Verification of Time Sensitive Networking based Ethernet enabled automotive communication systems

Wasiq Zia

Senior Principal Software Engineer, Verification IP R&D Cadence Design Systems

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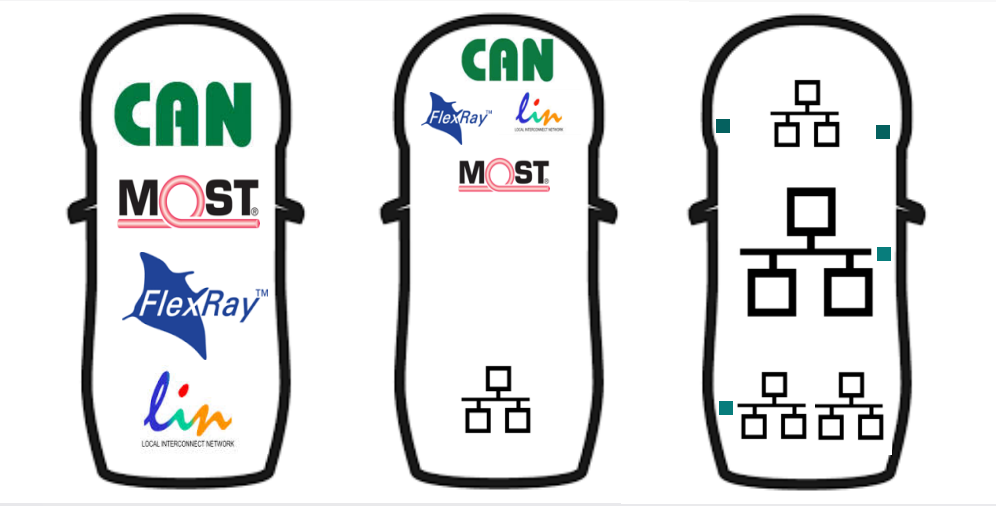
Automotive Network Connectivity Evolution



Disparate protocols, heavy network of jumbled wires, low bandwidth, difficult to debug

Automotive Ethernet is the cable **network** that connects most of in-vehicle components, like *cameras, sensors, meters, infotainments, human interfaces* and etc.

Easy access, debug, fast, high bandwidth

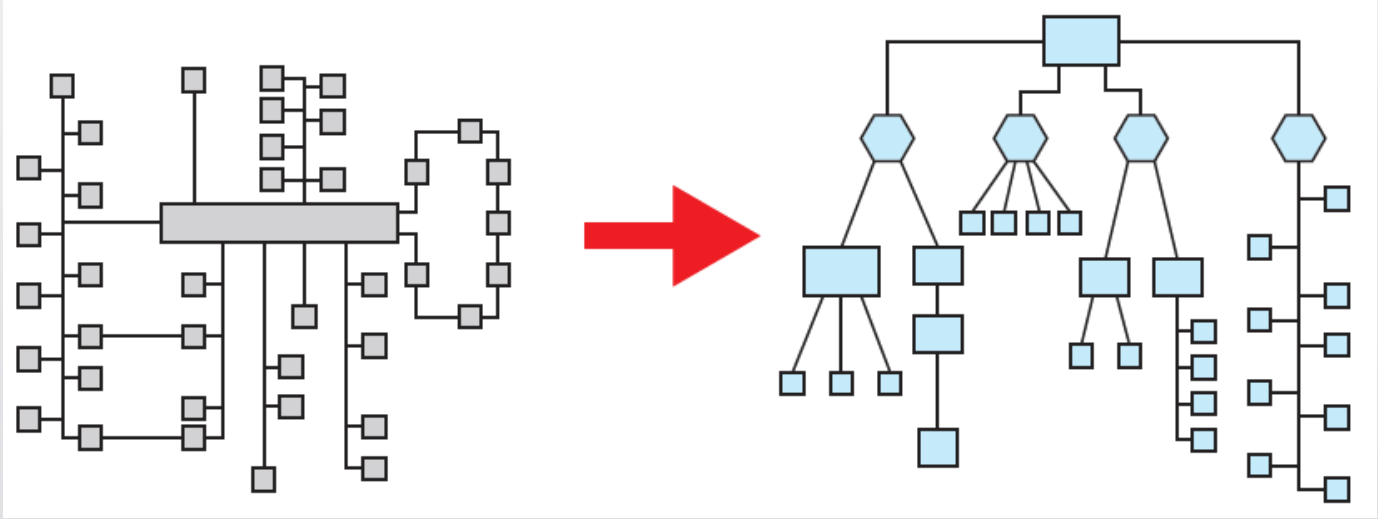
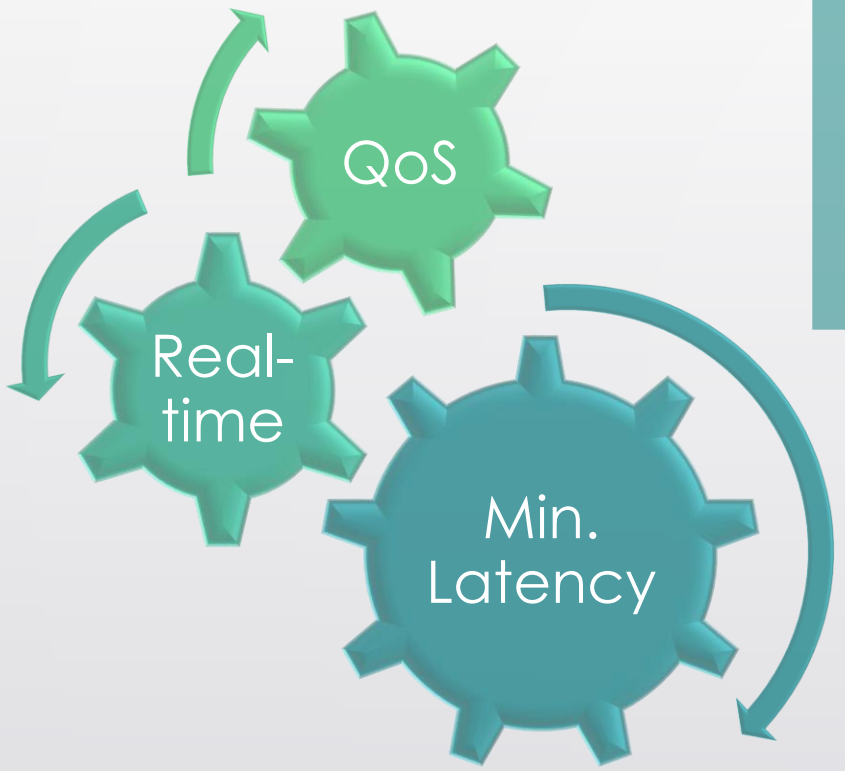


Image Source : Automotive Ethernet : An Overview, ixia Whitepaper

Characteristics of TSN based Automotive network

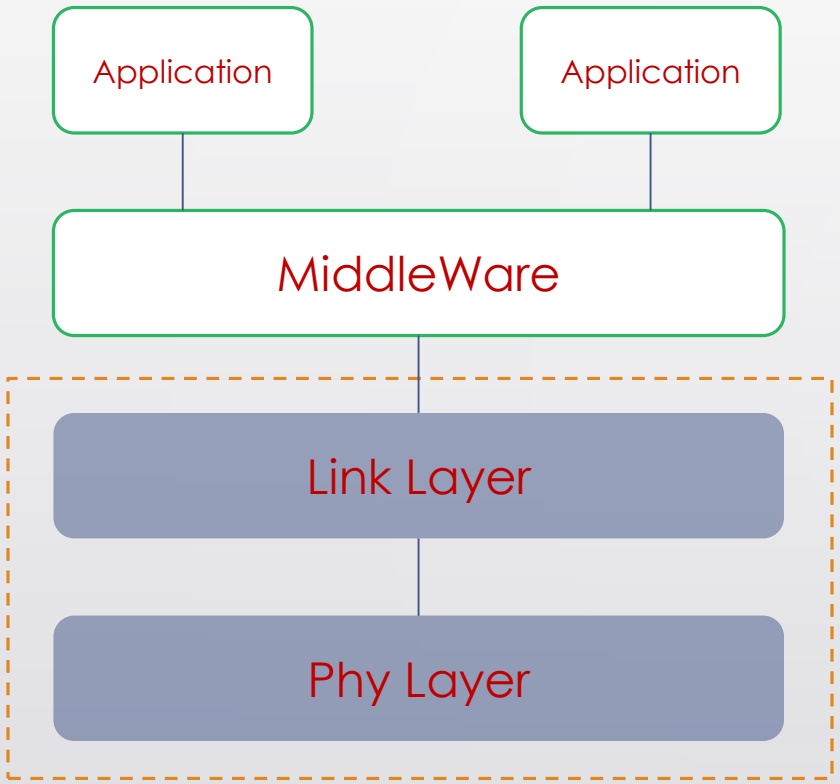


- Reduced worst-case delays
  - ✓ 4 µs or less per hop @1 Gbps for short messages *
- Improved robustness
  - ✓ Alternative paths with "instant" switchover
  - ✓ Seamless redundancy using multiple streams
  - ✓ Multiple clock sources with "instant" switchover
- Scalability
  - ✓ Reduced management traffic for reservations and configuration

- Economic: reusable, maintainable
- Hard Real-time, Latency-critical
- QoS: Priority control, bandwidth guaranteed
- Security: Ensuring safety system
- Low Power: power saving, green energy
- Being comparatively new, more opportunity for verification and improvements in system

* Reference : IEEE 802 Time-Sensitive Networking: Extending Beyond AVB by Michael D. Johas Teener, BRCM

The system and its layers…



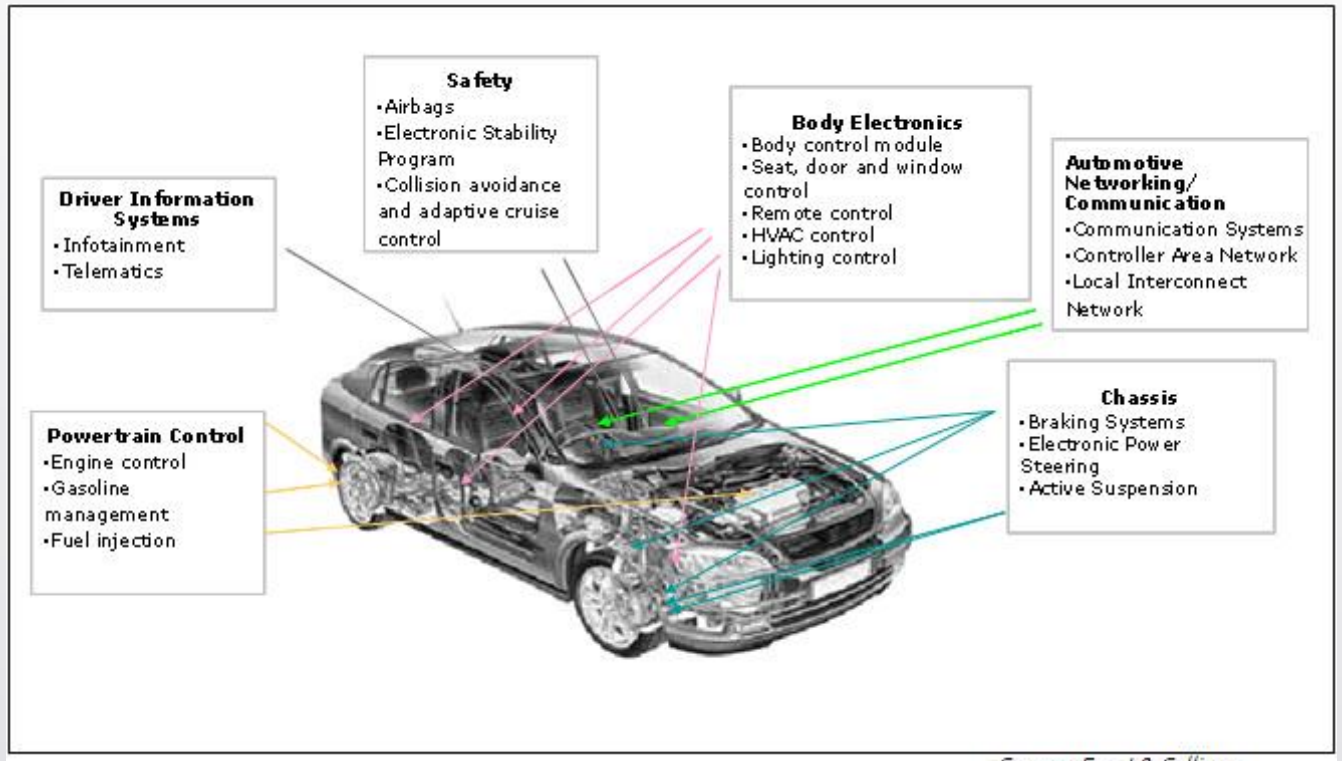
These blocks are typically the steering control, infotainment system, reverse parking assist, GPS system that provide the input to systems like AUTOSAR etc.
Ensures compliance with the various safety standards and establishing the safeguards. Middleware is taken care of by Fault Simulators

This layer contains all the different communication protocols used for automotive applications. The AVB/TSN/TTE etc. are part of this layer. Helps in scheduling traffic depending on the compliance standards enforced by the upper layer. Acts as the intermediate from compliance to physical layer.

Link and Physical layer require robust functional verification for ensuring that requirements are met.

Image Reference : Intra-Vehicle Networks: A Review
Shane Tuohy, Martin Glavin, *Member, IEEE*, Ciarán Hughes, Edward Jones, *Member, IEEE*,
Mohan Trivedi, *Fellow, IEEE*, and Liam Kilmartin, *Member, IEEE*,
IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS

Verification Challenges



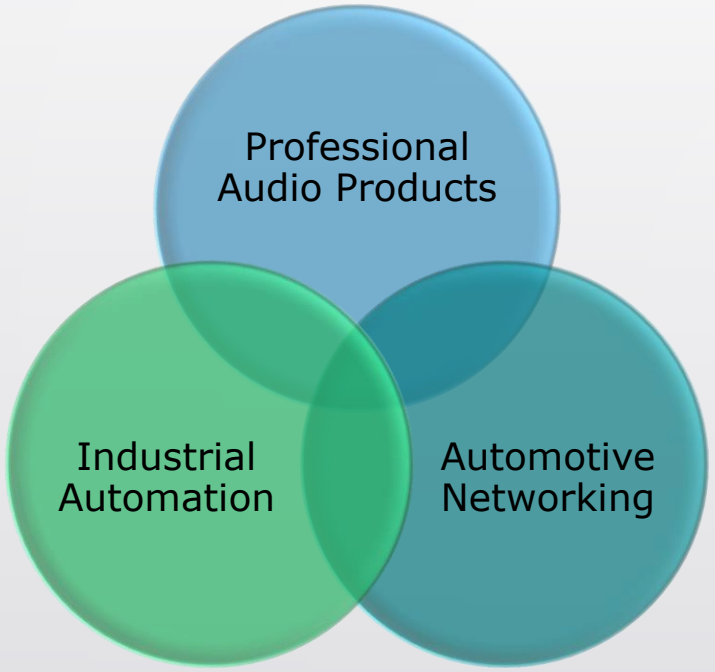
Source: Frost & Sullivan

- High compute power
- Long term reliability (~20 years)
- Extreme climates and temperature operation
- Higher bandwidth
- *All this at low power*

And the goal is to…

- Reduce accidents due to system failure
- No accidents due to hacks
- Zero component failures
- Zero human error related failures/accidents

Several protocols and still counting…



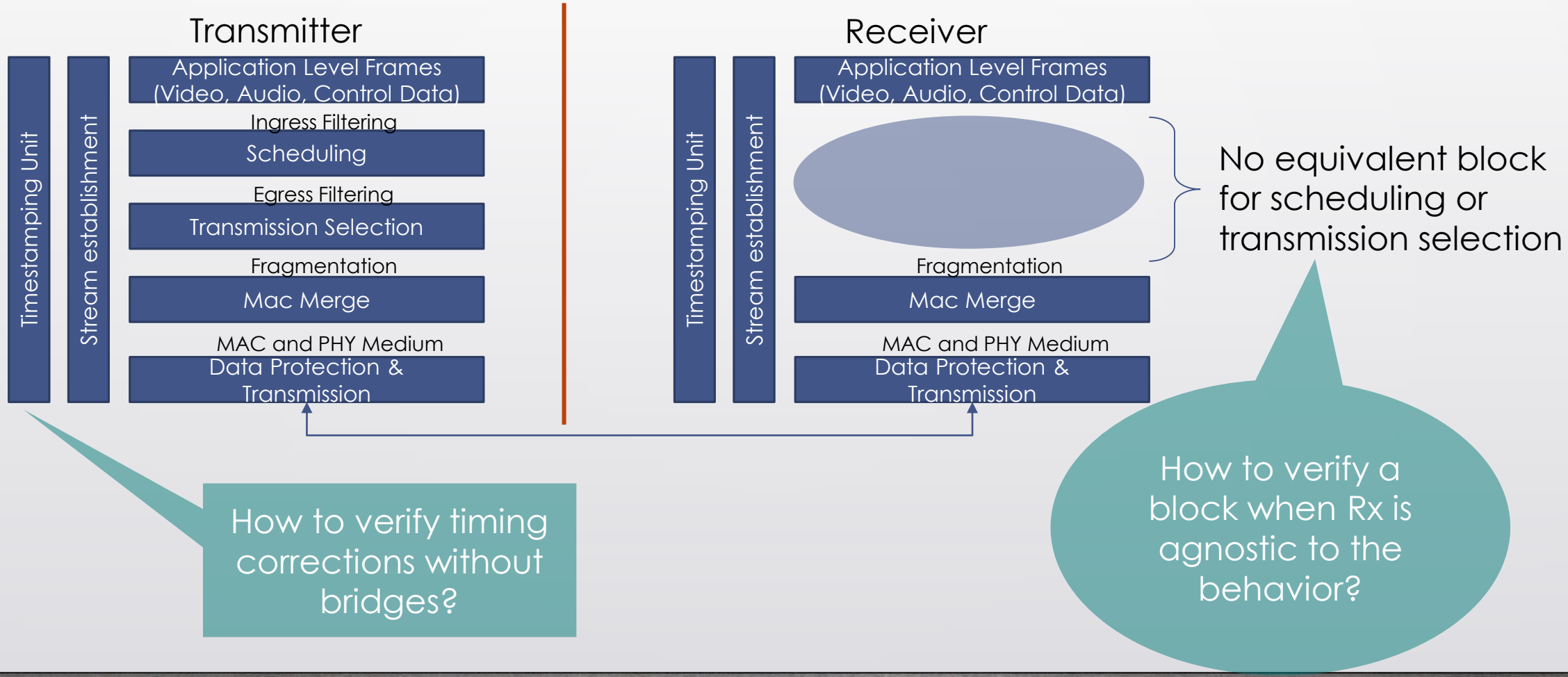
Base

- 802.1AS PTP Profiles
- Preemption and Interspersing(802.1Qbu and 802.3br)
- Credit Based Shaping (802.1Qav)
- Time Aware Shaping(802.1Qbv)
- Stream Reservation (802.1Qat)

Advanced

- 802.1Qca : Redundancy using the best path algorithms
- 802.1CB : Multipath frame duplication and recovery
- 802.1Qch : Cyclic Queuing
- 802.1Qci : Per-Stream filtering
- MSRP protocol for bandwidth reservation

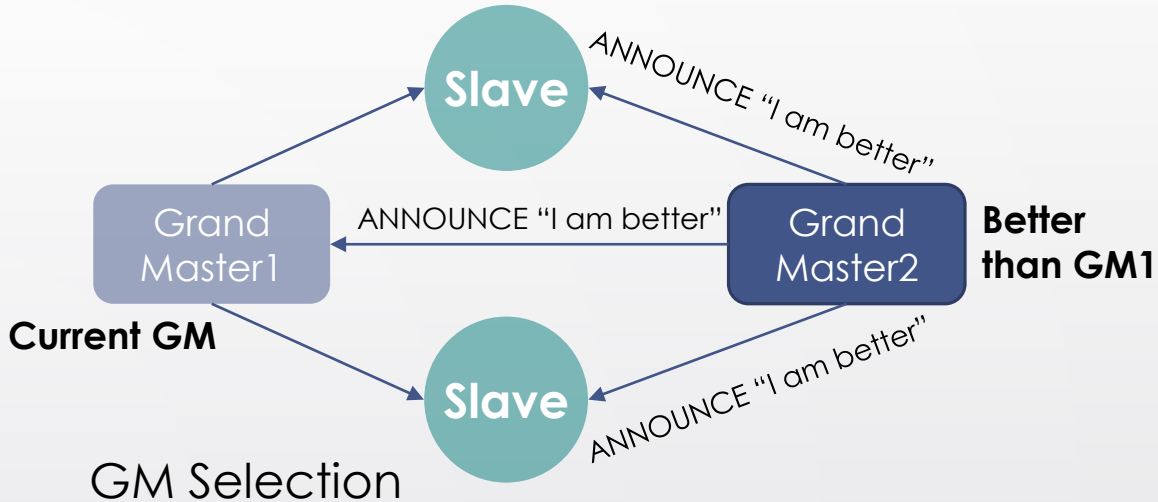
Scheduling and Timing Conundrum



Timestamping

802.1AS

- Synchronize all the clocks throughout the network
- Controls the gate events for time aware shaper
- Ensures that preemption delays are honored



GM Selection

- Ensure that peer delay mechanism works
- Use Best GM clock algorithm
- Provide correction field estimation
- Handle discontinuities
- Use multi-port verification component to validate clock correction

Clock Synchronisation

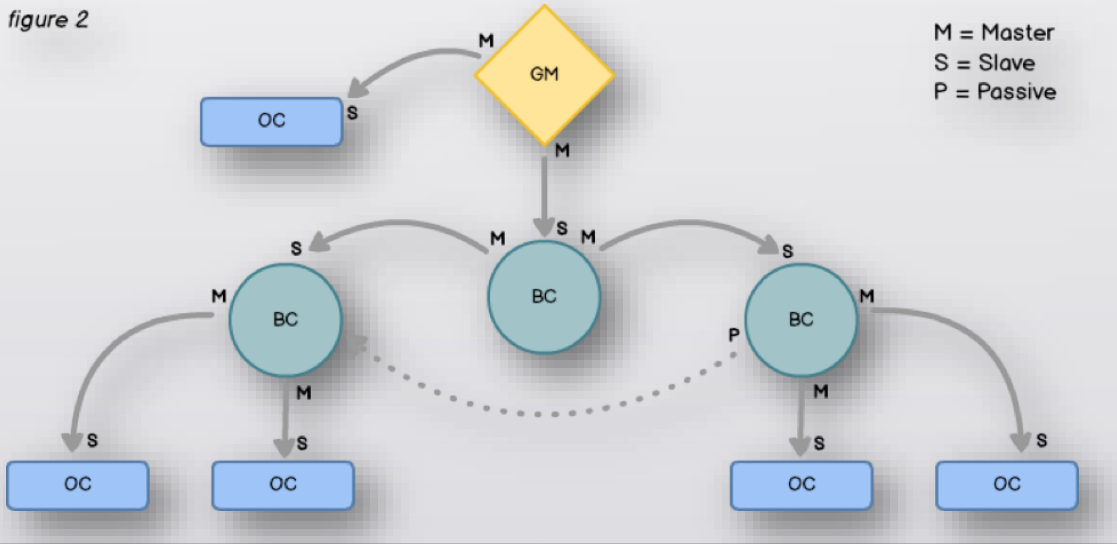


Image Source : http://www.luminex.be/improve-your-timekeeping-with-ptpv2

cadence

MSRP

- Used to create a path through a network for rank-based, latency guaranteed bandwidth reservations within a network
- Supports the reservation of resources for streams, each destined for one or more Listeners, and each from a single source

- Two types of end stations supported by MSRP:
  - Talker: Source of a stream
  - Listener: Destination for a stream

- Stream Registration
  - Talkers advertise one or more streams and specify the QoS requirements
  - Bridges propagate those advertisements throughout the network
  - Listener(s) request the stream
  - Bridges Forward Listener Ready toward Talker

Verification Challenges

- Packing of multiple talker attributes for different destination and streamid into a single MRPDU
- Checking and calculating the bandwidth reserved for a particular streamid by the end station
- Scheduling of streams and mapping to correct shaping queue

Scheduling

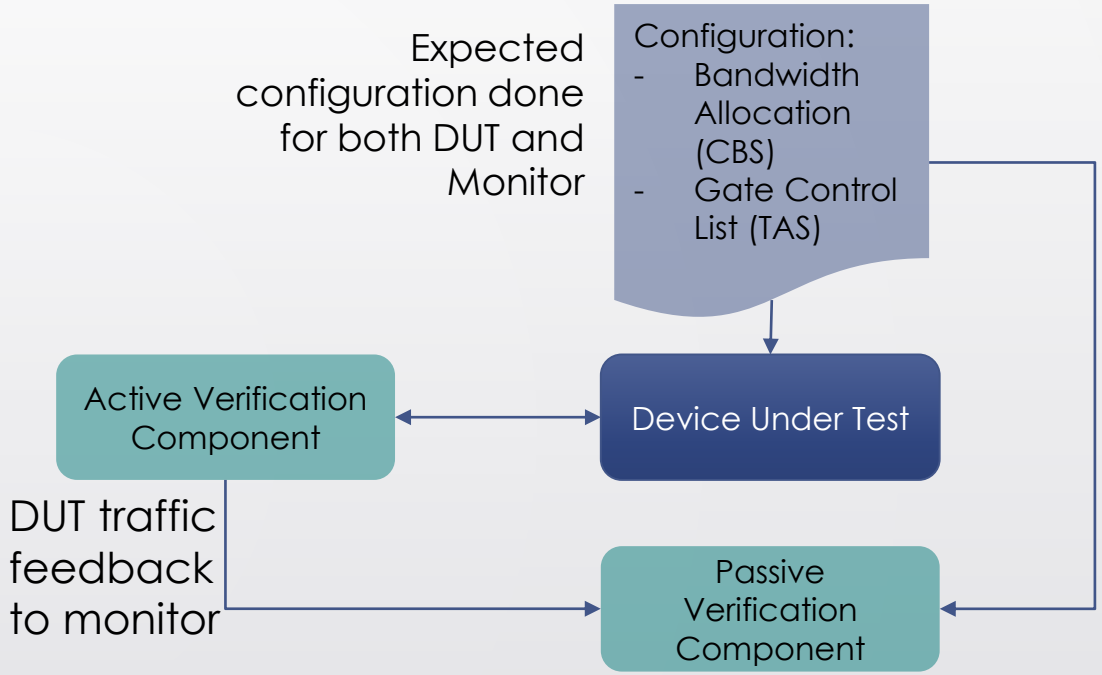
Credit Based Shaping

- Priority scheduling
- Insure quality of service

Time Aware Shaper

- Scheduling done on the basis of gate control events which are time synchronized
- Uses gates with priority queues

- Non-responsive and Rx agnostic protocols
- How does Rx determine bandwidth has been honored?
- Was the correct queue gate allowed to transmit frame according to gate control list?
- Did the gate control list recycle properly?
- Was the timestamp generated in sync?



- ✓ Evaluates the traffic according to priorities for bandwidth allocation
- ✓ Runs shadow Gate Control for TAS and does back calculation for timing to evaluate if correct gate transmitted
- x Does not work for Preempted packets conclusively

Transmission Selection

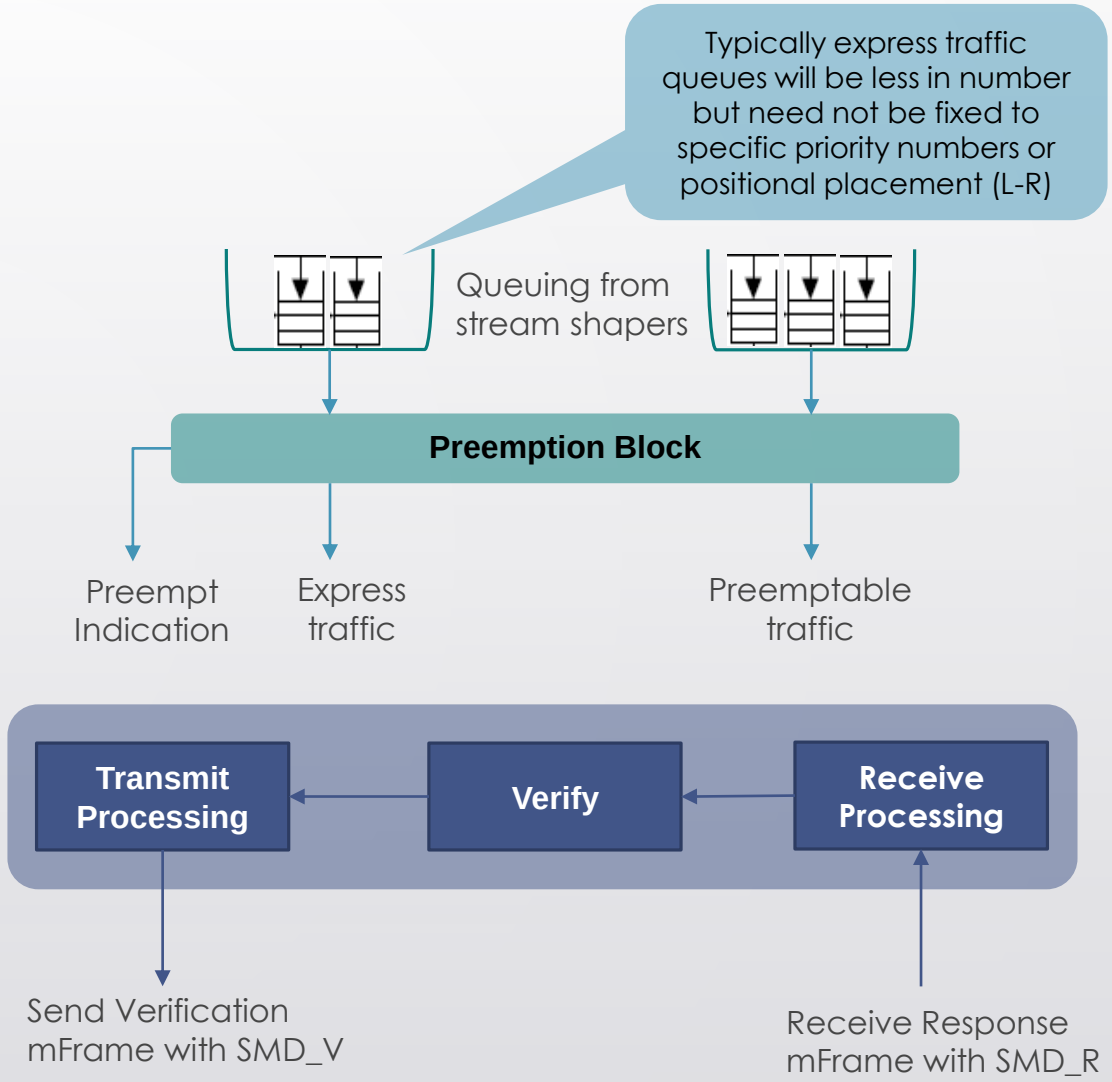
Preemption

- Select the traffic based on express and preemptable status

MacMerge Layer

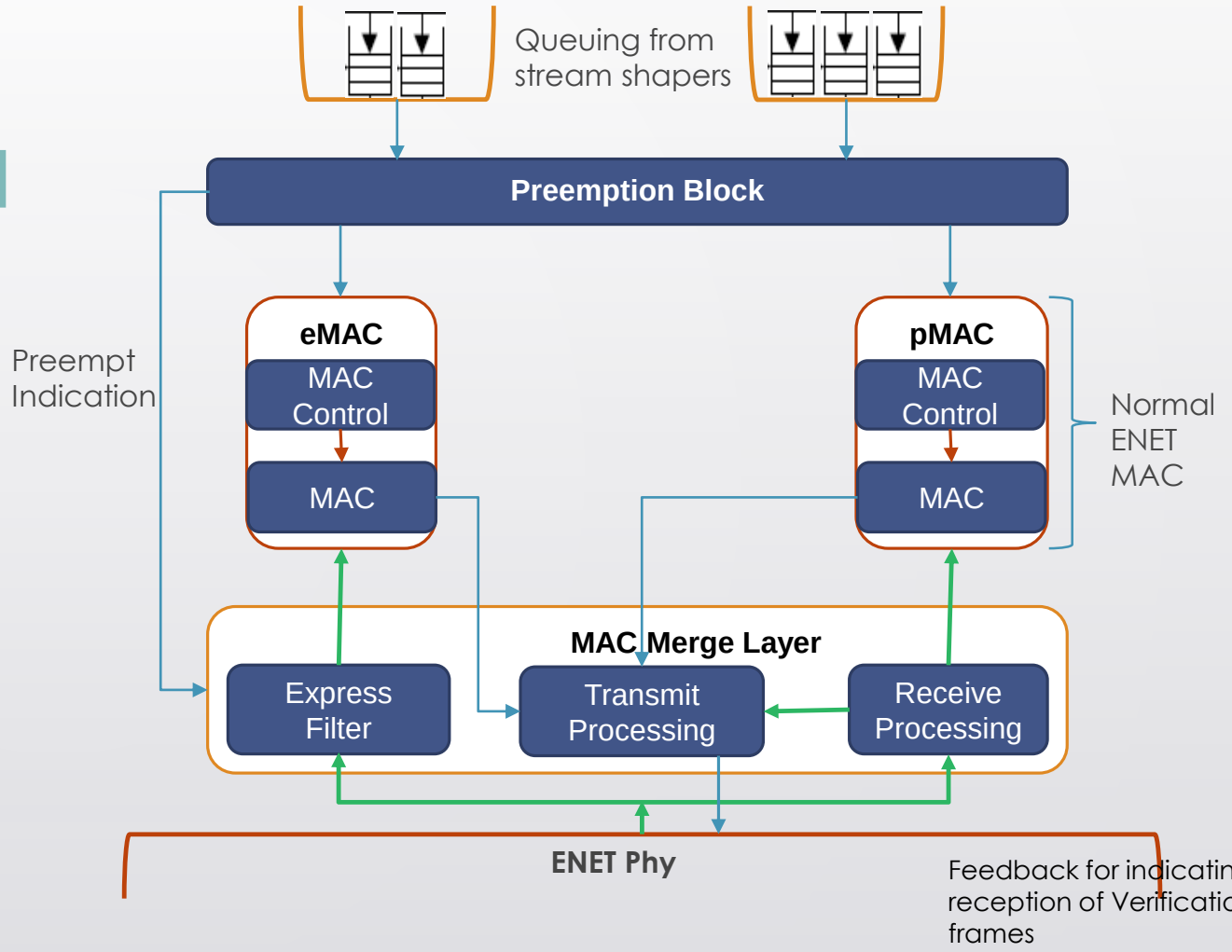
- Halts unimportant traffic to service interrupts
- Adds fragmentation

- Preemption when hold mechanism is not used
- Preemption when hold mechanism is used
- Verification of preemption capability
- Preemption hold timing violation checks



Transmission Selection

- Express traffic interrupt should interrupt normal traffic
- Timer violations for minimum guard period through calculation of preemption delay
- Fragment formats and fragment size violations
- Link to link delay for single hop calculation
- mFrame validation

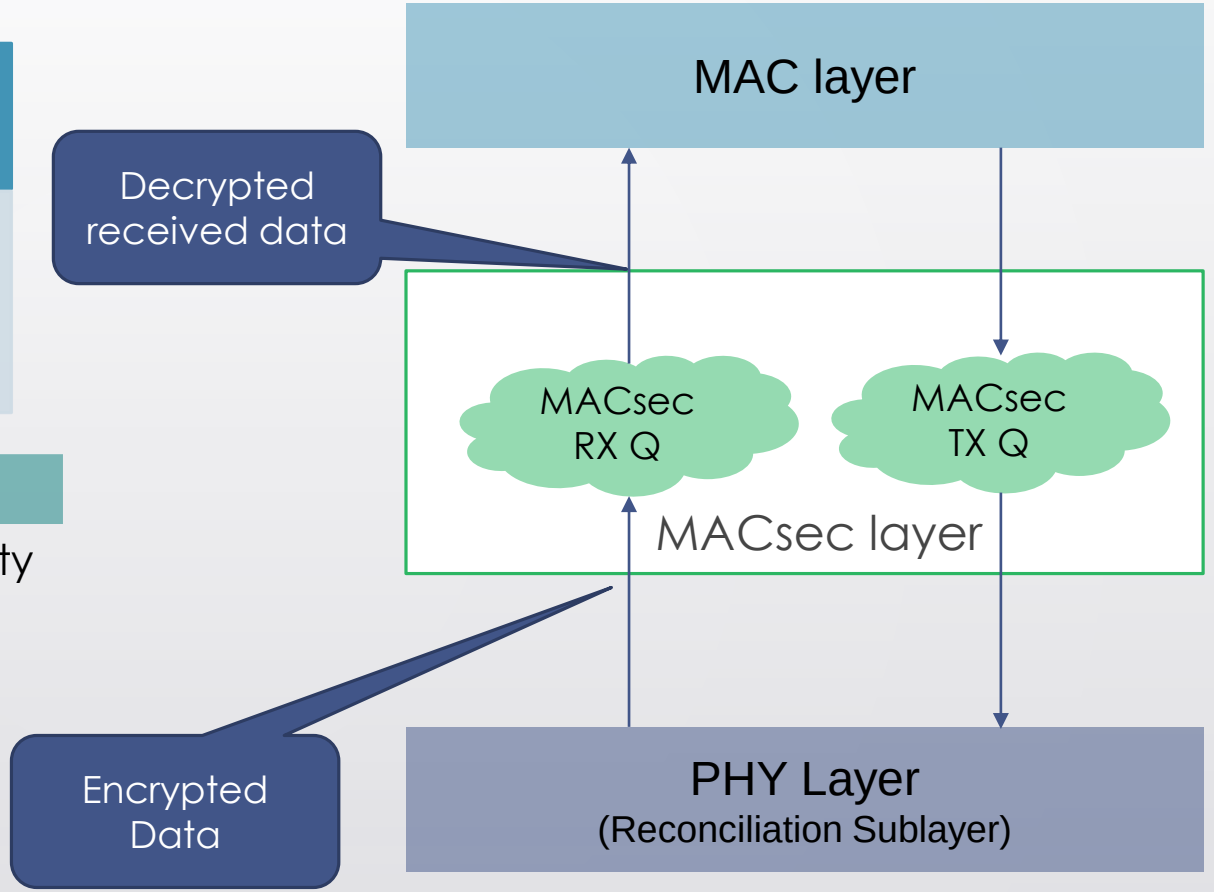


Security

802.1AE MACSec

- Encryption and decryption of the data payload using the GCM mechanism
- Ethernet MAC embedded with MACSec logic

- Verification of Integrity mode, confidentiality mode and both
- Authentication mode verification
- PN Replay feature : Out of order PN
- Configuration for key, PN etc.
- Error Injection
- Scoreboard hooks for data integrity check

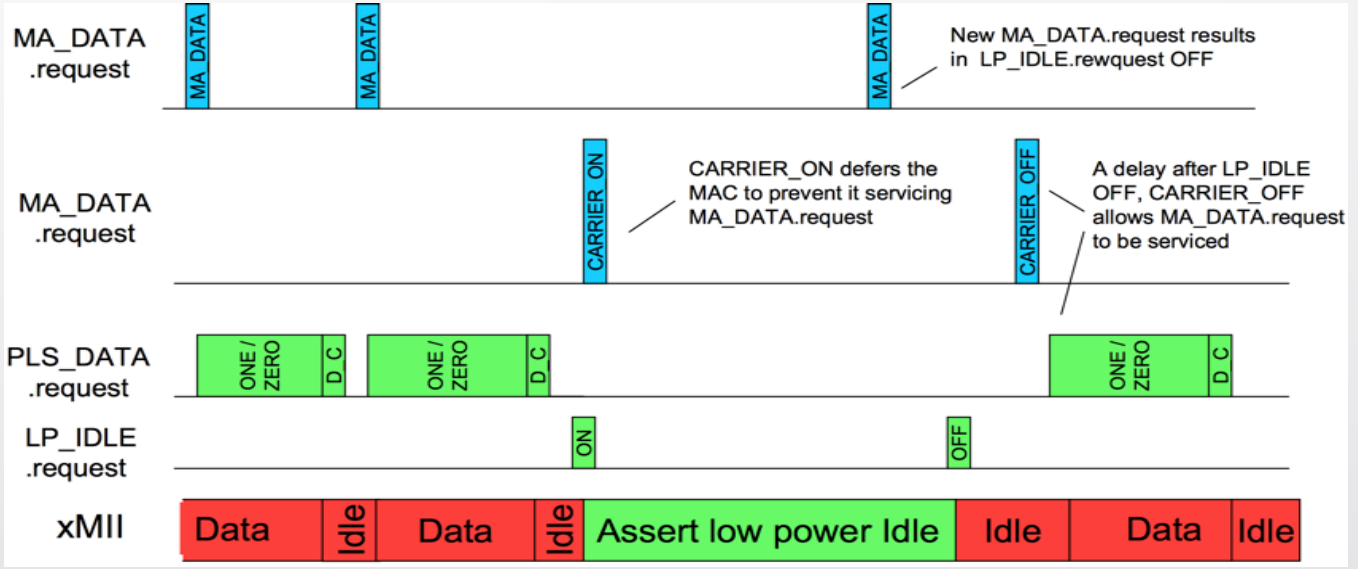


Energy Efficient Ethernet

802.3az

- EEE is green energy technology for Automotive Ethernet
- Keep link in "sleep" mode when no transmission occurs : IDLE/Sleep/Wake

- Ensure that sleep timers are validated
- Any traffic during low power should be discarded
- Low power Idle corruption

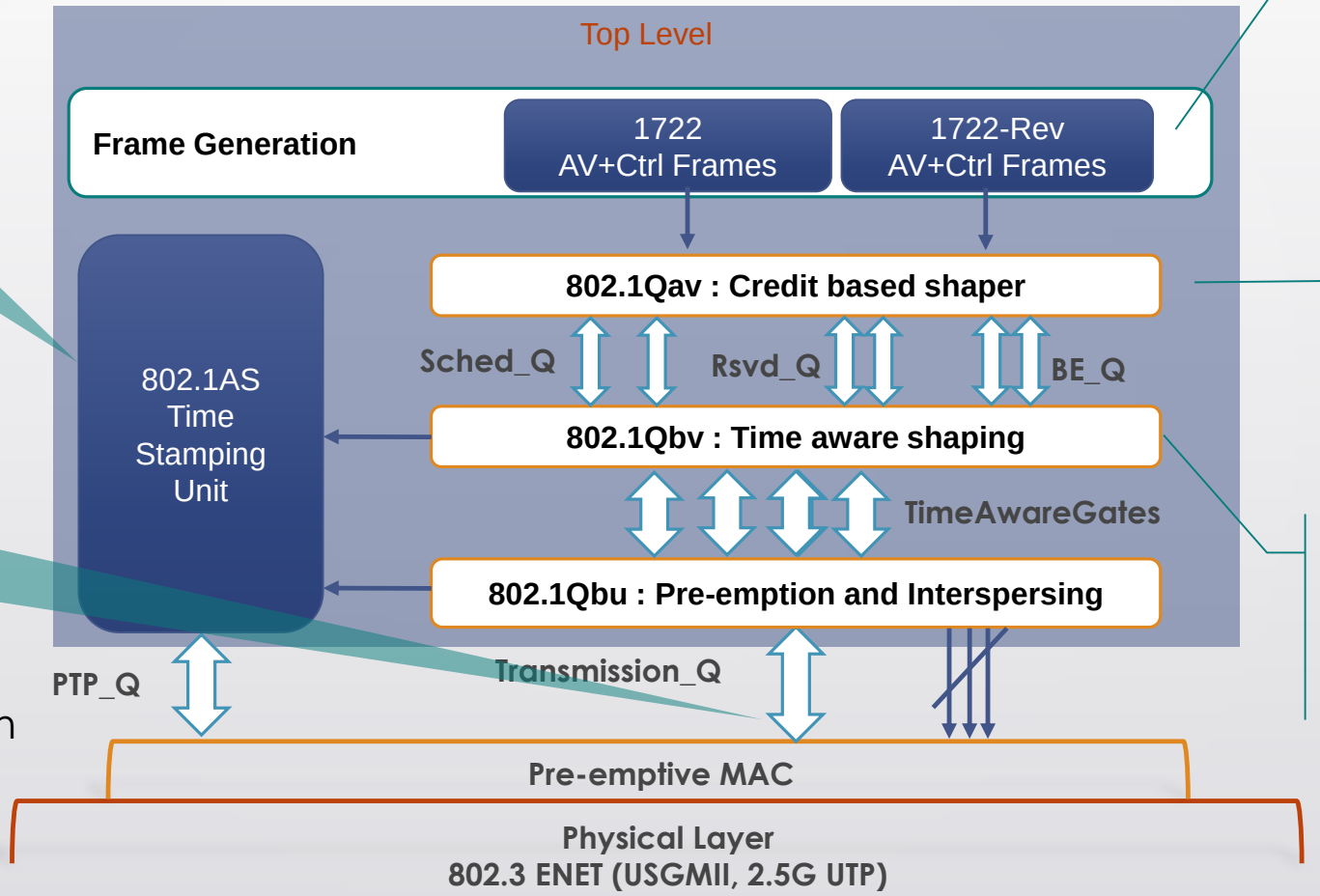


Full Stack Verification Environment

Timestamp generation and clock sync for the system

Preemption controlled through Hold register or Control directive

Not all layers need be present in every use model, the different functionalities can be selected based on enablement registers



General media format frame creation, packing and unpacking

Generated stream scheduling based on bandwidth allocation

Scheduled frames controlled on the basis of gate control list

Thank You