A Survey of Deterministic Networking

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Abstract

In networking research areas, real-time applications such as industrial networking, as well as audio and video streaming meet a fast-growing demand. To fulfill the demand of latest industrial use-cases, the Deterministic Networking (DetNet) workgroup is working on the implementation of Deterministic Networking, which provides real-time, deterministic services meet the boundary of data loss rates, jitter, and latency. This paper will introduce the goals, architecture, and a few use cases of DetNet.

keywords

Deterministic Networking, DetNet, real-time Ethernet communication, Time-Sensitive Networking, DetNet applications, DetNet architecture, routing area

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1. Introduction

As real-time applications like industrial networking as well as audio and video streaming moving into digital world, they met a fast-growing demand in the latest years. The Internet Protocol (IP), due to its design, only provides "Best-effort" service, which with bandwidth limitation, latency issue flow control, etc., is unreliable. To fulfill the demand of the latest industrial use-cases, the DetNet workgroup is working on the implementation of Deterministic Networking, which provides real-time, deterministic services to meet the boundary of data loss rates, jitter, and latency [RFC8578].

As the basis of Deterministic Networking, IEEE 802.1 Time-Sensitive Networking (TSN) and Audio Video Bridging (AVB) work on time-critical, low latency, synchronized, and reliable communications [TSN], having the common requirements at Layer 2. In cooperation with TSN, DetNet workgroup is responsible for the implementation at Layer 3, focusing on the architecture of DetNet, OAM, time-synchronization, low latency of packets, low loss of packets and high reliability [RFC8557] [Addanki20]. DetNet workgroup modifies the standards of data plane that can be implemented at Layer3 and the encapsulated over Layer 2, such as IP or MPLS through the encapsulation of GRE or pseudo wires [DetNet].

In this paper, Section 2 will introduce the goals of DetNet, which will introduce the demands and characteristics of DetNet. Section 3 will show the architecture of DetNet, mainly focus on the 2-layer structure of data plane. Section 4 will discuss a few use cases of DetNet in industrial applications.

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2. Goals

The main goal of DetNet is to implement the function of building a multi-hop path over IP and/or MPLS, which should accomplish the demands of restricted timing and throughput. In the meantime, to fulfill the requirements of low latency, congestion loss and jitter, high percentage of successful delivery in numerous characteristics of networking flows [RFC8557].

2.1 Requirements

In current network industries, a few attributes are commonly required by multiple sorts of applications, including the synchronization of time, deterministic packet flow, transmission operations of critical packets, protection from irregular nodes and multiple retained resources [Wikipedia01].

A deterministic packet flow consists of such characteristics:
1. Low packet loss: On Ethernet, it can achieve 10-9 to 10-12 of packet loss rate and 10-5 on wireless networks.
2. Latency: Require hard boundary of latency and tight jitter.
3. Bandwidth: Occupy at least half of reachable bandwidth.

4. Either multicast or unicast.
5. Other timing restrictions: Transmission latency such as congestion feedback are not acceptable.

2.2 Researching fields

DetNet mainly focus working on such fields: Data plane: Assisting Packet forwarding and data plane at Layer 3, using IP and/or MPLS. Controller plane [RFC8655]: The integration of management plane and control plane, assisting DetNet through IETF control plane. Information model for data flow: When setting up data flow, DetNet distinguish the information of operating and founding. Architecture: Consisting of time synchronization, OAM, data, management and control planes and safety components. YANG models: For usage in condition stating and device management.

2.3 Summary

This section discussed the goals of DetNet to meet demands of restricted timing and throughput, low latency, congestion loss and jitter, high percentage of successful delivery and the requirements in current networking industries and major research area of DetNet workgroup.

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3. Architecture

Deterministic Network consists of end systems, edge nodes and relay nodes, providing DetNet services. Edge and relay nodes are connected by transit nodes, but transit nodes are not supported by DetNet services. Including point-to-point links, all DetNet are attached to sub-networks. A DetNet data plane is constructed by DetNet service and forwarding sub-layers. The former one provides service including PW, UDP, GRE, and the other offers IPv6, IPv4, MPLS, etc. [RFC8655].

3.1 DetNet concept network

In a Deterministic Network, exists three main components: end systems, relay nodes and edge nodes, as you can see in Figure 3-1, a simple architecture of DetNet concept network, in which "Service" and "Svc" represent DetNet service sub-layer, "Forwarding" and "Fwd" represent for DetNet forwarding sub-layer. In this figure, you can also find the transit nodes, which provide the connection between edge nodes and relay nodes, but not able to aware DetNet.

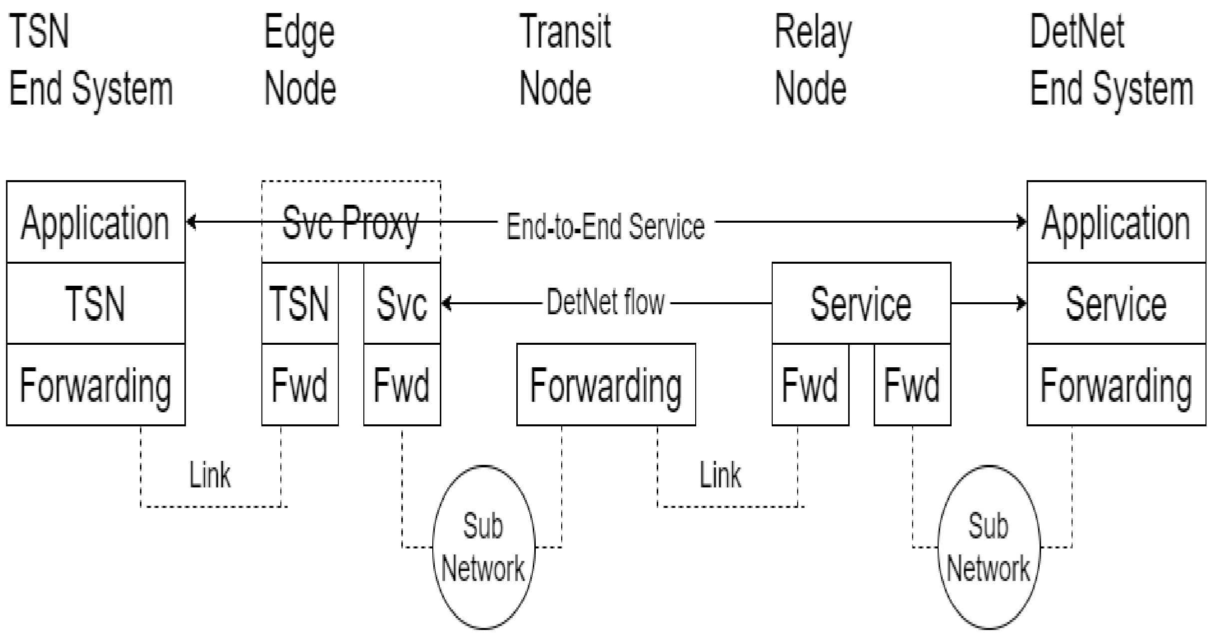

Figure 1 DetNet concept network [RFC8655]

3.2 DetNet service-related model

In this section, another observation of DetNet is shown in Figure 3-2, a DetNet service-related model with abstract components and points. DetNet UNI (U) provides the connection over data packets.

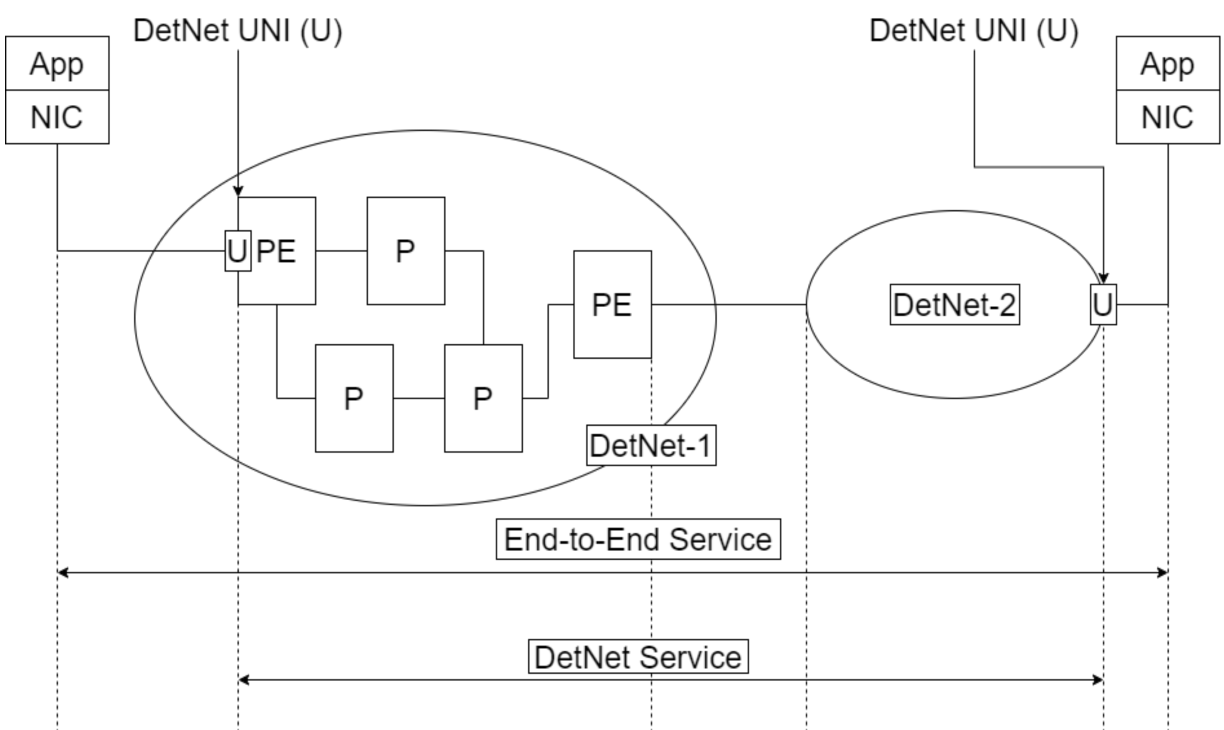

Figure 2 DetNet service-related reference model [RFC8655]

DetNet UNIs can offer multiple features, including encapsulation, status of resources, synchronization, signaling for reservation.

3.3 DetNet stack model

DetNet consists of two sub-layers: service sub-layer and forwarding sub-layer. As you can see in Figure 3-3, the stack model of DetNet, presenting such features:
1. Presenting "source" and "destination".
2. Service sub-layer: Packet sequencing, duplicate elimination, flow replication and merging, packet encoding and decoding.
(1) Packet sequencing: For security of DetNet, when doing packet replication and elimination, this function calculates the sequence number of packets.
(2) Duplicate elimination: According to the sequence number of packets, this function will drop those packets with duplicate numbers. Besides, it can also operate the member and compound flows.
(3) Flow replication and merging: These two functions are duel to each other. Packets will be replicated in flow replication function into multiple DetNet member flows. On contrary, flow merging function combines them.
(4) Packet coding and decoding: As a backup plan of flow replication and merging, they combine/calculate the origin of the information from packets.
3. Forwarding sub-layer: Resource allocation and explicit routes.
(1) Resource allocation: The service of resource allocation in forwarding sub-layer.
(2) Explicit routes: Preventing from network convergence in DetNet.

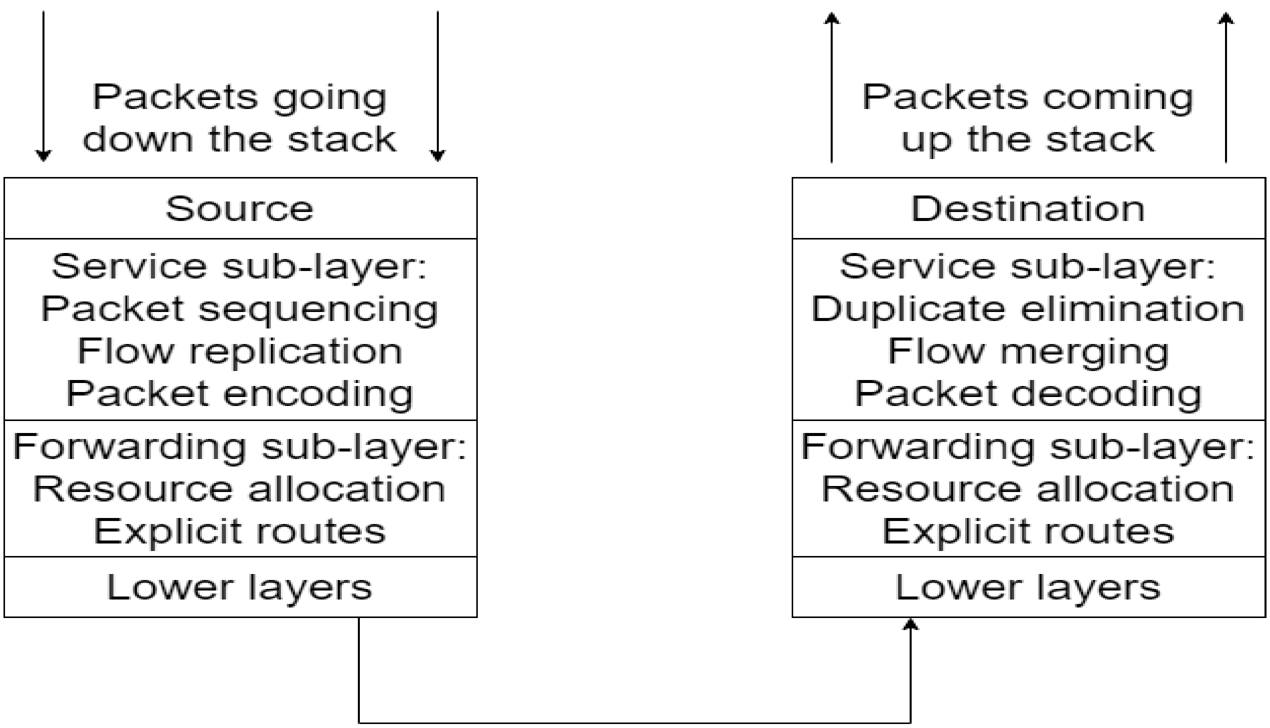

Figure 3 DetNet protocol stack [RFC8655]

3.4 Summary

This section discussed the components of DetNet: end systems, edge nodes and transit nodes, which was presented in two views. Furthermore, the to layers of DetNet: service sub-layer and forwarding sub-layer. By presenting the stack model of these two layers, we mentioned packet sequencing, duplicate elimination, flow replication and merging, packet coding and decoding, resource allocation, and explicit routes functions of these two layers.

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4. Use case

Deterministic network has the potential of being widely used in various industries, since DetNet can offer high reliable flows over multi-hop paths. The characteristics should be addressed to each use case are description of the use case, current solution, future solution and how can IETF support this use case [RFC8578] .

4.1 Building Automation Systems

Building Automation System (BAS) controls the equipment and sensors in the building to improve the comfort of residents, reduce energy consumption, and respond to accidents and emergencies.

For example, BAS uses sensors to detect the temperature of a room. Then, it controls HVAC to keep temperature constant and minimize energy consumption. The on-site network of the system uses delay-sensitive physical interfaces. Ethernet or wireless network transformation cannot be used if the network is not deterministic. Furthermore, different types of sensors included in the system also demand very strict and precise communication latency to ensure the safety of the building.

4.2 Pro Audio and Video

In audio and video industry, more and more demands for uninterrupted streaming, synchronized playback, and echo cancellation of network application emerge in recent years. On the other hand, the interconnections are changing from point-to-point hardware into wireless ones, to reduce the cost while rising flexibility. Thus, in foreseeable future, the industry has greater requirements for Deterministic Networks.

For example, broadcasting, audio and video production studios, cinemas, live broadcasting, live concerts, public broadcasting media and emergency systems in large venues (airports, churches, theme parks, stadiums).

4.3 Summary

This section discussed two use cases of DetNet: BAS as well as Pro Audio and Video. With the wide availability and flexibility of DetNet, other use cases include Electrical Utilities, Wireless for Industrial Applications, Machine to Machine, etc.

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5. Summary

In summary, this paper introduces the most representative technologies and research results in Deterministic Networking. The advance DetNet of fulfills the demands of low packet loss and low latency in industrial networking. Compared with TSN at Layer 2, it is expected that DetNet at Layer 3 will obtain larger scale and higher complexity.

Acronyms

DetNet	Deterministic Networking
IP	Internet Protocol
TSN	Time-Sensitive Networking
AVB	Audio Video Bridging
OAM	Administration, and Maintenance
MPLS	Multiprotocol Label Switching
GRE	Generic Routing Encapsulation
IETF	Internet Engineering Task Force
YANG	Yet Another Next Generation
NIC	Network Interface Card
UNI	User-Network Interface
PW	Pseudowir
UDP	User Datagram Protocol
IPv6	Internet Protocol version 6
IPv4	Internet Protocol version 4
BAS	Building Automation System
HVAC	Heating, Ventilation, and Air Conditioning

References

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

[TSN] Time-Sensitive Networking (TSN) Task Group https://1.ieee802.org/tsn/.

[RFC8557] Finn, N. and P. Thubert, "Deterministic Networking Problem Statement", RFC 8557, DOI 10.17487/RFC8557, May 2019, https://www.rfc-editor.org/info/rfc8557.

[Addanki20] V. Addanki and L. Iannone, "Moving a step forward in the quest for Deterministic Networks (DetNet)," 2020 IFIP Networking Conference (Networking), 2020, https://ieeexplore.ieee.org/document/9142788.

[DetNet] Deterministic Networking Working Group, https://datatracker.ietf.org/wg/detnet/about.

[Wikipedia01] Deterministic Networking, https://en.wikipedia.org/wiki/Deterministic_Networking.

[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.

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