



**HAL**  
open science

## RAW use cases

Georgios Papadopoulos, Pascal Thubert, Fabrice Theoleyre, C. J. Bernardos

► **To cite this version:**

Georgios Papadopoulos, Pascal Thubert, Fabrice Theoleyre, C. J. Bernardos. RAW use cases. [0] draft-bernardos-raw-use-cases-00, IETF. 2019. hal-02347735v1

**HAL Id: hal-02347735**

**<https://hal.science/hal-02347735v1>**

Submitted on 5 Nov 2019 (v1), last revised 7 May 2020 (v3)

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

RAW  
Internet-Draft  
Intended status: Standards Track  
Expires: January 6, 2020

G. Papadopoulos  
IMT Atlantique  
P. Thubert  
Cisco  
F. Theoleyre  
CNRS  
CJ. Bernardos  
UC3M  
July 5, 2019

RAW use cases  
draft-bernardos-raw-use-cases-00

Abstract

The wireless medium presents significant specific challenges to achieve properties similar to those of wired deterministic networks. At the same time, a number of use cases cannot be solved with wires and justify the extra effort of going wireless. This document presents deterministic wireless use cases, in continuation to the DetNet Use Cases document.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of [BCP 78](#) and [BCP 79](#).

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <https://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on January 6, 2020.

Copyright Notice

Copyright (c) 2019 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to [BCP 78](#) and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of

publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

## Table of Contents

1. Introduction . . . . .	3
2. Amusement Parks . . . . .	4
2.1. Use Case Description . . . . .	4
2.2. Specificities . . . . .	5
2.3. The Need for Wireless . . . . .	6
2.4. Requirements for RAW . . . . .	6
3. Wireless for Industrial Applications . . . . .	7
3.1. Use Case Description . . . . .	7
3.2. Specificities . . . . .	7
3.2.1. Control Loops . . . . .	7
3.2.2. Unmeasured Data . . . . .	7
3.3. The Need for Wireless . . . . .	8
3.4. Requirements for RAW . . . . .	8
4. Pro Audio and Video . . . . .	9
4.1. Use Case Description . . . . .	9
4.2. Specificities . . . . .	9
4.2.1. Uninterrupted Stream Playback . . . . .	9
4.2.2. Synchronized Stream Playback . . . . .	9
4.3. The Need for Wireless . . . . .	10
4.4. Requirements for RAW . . . . .	10
5. Gaming . . . . .	10
5.1. Use Case Description . . . . .	10
5.2. Specificities . . . . .	11
5.3. The Need for Wireless . . . . .	11
5.4. Requirements for RAW . . . . .	11
6. UAV platooning and control . . . . .	12
6.1. Use Case Description . . . . .	12
6.2. Specificities . . . . .	12
6.3. The Need for Wireless . . . . .	12
6.4. Requirements for RAW . . . . .	13
7. Edge Robotics control . . . . .	13
7.1. Use Case Description . . . . .	13
7.2. Specificities . . . . .	14
7.3. The Need for Wireless . . . . .	14
7.4. Requirements for RAW . . . . .	14
8. IANA Considerations . . . . .	14
9. Security Considerations . . . . .	14
10. Informative References . . . . .	14
Authors' Addresses . . . . .	16

## 1. Introduction

Based on time, resource reservation, and policy enforcement by distributed shapers, Deterministic Networking provides the capability to carry specified unicast or multicast data streams for real-time applications with extremely low data loss rates and bounded latency, so as to support time-sensitive and mission-critical applications on a converged enterprise infrastructure.

Deterministic Networking in the IP world is an attempt to eliminate packet loss for a committed bandwidth while ensuring a worst case end-to-end latency, regardless of the network conditions and across technologies. It can be seen as a set of new Quality of Service (QoS) guarantees of worst-case delivery. IP networks become more deterministic when the effects of statistical multiplexing (jitter and collision loss) are mostly eliminated. This requires a tight control of the physical resources to maintain the amount of traffic within the physical capabilities of the underlying technology, e.g., by the use of time-shared resources (bandwidth and buffers) per circuit, and/or by shaping and/or scheduling the packets at every hop.

Key attributes of Deterministic Networking include:

- o time synchronization on all the nodes,
- o centralized computation of network-wide deterministic paths,
- o multi-technology path with co-channel interference minimization,
- o frame preemption and guard time mechanisms to ensure a worst-case delay, and
- o new traffic shapers within and at the edge to protect the network.

Wireless operates on a shared medium, and transmissions cannot be fully deterministic due to uncontrolled interferences, including self-induced multipath fading. Scheduling transmissions enables to alleviate those effects by leveraging diversity in the spatial, time and frequency domains, enabling Reliable and Available Wireless (RAW).

The wireless and wired media are fundamentally different at the physical level, and while the generic Problem Statement [[RFC8557](#)] for DetNet applies to the wired as well as the wireless medium, the methods to achieve RAW necessarily differ from those used to support Time-Sensitive Networking over wires.

So far, Open Standards for Deterministic Networking have prevalently been focused on wired media, with Audio/Video Bridging (AVB) and Time Sensitive Networking (TSN) at the IEEE and DetNet [[I-D.ietf-detnet-architecture](#)] at the IETF. But wires cannot be used in a number of cases, including mobile or rotating devices, rehabilitated industrial buildings, wearable or in-body sensory devices, vehicle automation and multiplayer gaming.

Purpose-built wireless technologies such as [[ISA100](#)], which incorporates IPv6, were developed and deployed to cope for the lack of open standards, but they yield a high cost in OPEX and CAPEX and are limited to very few industries, e.g., process control, concert instruments or racing.

This is now changing:

- o IMT-2020 has recognized Ultra-Reliable Low-Latency Communication (URLLC) as a key functionality for the upcoming 5G,
- o IEEE 802.11 has identified a set of real-applications [[ieee80211-rt-tig](#)] which may use the IEEE802.11 standards. They typically emphasize strict end-to-end delay requirements.
- o the IETF has produced an IPv6 stack for IEEE Std. 802.15.4 TimeSlotted Channel Hopping (TSCH) and an architecture [[I-D.ietf-6tisch-architecture](#)] that enables Reliable and Available Wireless (RAW) on a shared MAC.

This draft extends the "Deterministic Networking Use Cases" [[RFC8578](#)] and describes a number of additional use cases which require deterministic flows over wireless links and possibly complex multi-hop paths called Tracks. This is covered mainly by the "Wireless for Industrial Applications" use case, as the "Cellular Radio" is mostly dedicated to the (wired) transport part of a Radio Access Network (RAN). Whereas the "Wireless for Industrial Applications" use case certainly covers an area of interest for RAW, it is limited to 6TiSCH, and thus its scope is narrower than the use cases described next in this document.

## 2. Amusement Parks

### 2.1. Use Case Description

The digitalization of Amusement Parks is expected to decrease significantly the cost for maintaining the attractions. By monitoring in real-time the machines, predictive maintenance will help to reduce the repairing cost as well as the downtime. Besides, the attractions may use wireless transmissions to interconnect

sensors and actuators, to privilege reconfigurability, and standardization.

Attractions may rely on a large set of sensors and actuators, which react in real time. Typical applications comprise:

- o emergency: safety has to be preserved, and must stop the attraction when a failure is detected;
- o video: augmented and virtual realities are integrated in the attraction. Wearable devices (e.g. glasses, virtual reality headset) need to offload one part of the processing tasks.
- o real-time interactions: visitors may interact with an attraction, like in a real-time video game. The visitors may virtually interact with their environment, triggering actions in the real world (through actuators) [[robots](#)]
- o geolocation: visitors are tracked with a personal wireless tag so that their user experience is improved.
- o predictive maintenance: statistics are collected to predict the future failures, or to compute later more complex statistics about the attraction's usage, the downtime, its popularity, etc.

## 2.2. Specificities

Amusement parks comprise a variable number of attractions, mostly outdoor, over a large geographical area. The IT infrastructure is typically multi-scale:

- o local area: the sensors and actuators controlling the attractions are co-located. Control loops trigger only local traffic, with a small end-to-end delay, typically inferior than 10 milliseconds, like classical industrial systems [[ieee80211-rt-tig](#)]
- o wearable devices are free to move in the park. They exchange traffic locally (identification, personalization, multimedia) or globally (billing, child tracking);
- o computationally intensive applications offload some tasks to a cloud, and data analytics rely on a centralized infrastructure (predictive maintenance, marketing).

### 2.3. The Need for Wireless

Amusement parks cover large areas and a global interconnection would require a huge length of cables. Wireless also increases the reconfigurability, enabling to update cheaply the attractions. The frequent renewal helps to increase customer loyalty.

Some parts of the attraction are mobile, e.g. trucks of a rollercoaster, robots. Since cables are prone to frequent failures in this situation, wireless transmissions are recommended.

Wearable devices are extensively used for a user experience personalisation. They typically need to support wireless transmissions. Personal tags may help to reduce the operating costs [[disney-VIP](#)] and to increase the number of charged services provided to the audience (VIP tickets, interactivity, etc.) Some applications rely on more sophisticated wearable devices such as digital glasses or VR headsets for an immersive experience.

### 2.4. Requirements for RAW

The network infrastructure has to support heterogenous traffic, with very different criticalities. Thus, flow isolation has to be provided.

We have to schedule appropriately the transmissions, even in presence of mobile devices. While the [[I-D.ietf-6tisch-architecture](#)] already proposes an architecture for synchronized, IEEE Std. 802.15.4 Time-Slotted Channel Hopping (TSCH) networks, 6TiSCH doesn't address real-time IPv6 flows. RAW might provide mechanisms helping to automatically adapt the network (i.e., schedule appropriately the transmissions, accross heterogeneous technologies, with strict SLA requirements).

Nowadays, long-range wireless transmissions are used for best-effort traffic, and [[IEEE802.1TSN](#)] is used for critical flows using Ethernet devices. However, we need an IP enabled technology to interconnect large areas, independent of the PHY and MAC layer to maximize the compliancy.

We expect to deploy several different technologies (long vs. short range) which have to cohabit in the same area. Thus, we need to schedule appropriately the transmissions to limit the co-technology interference, so that an end-to-end delay accross multiple technologies can be guaranteed. It is needed to understand which technologies RAW will cover and how they can be used cohabitating in the same area.

### 3. Wireless for Industrial Applications

#### 3.1. Use Case Description

A major use case for networking in Industrial is the control networks where periodic control loops operate between a sensor that measures a physical property such as the temperature of a fluid, a Programmable Logic Controller that decides an action such as warm up the mix, and an actuator that performs the required action, e.g., inject power in a resistor.

#### 3.2. Specificities

##### 3.2.1. Control Loops

Process Control designates continuous processing operations, e.g., heating Oil in a refinery or mixing drinking soda. Control loops in the Process Control industry operate at a very low rate, typically 4 times per second. Factory Automation, on the other hand, deal with discrete goods such as individual automobile parts, and requires faster loops, in the order of 10ms. Motion control that monitors dynamic activities may require even faster rates in the order of a few ms. Finally, some industries exhibit hybrid behaviours, like canned soup that will start as a process industry while mixing the food and then operate as a discrete manufacturing when putting the final product in cans and shipping them.

In all those cases, a packet must flow deterministically between the sensor and the PLC, be processed by the PLC, and sent to the actuator within the control loop period. In some particular use cases that inherit from analog operations, jitter might also alter the operation of the control loop. A rare packet loss is usually admissible, but typically 4 losses in a row will cause an emergency halt of the production and incur a high cost for the manufacturer.

##### 3.2.2. Unmeasured Data

A secondary use case deals with monitoring and diagnostics. This so-called unmeasured data is essential to improve the performances of a production line, e.g., by optimizing real-time processing or maintenance windows using Machine Learning predictions. For the lack of wireless technologies, some specific industries such as Oil and Gas have been using serial cables, literally by the millions, to perform their process optimization over the previous decades. But few industries would afford the associated cost and the Holy Grail of the Industrial Internet of Things is to provide the same benefits to all industries, including SmartGrid, Transportation, Building,



Commercial and Medical. This requires a cheap, available and scalable IP-based access technology.

Inside the factory, wires may already be available to operate the Control Network. But unmeasured data are not welcome in that network for a number of reasons. On the one hand it is rich and asynchronous, meaning that using them may influence the deterministic nature of the control operations and impact the production. On the other hand, this information must be reported to the carpeted floor over IP, which means the potential for a security breach via the interconnection of the Operational Technology (OT) network with the Internet technology (IT) network and possibly enable a rogue access.

### 3.3. The Need for Wireless

Ethernet cables used on a robot arm are prone to breakage after a few thousands flexions, a lot faster than a power cable that is wider in diameter, and more resilient. In general, wired networking and mobile parts are not a good match, mostly in the case of fast and recurrent activities, as well as rotation.

When refurbishing older premises that were built before the Internet age, power is usually available everywhere, but data is not. It is often impractical, time consuming and expensive to deploy an Ethernet fabric across walls and between buildings. Deploying a wire may take months and cost tens of thousands of US Dollars.

Even when wiring exists, e.g., in an existing control network, asynchronous IP packets such as diagnostics may not be welcome for operational and security reasons (see [Section 3.2.1](#)). An alternate network that can scale with the many sensors and actuators that equip every robot, every valve and fan that are deployed on the factory floor and may help detect and prevent a failure that could impact the production. IEEE Std. 802.15.4 Time-Slotted Channel Hopping (TSCH) [[RFC7554](#)] is a promising technology for that purpose, mostly if the scheduled operations enable to use the same network by asynchronous and deterministic flows in parallel.

### 3.4. Requirements for RAW

As stated by the "Deterministic Networking Problem Statement" [[RFC8557](#)], a Deterministic Network is backwards compatible with (capable of transporting) statistically multiplexed traffic while preserving the properties of the accepted deterministic flows. While the [[I-D.ietf-6tisch-architecture](#)] serves that requirement, the work at 6TiSCH was focused on best-effort IPv6 packet flows. RAW should be able to lock so-called hard cells for use by a centralized scheduler, and program so-called end-to-end Tracks over those cells.

Over the course of the recent years, major Industrial Protocols, e.g., [ODVA] with EtherNet/IP [EIP] and [Profinet], have been migrating towards Ethernet and IP. In order to unleash the full power of the IP hourglass model, it should be possible to deploy any application over any network that has the physical capacity to transport the industrial flow, regardless of the MAC/PHY technology, wired or wireless, and across technologies. RAW mechanisms should be able to setup a Track over a wireless access segment such as TSCH and a backbone segment such as Ethernet or WI-Fi, to report a sensor data or a critical monitoring within a bounded latency.

#### 4. Pro Audio and Video

##### 4.1. Use Case Description

Many devices support audio and video streaming by employing 802.11 wireless LAN. Some of these applications require low latency capability. For instance, when the application provides interactive play, or when the audio takes plays in real time (i.e. live) for public addresses in train stations or in theme parks.

The professional audio and video industry ("ProAV") includes:

- o Virtual Reality / Augmented Reality (VR/AR)
- o Public address, media and emergency systems at large venues (airports, train stations, stadiums, theme parks).

##### 4.2. Specificities

###### 4.2.1. Uninterrupted Stream Playback

Considering the uninterrupted audio or video stream, a potential packet losses during the transmission of audio or video flows cannot be tackled by re-trying the transmission, as it is done with file transfer, because by the time the packet lost has been identified it is too late to proceed with packet re-transmission. Buffering might be employed to provide a certain delay which will allow for one or more re-transmissions, however such approach is not efficient in application where delays are not acceptable.

###### 4.2.2. Synchronized Stream Playback

In the context of ProAV, latency is the time between the transmitted signal over a stream and its reception. Thus, for sound to remain synchronized to the movement in the video, the latency of both the audio and video streams must be bounded and consistent.

### 4.3. The Need for Wireless

The devices need the wireless communication to support video streaming via 802.11 wireless LAN for instance.

During the public address, the deployed announcement speakers, for instance along the platforms of the train stations, need the wireless communication to forward the audio traffic in real time.

### 4.4. Requirements for RAW

The network infrastructure needs to support heterogeneous types of traffic (including QoS).

Content delivery with bounded (lowest possible) latency.

The deployed network topology should allow for multipath. This will enable for multiple streams to have different (and multiple) paths through the network to support redundancy.

## 5. Gaming

### 5.1. Use Case Description

The gaming industry includes [IEEE80211RTA]:

- o Real-time Mobile Gaming: Different from traditional games, real time mobile gaming is very sensitive to network latency and stability. The mobile game can connect multiple players together in a single game session and exchange data messages between game server and connected players. Real-time means the feedback should present on screen as users operate in game. For good game experience, the end to end latency plus game servers processing time should not be noticed by users as they play the game.
- o Wireless Console Gaming: Playing online on a console has 2 types of internet connectivity, which is either wired or Wi-Fi. Most of the gaming consoles today support Wi-Fi 5. But Wi-Fi has an especially bad reputation among the gaming community. The main reasons are high latency, lag spikes and jitter.
- o Cloud Gaming: The cloud gaming requires low latency capability as the user commands in a game session need to be sent back to the cloud server, the cloud server would update game context depending on the received commands, and the cloud server would render the picture/video to be displayed at user devices and stream the picture/video content to the user devices. User devices might very likely be connected wirelessly.

## 5.2. Specificities

While a lot of details can be found on [IEEE80211RTA], we next summarize the main requirements in terms of latency, jitter and packet loss:

- o Intra BSS latency: less than 5 ms.
- o Jitter variance: less than 2 ms.
- o Packet loss: less than 0.1 percent.

## 5.3. The Need for Wireless

It is clear that gaming is evolving towards wireless, as players demand being able to play anywhere. Besides, the industry is changing towards playing from mobile phones, which are inherently connected via wireless technologies.

## 5.4. Requirements for RAW

- o Time sensitive networking extensions. Extensions, such as time-aware shaping and redundancy (FRE) can be explored to address congestion and reliability problems present in wireless networks.
- o Priority tagging (Stream identification). One basic requirement to provide better QoS for time-sensitive traffic is the capability to identify and differentiate time-sensitive packets from other (e.g. best-effort) traffic.
- o Time-aware shaping. This capability (defined in IEEE 802.1Qbv) consists of gates to control the opening/closing of queues that share a common egress port within an Ethernet switch. A scheduler defines the times when each queue opens or close, therefore eliminating congestion and ensuring that frames are delivered within the expected latency bounds.
- o Dual/multiple link. Due to the competitions and interference are common and hardly in control under wireless network, in order to improve the latency stability, dual/multiple link proposal is brought up to address this issue. Two modes are defined: duplicate and joint.
- o Admission Control. Congestion is a major cause of high/variable latency and it is well known that if the traffic load exceeds the capability of the link, QoS will be degraded. QoS degradation maybe acceptable for many applications today, however emerging time-sensitive applications are highly susceptible to increased

latency and jitter. In order to better control QoS, it is important to control access to the network resources.

## 6. UAV platooning and control

### 6.1. Use Case Description

Unmanned Aerial Vehicles (UAVs) are becoming very popular for many different applications, including military and civil use cases. The term drone is commonly used to refer to a UAV.

UAVs can be used to perform aerial surveillance activities, traffic monitoring (e.g., Spanish traffic control has recently introduced a fleet of drones for quicker reactions upon traffic congestion related events), support of emergency situations, and even transportation of small goods.

UAVs typically have various forms of wireless connectivity:

- o cellular: for communication with the control center, for remote maneuvering as well as monitoring of the drone;
- o IEEE 802.11: for inter-drone communications (e.g., platooning) and providing connectivity to other devices (e.g., acting as Access Point).

### 6.2. Specificities

Some of the use cases/tasks involving drones require coordination among drones. Others involve complex compute tasks that might not be performed using the limited computing resources that a drone typically has. These two aspects require continuous connectivity with the control center and among drones.

Remote maneuvering of a drone might be performed over a cellular network in some cases, however, there are situations that need very low latencies and deterministic behaviour of the connectivity. Examples involve platooning of drones or share of computing resources among drones (e.g., a drone offload some function to a neighbouring drone).

### 6.3. The Need for Wireless

UAVs cannot be connected through any type of wired media, so it is obvious that wireless is needed.

#### 6.4. Requirements for RAW

The network infrastructure is actually composed by the UAVs themselves, requiring self-configuration capabilities.

Heterogeneous types of traffic need to be supported, from extremely critical ones requiring ultra low latency and high resiliency, to traffic requiring low-medium latency.

When a given service is decomposed into functions -- hosted at different drones -- chained, each link connecting two given functions would have a well-defined set of requirements (latency, bandwidth and jitter) that have to be met.

### 7. Edge Robotics control

#### 7.1. Use Case Description

The Edge Robotics scenario consists of several robots, deployed in a given area (for example a shopping mall), inter-connected via an access network to a network's edge device or a data center. The robots are connected to the edge so complex computational activities are not executed locally at the robots, but offloaded to the edge. This brings additional flexibility in the type of tasks that the robots do, as well as reducing the costs of robot manufacturing (due to their lower complexity), and enabling complex tasks involving coordination among robots (that can be more easily performed if robots are centrally controlled).

A simple example of the use of multiples robots is cleaning, delivering of goods from warehouses to shops or video surveillance. Multiple robots are simultaneously instructed to perform individual tasks by moving the robotic intelligence from the robots to the network's edge (e.g., data center). That enables easy synchronization, scalable solution and on-demand option to create flexible fleet of robots.

Robots would have various forms of wireless connectivity:

- o IEEE 802.11: for connection to the edge and also inter-robot communications (e.g., for coordinated actions);
- o cellular: as an additional communication link to the edge, though primarily as backup, since ultra low latencies are needed.

## 7.2. Specificities

Some of the use cases/tasks involving robots might benefit from decomposition of a service in small functions that are distributed and chained among robots and the edge. These require continuous connectivity with the control center and among drones.

Robot control is an activity requiring very low latencies between the robot and the location where the control intelligence resides (which might be the edge or another robot).

## 7.3. The Need for Wireless

Deploying robots in scenarios such as shopping malls for the aforementioned applications cannot be done via wired connectivity.

## 7.4. Requirements for RAW

The network infrastructure needs to support heterogeneous types of traffic, from robot control to video streaming.

When a given service is decomposed into functions -- hosted at different robots -- chained, each link connecting two given functions would have a well-defined set of requirements (latency, bandwidth and jitter) that have to be met.

## 8. IANA Considerations

N/A.

## 9. Security Considerations

N/A.

## 10. Informative References

[disney-VIP]

Wired, "Disney's \$1 Billion Bet on a Magical Wristband",  
March 2015,  
<<https://www.wired.com/2015/03/disney-magicband/>>.

- [EIP] <http://www.odva.org/>, "EtherNet/IP provides users with the network tools to deploy standard Ethernet technology (IEEE 802.3 combined with the TCP/IP Suite) for industrial automation applications while enabling Internet and enterprise connectivity data anytime, anywhere.", <[http://www.odva.org/Portals/0/Library/Publications\\_Numbered/PUB00138R3\\_CIP\\_Adv\\_Tech\\_Series\\_EtherNetIP.pdf](http://www.odva.org/Portals/0/Library/Publications_Numbered/PUB00138R3_CIP_Adv_Tech_Series_EtherNetIP.pdf)>.
- [I-D.ietf-6tisch-architecture] Thubert, P., "An Architecture for IPv6 over the TSCH mode of IEEE 802.15.4", [draft-ietf-6tisch-architecture-24](#) (work in progress), July 2019.
- [I-D.ietf-detnet-architecture] Finn, N., Thubert, P., Varga, B., and J. Farkas, "Deterministic Networking Architecture", [draft-ietf-detnet-architecture-13](#) (work in progress), May 2019.
- [IEEE802.1TSN] IEEE standard for Information Technology, "IEEE 802.1AS-2011 - IEEE Standard for Local and Metropolitan Area Networks - Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks".
- [ieee80211-rt-tig] IEEE, "IEEE 802.11 Real Time Applications TIG Report", Nov. 2018, <[http://www.ieee802.org/11/Reports/rtatig\\_update.htm](http://www.ieee802.org/11/Reports/rtatig_update.htm)>.
- [IEEE80211RTA] IEEE standard for Information Technology, "IEEE 802.11 Real Time Applications TIG Report", Nov 2018.
- [ISA100] ISA/ANSI, "ISA100, Wireless Systems for Automation", <<https://www.isa.org/isa100/>>.
- [ODVA] <http://www.odva.org/>, "The organization that supports network technologies built on the Common Industrial Protocol (CIP) including EtherNet/IP."
- [Profinet] <http://us.profinet.com/technology/profinet/>, "PROFINET is a standard for industrial networking in automation.", <<http://us.profinet.com/technology/profinet/>>.



- [RFC7554] Watteyne, T., Ed., Palattella, M., and L. Grieco, "Using IEEE 802.15.4e Time-Slotted Channel Hopping (TSCH) in the Internet of Things (IoT): Problem Statement", RFC 7554, DOI 10.17487/RFC7554, May 2015, <<https://www.rfc-editor.org/info/rfc7554>>.
- [RFC8557] Finn, N. and P. Thubert, "Deterministic Networking Problem Statement", RFC 8557, DOI 10.17487/RFC8557, May 2019, <<https://www.rfc-editor.org/info/rfc8557>>.
- [RFC8578] Grossman, E., Ed., "Deterministic Networking Use Cases", RFC 8578, DOI 10.17487/RFC8578, May 2019, <<https://www.rfc-editor.org/info/rfc8578>>.
- [robots] Kober, J., Glisson, M., and M. Mistry, "Playing catch and juggling with a humanoid robot.", 2012, <<https://doi.org/10.1109/HUMANOIDS.2012.6651623>>.

#### Authors' Addresses

Georgios Z. Papadopoulos  
IMT Atlantique  
Office B00 - 114A  
2 Rue de la Chataigneraie  
Cesson-Sevigne - Rennes 35510  
FRANCE

Phone: +33 299 12 70 04  
Email: [georgios.papadopoulos@imt-atlantique.fr](mailto:georgios.papadopoulos@imt-atlantique.fr)

Pascal Thubert  
Cisco Systems, Inc  
Building D  
45 Allee des Ormes - BP1200  
MOUGINS - Sophia Antipolis 06254  
FRANCE

Phone: +33 497 23 26 34  
Email: [pthubert@cisco.com](mailto:pthubert@cisco.com)

Fabrice Theoleyre  
CNRS  
ICube Lab, Pole API  
300 boulevard Sebastien Brant - CS 10413  
Illkirch 67400  
FRANCE

Phone: +33 368 85 45 33  
Email: [theoleyre@unistra.fr](mailto:theoleyre@unistra.fr)  
URI: <http://www.theoleyre.eu>

Carlos J. Bernardos  
Universidad Carlos III de Madrid  
Av. Universidad, 30  
Leganes, Madrid 28911  
Spain

Phone: +34 91624 6236  
Email: [cjbc@it.uc3m.es](mailto:cjbc@it.uc3m.es)  
URI: <http://www.it.uc3m.es/cjbc/>