DETNET
Internet-Draft
Intended status: Standards Track
Expires: 27 August 2026

J. Zhao
CAICT
Q. Xiong
ZTE Corporation
Z. Du
China Mobile
M. Jadoon
InterDigital
L.M. Contreras
Telefonica
23 February 2026

# Enhanced Use Cases for Scaling Deterministic Networks
draft-zhao-detnet-enhanced-use-cases-05

## 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.

## Status of This Memo



## Copyright Notice

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 for DetNet Multi-domains . . . . . . . . . . . 17
  4.2. Requirements for DetNet Service Classification . . . . . . 18
  4.3. Requirements for Ultra-low or Zero Packet Loss . . . . . . 20
5. Security Considerations . . . . . . . . . . . . . . . . . . . 20
6. IANA Considerations . . . . . . . . . . . . . . . . . . . . . 20
7. Acknowledgements . . . . . . . . . . . . . . . . . . . . . . . 20
Appendix A. Simulation Results in Scientific Research . . . . . 21

A.1.  Simulation for the Long Distance and Latency . . . . . . 21
A.2.  Simulation for the Latency and Packet Loss . . . . . . . . 22
References . . . . . . . . . . . . . . . . . . . . . . . . . . 22
Informative References . . . . . . . . . . . . . . . . . . . . 23
Authors' Addresses . . . . . . . . . . . . . . . . . . . . . . 24

# 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,<br>Real time communication:1Mbps~200Mbps<br>Visual: 10Mbps~1Gbps |
| One-way maximum delay | Schedule communication:100ms<br>Dispatching communication:100ms<br>Real time communication:20ms~40ms<br>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:<br>downstream>50Mbps<br>upstream > 20Mbps<br>downstream>50kbps<br>Auxiliary assembly: >50Mbps<br>downstream: 1Mbps~30Mbps |
| One-way maximum delay | Maintenance guidance:20ms<br>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 multiple 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 it affect the integrity of the entire application. So AR/VR applications require ultra-low packet loss such as no more then 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<br>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 multiple 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.

Furthermore, 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 Rxs, e.g., user equipment (UE) or base station (BS), and a Sensing Service Consumer operating.

```
                      Sensing                                    Sensing
+-------------------+  Data    +----------------------------------+ Data    +--------------
-+
| Sensing Service  +----------| Cellular Core Network           +---------| Sensing Rx
 |
|                  |          |                                  |         |  (UE, BS)
 |
| Consumer         |          |                                  |         |
 |
+------------------+          |                                  |         +--------------
-+
                              +----------------------------------+
\___________________/        \___________________________________________________________
/
  DetNet-Enabled                        DetNet-Enabled
  Data Network                          Cellular System
```

Figure 9: Sensing Rx in the smart factory generating Sensing Data from the Sensing Signals and sending it to a 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 Rxs 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, is 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

* Requires DetNet and TSN interworking

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 for DetNet Multi-domains

Many applications require deterministic connectivity that spans multiple networks such as industrial automation, professional audio/video and electrical utilities described in [RFC8578]. And the applications mentioned in this document also have the multi-domains requirements for DetNet such as remote control, cloud VR and AR and ISAC-enabled smart factory. These networks may be operated by different administrative domains, utilize varying underlying link-layer technology domains (e.g.IP/MPLS, TSN, and RAW), or be deployed as different control areas to ensure scalability through multiple centralized controllers.

The networks and nodes in local area networks may be interconnected with heterogeneous wide area networks such as DetNet and TSN interworking. For example, in ISAC-enabled smart factory, factory domains may be interconnected for centralizing applications or functions relevant to the production context. The cross-domain scenarios are also particularly important in industrial internet, where control systems need to span multiple facilities or production lines. The different administrative domains need to be interconnected to achieve unified control over distributed systems, enabling efficient resource management and real-time decision-making. And cloud-based deployment also requires transmission through multiple heterogeneous networks when when organizations need to integrate distributed resources and applications across different network environments, enabling unified management and seamless operation of hybrid cloud architectures.

The primary challenge lies in maintaining deterministic behavior across domain boundaries, where traffic from one domain must seamlessly flow through another domain while preserving bounded latency and low packet loss rates. The [I-D.bernardos-detnet-multi-domain-pce] discusses the framework and the specific requirements on multi-domain DetNet solutions.

## 4.2. Requirements for DetNet Service 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 Applications | Differentiated Deterministic Requirements | | | | |
|---|---|---|---|---|---|---|---|
| | | | Bandwidth | Delay | Jitter | Packet Loss | Availability |
| 1 | Industrial Internet | Machine Vision | Low | Low | N/A | N/A | Medium |
| | | Remote Control | Low | Low | Ultra-low | N/A | High |
| | | AGV Control | Low~High | Low~Medium | N/A | N/A | Ultra-high |
| | | AR Assistance | Low | Low | Ultra-low | N/A | High |
| 2 | High Experience Video | Cloud VR and AR | Medium ~High | Low | N/A | Ultra-low or zero | N/A |
| | | Cloud Games | Low | High | N/A | N/A | N/A |
| | | Cloud Live Streaming | Medium | High | N/A | N/A | Medium |
| 3 | Intelligent Computing | Scientific Research | Ultra-high | Low | N/A | Ultra-low or zero | Ultra-high |
| | | Autonomous Vehicles | Ultra-high | Low | N/A | Ultra-low or zero | Ultra-high |
| 4 | ISAC-Enabled Smart Factory | Predictive Maintenance | Medium ~High | Ultra-low | Ultra-low | Ultra-low | High |
| | | Real-Time Process Optimization | Medium ~High | Ultra-low | Ultra-low | Ultra-low | High |

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

Figure 13: Characteristics of Typical Applications

Since the DetNet applications differ in their requirements, it demands specific desired deterministic behaviors. The DetNet flows MAY be classified based on the service SLAs requirements of applications in scaling networks as per [I-D.xiong-detnet-differentiated-detnet-qos]. 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.

### 4.3. Requirements for 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, Bin Tan, Lou Berger and Janos Farkas 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).

Throughput = Window_Size/RTT (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 than90%@100Gbps |
| 1ms | 256K | 100km | more than90%@100Gbps |
| 2ms | 512K | 200km | more than90%@100Gbps |
| 5ms | 1M | 500km | more than90%@100Gbps |
| 10ms | 8M | 1000km | more than90%@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:

Throughput = Min{MSS/RTT*C*(1/P)} (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 basical 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

Informative References

[I-D.bernardos-detnet-multi-domain-pce]
Bernardos, C. J., Contreras, L. M., Xiong, Q., and A. Mourad, "A PCE-based Control Plane Framework for Multi-Domain Deterministic Networking (DetNet)", Work in Progress, Internet-Draft, draft-bernardos-detnet-multi-domain-pce-00, 16 October 2025, <https://datatracker.ietf.org/doc/html/draft-bernardos-detnet-multi-domain-pce-00>.

[I-D.ietf-detnet-scaling-requirements]
Liu, P., Li, Y., Eckert, T. T., Xiong, Q., Ryoo, J., zhushiyin, and X. Geng, "Requirements for Scaling Deterministic Networks", Work in Progress, Internet-Draft, draft-ietf-detnet-scaling-requirements-09, 7 September 2025, <https://datatracker.ietf.org/doc/html/draft-ietf-detnet-scaling-requirements-09>.

[I-D.rc-detnet-data-unit-groups]
Robitzsch, S. and L. M. Contreras, "Data Unit Groups for DetNet-Enabled Networks", Work in Progress, Internet-Draft, draft-rc-detnet-data-unit-groups-00, 21 October 2024, <https://datatracker.ietf.org/doc/html/draft-rc-detnet-data-unit-groups-00>.

[I-D.xiong-detnet-differentiated-detnet-qos]
Xiong, Q., Zhao, J., Du, Z., Zeng, Q., and C. Liu, "Differentiated DetNet QoS for Deterministic Services", Work in Progress, Internet-Draft, draft-xiong-detnet-differentiated-detnet-qos-01, 27 June 2024, <https://datatracker.ietf.org/doc/html/draft-xiong-detnet-differentiated-detnet-qos-01>.

[I-D.xiong-detnet-flow-aggregation]
Xiong, Q., Jiang, T., and J. Joung, "Flow Aggregation for Enhanced DetNet", Work in Progress, Internet-Draft, draft-xiong-detnet-flow-aggregation-03, 14 October 2025, <https://datatracker.ietf.org/doc/html/draft-xiong-detnet-flow-aggregation-03>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8578] Grossman, E., Ed., "Deterministic Networking Use Cases", RFC 8578, DOI 10.17487/RFC8578, May 2019, <https://www.rfc-editor.org/info/rfc8578>.

[RFC8655] Finn, N., Thubert, P., Varga, B., and J. Farkas, "Deterministic Networking Architecture", RFC 8655, DOI 10.17487/RFC8655, October 2019, <https://www.rfc-editor.org/info/rfc8655>.

[RFC8664] Sivabalan, S., Filsfils, C., Tantsura, J., Henderickx, W., and J. Hardwick, "Path Computation Element Communication Protocol (PCEP) Extensions for Segment Routing", RFC 8664, DOI 10.17487/RFC8664, December 2019, <https://www.rfc-editor.org/info/rfc8664>.

[RFC9055] Grossman, E., Ed., Mizrahi, T., and A. Hacker, "Deterministic Networking (DetNet) Security Considerations", RFC 9055, DOI 10.17487/RFC9055, June 2021, <https://www.rfc-editor.org/info/rfc9055>.

[RFC9320] Finn, N., Le Boudec, J.-Y., Mohammadpour, E., Zhang, J., and B. Varga, "Deterministic Networking (DetNet) Bounded Latency", RFC 9320, DOI 10.17487/RFC9320, November 2022, <https://www.rfc-editor.org/info/rfc9320>.

Authors’ Addresses

Junfeng Zhao
CAICT
China
Email: zhaojunfeng@caict.ac.cn

Quan Xiong
ZTE Corporation
China
Email: xiong.quan@zte.com.cn

Zongpeng Du
China Mobile
China
Email: duzongpeng@chinamobile.com

Muhammad Awais Jadoon
InterDigital
Email: Muhammad.AwaisJadoon@InterDigital.com

Luis M. Contreras
Telefonica
Email: luismiguel.contrerasmurillo@telefonica.com