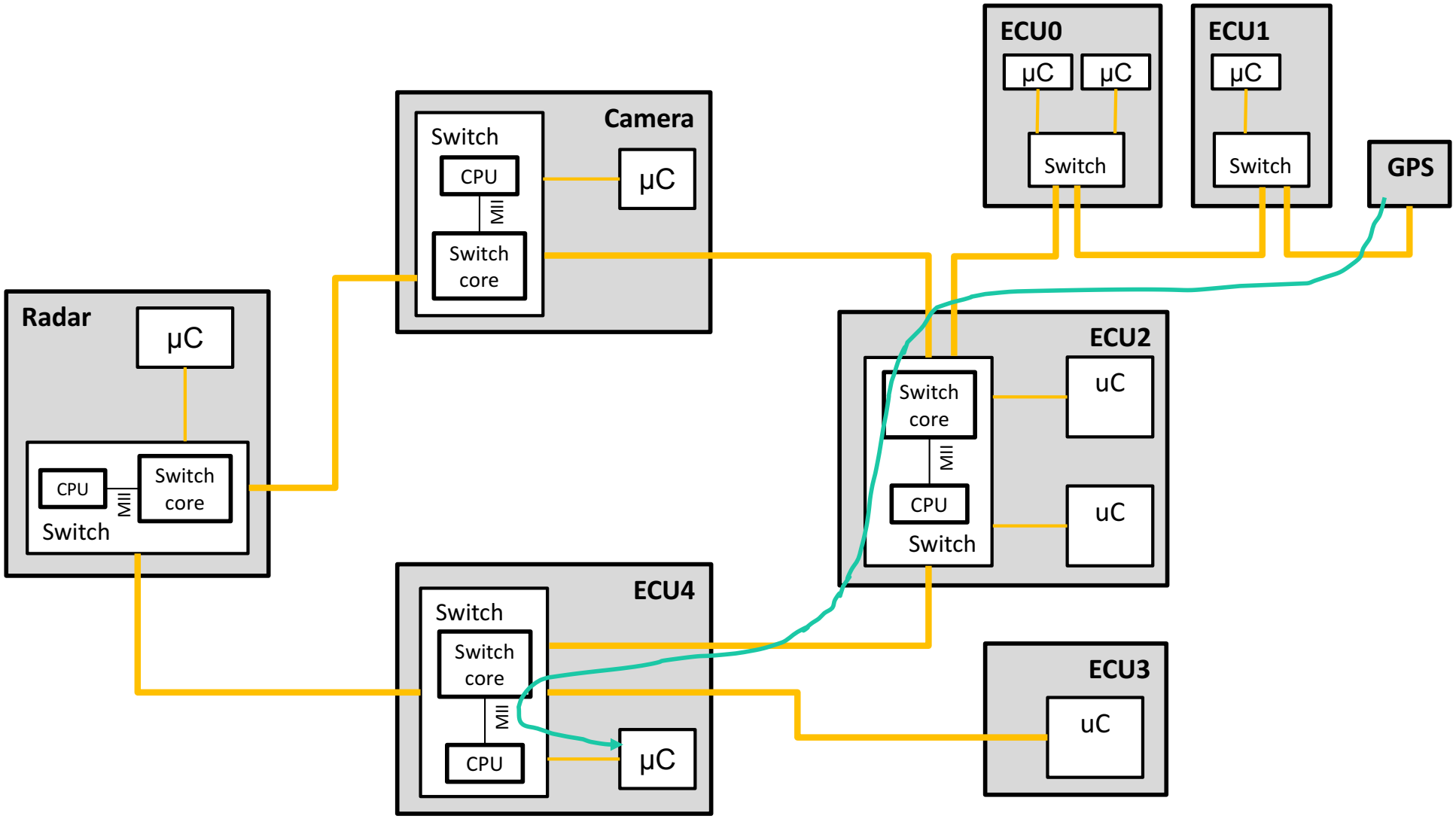
Clock Synchronization in Ethernet

Example network



GPS to ECU4

- Common that systems implement GPS corrections to bring down GPS error from ~10 meters to sub-meter precision, sometimes even centimeter level precision
- Task scheduling and variable Ethernet communication latency can cause an end-to-end delay to consumer application of 100-200 ms
- At 100 km/h, this leads to multiple meters of error
- Solution: GPS application time stamps data before transmitting, the consumer application can make temporal corrections without loss of GPS accuracy

Why do we need to synchronize clocks?

- Time stamp data and events
- Synchronous data acquisition
- Sensor fusion
- Synchronous actuation
  - Collision-imminent steering and braking
  - presentation of audio and video
- Big-data analytics without loss of temporal information
- Establish causal relationships that led to a failure
- Synchronized task execution
- Scheduling of packets on the network (e.g., TDMA)

IEEE Std 802.1AS-2011

- gPTP – Generalized Precision Time Protocol
  - Grand Master (GM)
  - Time Slave
  - Time Relay (i.e., Ethernet switches)

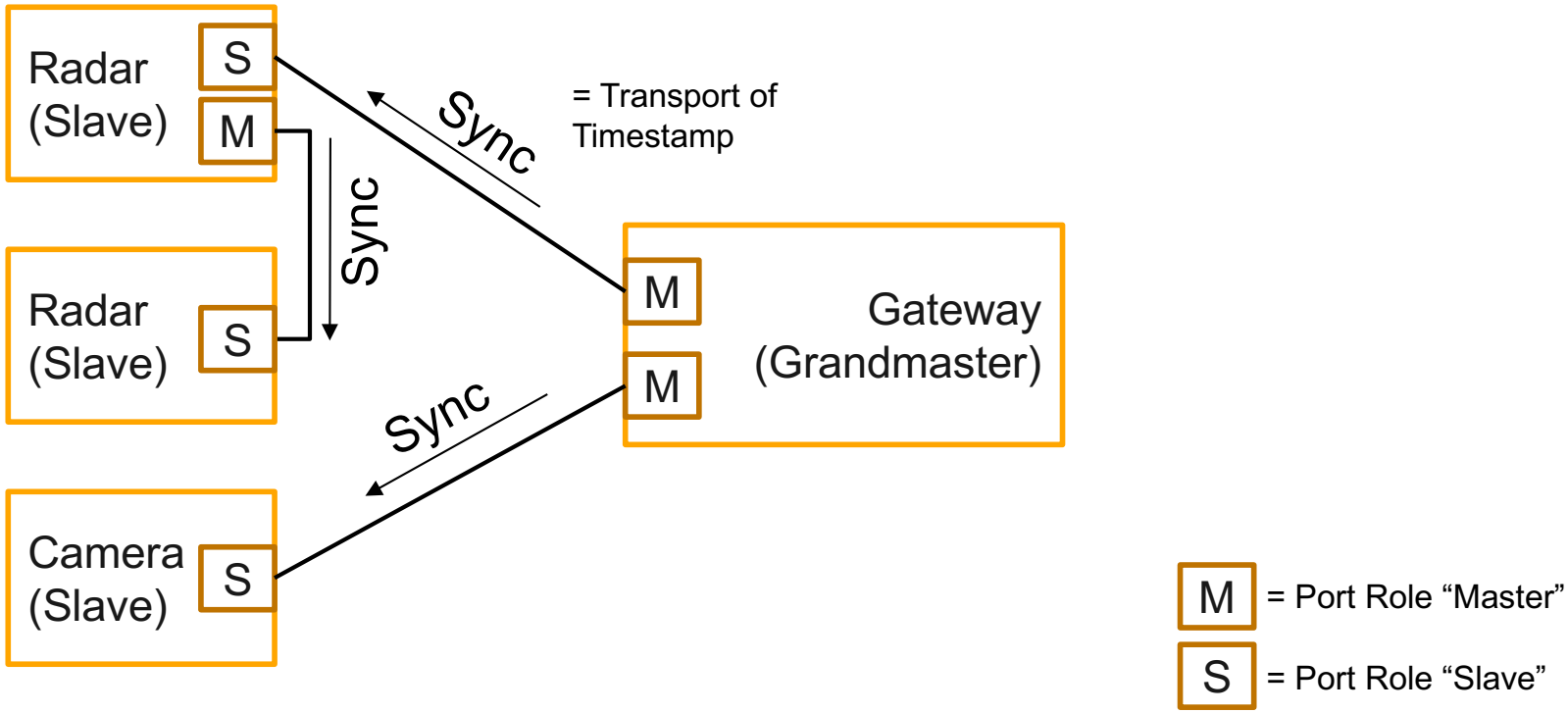
- BMCA – Best Master Clock selection Algorithm
  - ”GM capable” components
  - Distributed algorithm to elect GM
  - Re-elects new GM if current GM disappears

IEEE Std 802.1AS-2011

- gPTP (precision time protocol; profile of IEEE 1588 for full-duplex Ethernet and WiFi)
  - Time sync frames are transmitted by a Grand Master (GM)
  - Time sync frames are time stamped on ingress and egress
  - Time sync frames are modified with corrections based on time measurements and propagated through the network to time slaves
  - Time slaves adjust their time based on received time sync frames
  - Link delay is measured at each port
  - Syntonization: Rate ratio is measured by each endpoint and switch (except GM), because clocks may have different frequencies.
- BMCA (Best Master Clock selection Algorithm)
  - Election process based on Announce frames to select the Grand Master and configure port roles, thereby establishing a path to all time slaves
  - Priorities in Announce frames are configurable

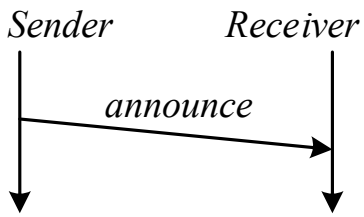
802.1AS at a glance

- Best Master Clock selection Algorithm (BMCA) to build spanning tree
- Alternative: static configuration



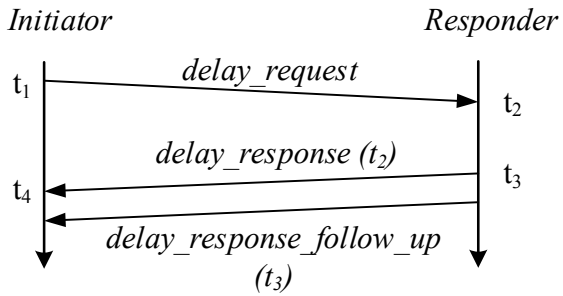
802.1AS: Three components

Announcement of best master



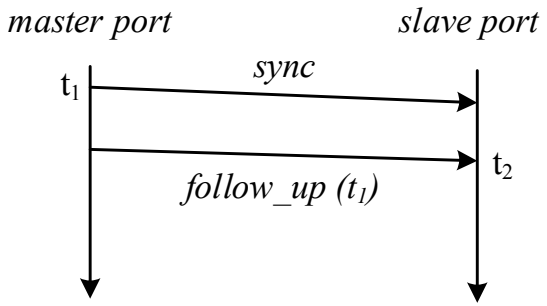
- Mostly not used
- Best clock is fixed
- Unless we have a plug & play network, or we need redundancy

Latency measurement



- Rarely in use (due to fixed wire lengths)
- Latency well known and preprogrammed

Distribution of time



- Always used

IEEE 802.1AS frame formats

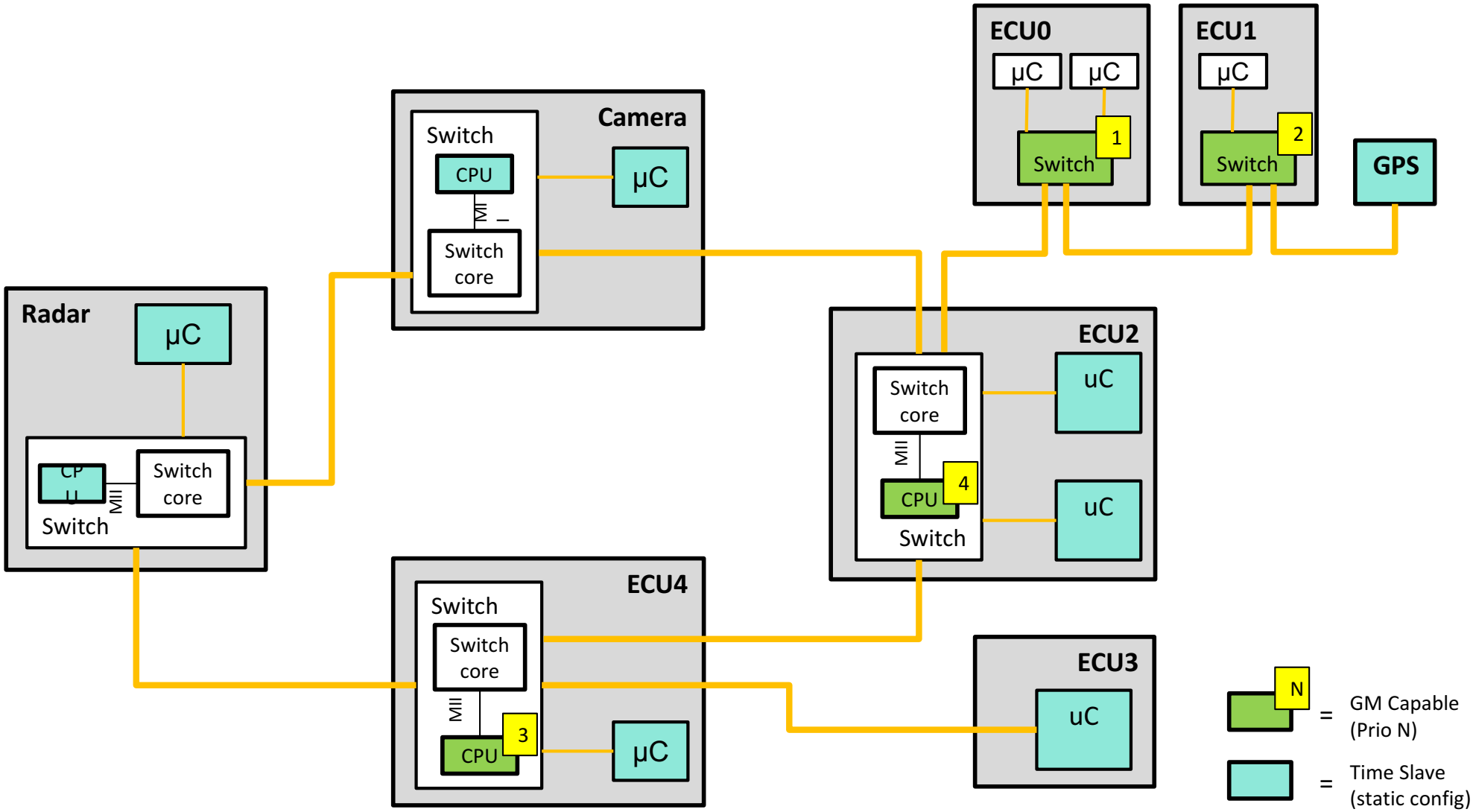
- Reserved multicast address: 01-80-C2-00-00-0E
- Reserved EtherType: 0x88F7
- 7 frame types
- Event frames are time stamped on ingress and egress

gPTP frame type	Function	Class	Value in header
Sync	Time sync	Event	0x0
Follow_Up	Time Sync	General	0x8
Pdelay_Req	Link Delay	Event	0x2
Pdelay_Resp	Link Delay	Event	0x3
Pdelay_Resp_Follow_Up	Link Delay	General	0xA
Announce	BMCA	General	0xB
Signaling	Power Saving (e.g., request reduced frequency in delay measurements)	General	0xC

Rest of this module

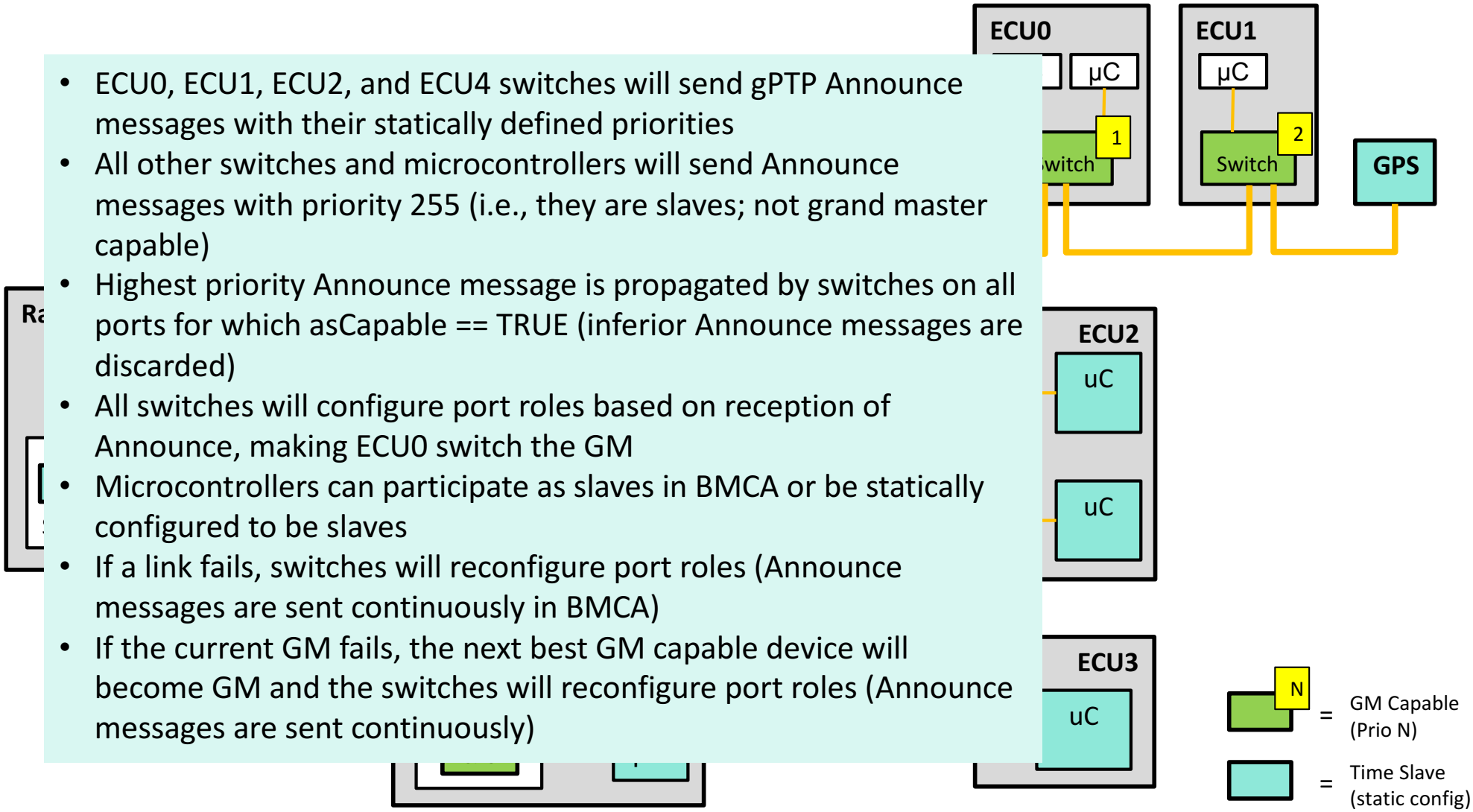
- Go through selected parts of Kevin Stanton's tutorial: http://ieee802.org/1/files/public/docs2014/as-kbstanton-8021AS-tutorial-0714-v01.pdf
- Application on an example
- Brief overview of recent amendments to the standard
  - Multiple time domains
  - Multiple synchronization paths
  - Multiple grand masters

1. BMCA, GM Capable devices, Time slaves, gPTP Announce frames

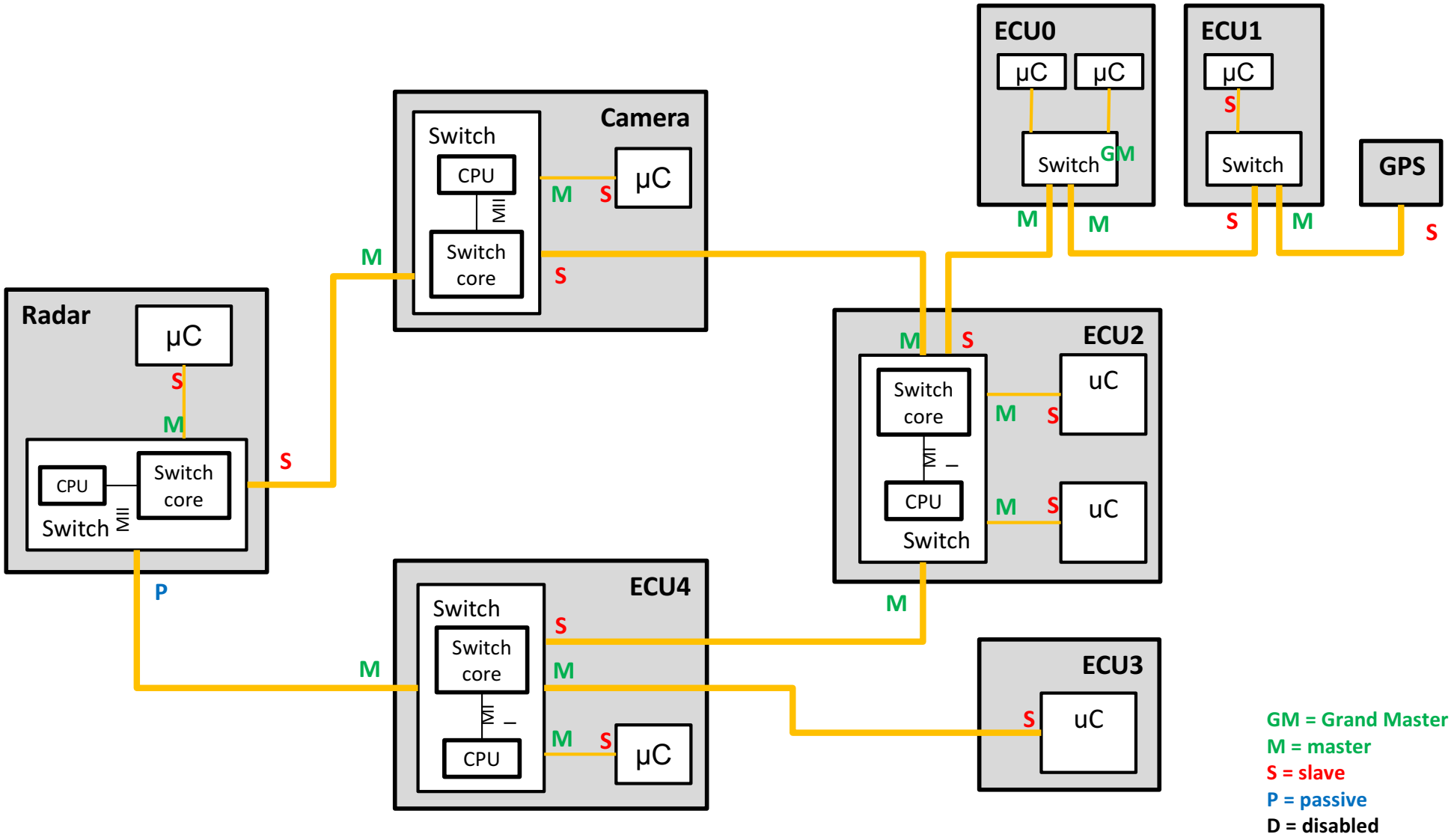


1. BMCA, GM Capable devices, Time slaves, gPTP Announce frames

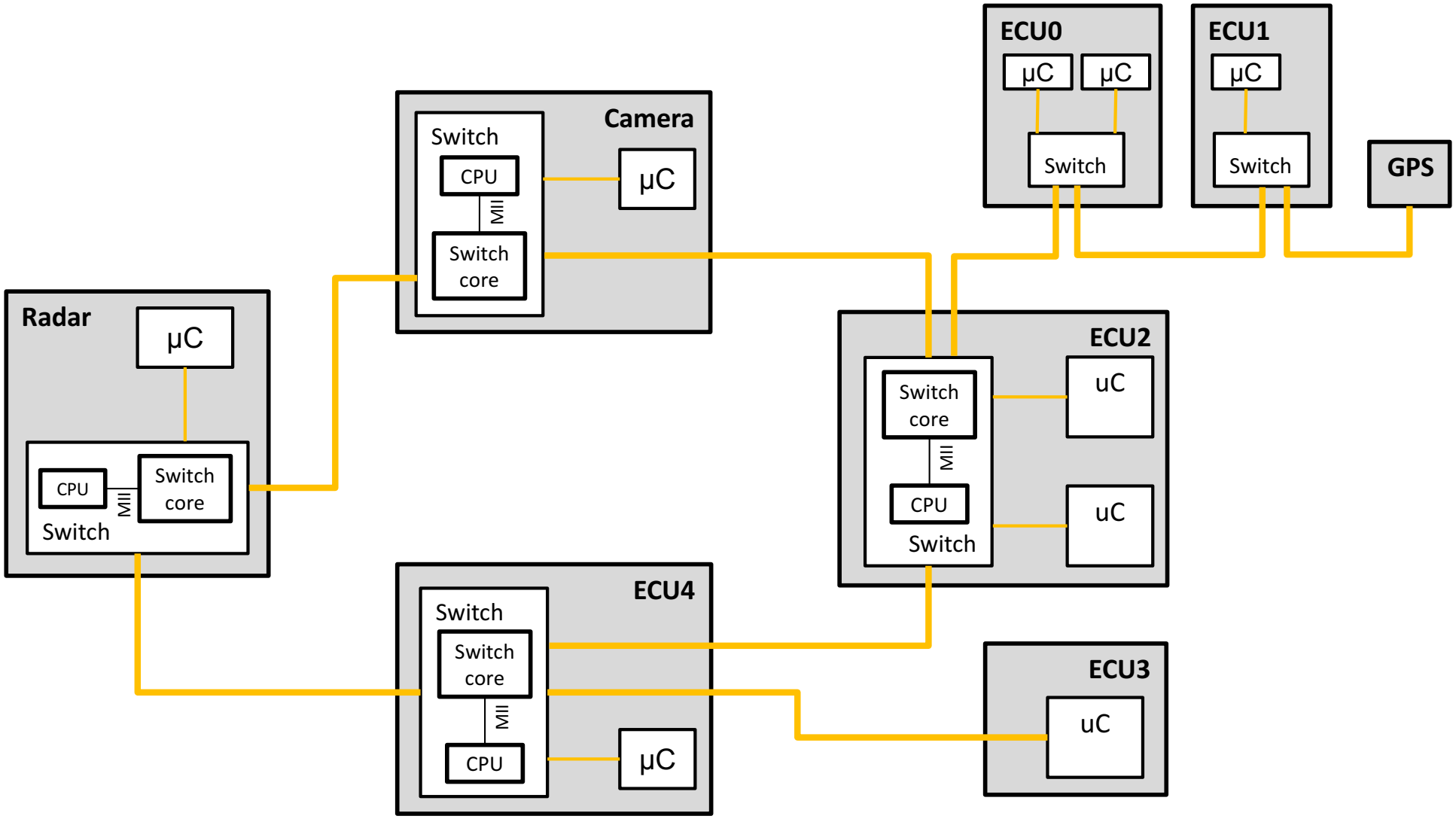
- ECU0, ECU1, ECU2, and ECU4 switches will send gPTP Announce messages with their statically defined priorities
- All other switches and microcontrollers will send Announce messages with priority 255 (i.e., they are slaves; not grand master capable)
- Highest priority Announce message is propagated by switches on all ports for which asCapable == TRUE (inferior Announce messages are discarded)
- All switches will configure port roles based on reception of Announce, making ECU0 switch the GM
- Microcontrollers can participate as slaves in BMCA or be statically configured to be slaves
- If a link fails, switches will reconfigure port roles (Announce messages are sent continuously in BMCA)
- If the current GM fails, the next best GM capable device will become GM and the switches will reconfigure port roles (Announce messages are sent continuously)



2. Port roles established and gPTP operation establishes time sync (a sync tree is created with the ECU0 Ethernet switch as the root)



Example network



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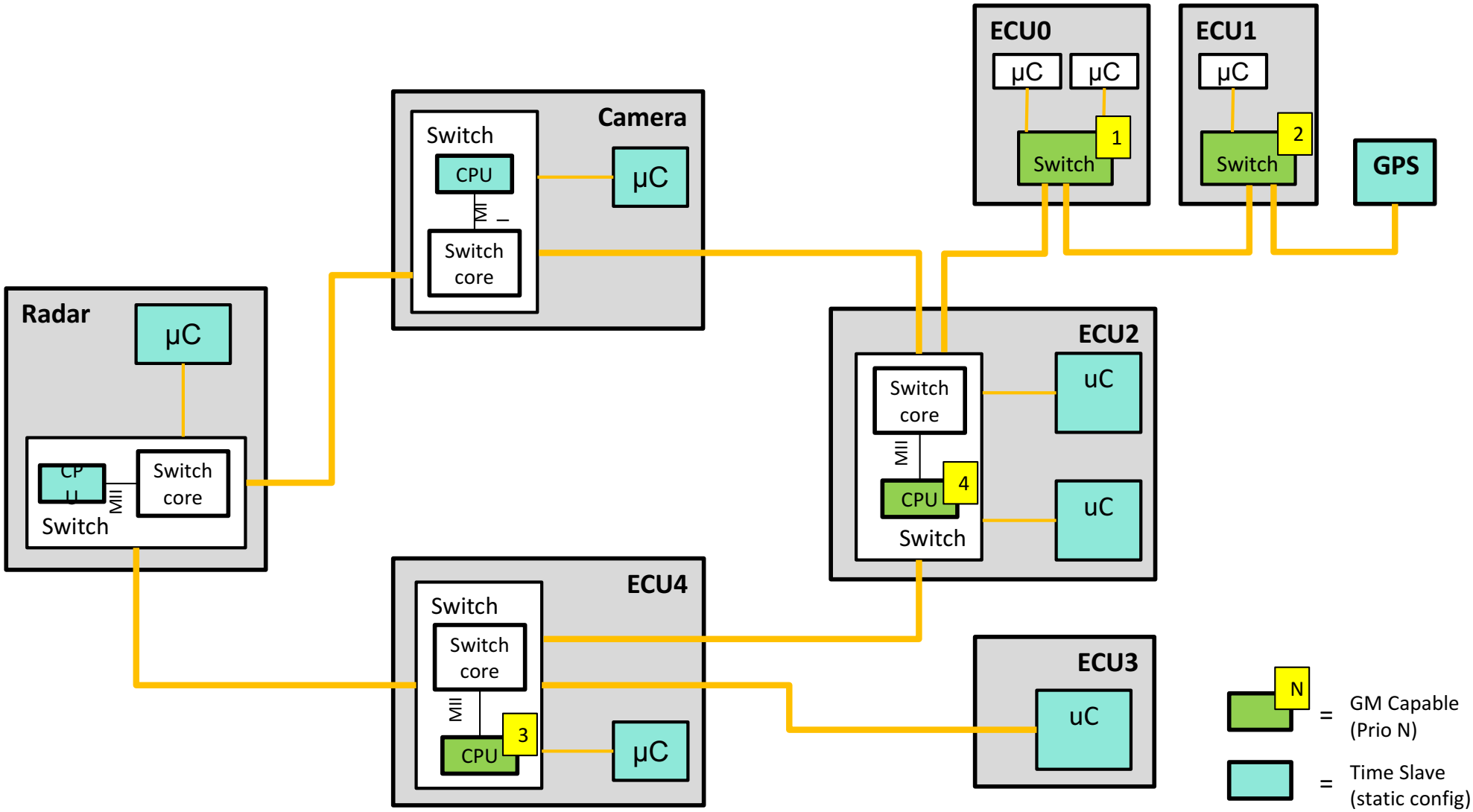

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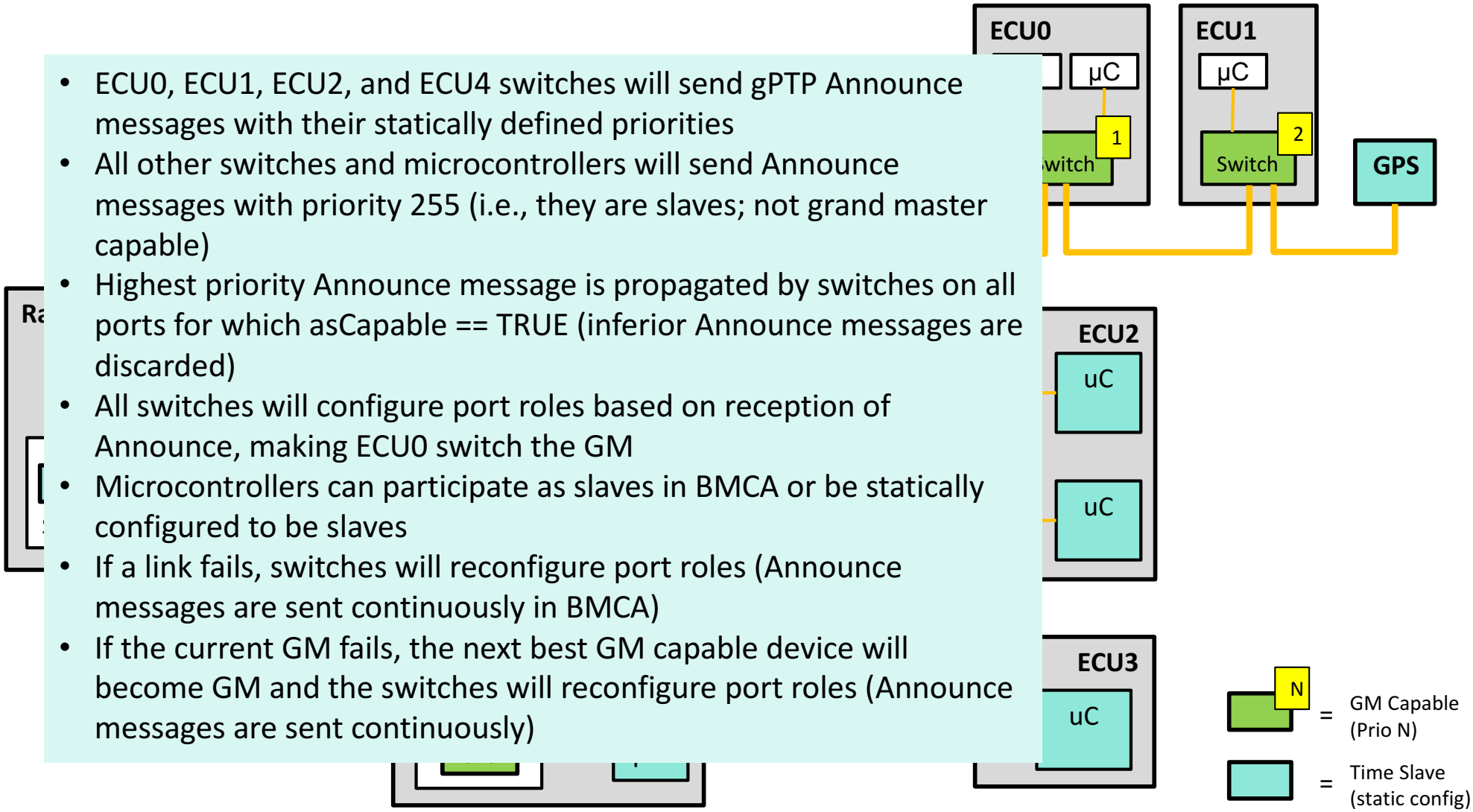

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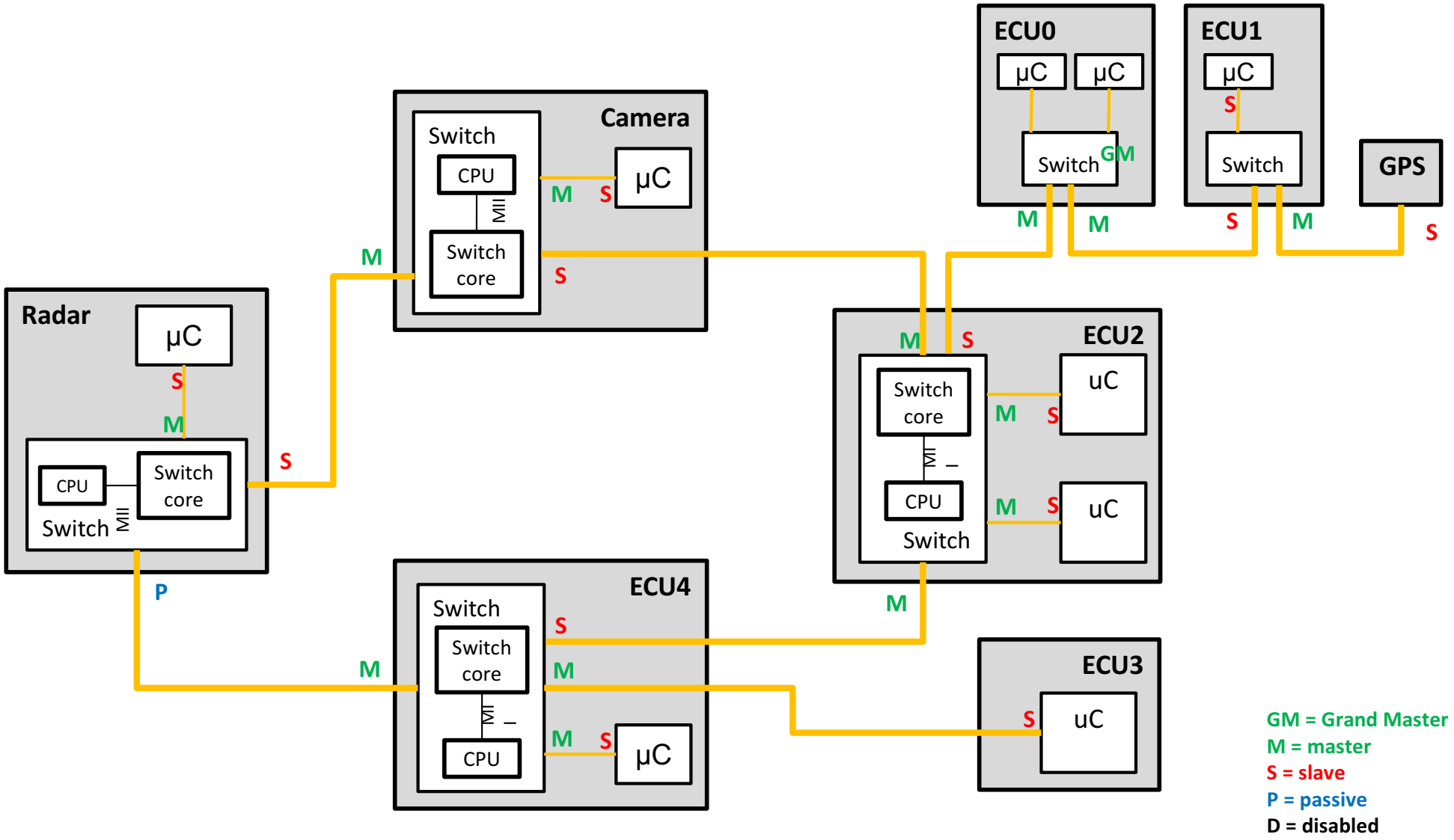
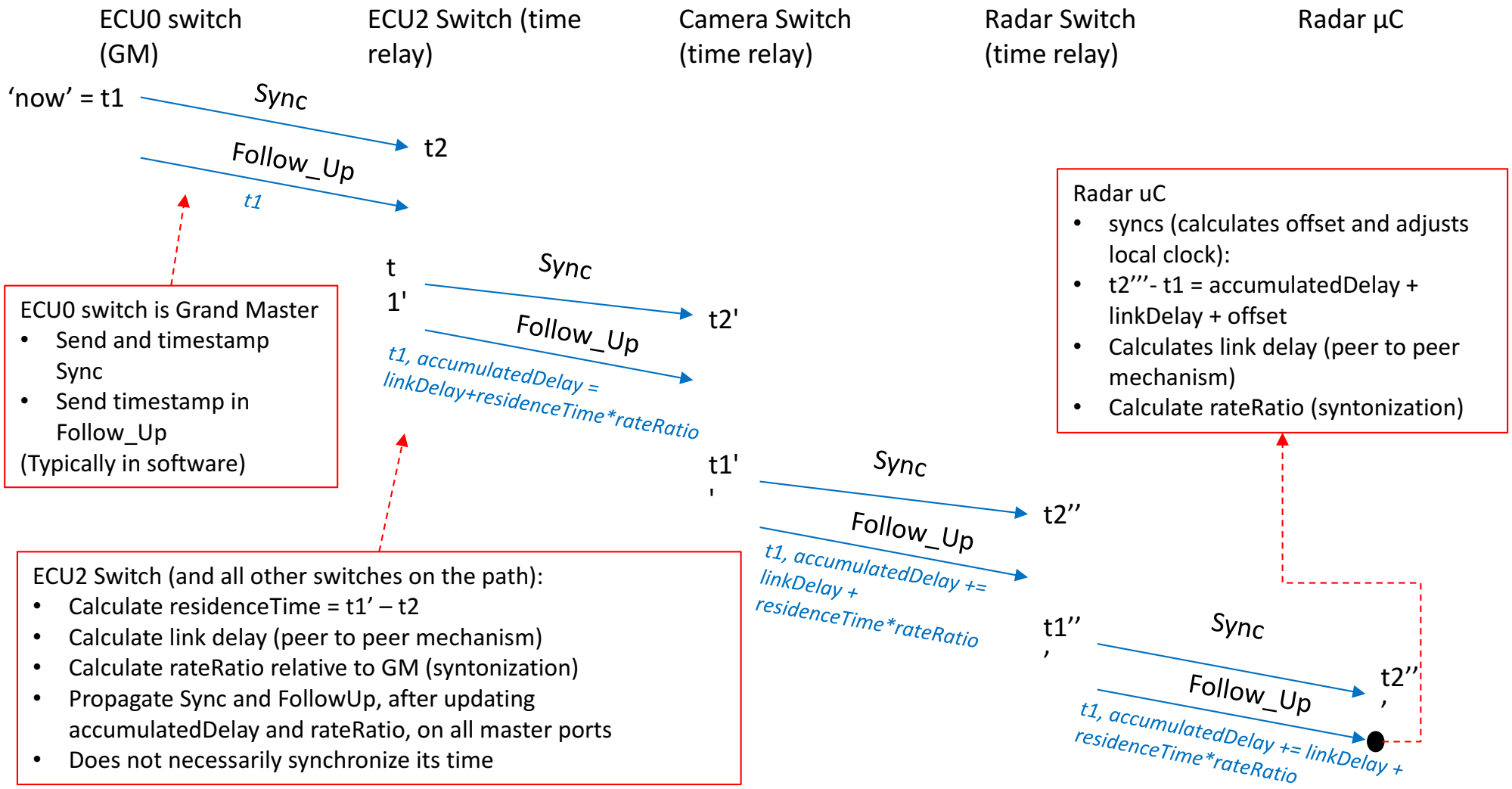


gPTP Sync and FollowUp in operation (ECU0 switch to Radar portion of the sync tree)



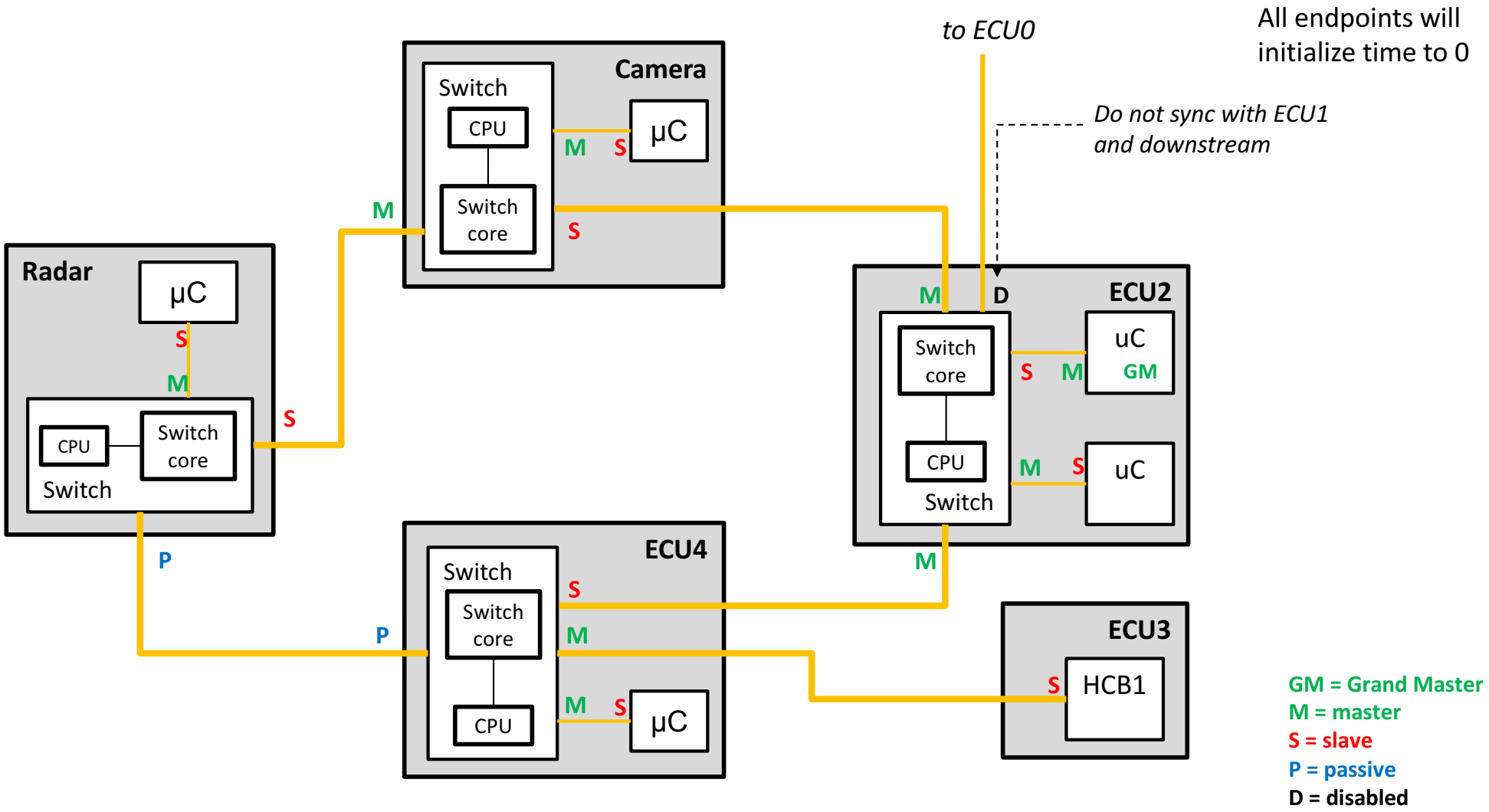
Recommended configurations

- Sync and FollowUp frequency: 8 times per second
- PDelay_Req frequency: 3 times in each direction per link per second
- Initial link delay parameters: calibrated (e.g., in automotive, constant wiring length, no plug and play)
- Frequency of Announce frames: 1 per second
- Static priorities and clock qualities defined for each Grand Master capable device.
- asCapable is set to true/false depending on the desired part of the network to participate in 802.1AS

Sync status

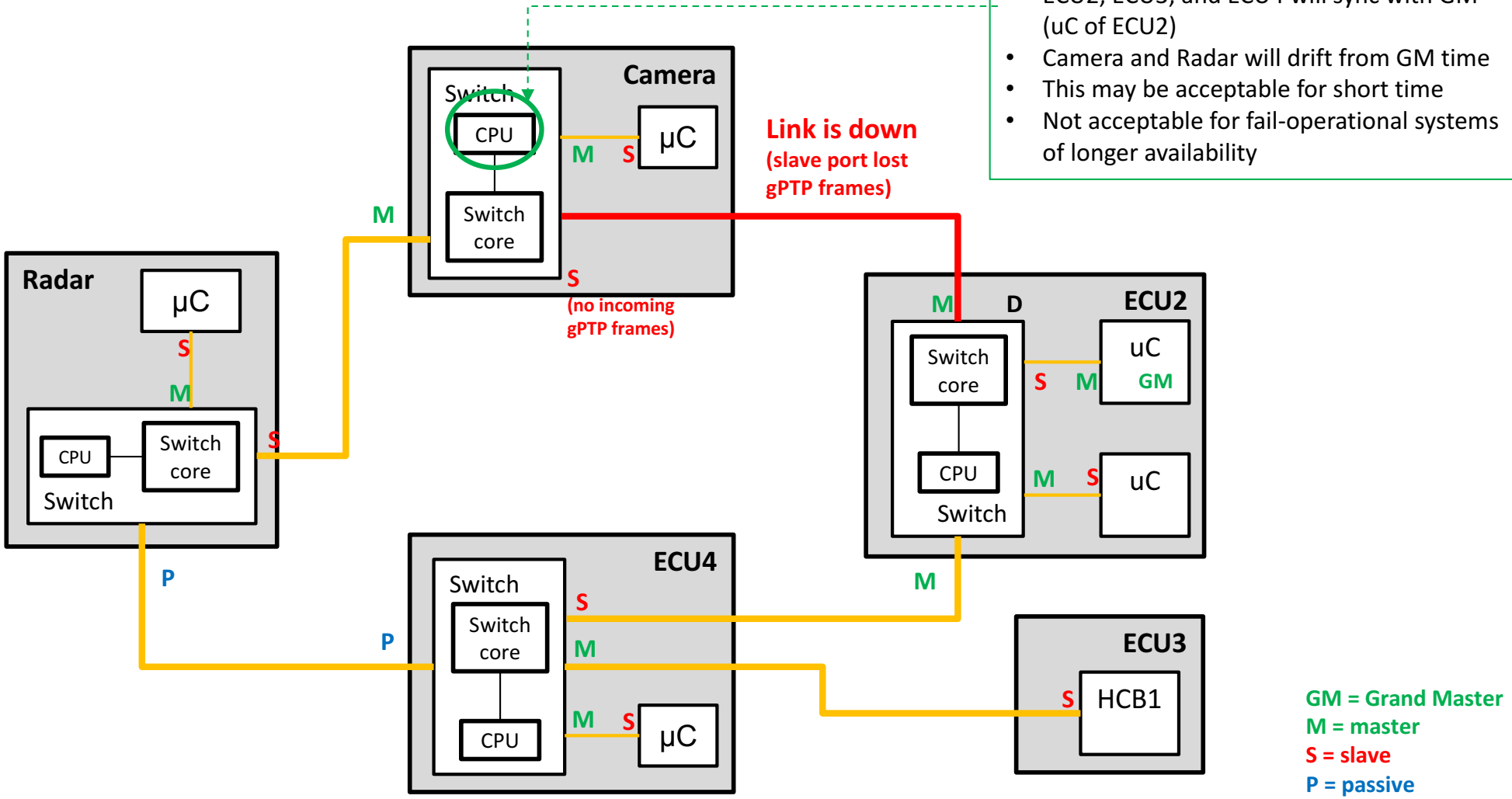
- 802.1AS does not define any mechanism to detect errors in the way slaves synchronize to the master
  - Can be done in the application layer by having each slave transmitting their synchronized time

Without BMCA (static port role configuration)



Link failures without BMCA
Proxy mode (non-802.1 standard)

Switch acts as “proxy GM”
- Uses the last known accumulated delay from GM
- Camera and Radar will sync with Camera switch, which is “proxy GM”
- ECU2, ECU3, and ECU4 will sync with GM (uC of ECU2)
- Camera and Radar will drift from GM time
- This may be acceptable for short time
- Not acceptable for fail-operational systems of longer availability



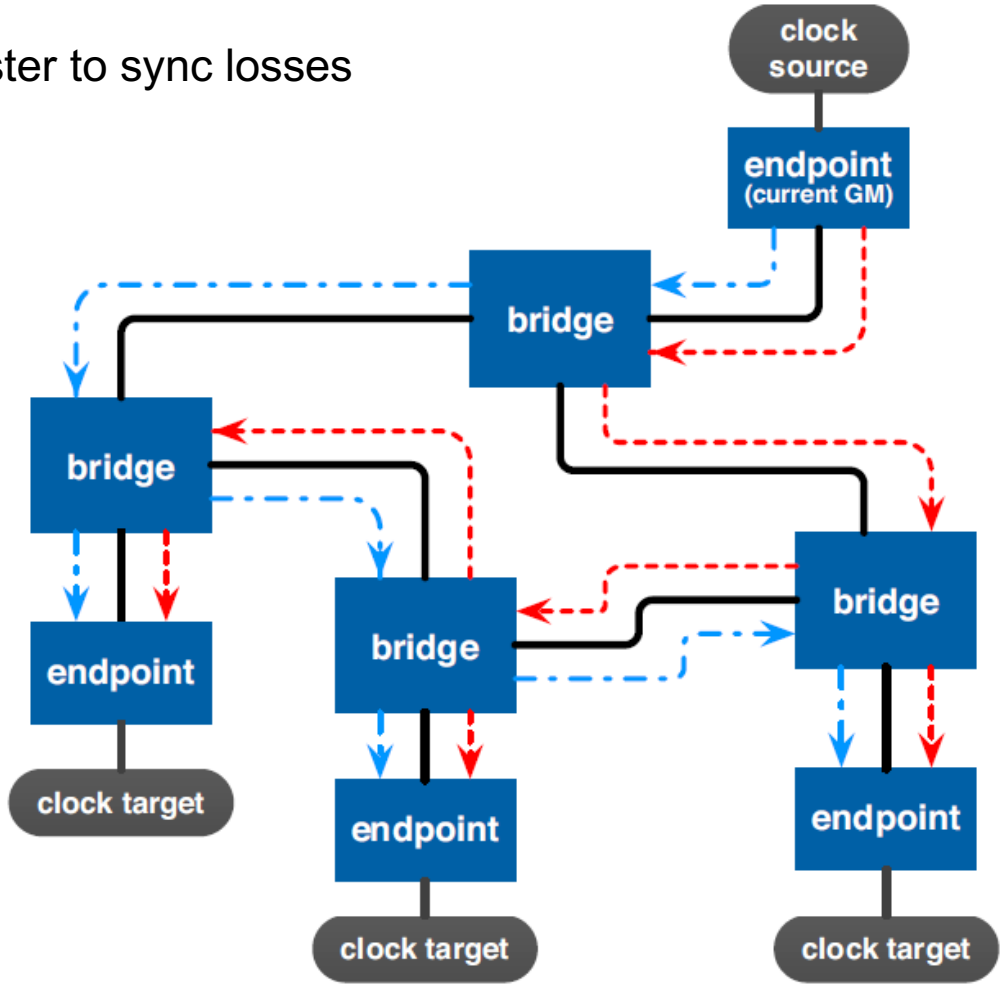
Other ways to implement redundancy

- Ongoing standardization project (mature, likely to be published in 2018)
- Drafts are available

- Redundant sync paths
- Redundant grand masters (hot standby)

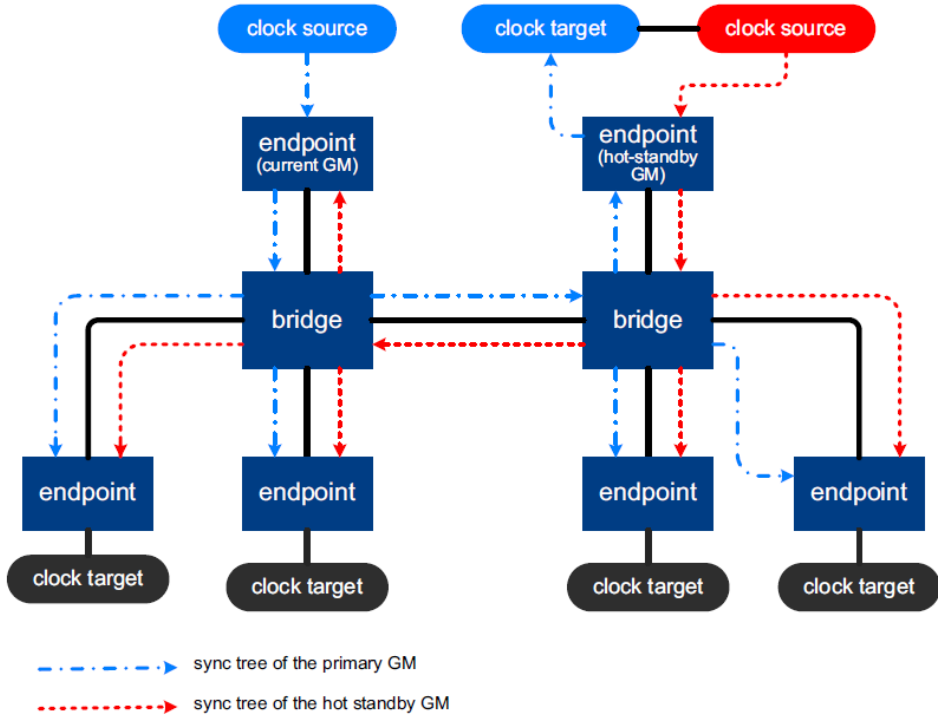
Redundant sync paths

- Two redundant synchronization trees from a single GM, with each synchronization tree in a different gPTP domain
- Time is transported on multiple paths
- Second sync tree (only) to react faster to sync losses



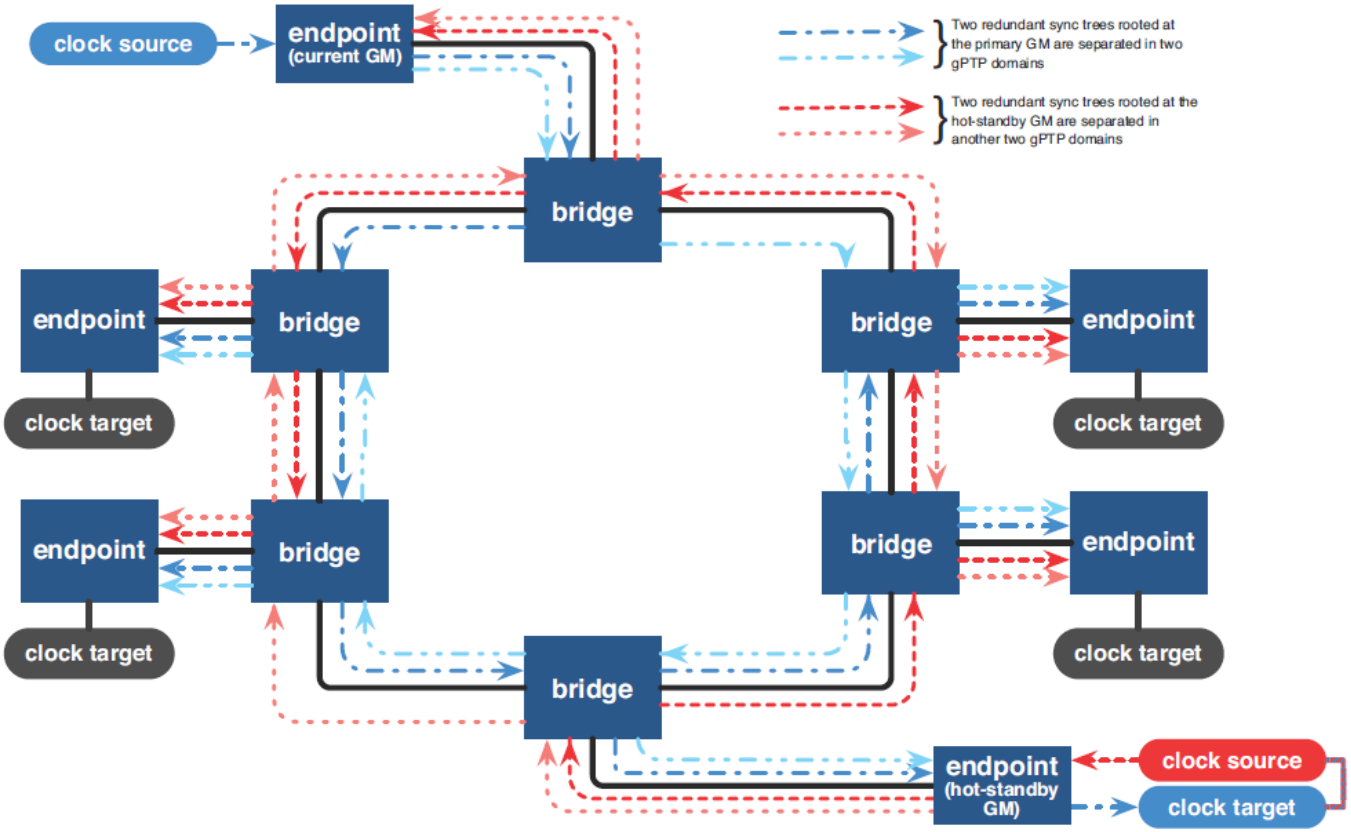
Grand Master redundancy

- One primary GM and one hot-standby GM (which are separated in two gPTP domains)
- Hot-standby operating: the secondary GM has to be synchronized to the primary GM
- (preselected) second GM will seamless take over the time transport when something happens with first GM
  - No time needed to select & announce new GM
  - Reduces grandmaster change over time



GM and synchronization path redundancy

- Each GM establishes two sync trees, resulting in a total of four sync trees that are separated in four gPTP domains
  - Preselected 2nd GM
  - Preconfigured redundant paths



Summary

- There are many applications that need global notion of time
  - GPS, Sensor fusion, Audio and video, Data logging and postprocessing
- 802.1AS provides 1-2 microsecond precision synchronization; network service to the application
  - Election of grand master and establish sync tree
  - Measure delays and rate differences
  - Propagate time frames through sync tree
- Several solutions exist to provide redundant synchronization