Active control and management system for providing the ultra-low latency service on deterministic networks

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***Abstract*— The ultra-low latency service provides very short network delays and can implement Internet services at the level of tactile interaction. However, in order to provide ultra-low latency end-to-end services over a long distance, the network infrastructure needs to support DetNet services. Therefore, this paper provides a reliable ultra-low latency network with limited latency and low jitter such as a DetNet network to provide such an ultra-low latency service, thereby providing a stable connection and improved network resource efficiency. In addition, this paper aims to provide an active DetNet network control and management system that can quickly adjust network resources according to predicted conditions and events to support ultra-low latency services.**

***Keywords*—ultra-low latency service, deterministic network, active control and management system, control plane, data plane**

I. INTRODUCTION

The ultra-low latency service provides very short network delays and can implement Internet services at the level of tactile interaction. Virtual reality, augmented reality, and mixed reality services, autonomous driving services for cars and aircraft, real-time remote device control services, real-time gaming services, and medical services such as remote examination and surgery are the fields of ultra-low latency services that require ultra-low latency. In order to provide ultra-low latency services, wireless access networks such as 5G study technologies that accommodates the demands of strict time delays so that extremely short transmission delays and safe data transmission can be controlled in an environment where communication subjects sending and receiving wireless data are concentrated. In addition, studies on highly reliable ultra-low-latency networks with limited latency and low jitter are in progress to provide ultra-low latency services to network infrastructure. In this regard, IEEE is in the process of standardizing Time Sensitive Networking (TSN), and IETF is in the process of standardizing Deterministic Networking (DetNet). Since TSN is limited to Layer 2, the network scalability is small, but standards adopted for specific use cases are specified, so a large part of standardization is in progress. DetNet can be extended to layer 3 or higher, so network scalability is large, but standardization is partially underway [1].

However, in order to provide ultra-low latency end-to-end services over a long distance, the network infrastructure needs to support DetNet services. DetNet service may be provided through DetNet End System (talker) requesting ultra-low latency service, DetNet Edge Node connected to DetNet End System, DetNet Relay Node that delivers DetNet service and packets, and Transit Node that delivers only DetNet packets, and DetNet End System (listener) providing a service for an ultra-low latency service request.

DetNet control and management technology is required to control and manage DetNet network nodes that provide DetNet services. The standardization organization (IETF, IEEE) provides a structure in which an independent DetNet controller such as a Software-Defined Networking (SDN) controller controls DetNet network nodes using a network configuration (NETCONF) protocol. The method in which an operator manually controls and manages DetNet network nodes using an SDN controller is not suitable as a control and management method for ultra-low latency services with limited delay time and high reliability. So, DetNet control and management system that can actively perform control and management functions for DetNet network nodes, which are highly reliable ultra-low latency network components with limited delay time and low jitter, to provide ultra-low latency services is needed.

Therefore, this paper provides a reliable ultra-low latency network with limited latency and low jitter such as a DetNet network to provide such an ultra-low latency service, thereby providing a stable connection and improved network resource efficiency. In addition, this paper aims to provide an active DetNet network control and management system that can quickly adjust network resources according to predicted conditions and events to support ultra-low latency services.

II. RELATED WORKS

IETF's DetNet is a representative wide-area time-determined networking technology. In order to overcome the spatial limitations of LAN-based narrow-area time-determined networking technology (TSN), IP/MPLS-based wide-area time-determined networking technology is being standardized [2]. DetNet's data plane has been standardized to a great extent, while the control/management plane is in the early stages.

The data plane of DetNet is composed of a service sub-layer and a forwarding sub-layer [3]. Each layer is classified according to the function provided for DetNet flow, and the service sub-layer classifies time-determined flows and provides service protection functions such as lossless delivery and rearrangement using the sequence number of the flow. Like TSN, the DetNet service protection function duplicates and

delivers packets through one or more paths, and deletes the duplicated packets through the sequence number of the received packet. The forwarding sub-layer provides resource reservation and explicit route setting functions for time-determined flows, which are the basis of wide-area time-scheduled networking technology. Resource reservation function provides all the various functions for assuring delay such as DSCP-based QoS and bandwidth allocation for time-determined flows, including narrow-area time-determined networking technologies such as filtering and policing for each stream, time-aware shaper, cyclic queuing and forwarding, and frame preemption [4]. Explicit route setting function keeps the route of the reserved time-determined flow unchanged due to recalculation of the route according to network status changes, and separates and delivers the route of time-determined flow and non-time-determined flow depending on the situation.

DetNet flows can be classified according to the required data plane layer. It is divided into a service forwarding flow that requires functions of both the service sub-layer and the forwarding sub-layer, a service flow that requires only the functions of the service sub-layer, and a forwarding flow that requires only the functions of the forwarding sub-layer.

The DetNet network is composed of an end system and a DetNet domain. The end system is divided into a DetNet aware end system and a DetNet non-aware end system. The DetNet domain consists of an edge node located at the domain boundary, and a relay node and a transit node located within the domain. DetNet-aware end system refers to an end system that can provide DetNet flow according to the information and packet format required in the DetNet domain, and the end system that does not is called a DetNet non-aware end system. The flow created by the DetNet non-aware end system is called an App flow, and the App flow includes L2 packets and IP packets. The edge node performs a service proxy function that maps the App flow received to the DetNet domain with the DetNet flow. The relay node processes the service forwarding flow or service flow transmitted from the edge node or other relay node, and the transmission node processes the forwarding flow.

As shown in Figure 1, the DetNet structure is divided into an application plane using NBI (North Bound Interface) between the end system and controller, a controller plane consisting of controller functions, and a network plane using SBI (South Bound Interface) between the controller and network nodes [3]. The application plane includes applications and services, and uses a flow management entity (FME) based on the flow information model [5] to perform service requests between the end system and the operator. The controller plane collects network topology information, network resources, and delay information. In addition, the controller plane calculates a path that satisfies the service protection and delay requirements using a controller plane function (CPF), and requests the required flow settings to the node on the calculated path. The network plane constituting the data plane represents all equipment and protocols regardless of the layer, and is generally composed of a network interface card (NIC) at the end system such as an IP host and a DetNet node such as an IP router and MPLS switch. The network plane transfers physical topology and resource information between the controller plane entity and the devices in the network plane using SBI based on the configuration YANG model [6], and sets the flow.

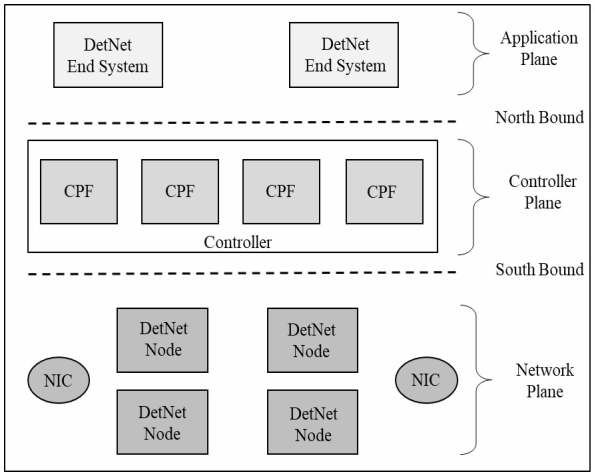

Figure 1. DetNet Architecture

III. ULTRA-LOW LATENCY SERVICE PROVISION SCENARIO

Figure 2 shows the DetNet network reference model supporting ultra-low latency service.

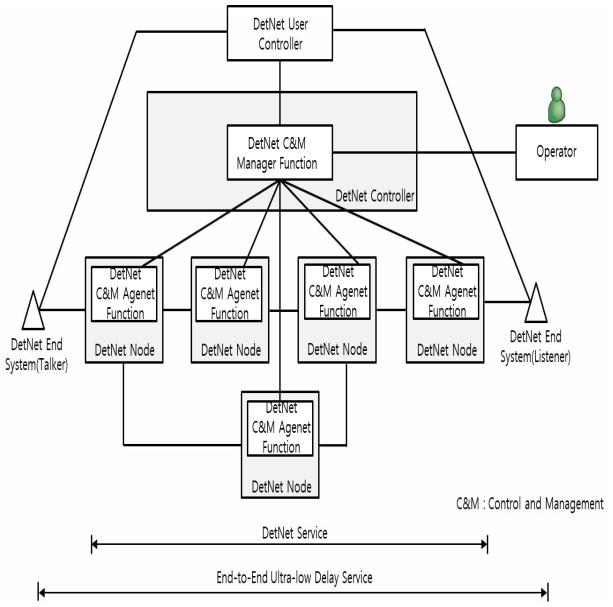

Figure 2. DetNet network reference model

DetNet network is composed of a DetNet network node (edge node, relay node, transient node), a DetNet controller that centrally controls and manages the DetNet network node, a DetNet user controller that receives requests for ultra-low latency service from the DetNet end system and requests DetNet service configuration for the corresponding ultra-low

delay service to the DetNet controller, and a DetNet end system corresponding to a transmitting terminal (talker) and a receiving terminal (listener). In Figure 2, data transfer between DetNet controller and DetNet network node uses the NETCONF protocol mechanism. In addition, YANG (Yet Another Next Generation) standardized by a standardization organization is used as a modeling language for data to be transmitted to NETCONF. And, the RESTCONF protocol mechanism is used between the DetNet controller and the DetNet user controller, and YANG is used as a modeling language for data to be transmitted to RESTCONF.

At the request of the operator, the DetNet network topology of DetNet network nodes is configured through the DetNet C&M (Control and Management) manager and agent functions. Then, when the DetNet end system makes a request to use the ultra-low latency service to the DetNet user controller, the DetNet user controller makes a DetNet service request to the DetNet controller to use this ultra-low delay service. According to the received DetNet service request, the DetNet controller makes a request to the DetNet C&M agent function located in the DetNet network node to set the resource, route, and QoS for the corresponding DetNet service by using the DetNet C&M manager function. The DetNet C&M agent function receiving a request for resource, route, and QoS configuration performs the corresponding resource, route, and QoS configuration on the corresponding DetNet network node. When the DetNet service setting is completed and the ultra-low latency service requested by the DetNet end system starts, the DetNet flow, which is a data packet corresponding to the ultra-low latency service, is delivered through the configured DetNet route.

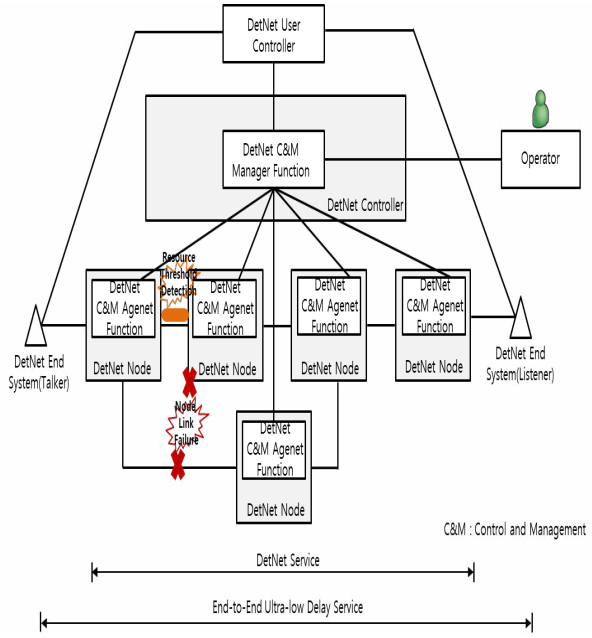

Figure 3. DetNet network reference model with resource and path problem events

However, as shown in Figure 3, there is a possibility that the bandwidth threshold may be exceeded in the route through which these DetNet flows are delivered, or the DetNet network node or link may fail.

In this way, when an event about a resource or route problem occurs, the method that the operator identifies and handles passively is not appropriate as a method that must maintain a determined delay time, such as an ultra-low latency service, and provide a reliable and safe service. So, when such a resource and route problem event occur, the resource and route problem event is transmitted to the DetNet C&M manager function located in the DetNet controller through the DetNet C&M agent function located in the DetNet network node. The DetNet C&M manager function takes action according to the conditions corresponding to this problem, establishes a new resource and route, and delivers it to the DetNet C&M agent function. The DetNet C&M agent function can then quickly resolve resource and route problems by setting up new resources and route received. Therefore, through the active DetNet network control and management system, even if resource and route problems occur in a DetNet network node, it is possible to quickly provide an ultra-low delay service with high reliability and a determined delay time.

IV. ACTIVE DETERMINISTIC NETWORK CONTROL AND MANAGEMENT SYSTEM

In this paper, as shown in Figure 4, the active DetNet control and management system is composed of DetNet controller and DetNet network nodes.

DetNet controller centrally controls and manages DetNet network nodes. DetNet controller consists of DetNet topology management manager function, DetNet resource management manager function, DetNet route management manager function, DetNet QoS management manager function, DetNet service control function, DetNet monitoring manager function, DetNet repository and NETCONF transmission client function.

The DetNet network node executes the command delivered to the corresponding DetNet network node according to the command requested from the DetNet controller. DetNet network node is composed of DetNet topology management agent function, DetNet resource management agent function, DetNet route management agent function, DetNet QoS management agent function, DetNet monitoring agent function, and NETCONF transmission server function.

The DetNet service control function receives the DetNet service configuration request transmitted by the DetNet user controller, which has received the ultra-low latency service request information transmitted from the DetNet end system, which is a user system. The DetNet service control function requests the DetNet network resource setting required to provide the DetNet service to the DetNet resource management manager function, requests the DetNet route setting to the DetNet route management manager function, and requests the DetNet QoS setting to the DetNet QoS management manager function. In addition, when the DetNet service control function receives DetNet resource, path and QoS configuration information through these three functions, it transmits the configuration information to the DetNet

network node through the NETCONF transmission client function.

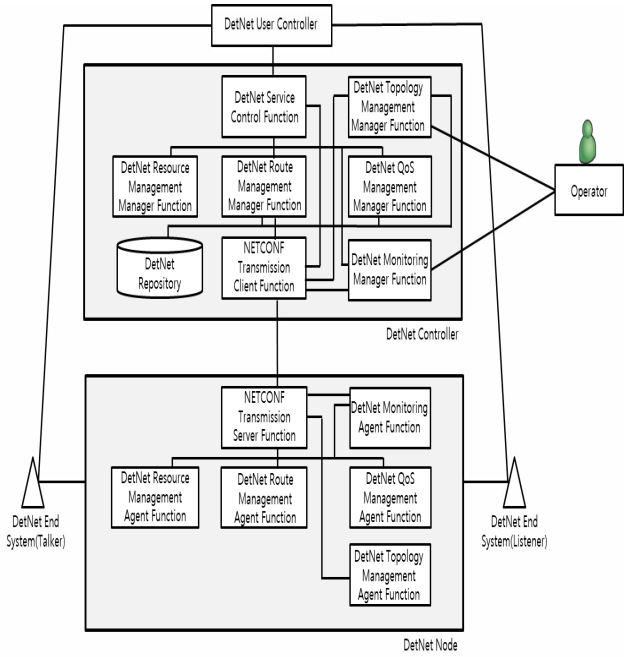

Figure 4. Architecture of active deterministic network C&M system

The DetNet topology management manager function requests node and link information to the DetNet topology management agent function when it receives topology requests for DetNet network nodes constituting the DetNet network through the operator. And the DetNet topology management manager function manages the DetNet network topology by collecting node and link information received from the DetNet topology management agent function. DetNet topology management manager functions manage information such as node name, node type (edge node, relay node, transient node), node address (MAC address, IP address), link name, and neighboring node address (MAC address, IP address) of the link.

The DetNet resource management manager function delivers delay time information and bandwidth information for each DetNet network node and link to the DetNet resource management agent function according to the DetNet network resource setting request of the DetNet service control function and the DetNet monitoring manager function, and also passes this information to the DetNet service control function and the DetNet monitoring manager function. In addition, the DetNet resource management manager function reflects and manages the delay time information and bandwidth information that performed setting commands to the corresponding node by the DetNet resource management agent function. DetNet resource management manager manages information such as the node name, node type, maximum and minimum time required to process traffic from a node, maximum and minimum time required for queue output from a node, link name, maximum bandwidth that a link can support, currently reserved bandwidth and link delay time.

The DetNet route management manager function delivers route information for each DetNet network node and link to the DetNet route management agent function according to the DetNet network route setting request of the DetNet service control function and the DetNet monitoring manager function, and also provides this information to the DetNet service control function and the DetNet monitoring manager function. In addition, the DetNet route management manager function reflects and manages the route information that executed setting commands to the corresponding node by the DetNet route management agent function. The DetNet route management manager function manages information such as DetNet route name, DetNet flow name, DetNet flow input path information, DetNet flow processing operation (forward, duplicate, delete), and DetNet flow output path information.

The DetNet QoS management manager function delivers QoS information for each DetNet network node and link to the DetNet QoS management agent function according to the DetNet network QoS setting request of the DetNet service control function and the DetNet monitoring manager function, and also provides this information to the DetNet service control function and the DetNet monitoring manager function. In addition, the DetNet QoS management manager function reflects and manages the QoS information that performed setting commands to the corresponding node by the DetNet QoS management agent function. The DetNet QoS management manager function manages information such as DetNet flow name, DetNet flow filtering information, DetNet flow input queue gate information, DetNet flow output queue gate information, and DetNet flow preemption information. DetNet flow filtering information is information used to pre-block or stop transmission of packet traffic that may cause problems, and DetNet flow input queue gate information is information used to deliver received packet traffic to a specific queue at a specified time. DetNet flow output queue gate information is information used to output the input packet traffic from the queue in a time-deterministic manner, and DetNet flow preemption information is information used to prevent transmission of time-sensitive traffic from being delayed by general packet traffic.

The DetNet monitoring manager function receives a problem event message from the DetNet monitoring agent when a problem such as a DetNet resource threshold exceeded or a DetNet path failure occurs while the DetNet network node and link are supporting ultra-low latency services.

The DetNet monitoring manager function analyzes the received problem event message and requests the DetNet resource management manager function to set up a new resource, requests the DetNet route management manager function to set a new route, and requests the DetNet QoS management manager to set a new QoS according to the conditions suitable for the problem occurrence. In addition, the DetNet monitoring manager function transfers newly set resource, path, and QoS configuration information from these three functions to the DetNet resource management agent

function, the DetNet route management agent function, and the DetNet OoS management agent function. So, after these three agent functions have finished executing commands according to the new setting information, the DetNet monitoring manager function is a function to quickly solve a problem that occurred by notifying the operator of the execution result.

The DetNet repository stores topology information, resource information, route information, and QoS information for each DetNet network node and link constituting the DetNet network.

The NETCONF transmission client function receives DetNet resource information, route information, and QoS information from the DetNet service control function and the DetNet monitoring manager function, and provides the received DetNet resource information, route information, and QoS information to the NETCONF transmission server function using the standard YNAG data model. In addition, the NETCONF transmission client function delivers the execution result or problem event information received from the NETCONF transmission server function to the DetNet service control function and the DetNet monitoring manager function.

The NETCONF transmission server function delivers the DetNet resource information, route information, and QoS information received from the NETCONF transmission client function to the DetNet resource management agent function, the DetNet route management agent function, and the DetNet QoS management agent function, respectively. In addition, the NETCONF transmission server function delivers the result of performing the DetNet resource information, route information, and QoS information received by these three functions, or the event information of a problem occurring in the DetNet network node and link to the NETCONF transmission client function.

The DetNet topology management agent function delivers the network node and link information to the DetNet topology management manager function through the NETCONF transmission server function and the NETCONF transmission client function according to the request for DetNet network node and link information received from the NETCONF transmission client function.

The DetNet resource management agent function performs the function of setting the DetNet resource information received from the NETCONF transmission server function to the corresponding DetNet network node. In addition, the DetNet resource management agent function delivers resource problem event information to the DetNet monitoring agent function when a situation exceeding the resource bandwidth and delay time threshold occurs.

The DetNet route management agent function performs the function of setting the DetNet route information received from the NETCONF transmission server function to the corresponding DetNet network node. In addition, the DetNet route management agent function delivers route problem event information to the DetNet monitoring agent function when a failure occurs in a link or node in the route.

The DetNet QoS management agent function performs the function of setting the DetNet QoS information received from the NETCONF transmission server function to the corresponding DetNet network node.

The DetNet monitoring agent function transmits a problem event message when receiving resource problem event information from the DetNet resource management agent function or receiving route problem event information from the DetNet route management agent function to the DetNet monitoring manager function through the NETCONF transmission server function and the NETCONF transmission client function.

V. CONCLUSION

This paper proposed the deterministic network control and management system that can actively perform control and management functions for DetNet network nodes, which are components of the DetNet network, to provide reliable ultra-low latency services with limited latency and low jitter. The active DetNet control and management system can quickly adjust network resources according to predicted conditions and events to support ultra-low latency services such as virtual, augmented and mixed reality services, autonomous driving services for cars and aircraft, and real-time remote device control services.

Therefore, this active DetNet control and management system is expected to provide an ultra-low-latency network infrastructure environment that provides ultra-low-latency services by supporting stable connections and improved network resource efficiency.

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