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RAW Use-Cases

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 wireless use-cases (such as aeronautical communications, amusement parks, industrial applications, pro audio and video, gaming, UAV and V2V control, edge robotics and emergency vehicles) demanding reliable and available behavior.

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Table of Contents

1. Introduction

Based on time, resource reservation, and policy enforcement by distributed shapers, deterministic networking (DetNet) 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 aims at eliminating packet loss for a committed bandwidth while ensuring a worst case end-to-end latency, regardless of the network conditions and across technologies. By leveraging lower layer (Layer 2 and below) capabilities, L3 can exploit the use of a service layer, steering over multiple technologies, and using media independent signaling to provide high reliability, precise time delivery, and rate enforcement. Deterministic networking 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., using 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:

* time synchronization on all the nodes,

* multi-technology path with co-channel interference minimization,

* frame preemption and guard time mechanisms to ensure a worst-case delay, and

* new traffic shapers within and at the edge to protect the network.

Wireless operates on a shared medium, and transmissions cannot be guaranteed to be fully deterministic due to uncontrolled interferences, including self-induced multipath fading. The term RAW stands for Reliable and Available Wireless, and refers to the mechanisms aimed for providing high reliability and availability for IP connectivity over a wireless medium. Making Wireless Reliable and Available is even more challenging than it is with wires, due to the numerous causes of loss in transmission that add up to the congestion losses and the delays caused by overbooked shared resources.

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, e.g., due to the wireless radio channel specifics.

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 [RFC8655] at the IETF. But wires cannot be used in several 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 with 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 [I-D.ietf-raw-technologies]:

* IMT-2020 has recognized Ultra-Reliable Low-Latency Communication (URLLC) as a key functionality for the upcoming 5G.

* 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.

* The IETF has produced an IPv6 stack for IEEE Std. 802.15.4 TimeSlotted Channel Hopping (TSCH) and an architecture [RFC9030] that enables RAW on a shared MAC.

Experiments have already been conducted with IEEE802.1 TSN over IEEE802.11be [IEEE80211BE]. This mode enables time synchronization, and time-aware scheduling (trigger based access mode) to support TSN flows.

This document extends the "Deterministic Networking use-cases" document [RFC8578] and describes several additional use-cases which require "reliable/predictable and available" 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) link 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. Aeronautical Communications

Aircraft are currently connected to ATC (Air-Traffic Control) and AOC (Airline Operational Control) via voice and data communication systems through all phases of a flight. Within the airport terminal, connectivity is focused on high bandwidth communications while en-route high reliability, robustness and range are the focus.

2.1. Problem Statement

Up to 2020, civil air traffic has been growing constantly at a compound rate of 5.8% per year [ACI19] and despite the severe impact of the COVID-19 pandemic, air traffic growth is expected to resume very quickly in post-pandemic times [IAT20] [IAC20]. Thus, legacy systems in air traffic management (ATM) are likely to reach their capacity limits and the need for new aeronautical communication technologies becomes apparent. Especially problematic is the saturation of VHF band in high density areas in Europe, the US, and Asia [KEAV20] [FAA20] calling for suitable new digital approaches such as AeroMACS for airport communications, SatCOM for remote domains, and LDACS as long-range terrestrial aeronautical communication system. Making the frequency spectrum's usage more efficient a transition from analog voice to digital data communication [PLA14] is necessary to cope with the expected growth of civil aviation and its supporting infrastructure. A promising candidate for long range terrestrial communications, already in the process of being standardized in the International Civil Aviation Organization (ICAO), is the L-band Digital Aeronautical Communication System (LDACS) [ICAO18] [I-D.ietf-raw-ldacs].

2.2. Specifics

During the creation process of new communication system, analog voice is replaced by digital data communication. This sets a paradigm shift from analog to digital wireless communications and supports the related trend towards increased autonomous data processing that the Future Communications Infrastructure (FCI) in civil aviation must provide. The FCI is depicted in Figure 1:

```
 Satellite
#         #
#          # #
#            #   #
#             #      #
#               #        #
#                #          #
#                  #            #
# Satellite-based   #              #
#   Communications   #                 #
#      SatCOM (#)     #                   #
#                      #                   Aircraft
#                       #                 %         %
#                        #              %             %
#                         #           %     Air-Air     %
#                          #        %     Communications   %
#                           #     %         LDACS A/A (%)    %
#                           #   %                              %
#                            Aircraft  % % % % % % % % % %  Aircraft
#                                 |           Air-Ground           |
#                                 |         Communications         |
#                                 |           LDACS A/G (|)        |
#      Communications in          |                                |
#    and around airports          |                                |
#         AeroMACS (-)            |                                |
#                                 |                                |
#         Aircraft-------------+  |                                |
#                              |  |                                |
#                              |  |                                |
#         Ground network       |  |         Ground network         |
SatCOM <---------------------> Airport <-----------------------> LDACS
ground                          ground                          ground
transceiver                   transceiver                    transceiver
```

Figure 1: The Future Communication Infrastructure (FCI): AeroMACS for Airport/Termina Maneuvering Area domain, LDACS A/G for Terminal Maneuvering/En-Route domain, LDACS A/G for En-Route/Oceanic, Remote, Polar domain, SatCOM for Oceanic, Remote, Polar domain domain communications

2.3. Challenges

This paradigm change brings a lot of new challenges:

*Efficiency: It is necessary to keep latency, time and data overhead of new aeronautical datalinks at a minimum.

*Modularity: Systems in avionics usually operate up to 30 years, thus solutions must be modular, easily adaptable and updatable.

*Interoperability: All 192 members of the international Civil Aviation Organization (ICAO) must be able to use these solutions.

*Dynamicity: the communication infrastructure needs to accommodate mobile devices (airplanes) that move extremely fast.

2.4. The Need for Wireless

In a high mobility environment such as aviation, the envisioned solutions to provide worldwide coverage of data connections with in-flight aircraft require a multi-system, multi-link, multi-hop approach. Thus air, ground and space-based datalink providing technologies will have to operate seamlessly together to cope with the increasing needs of data exchange between aircraft, air traffic controller, airport infrastructure, airlines, air network service providers (ANSPs) and so forth. Wireless technologies have to be used to tackle this enormous need for a worldwide digital aeronautical datalink infrastructure.

2.5. Requirements for RAW

Different safety levels need to be supported, from extremely safety critical ones requiring low latency, such as a WAKE warning - a warning that two aircraft come dangerously close to each other - and high resiliency, to less safety critical ones requiring low-medium latency for services such as WXGRAPH - graphical weather data.

Overhead needs to be kept at a minimum since aeronautical data links provide comparatively small data rates on the order of kbit/s.

Policy needs to be supported when selecting data links. The focus of RAW here should be on the selectors, responsible for the track a packet takes to reach its end destination. This would minimize the amount of routing information that must travel inside the network because of precomputed routing tables with the selector being responsible for choosing the most appropriate option according to policy and safety.

2.5.1. Non-latency critical considerations

Achieving low latency is a requirement for aeronautics communications, though the expected latency is not extremely low and what is important is to keep the overall latency bounded under a certain threshold. This use-case is not latency-critical from that view point. On the other hand, given the controlled environment, end-to-end mechanisms can be applied to guarantee bounded latency where needed.

3. Amusement Parks

3.1. Use-Case Description

The digitalization of Amusement Parks is expected to decrease significantly the cost for maintaining the attractions. Such deployment is a mix between multimedia (e.g., Virtual and Augmented Reality, interactive video environments) and non-multimedia applications (e.g, industrial automation for a roller-coaster, access control).

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

* Emergency: the safety of the operators / visitors has to be preserved and the attraction must be stopped appropriately when a failure is detected.

* Video: augmented and virtual realities are integrated in the attraction. Wearable mobile devices (e.g., glasses, virtual reality headset) need to offload one part of the processing tasks.

* 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) [KOB12].

* Geolocation: visitors are tracked with a personal wireless tag so that their user experience is improved. This requires special care to ensure that visitors' privacy is not breached, and users are anonymously tracked.

* Predictive maintenance: statistics are collected to predict the future failures, or to compute later more complex statistics about the attraction's usage, the downtime, etc.

* Marketing: to improve the customer experience, owners may collect a large amount of data to understand the behavior, and the choice of their clients.

3.2. Specifics

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

* 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 less than 10 ms, like classical industrial systems [IEEE80211-RT-TIG].

* Wearable mobile devices are free to move in the park. They exchange traffic locally (identification, personalization, multimedia) or globally (billing, child tracking).

* Computationally intensive applications offload some tasks. Edge computing seems an efficient way to implement real-time applications with offloading. Some non-time-critical tasks may rather use the cloud (predictive maintenance, marketing).

3.3. The Need for Wireless

Removing cables helps to change easily the configuration of the attractions, or to upgrade parts of them at a lower cost. The attraction can be designed modularly, upgrade or insert novel modules later in the lifecycle of the attraction. Novelty of attractions tends to increase the attractiveness of an amusement park, encouraging previous visitors to visit regularly the park.

Some parts of the attraction are mobile, like trucks of a roller-coaster or robots. Since cables are prone to frequent failures in this situation, wireless transmissions are recommended.

Wearable devices are extensively used for a user experience personalization. They typically need to support wireless transmissions. Personal tags may help to reduce the operating costs [DISNEY15] and to increase the number of charged services provided to the audience (e.g., VIP tickets or interactivity). Some applications rely on more sophisticated wearable devices such as digital glasses or Virtual Reality (VR) headsets for an immersive experience.

3.4. Requirements for RAW

The network infrastructure must support heterogeneous traffic, with very different critical requirements. Thus, flow isolation must be provided.

The transmissions must be scheduled appropriately even in presence of mobile devices. While the [RFC9030] already proposes an architecture for synchronized, IEEE Std. 802.15.4 Time-Slotted Channel Hopping (TSCH) networks, the industry requires a multi-technology solution, able to guarantee end-to-end requirements across heterogeneous technologies, with strict SLA requirements.

Nowadays, long-range wireless transmissions are used mostly for best-effort traffic. On the contrary, [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 layers.

It is expected that several different technologies (long vs. short range) are deployed, which have to cohabit in the same area. Thus, we need to provide layer-3 mechanisms able to exploit multiple co-interfering technologies (i.e., different radio technologies using overlapping spectrum, and therefore, potentially interfering to each other).

It is worth noting that low-priority flows (e.g., predictive maintenance, marketing) are delay tolerant: a few minutes or even hours would be acceptable. While classical unscheduled wireless networks already accomodate best-effort traffic, this would force several colocated and subefficient deployments. Unused resources could rather be used for low-priority flows. Indeed, allocated resources are consuming energy in most scheduled networks, even if no traffic is transmitted.

3.4.1. Non-latency critical considerations

While some of the applications in this use-case involve control loops (e.g., sensors and actuators) that require bounded latencies below 10 ms, that can therefore be considered latency critical, there are other applications as well that mostly demand reliability (e.g., safety related, or maintenance).

4. Wireless for Industrial Applications

4.1. Use-Case Description

A major use-case for networking in Industrial environments is the control networks where periodic control loops operate between a collection of sensors that measure a physical property such as the temperature of a fluid, a Programmable Logic Controller (PLC) that decides an action such as warm up the mix, and actuators that perform the required action, such as the injection of power in a resistor.

4.2. Specifics

4.2.1. Control Loops

Process Control designates continuous processing operations, like heating oil in a refinery or mixing drinking soda. Control loops in the Process Control industry operate at a very low rate, typically four times per second. Factory Automation, on the other hand, deals with discrete goods such as individual automobile parts, and requires faster loops, on the order of milliseconds. Motion control that monitors dynamic activities may require even faster rates on the order of and below the millisecond.

In all those cases, a packet must flow reliably 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 a loss of multiple packets in a row will cause an emergency halt of the production and incur a high cost for the manufacturer.

Additional details and use-cases related to Industrial applications and their RAW requirements can be found in [I-D.ietf-raw-industrial-requirements].

4.2.2. Monitoring and diagnostics

A secondary use-case deals with monitoring and diagnostics. This data is essential to improve the performance 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. One of the goals 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 monitoring and diagnostics data are not welcome in that network for several reasons. On the one hand it is rich and asynchronous, meaning that it may influence the deterministic nature of the control operations and impact the production. On the other hand, this information must be reported to the operators 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.

4.3. The Need for Wireless

Wires 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, like in the case of an existing control network, asynchronous IP packets such as diagnostics may not be welcome for operational and security reasons. For those packets, the option to create a parallel wireless network offers a credible solution that can scale with the many sensors and actuators that equip every robot, every valve and fan that are deployed on the factory floor. It may also help detect and prevent a failure that could impact the production, like the degradation (vibration) of a cooling fan on the ceiling. 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.

4.4. 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 6TiSCH Architecture [RFC9030] 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 (i.e., scheduled cells [I-D.ietf-6tisch-terminology]) for use by a centralized scheduler, and leverage time and spatial diversity over a graph of end-to-end paths called a Track that is based on 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 and a wired or wireless backbone to report both sensor data and critical monitoring within a bounded latency and maintain the high reliability of the flows over time. It is also important to ensure that RAW solutions are interoperable with existing wireless solutions in place, and with legacy equipment whose capabilities can be extended using retrofitting. Maintainability, as a broader concept than reliability is also important in industrial scenarios [MAR19].

4.4.1. Non-latency critical considerations

Monitoring and diagnostics applications do not require latency critical communications, but demand reliable and scalable communications. On the other hand, process control applications involve control loops that require a bounded latency, thus are latency critical, but can be managed end-to-end, and therefore DetNet mechanisms can be applied in conjunction with RAW mechanisms.

5. Pro Audio and Video

5.1. Use-Case Description

Many devices support audio and video streaming [RFC9317] 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 plays in real time - meaning live for public addresses in train stations or in theme parks.

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

- *Virtual Reality / Augmented Reality (VR/AR)
- *Production and post-production systems such as CD and Blu-ray disk mastering.
- *Public address, media and emergency systems at large venues (e.g., airports, train stations, stadiums, and theme parks).

5.2. Specifics

5.2.1. Uninterrupted Stream Playback

Considering the uninterrupted audio or video stream, a potential packet loss 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 viable in application where delays are not acceptable.

5.2.2. Synchronized Stream Playback

In the context of ProAV over packet networks, 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.

5.3. The Need for Wireless

The devices need the wireless communication to support video streaming via IEEE 802.11 wireless LAN for instance. Wireless communications provide huge advantages in terms of simpler deployments in many scenarios, where the use of a wired alternative would not be feasible. Similarly, in live events, mobility support makes wireless communications the only viable approach.

Deployed announcement speakers, for instance along the platforms of the train stations, need the wireless communication to forward the audio traffic in real time. Most train stations are already built, and deploying novel cables for each novel service seems expensive.

5.4. 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 (tracks) through the network to support redundancy.

5.4.1. Non-latency critical considerations

For synchronized streaming, latency must be bounded, and therefore, depending on the actual requirements, this can be considered as latency critical. However, the most critical requirement of this use-case is reliability, by the network providing redundancy. Note that in many cases, wireless is only present in the access, where RAW mechanisms could be applied, but other wired segments are also involved (like the Internet), and therefore latency cannot be guaranteed.

6. Wireless Gaming

6.1. Use-Case Description

The gaming industry includes [IEEE80211RTA] real-time mobile gaming, wireless console gaming, wireless gaming controllers and cloud gaming. Note that they are not mutually exclusive (e.g., a console can connect wirelessly to the Internet to play a cloud game). For RAW, wireless console gaming is the most relevant one. We next summarize the four:

* 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 (E2E) latency plus game servers processing time must be the same for all players and should not be noticeable as the game is played. RAW technologies might help in keeping latencies low on the wireless segments of the communication.

*Wireless Console Gaming: while gamers may use a physical console, interactions with a remote server may be required for online games. Most of the gaming consoles today support Wi-Fi 5, but may benefit from a scheduled access with Wi-Fi 6 in the future. Previous Wi-Fi versions have an especially bad reputation among the gaming community. The main reasons are high latency, lag spikes, and jitter.

*Wireless Gaming controllers: most controllers are now wireless for a freedom of movement.Controllers may interact with consoles or directly with gaming server in the cloud. A low and stable end-to-end latency is here of predominant importance.

*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.

6.2. Specifics

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

*Intra Basic Service Set (BSS) latency is less than 5 ms.

*Jitter variance is less than 2 ms.

*Packet loss is less than 0.1 percent.

6.3. The Need for Wireless

Gaming is evolving towards wireless, as players demand being able to play anywhere, and the game requires a more immersive experience including body movements. Besides, the industry is changing towards playing from mobile phones, which are inherently connected via wireless technologies. Wireless controllers are the rule in modern gaming, with increasingly sophisticated interactions (e.g., haptic feedback, augmented reality).

6.4. Requirements for RAW

* Time sensitive networking extensions: extensions, such as time-aware shaping and redundancy can be explored to address congestion and reliability problems present in wireless networks. As an example, in haptics it is very important to minimize latency failures.

* 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 (like best-effort) traffic.

* 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. Note though, that while this requirement needs to be signalled by RAW mechanisms, it would be actually served by the lower layer.

* Dual/multiple link: due to the fact that competitions and interference are common and hardly in control under wireless network, to improve the latency stability, dual/multiple link proposal is brought up to address this issue.

* 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 may be acceptable for many applications today, however emerging time-sensitive applications are highly susceptible to increased latency and jitter. To better control QoS, it is important to control access to the network resources.

6.4.1. Non-latency critical considerations

Depending on the actual scenario, and on use of Internet to interconnect different users, the communication requirements of this use-case might be considered as latency critical due to the need of bounded latency. But note that in most of these scenarios, part of the communication path is not wireless and DetNet mechanisms cannot be applied easily (e.g., when the public Internet is involved), and therefore in these cases, reliability is the critical requirement.

7. Unmanned Aerial Vehicles and Vehicle-to-Vehicle platooning and control

7.1. 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 (i.e., the Spanish traffic control has recently introduced a fleet of drones for quicker reactions upon traffic congestion related events [DGT2021]), support of emergency situations, and even transportation of small goods (e.g., medicine in rural areas). Note that the surveillance and monitoring application would have to comply with local regulations regarding location privacy of users. Different considerations have to be applied when surveillance is performed for traffic rules enforcement (e.g., generating fines) as compared to when traffic load is being monitored.

Many types of vehicles, including UAVs but also others, such as cars, can travel in platoons, driving together with shorter distances between vehicles to increase efficiency. Platooning imposes certain vehicle-to-vehicle considerations, most of these are applicable to both UAVs and other vehicle types.

UAVs/vehicles typically have various forms of wireless connectivity:

* Cellular: for communication with the control center, for remote maneuvering as well as monitoring of the drone;

* IEEE 802.11: for inter-drone communications (i.e., platooning) and providing connectivity to other devices (i.e., acting as Access Point).

Note that autonomous cars share many of the characteristics of the aforemention UAV case, and therefore it is of interest for RAW.

7.2. Specifics

Some of the use-cases/tasks involving UAVs require coordination among UAVs. 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 UAVs.

Remote maneuvering of a drone might be performed over a cellular network in some cases, however, there are situations that need very low latency and deterministic behavior of the connectivity. Examples involve platooning of drones or sharing of computing resources among drones (like, a drone offload some function to a neighboring drone).

7.3. The Need for Wireless

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

7.4. Requirements for RAW

The network infrastructure is 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 UAVs -- chained, each link connecting two given functions would have a well-defined set of requirements (e.g., latency, bandwidth and jitter) that must be met.

7.4.1. Non-latency critical considerations

Today's solutions keep the processing operations that are critical local (i.e., they are not offloaded). Therefore, in this use-case, the critical requirement is reliability, and only for some platooning and inter-drone communications latency is critical.

8. Edge Robotics control

8.1. Use-Case Description

The Edge Robotics scenario consists of several robots, deployed in a given area (like a shopping mall), inter-connected via an access network to a network 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).

Simple examples of the use of multiple robots are cleaning, video surveillance (note that this have to comply with local regulations regarding user's privacy at the application level), search and rescue operations, and delivering of goods from warehouses to shops. Multiple robots are simultaneously instructed to perform individual tasks by moving the robotic intelligence from the robots to the network's edge. That enables easy synchronization, scalable solution, and on-demand option to create flexible fleet of robots.

Robots would have various forms of wireless connectivity:

* IEEE 802.11: for connection to the edge and also inter-robot communications (i.e., for coordinated actions).

* Cellular: as an additional communication link to the edge, though primarily as backup, since ultra-low latency is needed.

8.2. Specifics

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 latency (0.5-20 ms [Groshev2021]) between the robot and the location where the control intelligence resides (which might be the edge or another robot).

8.3. The Need for Wireless

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

8.4. 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 must be met.

8.4.1. Non-latency critical considerations

This use-case might combine multiple communication flows, with some of them being latency critical (like those related to robot control tasks). Note that there are still many communication flows (like some offloading tasks) that only demand reliability and availability.

9. Instrumented emergency medical vehicles

9.1. Use-Case Description

An instrumented ambulance would be one that one or multiple network segments to which are connected these end systems such as:

*vital signs sensors attached to the casualty in the ambulance. Relay medical data to hospital emergency room,

*radio-navigation sensor to relay position data to various destinations including dispatcher,

*voice communication for ambulance attendant (like to consult with ER doctor), and

*voice communication between driver and dispatcher.

The LAN needs to be routed through radio-WANs (a radio network in the interior of a network, i.e., it is terminated by routers) to complete the network linkage.

9.2. Specifics

What we have today is multiple communication systems to reach the vehicle via:

*A dispatching system,

*a cellphone for the attendant,

*a special purpose telemetering system for medical data,

*etc.

This redundancy of systems does not contribute to availability.

Most of the scenarios involving the use of an instrumented ambulance are composed of many different flows, each of them with slightly different requirements in terms of reliability and latency. Destinations might be either at the ambulance itself (local traffic), at a near edge cloud or at the general Internet/cloud. Special care (at application level) have to be paid to ensuring that sensitive data is not disclosed to unauthorized parties, by properly securing traffic and authenticating the communication ends.

9.3. The Need for Wireless

Local traffic between the first responders/ambulance staff and the ambulance equipment cannot be done via wired connectivity as the responders perform initial treatment outside of the ambulance. The communications from the ambulance to external services must be wireless as well.

9.4. Requirements for RAW

We can derive some pertinent requirements from this scenario:

* High availability of the inter-network is required. The exact level of availability depends on the specific deployment scenario, as not all emergency agencies share the same type of instrumented emergency vehicles.

* The inter-network needs to operate in damaged state (e.g. during an earthquake aftermath, heavy weather, wildfire, etc.). In addition to continuity of operations, rapid restore is a needed characteristic.

* The radio-WAN has characteristics similar to cellphone -- the vehicle will travel from one radio coverage area to another, thus requiring some hand-off approach.

9.4.1. Non-latency critical considerations

In this case, all applications identified do not require latency critical communication, but do need high reliability and availability.

10. Summary

This document enumerates several use-cases and applications that need RAW technologies, focusing on the requirements from reliability, availability and latency. Whereas some use-cases are latency-critical, there are also several applications that are non-latency critical, but that do pose strict reliability and availability requirements.

11. IANA Considerations

This document has no IANA actions.

12. Security Considerations

This document covers several representative applications and network scenarios that are expected to make use of RAW technologies. Each of the potential RAW use-cases will have security considerations from both the use-specific perspective and the RAW technology perspective. [RFC9055] provides a comprehensive discussion of security considerations in the context of deterministic networking, which are generally applicable also to RAW.

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