Energy Efficient and Enhanced-type Data-centric Network Architecture

Shanming Zhang[a], Hidetoshi Takeshita, Satoru Okamoto, Naoaki Yamanaka
Keio University, Japan

Abstract

Information-centric networking (ICN) as an alternative has been researched for future Internet architecture. In this paper, a novel network architecture called Energy Efficient and Enhanced-type Data-centric Network (E^3-DCN) is proposed for ICN. E^3-DCN not only realizes ICN but also has the ability of data generation by organizing and combining relevant resource such as original data and kinds of processing services. In addition, in order to improve energy efficiency of data transmission, E^3-DCN chooses optimal transmission path to transmit data based on packet switching and optical switching. Moreover, based on current traffic situation, E^3-DCN reconfigures network topology such as unused nodes and links to operate in sleep mode for energy saving dynamically. And meanwhile, data caching strategies are applied into E^3-DCN for data distribution based on the distribution of users. Data caching shortens transmission distance, so data transmission energy, latency and network load is decreased. Based on these approaches, E^3-DCN achieves an energy efficient network.

Keywords: ICN, Future Internet, E^3-DCN, Data Generation, Energy Efficient, Data Caching

1. Introduction

Current Internet architecture, which is host-centric communication model based on Transmission Control Protocol/Internet Protocol (TCP/IP), focuses on location where data exists. User must request specified server to get desired data using Uniform Resource Locator (URL) or IP address. Along with the increasing of Internet users and services, there are some fatal issues emerged e.g., network congestion, location dependence, mobility, network power consumption, Quality of Service (QoS), so that the current Internet cannot meet future Internet's requirements [1]. Therefore, Information-centric networking (ICN) has been proposed for future Internet. ICN, which changes traditional communication model from "host-to-host" to "user-to-data", focuses on what data is contained in network [2]. The basic idea of ICN is that user doesn't consider where data exists and directly use data name to request and get data. Moreover, ICN also supports multiple communication ways such as unicast, multicast and so on. ICN has been explored by several projects such as Content-centric Networking (CCN) [3], Networking of Information (NetInf) [4] [5], Data -centric Networking (DCN) [6] [7].

In this paper, we propose a novel network architecture called Energy Efficient and Enhanced-type Data-centric Network (E^3-DCN) for ICN. E^3-DCN not only realizes ICN but also realizes a self-organizing network that can achieve optimization of resources and network energy consumption. E^3-DCN has the ability of data generation. It can organize and combine relevant resource, such as original data and kinds of processing software and services as data materials, to generate desired data. In E^3-DCN, users directly use data name to request and get desired data. When the requested data is not found, E^3-DCN automatically organizes and combines relevant data materials to generate the requested data. In addition, E^3-DCN also takes into account the network energy consumption issue. In order to improve energy efficiency of data transmission, E^3-DCN chooses optimal data transmission path and transmission technology to transmit data based on packet switching and optical path/circuit switching. Moreover, according to current traffic situation, E^3-DCN can dynamically reconfigure network topology for saving power consumption of the network such as unused data links and switches are shut down. Advanced data caching strategies, which make E^3-DCN like energy efficient Content Delivery Network (CDN), are used for data distribution. Because data caching makes the distance of data transmission become shorter, so data transmission energy, latency and network load can be decreased. And meanwhile, data caching makes E^3-DCN better support mobility of mobile devices which can get data from the nearest data source quickly while moving.

A prototype of the E^3-DCN system is designed and constructed on Japan Gigabit Network-eXtreme (JGN-X) which is a multiple layer network testbed of Japan and can provide slice networks by network virtualization technology [8] (Detail is introduced in next section). E^3-DCN is composed of two overly networks on three slice networks. Two overlay networks, one is Data Centric Overlay Network (DCON) realized ICN, and another is Data Generation Overlay Network (DGON) used for data generation. Three slice networks are Control Plane Slice (CPS), Packet Switching Slice (PSS) and Circuit Switching Slice (CSS). Three slice networks as network infrastructure of E^3-DCN are used for data transmission and network energy efficiency optimization.

The rest of the paper is organized as follows: In section two, research background and related work, including ICN research projects, Ubiquitous Grid Networking Environment

[a]School of Science for Open and Environmental Systems,
Graduate School of Science and Technology, Keio University.
3-14-1 Hiyoshi, Kouhoku-ku, Yokohama, 223-8522, Japan
shanming.zhang@yamanaka.ics.keio.ac.jp

(uGrid) and JGN-X, are described. In section three and four, we present our proposal E^3-DCN architecture and energy optimized strategies in detail. In section five, the related evaluations are presented. In section six, we describe our experiments and E^3-DCN prototype base on JGN-X. At last, we give our conclusions and future work.

2. Background

2.1 ICN Research Projects

CCN is an entirely new architecture based on name-based routing for ICN. In CCN, user sends "Interest" packet with data name to request desired data. "Data" packet as response is returned from data source following the track of "Interest" packet. And meanwhile, the transmitted data is cached at every intermediate node for future requests. CCN realizes the concept of ICN, but there are some problems existed in CCN such as every node holds a large number of data names as routing information cause routing delay problem. And it is very difficult to manage a huge number of cached data [9]. NetInf, which is also proposed for ICN, adopts hybrid name-based routing and Name Resolution Server (NRS) that implements matching among data name and IP address. User directly sends request holding data name to get data. The request is firstly forwarded toward NRSs based on name-based routing. If an NRS is available, data name can be resolved into a set of IP addresses of servers holding desired data. Subsequently, NRS chooses the best server to request data based on IP-based routing [4] [5]. Since NetInf adopts name-based routing and IP routing, NetInf can easily connect different networks into a single Information-centric network. Therefore, NetInf has better scalability than CCN. However, delay problem still exists due to a large number of data names as routing information. Furthermore, NRS optimal distribution is also an important issue [10] [11]. DCN is also proposed for ICN. DCN meets not only needs of human communication but also needs of Machine-to-Machine (M2M) communication for future Internet [12] [13] [14]. DCN adopts "route attraction" and "route aggregation" to reduce routing information comparing to CCN and NetInf. Furthermore, it makes the management of data cached become easier than CCN and NetInf [7]. Nevertheless, DCN doesn't take into account network energy consumption issue.

Actually, the network energy consumption as common problem exists in not only DCN but also in other ICN projects such as CCN, NetInf, DONA [15], PSIRP [16], and PURSUIT [17]. Another common problem of these ICN projects is that can only provide original data and cannot reuse kinds of service resources such as original data, processing software and services to process or generate various data to meet user's requirements and conditions. For example, according to user device monitor size, an original image can be processed into different size or pixel on network to meet different device monitor size to display. This way not only improves service quality but also reduces the amount of images suited for kinds of devices. And meanwhile, this way also improves services utilization rate.

2.2 Ubiquitous Grid Networking Environment (uGrid)

The Ubiquitous Grid Networking Environment (uGrid) has been proposed for ubiquitous society in 2007 [18]. In uGrid, everything assigned an IP address from a device to a program is defined as Service-Part (SP). User can not only use desired SP but also enjoy mash-up service provided by combining several SPs. In order to provide mash-up service, two core technologies Service-Routing (SR) and Service-Signaling (SS) are realized [19] [20]. Service-Routing extended Open Shortest Path First Traffic Engineering extension (OSPF-TE) [21] is used for searching relative SPs and computing optimal service flow path of mash-up service. Service-Signaling extended Resource Reservation Protocol Traffic Engineering extension (RSVP-TE) [22] is used for connecting selected SPs and establishing service flow path. Then, data is transported through SPs under established service flow path. In other words, the SR and SS technologies can be applied to generate kinds of data by combining SPs on network. However, uGrid cannot support multicast communication, and doesn't take into account network energy consumption issue.

2.3 Network Virtualization Technology of JGN-X

Network virtualization technology of JGN-X aims to isolate computational resources inside network (e.g., routers and switches) act as network resources [23] [24]. Its features such as topology awareness, re-configurability, resource isolation, programmability and network abstraction, make it different from traditional concepts such as Virtual Private Networks (VPNs) and overlay network. Based on network virtualization technology of JGN-X, a slice is defined as an isolated set of computational and network resources allocated and deployed across the entire network. Each slice can be considered as different network abstraction. And meanwhile these slices are isolated from each other and have no cross-talk between them. Therefore, In JGN-X, one slice as one network may be defined an arbitrary network architecture which is consisted of arbitrary protocols, data frame and message format, and rules of actions such as whether to transmit data via circuits or packets, how to route data within a slice [25] [26]. It is possible that multiple network architectures and services with slices per user and even per application can be concurrently implemented on a single shared physical infrastructure such as Figure.1, Slice #1, #2, #3 are defined as different layer switched network.

Therefore, in order to solve network energy consumption issue of ICN and uGrid, reuse service resource issue of ICN, multicast communication issue of uGrid, our proposal is constructed on network virtualization platform of JGN-X. Our challenge not only applies multiple slices as network infrastructure to construct our proposal but also research how to achieve the network energy efficiency optimization in data transmission, network topology and data distribution [27].

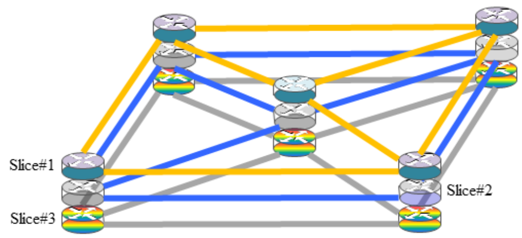


Figure.1. Multiple Slice Networks in JGN-X

3. E^3-DCN Architecture

We design multi-overlay networks Data Centric Overlay Network (DCON) and Data Generation Overlay Network (DGON) to realize network functions through combining them such as Figure.2. DCON is an extension of DCN and realizes a non-IP network. The uGrid concept is imported into DGON to realize data generation function. In E^3-DCN, DCON handles pre-registered data and receives all users' requests. User sends query into DCON and gets an exact matched data from DCON. If the requested data is not found in DCON, the network will automatically request DGON from DCON to generate the requested data. Finally, the generated data will be pushed into DCON and provided to user from DCON. If E^3-DCN can't provide the requested data from DCON and DGON, user will receive a "NACK" message which indicates the requested data has not been published into E^3-DCN by service provider.

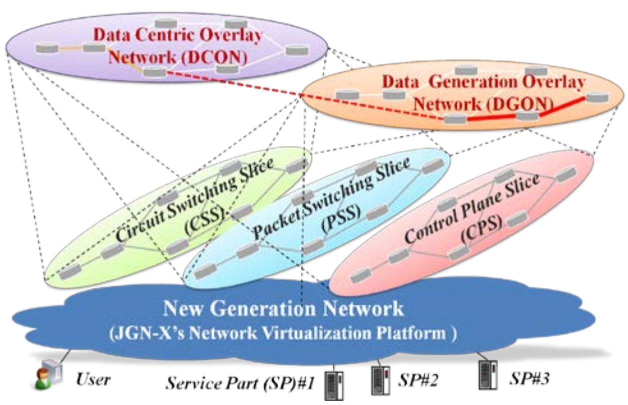


Figure.2. Overview of E^3-DCN Architecture

In order to realize the optimization of network resource and energy consumption, we adopt multi-slice networks as network infrastructure to construct our proposal based on JGN-X's network virtualization platform. In current Internet, the overlay network service receives all data requests, and the data is transmitted via underlay network such as current peer-to-peer (P2P) overlay network application. Because current Internet's overlay network services cannot collect detailed underlay network resources information, it cannot manage and control the underlay network. In other words, it is impossible to realize the optimization of underlay-network resources. In order to solve this problem, Generalized Multi-protocol label switching (GMPLS) user-to-network interface (UNI) signaling based P2P as an underlay network control technology has been proposed in [28]. The control technology can collect underlay network information and control the underlay network. Therefore, in order to achieve network resource optimization in our proposal, we adopt the control technology to manage and control underlay network. In addition, in JGN-X network virtualization Platform, a slice, which is composed of virtual nodes (VNs), virtual links and management system [25], has independent network and computational resources. One slice network can be used as one independent network infrastructure. And meanwhile, the slice network resource information can be collected at any time such as bandwidth, underlay physical links of virtual link, traffic situation, geographical location of VNs, and so on. Therefore, using above control technology, we can compute optimal data transmission path based on slice network according to collected network resource information. Additionally, JGN-X is an optical/electric packet/path integrated switching network [24]. Therefore, for the optimization of data transmission energy, we adopt multi-slice networks that one is packet switching slice network and another is circuit switching slice network to transmit data. And moreover, according to collected network resource information, the optimal energy network topology can be also computed and reconfigured at any time.

3.1 Multi-slice networks as Network Infrastructure

The separation of control plane from data plane is a key feature of E^3-DCN architecture. The control plane collects underlay network resource information, and manages and controls underlay network such as where the traffic is sent. The data plane is used for forwarding traffic based on the result determined by control plane. Therefore, we use a slice called Control Plane Slice (CPS) as control plane network. Packet switching based on statistical multiplexing is very efficient because it can share link resource with other users. But switching energy and latency problems exist in packet switching. Path/circuit switching is low-energy and low-latency. Path/circuit switching is suitable for real-time application and large data transmission. But the circuit path established between sender and receiver must set up prior to data transmission, so it doesn't suit for small data transmission and cannot share link resource to others. Therefore, in order to achieve the optimization of data transmission energy, we adopt two slices for data plane, one is Packet Switching Slice (PSS) and another is Circuit Switching Slice (CSS). Three slice networks as network infrastructure are shown in Figure.2. CPS is used as control plane network and exchanges kinds of routing and management message such as DCON's routing messages, data information, DGON's Service-Routing and Service-Signaling protocol messages. PSS provides a main network topology of E^3-DCN. The topology of PSS should be projected to a logical topology of CPS. A Generic Routing Encapsulation (GRE) tunnel is applied between two VNs of CPS to match both topologies. CSS's topology is not fixed and can be controlled and reconfigured dynamically. For example, an optical path is set-up or tear-down between two VNs of CSS at the beginning or end of data transmission. In E^3-DCN, data are mainly exchanged via PSS. If high bandwidth transmission is required and/or long holding time transmission is required, CSS is configured and used to bypass packet switching to reduce data transmission energy and ensure Quality of Service (QoS).

Two overlay networks DCON and DGON which are constructed on three slices. User's query is sent to DCON, if the requested data is found in DCON, the data is transported to user via PSS or CSS. If the requested data are not found in DCON, then the query is sent to DGON. In DGON, the requested data is generated by connecting Service-Parts, and provided to DCON via PSS or CSS. Figure.3 shows a semantic diagram of E^3-DCN logical node architecture. The logical node is connected to three slices and users. Ethernet is used as a kind of access method. And Virtual Local Area Network (VLAN) technology is applied to distinguish these slices. Finally, the logical architecture will be mapped into JGN-X's network virtualization platform.

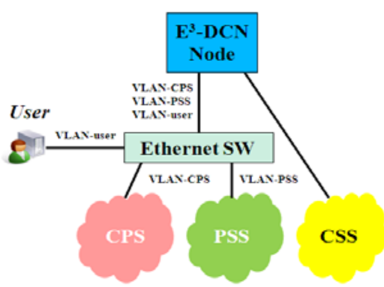


Figure.3. Architecture of E^3-DCN Logic Node

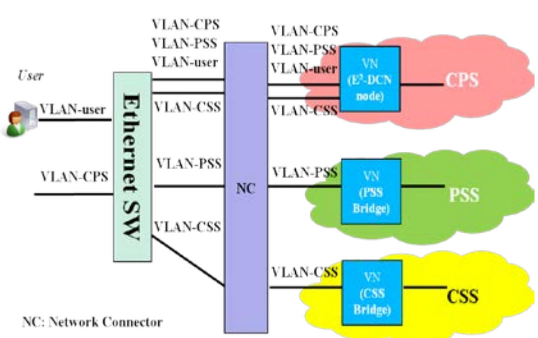


Figure.4. E^3-DCN Node on JGN-X

In JGN-X, a virtual link is defined between two VNs. Therefore, each slice's virtual link is terminated at each slice's VN. Links between E^3-DCN node and each slice shown in Figure.4 are terminated at the VN within each slice. As a result, E^3-DCN node is composed of three VNs. Three VNs are connected via a network constructed in the real world. In JGN-X, a link between the VN and the real world is made by a network connector (NC). Figure.4 shows a composite structure diagram of E^3-DCN node including NC and three VNs. The VN of CPS has main for E^3-DCN node, other two VNs have a role in Ethernet Bridge or Ethernet switch which connects virtual network in the slice and the Ethernet switch in the real network [29].

3.2 Multi-overlay Networks for Network Function

- **Data-centric Overlay Network (DCON)**

In order to realize an energy efficient ICN, We define a brand new communication mode for DCON. In CCN, NetInf and DCN, request packets and data packets, which are equal numbers, are transmitted in hop-by-hop. This way results in a lot of useless traffic is transmitted and processing is occurred in intermediate nodes before the best data source is determined. And meanwhile, this issue can also result in energy consumption is increased especially when the user is more. In order to avoid this issue, we design a new communication model for DCON which includes four phases Exploration, Response, Request and Transmission such as Figure.5. In Exploration phase, data sources holding requested data are searched by exploration messages forwarded in hop-by-hop. When data source node receives the exploration message, data source sends response message to user based on track of exploration message. This phase is called Response. During Response, the optimal transmission path can be determined in intermediate nodes by Route Selection which is a function of DCON node. For example, the best data source's response is the fastest, so its track as optimal transmission path is applied, and other responses are discarded at the intermediate node. In Request and Transmission phases, according to the optimal data transmission path, the request packets for data transmission are sent to optimal data source, the optimal data source sent data packets to response request.

The proposed communication model is different from TCP 3-way handshake communication model [30]. TCP 3-way handshake shakes hand with a specified host, whereas our model shakes hand with an optimal data source chosen from any number of data sources. The advantages of DCON communication model are that useless traffic, processing and energy consumption can be avoided comparing to CCN, NetInf and DCN. Moreover, when requested data cannot be directly provided from DCON, DCON will request DGON to generate the request data. Because multiple DCON nodes existed in DCON can send request to DGON for data generation, how to decide the optimal request node becomes a problem. By our communication model, this problem can be solved because the optimal request node can be determined in Response phase before requesting DGON. In

Figure.5, the optimal path is Node 1 -> Node 2 -> Node6, because amount of hops is the minimum.

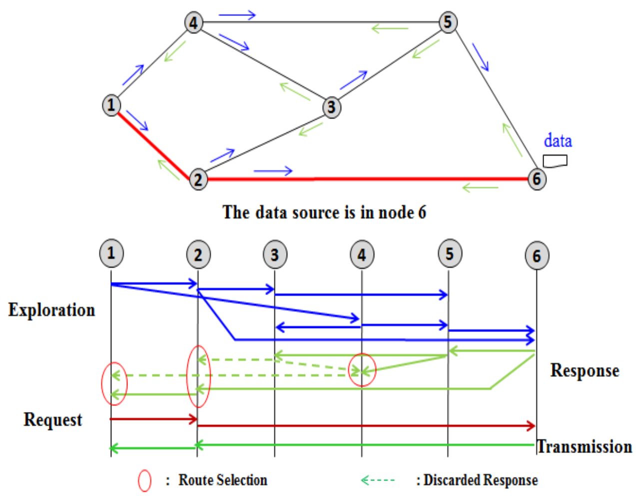


Figure.5. Communication Model of DCON

We define four type packets to realize our communication model. They are Exploration Packet, Response Packet, Request Packet and Data Packet. They all contain data name item. Exploration Packet as exploration message is used for exploring data source. Response Packet as response message is used for responding exploration. And it contains a cost item shows the minimum transmission energy cost from data source to current intermediate node. Exploration Packet and Response Packet as routing message is routed in CPS. And they are used in Exploration and Response phase to decide the optimal data transmission path for data request and transmission. Request Packet as request message is sent to optimal data source. And Data Packet is used for carrying data block from optimal data source to user. Request Packet is routed in CPS. Data Packet is transmitted in PSS or CSS.

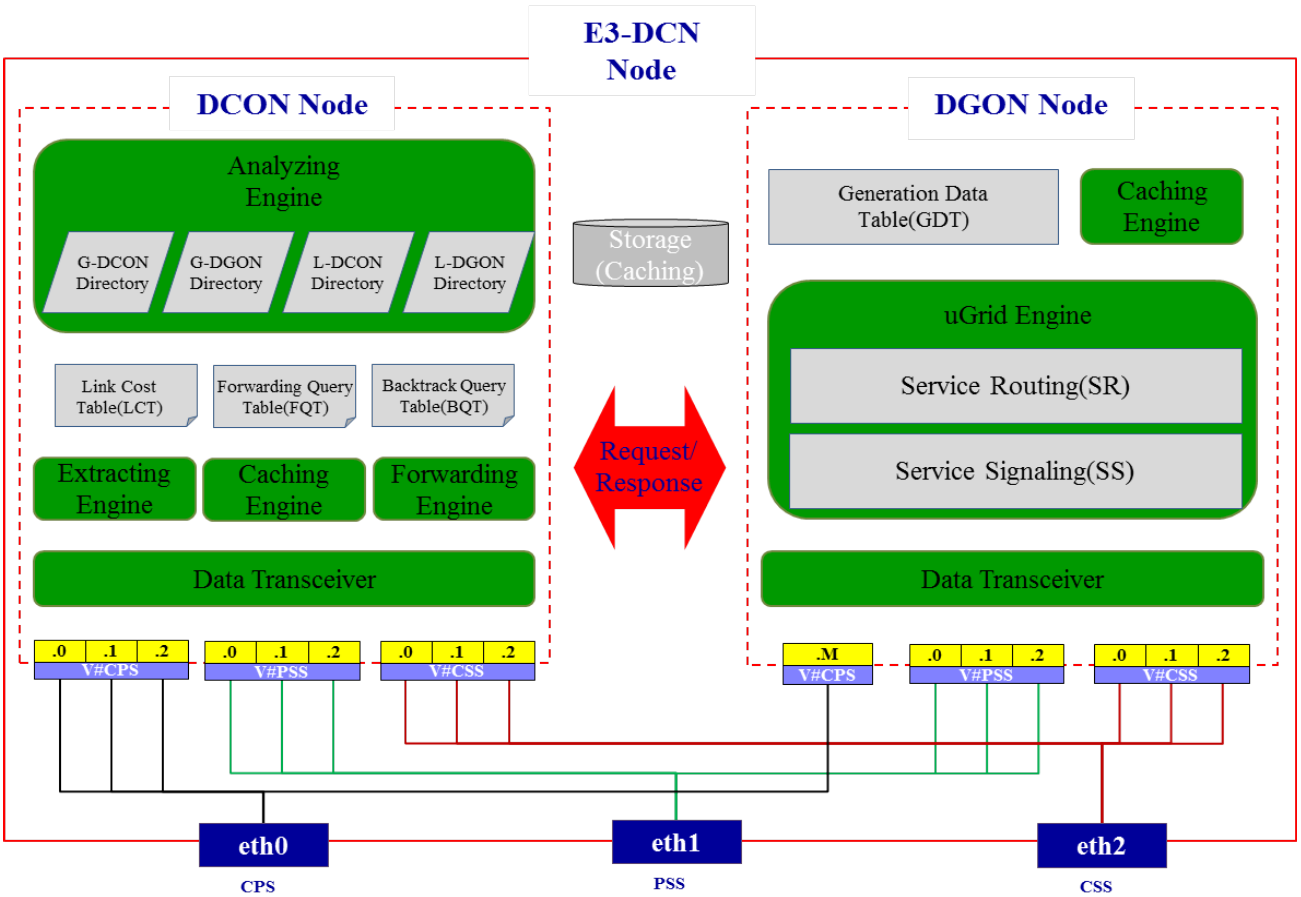
DCON is overlaid on CPS holds topology and link status information of PSS and CSS. Therefore, routing topology of DCON can be abstracted as adjacent nodes are connected with one or two links. The case of two links shows one is PSS's link and another is CSS's. The case of one link shows only PSS or CSS link exists. Each link has a weight that indicates data transmission energy cost. DCON routing includes Exploration and Response phases. We design three tables to realize DCON routing. They are Backtrack Query Table (BQT), Forwarding Query Table (FQT) and Link Cost Table (LCT) shown in Figure.6. LCT maintains link cost as weight used for computing the optimal transmission path. In Exploration phase, BQT is used for recording track where exploration message comes from. FQT records exploration message's forwarding directions where go to. In Response phase, the minimum data transmission energy cost from data source to current intermediate node is hold by Response Packet. Based on LCT, the next hop which link is used among PSS and CSS is computed by Route Selection. Finally, the result is reflected into Response Packet sent to adjacent node based on BQT and FQT, and meanwhile updated into BQT and FQT for next Request phase.

DCON node model is shown in Figure.6. It contains four engines Extracting Engine, Analyzing Engine, Forwarding Engine and Caching Engine, four directories G-DCON, G-DGON, L-DCON and L-DGON Directory (G: Global, L: Local), three routing tables Backtrack Query Table (BQT), Forwarding Query Table (FQT) and Link Cost Table (LCT) described on above. Extracting Engine is mainly responsible for extracting information from user's query. The extracted information such as data name is delivered to Analyzing Engine to judge whether the requested data exists and whether can be provided from current node. Then, based on the judged result, Forwarding Engine continues to explore the requested data, or responses the data exploration, or provide requested data from current node. The Route Selection included in Forwarding Engine is used for determining the optimal transmission path. Caching Engine is responsible for caching data. G-DCON keeps all data information of DCON which shows these data can be directly provided from DCON. G-DGON keeps the information of data generated in DGON. When the request data information does not exist in G-DCON and GDGON, the current node as Sorry Server sends the "NACK" message to response user [31]. L-DCON keeps local data information that shows what data can be directly provided from current node. And L-DGON keeps generated data information. If the requested data exists in L-DGON, Forwarding Engine requests DGON to generate the requested data according to data name. Least Recently Used (LRU) is applied into directories for quick retrieval [32]. Data Transceiver is responsible for receiving and forwarding packets from every interface such as V#CPS.1, V#PSS.1, V#CSS.1 shown in Figure.6. It can communicate with other engines. Figure.6 is shown an E^3-DCN node holds three branches and adopts virtual interfaces to connect three slice network based on VLAN technology.

- **Data Generation Overlay Network (DGON)**

DGON is responsible for data generation based on Service-Routing and Service-Signaling technologies. Its routing topology is the same as DCON's that there are one or two links between adjacent nodes. The optimal data transmission path connected with several Service-Parts can be computed based on the routing topology.

DGON node model is shown in Figure.6. It is composed of uGrid Engine, Caching Engine and Generation Data Table. uGrid Engine includes Service-Routing and Service-Signaling modules. Generation Data Table keeps data generation information such as data name and Service-Part information. The request of data generation is sent from DCON when DCON can't directly provide the requested



data. DGON extracts data name based on data generation request. According to data name, Service-Part information is resolved based on Generation Data Table. Then, uGrid Engine performs Service-Routing to get the optimal data transmission path, and executes the Service-Signaling to establish connection connected selected Service-Parts to generate data. Next, the generated data is cached by Caching Engine and its information is registered into DCON. At last, the generated data is provided to user from DCON. Data Transceiver is the same as DCON's.

3.3 Overview of E^3-DCN Service

The overview of E^3-DCN service is shown in Figure.7 (The unused links are not drawn in DCON and DGON). E^3-DCN node connects with three slices and includes two overlay network nodes. Service provider publishes data "a.avi" into E^3-DCN using ***publishData*** Application Programming Interface (API). The "a.avi" can be generated by combining Service-Parts A and B. Its data information is registered into GDT of DGON and directories of DCON. User1, User2 and User3 request the same data "a.avi" using ***getData*** API. Their queries are sent to DCON. The data generation request is sent to DGON from node5 of DCON. The optimal data source and transmission path of DCON is determined based on proposed communication model. And the optimal data transmission path finally forms a multicast tree to transmit "a.avi" from node5 of DCON. The energy efficiency of data transmission path is based on CSS and PSS. DGON's data transmission path is changed at node2 from CSS to PSS, and DCON's data transmission path is changed at node4 and node3.

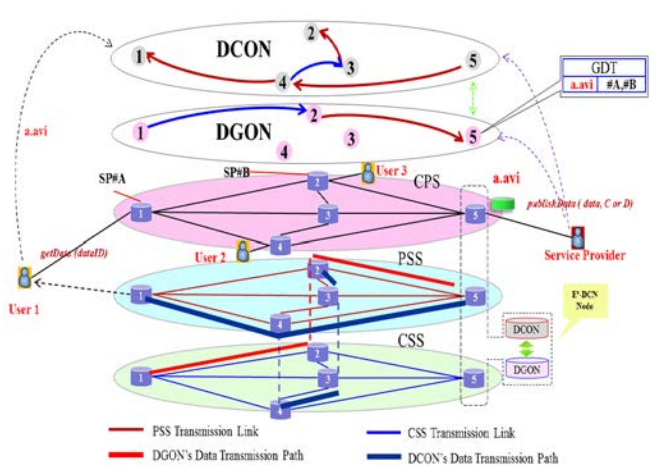


Figure.7. Overview of E^3-DCN Service

4. Energy Optimized Strategies in E^3-DCN

There are different level approaches they are device-level, equipment-level and network-level can be applied to realize energy efficient network [33]. About E^3-DCN, we mainly focus on network-level approach which is used for achieving dynamic network-level energy efficiency optimization such as topology and route optimization, data/service relocation and caching optimization, reducing traffic peak and optical switching for bulk traffic. Therefore, there are three energy optimized strategies are applied to E^3-DCN.

- **Strategy I: Dynamic Network Reconfiguration**

Initially, a network topology is designed based on some requirements such as minimum transport delay, minimum network resources, accommodate traffic demand, and ensure resiliency. The network is usually designed to endure the maximum traffic demand, but traffic demand is dynamically changed in practice. In case of the lower traffic demand, energy efficient traffic engineering (TE) [34] [35] [36] can be applied to concentrate the traffic into limited number of links and nodes, and then unused links and nodes are shutdown to save operating power consumption. In E^3-DCN, the energy efficient TE is applied to virtual networks. The topology of virtual network is dynamically reconfigured to contain the minimum number of nodes and links. To realize the operation energy saving in the real network, JGN-X's network virtualization platform should support real node and link's shutdown operation. Service-Copy is another dynamic reconfiguration approach [37]. A Service-Part, which provides processing function i.e. software, can be easily copied from a computer to other computers. Virtual Machine (VM) copy/migration is also an example of the Service-Copy. Though Service-Copy consumes additional power consumption, there are some advantages as follows: 1) Shorter data transmission route can be formed by coping Service-Part. Data transmission and switching energy consumption can be also reduced. 2) The copied Service-Part can be shared for other users. 3) By Service-Copy, the same Service-Parts are distributed multiple places, so that network congestion can be voided in some degree. 4) It is not need to add the new computer for copied Service-Part.

- **Strategy II: Circuit Switching Bypass**

In general, data transmission cost of packet switching network is cheaper comparing to circuit switching network. This is because the bandwidth can be shared among traffic flows based on statistical multiplexing in packet switching network. However, the routing and transmission delay issue exists in packet switching. Therefore when a large data is transmitted or strict quality of service (QoS) preservation is required, circuit switching is preferred, and packet switching is avoided in as far as possible. This is called "circuit switching bypass" [38] [39]. In E^3-DCN, links in DCON and DGCON are provided via CSS and PSS. A link of CSS is composed of link termination Ethernet switches, transmission links, and circuit switches. A link of PSS is composed of link termination Ethernet switches, transmission links, and packet switches. In [40], it has been shown that an optical circuit switch requires 0.5 nJ/bit switching energy and electrical packet switch such as an Ethernet switch and an IP router requires 10 nJ/bit switching energy. The link of PSS is more energy consumption, but its transport cost is cheaper. On the contrary, the link of CSS requires less energy consumption but its transport cost is higher. Therefore, to determine which links should be used, an energy consumption estimation algorithm is required. And for transmitting data by optimal transmission path, an optimized energy routing algorithm is also required. The algorithm can compute energy optimized path according to some parameters such as data size, data transmission speed, flow duration time, and some QoS items.

- **Strategy II: Caching Optimization**

An excellent caching strategy can not only shorten the response time but also reduce the routing and transmission distance between data and user so as to achieve better energy saving. And meanwhile, data caching inside network can also reduce the total network load and avoid network congestion [41] [42]. Because E^3-DCN can be used as a CDN application, data caching strategy becomes a very important issue. We are studying the optimized data caching strategy for DCON and DGON. And we will also consider to extend Open Shortest Path First (OSPF) and Border Gateway Protocol (BGP) for sharing cached data among autonomous systems (AS)'s cache router to achieve scalability.

5. Evaluations

The energy consumption of transmission and network performance of DCON were evaluated. We simulated three networks DCON, CCN/DCN/NetInf (CDNI) and TCP/IP. The parameters of network topology used in simulations are shown in Table I.

Table I. The Parameters of Simulations

Topology Nodes	5000
Topology Edges	34972:Used in CDNI and TCP/IP 69944:Used in DCON
Cost of CSS's link	Range: 1~100
Cost of PSS's link	Range: 1~100
Request Users	From 100 to 2500
Data Source	1

Every network topology contains 5000 nodes. DCON takes into account the optimization of energy consumption for data transmission based on PSS and CSS, so there are two edges one is PSS link and another is CSS link exist in between adjacent nodes of DCON. Because CCN/DCN/NetInf and TCP/IP only uses PSS or CSS to transmit data and doesn't take into account data transmission energy computation problem, there is only one PSS or CSS link exists between adjacent nodes of its topology. Therefore, the amount of edges of network topology used in CCN/DCN/NetInf and TCP/IP is 34972, used in DCON's is 69944. The link cost that indicates data transmission energy consumption is random positive integer. Its value range is between 1 and 100. Only one data source exists in each network. The amount of request user increases from 100 to 2500.

We evaluated data transmission energy consumption cost by comparing DCON with CCN/DCN/NetInf networks. Because CCN, DCN and NetInf all use name-based routing, they are considered as the same type network in simulations. The network performance is evaluated by comparing with TCP/IP network. Because TCP/IP network supports point-to-point communication channel, with the increasing of user, the used links of channels between adjacent nodes will be increased. Because DCON realizes ICN and can aggregate the same requests to one in intermediate node, there is only one link used between adjacent nodes when all users request for the same data. Therefore, the network performance is evaluated based on the amount of used links. The number of used links is more that indicates the network performance is lower, because network congestion and delay problem occur easily.

The evaluation of data transmission energy consumption is shown in Figure.8. The energy consumption cost of DCON is less than CCN/DCN/NetInf about 40%. The result shows that DCON uses the optimal energy route to transmit data in contrast to CCN, DCN and NetInf. This is because DCON can choose the minimum energy consumption link for transmission based on PSS and CSS. CCN, DCN and NetInf don't take into account energy consumption problem in data transmission and only compute data transmission route based on PSS or CSS network. Therefore, the total data transmission energy consumption of DCON is less than of CCN/DCN/NetInf.

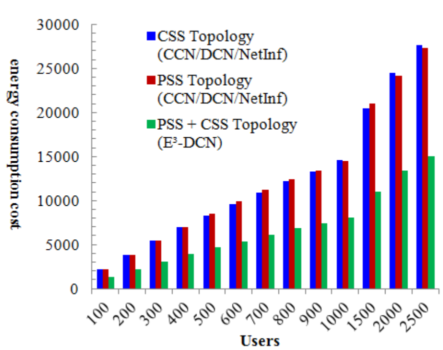


Figure.8. Evaluation of Energy Consumption

The evaluation of network performance result is shown in Figure.9. The amount of used links of our proposal is far less than TCP/IP network. This is because TCP/IP network adopts point-to-point communication channel to transmit data, and these links of channels between adjacent nodes are independent and cannot be aggregated into one when all users request the same data. In our proposal, when all users request the same data, these requests can be aggregated into one request in intermediate node. Between adjacent nodes, only one channel is established and data packet is transmitted by multicast in intermediate node according to aggregated request information. The result also shows that with the increase of user request, the nodes aggregated request become more in DCON so that the amount of used links becomes less than TCP/IP network.

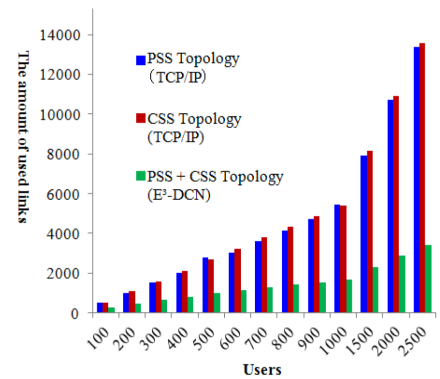


Figure.9. Network Performance Evaluation

6. Experiments

In order to validate our proposal, we have realized non-IP communication network DCON, data generation of DGON and data transmission using PSS and CSS.

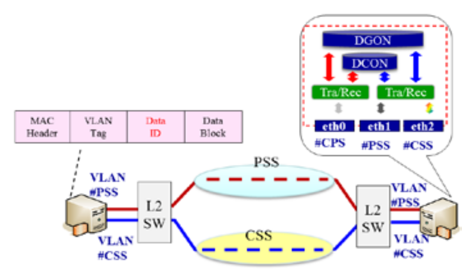


Figure.10. Communication between Two Nodes of DCON

The transmission mechanism of DCON is shown in Figure.10. Based on raw socket technology that can directly send and receive data from data link layer with specified interface [43], we defined data packet encapsulated in Ethernet frame including items Data ID, Data Block. Because VLAN technology is applied to distinguish PSS and CSS slices, so VLAN Tag is also encapsulated in frame. Based on this mechanism, we demonstrated DCON network composed of 6 DCON nodes with Ethernet and optical switches and exhibited in the 5th Symposium of New Generation Network in Tokyo of Japan [44], MPSL2012 international conference [45] and KEIO TECHNO-MALL 2012 [46].

Service-Routing and Service-Signaling technology were imported into DGON for data generation through combining Service-Parts. In Cloud Symposium of Japan 2013 [47], E^3-DCN prototype, shown in Figure.11, was composed of DCON and DGON overlay networks based on JGN-X. DGON realized data generation by combining Sendai data center in Tohoku area of Japan, Keio University in Kanagawa Japan, and Cloud Symposium Place in Tokyo Japan, three places' Service-Parts. DCON only deployed in Cloud Symposium place because it is non-IP network. The generated data of DGON was pushed into DCON and then transmitted to users.

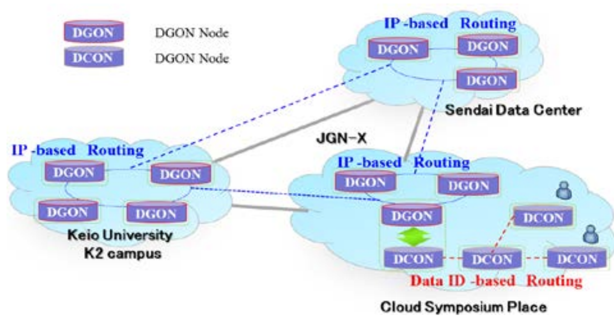


Figure.11. Overview of E^3-DCN Prototype

7. Conclusions and Future Work

We have proposed the architecture of E^3-DCN based on JGN-X network virtualization platform in this paper. E^3-DCN is composed of two overlay networks DCON and DGON, and three slice networks CPS, PSS and CSS. DCON realizes an ICN. DGON, which is data generation network, not only can generate requested data for DCON by combining Service-Parts, but also can improve resource utilization rate. CPS as control plane is used for control network. PSS and CSS are used for data transmission. E^3-DCN not only solves problems existed in CCN, DCN, NetInf and uGrid but also achieves an energy efficient ICN network by reconfigure network topology, circuit switching bypass and data caching. By evaluations, the optimization of data transmission energy efficiency can be achieved based on PSS and CSS comparing to other ICN projects. And the network performance is better than current TCP/IP network. Furthermore, we have developed the prototype of E^3-DCN to validate our proposal on JGN-X.

About future works, we will continue to study optimal energy algorithms for data transmission, dynamic network reconfiguration, circuit switching bypass and optimal data caching. And we will also study and develop E^3-DCN APIs to get underlay network information for energy algorithms and network management. Finally, we will integrate these energy optimized algorithms and network management with prototype of E^3-DCN on JGN-X.

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Shanming Zhang received the B.S. degree in computer science from Changchun University of Technology, China, in 2006. He joined Sony Global Information System (Dalian) Co., Ltd, China, in 2006. He was engaged in the development of information system and maintenance. He enrolled and received the M.E. degree in electronics engineering from Keio University in 2011 and 2013, respectively. He is currently working toward the Ph.D. degree in Graduate School of Science and Technology, Keio University, Japan. His research interests include Information-centric networking, network functions virtualization, network energy efficiency and data caching. He is a member of the IEICE and a student member of the IEEE.

Hidetoshi Takeshita graduated from Shizuoka University, Japan where he received the B.E in 1974. In 1974 he joined NEC Corporation, Tokyo, Japan, where he engaged in the development of electronic switching systems, digital switching systems, and system engineering for fixed and mobile carriers. He graduated from Keio University where he received the Ph.D. degree in Sept. 2012. From 2010 to 2012, he was a Research Assistant of Keio University Global COE Program, and from June to September in 2012, he was a researcher in Graduate School of Science and Technology of Keio University. Since Oct. 2012, he has been a project assistant professor. He is a member of the IEEE, and the IEICE.

Satoru Okamoto is a Project Professor at Keio University, Yokohama, Japan. He received his B.E., M.E. and Ph.D. degrees in electronics engineering from Hokkaido University, Hokkaido, Japan, in 1986, 1988 and 1994. In 1988, he joined Nippon Telegraph and Telephone Corporation (NTT), Japan, where, he conducted research on ATM cross-connect system architectures, photonic switching systems, optical path network architectures, and participated in development of GMPLS-controlled HIKARI router ("photonic MPLS router") systems. He joined Keio University in 2006. He is now researching future IP + optical network technologies, and application over photonic network technologies. He was the chair of the IEICE Technical Committee on Photonic Network (PN) (2010-2011). He is an IEICE Fellow and an IEEE Senior Member.

Naoaki Yamanaka graduated from Keio University, Japan where he received B.E., M.E., and Ph. D. degrees in engineering in 1981, 1983 and 1991, respectively. In 1983 he joined Nippon Telegraph and Telephone Corporation's (NTT's) Communication Switching Laboratories, Tokyo, Japan, where he was engaged in the research and development of a high-speed switching system and technologies for Broadband ISDN services. Since 1994, he has been active in the development of ATM-based backbone networks and system. He is now researching the future optical IP network, and optical MPLS router systems. He is currently a professor of Keio University. He is a vice director of Asia Pacific Board at IEEE Communications Society. He is an IEEE Fellow and an IEICE Fellow.