Nendica Contribution

Technological Enhancement of Networking for Flexible Factory IoT

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Enhancements of IEEE 802 technologies for the future

Within factory networks, applications need to meet various requirements and provide QoS at application level. Different types of data flow between factory applications and network nodes, such as devices, access points, gateways, switches, bridges, and routers. To keep QoS across the factory network with priority control, data attributes are introduced at network nodes. Data attributes are defined based on the type of application and its corresponding requirements. These attributes are attached to the data field and mapped to appropriate traffic types. Setting data attributes for factory applications rather than extending traffic types is essential for backward compatibility to existing standards.

Coordination mechanism is required in order to ensure end-to-end QoS provisioning over the entire factory network in the brownfield where various facilities and equipment with different standards, of different generations, and by different vendors coexist. The following control functions over the wired/wireless network are anticipated for coordination purpose.

1. Data flow control across wireless nodes.
2. Frequency control forwarding data to wireless links with different path (or frequency channel).
3. Spatial control for wireless links, i.e. power and antenna directivity.

<u>**Network Scenario**</u>

Coordination is achieved by a coordinator managing the factory network. As illustrated in Figure a, the Bridge/AP of each local area network (LAN[1]) is deployed for a specific application. L2 data frames generated from the same LAN need to be forwarded with the same data attributes towards the same application server, and vice versa. The control policy could be provided by the coordinator for each LAN for the ease of implementation, rather than provided on individual device basis.

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[1] Covering both Basic Service Set (BSS) for AP and LAN segment for bridge.

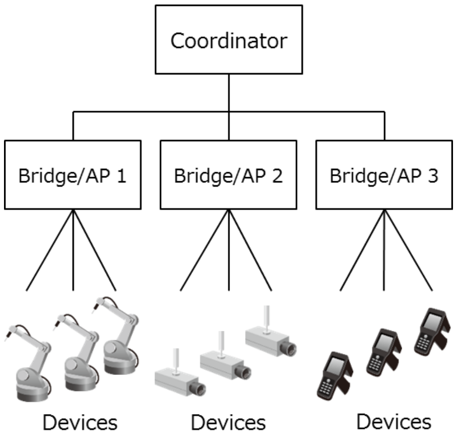

Figure a coordinator on the plain network scenario

A more flexible scenario is illustrated in Figure b, where each application needs to be supported across multiple Bridge/APs and a single Bridge/AP is serving multiple applications simultaneously. The data frames for the same application may be sourced from different LANs which could be aggregated and forwarded in bulk size. The control policy should be provided on the individual device basis and the policy template can be created according to application requirements.

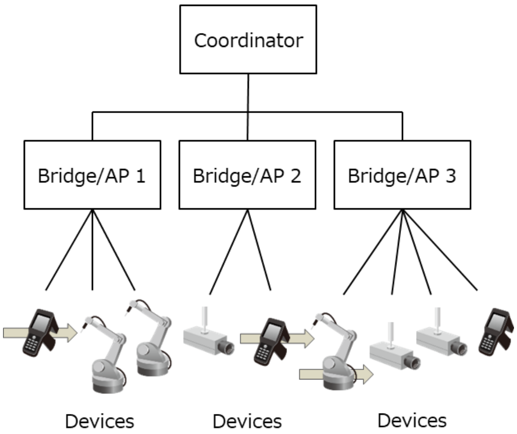

Figure b coordinator on the flexible network scenario

The coordinator cannot manage or configure each system locally and it does not have control over the changing wireless environment. However, it can set policies for transmission of application data in order to tolerate the degradation in the network due to these changes. Wireless link or path quality is changing rapidly (from milliseconds to seconds) due to multipath fading and shadowing in the closed environment of factories where human, product and material handling equipment e.g. forklift trucks and AGVs (automated guided vehicles) are moving. It is required to reserve minimum bandwidth for priority application by enhancing bridge functions, despite the degradation in the local link quality. Also for the purpose of reliability, queueing and forwarding mechanisms for redundancy need to be defined to use data attributes over bridges. The factory network has to ensure, assisted by coordinator functionalities, that bulk data transferred to wireless devices does not impact the transmission of the low-latency real-time messaging and streaming data.

For coordination and control of factory network made up of several tens systems tightly, huge network and computing resources would be required. Tight control directly conducted by the coordinator is impractical. This implies the necessity for hierarchical control consisting of (1) centralized coordinator which implements the global control for coordination of independent systems to satisfy requirements of each factory applications, and (2) the distributed coordination agent on each individual Bridge/AP which serves as local control for each system according to control policy. The control policy implies how radio resources of time, frequency, and space are utilized to optimize operation of entire network in a factory.

To realize the hierarchical control, more information need to be concentrated on local systems to operate autonomously with quick response. For this purpose, the following three items need to be defined.

A) Control policy: messages and interfaces between a coordinator and various systems.

B) Information on wireless environment: link/path quality.

C) Data attributes: common information including various requirements, bandwidth (or data size at an application level and data frequency), latency, affordability of packet loss. Traffic types expressed by three bits may not be sufficient for factory applications.

<u>Key to close the gap</u>

There are two approaches to realizing coordination depending on situations where single-standardized but decentralized and independent wireless systems coexist, and heterogonous wireless and wired systems coexist in the same space.

<u>Coordination of single-standardized but decentralized and independent wireless systems</u>

Technically, coordination of single-standardized system can work efficiently because a coordinator specifically directs frequency, timing and output to be used for each transmitter if each control sequences are defined in the standard.

Coordination of heterogonous wireless and wired systems

The control policy is exchanged vertically and may be left to individual vendor to implement. Information on wireless environment is handled within each system and may be a vendor specific matter. Data attributes are common information to be shared among systems provided by multiple vendors and need to be standardized for the brownfield of factory environment. In addition, data attributes may be extensionally defined, for example, by using Tag Protocol Identifier (TPID) and VLAN tag in std. 802.1Q-2014.

Besides common data attributes, a network reference model for flexible factory IoT network should be a generic representation which includes multiple network interfaces, multiple network access technologies, and multiple network subscriptions. The network reference model (NRM) in Draft Standard IEEE P802.1CF [4] is appropriate for this purpose and can be used to generalize the concept of coordinator and to explain how data attributes are managed as informative description as well. The minimum enhancement could be achieved by creating a factory profile consisting of the reference model and data attributes. Detail investigation is required if any protocols shall be added.

The aforementioned network scenarios in factory can be mapped to 802.1CF NRM as depicted in Figure c. Bridge/AP represents the node of attachment (NA) providing wired/wireless access through R1 to the terminals (devices). L2 data frames with common data attributes are aggregated and forwarded to the second level bridges, represented as backhaul (BH) through R6 datapath interface. The coordinator is located in the access network control (ANC) providing control policy to the underlay bridge/APs through R5 control interface[2].

[2] Refer to Clause 5 of Draft IEEE Standard P802.1CF for detailed information of network reference model (NRM).

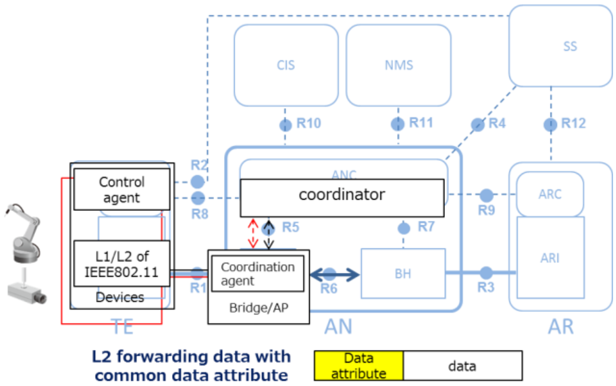

Figure c mapping factory network to 802.1CF NRM

The coordinator fitting well in the role of ANC provides enhancements to 802.1 protocols and procedures, e.g. SRP, for time sensitive applications. More complex TSN use cases benefit from the complete knowledge of streams in the network, especially for the one going through wireless medium, which is stored and processed by the coordinator.

In the case that accumulated latency cannot be guaranteed as promised due to e.g. radio fluctuation, the coordinator may respond quickly based on its knowledge of the global network resources and adjust parameter settings amongst all bridges/APs. Control policy shall be provided to keep sufficient radio resources for the short-term fluctuation and also be provided by the coordinator to re-allocate network resources adaptively to establish stable streams even on wireless medium. It ensures that the end-to-end QoS provided by the factory network meet the different requirements from the wide variety of factory applications.

Conclusions

A factory is called as brownfiled where various facilities and equipment with different standards, of different generations, and by different vendors, coexist in the same sites. There is also a variety of data from factory applications flowing into network nodes and data attributes attached to the data field that need to be introduced for priority control at each node. The hierarchical control consisting of global control for coordination of independent systems and distributed and local control for each system according to control policy is promising to adapt to short-term fluctuation of wireless link and to optimize wireless resources of entire network in a factory. Such operation is explained by network reference model to configure a flexible factory profile.

Two approaches to realizing coordination have been described depending on situations where single-standardized but decentralized and independent wireless systems coexist, and heterogonous wireless and wired systems coexist in the same space. Each of them will be efficient and both will be better to improve performance.