E^3-DCN: Energy Efficient Optical Network for Data-centric Network

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***Abstract*—One of new applications on a new generation network (NwGN) is a contents centric network (CCN). The target of CCN is contents based networking. We enhanced a concept of CCN to machine-to-machine communications, streaming communications, and contents creation services within the network. This is called an enhanced-type data-centric network (E^3-DCN). To develop E^3-DCN, orchestration between packet switching and circuit switching is important. This paper provides an E^3-DCN concept and architecture to realize energy efficient optical networking.**

Keywords-component; enegy effcient; data-centric; network virtualization

I. Introduction

The IP network technology provides the Internet, local area networks (LANs) and virtual private networks (VPNs) in companies, data center communications, and home networks. Some problems such as realizing a high availability network, increasing power consumption of IP router equipment, and realizing an end-to-end bandwidth guarantee, are noticeable. It is quite difficult to solve these problems by using IP technologies with low cost. Therefore, a new generation network (NwGN) and a Future Networks both are based on "Clean Slate" approach to solve these problems are now widely studying in Japan, EU, and USA [1-3].

Researches of NwGN and the Future Networks have been started in 2006. Many new network concepts, architectures, and solution technologies were proposed. Now, a network virtualization [4] and a Contents-centric Network (CCN) [5-7] become leading technological targets of NwGN and the Future Network. The network virtualization is developing as a testbed network construction technology for several new applications and protocols including a non-IP protocol on NwGN. Regarding with CCN, concept level system proposals and testbed network construction for proof-of-concept are ongoing.

CCN is mainly transport large size content as a transport unit. An original content are stored in the network nodes and cached in the transit node(s) if required. We have extended the concept of CCN into machine-to-machine (M2M) communications which transport small size data. This is defined as a Data-centric network (DCN) [8].

Before "Cloud" became a famous technical word, "Grid Computing" was widely studied. This technology is a good precursor of the ubiquitous society in which everything, including CPU, memory, and storage, will be interconnected by an IPv6 network. With the advance of ubiquitous society including IPv6, it is expected that various devices, software, and processing functions all over the world will be connected to the networking environment. As a new framework for ubiquitous society era, the ubiquitous grid networking environment (uGrid) has been proposed [9, 10]. In uGrid, the devices connected to the network are defined as "Service-Part (SP)". The content is one of the SPs. Users can use their desired SPs in the uGrid service network, and moreover, they can use new mash-up services provided by connecting SPs via logical cables. When a user selects the several SPs such as a camera; an original content, a CPU in the data center; video encoder processor, an H.264 encoder software; video encoder processing, and a high-definition (HD) monitor; video viewer, the user can enjoy watching the HD video from low resolution camera image. This means that the new content can be generated in the network.

The uGrid concept can be applied into DCN. This is called an enhanced-type DCN (E-DCN). In E-DCN, a user requests data name or identifier (ID) from the network. If the exactly matched requested data are not found in the network, the network constructs the requested data under uGrid manner. E-DCN will be constructed on the network virtualization platform (NVP) which is built in the NwGN testbed in Japan [11].

E-DCN will be applied to a contents delivery network (CDN) application. Energy efficiency in CDN is important to reduce the data/contents transport power consumption. To realize the energy efficient CDN, a data delivery route in E-DCN and a data transmission method of E-DCN should be optimized to reduce data transmission energy. This paper presents an energy efficient E-DCN (E^3-DCN) concept and architecture on the NwGN's NVP.

II. E^3-DCN Architecture on NwGN

A. *E^3-DCN over NwGN testbed Network*

DCN is an M2M enhanced version of CCN. Both DCN and CCN handle pre-resisted data/contents. When a user sends a query into the network, the user can get an exact matched data or a NACK message from the network. In case of E-DCN, when the exact matched data are not found in the network, the

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network request a data material and data generation into the uGrid. We designs combination of two networks i.e. a data generation network and a data transport network over NVP.

In NwGN, a slice which is composed of virtual nodes (VNs), virtual links, a VN management system, and a virtual network management system is presented [4, 11]. We expect and request to NwGN that the slice user can get information such as bandwidth and length of virtual links and geographical location of VNs. It is difficult to get this information over the current Internet. In E[3]-DCN, this information is used for optimization of the data transport route. Additionally, an NwGN testbed network can provide multi-slice, i.e. a packet switching slice and a path/circuit switching slice, traffic engineering (TE) capability into E[3]-DCN for realizing transport switching energy optimization.

B. *E[3]-DCN Design on NwGN*

To realize the E[3]-DCN, three slices on NVP are used. Slices are a circuit switching slice (CSS), a packet switching slice (PSS), and a control plane slice (CPS). CPS makes an IP based control plane (C-Plane) network and exchanges DCN query messages, data/content information messages, uGrid signaling and routing protocol messages [10]. PSS provides a main network topology of E[3]-DCN. The topology of PSS namely adjacency of VNs should be projected to a logical topology of CPS. CSS is dynamically controlled. An optical path is set-up/tear-down between two VNs in CSS, when the data transport is required or ended. In the E[3]-DCN, data are mainly exchanged via PSS, if large bandwidth transmission is required and/or long holding time transmission is required, CSS is used to bypass packet switching nodes.

Two overlay networks are constructed on three slices. They are a data generation overlay network (DGON) and a data-centric overlay network (DCON). DGON corresponds with the uGrid network and DCON corresponds with DCN. Figure 1 shows a conceptual view of the E[3]-DCN architecture.

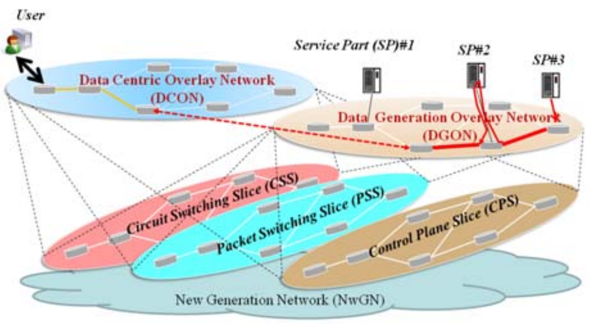

Figure 1. E[3]-DCN architecture on NwGN.

A user's query is sent to DCON, if the requested data are found in DCON, data are transported to the user via PSS and CSS by applying CCS routing techniques []. If the requested data are not found in DCON, the query is sent to DGON. In DGON, the requested data are generated from Service-Parts and registered to DCON. DGON is extension of uGrid, and applies "Service Routing" [10] technology to choose the optimal SPs for generating data.

C. *E[3]-DCN Node Design*

Figure 2(a) shows a semantic diagram of the E[3]-DCN logical node architecture. The node is connected three slices and users. VLAN is applied to separate each slice when Ethernet is used. This logical architecture should be mapped into NVP. A virtual link is defined between two VN. Therefore, each slice's virtual link is terminated at each slice's VN. Links between E[3]-DCN node and each slice shown in Fig. 2(a) should be terminated at VN within each slice. As a result, the E[3]-DCN node should be composed of three VN. Three VNs should be connected via a network constructed in the real world. In NVP, a network connector (NC) supports making a link between VN and the real world. Figure 2(b) shows an implementation design of one E[3]-DCN node using NC.

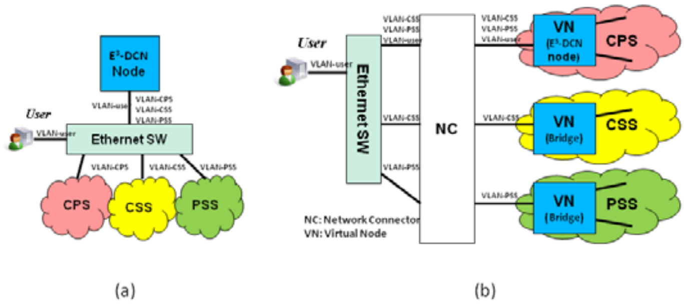

Figure 2. E[3]-DCN node design on NVP. (a) Basic node architecture, (b) Implementation design for NVP.

VN in CPS has a role as a main E[3]-DCN node, other VNs have a role in Ethernet bridge which connects virtual network in the slice and the Ethernet switch in the real network.

III. ENERGY EFFICIENT ROUTING STRATEGIES IN E[3]-DCN

A. *Energy Optimized Routing Strategies in E[3]-DCN*

Priority of energy efficiency is increasing due to environmental concerns. Optical networking is one of the promised solutions to lead energy efficient transport networks. There are different levels of approaches to realize energy efficient transport network. They are a device-level, an equipment-level, and a network-level approaches. E[3]-DCN applies the network-level approach. Examples of the network-level approaches are as follows [13]: (a) topology and route optimization, (b) data/service relocation and caching, (c) lowering peak data-rate, (d) optical switching for bulk traffic. We focused on a new architecture that supports dynamic network-level optimization for energy efficiency. Two energy optimized routing strategies are applied to DCON and DGON.

B. *Strategy I: Dynamic Network Reconfiguration*

Initially, a network topology is designed by requirements such as accommodate traffic demand, minimum transport delay, minimum network resources, and ensure resiliency. Traffic demand is dynamically changed, but the network is designed to endure the maximum traffic demand. In case of the lower traffic demand, energy efficient TE [14, 15] can be applied to concentrate the traffic into limited number of links and nodes and then unused links and nodes are shutdown to save the operating power consumption. In the E[3]-DCN, the energy efficient TE is applied to virtual networks. A virtual network topology is dynamically reconfigured to minimize number of nodes and links. To realize the operation power saving in the real network, NVP should support real node's and link's shutdown operation.

We have proposed another dynamic reconfiguration approach named as "Service-Copy" [16]. An SP which provides processing function i.e. software can be easily copied from one computer to other computers. Virtual machine copy / migration are examples of the Service-Copy. Concept of the Service-Copy is simple. Copying SP requires additional power consumption. However, there are some total power reduction possibilities.

C. Strategy II: Optical Circuit Switching Bypass

In general, data transport cost with a packet switching network i.e. PSS is cheaper than with a circuit switching network i.e. CSS. This is because, in PSS, small traffic flows can share the bandwidth by statistical multiplexing. However, if statistical multiplexing is not working, as a small number of flows share the whole bandwidth and strict QoS preservation is required, CSS is preferred and avoiding the packet switching as much as possible. This is called "circuit switching bypass". In E[3]-DCN, links in DCON and DGON are provided via CSS and PSS. A link on CSS is composed with link termination Ethernet switches, transmission links, and circuit switches. A link on PSS is composed with link termination Ethernet switches, transmission links, and packet switches. Figure 3 shows an example of both links. If an optical circuit switch is applied, it requires 0.5 nJ/bit switching energy in each optical switch [17]. On the other hand, 10 nJ/bit switching energy is required in the packet switch [17].

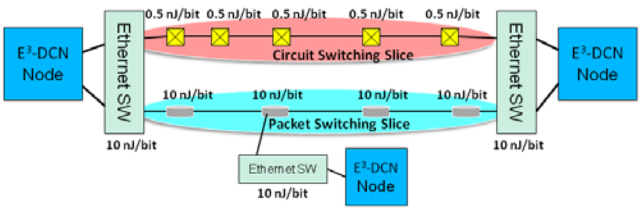

Figure 3. Link construction example on CSS and PSS.

As shown in Fig. 3, the link on CSS requires {22.5 nJ/bit switching energy} + {8 transmission links of transmission energy}. On the other hand, the link on PSS requires {60.0 nJ/bit switching energy} + {7 transmission links of transmission energy}. In general, the transmission energy is smaller than switching energy. The link on PSS is more energy consuming, more flexible, and cheaper transport cost. The link on CSS requires less energy consumption but higher cost.

To determine which links should be used, an energy consumption estimation algorithm of the virtual link and taking required parameter from NVP are required. An energy optimized routing algorithm which uses data size, data transmission speed, flow duration time, and required QoS, etc. as parameters are now developing.

IV. CONCLUSION

In this paper, the E[3]-DCN architecture over the NwGN's testbed which provides a network virtualization platform was presented. Two types of energy efficient routing strategies both can be applied to E[3]-DCN were also discussed. The E[3]-DCN is constructed as an overlay network and composed of three slices: the control plane slice, the packet switching slice, and the circuit switching slice. We are now developing detailed E[3]-DCN node design and implementing it to NwGN's testbed. More work is required to develop an energy efficient routing algorithm for realizing the optical circuit switching bypass strategy.

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