Vol.2015-AVM-91 No.23
2015/12/4

省電力動画像配信のための ICN ネットワーク消費電力量評価

青木大樹[†1]　竹中幸子[†1]　金井謙治[†1]　甲藤二郎[†1]　中里秀則[†1]　広瀬真里枝[†2]

概要：Information Centric Networking (ICN) は、コンテンツ名を IP アドレスの代わりに利用する次世代のネットワーク基盤として注目されている新しい枠組みである。現状、ICN には多くの課題があり、特にその消費電力特性は十分に検討されていない。そこで、本稿は ICN ネットワークの消費電力特性を評価するために、まず PC、Access Point、スマートフォンといった実機の消費電力量を計測し、消費電力量モデルを構築する。そして電力モデルと ICN シミュレータの一つである ndnSIM を利用して、ICN ネットワーク全体における消費電力特性を評価する。

キーワード：ICN, CCN, 電力量, 消費電力.

Energy Consumption Evaluation of ICN Toward Power-Saving Video Delivery

DAIKI AOKI[†1]　SAKIKO TAKENAKA[†1]　KENJI KANAI[†1]　JIRO KATTO[†1]
HIDENORI NAKAZATO[†1]　MARIE HIROSE[†2]

Abstract: Information Centric Networking (ICN) is a new networking paradigm in which the network provides users with named content, instead of communication channels between hosts. However, many issues, such as naming, routing, resource control, and security, still need to be resolved before it can be realized practically. Further, the energy efficiency of ICNs has not been sufficiently considered. In this study, we evaluate the energy consumption of an ICN network by first measuring the power consumption of actual PCs/smartphones and constructing an energy consumption model. Then, by using the model and the simulator ndnSIM, we calculate the energy consumed by the network.

Keywords: ICN, CCN, Energy, Power Consumption

1. INTRODUCTION

Recently, mobile traffic in networks has witnessed exponential growth. Moreover, Cisco has announced that mobile video traffic, in particular, has the largest growth among mobile application traffic and will generate over 69 percent of mobile traffic by 2019 [3] because video content has substantially higher bit-rates than other mobile content types. We believe that Information Centric Networking (ICN), such as Content Centric Networking (CCN) [2] and Named Data Networking (NDN) [1], is a promising solution for dealing with this traffic explosion because of its new network paradigm. The main concept underlying ICN is the provision of content-based routing, instead of IP-based routing, and an in-network caching mechanism. These unique features enable users to obtain requested content with lower network latencies because the content can be delivered to them from the nearest cached node, instead of the origin content servers [7]. Thus, ICN can reduce network traffic primarily in core networks. In addition, this traffic reduction is expected to contribute significantly to green networking.

†1 早稲田大学　基幹理工学研究科
Graduate School of Fundamental Science and Engineering, Waseda University
†2 パナソニックアドバンストテクノロジー（株）
Panasonic Advanced Technology Development Co., Ltd.

To verify whether ICN can contribute significantly to green networking, we analyze and evaluate the energy consumption characteristics of ICN. First, we construct an energy consumption model for core and edge networks. Next, we observe the actual energy consumption for different network conditions in order to determine the model parameters. Then, we evaluate the network performances of ICN using ndnSIM [9] in a typical network topology. The results obtained confirm that ICN can contribute substantially to green networking.

The remainder of this paper is organized as follows. Section II discusses related work. Section III presents our energy consumption model. Section IV evaluates the energy consumption characteristics of various devices. Section V evaluates the energy consumption in simulated network topologies. Section VI concludes this paper.

2. RELATED WORK

2.1 CCN/NDN

CCN/NDN is one of the architectures for ICN. In CCN/NDN delivery, two message types called Interest and Content Object are exchanged. Interest messages are used to request data by specifying the content chunk name. The name prefix in the message is used to limit the data that are most suitable from the collection of the same prefix. Content Object messages are used to supply data in response to the Interest messages. These messages are primarily composed of a name, publisher, and a chunk of data. They also contain data payload, cryptographic signature, publisher identification, and other information about signing. In communication, a data consumer broadcasts an Interest message over all available connectivity, and any nodes with the content that satisfies the Interest must respond with at most one Content Object message. In order to satisfy the Interest, the content name in the Interest message has to be a prefix of the content name in the Content Object message. One of the key features of CCN/NDN is its router's content caching mechanism. Content that goes through a CCN/NDN router is cached. This feature reduces network congestion and improves content delivery time because the clients can fetch the content from the nearest cache rather than the origin content server.

2.2 Power consumption models for various networks

Much research has been conducted on power consumption evaluation in various network types.

In [4], Kamiyama et al. evaluated the power consumption of smartphones. To calculate and visualize the power consumption characteristics, they developed an application that collects the CPU utilization statistics of various smartphone components (e.g., display, network interfaces, and mobile apps). Then, they collected each CPU utilization component under various user usage scenarios and constructed power consumption models for each component based on actual observations.

In [5], Arnold et al. theoretically estimated the power consumption for base stations. They constructed theoretical power consumption models of macro and micro base stations for heterogeneous wireless networks. The results obtained showed that a macro base station could provide energy-efficient transmission to users located within its 1500 m coverage area.

In [6], Nakai et al. proposed a power consumption model for CCNx routers. Because the power consumption characteristics heavily depend on the hardware characteristics of CCN routers, they built the power consumption model based on the minimum hardware configuration. Further, they verified the power consumption model by conducting actual observations for a CCNx router.

Using these studies as our basis, we built a combined energy consumption model for core and edge networks, and observed the actual energy characteristics of the combined network using a hardware measurement tool called Power Monitor [8].

3. ENERGY CONSUMPTION MODEL

In this section, we present the energy consumption model constructed for the combined network. We separately model the energy consumption of network areas, such as core networks, edge networks, access networks, and users. Then, we combine these separate models to estimate the energy consumption of the overall network.

To evaluate the energy consumption of the combined network, we separately build energy consumption models for each network device, such as core servers, edge servers/routers, Access Points (APs)/base stations, and user terminals. An assumed network topology and model parameters are shown in Fig. 1 and Table 1, respectively. As shown in the figure, the users connect to the edge server/router via Ethernet, Wi-Fi, and cellular networks.

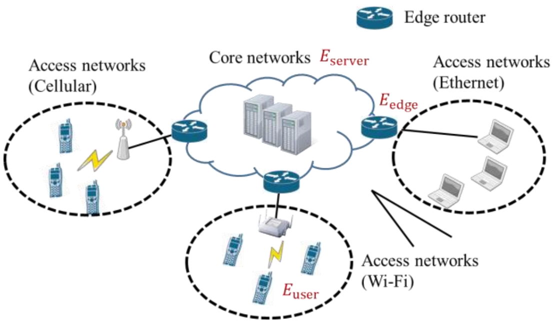

Figure 1 Assumed network topology

Table 1 Parameter definitions for energy consumption model

Parameter	Denition
E_{total}	the total energy consumption in the network
E_{server}	the energy consumption of the server
E_{edge}	the energy consumption of the edge server
E_{ap}	the energy consumption of the access point
E_{user}	The energy consumption of the user device
E_{TX}	the energy consumption of the transmission
E_{RX}	the energy consumption of the receipt
$P(th)$	the energy consumption of the transmission per 1bit
$P'(th)$	the energy consumption of the receipt per 1bit
D	the size of the data

The energy consumption for the combined network is simply computed by summing the energy consumed by the core networks, edge networks, access networks, and users. Thus, let E_{total} denote the total energy consumption for the combined network. Then, E_{total} can be formulated as

$$E_{total} = \Sigma E_{server} + \Sigma E_{edge} + \Sigma E_{ap} + \Sigma E_{user} \quad (1)$$

where Eserver, Eedge, Eap, and Euser are the energy consumed by a core server, an edge server, an AP, and a user terminal (a smartphone or PC).

In addition, the energy consumed by each device is computed by summing the energy consumed for data transmission and reception. Therefore, let ETX and ERX denote the energy consumed for transmission and reception, respectively.

Consequently, the energy consumed by each device can be formulated as

$$E_{server}, E_{edge}, E_{ap}, E_{user} = E_{TX} + E_{RX} \quad (2)$$

Note that the energy consumptions for transmission and reception vary according to device type and hardware configuration. Further, the energy consumptions for transmission and reception depend on throughput performance and data transmission. Thus, let P(th), P'(th), and D denote the energy consumption for 1-bit throughput data transmission, 1-bit throughput data reception, and transmission data, respectively. Consequently, the energy consumption for transmission and reception can be formulated as

$$E_{TX} = P(th) * D \quad (3)$$

$$E_{RX} = P'(th) * D \quad (4)$$

4. ENERGY CONSUMPTION EVALUATIONS

Next, in order to define the energy consumption parameter for 1-bit data transmission and reception (P(th) and P'(th)), we used a hardware power measurement tool to evaluate the energy consumption characteristics for three typical devices: a smartphone, an AP, and a low-energy compact PC.

4.1 Energy consumption characteristics of a smartphone

First, we observe the energy consumption characteristics of a smartphone. The experimental environment utilized is shown in Fig. 2. As shown in the figure, the smartphone, called "MEDIAS N-06E," was connected to a server PC via IEEE 802.11n. Bulk data were then transmitted over TCP/UDP, with transmission data sizes 10, 50, 60, 70, 80, 90, and 100 MB. Each packet had a fixed size of 1000 B in both protocols. During the evaluations, we measure the energy consumed by the smartphone using a hardware power measurement tool called "Power Monitor [8]."

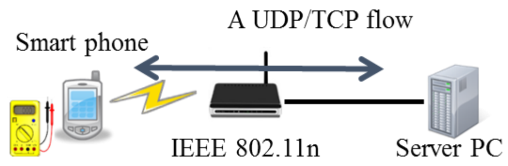

Figure 2 Experimental environment for smartphone energy consumption evaluations.

The energy consumptions for various transmission data sizes are shown in Fig. 3. As shown in the figure, the energy consumption increased with transmission data size for both protocols. In the evaluations, the throughputs did not significantly change for most of the transmission sizes, as shown in Fig. 4. Consequently, the transmission time increased with transmission data size, as shown in Fig. 5. As a result, the smartphone consumed more energy to transmit larger data. Further, UDP was found to be more energy-efficient than TCP.

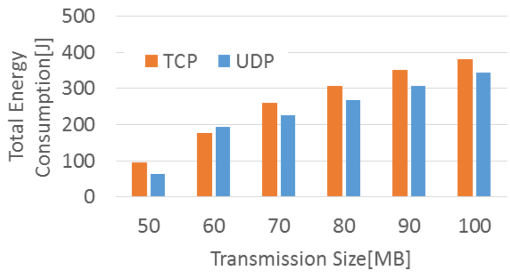

Figure 3 Comparison of energy consumption characteristics for various data transmission sizes

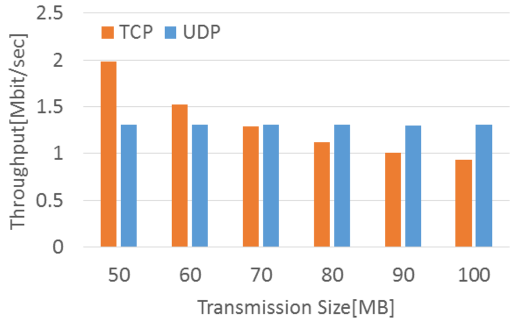

Figure 4 Comparison of throughput characteristics for various data transmission sizes

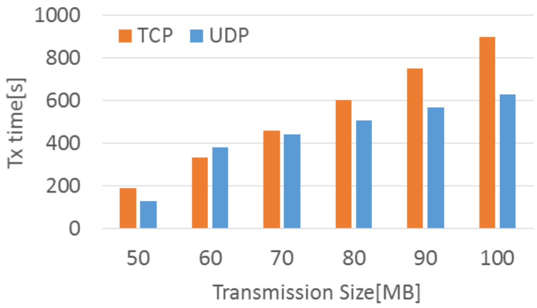

Figure 5 Comparison of transmission times for various data transmission sizes

Fig. 6 shows the energy consumption for 1-bit transmission. As shown in the figure, the throughput accounted for most of the energy consumption for the 1-bit data transmission. In addition, energy consumption increased with transmission time.

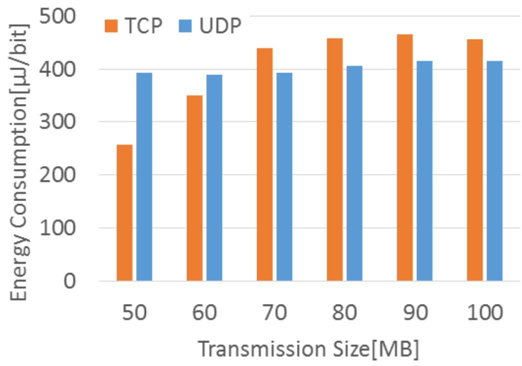

Figure 6 Comparison of energy consumptions for 1-bit transmission with various data transmission sizes

4.2 Energy efficiency of data transmission and reception

Next, we observed the energy consumptions for data transmission and reception by the low-energy compact PC, AP, and smartphone. The experimental environments utilized are shown in Fig. 7. As shown in the figure, we employed two different experimental environments—one for the wireless connection case and another for the wired connection case. In the wireless scenario, the smartphone was connected to the server PC via IEEE 802.11n. In the wired scenario, the low-power compact PC was directly connected to the server PC via Gigabit Ethernet. During the evaluations, we measured the energy consumed by the smartphone and client PC using hardware power measurement tools called "Power Monitor," and "Wat Monitor [11]," respectively.

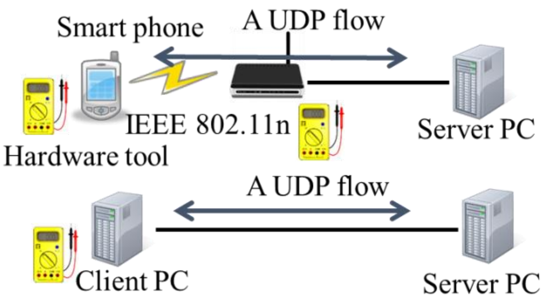

Figure 7 Experimental environments for energy consumption evaluations for smartphone and low-power compact PC

A UDP flow was transmitted for 30 sec using Iperf [8]. For this flow, we evaluated energy consumptions for both uplink and downlink, and computed the energy consumptions for 1-Mbit data transmission and reception from the measurement values.

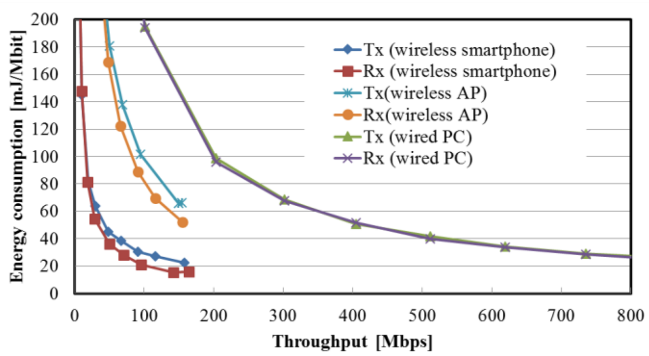

Figure 8 Comparison of energy consumptions for 1-Mbit data transmission and reception for various devices

A comparison of energy consumptions for 1-Mbit data transmission and reception is shown in Fig. 8. We defined these energy consumptions as the energy efficiency for data transmission and reception. As shown in the figure, the energy efficiency depended on the throughput irrespective of the devices. As the throughput increased, the energy efficiency increased. This is because the transmission time decreased as the throughput increased, and the device can save greater energy for 1-Mbit transmission and reception. Further, in case of wireless communication, the results indicated that the energy consumption for transmission was higher compared with the reception case. This is because the device consumes larger transmission power in order to communicate with a farther AP. In contrast, in case of wired communication, the energy consumption for the transmission was the same as that for the reception. In this experiment, we observed the total energy when the PC, the AP, and the smartphone transmitted and received data. As expected, the PC was found to consume the most energy because the PC equips larger-scale and higher-performance hardware compared with the AP and the smartphone.

5. Evaluation of energy consumption characteristics

To evaluate the energy consumption of the various network topologies, we used a simulator, "ndnSIM" [9]. We assumed four scenarios. In one scenario, the contents were saved at the edge of the servers and the user terminals were PCs or smartphones. In another scenario, the contents were saved at the center of the networks and the user terminals were PCs or smartphones. The four scenarios are summarized in Table 2.

Table 2 The four scenarios used to evaluate the energy of the various network topologies

Scenario	Backbone	Access	Content
Origin (wired)	1Gbps, 10msec	1Gbps, 10msec	Origin
Edge cache (wired)			Edge
Origin (wireless)	1Gbps, 10msec	100Mbps, 100msec	Origin
Edge cache (wireless)			Edge

In the experimental network, there were four users demanding contents. Interests went to the edge servers or the core servers. Then, the servers returned the requested contents (Fig. 9). The energy consumption was calculated for this scenario, as shown in Fig. 10.

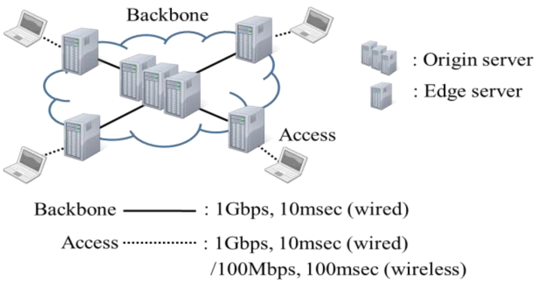

Figure 9 The experimental network topology

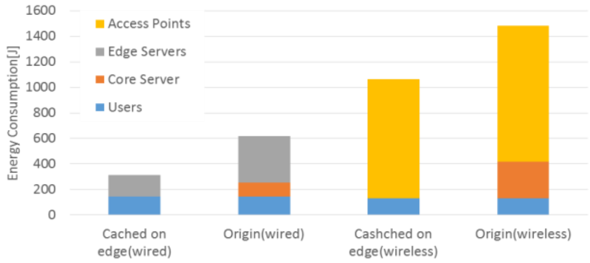

Figure 10 Total energy consumption

Each of the four users desired 100 MB of contents, and so they sent the Interests to the servers. Contents were then sent to each of them. Each link had a 10 ms delay. Servers transmit larger data sizes than users. Thus, the servers consumed much more energy than the users. The users consumed the same amount of energy when the contents were saved at the edge server instead of the core server. During this period of time, the total energy consumption for the edge scenario was 70% that of the origin scenario. In addition, the total energy consumption when a user connected to the Internet via a wired connection was 50% of the energy consumption when the user connected wirelessly to the Internet.

The link throughputs contribute significantly to energy consumption (Figs. 11 and 12). “Out” signifies uplink throughputs while “In” signifies downlink throughputs. The throughput of the link that receives or transmits the contents is high because the data sizes of the contents are larger than the data sizes of the Interests (requests).

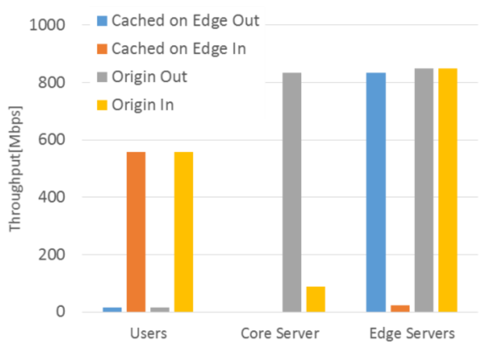

Figure 11 Throughputs of the links (wired)

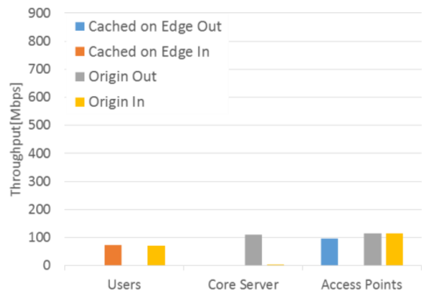

Figure 12 Throughputs of the links (wireless)

When the link throughputs were high, the energy efficiency was also high (Figs. 13 and 14). The energy efficiency was very low when Interests (requests) were being received or transmitted. Further, the energy per bit was approximately three times higher when the users wirelessly connected to the Internet than with a wired connection. The data sizes were large when content was being received or transmitted (Figs. 15 and. 16). Because each user wanted 100 MB of content, the core server sent 400 MB of data.

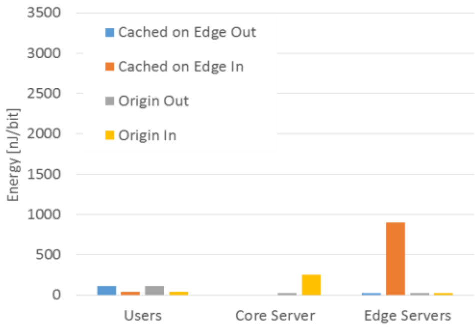

Figure 13 Energy consumptions per bit (wired)

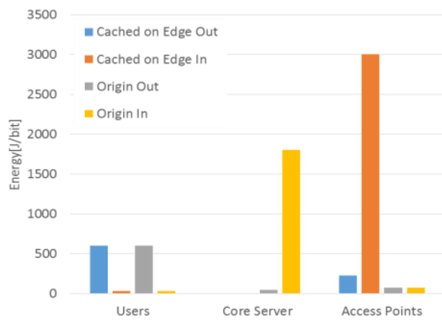

Figure 14 Energy consumptions per bit (wireless)

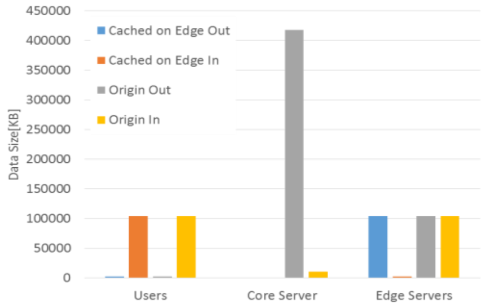

Figure 15 Data sizes (wired)

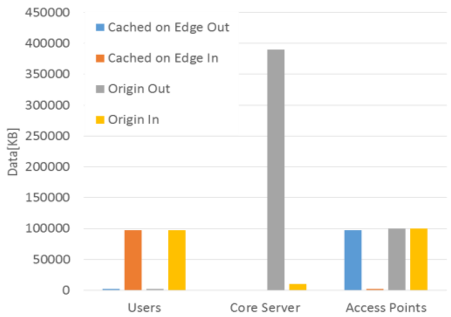

Figure 16 Data sizes (wireless)

6. Discussion

In the experimental network, the total energy consumption for the edge scenario was 70% that of the origin scenario of the origin scenario. The total energy consumption when a user connected to the Internet via a wired connection was 50% of the energy consumption when the user connected wirelessly to the Internet. Probably, we can cut the energy to use edge servers which have the contents and to connect to the Internet via a wired connection though the ratio of energy consumption is changed when the network changes. Since the energy efficiency is high if the link throughputs are high, we had better to change the equipment or a communication system with the high link throughputs. The data sizes only contribute to the amount of the energy. Though they don't directly effect the energy efficiency, when the transmitted data is very large the link throughputs are probably changed because of the congestion.

7. Conclusions

This paper proposed a method for evaluating the energy consumption of networks by modeling the energy consumption. If the data content that consumers request are cached in the edge servers, the energy required for transmission and reception is large. However, the total energy consumption for such an edge scenario is 70% that of an origin scenario. Further, the total energy consumption when a user connects to the Internet via a wired connection is 50% that of the energy when the user connects wirelessly. For larger networks than the network used in this simulation, the energy consumption will be greater because the number of transmitting devices will increase. Thus, the effect of caching contents will also increase substantially. However, the rate may be different if the simulated networks are different.

Acknowledgement This paper has been partially supported by the FP7/NICT EU/JAPAN GreenICN Project and by "Research and Development on Fundamental and Utilization Technologies for Social Big Data", NICT, JAPAN. The authors also thank to Mr. Kenichi Nakamura of Panasonic Corporation for his helpful comments.

References

1) L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, K. Claffy, P. Crowley, C. Papadopoulos, L. Wang, and B. Zhang, "Named data networking," ACM SIGCOMM Computer Communication Review, vol. 44, issue 3, Jul. 2014.
2) V. Jacobson, D. K. Smetters, J. D. Thornton, M. F. Plass, N. H. Briggs, and R. L. Braynard, "Networking named content," Proceedings of CoNEXT 2009, December 1-4, 2009, pp. 1-12.
3) Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014–2019. [Online], http://www.cisco.com/web/JP/solution/isp/ipngn/literature/pdf/white_paper_c11-520862.pdf
4) T. Kamiyama, H. Inamura, and K. Ohta, "Evaluation of a model-based energy profiler for Android," DICOMO 2013, July 2013 (in Japanese).
5) O. Arnold, et al. "Power consumption modeling of different base station types in heterogeneous cellular networks." IEEE Future Network and Mobile Summit, 2010.
6) Y. Nakai, K. Tsukamoto, Y. Koizumi, and T. Hasegawa, "A proposal of a power consumption model of a CCNx router," IEICE Technical Report, vol. 113, no. 473, pp. 111-116, 2014
7) H. Shimizu, H. Asaeda, M. Jibiki, and N. Nishinaga, "Content hunting for in-network cache: Design and performance analysis," IEEE International Conference on Communications (ICC), 2014, pp. 3172-3177.
8) Power Monitor, [Online]: https://www.msoon.com/LabEquipment/PowerMonitor/
9) ndnSIM, [Online]: http://ndnsim.net/2.0/
10) Iperf, [Online]: http://iperf.fr/
11) Wat Monitor (in Japanese). [online]: http://www.sanwa.co.jp/product/syohin.asp?code=TAP-TST10