16th International Conference on Network and Service Management
November 2, 2020

A PCE-Based Framework for Future Internet Deterministic and Time-Sensitive Networks

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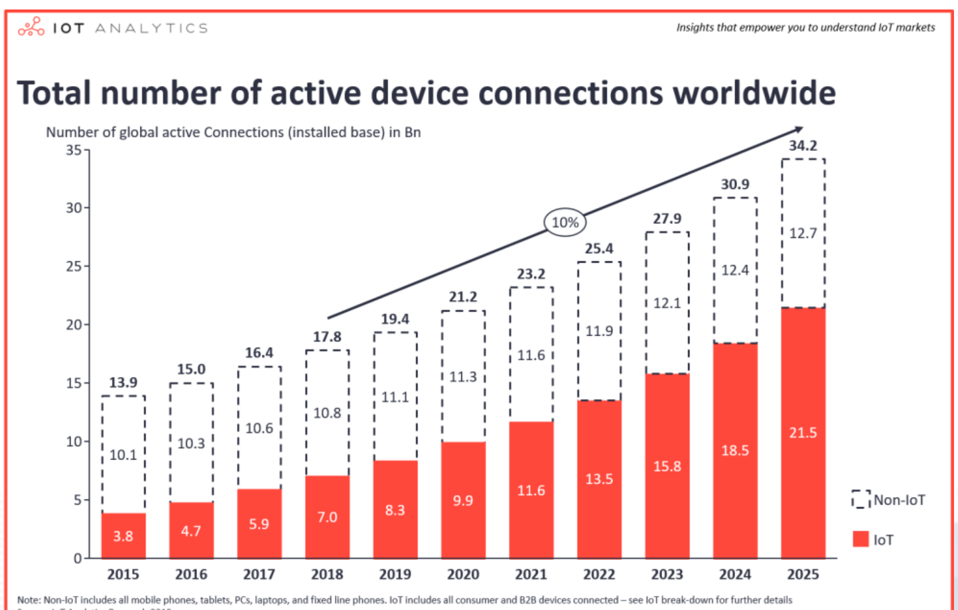
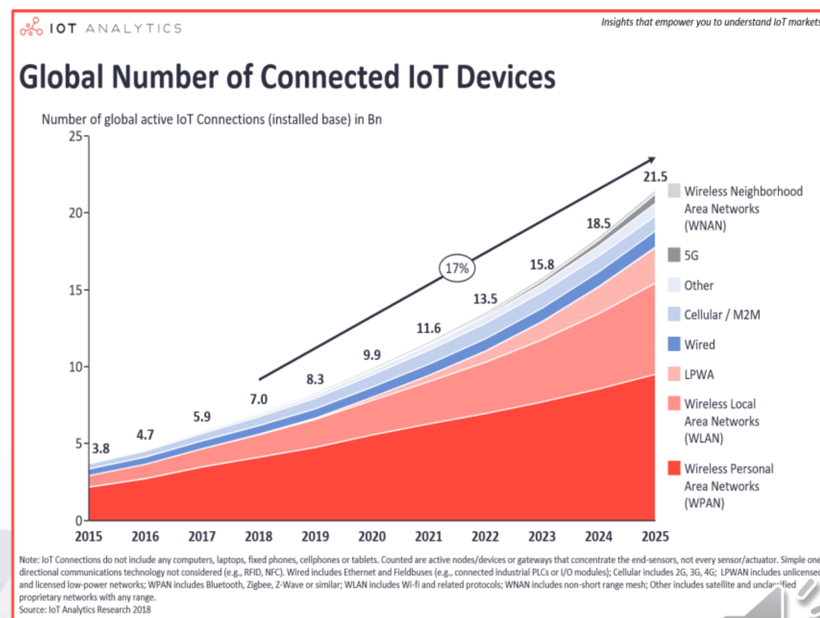
Future Internet
Wireless Connected Devices

- Number of wireless interconnected devices currently at 21b – and accelerating
  - Wireless Personal Networks (WPAN)
  - Wireless Local Area Networks (WLAN
  - Low-power Wide Area Networks (LPWAN)
  - Wireless Neighbourhood Area Networks (WNAN)
- Global IoT Market: $191B market (2020), forecasted to exceed $1,000B by 2025

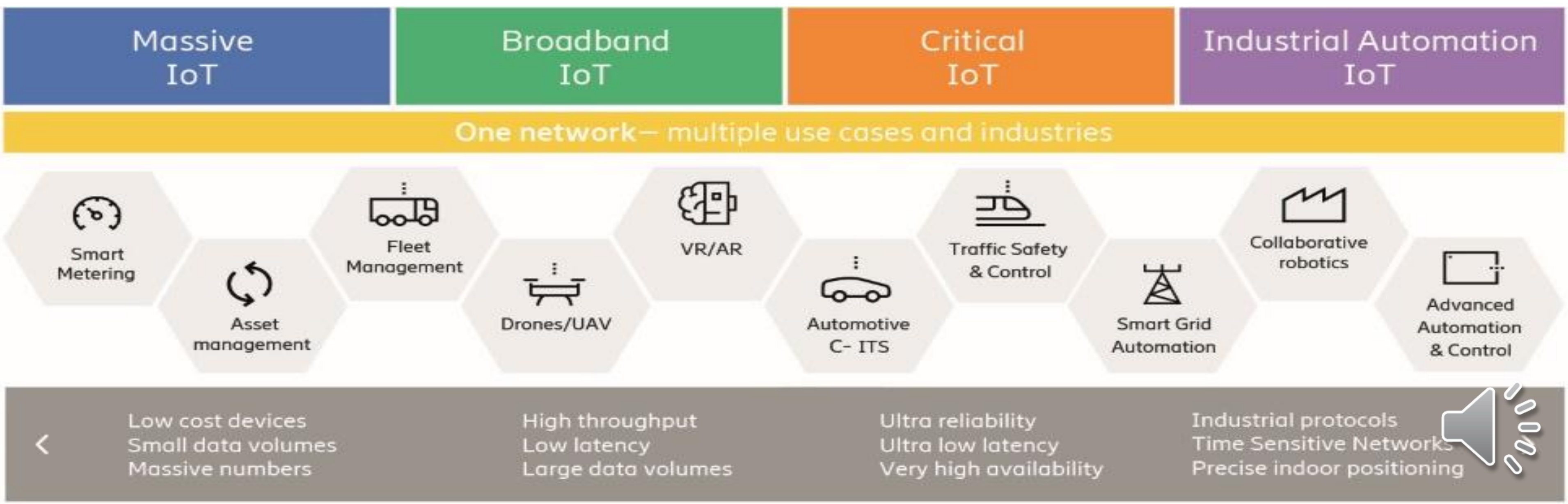




Future Internet

Rise of IoT/IoE and beyond

- For beyond 5G and Network 2030, Ultra-Reliable Low-Latency Communications (URLLC) applications, which require reliable communication between nodes and ultra-low latency communication
- Other wireless application types including Massive Machine Type Communications (mMTC) require support for an exponentially large number of devices which may only transmit information sporadically, such as the massive Internet of Things (mIoT) factory use cases.
- We are investigating the concept of determinism for these emerging network types, allowing resource allocation mechanisms to be intelligently controlled for lossless data transmission and energy efficiency.

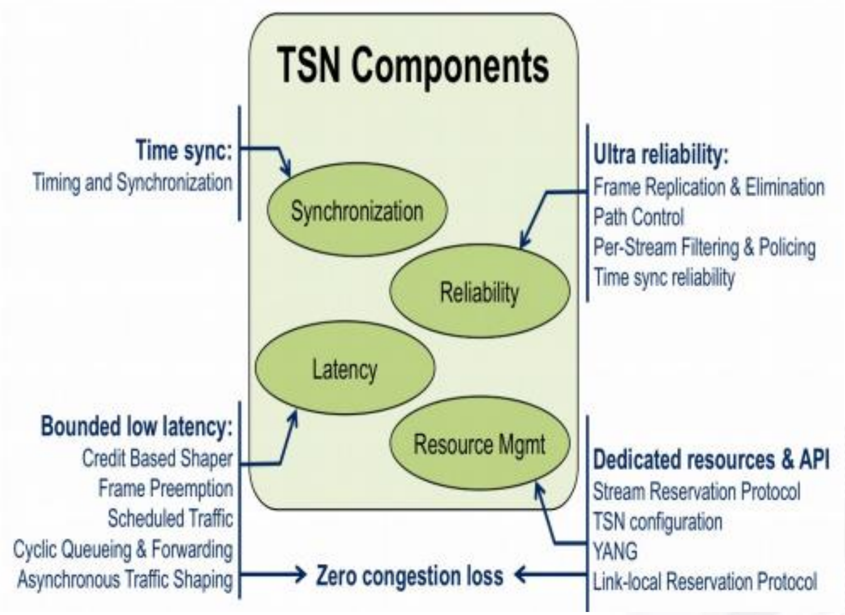


Future Internet
Beyond 5G and Network 2030 (ITU-T)

- Beyond 5G a joint IEEE 802 and ITU-T SG15 Workshop
  - Joint IEEE 802 and ITU-T Study Group 15 workshop "Building Tomorrow's Networks" concluded further study required for TSN applicability to 5G
- ITU-T FG NET-2030 Published Several Technical Reports
  - "New Services and Capabilities for Network 2030: Description, Technical Gap and Performance Target Analysis" (October 2019)
  - "Representative use cases and key network requirements for Network 2030" (January 2020)
  - "Network 2030 - Gap Analysis of Network 2030 New Services, Capabilities and Use cases" (June 2020)
  - "Network 2030- Additional representative use cases and key network requirements for Network 2030" (June 2020)
  - "Network 2030 Architecture Framework" (June 2020)
  - "Network 2030 - Terms and Definitions" (June 2020)
- Both activities concluded for mobile fronthaul and 5G mobile transport
  - IEEE 802.1 TSN is applicable to 5G transport, e.g., 802.1CM TSN for Fronthaul
  - ITU-T SG 15 should continue to collect NET2030 and IMT2020 requirements
  - ITU-T Q13/15 in cooperation with 3GPP and CPRI should continue to collect synchronization requirements for 5G
- **"Applicability of deterministic TSN to 5G fronthaul and beyond requires further study"**

Time-Sensitive Networks
Leveraging IEEE 802 TSN

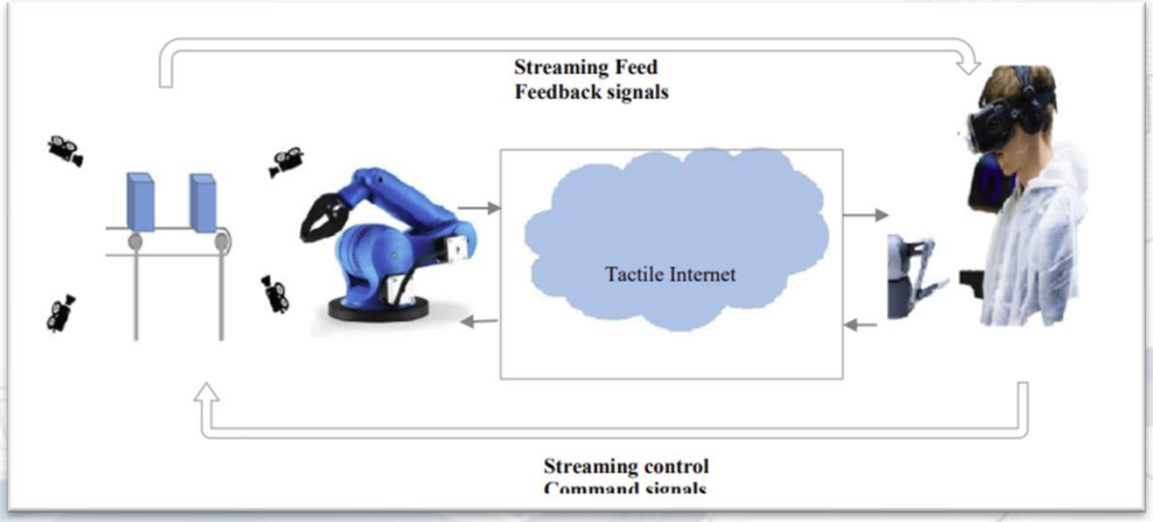
- Time Sensitive Networking is an enhancement to IEEE 802 networks enabling the convergence of real-time control with time-critical streaming.



- However, like generalized Ethernet, TSN lacks deterministic and traffic engineered capabilities.

Future Internet
Deterministic and Time-Sensitive Networks

- Time-Sensitive Networking (TSN)
  - The Time-Sensitive Networking (TSN) is a set of updates to the IEEE Ethernet standard that aims to empower standard Ethernet with time synchronization and deterministic network communication capabilities.
- Let's try to define "Deterministic and Time Sensitive Networks"
  - **Time synchronization** for network nodes and hosts and **optimal transmission** windows
  - **Selection of energy efficient links** and **resource reservation** for critical data streams (buffers and schedulers in network nodes and bandwidth on links)
  - Ensure **extraordinarily low packet loss ratios**, starting at 10–6 and extending to 10–10 or better, and consequently, a guaranteed end-to-end latency for a reserved flow.
  - **Convergence of critical data streams** with **general data streams** and applying **QoS features** (including ordinary best-effort) over a single network, ensure reliable delivery even when critical data streams are at risk of congestion.



Deterministic and Time-Sensitive Networks

Need for low-latency and high-reliability

- Performance requirements for low-latency and high-reliability Use Cases (source 3GPP TS 22.261)

Scenario	End-to-end latency (note 3)	Jitter	Survival time	Communication service availability (note 4)	Reliability (note 4)	User experienced data rate	Payload size (note 5)	Traffic density (note 6)	Connection density (note 7)	Service area dimension (note 8)
Discrete automation – motion control (note 1)	1 ms	1 µs	0 ms	99,9999%	**99,9999%**	**1 Mbps up to 10 Mbps**	Small	1 Tbps/km²	100 000/km²	**100 x 100 x 30 m**
Discrete automation	10 ms	100 µs	0 ms	99,99%	**99,99%**	**10 Mbps**	Small to big	1 Tbps/km²	100 000/km²	1000 x 1000 x 30 m
Process automation – remote control	50 ms	20 ms	100 ms	99,9999%	**99,9999%**	**1 Mbps up to 100 Mbps**	Small to big	100 Gbps/km²	1 000/km²	300 x 300 x 50 m
Process automation – monitoring	50 ms	20 ms	100 ms	99,9%	**99,9%**	**1 Mbps**	Small	10 Gbps/km²	10 000/km²	300 x 300 x 50
Electricity distribution – medium voltage	25 ms	25 ms	25 ms	99,9%	**99,9%**	**10 Mbps**	Small to big	10 Gbps/km²	1 000/km²	100 km along power line
Electricity distribution – high voltage (note 2)	5 ms	1 ms	10 ms	99,9999%	**99,9999%**	**10 Mbps**	Small	100 Gbps/km²	1 000/km² (note 9)	200 km along power line
Intelligent transport systems – infrastructure backhaul	10 ms	20 ms	100 ms	99,9999%	**99,9999%**	**10 Mbps**	Small to big	10 Gbps/km²	1 000/km²	2 km along a road
Tactile interaction (note 1)	0,5 ms	TBC	TBC	[99,999%]	**[99,999%]**	**[Low]**	[Small]	[Low]	[Low]	**TBC**
Remote control	[5 ms]	TBC	TBC	[99,999%]	**[99,999%]**	**[From low to 10 Mbps]**	[Small to big]	[Low]	[Low]	**TBC**

NOTE 1: Traffic prioritization and hosting services close to the end-user may be helpful in reaching the lowest latency values.
NOTE 2: Currently realised via wired communication lines.
NOTE 3: This is the end-to-end latency the service requires. The end-to-end latency is not completely allocated to the 5G system in case other networks are in the communication path.
NOTE 4: Communication service availability relates to the service interfaces, reliability relates to a given node. Reliability should be equal or higher than communication service availability.
NOTE 5: Small: payload typically ≤ 256 bytes
NOTE 6: Based on the assumption that all connected applications within the service volume require the user experienced data rate.
NOTE 7: Under the assumption of 100% 5G penetration.
NOTE 8 Estimates of maximum dimensions; the last figure is the vertical dimension.
NOTE 9: In dense urban areas.
NOTE 10: All the values in this table are targeted values and not strict requirements.

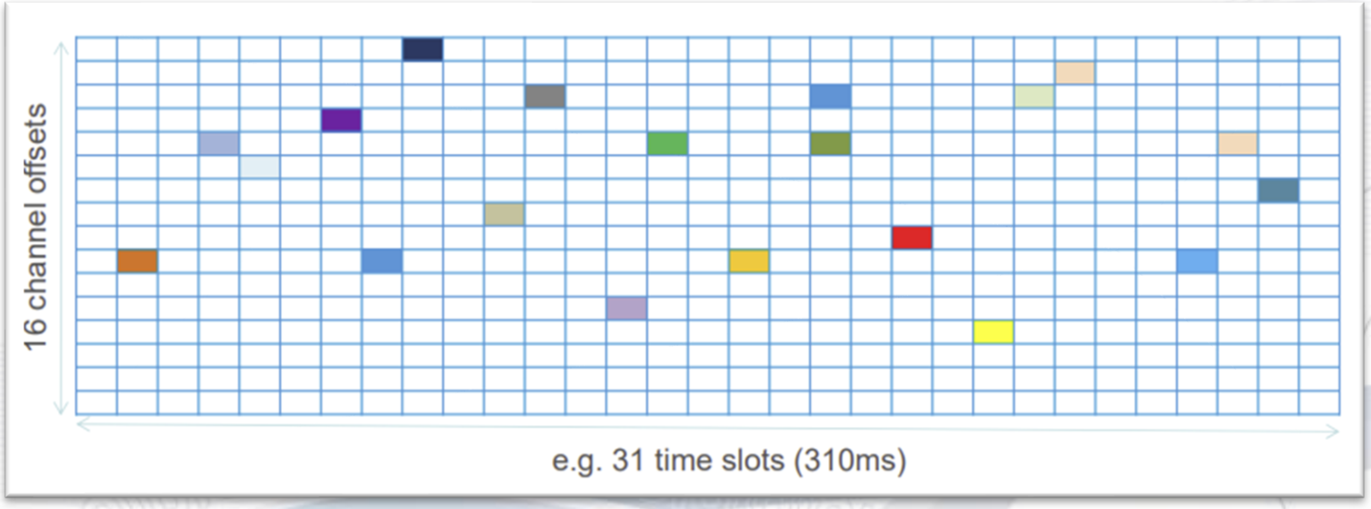
- Latency & Jitter are 2 key metrics for Ultra Low Latency (ULL) applications
- ULL applications often require deterministic latency, i.e., all frames of a given application traffic flow must not exceed a prescribed boundary

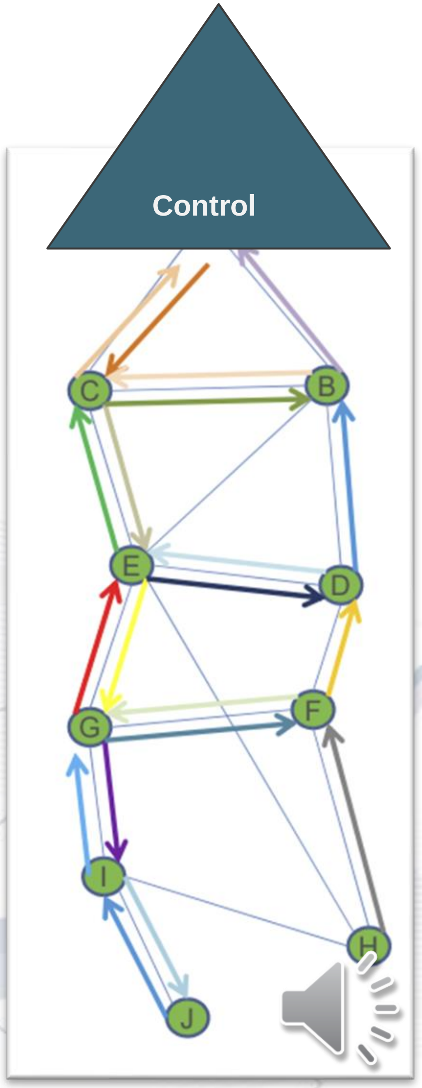
Deterministic and Time-Sensitive Networks
What are the Research Questions?

- Identify a centralized SDN and Orchestration framework for TSN flow management
- Ensure TSN interworking with Deterministic Networking to achieve E2E deterministic latency for Layer-2 and Layer-3 services
- Mechanism to ensure a bounded worst-case delay for low priority traffic in TSN networks
- Collection and management of TSN performance data for fronthaul operational efficiency

Future Internet
Deterministic and Time-Sensitive Networks

- Centrally scheduled operations would bring benefits in wireless
  - High delivery ratio through path redundancy and collision elimination
  - Bounded maximum latency (and jitter)
  - Reserved scheduled transmission opportunities for critical traffic
  - Shared scheduled transmission opportunities & dynamic allocation for best effort
- Schedule transmission to maintain the medium free at critical times
  - T+FDM with CG-Mesh
  - Time Slotted Channel Hopping (TSCH) TSCH





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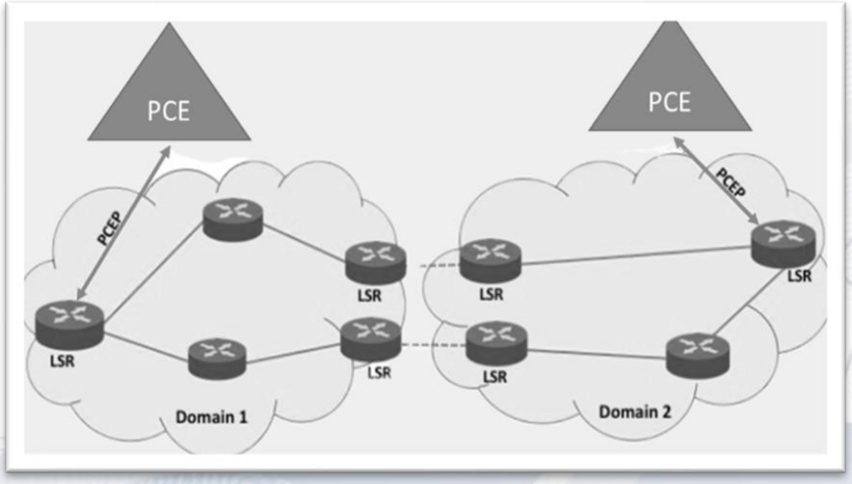
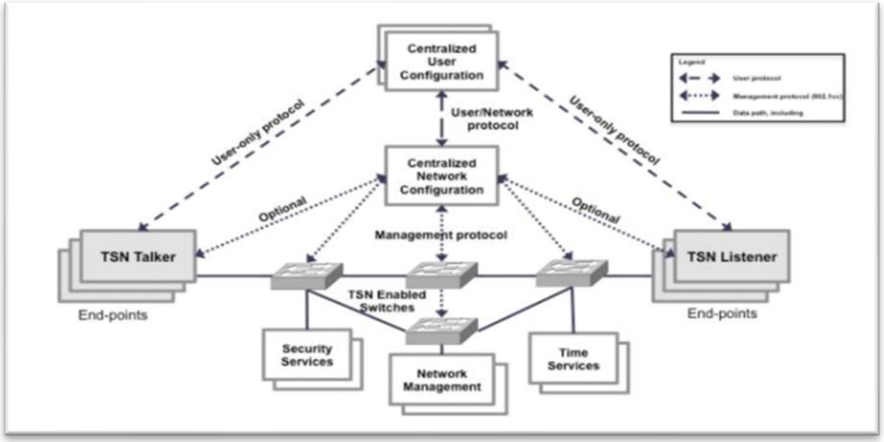
Deterministic and Time-Sensitive Networks

- Using the Path Computation Element
  - May be used for stochastic path selection
  - Separation deterministic path computation and routing
  - Centralized optimization for deterministic flows (currently applied to LSPs, SFCs and SR)
- Path Computation Element Protocol
  - A request/response protocols which operates over TCP
  - Reliability and in-order delivery
  - Security delegated to TCP security issues
  - PCE and PCC open a session
  - Negotiate parameters and function learning capabilities



Future Internet
Deterministic and Time-Sensitive Networks

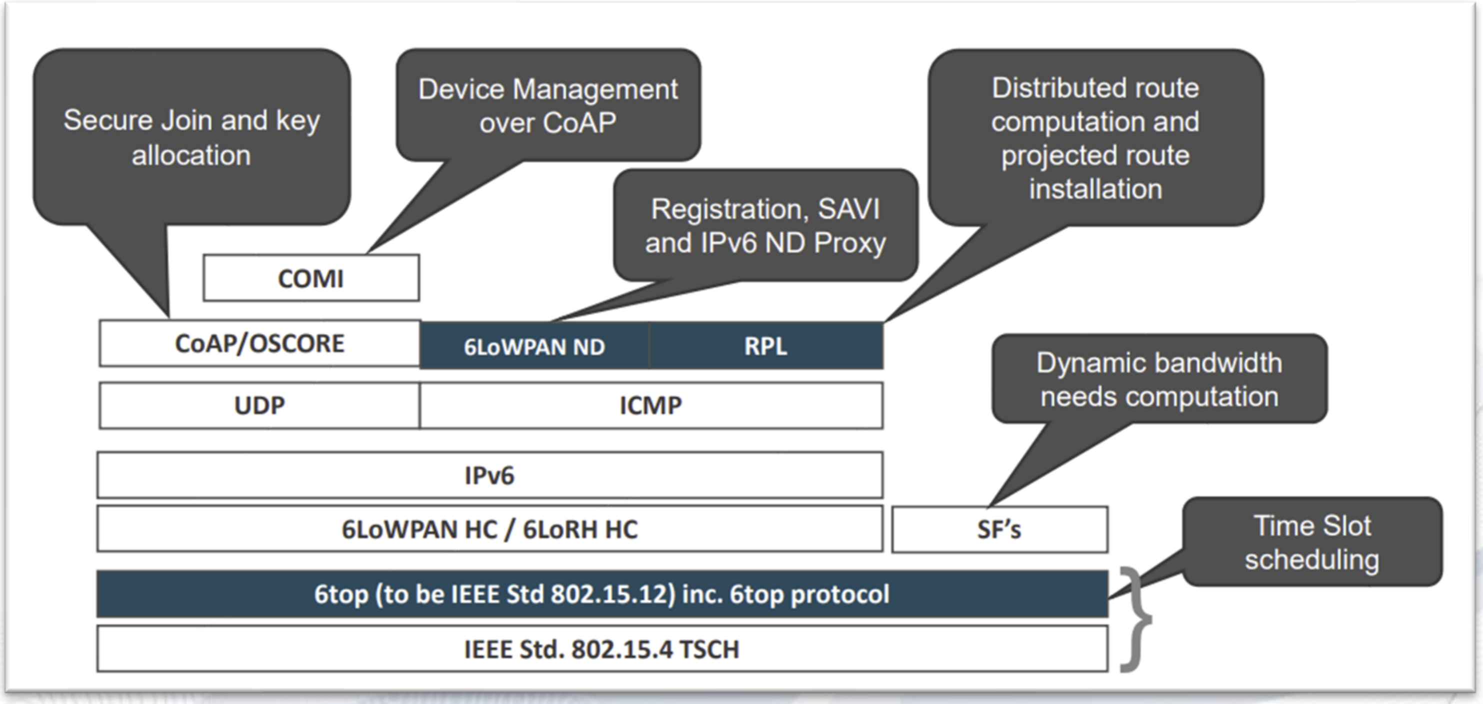
- A Centralized PCE-based Framework for Deterministic TSN using IEEE 802.1Qca



- Using IEEE 802.1Qca Path Control and Reservation (PCR)
  - IEEE 802.1Qca Path Control and Reservation (PCR) specifies extensions to the Intermediate Station to Intermediate Station (IS-IS) protocol to configure multiple paths in bridged networks.
- The IEEE 802.1Qca standard uses Shortest Path Bridging (SPB) ala software-defined networking (SDN) hybrid mode - the IS-IS protocol handles basic functions, while the Centralized Network Configuration node (PCE) would manage explicit paths. This could be via a single global Path Computation Elements (PCEs) at dedicated server nodes.
- Once the PCE, or PCEs, compute a path the IEEE 802.1Qca protocols would configure an explicit forwarding path (a predefined path for each stream), reserve bandwidth, provides data protection and redundancy, and distribute flow synchronization and flow control messages.

Future Internet
Deterministic and Time-Sensitive Networks

- A Centralized PCE-based Framework for Deterministic TSN using 6TSCH
  - Stochastic routing for large scale monitoring (RPL)
  - Separation of resources between deterministic and stochastic (TSCH)
  - Leveraging IEEE standards 802.15.4 and IETF 6LoWPAN and PCE



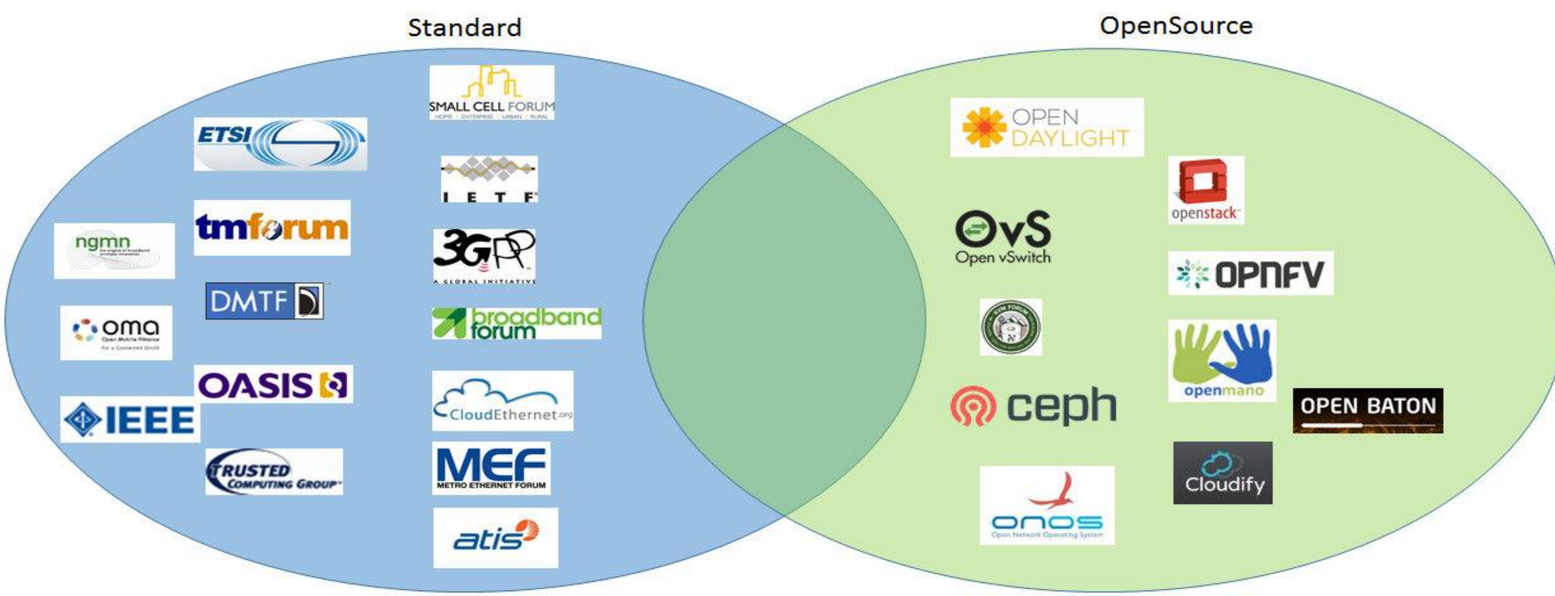
Why Standardise, and Which SDO?

Standardisation for a purpose

- Reduce development and operational costs
- Ensure interoperability

Leverage existing work, but develop solution(s) where gaps exists

- Architecture and Use Cases (ITU-T)
  - SG15 is working with IEEE 802.1 TSN and 3GPP (5G) related to its transport-related Recommendations.
  - FG NETWORK 2030 Requirements mainly done (thanks ITU-T)
- Radio and Physical Layers (IEEE)
  - IEEE 802.1 Time Sensitive Networking (TSN) Task Group [TSN] is developing extensions to support time sensitive networking using IEEE 802.1 networks.
- Control Plane & Signaling (IETF)
  - IETF Deterministic Networking (detnet) and Reliable and Available Wireless (raw) working groups



Future Internet
NG-CDI Project

- Next Generation Converged Digital Infrastructure (NG-CDI) www.ng-cdi.org
  - Developing a completely new architecture for digital infrastructures, composed of highly-dynamic network functions based on a micro-NFV approach that are collectively able to adapt to the real-time requirements of future digital services.
  - Creating a new **autonomic framework** for digital infrastructure to **equip the nodes of the infrastructure network with the ability to understand their state, detect and diagnose disruptions** to service, and **take autonomous actions**.
  - Implementing approaches for the successful integration of these technologies within the business functions with an aim to improve service assurance and organisational value.

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Questions?

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CNSM 2020