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Enhanced Use Cases for Scaling Deterministic Networks
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Abstract

This document describes use cases and network requirements for scaling deterministic networks which is not covered in RFC8578, such as industrial internet, high experience video, intelligent computing, and ISAC-enabled smart factory and outlines the common properties implied by these use cases.

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Table of Contents

1. Introduction	3
1.1. Requirements Language	3
2. Terminology	4
3. Enhanced Use Cases and Network Requirements	4
3.1. Industrial Internet	4
3.1.1. Use Case Description	4
3.1.1.1. Machine Vision	4
3.1.1.2. Remote Control	5
3.1.1.3. AGV Intelligent Control	6
3.1.1.4. AR Assistance	6
3.1.2. Requests to the IETF	7
3.2. High Experience Video	8
3.2.1. Use Case Description	8
3.2.1.1. Cloud VR and AR	8
3.2.1.2. Cloud Games	9
3.2.1.3. Cloud Live Streaming	10
3.2.2. Requests to the IETF	10
3.3. Intelligent Computing	10
3.3.1. Use Case Description	11
3.3.1.1. Scientific Research	11
3.3.1.2. Autonomous Vehicles	12
3.3.2. Requests to the IETF	12
3.4. ISAC-Enabled Smart Factory	13
3.4.1. Use Case Description	13
3.4.1.1. Predictive Maintenance	14
3.4.1.2. Real-Time Process Optimization	14
3.4.1.3. Safety Control and Maintenance	15
3.4.1.4. Interconnection of Time Sensitive Domains	16
3.4.2. Requests to the IETF	16
4. Use Case Common Themes	17
4.1. Requirements with Deterministic Classification	17
4.2. Requirements with Ultra-low or Zero Packet Loss	19
5. Security Considerations	19
6. IANA Considerations	19
7. Acknowledgements	19
Appendix A. Simulation Results in Scientific Research	19
A.1. Simulation for the Long Distance and Latency	19

A.2. Simulation for the Latency and Packet Loss	20
References	21
Informative References	21
Authors' Addresses	22

1. Introduction

According to [RFC8655], Deterministic Networking (DetNet) operates at the IP layer and delivers service which provides extremely low data loss rates and bounded latency within a network domain. The bounded latency indicates the minimum and maximum end-to-end latency from source to destination and bounded jitter (packet delay variation). [RFC8578] has presented use cases for diverse industries and these use cases differ in their network topologies and requirements. It should provide specific desired behaviors in DetNet.

[I-D.ietf-detnet-scaling-requirements] focus on the scaling deterministic networks and describes the enhanced requirements for DetNet enhanced data plane including the deterministic latency guarantees and it also mentioned the enhanced DetNet should support different levels of application requirements which is important for the DetNet deployment. There are a variety of use cases in scaling deterministic networks which is not covered in [RFC8578]. It is required to provide the typical use cases for scaling deterministic networks and analyze the SLAs requirements and desired behaviors in enhanced DetNet.

The industries covered by the use cases in this document are:

- * Industrial Internet (section 3.1)
- * High Experience Video (section 3.2)
- * Intelligent Computing (section 3.3)
- * ISAC-Enabled Smart Factory(section 3.4)

This document describes use cases and network requirements for scaling deterministic networks including industrial internet, high experience video and intelligent computing and outlines the common properties implied by these use cases.

1.1. Requirements Language

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].

2. Terminology

The terminology is defined as [RFC8655] and [RFC8578].

3. Enhanced Use Cases and Network Requirements

3.1. Industrial Internet

3.1.1. Use Case Description

In the industrial internet, the entire industrial process can be roughly divided into research and development design, production manufacturing, operation and maintenance services. The typical application prospects of deterministic networks mainly include ultra-high definition video, cloud-based robots, remote control, machine vision, and cloud-based AGV. The scenarios such as machine vision, AGV intelligent control, remote control, and AR assisted robotic arm control demand deterministic requirements.

3.1.1.1. Machine Vision

The machine vision system needs to achieve real-time remote monitoring function, which requires high-speed and large connectivity characteristics. It can monitor the production process execution management system (MES) of manufacturing enterprises through mobile and portable terminals without entering the workshop, and obtain the operating status of the visual inspection system, such as normal operating time, effective operating time, fault cause etc. It is bandwidth sensitive and demand cloud-based deployment and wide area networks requirements.

The following table shows the main network requirements of machine vision. (These metrics are based on 3GPP Standard 3GPP TS 22.104, 3GPP TR 22.261, and 3GPP TR 22.829.)

Machine Vision Requirement	Attribute
Bandwidth	Real time upload of image information:>50M
One-way maximum delay	10 ms
Availability	99.99%

Figure 1: Requirements of Machine Vision

3.1.1.2. Remote Control

Remote control can ensure personnel safety, improve production efficiency, and achieve assistance from multiple production units. In order to achieve the effect of remote control, the controller needs to send status information to the controller through a communication network based on remote perception. The controller analyzes and makes decisions based on the received status information, and then sends corresponding action instructions to the controller through the communication network. The controller executes the corresponding actions based on the received action instructions, completing the remote control process. In order to guarantee control effectiveness, communication network latency, jitter, and reliability are even more important. The typical application is cloud-based PLC (Programmable Logic Controller). It is jitter sensitive and cloud-based PLC demand wide area networks requirements.

The following table describes requirements of Cloud-based PLC.
(These metrics are based on 3GPP Standard 3GPP TS 22.104, 3GPP TR 22.261, and 3GPP TR 22.829.)

Cloud-based PLC Requirement	Attribute
Bandwidth	Image/video stream upload, upstream>50Mbps; PLC control command issued, downstream>50kbps;
One-way maximum delay	Within workshop level equipment:1ms Workshop level equipment room:10ms Remote operation in the park/city/ wide area: image upstream:20ms; Command issuance:10ms;
Maximum jitter	Less than 100 us
Availability	99.999%

Figure 2: Requirements of Cloud-based PLC

3.1.1.3. AGV Intelligent Control

Automated Guided Vehicle (AGV) is an intelligent device widely used in highly automated places such as factory workshops, airports, ports, freight warehouses, etc. It generally consists of three parts: walking, navigation, and control systems. The automated AGV is equipped with a camera to capture the scene in front of the vehicle and upload it to the MEC and navigation system in real-time through a 5G module for image analysis and route planning, achieving fully automated logistics transportation. AGV has a certain driving speed and is often used in cluster operation scenarios. Therefore, a network connection with high deterministic delay and jitter is required to transmit control signals.

The following table describes requirements of AGV intelligent control. (These metrics are based on 3GPP Standard 3GPP TS 22.104, 3GPP TR 22.261, and 3GPP TR 22.829.)

AGV Intelligent Control Requirement	Attribute
Bandwidth	Schedule communication:>1Mbps, Real time communication:1Mbps~200Mbps Visual: 10Mbps~1Gbps
One-way maximum delay	Schedule communication:100ms Dispatching communication:100ms Real time communication:20ms~40ms Visual: 10ms~100ms
Availability	99.9999%

Figure 3: Requirements of AGV Intelligent Control

3.1.1.4. AR Assistance

With the intelligent and networked transformation and upgrading of industrial manufacturing equipment, more and more AR assisted intelligent robots will be used in advanced manufacturing. At the same time, there are scenarios where multiple robot systems work together, such as welding, stamping, etc. The robotic arm is the most widely used automated mechanical device in the field of robotics technology, in areas such as industrial manufacturing, medical treatment, entertainment services, military, semiconductor manufacturing, and space exploration. The more axis joints of the AR assisted robotic arm, the higher the degree of freedom, and the

larger the angle of the operating range.

The following table describes requirements of AR Assistance. (These metrics are based on 3GPP Standard 3GPP TS 22.104, 3GPP TR 22.261, and 3GPP TR 22.829.)

AR Assistance Requirement	Attribute
Bandwidth	Maintenance guidance: downstream>50Mbps upstream > 20Mbps downstream>50kbps Auxiliary assembly: >50Mbps downstream: 1Mbps~30Mbps
One-way maximum delay	Maintenance guidance:20ms Auxiliary assembly:10ms
Maximum jitter	Less than 500 us
Availability	99.999%

Figure 4: Requirements of AR Assistance

3.1.2. Requests to the IETF

- * Real-time remote monitoring, which requires high-speed connectivity
- * Cloud-based deployment, which requires transmission through heterogeneous networks
- * Cloud-based centralized management
- * Remote control is jitter sensitive, e.g. less than 100us
- * Industrial camera images with high definition, with little or no compression, which requires high bandwidth
- * Low end-to-end delay requirements differ from applications and services, such as 10ms and 20ms

3.2. High Experience Video

3.2.1. Use Case Description

High Experience Video refers to video content that delivers an exceptional viewing experience through advanced technologies and production techniques. It demands high-quality transmission to ensure that the content is delivered without compromising its integrity and impact. High Experience Video relies on deterministic networks to deliver the best possible viewing experience, which requires a combination of low latency, low jitter, high bandwidth, and high reliability. The typical scenarios of High Experience Video involve applications that have high requirements for video quality, transmission speed, and user experience such as cloud VR and AR, cloud games and cloud live streaming.

3.2.1.1. Cloud VR and AR

Augmented Reality (AR) or Virtual Reality (VR) media applications, collectively called eXtended Reality (XR) applications place extremely high demands on network transmission including high throughput, low latency, and high reliability. The key feature of cloud VR/AR is that content and rendering is on the cloud. By utilizing the cloud capabilities, VR/AR user experience is improved and terminal costs are reduced. Cloud AR/VR services are latency sensitivity, and different levels of experience require differentiated latency. Cloud VR/AR rendering and streaming latency are divided into three parts: cloud processing, network transmission, and terminal processing. Cloud VR/AR operation latency is divided into cloud rendering latency and terminal secondary rendering and refresh rendering processes.

Moreover, AR/VR applications typically involve a large amount of data transmission, such as high-definition video streams, real-time rendering data. For some cases, a single packet loss during transmission will affect the integrity of the entire application. So AR/VR applications require ultra-low packet loss such as no more than 0.001% and for particular packets, it demands zero packet loss.

The following table describes requirements of Cloud VR/AR. (These metrics are based on 3GPP TR 22.261).

Requirement	Bandwidth	One-way maximum delay	Packet loss rate
Cloud VR/AR Video comfortable experience	downstream >75Mbps	50ms	no more than 0.001%
Cloud VR/AR Video comfortable experience full perspective	downstream >140Mbps	50ms	no more than 0.001%
Cloud VR/AR strong interaction comfortable experience I frame and P frame	downstream >260Mbps	15ms	no more than 0.001%
Cloud VR/AR strong interaction 8K ideal experience I frame and P frame	downstream 1Gbps	8ms	no more than 0.0001%

Figure 5: The Requirements of Cloud VR/AR

3.2.1.2. Cloud Games

Cloud Game is an online gaming technology based on cloud computing technology. Cloud gaming technology enables lightweight devices with relatively limited graphics processing and data computing capabilities to run high-quality games. In cloud game scenarios, game related computing is not run on the user terminal, but on a cloud server, which renders the game scene as a video and audio stream and transmits it to the user terminal through the network. The user's cloud gaming experience relies on a high-quality, low latency network environment.

The following table describes requirements of Cloud Games:

Requirement	Bandwidth	One-way maximum delay	Video resolution
Junior level	>8Mbps	150ms	720P
3A professional level	>12Mbps	60ms	1080P
Level of esports	>40Mbps	60ms	4K

Figure 6: Requirements of Cloud Games

3.2.1.3. Cloud Live Streaming

For scenarios such as concerts, press conferences, sports events, and live events, cloud live streaming uses 5G uplink high bandwidth to transmit 8K/VR videos. Combined with various applications such as video analysis based on live streaming services, character and scene recognition, real-time presentation of athlete and event data, and VR live streaming interaction, it provides a brand new and rich event viewing experience.

The following table describes requirements of Cloud live streaming:

8K live streaming 8K video feedback	Attribute
Bandwidth	upstream>100Mbps
One-way maximum delay	200ms
Availability	99.9%
Frame rate	60

Figure 7: Requirements of Cloud Live Streaming

3.2.2. Requests to the IETF

- * High requirements for video quality and transmission speed
- * Cloud processing with real-time interaction
- * Cloud-based deployment, which requires transmission through heterogeneous networks
- * No jitter requirements
- * Packet loss is less than 0.001% or zero
- * End-to-end delay requirements differ from applications and services, such as 8ms, 15ms, 50ms, 150ms, 200ms and so on

3.3. Intelligent Computing

3.3.1. Use Case Description

Intelligent computing refers to the integration of artificial intelligence (AI) techniques with computational methods to enhance the performance, efficiency, and capabilities of computing systems. It involves the use of algorithms, machine learning models, and other AI approaches to solve complex problems, analyze large datasets, and improve decision-making processes. Intelligent Computing has specific requirements for deterministic networks to ensure reliable and predictable performance such as predictable latency, low packet loss rate, high throughput and reliability. The typical scenarios involve applications such as AI-based scientific research and autonomous vehicles and so on.

3.3.1.1. Scientific Research

Intelligent computing is used to provide computing and data analysis capabilities, which are crucial for handling large-scale scientific simulations and datasets such as astronomy, climate science, and bioinformatics. In scientific research, a large amount of computing power resources such as CPU, GPU, memory, and other P-level or higher are usually required. The network needs to provide services for data volume of 10G to 100G or above, which requires high bandwidth, high reliability and high throughput with ultra-low packet loss. Many applications in scientific research, such as remote observations, real-time data analysis, and distributed computing, require networks to provide stable low latency and high reliability. It must provide millisecond or even microsecond level latency and jitter guarantees. For example, in nuclear fusion experiments, the carrier network is required to have 99.999% availability.

Futhermore, scientific research may require massive data transmission between HPCs. The scenario of thousands of kilometers of big data migration mainly refers to the high-throughput transmission of massive data between scientific research institutions. At present, research institutions in some countries, such as the US ESnet6 and the EU EuroHPC program, are deploying wide area RDMA networks to support the construction and operation of high-performance computing and data interconnection infrastructure. In this scenario, data transmission is usually carried out regularly or in demand, with each transmission ranging from a few terabytes to several hundred terabytes, data transmission costs and security are both required.

3.3.1.2. Autonomous Vehicles

Intelligent computing is used in the development of self-driving cars, which rely on AI algorithms for perception, decision-making, and control. Autonomous vehicles refers to the technology of vehicles that are capable of navigating without the need for human input such as identifying other vehicles, pedestrians, and traffic signals. It relies heavily on deterministic forwarding to ensure safe, efficient, and reliable operation. It is also challenging for big data management of autonomous driving. Vehicles record data from 4K HD cameras, laser scanners, and radars on the road. Each vehicle can generate 80TB of data per day, which requires data-intensive transmission.

V2X (Vehicle-to-Everything) is a fundamental component of the autonomous driving ecosystem, providing the necessary communication backbone that enables vehicles to interact with their environment in a safe and efficient manner. V2X provides the communication infrastructure that enables vehicles to exchange information with each other (V2V), with roadside infrastructure (V2I), with pedestrians (V2P), and with the network (V2N). This exchange of information is crucial for autonomous vehicles to make informed decisions, improve navigation accuracy, and enhance overall road safety. The following table describes requirements of 5G V2X which is divided into four scenarios. (These metrics are based on 3GPP TR 22.886)

Requirement	Communication Delay	Availability
Vehicles Platooning	10~25ms	99%~99.99%
Extended Sensors	3~100ms	99%~99.999%
Advanced Driving	3~100ms	99%~99.999%
Remote Driving	5ms	99.999%

Figure 8: The Requirements of Autonomous Vehicles

3.3.2. Requests to the IETF

- * Real-time communication

- * Data-intensive transmission with high-throughput and ultra-low packet loss
- * Low bounded latency, such as us~ms
- * High availability, such as 99.999%

3.4. ISAC-Enabled Smart Factory

3.4.1. Use Case Description

A Smart Factory enabled by Integrated Sensing and Communication (ISAC)-enabled cellular networks utilizes Radio Frequency (RF) signals (aka Sensing Signals) to construct an environmental mapping, detect and track objects, enable precise localization, and facilitate collision avoidance for Autonomous Guided Vehicles (AGVs) and robotic systems. ISAC systems encompass one or more Sensing Transmitters (Tx) that transmit sensing signals and one or more Sensing Receivers (Rx) that generate Sensing Data. Sensing Data are used in the cellular network to describe the detected target objects in shape, location, orientation, material, and spatial relationships among each other. Sensing Data are then exposed to the Sensing Service Consumer that requested them and are used for real-time monitoring and decision-making by a Sensing Service Consumer. This reduces reliance on dedicated sensors while optimizing communication resources. Similar use cases have been considered in ETSI ISG ISAC. The described workflow shown in Figure and illustrates a DetNet-enabled cellular network as described in 3GPP TS 23.501, that contains core network (CN) and Sensing Rx, e.g., user equipment (UE) or base station (BS), and a Sensing Service Consumer operating.

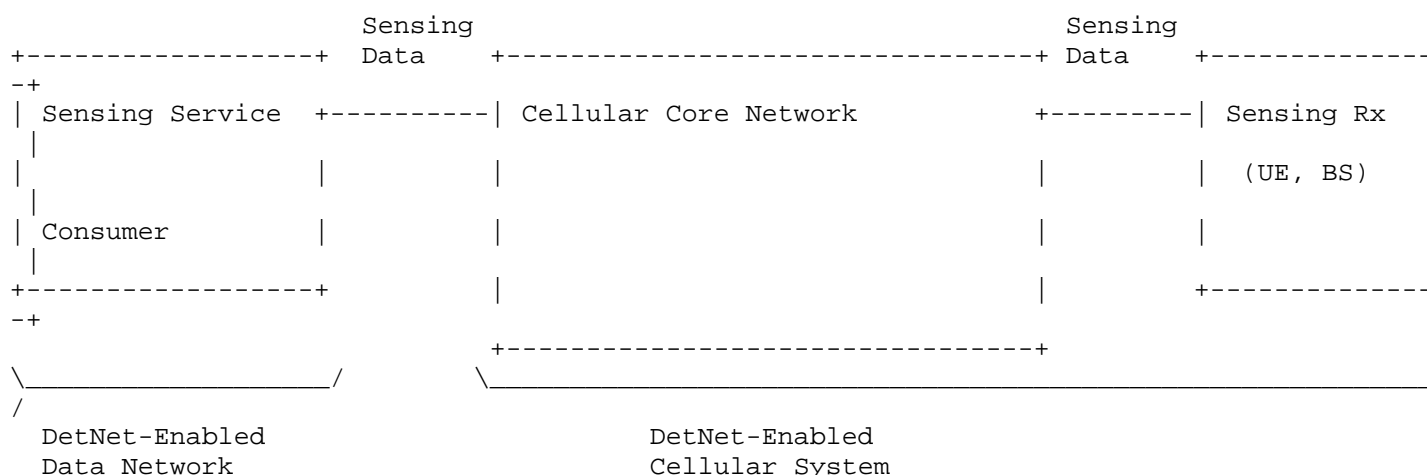


Figure 9: Sensing Rx in the smart factory generating Sensing Data from the Sensing Signals and sending it to a cellular core network and Sensing Service Consumer for real-time decision making

DetNet is critical for ensuring low-latency, bounded jitter, and high-reliability exchange of Sensing Data between Sensing Rx's and the network. The Sensing Data extracted from Sensing Signals at the Sensing Rx must be delivered deterministically to enable accurate and timely control of factory operations, such as predictive maintenance, AGVs coordination, safety enforcement, and autonomous route planning for AGVs.

3.4.1.1. Predictive Maintenance

Predictive maintenance in a Smart Factory leverages ISAC to detect early signs of equipment wear, misalignment, or failures by analyzing environmental changes. The system can monitor machine vibrations, structural integrity, and operational anomalies.

To enable real-time fault detection and proactive maintenance, the network must support low-latency, high-reliability, and deterministic data delivery to ensure timely analysis and decision-making. Delays or packet loss in Sensing Data transmission can result in missed failure indicators, leading to unplanned downtime and costly repairs.

Requirement	Attributes
Bandwidth	10Mbps~1Gbps (depending on sensing resolution)
One-way delay	less than 5ms (for real-time anomaly detection)
Maximum jitter	less than 50us(to ensure stable data transmission)
Availability	99.999%(to prevent data loss and ensure continuous monitoring)

Figure 10: The Requirements of Predictive Maintenance

3.4.1.2. Real-Time Process Optimization

In a Smart Factory, real-time process optimization relies on sensing to dynamically adjust production parameters, robotic operations, and workflow scheduling based on real-time environmental and operational data. Processed Sensing Data measured from Sensing Signals are used to provide instantaneous feedback on equipment status, material flow, and environmental conditions, enabling adaptive decision-making to maximize efficiency and reduce downtime.

To ensure precise control and automation, the network must provide ultra-low latency, deterministic jitter, and high availability to support time-sensitive end-to-end data exchange between sensing receivers and the cellular network and between the cellular network and the control systems. Any delay or jitter in data transmission can lead to inefficiencies, product defects, or production line disruptions.

Requirement	Attributes
Bandwidth	100 Mbps~10 Gbps (depending on sensing resolution)
One-way delay	less than 1ms (for closed-loop process control)
Maximum jitter	less than 10us(for precise synchronization)
Availability	99.999%

Figure 11: The Requirements of Real-Time Process Optimization

3.4.1.3. Safety Control and Maintenance

Safety control in a Smart Factory relies on ISAC-enabled RF-based sensing to detect potential hazards, such as worker proximity to dangerous machinery, unexpected obstacles in AGV paths, or emergency situations like fires or equipment failures. Unlike traditional sensor-based systems, ISAC uses Sensing Signals (RF or non-RF) to track moving objects, monitor workspaces, and trigger real-time safety mechanisms without requiring additional sensing infrastructure.

To ensure instantaneous hazard detection and response, the network must support ultra-low latency, high availability, and deterministic jitter in and end-to-end fashion to guarantee timely activation of emergency protocols, such as stopping machines, rerouting AGVs, or alerting human operators. Any delay or packet loss when exchanging Sensing Data between Sensing Rxs and the cellular network or exchanging Sensing Results between the cellular network and the application could result in serious safety risks, including workplace accidents and equipment damage.

Requirement	Attributes
Bandwidth	100 Mbps~10 Gbps (for real-time updates)
One-way delay	less than 1ms (for immediate hazard response)
Maximum jitter	less than 10us(for precise situation)
Availability	99.999999%

Figure 12: The Requirements of Real-Time Process Optimization

3.4.1.4. Interconnection of Time Sensitive Domains

Some industrial production environments are basing their internal communications on layer-2 Time Sensitive Networking. The deterministic behavior is then constrained into the boundaries of the factory domains.

However, it can be of interest to interconnect such domains for centralizing applications or functions relevant to the production context. In order to do so, it is necessary to guarantee deterministic behavior as well in the network used for interconnecting such domains.

[5G-ACIA] describes some initial scenarios of DetNet and TSN interworking. The purpose of this use case is to allow the practical interconnection of such domains. The expectation is that the interconnection of those domains handle the flows exiting the TSN domains providing bounded latency and extremely low losses when passing through the DetNet domain in a transparent manner.

3.4.2. Requests to the IETF

To support Smart Factory ISAC use cases, the following enhancements to DetNet are required:

- * Ultra-low latency networking (as low as 1ms) for closed-loop control and real-time process optimization.
- * Stringent jitter requirements (as low as 10us) to support precise sensing-based control.
- * High bandwidth support (up to 10Gbps) for high-resolution sensing data transmission.

- * High availability (up to 99.999999%) to ensure robust industrial operations.
- * Provide bounded latency for TSN flows
- * Provide low packet losses, as low as the frame losses in TSN

DetNet should provide predictable and deterministic communication for ISAC-enabled Smart Factories, ensuring timely and precise Sensing Data delivery for industrial automation and control operations.

4. Use Case Common Themes

4.1. Requirements with Deterministic Classification

The above applications differ in the network ranges and SLAs requirements such as bounded latency, jitter, bandwidth, availability and packet loss. The classification should consider the characteristics such as traffic specification and service requirements. The following table summarizes deterministic requirements of industrial internet, cloud video and intelligent computing applications, etc.

Use Cases		Typical	Differentiated Deterministic Requirements					
		Applications	Bandwidth	Delay	Jitter	Packet Loss	Avail	
ability								
1 Medium high -high high	Industrial	Machine Vision	Low	Low	N/A	N/A	Med	
	Internet							
		Remote Control	Low	Low	Ultra-low	N/A	Hig	
		AGV Control	Low~High	Low~Medium	N/A	N/A	Ultra	
		AR Assistance	Low	Low	Ultra-low	N/A	Hig	
2 A	High	Cloud VR and AR	Medium	Low	N/A	Ultra-low	N/	
	Experience		~High			or zero		
	Video							
		Cloud Games	Low	High	N/A	N/A	N/A	
		Cloud Live Streaming	Medium	High	N/A	N/A	Med	
3 a-high	Intelligent	Scientific Research	Ultra-high	Low	N/A	Ultra-low	Ultr	
	Computing					or zero		
		Autonomous Vehicles	Ultra-high	Low	N/A	Ultra-low	Ultr	
						or zero		
4 gh	ISAC-Enabled	Predictive	Medium	Ultra-low	Ultra-low	Ultra-low	Hi	
	Smart	Maintenance	~High					
	Factory							
		Real-Time Process	Medium	Ultra-low	Ultra-low	Ultra-low	Hi	
		Optimization	~High					

gh		Safety Control	Medium	Ultra-low	Ultra-low	Ultra-low	Hi
		and Maintenance	~High				

Figure 13: Characteristics of Typical Applications

Since the DetNet applications differ in their requirements, it demands specific desired deterministic behaviors. The flow aggregation based on the classification of deterministic services should be taken into considerations as discussed in [I-D.xiong-detnet-flow-aggregation]. It is required to provide latency, bounded jitter and packet loss dynamically and flexibly in all scenarios for each characterized flow.

4.2. Requirements with Ultra-low or Zero Packet Loss

Some high-throughput, low-latency applications such as intelligent computing demand ultra-low packet loss which is critical to ensure real-time data processing, maintain data integrity, optimize resource utilization, and support scalable and reliable operations. And some applications such as AR/VR do not fit as payload into a single IP packet and may be fragmented into multiple smaller chunks as discussed in [I-D.rc-detnet-data-unit-groups]. It demands zero packet loss for some chunks while a single packet loss can lead to the loss of the whole application. The DetNet node should provide the deterministic behavior to perform any DetNet queuing, shaping, scheduling, ordering or dropping to guarantee the packet loss on particular packets.

5. Security Considerations

Security considerations for DetNet are covered in the DetNet Architecture [RFC8655] and DetNet use cases [RFC8578] and DetNet security considerations [RFC9055].

6. IANA Considerations

This document makes no requests for IANA action.

7. Acknowledgements

The authors would like to acknowledge Aihua Liu and Bin Tan for their thorough review and very helpful comments.

Appendix A. Simulation Results in Scientific Research

The throughput of RDMA over network in scientific research application is verified with different performances such as distance, message size, latency and packet loss. The simulation result shows that, the throughput of RDMA over 1000 kilometers is directly proportional to the length of message size, and inversely proportional to the network packet loss rate and latency. To ensure 80% throughput of links over 100Gbps and 1000 kilometers, the message length needs to be greater than 512KB, resulting in extremely strict packet loss rate indicators due to increased latency.

A.1. Simulation for the Long Distance and Latency

The impact of long distance and latency on throughput performance is shown in Figure 14. The selection of delay parameters in this experiment is mainly aimed at wide area scenarios of 100-2000 km, with round trip time (RTT) of 1-20 ms.

As latency increases (1-20 ms), the RDMA message size needs to be continuously increased to achieve high-performance transmission with 100% throughput. Due to the maximum message length of 2 GB, a bandwidth of 100 Gbit/s can be achieved without loss, satisfying the throughput theoretical calculation equation (1).

$$\text{Throughput} = \text{Window_Size} / \text{RTT} \quad (1)$$

The overall analysis shows that by adjusting RDMA parameters (such as message length), high-performance transmission of 1000km (with over 90% throughput) can be achieved. The message length setting is actually related to the specific network application, device buffer, and buffer threshold settings, and the increase of message length is unlimited.

RTT latency	message length(byte)	distance	Throughput(Gbps)
less than 1ms	less than 1024	less than 100km	more than 90% @ 100Gbps
1ms	256K	100km	more than 90% @ 100Gbps
2ms	512K	200km	more than 90% @ 100Gbps
5ms	1M	500km	more than 90% @ 100Gbps
10ms	8M	1000km	more than 90% @ 100Gbps

Figure 14: The Impact of Long-distance Delay on Throughput

A.2. Simulation for the Latency and Packet Loss

The traditional RDMA adopts the Go-Back-N retransmission mechanism, which retransmits all data packets after the dropped data packet N. Loss of packets can cause significant performance degradation in RDMA. However, TCP only needs to retransmit lost individual packets, and the latest RDMA network cards have started using selective repeat. Therefore, the calculation formulas for TCP packet loss rate (p), latency, and bandwidth can be referred to:

$$\text{Throughput} = \text{Min}\{\text{MSS} / \text{RTT} * C * (1/P)\} \quad (2)$$

The actual testing performance of RDMA differs from that of TCP, and the main impact of wide area networks is latency, with retransmission and congestion control algorithm models being similar. Therefore, the theoretical rate of RDMA is empirically judged by adjusting the value of parameter C in equation (2) (TCP empirical value C is 1.0).

When both bigger delay and packet loss coexist and over 80% throughput of a 100G link, the packet loss rate in the data center must be less than 0.005%. In the scenario of wide area interconnection in DCs, due to the increase in retransmission cost and response time caused by basic line delay, the packet loss threshold is more strict and harsh in the data center, requiring the network to achieve lossless as much as possible. In a wide area scenario, even with the optimization algorithm of selective retransmission, it is difficult to achieve a bandwidth utilization rate of over 70% when the packet loss rate is less than 0.001%.

References

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