Abstract—This paper presents a concept of the Energy Efficient and Enhanced-type Data-centric Network (E\(^3\)-DCN). For future network technology, the Contents-centric Network (CCN) is widely studied. DCN is an extended version of CCN. M2M communication and mobility of the data are supported.

In the enhanced-type DCN, a user requests data name or identifier to the network. If the exactly matched requested data are not found in the network, the network constructs the requested data. E\(^3\)-DCN provides an energy efficient contents delivery network on the network virtualization platform.

Keywords—data-centric; energy efficient; network virtualization; transmission energy; contents delivery network

I. INTRODUCTION

Transmission Control Protocol / Internet Protocol (TCP/IP) is one of the most used and succeeded technologies in IP network technologies. IP is the most important network technology in an information and communication society because of its easy attachment to the network and low cost of the network construction and operation. The IP network technology provides the Internet, local area networks (LANs) and virtual private networks (VPNs) in companies, data center communications, and home networks.

Recently, some problems such as realizing a high availability network, increasing power consumption of IP router equipment, increasing a network operation cost, 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 which 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, research phase is moved from divergence to convergence. 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 tested network construction technology for several new applications and protocols including a non-IP protocol on NWGN. Regarding with CCN, concept level system proposals and tested network construction for proof-of-concept are ongoing.

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CCN mainly transports 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. The grid computing can realize a high performance virtual machine (VM) by combining high performance computers in a seamless manner. 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 [9-15]. In uGrid, the devices connected to the network are defined as “Service-Part”. The content is one of the Service-Parts. Users can use their desired Service-Parts in the uGrid service network, and moreover, they can use new mash-up services provided by connecting Service-Parts via logical cables. For example [11], it is expected that the uGrid realizes the next generation image distribution system by connecting Service-Part associated with video processing. In [11], when a user selects the several Service-Parts such as a camera; an original content, a CPU in the data center; video encoder processor (super-resolution or up-conversion), an H.264 encoder software; video encoder processing, and a high-definition (HD) monitor; video viewer, the user can enjoy watching the processed/enhanced HD image 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 which is built in the JGN-X testbed network [16].

JGN has been started as Japan Gigabit Network from 1999. In 2011, JGN-X is introduced as a testbed for establishing and expanding of NWGN. JGN-X has cutting-
edge network performance, functions, and technologies
including wireless/optical integration, network virtualization,
and advanced operation of various virtualization layers.

E-DCN will be applied to a contents delivery network
(CDN) application. Energy efficiency in CDN is very
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 proposes an energy efficient E-DCN (E'-
DCN) concept and E'-DCN architecture on the JGN-X
network virtualization platform.

This paper is organized as follows. Section II describes
an overview of DCN and the uGrid. In Section III, E'-DCN
architecture over the network virtualization platform is
proposed. Realizing the energy efficient networking in E'-
DCN is discussed in IV. Finally, we summarize the paper in
V.

II. DATA-CENTRIC NETWORK (DCN) AND UBIQUITOUS
GRID NETWORKING ENVIRONMENT (UGRID)

A. Data-centric Network (DCN)

Current IP network provides data communication
capability among any network terminals. Network terminals
are personal computers, server computers, sensors, cellar
phones, smart phones, and so on. The primary use of
network has shifted from communication between two
terminals (e.g. telephony, streaming) to data access and data
distribution (e.g. web, content delivery). DCN focused on
creating novel network architecture to easily get the expected
data from enormous data in the network.

Figure 1 shows transition of network architectures.
Conventional public switched telephone network (PSTN)
focused on human-to-human communication i.e. voice
communication over point-to-point circuit switching network.
Current Internet focused on human-to-machine communication i.e. web access over point-to-point packet
switching network. Future DCN focused on the future
sensor-to-sensor and M2M communication i.e. many-to-
many data distribution networking. In the DCN, terminal
will communicate using only expected data’s ID. It is not
going to think which terminal has the expected data, like IP.

To realize M2M communication service, four major
requirements can be defined.

[R1] M2M terminals shall be in large amount, very low price,
and low functional.

Over 50 billion terminals will be connected to the
network. Most terminals, e.g. sensors, will be very low
functional equipment and very low price. It shall be
required easy access to the network and simple
transmission protocols.

[R2] Terminals and also networks shall be highly mobile and
easy to modify/upgrade its functions.

It shall be required that mobility of terminals, redeployment of terminals and servers including VM
migration, and exchange terminal equipment can be
done with minimum configuration. The network shall
be reconfigurable like Ethernet.

[R3] Data shall be dynamically changed.

Data provided from M2M terminals will be
dynamically changed such as frequently and irregularly
added, moved, updated, and deleted. It is quite difficult
when the data are accessed. In case of the sensor’s
status data, it is temporarily stored and removed from
the sensor itself. The network shall follow the temporal
data and shall be accessible them to users.


Large amount of terminals will generate enormous data
and many service servers use them. Many-to-Many
communications, such as broadcast, multicast,
publish/subscribe, and query/key-value-store, will
become majority rather than unicast communication.
The network shall support Many-to-Many
communication efficiently.

DCN should support these requirements, keep CCN’s
advantage points, and improve disadvantage points.

CCN has following features:

- Routing is done by a content ID (or name) rather
  than a location-dependent address e.g. IP address.
  Terminal does not need to be conscious of an
  endpoint’s location.

- End-to-end communication between terminals is not
  required by using content cache in the transit node.

- The content-based security is applied. Trust travel
  with the content itself, rather than transport level
  security mechanisms such as IPsec and secure
  socket layer (SSL).

To support M2M communication in CCN, large number
of content IDs (over 50 billion) will cause a problem. In
CCN, ID by ID route information shall be hold in transit
nodes. Large number of contents exhausts a routing table. To
solve this problem, hierarchical domain-level ID prefix likes a
border gateway protocol (BGP) inter-domain routing is
introduced. However, when mobility is introduced, data
which have different IDs but the same prefix are distributed
in whole network area. Routing table reduction by the prefix
consolidation does not work effectively. The DCN will solve
the problem [17].
B. Ubiquitous Grid Networking Environment (uGrid)

IPv6 will change the world. That is to say, everything all over the world will be connected to the network. The uGrid extend the potential of “everything” from peripheral devices, cameras, televisions, home electronics, sensors, and so on, into CPU, memory, storage, VM, and program. Figure 2 shows an overview of the uGrid. In the uGrid, everything from devices to program is defined as a Service-Part and new services are provided by composing Service-Parts on the uGid network. For example, HD processing is performed for the video camera in the stadium and processed data are provided to the user who has HD monitor and requests the HD video streaming. By placing Service-Parts on the network and sharing them with users, each user can receive various services having only a minimal equipment.

Figure 2. An overview of the uGrid environment.

Figure 3 shows a service provisioning example in the uGrid network [13]. The network is divided into a control-plane (C-Plane) and a data-plane (D-Plane) which actually transports data. A uGrid server manages all Service-Parts. Service provisioning procedure is as follows:

1. If a Service-Part is added, modified, or removed from the network, Service-Part’s information is advertised by using link-state intra-domain routing protocol like open shortest path first (OSPF) and intermediate system to intermediate system (IS-IS).
2. When user requests a new service to the uGrid server. Required Service-Parts names or IDs (Service-Part A, B, and C) may be specified by the user.
3. The uGrid-server selects one Service-Part from Service-Parts with the same function. Selected Service-Part sequence provides a minimum cost service provisioning route: “Service-Routing”. Selected Service-Parts are reserved for requested service: “Service-Signaling”. In the Service-Signaling, service layer resources and also transport layer resources are reserved by using generalized multi-protocol label switching (GMPLS) resource reservation protocol traffic engineering extension (RSVP-TE). In the uGrid, GMPLS is extended from transport layer signaling and routing protocols to service layer signaling and routing protocols.

III. ENERGY EFFICIENT AND ENHANCED-TYPE DATA-CENTRIC NETWORK (E3-DCN) ARCHITECTURE

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 network request a data material and data generation into the uGrid network. In this section, combination of 2 networks i.e. a data generation network and a data transport network over the network virtualization platform is presented.

In the current Internet, the requested data are indicated by the universal resource locator (URL). URL indicates the server machine. The domain name system (DNS) provides the IP address of the server. A service layer data transport application is used to transport the requested data to the user. In case of the overlay network e.g. peer-to-peer (P2P), a data name query is sent to the overlay network, found data are sent via underlay network i.e. the Internet. Data transport is done under the shortest path routing manner. Therefore, it is difficult to realize optimization of network resources. This is because an overlay network service provider is not able to manage the underlay network. To solve this problem, GMPLS user-to-network interface (UNI) signaling based P2P CDN has been proposed [18]. On the other hand, in the NWGN, a slice which is composed of virtual nodes, virtual links, virtual node management system, and virtual network management system is presented [16, 19]. We expect and request to JGN-X that the slice user, i.e. E3-DCN service provider, can get information such as bandwidth and length (or delay) of virtual links and geographical location of virtual nodes. It is difficult to get this information over the current Internet. In E3-DCN, this information is used for optimization of the data transport route. Additionally, an NWGN testbed network on JGN-X has optical/electric packet / path integrated switching network. This leads multi-slice, i.e. a packet switching slice and a path/circuit switching slice, traffic engineering (TE) [20] capability into E3-DCN for realizing transport switching energy optimization.

To realize the E3-DCN, two types of network architectures are proposed. They are called E3-DCN Type-Z.
and E³-DCN Type-S. Both architectures use three slices on the JGN-X network virtualization testbed. Slices are a circuit switching slice (CSS), a packet switching slice (PSS), and a control plane slice (CPS). CPS makes an IP based C-Plane network and exchanges DCN/CCN query messages, data / content information messages, and GMPLS protocol messages. PSS provides a main network topology of E³-DCN. The topology of PSS namely adjacency of virtual nodes should be projected to a logical topology of CPS. A generic routing encapsulation (GRE) tunnel can be applied between two CPS virtual nodes to match both slice networks' topologies. CSS is dynamically controlled. An optical path is set-up / tear-down between two virtual nodes in CSS, when the data transport is required or ended. In the E³-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.

A. E³-DCN Type-Z Architectures

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 4 shows a conceptual view of the E³-DCN Type-Z architecture.

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. 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.

Figure 5 shows a semantic diagram of the E³-DCN logical node architecture. The node is connected three slices and users. If Ethernet is used as an access method, a virtual LAN (VLAN) technology is applied to separate each slice. This logical architecture should be mapped into JGN-X’s network virtualization platform. A virtual link is defined between two virtual nodes. Therefore, each slice’s virtual link is terminated at each slice’s virtual node. Links between E³-DCN node and each slice shown in Fig 5 should be terminated at the virtual node within each slice. As a result, the E³-DCN node should be composed of three virtual nodes. Three virtual nodes should be connected via a network constructed in the real world. In the JGN-X’s network virtualization platform, a network connector (NC) supports making a link between the virtual node and the real world. Figure 6 shows an implementation design of one E³-DCN node using NC.

B. E³-DCN Type-S Architectures

One overlay network is constructed on three slices. Only DGON is constructed. A user’s query is directly sent to DGON. Figure 7 shows a conceptual view of the E³-DCN Type-S architecture. Data cache and security mechanism should be introduced to DGON. This leads to enormous
modification to the uGrid implementation. The merit of Type-S architecture is simple structure. Only one overlay network is constructed.

Figure 7. E³-DCN Type-S architecture.

IV. ENERGY OPTIMIZED ROUTING STRATEGIES

Priority of energy efficiency is increasing due to environmental concerns. Conventional networks have focused on performance and scalability. Energy efficiency will be one of the important design principles of future networks. There are different levels of approaches to realize energy efficient network. They are a device-level, an equipment-level, and a network-level approaches. E³-DCN applies the network-level approach. However, the device-level and equipment-level approaches also can be taken.

Examples of the network-level approaches are as follows [21]:
- Topology and route optimization
- Data/service relocation and caching
- Lowering peak data-rate
- 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.

A. 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 [22-24] 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 E³-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, the JGN-X network virtualization platform should support real node’s and link’s shutdown operation.

We have proposed another dynamic reconfiguration approach named as “Service-Copy” [25]. A Service-Part which provides processing function i.e. software can be easily copied from one computer to other computers. VM copy / migration are examples of the Service-Copy. Concept of the Service-Copy is simple. Copying the Service-Part requires additional power consumption. However, there are some total power reduction possibilities.

- Example 1) The copied Service-Part can provide shorter transmission path. It reduces transmission and switching power consumption.
- Example 2) The copied Service-Part can share among several transmission paths. It reduces the number of active computers.

B. Strategy II: Circuit Switching Bypass

In general, data transport cost with a packet switching network is cheaper than with a circuit switching network. This is because, in the packet switching network, 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, the circuit switching is preferred and avoiding the packet switching as much as possible. This is called “circuit switching bypass”. In E³-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 8 shows an example of both links. If an optical circuit switch is applied to the circuit switch, it requires 0.5 nJ/bit switching energy in each optical switch [26]. On the other hand, 10 nJ/bit switching energy is required in the packet switch [26].

Figure 8. Link construction example on CSS and PSS.

As shown in Fig.8, the link on CSS requires \( \{22.5 \text{nJ/bit switching energy}\} + \{8 \text{transmission links of transmission energy}\} \). On the other hand, the link on PSS requires \( \{60 \text{nJ/bit switching energy}\} + \{7 \text{transmission links of transmission energy}\} \). 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 the network virtualization platform are required. An energy optimized routing algorithm which uses data size, data transmission speed, flow duration time, and required QoS, etc. as parameters should be developed.
V. CONCLUSION

In this paper, the E3-DCN architecture over the JGN-X’s network virtualization platform and two types of energy efficient routing strategies both can be applied to E3-DCN were discussed. The E3-DCN is constructed as an overlay network and composed of three slices: CPS, PSS, and CSS. To realize the E3-DCN, modification of the network virtualization platform is required. We are now developing detailed E3-DCN node design and implementation, evaluating energy efficient routing algorithm, and implementing prototype E3-DCN network testbed on JGN-X.

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