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Requirements for Reliable Wireless Industrial Services

Abstract

This document provides an overview on communication requirements for handling reliable wireless services within the context of industrial environments. The goal of the draft is to bring awareness to communication requirements of current and future wireless industrial services; how can they co-exist with wired infrastructures; key drivers for reliable wireless integration; relevant communication requirements to take into consideration; current and future challenges derived from the use of wireless.

Status of This Memo

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Table of Contents

1. Introduction

Within industrial environments, short-range wireless standards, such as IEEE 802.11ax, are gaining prominence as there exists an increasing need for flexibility in terms of infrastructure layout, of processes support. Wireless, and specifically Wireless Fidelity (Wi-Fi), is now reaching a maturity point where the available transmission rates become highly competitive in comparison to wired environments, thus increasing flexibility, providing a lower cost and higher availability in scenarios requiring, for instance, mobility support. There are, nonetheless, barriers to the integration of wireless in industrial environments. Firstly, being wireless a shared medium, it experiences challenges such as interference and signal strength variability depending on its surroundings. These features raise issues concerning critical services availability, resilience, and security support. Secondly, wireless relies on probabilistic Quality of Service (QoS) and therefore requires tuning to be able to support time-sensitive traffic with bounded latency, low jitter, zero congestion loss. However, the recent advancements of OFDMA-based wireless in the context of IEEE 802.11 standards such as 802.11ax and 802.11be bring in interesting features in the context of supporting critical industrial applications, e.g., a higher degree of flexibility in terms of resource management; frequency allocation aspects that can provide better traffic isolation, or even mechanisms that can assist a tighter time synchronization across wireless environments, thus providing the means to better support traffic in converged networks. Still, being able to address the communication challenges that exist in industrial domains require a better understanding of communication requirements that the existing and future industrial applications may attain. Hence, the focus of this draft is on discussing industrial application requirements, currently and for the future and how to best support time-sensitive applications and services within industrial converged networks. For that purpose, the draft debates on wireless industrial services collected from related normative and informational references on the industrial domain; debates on key drivers for the integration of wireless; debates on specific wireless mechanisms that may assist such integration and challenges thereof; and elaborates on specific requirements to observe both for current wireless services as well as for a subset of future industrial wireless services.

2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119]. In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying significance described in RFC 2119.

3. Definitions

* Latency (aka bounded latency), concerns the end-to-end transmission delay between a transmitter and a receiver, when a traffic flow is triggered by an application. By definition, latency corresponds to the time interval between sending the first packet of a flow from a source to a destination, until the instant of reception of the last packet of that flow.

* Periodicity stands for whether or not the data transmission is executed in a periodic fashion and whenever possible, the specific periodicity per unit of time has been specified.

* "Transmit data size" corresponds to the data payload in bytes.

* Tolerance to packet loss is presented as "0" (zero congestion loss); tolerant (the application has tolerance to packet loss). Packet loss occurs when packets fail to reach a specific destination on a network. Packet loss is usually measured as a percentage of packets loss in regards to the overall packets sent. In the context of deterministic networking and in particular, of Time-sensitive Networking (TSN), a packet is lost when it is not received within a specific deadline.

* "Time sync" refers to the need to ensure IEEE 1588 synchronization.

* "Node density" provides (wherever available) a glimpse into the number of end-nodes per 20mx20m.

4. Wireless Industrial Services Today

This section describes industrial applications where IEEE 802.11 is already being applied, derived from an analysis of related work.

Industrial wireless services focused on the strengthening of industrial manufacturing environments have been intensively documented via the IEEE Nendica group [NENDICA], the Internet Industrial Consortium [IIC], the OPC FLC working group [OPCFLC]. The IEEE Nendica 2020 report [NENDICA] comprises several end-to-end use-cases and a technical analysis of the identified features and functions supported via wireless/wired deterministic environments. Based on surveys to industry, the report provides a first characterization of wireless services in factories (Wi-Fi 5), characterizing the scenarios in terms of aspects such as as payload size in bytes, communication rate, arrival time tolerance, node density.

The IEEE 802.11 RTA report [IEEERTA] provides additional input concerning the support of wireless for time-sensitive and real-time applications. For each category of application, the report provides a description, basic information concerning topology and packet flow/traffic model, summarizing the problem statement (main challenges). The industrial applications in this report are a subset and have also considered sources such as IEEE Nendica, IEC/IEEE 60802 Use-cases, as well as 3GPP TR 22.804. The report aggregates the different services in 3 classes (A,B,C) and provides communication requirements for each class categorized as: bounded latency (worst-case one-way latency measured at the application layer); reliability (defined as the percentage of packets expected to be received within the latency bound); time synchronization needs (in the order of micro/milliseconds); throughput needs (high, moderate, low). The report concludes with guidelines concerning implementation aspects, e.g., traffic classification aspects and new capabilities to support real-time applications.

The Avnu Alliance provides a white paper describing steps for the integration of TSN over WiFi [AVNU2020], briefly describing the integration of Wi-Fi in specific applications such as: closed loop control, mobile robots, power grid control, professional Audio/Video, gaming, AR/VR. The document also raises awareness to the possibility of wireless replacing or being complementary to wired within connected cabines, i.e., in regards to the wiring harness within vehicles (cars, airplanes, trains), which are currently expensive and which require a complex onboarding. Wireless can assist in lowering the costs, if it can be adapted to the critical latency, safety requirements and regulations. Such cases would require 100 micosecond level cycles, according to Avnu. The communication requirements are summarised in terms of whether or not IEEE 1588 synchronisation is required; the typical packet size (data payload); bounded latency; reliability.

Manufacturing wireless use-cases have also been debated in the context of 5G ACIA [ACIA], NICT [NICT], and IETF Deterministic Networking [RFC8578]. These sources provide an overview on user stories, and debate on the challenges brought by the integration of wireless. However, communication requirements are not presented in a systematic way. Lastly, the IETF RAW working group has an active draft which provides an initial overview on the challenges of wireless industrial use-cases [IETFRAW-USECASES].

Derived from the analysis of the aforementioned sources, this section provides a description of categories of applications, and respective communication requirements. The following categories of applications are addressed:

*Equipment and process control.

*Quality supervision.

*Factory resource management.

*Display.

*Human safety.

*Industrial systems.

*Mobile robots.

*Drones/UAV control.

*Power grid control.

*Communication-based train networks.

*Mining industry.

*Connected cabin.

The selected communication requirements and which are presented for each category of applications have been extracted from the different available related work. The parameters are: bounded latency; periodicity; transmit data size; tolerance to packet loss; time synchronization needs; node density characterization.

4.1. Equipment and Process Control Services

This category of industrial wireless services refers to the data exchange required to send, for instance, commands to mobile robots/ vehicles, production equipment, and also to receive status information. Reasons for wireless integration concern: flexibility of deployment, reconfigurability, mobility, maintenance cost reduction.

In this category, examples of applications and respective communication requirements are:

*Control of machines and robots.

-Bounded latency: below 10 ms.

-Periodic.

-Transmit data size (bytes): 10-400 (small).

-Tolerance to packet loss: 0.

-Time synchronization: IEEE 1588.

-Node density: 1 to 20 (per 20mx20m area).

*AGVs with rails

-Bounded latency: 10 ms-100ms.

-Periodic, once per minute.

-Transmit data size (bytes): 10-400 (small).

-Tolerance to packet loss: 0.

-Time synchronization: IEEE 1588.

-Node density: 1 to 20 (per 20mx20m area).

*AGVs without rails

-Bounded latency:1 s.

-Periodic, once per minute.

-Transmit data size (bytes): 10-400 (small).

-Tolerance to packet loss: 0.

-Time synchronization: IEEE 1588.

-Node density: 1 to 20 (per 20mx20m area).

*Hard-real time isochronous control, motion control

-Bounded latency: 250us - 1ms.

-Periodic.

-Transmit data size (bytes): 10-400 (small).

-Tolerance to packet loss: 0.

-Time synchronization: IEEE 1588.

-Node density: 1 to 20 (per 20mx20m area).

*Printing, packaging

-Bounded latency: below 2 ms.

-Transmit data size (bytes): 10-400 (small).

-Tolerance to packet loss: 0.

-Time synchronization: IEEE 1588.

-Node density: over 50 to 100.

*PLC to PLC communication

-Bounded latency: 100 us-50 ms.

-Transmit data size (bytes): 100-700.

-Tolerance to packet loss: 0.

-Time synchronization: IEEE 1588.

*Interactive video

-Bounded latency: 50 -10 ms.

-Time synchronization: 10-1[micro]s.

*Mobile robotics

-Bounded latency: 50 -10 ms.

*AR/VR, remote HMI

-Bounded latency: 10 - 1 ms.

-Time synchronization: ~1 [micro]s.

-Time synchronization: 10-1[micro]s.

*Machine, production line controls

-Bounded latency: 10 - 1 ms.

4.2. Quality Supervision Services

Quality supervision comprises industrial services that collect and assess information related to products and states of machines during production. Reasons for wireless integration concern: flexibility of deployment, maintenance cost reduction.

Examples of applications in this category, and their communication requirements are:

*Inline inspection

-Bounded latency: bellow 10ms.

-Time synchronization: 10-1[micro]s.

-Periodic, once per second.

-Transmit data size (bytes): 64-1M.

-Tolerance to packet loss: 0.

-Node density: 1-10 (per 20mx20m).

*Machine operation recording

-Bounded latency: over 100 s.

-Time synchronization: 10-1[micro]s.

-Periodic, once per second.

-Transmit data size (bytes): 64-1M.

-Tolerance to packet loss: 0.

-Node density: 1-10 (per 20mx20m).

*Logging

-Bounded latency: over 100s.

-Time synchronization: 10-1[micro]s.

-Transmit data size (bytes): 64-1M.

-Tolerance to packet loss: 0.

-Node density: 1-10 (per 20mx20m).

4.3. Factory Resource Management Services

Refers to capturing information about whether production is proceeding under proper environmental conditions, and whether staff and devices contributing to productivity enhancement are being managed appropriately. Reasons for wireless integration concern: flexibility of deployment, reconfigurability, maintenance cost reduction.

Services debated in this context are:

*Machine monitoring

-Bounded latency: 100ms-10s.

-Periodic.

-Time synchronization: 10-1[micro]s.

-Transmit data size (bytes): 10-10M.

-Tolerance to packet loss: 0.

-Node density: 1-30.

*Preventive maintenance

-Bounded latency: over 100ms.

-Periodic, once per event.

*Positioning, motion analysis

-Bounded latency: 50ms-10s.

-Periodic, once per second.

*Inventory control

-Bounded latency: 50ms-10s.

-Periodic, once per second.

*Facility control environment

-Bounded latency: 1s-50s.

-Periodic, once per minute.

*Checking status of material, small equipment

-Bounded latency: 100ms-1s.

-Sporadic, 1 to 10 times per 30 minutes.

4.4. Display Services

This category of services targets workers, allowing them to receive requested support information. It also targets managers in regards to monitoring of production status and processes. Reasons for wireless integration are: scalability, flexibility of deployment, mobility support. Examples of services are:

*Work commands, e.g., wearable displays

-Bounded latency: 1-10s.

-Sporadic, once per 10s-1m.

-Transmit data size (bytes): 10-6K.

-Tolerance to packet loss: yes.

-Node density: 1-30

*Display information

-Bounded latency: 10s.

-Sporadic, once per hour.

-Transmit data size (bytes): 10-6K.

-Tolerance to packet loss: yes.

-Node density: 1-30.

*Supporting maintenance (video, audio)

-Bounded latency: 500ms.

-Sporadic, once per 100ms.

-Transmit data size (bytes): 10-6K.

-Tolerance to packet loss: yes.

-Node density: 1-30.

4.5. Human Safety Services

Refers to industrial wireless services that concern collecting data to infer about potential dangers to workers in industrial environments. The need for wireless integration concerns: support for pervasive deployment; mobility.

Examples of services are:

*Detection of dangerous situations/operations

-Bounded latency: 1s.

-Periodic, 10 per second (10 fps).

-Transmit data size (bytes): 2-100K.

-Tolerance to packet loss: yes.

-Node density: 1-50.

*Vital sign monitoring, dangerous behaviour detection

-Bounded latency: 1s-50s.

-Periodic, once per minute.

-Transmit data size (bytes): 2-100K.

-Tolerance to packet loss: 0.

-Node density: 1-30.

4.6. Mobile Robotics Services

Refers to services that support the communication between robots, e.g., task sharing; guidance control including data processing, AV, alerts. Reasons to consider wireless integration are: the need to support mobility and reconfigurability.

*Video operated remote control

-Bounded latency: 10-100ms.

-Transmit data size (bytes): 15-150K.

-Tolerance to packet loss: yes.

-Node density: 2-100.

*Assembly of robots or milling machines

-Bounded latency: 4-8ms.

-Transmit data size (bytes): 40-250.

-Tolerance to packet loss: yes.

-Node density: 2-100.

*Operation of mobile cranes

-Bounded latency: 12ms.

-Periodic, once per 2-5ms.

-Transmit data size (bytes): 40-250.

-Tolerance to packet loss: yes.

-Node density: 2-100.

*Drone/UAV air monitoring

-Bounded latency: 100ms.

-Tolerance to packet loss: yes.

4.7. Power Grid Control

Power grid control concerns services that support communication links for predictive maintenance and to isolate faults on high voltage lines, transformers, reactors, etc. Reasons to integrate wireless concern: wire replacement maintenance cost reduction.

*Bounded latency: 1-10ms.

*Transmit data size (bytes): 20-50.

*Time synchronization: IEEE 1588.

*Tolerance to packet loss: yes.

*Node density: 2-100.

4.8. Wireless Avionics Intra-communication

Wireless integration is also relevant to industrial environments in the context of replacing cabling. Within the context of avionics [AVIONICS], *Wireless Avionics Intra-communication (WAIC)* systems [WAIC] are expected to significantly benefit from determinist communications, given their higher criticality. For instance, flight control systems, integrating a large number of endpoints (sensors and actuators), require high reliability and bounded latency to assist in estimating and controlling the state of the aircraft. Real-time data needs to be delivered with strict deadlines for most control systems.

The WAIC standardization process is still ongoing, without a clear indication about the frequencies that would be reserved for such systems, although the frequency band 4.2 GHz to 4.4 GHz is the one that currently seems most popular. Nevertheless, independently of the allocated frequency bands, the determinisc guarantees required by WAIC services may be achieved by means of the integration of functionality developed in current wireless standards.

However, the following requirements are expected to be supported by wireless technology in order to ensure the deterministic operation of WAIC systems:

*Must provide deterministic behaviour in short radio ranges (< 100m).

*Must use low transmit power levels for low rate (10mW) and high rate (50mW) applications.

*Must ensure good system reconfigurability.

*Must support dissimilar redundancy.

In terms of potential KPIs, specific communication requirements can be identified:

* Latency: 20-40ms [PARK2020].

* Packet payload: small (e.g., 50 bytes) and variable bit rate [PARK2020].

* Support between 125 to 4150 nodes [AVIONICS].

* Maximum distance between transmitter and receiver: 15m [AVIONICS].

* Aggregate average data rate of network (kbit/s): 394 to 18385 [AVIONICS].

* Latency: below 5s for High data rate Inside (HI) applications [AVIONICS].

* Jitter: below 50ms for HI applications [AVIONICS].

As an example of current standards that may support the deterministic requirements of WAIC system, we can point to IEEE 802.11ax, which is being devised to operate between 1 and 7GHz (in addition to 2.4 GHz and 5GHz). The WAIC requirement for high reliability and bounded latency may be supported by 802.11ax capability of dividing the spectrum in frequency resource units (RUs), which are assigned to stations for reception and transmission by a central coordinating entity, the wireless Access Point. Reliability can be achieved by assigning more than one RU to the same station, for instance (an aspect that is not covered by IEEE 802.11ax but already under discussion for IEEE 802.11be). Through the central scheduling of the RUs contention overhead can be avoided, which increases efficiency in scenarios of dense deployments as is the case of WAIC applications. In this context, OFDMA and the concept of spatial reuse is relevant, to assist large-scale simultaneous transmission, while at the same time preventing collision and interference, and guaranteeing high throughput [ROBOTS1].

5. Additional Reliable Wireless Industrial Services

This section provides examples of additional wireless industrial services. We have specifically selected three different examples of such use-cases: i) remote AR/VR for maintenance and control; ii) decentralized shop-floor communication and iii) wireless cabin intra-communications. Based on these examples, wireless integration recommendations are debated and a list of specific requirements is provided.

5.1. AR/VR Services within Flexible Factories

5.1.1. Description

While Video is today integrated both into industrial automation systems, and also used with the shop-floor to assist the worker, the integration of AR/VR in the shop-floor in industrial environments is still in the beginning. It is, however, being applied within the electric industry as a way to improve productivity and safety of workers, also overlaying real-time metadata over equipment under maintenance or operation.

In this context, it is important to ensure that the AR/AV traffic does not interfere with the critical traffic of the production system, i.e., performance characteristics like latency and jitter for the critical traffic shall be independent from disturbances. Moreover, it is also important to provide the AR/VR application with low latency, also in the verge of mobility.

5.1.2. Wireless Integration Recommendations

The support of AR/AV in the context of remote maintenance environments is bound to increase within industrial environments, given the relevancy in terms of remote maintenance and equipment operations. It is also relevant to consider its use within the context of worker safety and it can be foreseen that AV-based remote maintenance will, in the future, be supported via mobile devices carried by workers on the go. Wireless is therefore a key communication asset for this type of applications. In terms of traffic in a converged network, AR/AV is a bandwidth intensive real-time service. It therefore requires specific handling (other than Best Effort, BE). Moreover, the AR/AV traffic flows must not create disturbance when transmitted via wireless. Hence, traffic isolation is an important aspect to ensure for this type of traffic profile.

A third aspect to address in the future concerns the fact that there will most likely be the need to support multiple AR/AV streams from different end-users within a single Wireless Local Area Network (WLAN), thus increasing the need for traffic isolation. A fourth aspect concerns the fact that VR systems, if not adequately support, result in VR sickness. Specific network and non-network requirements have already been identified by IEEE 802, MPEG, 3GPP. Such requirements contemplate, for instance, support of higher frame rates, reducing the motion-to-photon latency, higher data transmission rates, low jitter, etc.

5.1.3. Requirements Considerations

In such applications, to ensure minimum interference, a few aspects need to be ensured:

* The AR/AV traffic needs to be isolated in order to prevent interference, i.e., it SHOULD have a specific CoS assigned (downlink and uplink).

* Between wireless devices (stations) and AP, there is the need to ensure that the AR/AV traffic is handled in a way that does not hinder critical traffic.

* Low mobility SHOULD be supported.

* Multiple user support SHOULD be provided.

* VR sickness MUST be prevented [IEEERTA].

* A tight integration of the AR/VR systems with production systems SHOULD be address in way compatible with the deterministic wired infrastructure. For instance, Audio Video Bridging (AVB) in the wired TSN infrastructure. Specifically, AVB is usually blocked by the time-aware shaper, and impacted by: TAS, CBS, FIFO and FPNS (fixed priority non-preemptive scheduling).

* A software-based mechanism on the AP SHOULD support an adequate mapping of CoS to the wireless QoS (e.g., EDCA UPs).

* MAC layer contention MUST be mitigated for all wireless stations within the area (within the range of the same AP or not).

Specific communication requirements:

* Latency: 3-10ms [IEEERTA].

* Bandwidth, 0.1-2Gbps [IEEERTA].

* Data payload, over 4Kbytes [IEEERTA].

5.2. Decentralized Shop-floor Communication Services

5.2.1. Description

The increasing automation of industrial environments implies an increase in the number of integrated nodes, including mobile nodes. Wireless is, for instance, a key driver for scenarios involving mobile vehicles [NICT]. NICT also describes already production environments, in particular environments with elevated temperatures, where wireless communication is used to support safety of workers and to remotely monitor production status. Such environments comprise different applications (e.g., safety of workers, mobile robots, factory resource management) and debate on the interconnection of different wireless technologies and devices, from PLCs, to autonomous mobile robots, e.g., UAVs, AGVs. Wireless/wired integration mechanisms have also been debated in the cost of self-organizing production lines [DIETRICH2018]. Therefore, the notion of flexible and heterogeneous shop-floor communication is already present in industrial environments, based on hybrid wired/wireless systems and the integration of multi-AP environments.

5.2.2. Wireless Integration Recommendations

Prior related work debates on centralized communication architectures (infrastructure mode), and for this case, the issue of connectivity is usually circumvented via multiple AP coordination mechanisms. Within the context of multi-AP coordination and assuming TDMA-based communication, a well-organized schedule can prevent collisions [FERN2019]. Hence, for this specific type of scenario, the main issue concerns handling handovers in a timely and precise way, capable of providing deterministic guarantees. However, with an increase on the number of nodes on a shop-floor, connectivity issues become more complex.

Therefore, it is relevant to explore also the possibility of a "decentralized" approach to shop-floor communication, considering both mobile and static nodes. In this case, and from a topology perspective, wireless industrial services are expected to be provided over both ad-hoc and infrastructure mode. Within the ad-hoc communication areas, there is control-based traffic integrated with sensing (critical, non-critical), with real-time traffic, as well as time-triggered traffic. Each node is responsible for managing its access to the medium, thus requiring a cooperative protocol approach.

5.2.3. Requirements Considerations

In such environment, connectivity becomes more complex requiring additional support:

* A wider variety of traffic profiles MUST be supported, thus increasing the management complexity.

* Devices communicating via ad-hoc mode MUST integrate a collaborative communication approach, e.g., relaying, cluster-based scheduling approach.

* Low mobility MUST be supported (e.g., up to 2 m/s within a BSS).

* Multi-AP coordination MUST still be integrated.

*Frequent handover MUST be supported, ideally with a make-before-break approach.

*Neighbor detection and coverage problem detection MUST be implemented in ad-hoc nodes.

Specific communication requirements: * Latency: 20-40ms [ROBOTS1]. * Packet payload: small (e.g., 50 bytes) and variable bit rate [ROBOTS1].

5.3. Autonomous Airborne Services

Description

Over the last decade several services emerged that rely on the autonomous (total or partial) operation of airborne systems. Examples of such systems are: logistic drones; swarm of drones (e.g. for surveillance); urban Air Mobility [UAM18]; single Pilot operation of commercial aircrafts [BBN8436].

Such autonomous airborne systems rely on advances in communications, navigation, and air traffic management to mitigate the significant workload of autonomous operations, namely by means of air-ground collaborative decision making. Such decision making processes rely on expanding the role of ground operators, including tactical (re-routing) and emergency flight phases, as well as higher levels of decision support including systems monitoring in real-time.

Such air-ground collaborative decision making process can only be possible with the support of a reliable wireless network able to assist in the required data exchange (of different types of traffic) within significant constraints in terms of delay and error avoidance.

5.3.1. Wireless Integration Recommendations

Independently of the type of application (logistics, surveillance, urban air mobility, single pilot operation), an autonomous airborne system can be models as a multi-agent system, in which agents need to use a wireless network to communicate reliably between them and in possible with a control entity. The nature and position of such agentes differ from application to application. For instance, all agents may be collocated in the same or different flying vehicles.

A high-performance and reliable wireless network has an important role in meeting the challenges of autonomous airborne systems, such as coordination and collaboration strategies, control mechanisms, and mission planning algorithms. Hence, wireless technologies plan a central role in the creation of the needed networking system, including air-to-air communications (single or multi-hop) but air-to-ground communications.

Air-to-air communications allow all airborne agents to establish efficient communication, allowing the reception of error prune data exchanged within the required time frames. For instance, in a swarm drones can either communicate with each other directly, or indirectly by constructing multi-hop communication paths with other drones.

In what concerns air-to-ground communications, airborne agents communicate with a control center, such as a ground station, to obtain real-time updated information (e.g. mission related). Air-to-ground communication is usually direct communication.

The air-to-air and air-to-ground communications are combined through a communication architecture, which can be of different types. In small autonomous systems (single drones used for logistics), a central control station is deployed with enough powerf to communicate with the drone. In autonomous systems with a large number of agents, a decentralized approach should be used.

5.3.2. Requirements Considerations

When analysing the major properties of wireless communication architectures, the first priority should go to requirements of high coverage and maintaining connectivity. The former plays an important role in gathering the information needed for the operation of the autonomous system, while maintaining connectivity ensures the real-time communication within the system.

However, autonomous systems may operate in unknown environments, with the unpredicted appearance of threats and obstacles in time and space. Hence such systems should rely on wireless technology that has a high level of reliability and availability. For instance, wireless technology that is able to keep two neighbour agents connected, even when their direct link drops below the required minimum signal-to-noise ratio (SNR) or receive signal strength indicators (RSSI) range. On a system level, wireless network technologies, such as routing, should be able to react cognitively to changes of the environment to adapt the communication system in order to ensure the needed coverage and connectivity levels.

In this sense it is required the investigation of routing protocols able to ensure the desirable level or reliability and availability of complete system. This means that the wireless routing function should fulfill a set of requirements, including: * Suitable for dynamic topologies. * Scalable with the number of networked agents. * Ensure low values of packet delays (KPI depends upon the specific application). * Ensure high values of packet delivery (KPI depends upon the specific application). * Ensure fast recovery in the presence of interrupted communications. * Ensure low cost in terms of the utilization of network resources (e.g. network queues, transmission opportunities). * Ensure high robustness to link failure.

6. Security Considerations

This document describes industrial application communication requirements for the integration of reliable Wi-Fi technologies. The different applications have security considerations which have been described in the respective sources [IEEERTA], [NICT], [IIC], [AVNU2020], [ACIA].

7. IANA Considerations

This document has no IANA actions.

8. Acknowledgments

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