Wired/Wireless Convergence for Factory IoT

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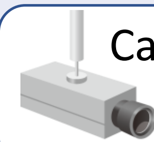
Scope of Presentation

- IEEE 802 Network Enhancements for the Next Decade Industry Connections Activity (ICA) will enable industry consensus building on the market/application requirements and identify gaps and trends not currently addressed by IEEE 802 standardization of new solutions.
- Factory IoT (or Automation) is one of promising spaces for ICA.

Usage	Network Density	System Complexity	Dominant Data Flow
Mobile, Home, Small office	Low	Independent system	Downstream
Large office, Conference room	High	Homogeneous system	Downstream
Factory, Warehouse, Shopping mall, Station, Airport, Stadium	**High**	**Multiple independent systems, Heterogeneous systems**	**Fragmented, Upstream**

Wireless Applications in Factories

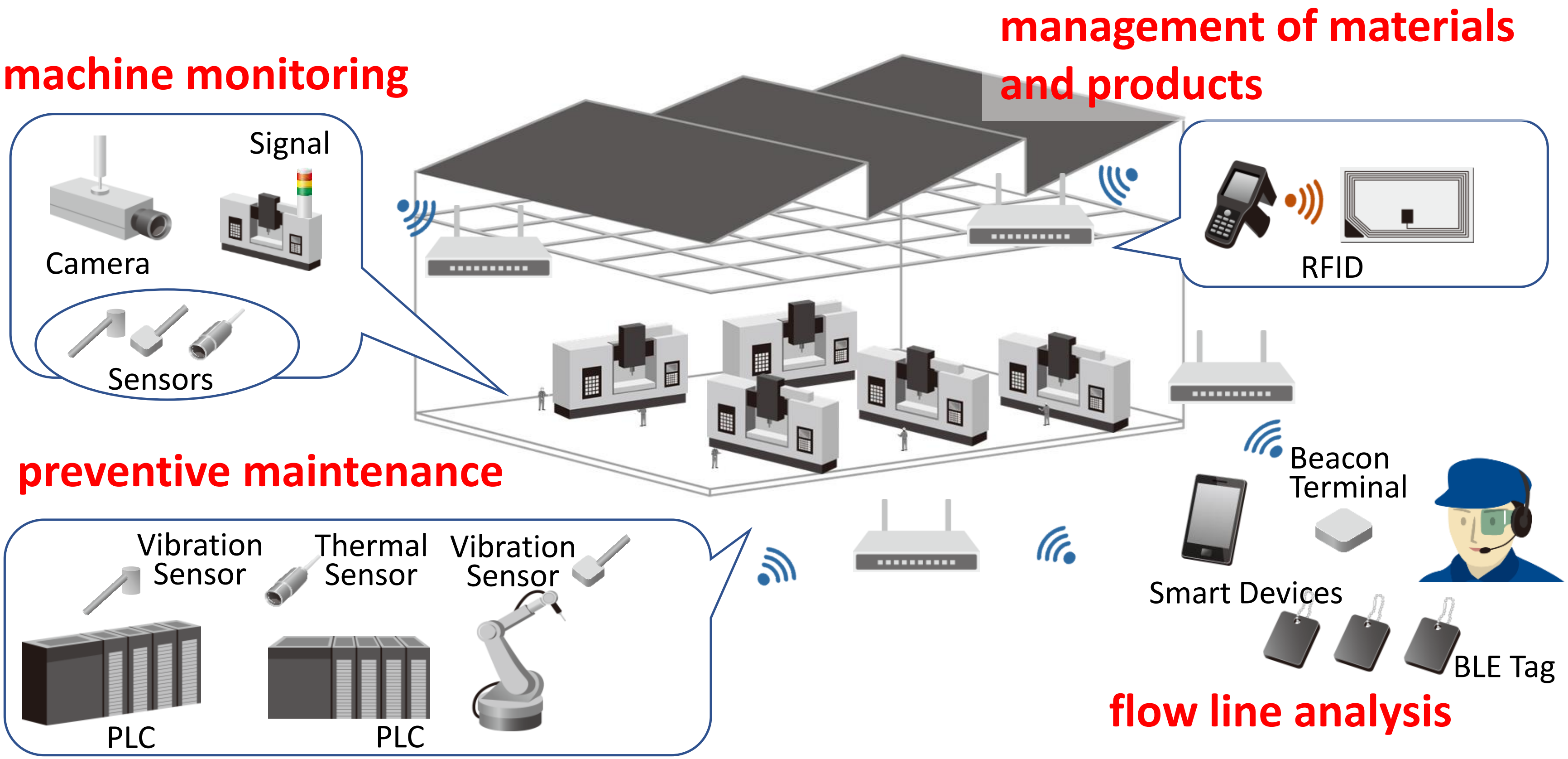
Category	Wireless Applications
Control	Machine, Robots
	AGV w/wo Rails
	Rotary Equipment
Quality	Inline Inspection, Pokayoke (notifying process failure or stop process)
	Machine Operation/Production Recoding
	Logging
Management	Preventive Maintenance for Tools and Machines
	Positioning, Motion Analysis, Inventory Control
	Facility Environment Control
Display	Work Instruction
	Andon (notifying quality or process problems to managers and workers)
Safety	Dangerous Behavior Detection
	Vital Sign Monitoring
	Emergency Warning



Source: Flexible Factory Project

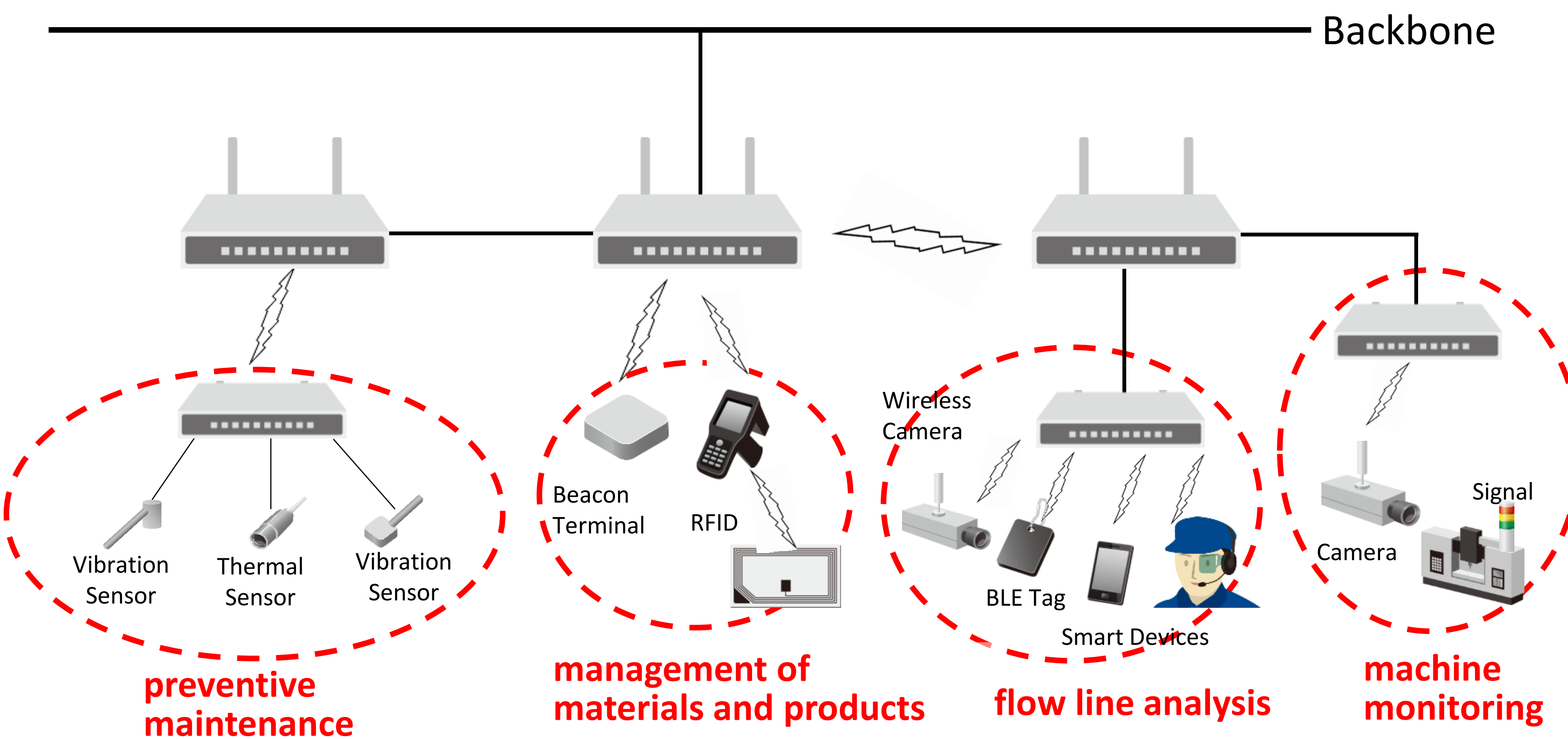
Example: Wireless Applications for Factory IoT

- A variety of applications are networked for management of production quality and resources, e.g. inspections, monitoring, and instructions with on-the-spot feedback.



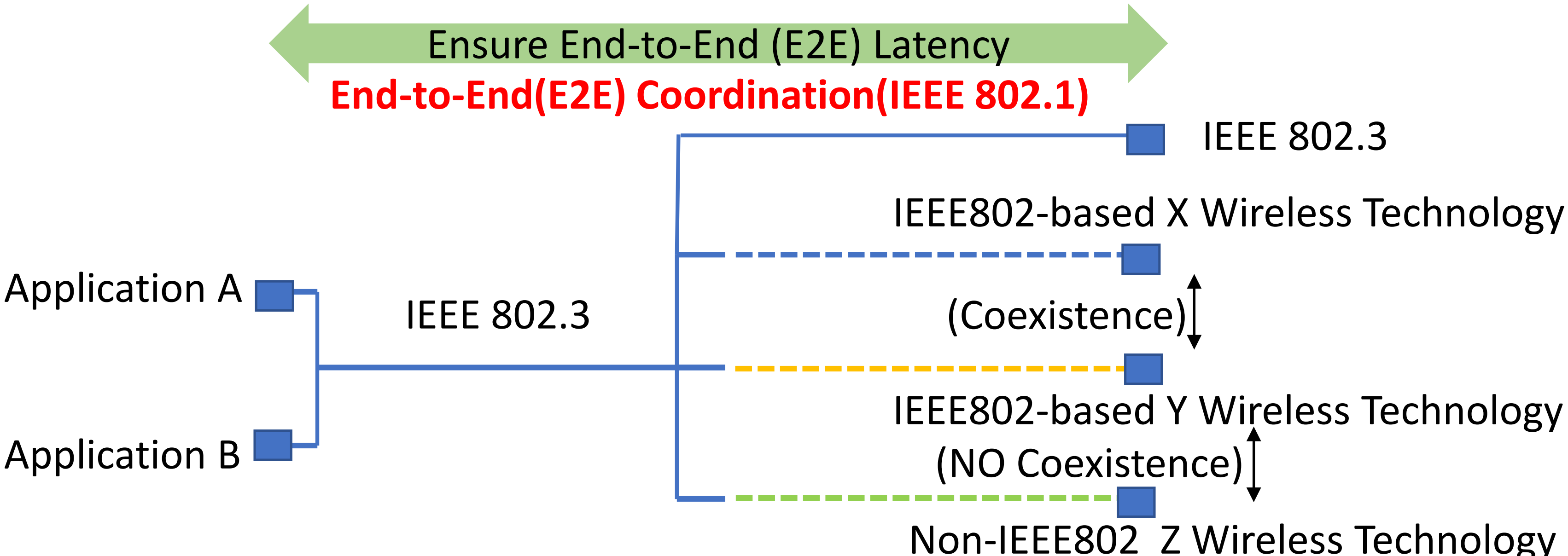
Example: Holistic View of Network for Factory IoT

- Wired and wireless links and bridging are mixed for each application.



Goal:E2E Network Topology for Factory IoT

- End-to-End (E2E) network topology for a factory today is configured by combination of wired LAN, such as 802.3, IEEE802-based and non-IEEE802 wireless technologies.
- In order for factory IoT system to work well under such network topology, data frame is treated in a mix of different technologies by high-level E2E coordination.



Observations

- Many functions of existing standards may be used effectively for the provision of low-latency, low-jitter, bandwidth reservation, and priority control in heterogeneous networks for factories as well.
  - ✓ Stream Reservation Protocol (SRP)/Multiple Stream Reservation Protocol (MSRP). [802.1Qat]
  - ✓ Forwarding and Queuing for Time-Sensitive Streams (FQTSS) [802.1Qav]
  - ✓ Generalized Precision Time Protocol (gPTP)[802.1AS]
  - ✓ Priority-based Flow Control (PFC) [802.1Qbb]
  - ✓ Congestion Notification (CN) [802.1Qbb]
  - ✓ Enhanced Transmission Selection (ETS) [802.1Qaz]
  - ✓ Access Categories (ACs) for Priority in EDCA [802.11e]
  - ✓ Quality-of-service Management Frame (QMF) [802.11ae]

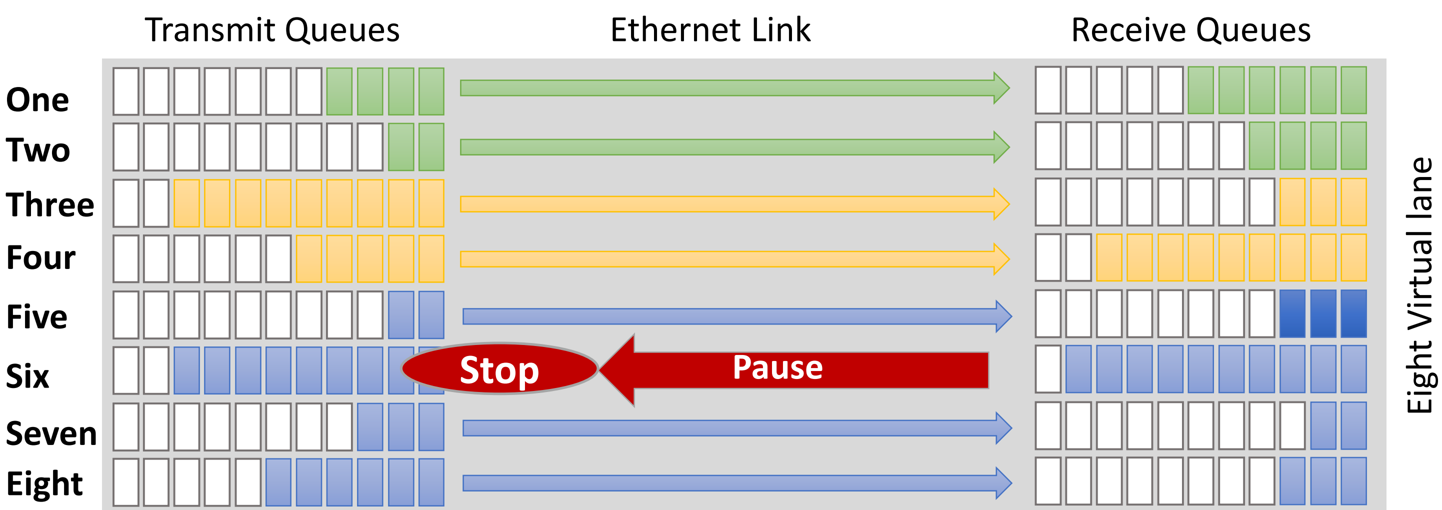
Features of Wireless Networks in Factories

- As we presented[1][2], several unique features of wireless commutations shall be considered for factories.
  - ✓ Available bandwidth is narrow and dynamically fluctuating with possible outage due to interference and/or fading compared to the case of the wired communication. The fading has random or burst-loss nature affected by radio propagation in spatial environment of a factory.
  - ✓ Congestion occurs caused by not only overloading of data streams at the nodes but also wireless link-quality deterioration.
  - ✓ Variety of data types with different priority-class should be involved. E.g., M2M-type data are sometimes periodical and short packets with low latency, which are transmitted from many sensors at a time.

[1] https://mentor.ieee.org/802.1/dcn/17/1-17-0003-00-ICne-wireless-communications-in-the-manufacturing-fields.pdf
[2] https://mentor.ieee.org/omniran/dcn/17/omniran-17-0057-00-00ic-how-we-see-needs-for-coordination.pdf

Example of PFC in IEEE 802.1Qbb

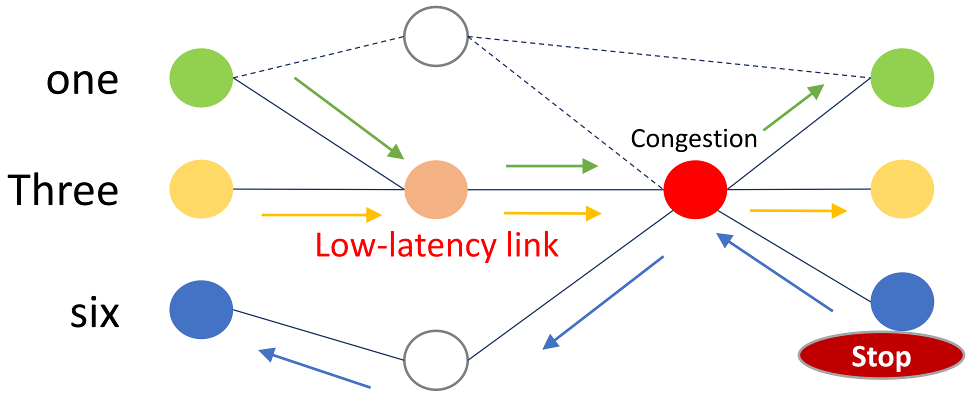
- Priority-based Flow Control（PFC）creates eight separate virtual links on the physical link. It enables pause based on user priorities or classes of service.
- What happens if wireless links are mixed in the virtual Ether link without coordination?



Pier to Pier Virtual Ether Link

Example to Come Short with Multi-hop links

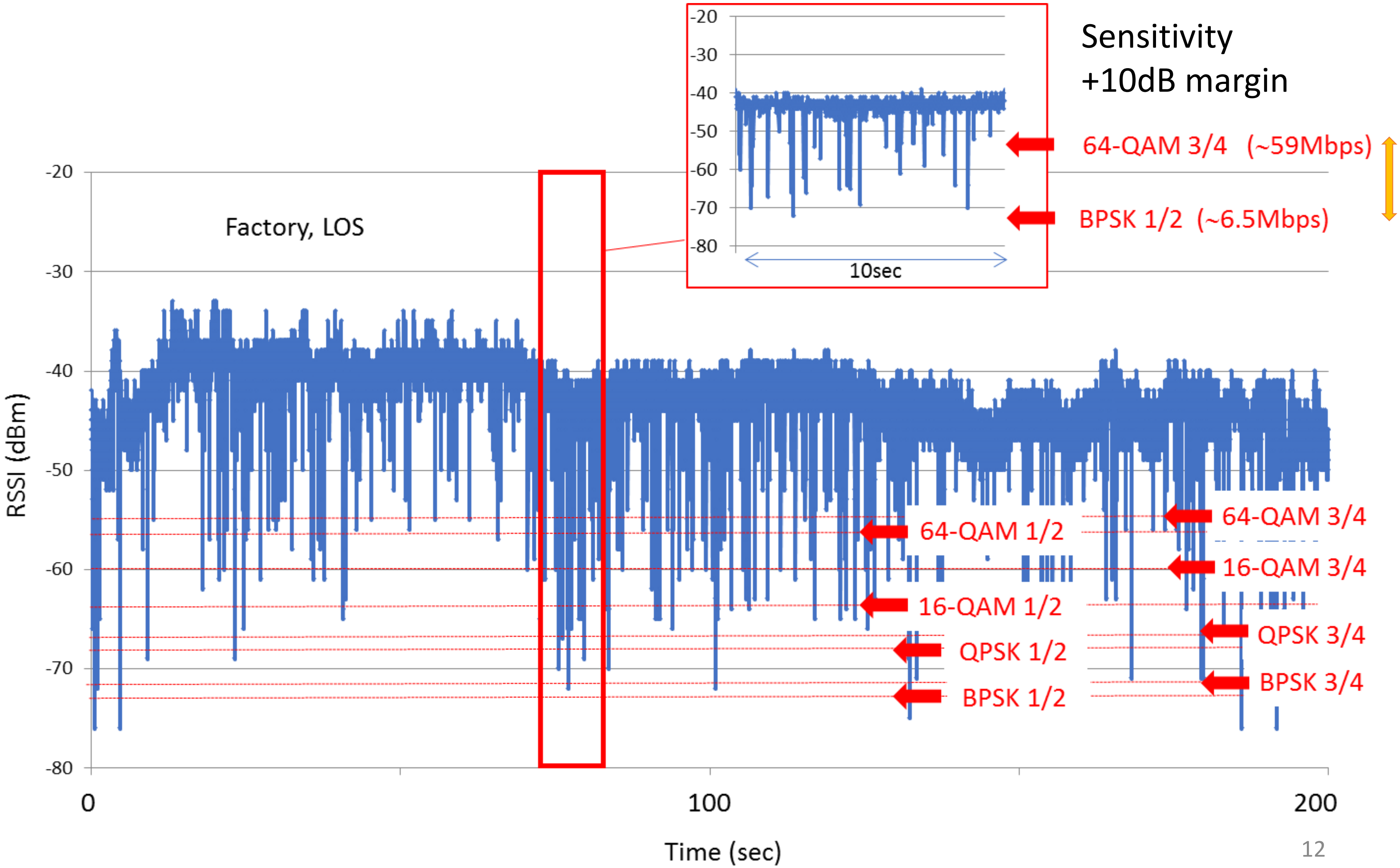
- Data streams rush into the physical link with the lowest latency regardless of actual bandwidth at that time.
- Unnecessary stopping/interruption may occur in some cases without dynamic load balance among physical links.
- The dynamic load balancing is not supported so far for wireless links adapted to narrow and fluctuating bandwidth.



<u>Physical</u> Network with Multi-hop Links

Data streams of "one" and "three" rush into the lowest-latency link that causes congestion. It results in stopping data stream of "six."

How Fast is the Rate of Bandwidth Fluctuation

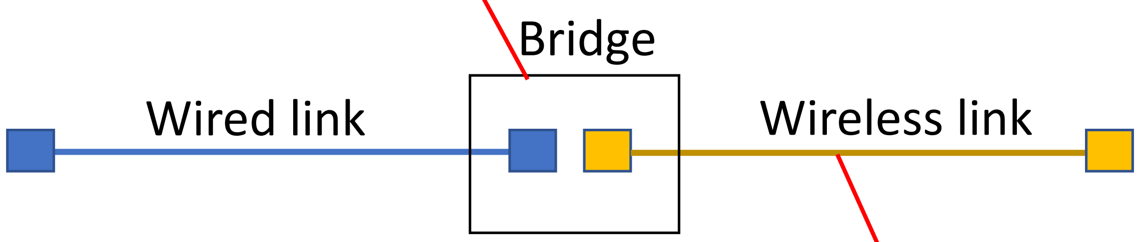


What are Essentials?

- For the physical network of wired/wireless links, unaffordable delay (or stopping data stream) may occur at the wired-wireless bridging with the wireless link.

Unpredictable data steam beyond bridging capacity

- Narrower and fluctuating bandwidth of the wireless link.
- Various types of data streams transmitted in factories .



Dynamic link quality deterioration of wireless link

- Random/burst fading in multipath-rich environments .
- Interference with noises from machines.
- Radio resources shared with other uncoordinated wireless systems.

Our Major Concerns for Networks in Factories

- Unpredictable data steam beyond bridging capacity.
  - ✓ Wireless links, which are characterized by variable delays and bandwidth change dynamically, may become bottlenecks in the virtual LANs. *Does the adaptive feature in the stream or flow control of 802.1Q still work well?*
  - ✓ With increasing types of data, *will QoS be relayed appropriately between the wired and the wireless bridging, e.g., with 802.1p and 802.11e?*
- Dynamic link quality deterioration of wireless link.
  - ✓ In case that the same frequency band is shared, different wireless links may be affected mutually. When links are established, then the corresponding bandwidth for each link is determined without coordination in current 802.1Q and 802.11 DCF/EDCA. *Can data stream be managed in the virtual LANs ?*

DCF: Distributed Coordination Function
EDCA: Enhanced Distributed Channel Access