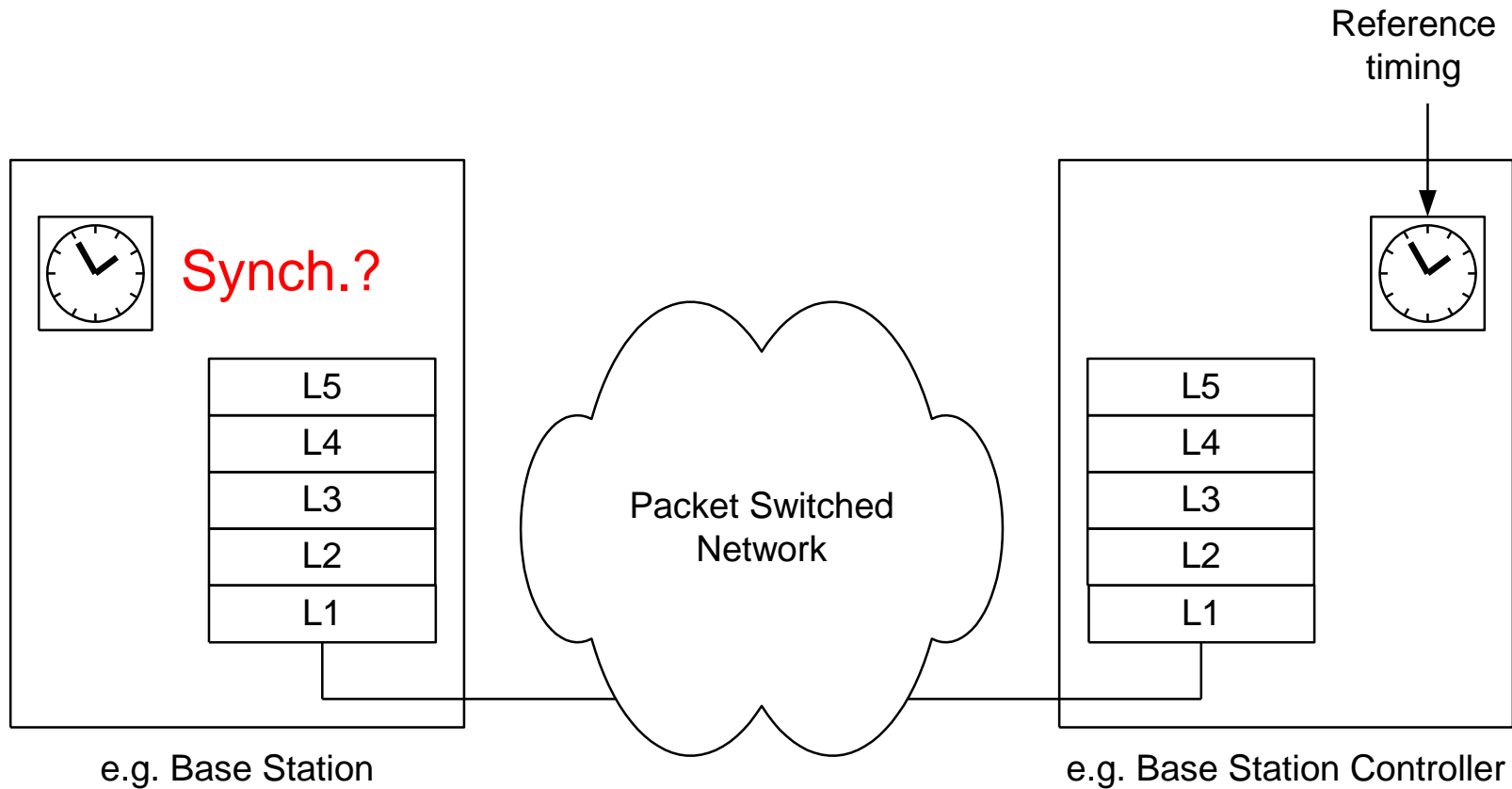




2. Network Synchronization Techniques



Synch. Distribution: the Problem





Synch. Distribution: Fundamental Options

1. Free-running accurate oscillator
2. Off-the-air (GPS)
3. From the (packet) network
 - 3.1. Over the physical layer
 - 3.2. Over higher protocol layers
4. Combinations

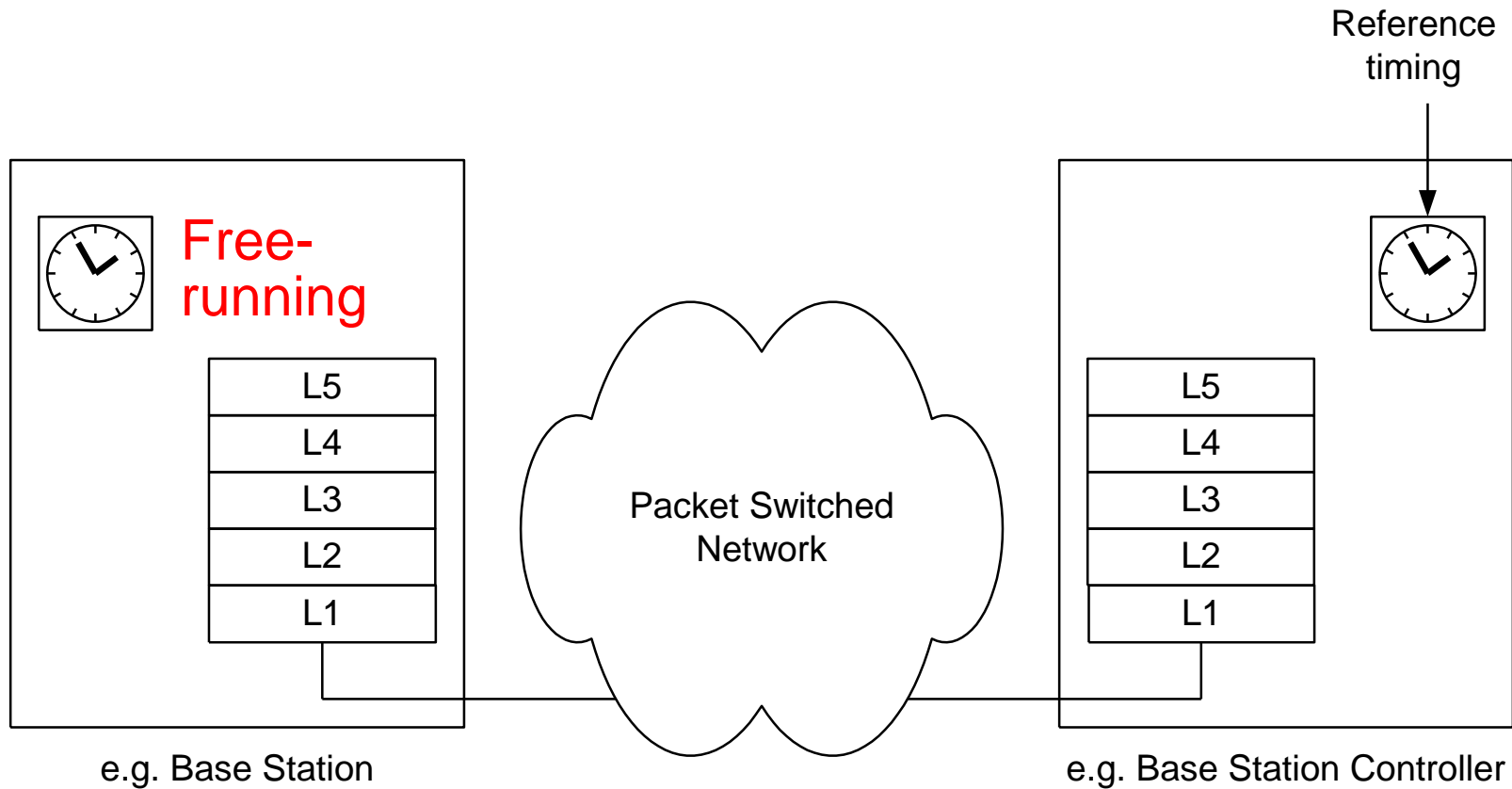


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2.1. Free-running Oscillator

Option 1: Free-running Oscillator





Option 1: Free-running Oscillator

- Free-running oscillator in the Base Station with adequate frequency accuracy (e.g. $5E-8$ in the case of GSM and UMTS)
- Only frequency synchronization is possible, but not phase nor time-of-day synchronization
- State-of-the art atomic Rubidium oscillators:
 - ❖ Frequency drift: $5E-10$ / year
 - ❖ Temperature sensitivity: $2E-10$ over $[-5^{\circ}\text{C}$ to $55^{\circ}\text{C}]$
- Issue: cost of these oscillators

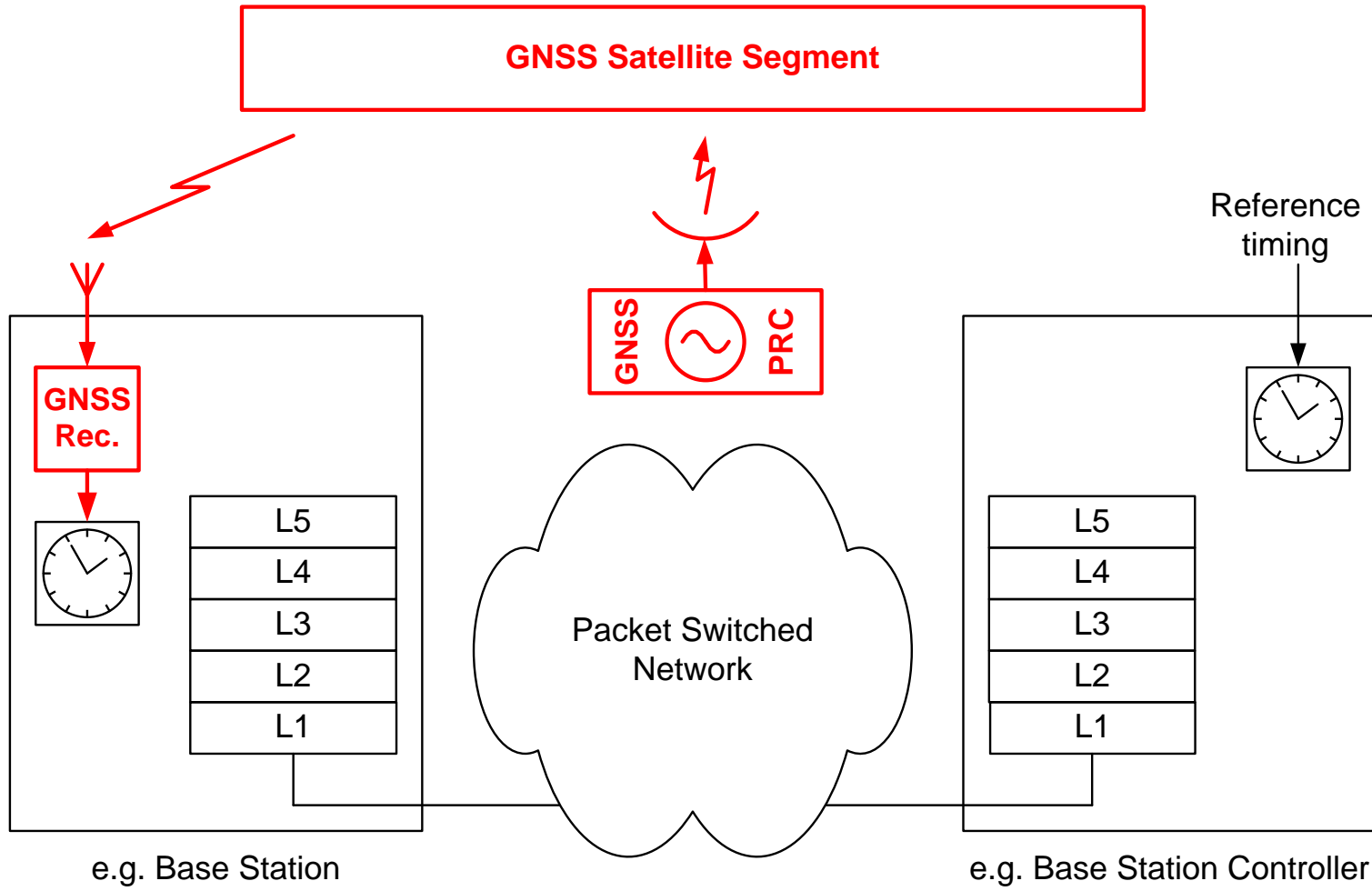


2.2. Off-the-air (GNSS)

(GNSS = Global Navigation Satellite System, e.g. GPS, Glonass, Galileo)



Option 2: Off-the-air (GNSS)





Option 2: Off-the-air (GNSS)

- Use GNSS-receiver as source for frequency, phase and time-of-day synchronization
- State-of-the art (synchronization grade) GPS-receivers:
 - ❖ Frequency accuracy: $1\text{E-}12$ (over 20 000 s)
 - ❖ Time accuracy: 50 ns (rel. UTC)
- **Mature technology**
- Issue: antenna installation



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2.3. From the (Packet) Network



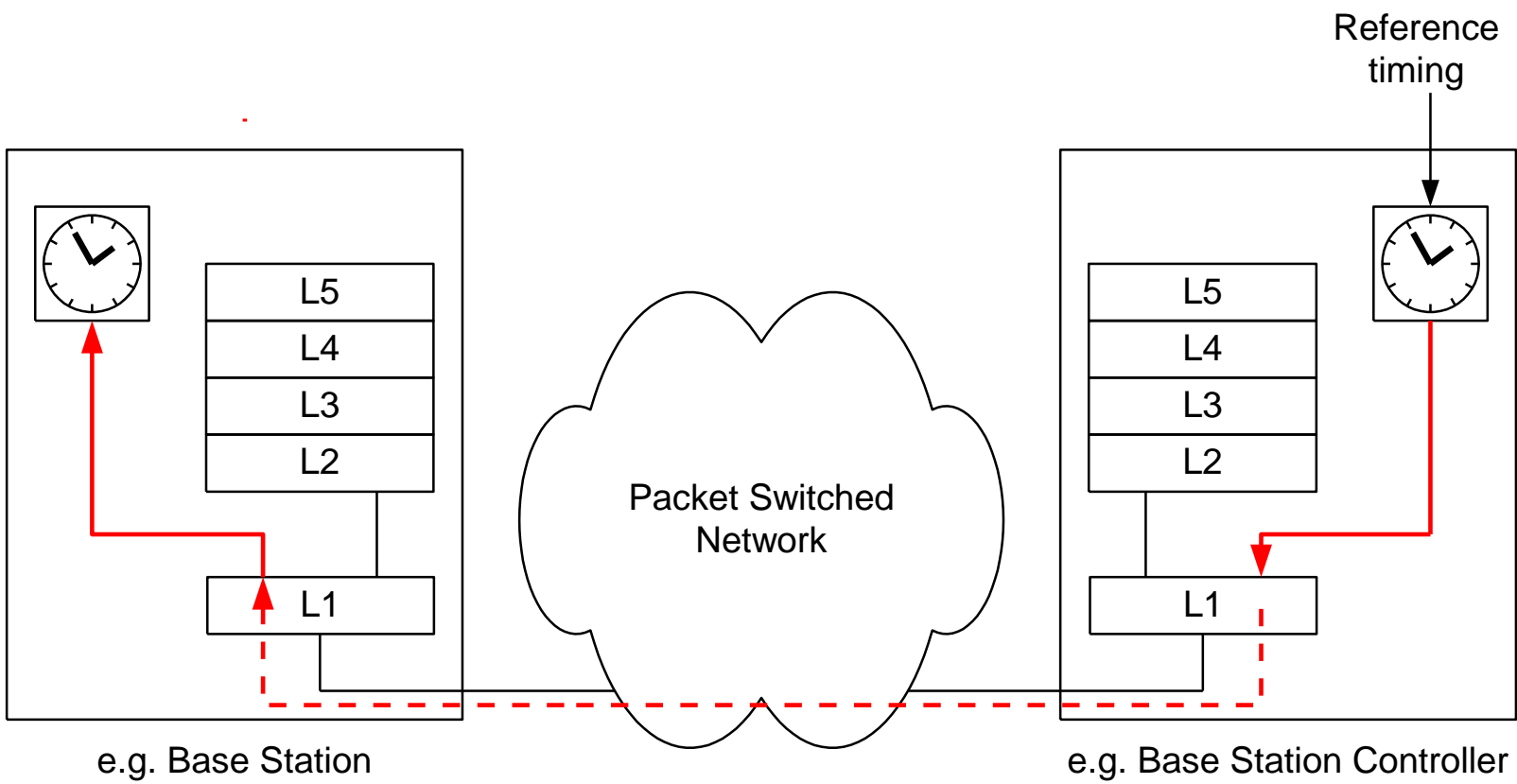
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2.3.1. From the Network over the Physical Layer



Option 3.1.: Physical Layer





Option 3.1.: Physical Layer

- Physical signal carries synchronization (in the line code)
- Only frequency synchronization, but not phase nor time-of-day synchronization
- Legacy: E1, DS1, SDH, SONET
- Future: **synchronous Ethernet:**
 - ❖ Initially proposed by British Telecom
 - ❖ Work in progress within ITU-T and IEEE
 - ❖ Explicitly mentioned in new ITU-T Rec. G.8261 (G.pactiming)
 - ❖ Will probably have SSM (Synchronization Status Message)



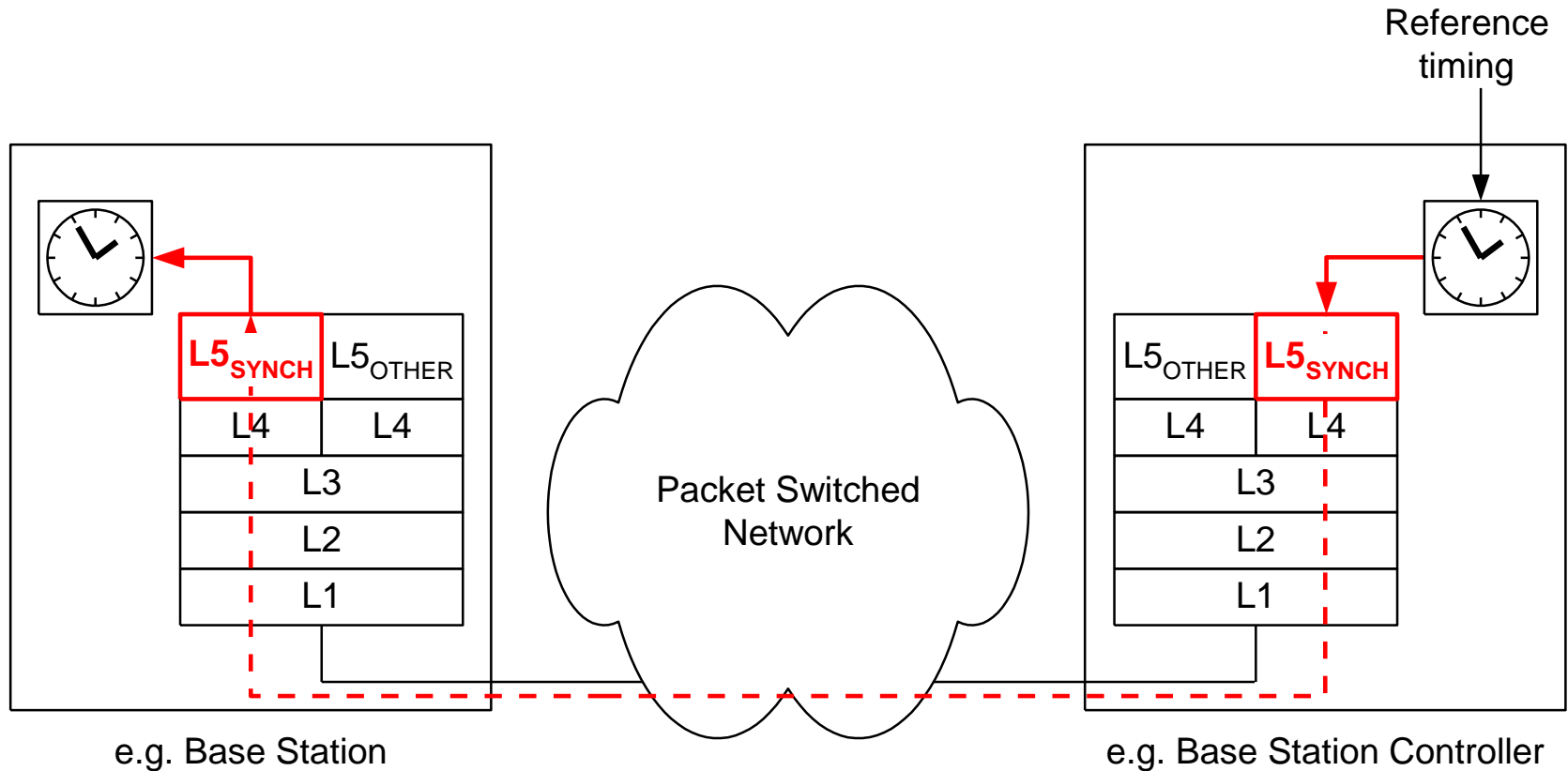
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2.3.2. From the Network over Higher Layers



Option 3.2.: Higher Layers





Option 3.2.: Higher Layers

- Use a packet based protocol in order to convey timing.
- Packet Delay Variation (PDV) generated in the packet switched network must be mitigated with some technique by the protocol entities.
- Many configurations and techniques are **envisageable**, see following slides.

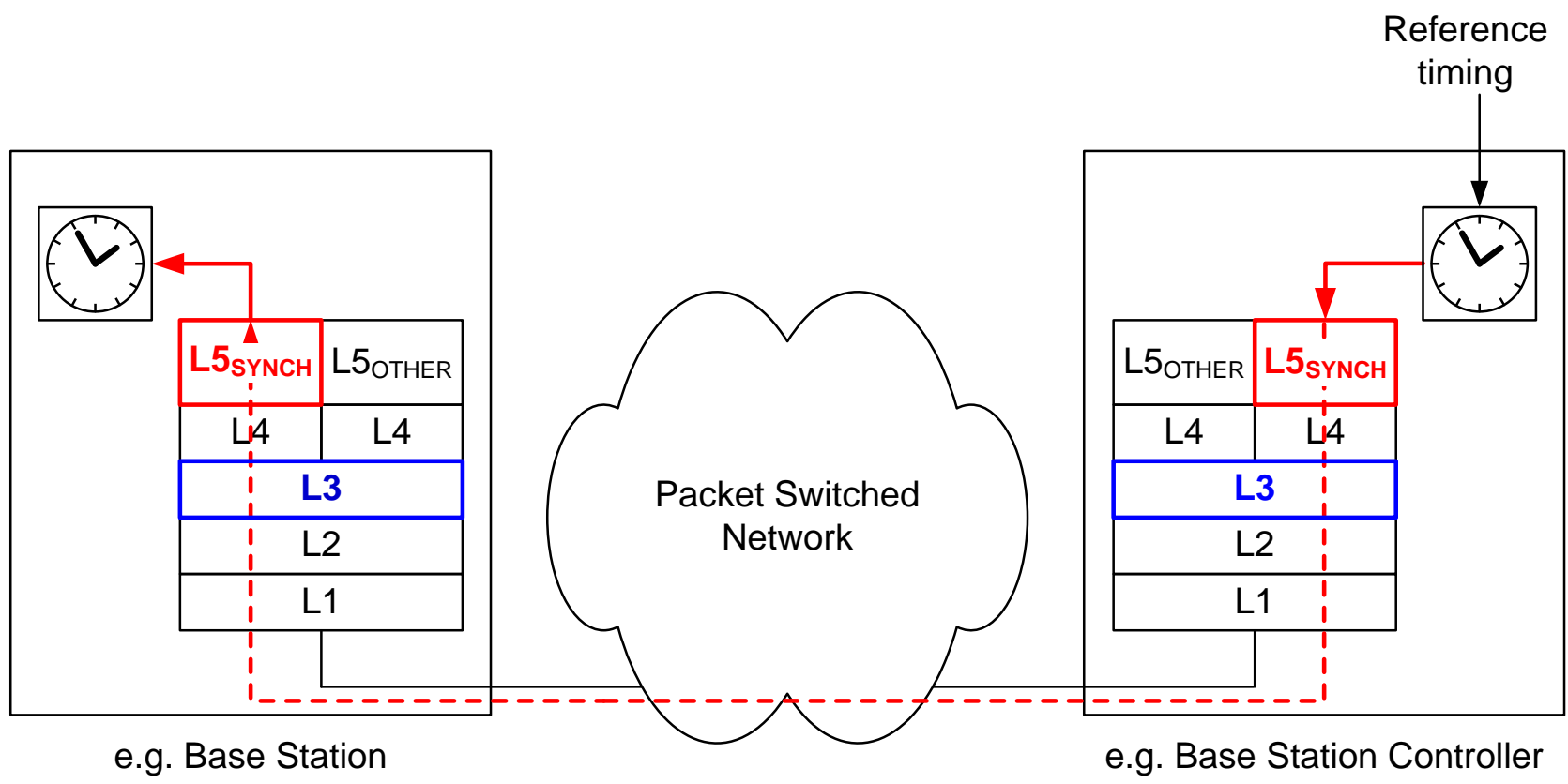


Synch. Over Higher Layers

- Distinction A:
 - ❖ With Layer 3 routing
 - ❖ Without Layer 3 routing (with Layer 2 switching)
- Distinction B:
 - ❖ One-way protocol: Adaptive Clock Recovery (ACR)
 - ❖ Two-way protocol: Two-Way Time Transfer (TWTT)
- Distinction C:
 - ❖ Without hardware assistance
 - ❖ With hardware assistance



With Layer 3 Routing



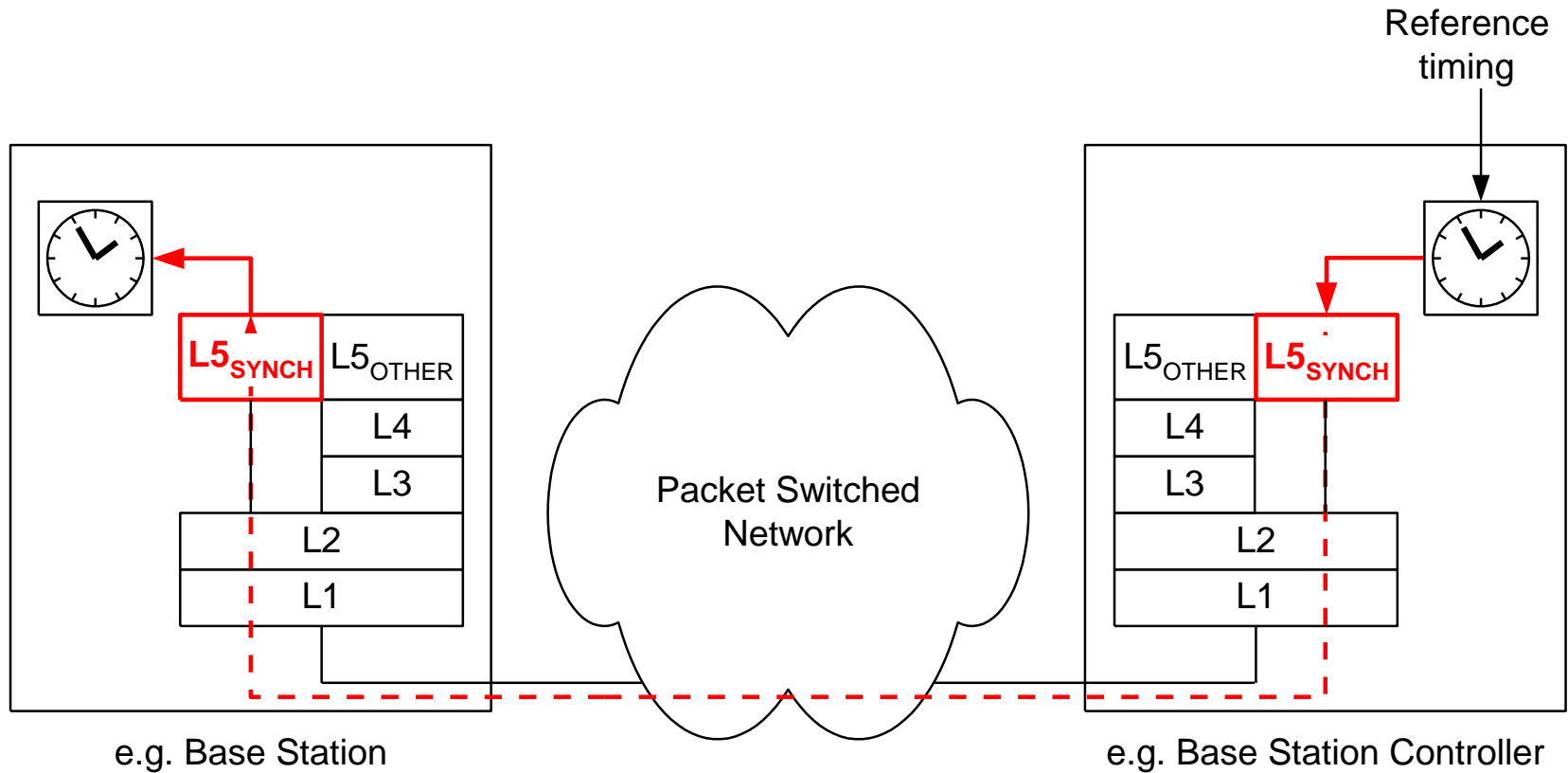


With Layer 3 Routing

- Synchronization protocol sits above IP (L3) and UDP (L4).
- Synch. packets can in principle traverse any IP or IP/MPLS network.
- Example 1: PTP V2 (IEEE 1588 V2)
 - ❖ Possible implementation: PTP over UDP over IP over LLC over MAC over Ethernet PHY
- Example 2: NTP (RFC 1305):
 - ❖ NTP over UDP over IP over LLC over MAC over Ethernet PHY



Without Layer 3 Routing





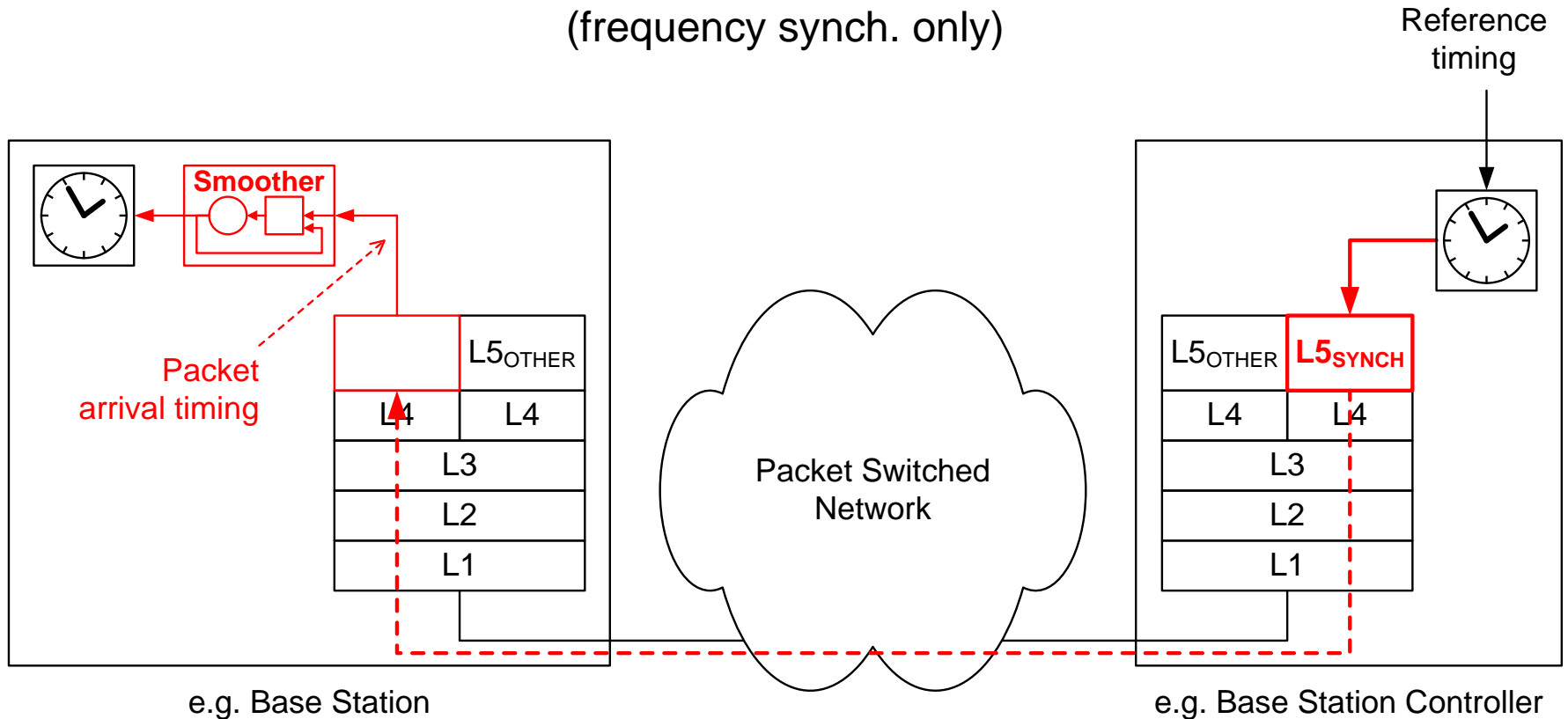
Without Layer 3 Routing

- Synchronization protocol sits above LLC and MAC (L2).
- Synch. packets can be switched via L2 switches.
- Synch. Packets cannot be routed via L3 router.
- Range limited to the L2 sub-networks.
- Example 1: PTP Version 1 (IEEE 1588 V1):
 - ❖ No L3 routing, even with implementations based on IP
- Example 2: « Ranging » in DOCSIS:
 - ❖ Uses MAC management messages (SYNC, RNG-REQ, RNG-RSP)



One-way: Adaptive Clock Recovery (ACR)

Adaptive Clock Recovery based on packet arrival timing
(frequency synch. only)

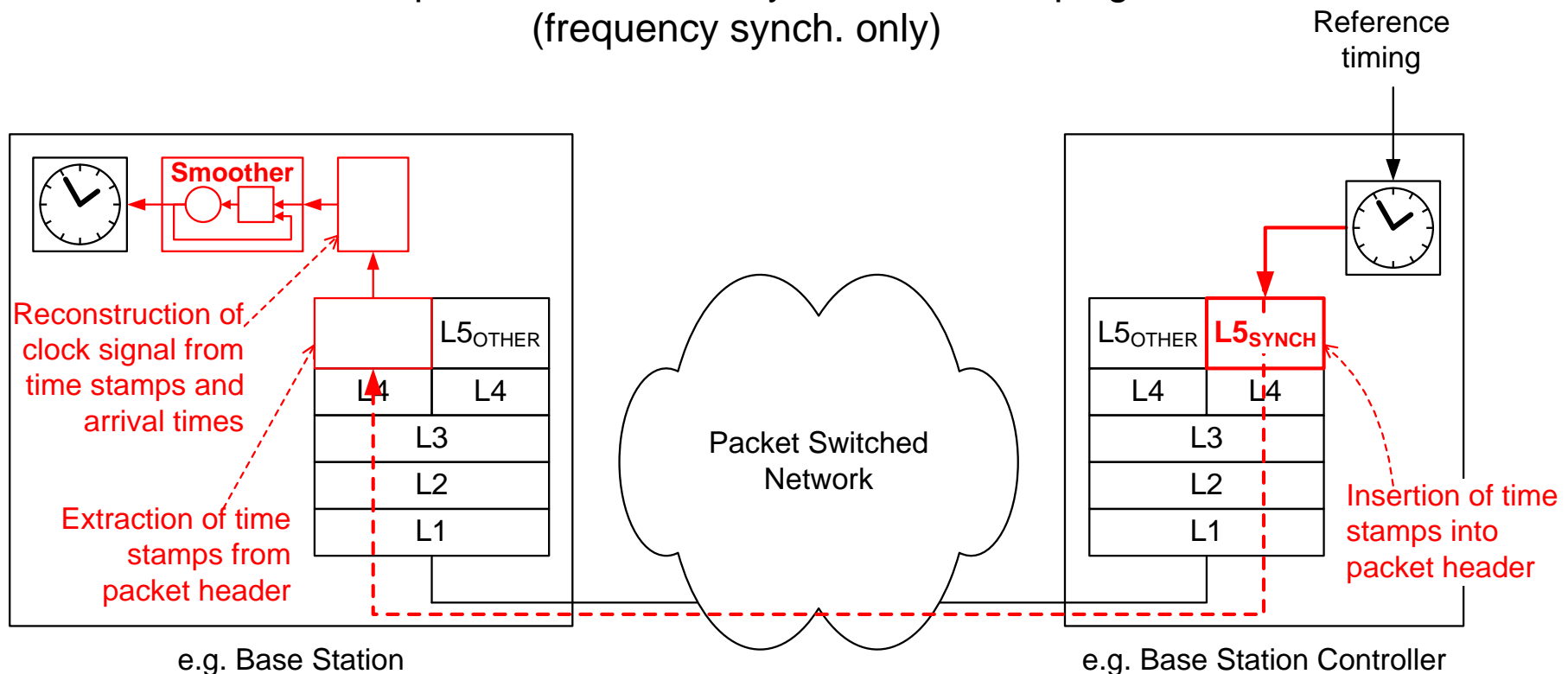


(Theoretical possibility, no known realization)



One-way: Adaptive Clock Recovery (ACR)

Adaptive Clock Recovery with Timestamping (frequency synch. only)



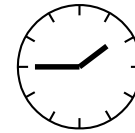
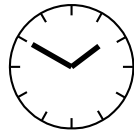
Examples: RTP implementations with proprietary RTP profiles)



Two-Way Time Transfer (TWTT)

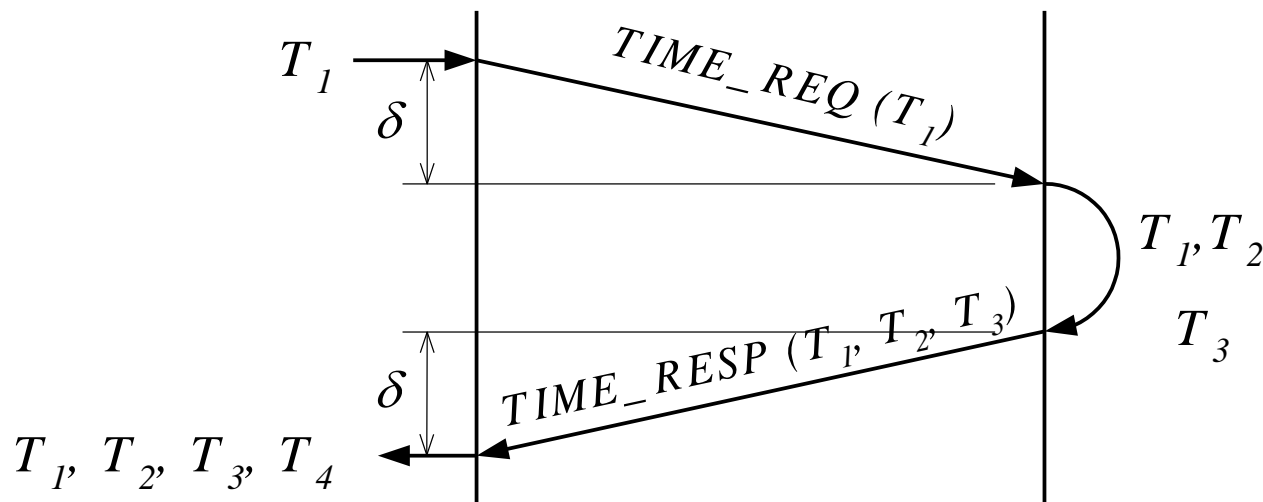
Slave (S)

Master (M)



$$t_S = t_M + \theta$$

t_M



Example: NTP (RFC 1305)



Two-Way Time Transfer (TWTT)

t_M = time scale of master clock

t_S = time scale of slave clock

δ = time offset of slave clock relative to master clock

θ = one way packet delay (assumption: symmetrical)

T_1 = transmit time of TIME_REQ on timescale t_S

T_2 = receive time of TIME_REQ on timescale t_M

T_3 = transmit time of TIME_RESP on timescale t_M

T_4 = receive time of TIME_RESP on timescale t_S



Two-Way Time Transfer (TWTT)

$$T_2 = T_1 - q + d$$

$$T_4 = T_3 + q + d$$

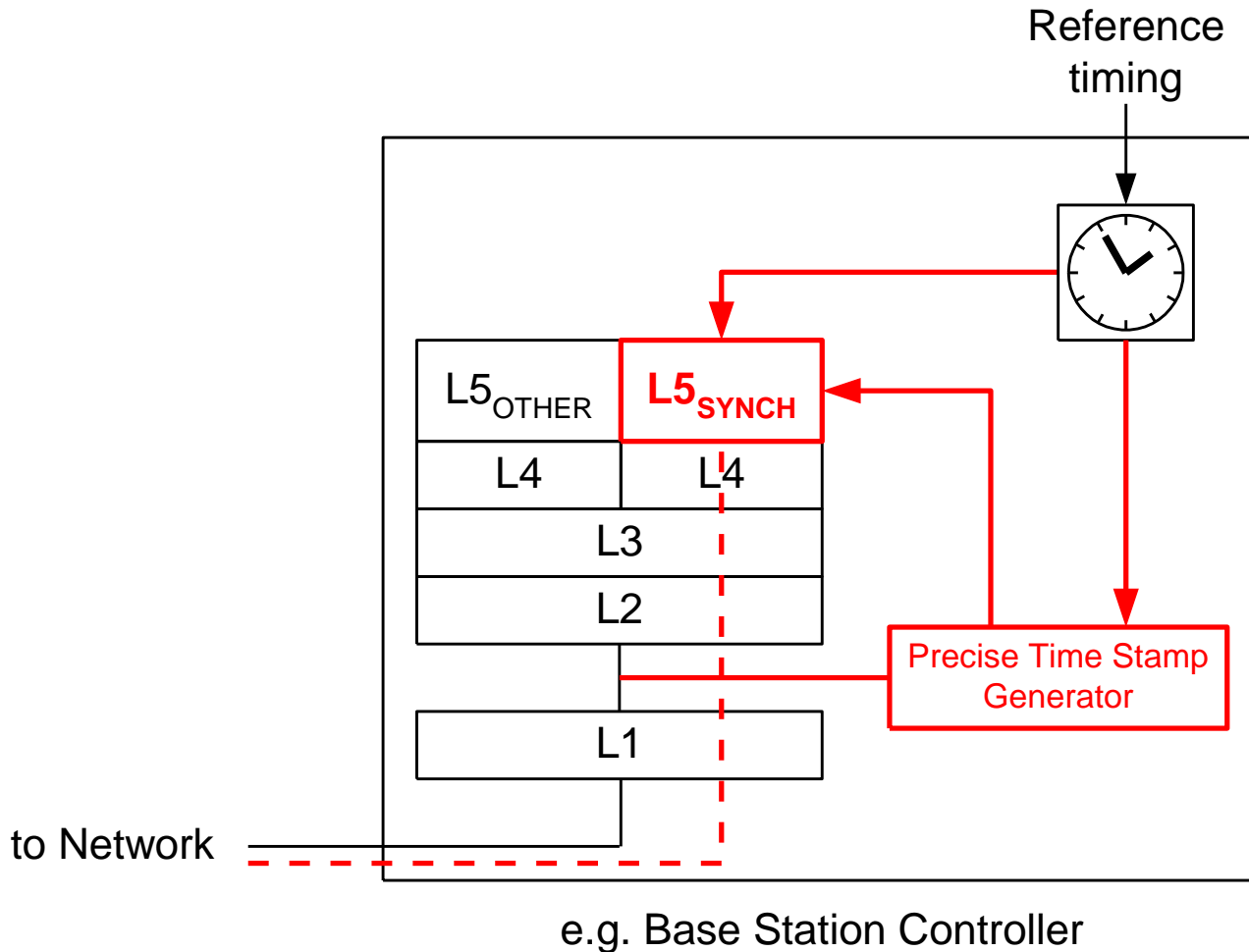
\hat{U}

$$q = \frac{(T_4 - T_3) - (T_2 - T_1)}{2}$$

$$d = \frac{(T_4 - T_3) + (T_2 - T_1)}{2}$$



TWTT with Hardware Assistance



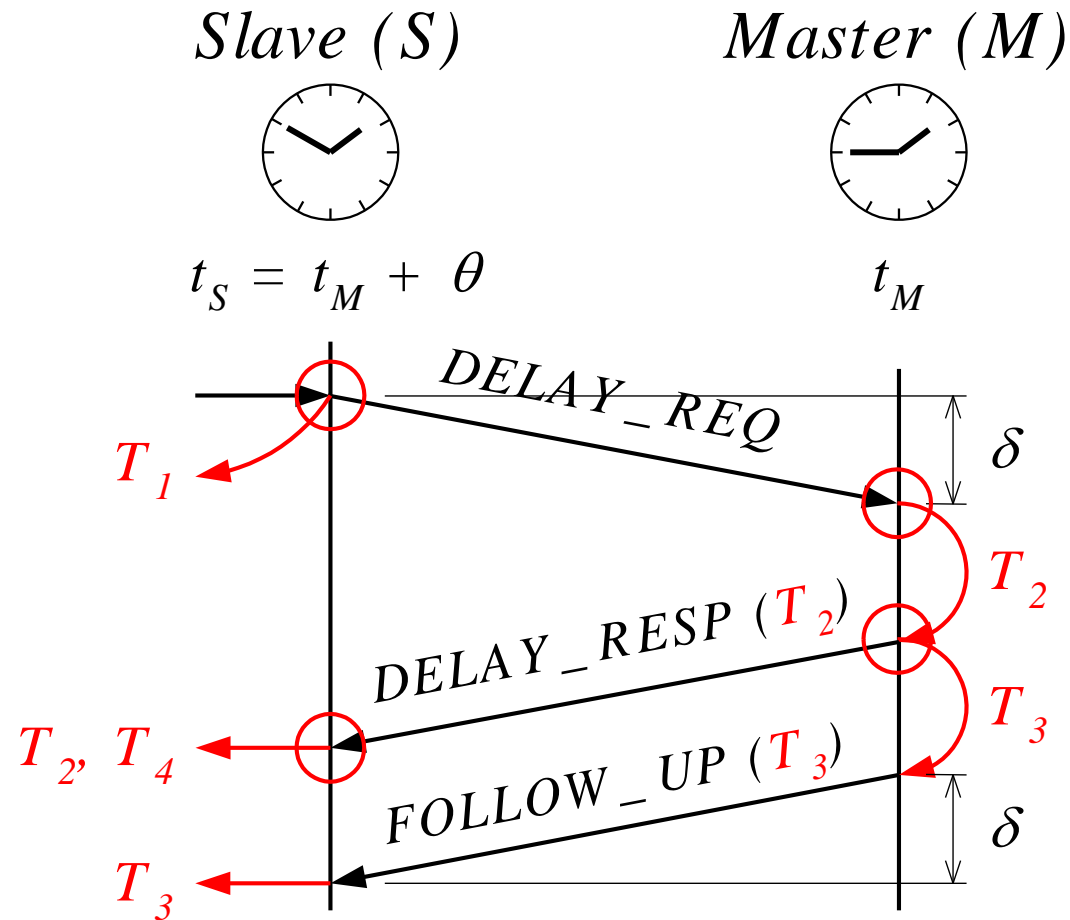


TWTT with Hardware Assistance

- Not only the network, but also the protocol stacks in the end systems generate delay and delay variations.
- The idea is to mitigate the protocol stack delay with appropriate electronic hardware and a modified TWTT protocol.
- A hardware « Precision Time Stamp Generator » measures the frame receive and transmit times at or close to the Physical Layer (Layer 1).
- An additional « Follow-up Message » is used to communicate the so measured frame transmit times to the other end system.
- The TWTT calculation exploits the time values measured by the Precise Time Stamp Generator.
- Example: PTP (IEEE 1588)



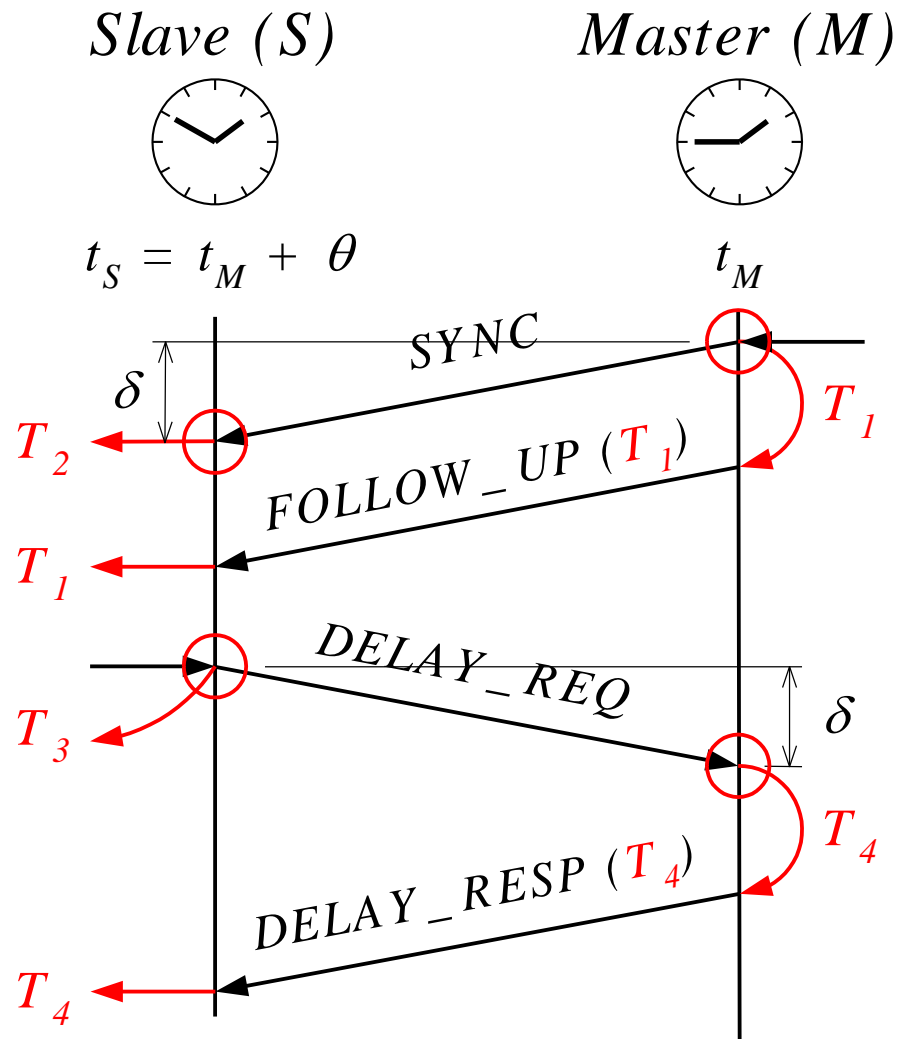
TWTT with Hardware Assistance



(Theoretical Possibility)



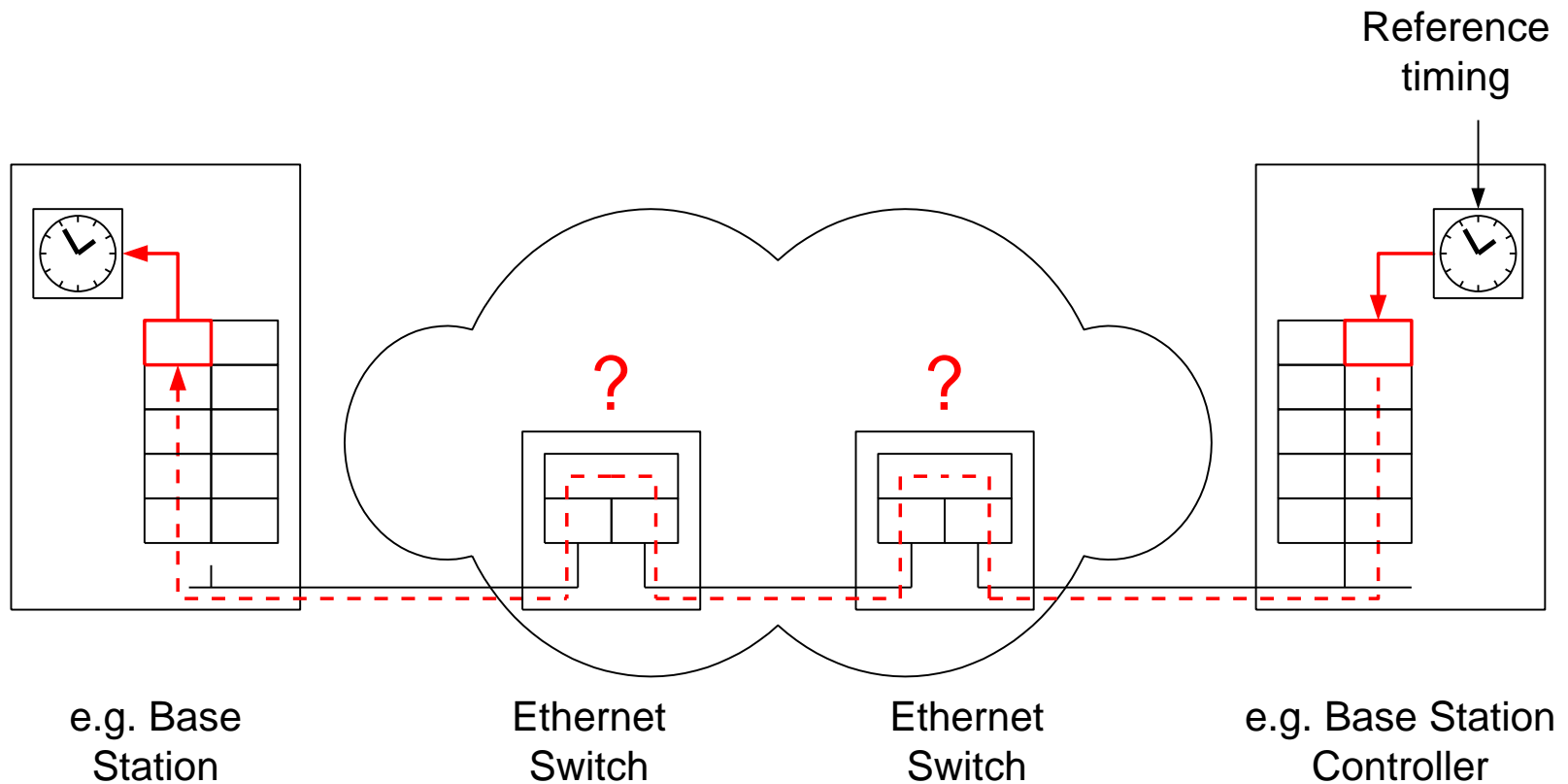
TWTT with Hardware Assistance



Example:
PTP (IEEE 1588)



Hardware Assist.: Intermediate Nodes





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3. Conclusions



Conclusions: Network Synchronization

1. **Free-running accurate oscillator** (f only)
 - ❖ Atomic Rubidium oscillators; expensive!
2. **Off-the air (GPS)** (f, ϕ , t)
 - ❖ **Mature solution**; antenna installation sometimes an issue.
3. **From the (packet) network**
 - 3.1. **Over the physical layer** (f only)
 - ❖ Synchronous Ethernet: proposed; when available?
 - 3.2. **Over higher protocol layers** (one-way: f; two-ways: f, ϕ , t)
 - ❖ IEEE 1588 V1: available today, for L2 sub-networks only.
 - ❖ IEEE 1588 V2: Q1/200; Expected to be suitable for telecom networks.
 - ❖ NTP: Questionable whether it can deliver μ s accuracy (usually ms).
 - ❖ Proprietary solutions based on ACR available today.
 - ❖ For all solutions: What performance for which network configuration and which traffic load?



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Thank you