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FACULTY OF
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Communication Networks

Resource Allocation Protocol (RAP) for Inter-domain QoS Signaling in TSN

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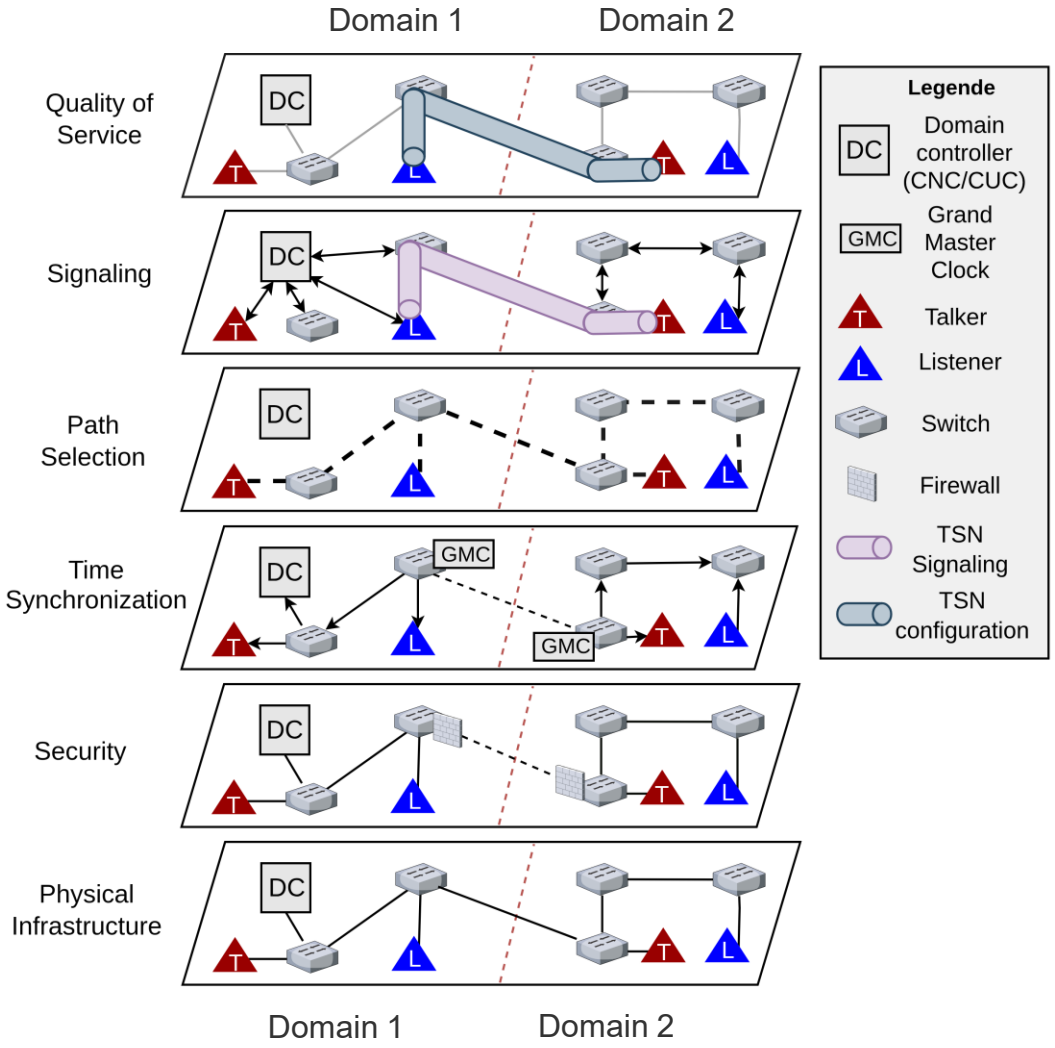
Agenda

- Introduction to inter-domain communication
- Related work on inter-domain QoS signaling
  - Published research
  - IEEE contributions
- Concept for inter-domain QoS signaling
- Discussion

Inter-Domain Communication

- What is a TSN domain?
  - Configuration domain (IEEE Std 802.1Qdj-2024)
    - Set of devices with
      - Common TSN configuration model
      - Under a single administration
- Coherent configuration of TSN domains
  - Physical infrastructure
  - Security
    - Firewalls, IDS, protocol security, ...
  - Time synchronization
    - gPTP
  - Path selection
    - RSTP/MSTP, 802.1Qca, VLAN IDs, ...
  - QoS signaling
    - Distributed, centralized signaling
  - Quality of service
    - Compatibility of TSN shapers and scheduling



Inter-Domain Communication

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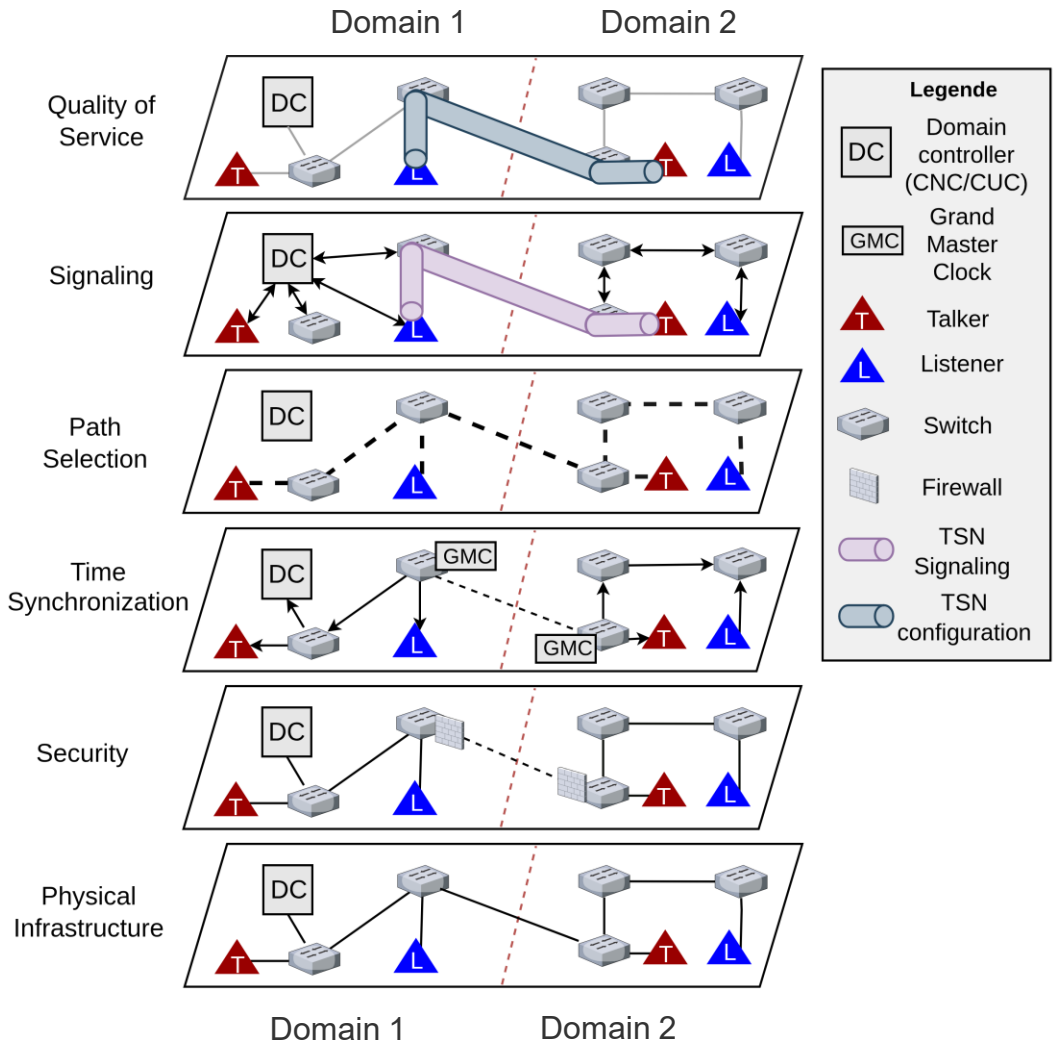
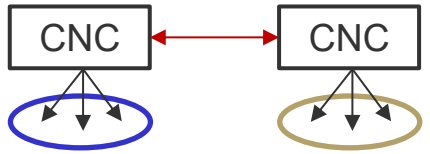
This presentation focuses on inter-domain signaling

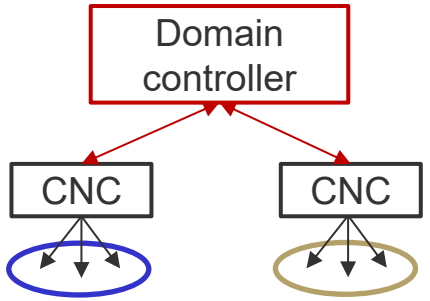


Related Work – Published Research

- Boehm et al. [1], [2]
  - Inter-domain signaling for multiple centralized domains via custom east-west bound interface
  - Uses OpenFlow for signaling and prototyping → not applicable to real deployments



- Bhattacharjee et al. [3]
  - Hierarchical signaling scheme via multiple centralized domains
  - Additional domain controller that orchestrates signaling procedure
  - Limited to centralized domains



Limitations
→ No concept for support of distributed domains
→ Additional protocols or control entities required

References

[1] Böhm, Martin, J. Ohms, and D. Wermser. "Multi-domain time-sensitive networks-an east-westbound protocol for dynamic TSN-stream configuration across domains.“, *IEEE ETFA*, 2019.

[2] Böhm, Martin, and D. Wermser. "Multi-domain time-sensitive networks—Control plane mechanisms for dynamic inter-domain stream configuration.“, *MDPI Electronics,* 2021.

[3] Bhattacharjee, Sushmit, K. Alexandris, and T. Bauschert. "Hierarchical control plane framework for multi-domain TSN orchestration.“, *IEEE NetSoft,* 2023.

Related Work – IEEE Contributions

- Hantel et al. [1]
  - “Domain edge ports” share information about QoS requirements with neighboring domains
- Steindl et al. [2], [3]
  - TSN domains viewed as virtual bridges for transparent signaling
  - Distributed signaling protocol called TSN Inter-domain Protocol (TIDP)
- Dorr et al. [4]
  - Similar use of RAP for inter-domain signaling
- Farcas et al.
  - RAP requires a SDN controller (e.g., CNC) for path configuration with TE-VIDS in 60802 industrial automation deployments [5]
  - Inter-domain signaling messages should be compliant to the TSN UNI, e.g., 802.1Qdj. [6][7]
  - Proposes to use a higher-level domain controller for TSN domains that are under a single administration [8]

Related Work – IEEE Contributions

References

[1] Mark Hantel et al. “TSN Interdomain Communications”, https://www.ieee802.org/1/files/public/docs2018/60802-Hantel-TSN-Interdomain-Communications-0718.pdf, July 2018.

[2] Gunter Steindl et al. “Inter TSN Domain Communication Concept “, https://www.ieee802.org/1/files/public/docs2020/60802-Steindlet-al-InterTsnDomainCommunication-0620-v3.pdf, June 2020.

[3] Gunter Steindl et al. “ TSN Inter Domain Communication Concept “, https://www.ieee802.org/1/files/public/docs2020/new-SteindlTSN-inter-domain-communication-0120-v4.pdf, January 2020.

[4] Josef Dorr. “ RAP in Industrial Automation – Follow-up: Workflow and Benefits “. https://www.ieee802.org/1/files/public/docs2021/60802-dorr-RAPinIndustrialAutomation-0521-v02.pdf, May 2021.

[5] János Farkas. “Central and Distributed Components for TSN Configuration”. https://www.ieee802.org/1/files/public/docs2021/60802-farkas-central-and-distributed-configuration-components-0521-v02.pdf, May 2021.

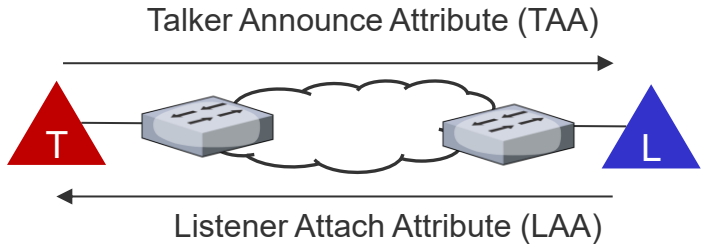
[6] János Farkas et al. “TSN Network Configuration Entity”. https://www.ieee802.org/1/files/public/docs2021/60802-farkas-tsn-network-configuration-entity-0721-v01.pdf, July 2021.

[7] János Farkas et al. “TSN Inter-domain Considerations”. https://www.ieee802.org/1/files/public/docs2021/new-farkas-inter-domain-considerations-0721-v01.pdf, July 2021.

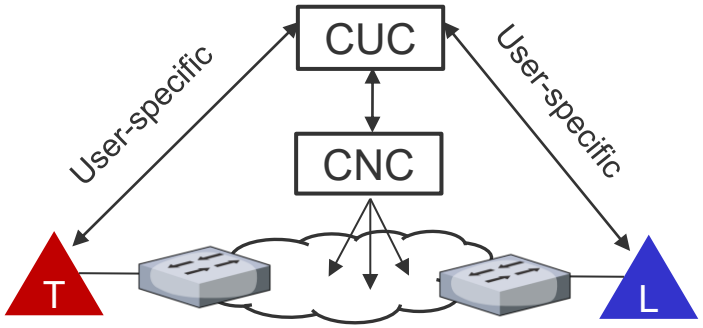
[8] János Farkas et al. “Deterministic 6G: Some Thoughts on Multiple Configuration Domains”. https://www.ieee802.org/1/files/public/docs2024/new-farkas-multiple-configuration-domains-0924-v01.pdf

Recap: TSN QoS Signaling

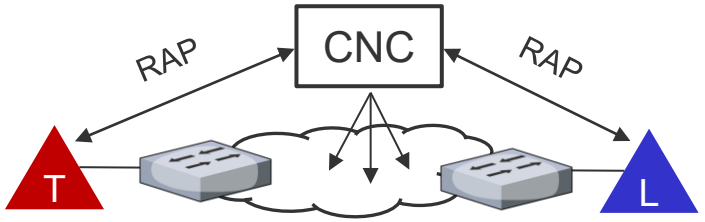
- IEEE P802.1Qdd -> now IEEE P802.1DD
  - Resource Allocation Protocol (RAP)



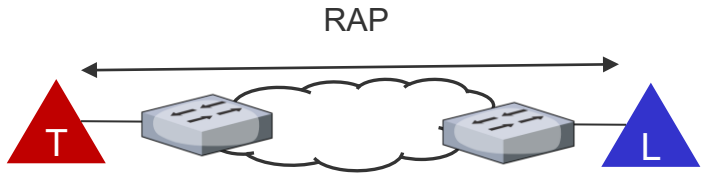
- IEEE Std 802.1Qcc
  - Three configuration models
  - QoS signaling from end stations (users) to bridges (network)



Fully centralized model



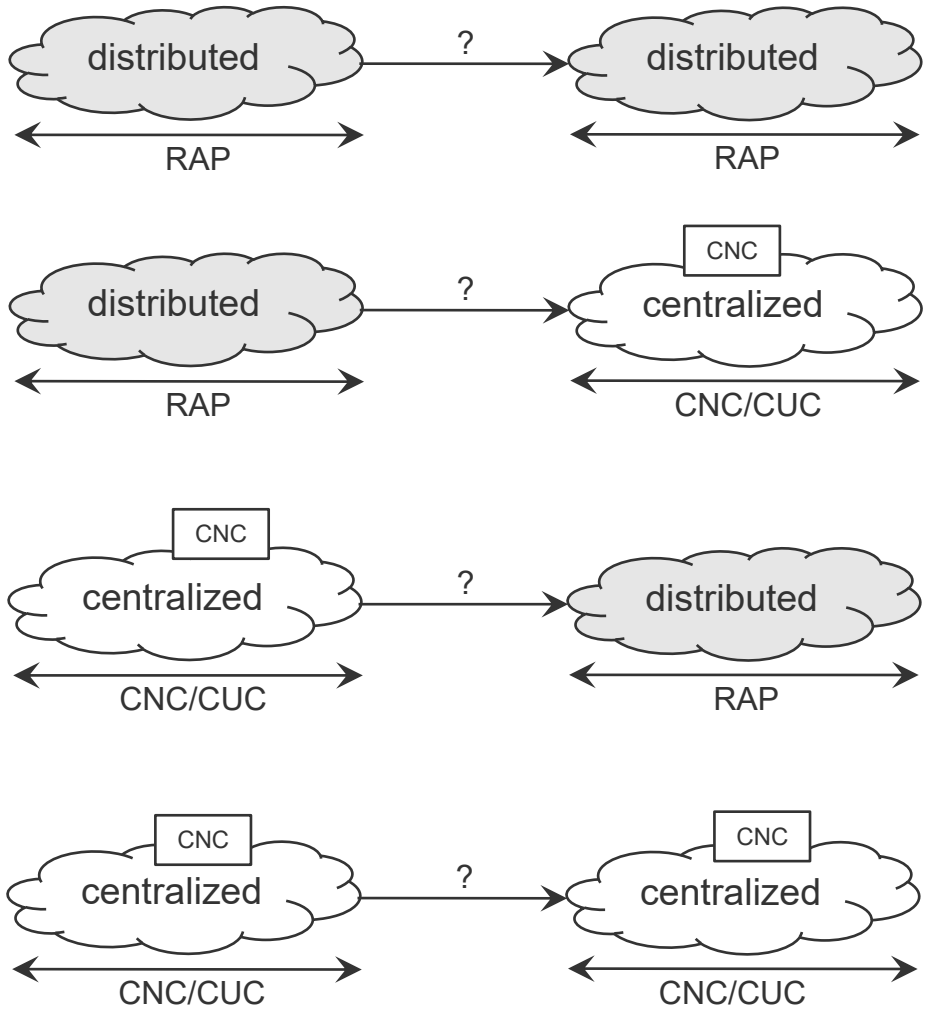
Centralized network/ distributed user model



Fully distributed model

Inter-Domain Signaling – Problem Statement

- Design goals
  - End-to-end inter-domain signaling across
    - centralized and distributed domains
    - Without additional controllers, hierarchies, and protocols
    - Under multiple distinct administrations
- Transitions between domains of different configuration models
  - Four possible domain transitions
    - Distributed-Distributed
    - Distributed-Centralized
    - Centralized-Distributed
    - Centralized-Centralized

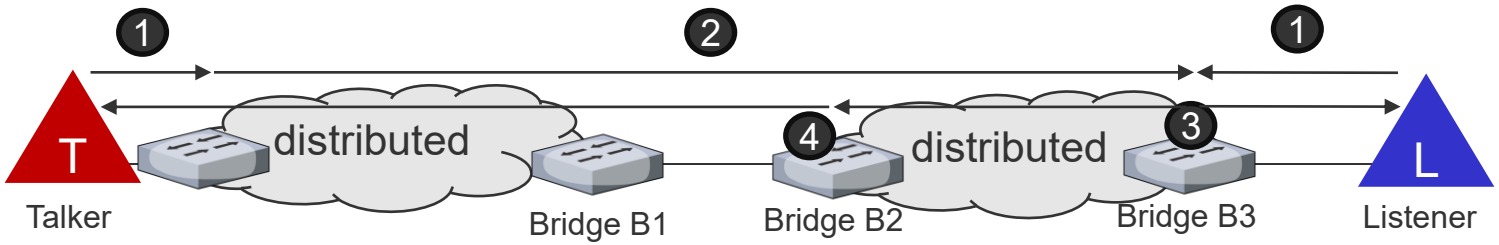


Distributed-Distributed Domain Transition

- Prerequisite
  - Domains are physically connected
  - Paths and VLANs are preinstalled

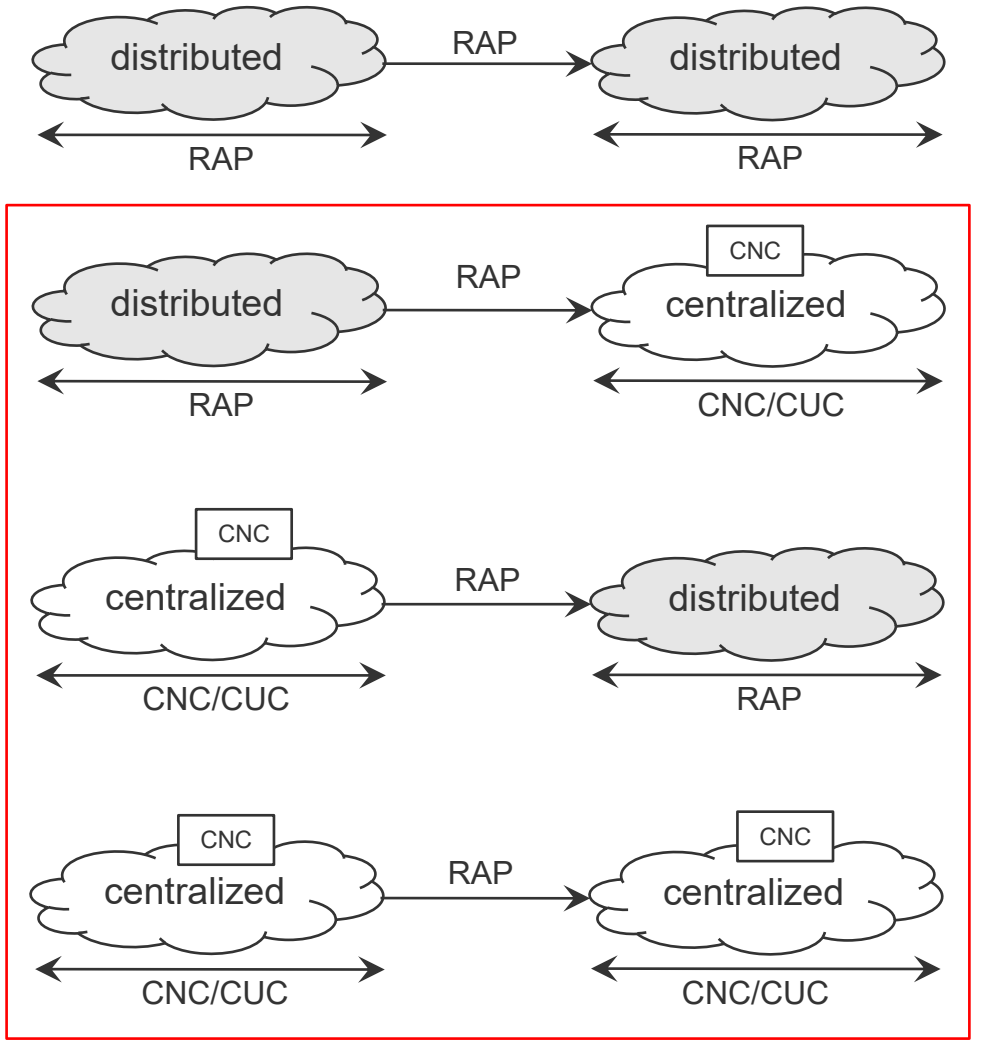
- Signaling scheme
  - RA class attributes are exchanged to form an RA class domain

1. Talker announces Talker Announce Attribute (TAA) and Listener announces Listener Attach Attribute (LAA)
2. Bridges forward the TAA until it meets the LAA
3. Bridge B3 admits the stream, forwards the LAA to B2, and forwards the TAA to the Listener
4. Process is repeated until the LAA reaches the Talker



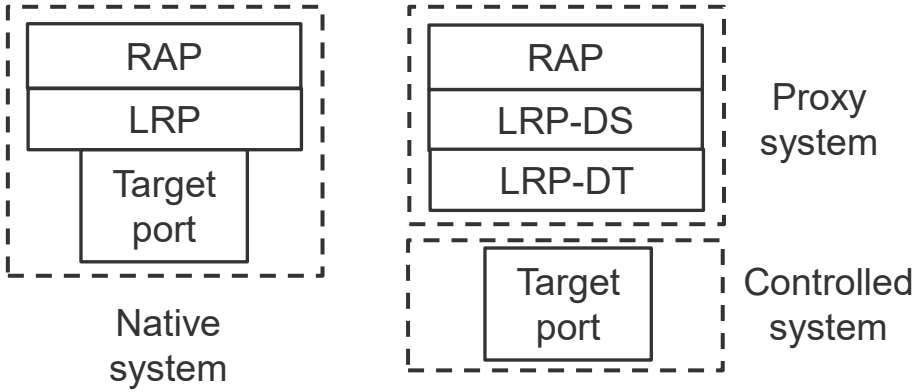
Inter-Domain Signaling – RAP Usage

- We use RAP proxy and controlled systems to exchange RAP messages between
  - A bridge and CNC across a **distributed-centralized** domain transition
  - A CNC and bridge across a **centralized-distributed** domain transition
  - Two CNCs across a **centralized-centralized** domain transition



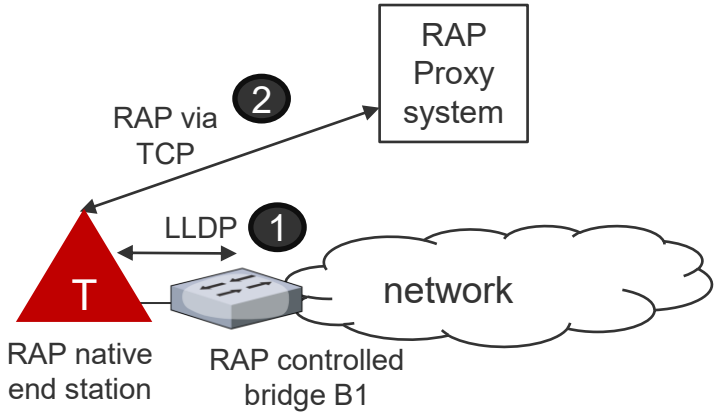
Recap: Link-local Registration Protocol (LRP)

- LRP system types
  - Native system
    - One device including RAP, LRP, and physical target port
  - Proxy system + controlled system
    - Proxy system
      - One device implementing RAP and LRP
    - Controlled system
      - One device including the physical target port
      - Only announces the address and application information of proxy system via **LLDP** to neighbor system



- LRP connection setup of RAP
  - LRP is used to connect RAP end station with RAP proxy system
  - This can be manually configured or automated with LLDP

  1. RAP controlled bridge announces address information of CNC
  2. → Direct TCP connection is established between RAP proxy system and RAP native end station

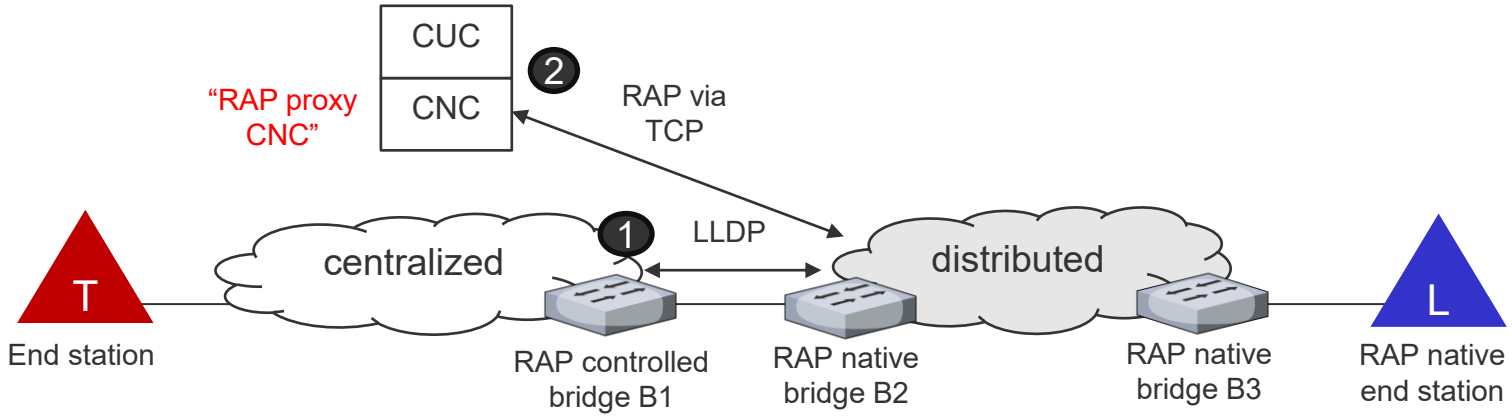


Centralized-Distributed Domain Transition

- Needed RAP capabilities
  - CNC must be able to act as a RAP proxy system

- LRP connection setup

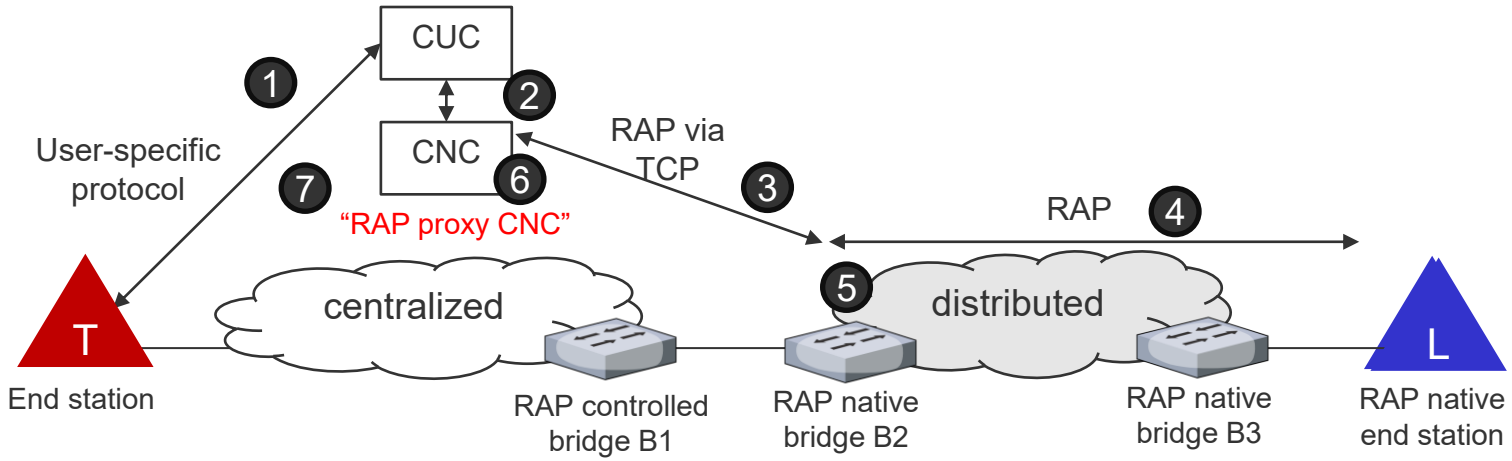
1. RAP controlled bridge B1 announces address information of “RAP proxy CNC” via LLDP, or manual configuration
2. “RAP proxy CNC” and RAP native bridge B2 establish a TCP tunnel for exchanging RAP attributes



→ Direct TCP connection is established between “RAP proxy CNC” and native Bridge B2

Centralized-Distributed Domain Transition

- Signaling scheme
  1. RAP endpoint requests a stream from CUC
  2. CUC knows other end point is in a different domain and requests “inter-domain stream” from CNC
  3. CNC injects RAP attribute into distributed domain
  4. TAA flows along distributed domain until it meets the LAA
  5. Resources are reserved hop-by-hop and LAA flows back until it reaches CNC
  6. CNC reserves resources and reconfigures the centralized network
  7. CNC notifies CUC, CUC notifies Talker about reservation result.



Discussion

- Required capabilities for implementing the concept
  - IEEE P802.1DD
    - "RAP proxy CNC"
      - Capability to receive/inject/forward RAP attributes to other domains
  - IEEE Std 802.1Qdj
    - "Inter-domain stream request"
      - CUC must be able to request a stream for an end station whose communication partner is outside the domain to trigger inter-domain signaling

- Publication
  - Osswald, L., S. Lindner, L. Bechtel, and M. Menth,
    "A Unified Inter-Domain QoS Signaling Scheme for Time-Sensitive Networking", under review in IEEE OJ-COMS.
- Related publications
  - Wüsteney, L., D. Hellmanns, M. Schramm, L. Osswald, R. Hummen, M. Menth, and T. Heer.
    "Analyzing and Modeling the Latency and Jitter Behavior of Mixed Industrial TSN and DetNet Networks.",
    ACM CoNEXT, 2022.
  - L. Osswald, S. Lindner, L. Bechtel, T. Heer, and M. Menth,
    "Secure Resource Allocation Protocol (SecRAP) for Time-Sensitive Networking.", IEEE ETFA, 2024.