Configuration Enhancements for Wireless TSN

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Problem Space

Wireless technologies are enabling deterministic transmissions based on scheduling (and precise time synchronization)

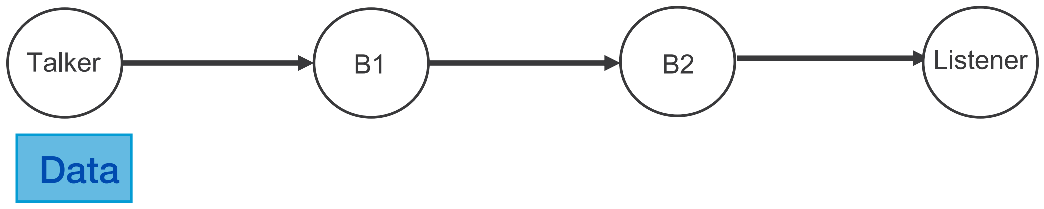
The 802.1 TSN configuration interfaces and tools should enable **seamless integration of Wired and Wireless TSN**

A few specifics of wireless communications needs to be recognized and addressed to enable **efficient operation with minimal configuration changes**

Wireless is different, we should consider it as part of configuration

Wired TSN

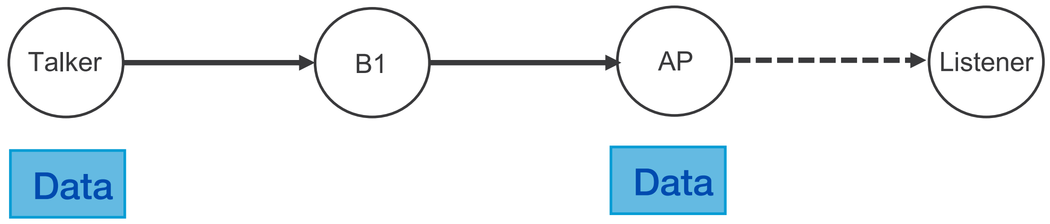
→ Wired: Constant Link Speed (e.g., 100 Mbps, 1 Gbps, …)



- Bridge and link capabilities don't change
- Scheduling (e.g., IEEE 802.1Qbv) doesn't need to change
- Only in case of new streams or topology updates

Wired + Wireless TSN

- - - → Wireless: Variable Link Speed (e.g. function of power, noise, bandwidth, coding)



Variable and typically slower speed can lead to longer end-to-end latencies or violations of Key Performance Indicators (KPIs)

- Bridge and link capabilities are **different and change over time** (wireless is random)
- How to deal with change?
  1) Do nothing (assume worst case always)
  2) Enable E2E configuration tools to be aware of the variability of (wireless) bridges/links
- **This contribution will discuss a proposal to enable option 2)**

Use Cases in Industrial Automation

- Use case document *Use Cases IEC/IEEE 60802* contains clause *2.5.3 Use case 09: Wireless* with 3 use case scenarios
- One listed requirement reads, *Support of wireless for cyclic real-time*
- Furthermore, *Useful 802.11 mechanisms: synchronization support, extensions from .11ax* are mentioned
- In addition, use cases evolve in the industry that need wireless connectivity with deterministic behavior, e.g.:
  - Autonomous Mobile Robots (AMR)
  - Automated Ground Vehicles (AGV)
  - Connectivity to Stationary Robotic
  - Remote Assistance (RA)

Contributions

I. Enable TSN configuration (CNC, TDE) to obtain information about the variability of link delays (e.g., capturing the wireless dynamic behavior due to propagation, noise, mobility of the wireless part of the network).

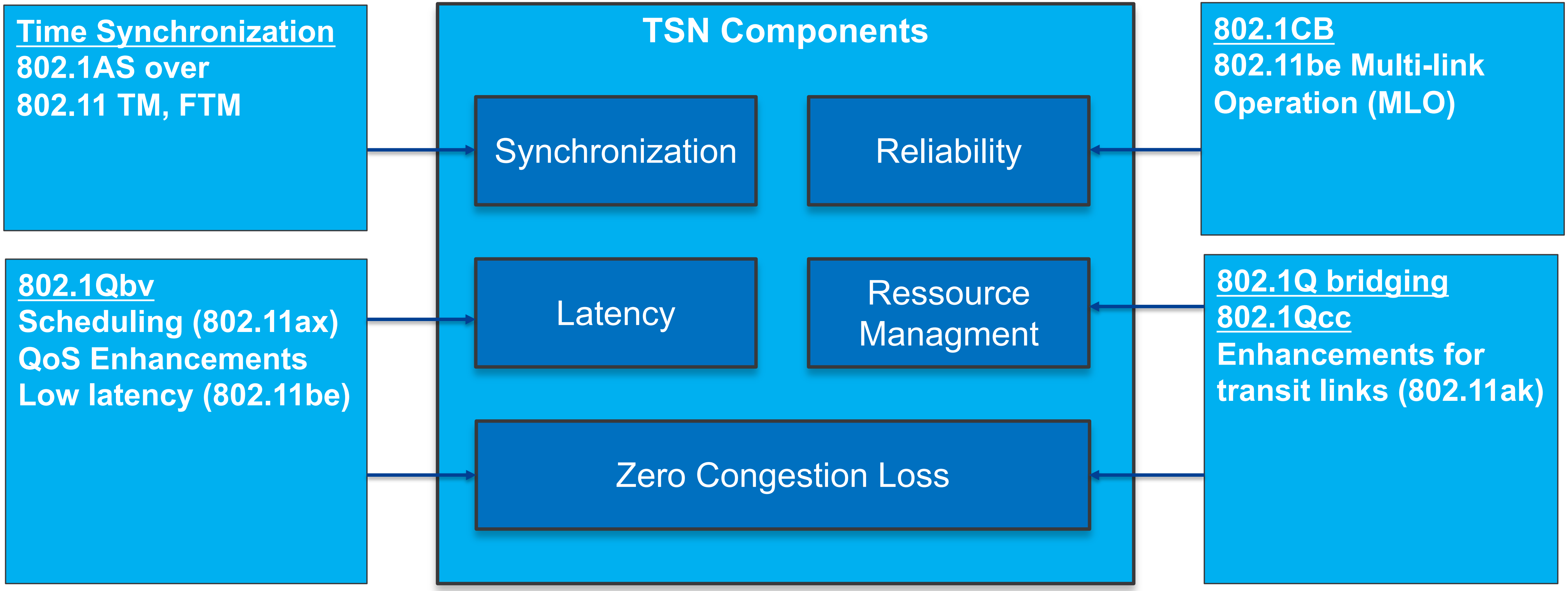
- *Delay CDF:[(*$delay_0$*,* $perc._0$*),(*$delay_1$*,* $perc._1$*), …, (*$delay_n$*,* $perc._n$*)] including Update Interval*

The existing definitions (bridge capabilities) in IEEE 802.1Qcc-2018 (*Table 12-38—Bridge Delay attributes*) only provides max and mix delay values, not enough to describe practical operation points other than worst-case conditions.

II. Define a mechanism to enable notifications of change in the characteristics and capabilities of the wireless links

CDF (Cumulative Distribution Function)

A TSN-Toolbox for IEEE 802.11 Networks



Inspiration and Source: IEEE 802.1TSN WG

Challenges of wireless networks (incl. 802.11 and 5G)

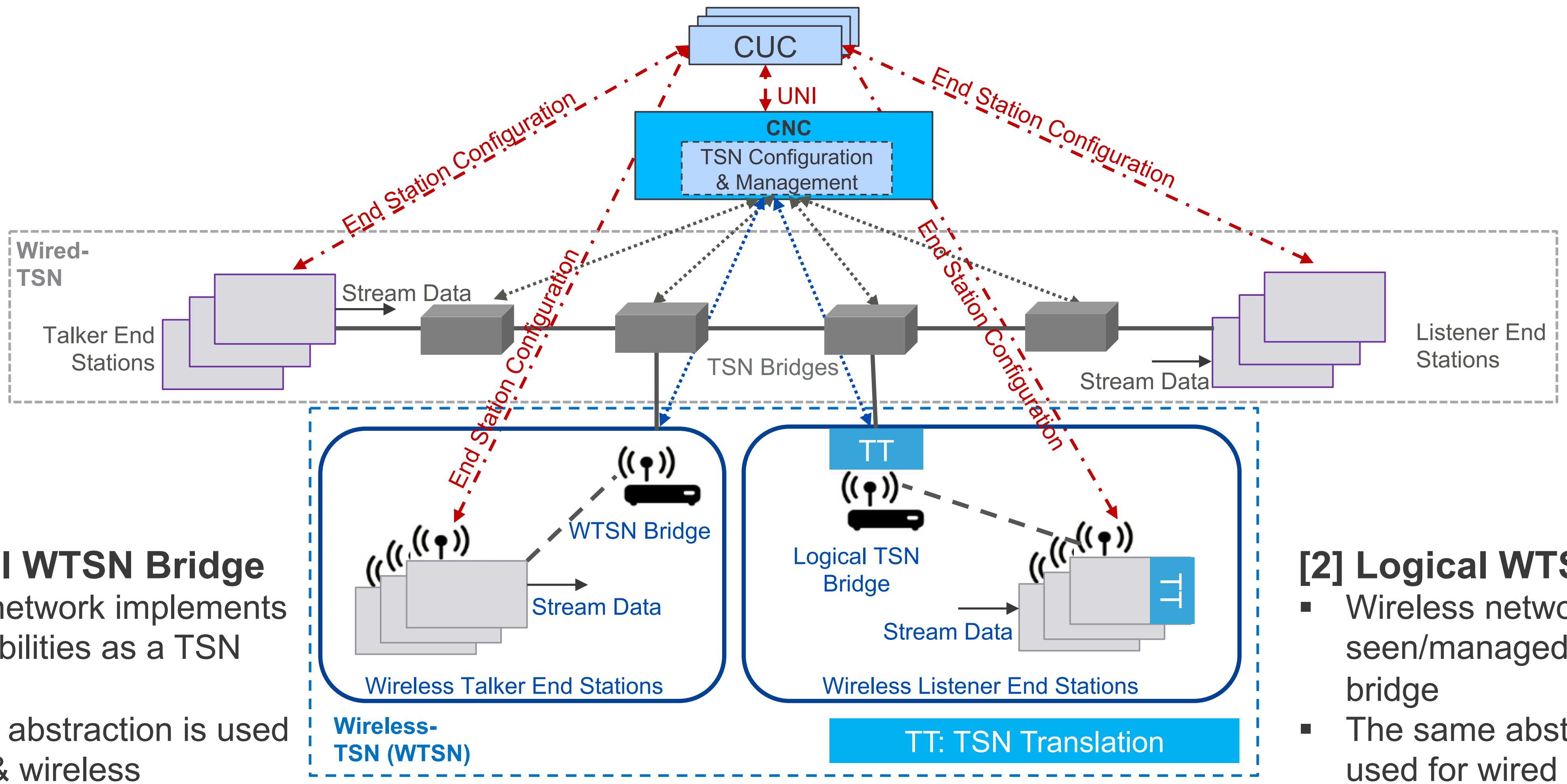
Wireless is different from other mediums in the 802.1 TSN ecosystem

- Fading leads to a wide variation in transmission speed (e.g. 1000->100Mb/s)
- Shared medium access can cause variable delay and jitter (e.g. random back-off, wireless scheduling delay)
- Path loss variability, and Station (STA) Mobility can cause change in best serving AP and thus TSN Bridge end-point

- Thus, link characteristics and physical path from TSN talker to listener can change significantly

- This has impact regarding the applications that can use such network (links), different requirements needs to be considered

TSN Configuration & Management Models [1] & [2]



[1] Physical WTSN Bridge

- Wireless network implements TSN capabilities as a TSN bridge
- The same abstraction is used for wired & wireless links/bridge ports
- E.g., a WLAN operating as an 802.1Q/TSN bridge

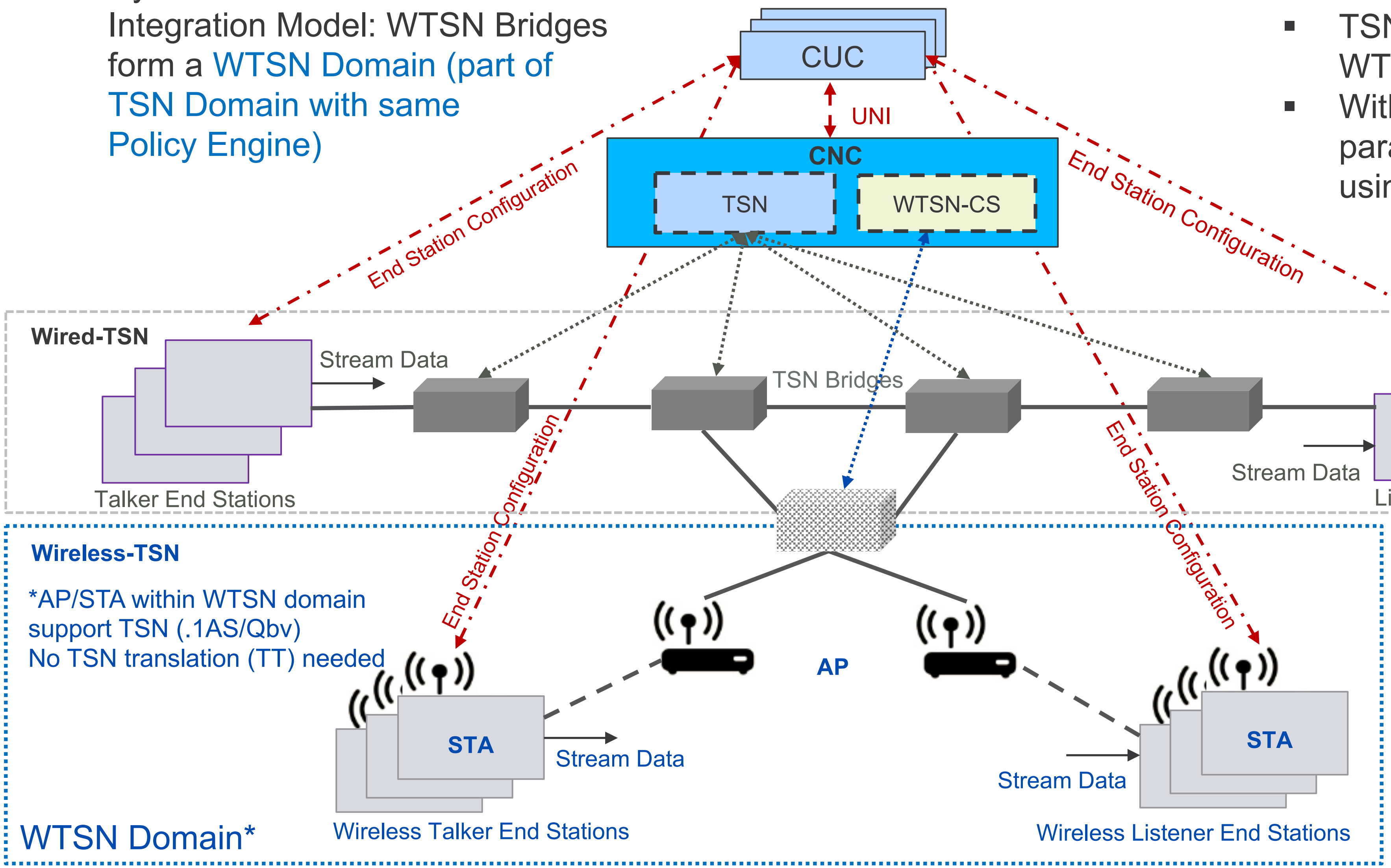
[2] Logical WTSN Bridge

- Wireless network is seen/managed as a TSN bridge
- The same abstraction is used for wired & wireless links/bridge ports
- E.g., 5G-TSN integration in Rel. 16

TSN Configuration & Management: [3] Hybrid Model

Hybrid Wired-Wireless 802.1 TSN Integration Model: WTSN Bridges form a WTSN Domain (part of TSN Domain with same Policy Engine)

- TSN CNC is aware of WTSN domain via WTSN-CS (logical part of CNC)
- With it, CNC discovers wireless-specific parameters (I) and receives notifications using remote management (II)



- CNC can adapt (e.g., end2end scheduling, end2end path selection) accordingly
- CNC (WTSN-CS) doesn't manage short-term changes in wireless links (WTSN bridge abstracts this aspect)

WTSN-CS: WTSN Configuration and Scheduling

Benefits of being Wireless-Aware

CNC knows the WTSN dynamic range

- Realistic range of MCS/data-rates can be used to report reasonable delay bounds to CNC
- CNC scheduling can account for wireless variability (e.g., 99.9%-ile, 99.99% vs. 100%-ile worst-case)

Flexibility

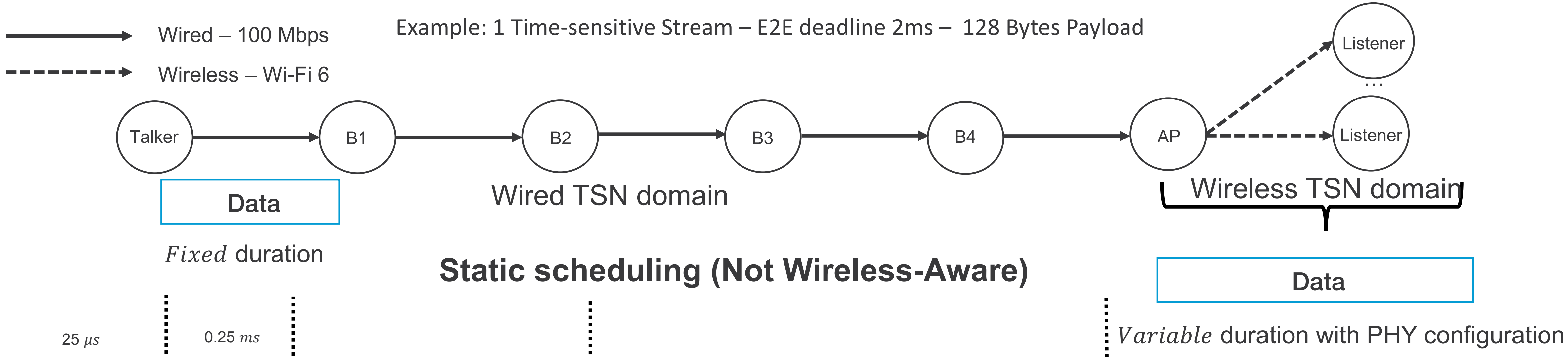
- Designers can determine trade-off between necessity for gate re-computation vs. efficiency
- Systemic degradation can still be accommodated (i.e. by exception)

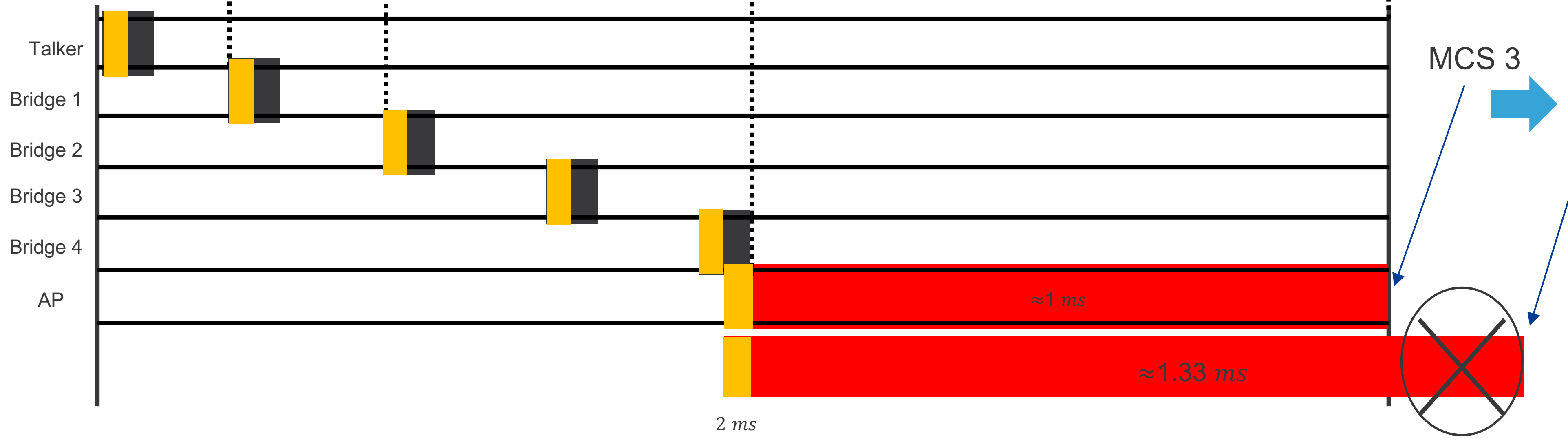
Key E2E TSN Benefits

- Gate over-runs (e.g. due to low speeds) mitigated via proactively scheduling of upstream wired nodes
- Overall latency can be reduced by using high-confidence 99%-ile delay bounds

MCS: Modulation and Coding Scheme

Static IEEE 802.1Qbv based Scheduling

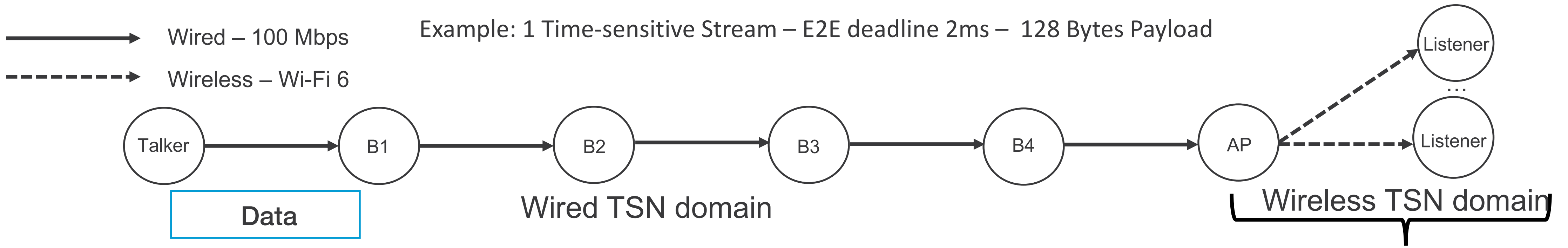




Wireless dynamics breaks the schedule or require re-scheduling to account for higher latency (worst-case conditions)

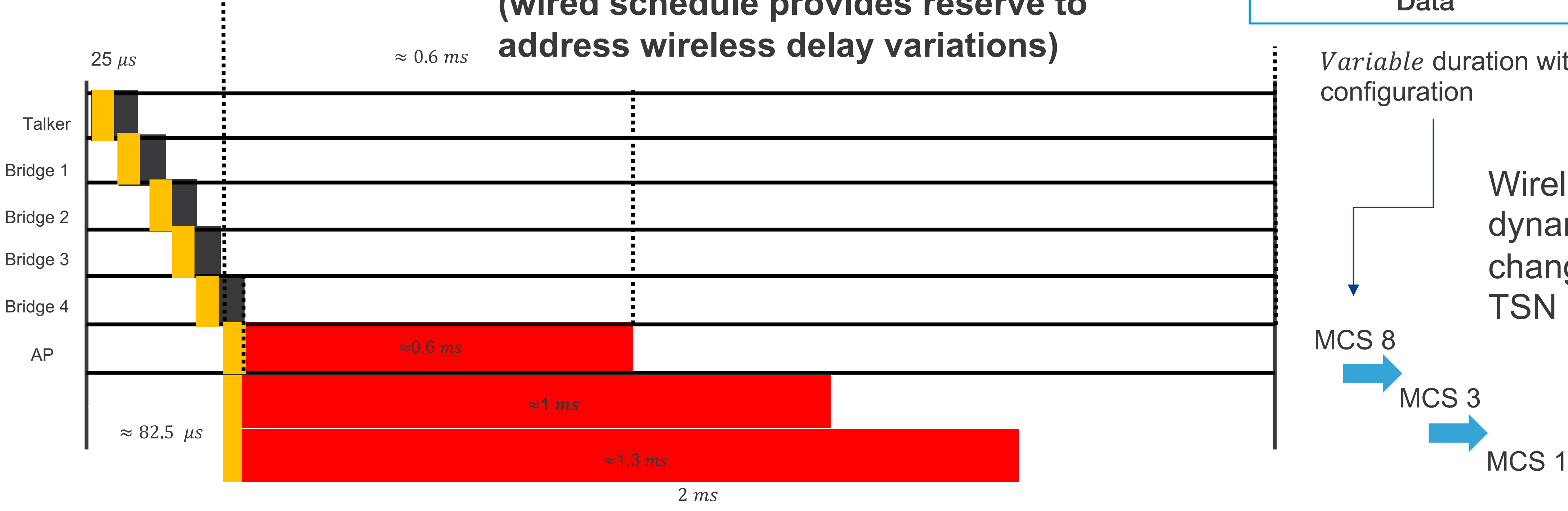
MCS: Modulation and Coding Scheme

Wireless-Aware IEEE 802.1Qbv based Scheduling



Fixed duration

Wireless-Aware Scheduling Strategy (wired schedule provides reserve to address wireless delay variations)



Variable duration with PHY configuration

Wireless dynamics don't change the TSN schedule

Contribution I (to IEEE 802.1Qdj – Configuration Enhancements for TSN)

The following parameters are needed to consider characteristics of wireless links/ports:

- *LinkDelayVariability Descriptor: characterizes the variability of the link*
  - *Update Interval: minimal interval for which the delay descriptor is valid. If not updated, the descriptor is valid for another interval.*
  - *Delay CDF:*$[(delay_0, perc._0),(delay_1, perc._1), \ldots, (delay_n, perc._n)]$
- The logical component *WTSN Configuration and Scheduling (WTSN-CS)* manages and computes configurations based on this data

Name	Data Type	Operations supported	References
UpdateInterval	See next slide	RW	Tbd.
LinkDelayVariability	See next slide	RW	Tbd.

Contribution I (to YANG Data Model): *LinkDelayVariability* Descriptor [128 Bytes],

B0 B7	B8 B15	B16 B23	B24 B31	B32 B39	B40 B47	B48 B53		B54 B63
UpdateInterval	Delay0	Perc.0	Delay1	Perc.1	Delay2	Perc.2	…	Reserved

Field	Description
UpdateInterval	Minimal interval in msec for which the reported delay values are valid. If not updated, the descriptor is valid for another interval.
Delay0	Delay in msec
Perc0	Percentile for Delay0
Delay1	Delay in msec
Perc1	Percentile for Delay1
Delay2	Delay in msec
Perc2	Percentile for Delay2
…	…
Delay5	Delay in msec
Perc5	Percentile for Delay5

Contribution II (to IEEE 802.1Qdj)

- A mechanisms is needed to enable notifications of change in the characteristics and capabilities of the wireless links, represented by the WTSN Domain (assuming data objects exist, pulling might be expensive)
- YANG-PubSub provides a mechanism to subscribe to data objects of a YANG model to get notifications upon change
  - Is this an exercise for IEC/IEEE System AdHoc as well, meeting Plug & Produce requirements ?
- The CNC consumes these notifications through the logical component *WTSN Configuration and Scheduling (WTSN-CS)*
- Hooks to content of IEEE 802.1Qdj, Draft 01, Annex Z: *Notifications to prevent polling, e.g. for stream status changes, long running CNC operations like scheduling, ...*

Contribution II (to Content of IEC/IEEE 60802)

- Clause 6.8 contains management definitions and considerations
- It comprises components and sub-components such as TDME, TDE, and NPE, as well as CNC and CUC
- The TDE description contains the following: *The TDE detects added or removed IA-devices and alerts the CNC if needed*
- Is YANG-PubSub something to support agility and flexibility in Wired TSN (Plug & Produce) as well?

YANG Subscriptions Concept

Subscription to updates

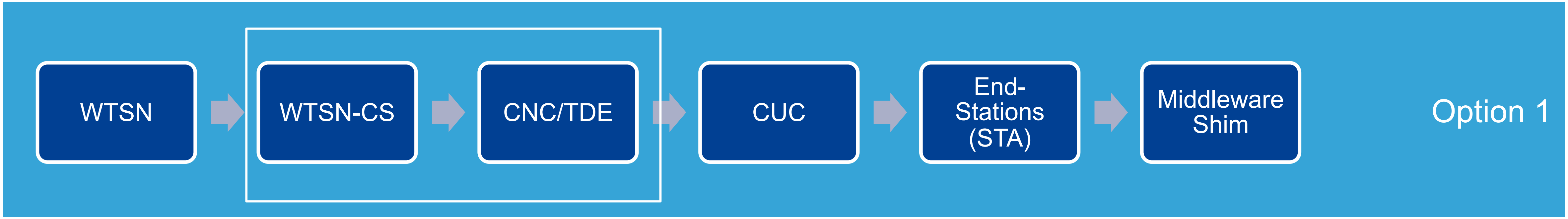
- Any YANG subtree on device
- Statically configured or dynamically signaled
- Standards based subscribe

Streaming of updates

- Customized to recipient
- Periodic or on-change
- Encoding (XML, JSON, …)
- Transport (NETCONF, HTTP/2, …)
- Priority subscriptions
- Standards based push

- No expensive polling needed
- Granular subscriptions possible **ON-Change** OR **Periodic**
- Useful for wireless and wired use cases related to schedulung and beyond
- Resources on subscription:
  https://datatracker.ietf.org/doc/html/rfc8641 [Subscribing to YANG Datastores]
  https://datatracker.ietf.org/doc/html/rfc8639 [Subscribing to Events]

Contribution II (User Stories, Examples, tbd.)



- Option1 follows the IEEE 802.1 / Qcc workflow

- Option 2 follows the work in IEC/IEEE 60802

Summary

- Wireless-TSN is available
- Use cases do exist, End-to-end solutions are needed
- Hybrid Configuration and Management Model allows seamless integration with TSN according to IEEE 802.1 definitions
- Wireless specifics require additional information on wireless infrastructure to configure and manage the network accordingly
- An enhanced notification mechanism would address change in conditions of wireless infrastructure
- Contributions I and II are configuration enhancements for TSN, and in this sense pertain to P802.1Qdj

Thank you!