An Optimal Information Centric Networking Model for the Future Green Network

Quang. N. Nguyen[1], Arifuzzaman. M[2], T. Miyamoto[3] and Sato. Takuro[4]
[1,2,3,4] Graduate School of Information and Telecommunication Studies
Waseda University
Tokyo, Japan
quang.nguyen@fuji.waseda.jp[1], arif@fuji.waseda.jp[2], miyamoto33@fuji.waseda.jp[3], t-sato@waseda.jp[4]

***Abstract*—In order to address the energy flaw and enhance the energy efficiency of Information Centric Networking (ICN) Architecture, this research proposes an innovated optimal ICN model with adaptive power consumption ability based on the popularity of the content to adapt content router link rate to its real-time utilization for optimizing the ICN router operating power value and based on the interest traffic to the server to select the optimal working mode for the server/content provider. With this dynamic control/adaptive mechanism, the proposed architecture can provide higher reliability with dynamic energy efficiency consumption and better cost-effectiveness for the future ICN infrastructure system to reduce electricity usage, cost and greenhouse gases, then solve global warming issues.**

Keywords—Information Centric Networking (ICN); Future Internet; Green Network; Adaptive Link Rate (ALR)

I. Introduction

Nowadays, Information and Communication Technology (ICT), particularly communication technology is one of the fields which form the basis for all industry and lay the cornerstone for economic and social activities. From the communication technology perspective, the new concept of Information-Centric Networking (ICN)/Content Centric Networking (CCN) [1], is principal to our efforts to build an ideal society because it is vital to the concept of "universal, ubiquitous and flexible" era. ICN is considered as the global-scale future Internet paradigm because its mechanism is significantly efficient compared with the current IP-based Internet (based on named data networking to disseminate information effectively instead of host name to avoid constraint of the current Internet implementation).

Though ICN will bring benefits to the network player and the users [2], ICN Architecture still has different problems, such as: routing and caching or interest flooding problem, and particularly energy consumption problem which has not been yet sufficient considered. Hence, finding an energy efficient model in ICN becomes more and more significant, especially in case of growing need for ICN and the importance of energy consumption due to economical and environmental concerns [3].

In fact, both of current IP-based Internet infrastructure and conventional ICN architecture consume a large amount of energy because network components and devices (including routers, servers) always operate at maximum power capacity even with low traffic case, then remain under-utilized most of the time [4]. This working mechanism undoubtedly wastes a lot of energy. Furthermore, the network backbone links are utilized only by 30 % - 40 % or less [5]. Therefore, the objective of this research proposal is to design a dynamic energy efficient ICN model for Future Internet by adapting router link-utilization with popularity of contents and server with its optimal operating mode to optimize the network energy consumption value.

The rest of the paper is organized as follows: In Section 2, we state related works. Our proposed optimal green ICN scheme is elaborated in Section 3. Then, the mathematical models for energy consumption evaluation are described in Section 4. We present the simulation results and discussion of the efficiency of the proposal scheme in Section 5. Finally, Section 6, we make a conclusion and discuss directions for our future work.

II. Related Work

This section summarizes the most remarkable works related to our research proposal.

For reducing energy consumption of network devices, Adaptive Link Rate (ALR) [6] is one of the research themes drawing most of the attention in greening network up to now. This technique is designed to allow the link rate change according to the real utilization of the device dynamically as a response to device's low utilization periods for matching the real network usage. Hence, many later researches have based on this ALR technique and the energy-proportional computing paradigm [7] as their approaches for Green Network. The most notable works related to ALR are [8][9].

Regarding the network power consumption approaches, a number of works proposed power consumption model of storage server system then discuss some mechanisms that can be applied for network energy efficiency [10][11].

This article is different from the previous works since we take into consideration to find the adaptive solutions for both server (content provider) and content routers with caching ability for greening the ICN system. By utilizing the suitable network devices and components: ICN content routers support ALR technique and server allows network managers to set the threshold value (upper limit) of power consumption, e.g. Intel Intelligent Power Node Manager [12], our adaptive algorithm provides an efficient solution to optimize the energy consumption of ICN. For the power consumption of network devices in case of current IP-based network and conventional ICN, we refer to the power

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consumption data in [13]. However, in our proposal we do not consider the sleep mode because it is difficult to estimate the energy efficiency of the sleeping mode during the transition time and "wake-up" periods.

III. Proposed Green ICN Topology and Scheme

The power consumption of a network system is the total power consumption of all the components and devices that make up the network system. For scope of our research, we do not consider the overhead power consumption of network, e.g. air conditioning and lighting energy. Then, in our proposal, we determine server and router as 2 main kinds of device that constitute a network system. For the purpose of power consumption evaluation, both the current IP-based network system and ICN system share the same power consumption for servers, whereas a ICN router consume slightly higher power compared to a normal IP router because of the ICN content router's caching function. In more detail, there are 3 main elements for server power consumption: embodied power, power for server storage and operating power of server. A normal IP router power consumption is the combination of embodied power and working power of router, whereas there is one additional element (power to cache memory) in ICN content router and the ICN router also consumes more for embodied and working power, compared to the IP router [13]. Therefore, in our proposal, we use dynamic algorithm with adaptive power consumption based on the popularity of the content to optimize the operating power value of ICN content router and based on the interest traffic to the server to optimize operating power of server. Since we realize that these are 2 feasible power values that we can utilize to optimize for the whole ICN system.

Further detail for total energy consumption evaluation based on Mathematical models and comparison of different network systems, including: current IP-based network system, conventional ICN system and our proposed ICN system are clarified in the next Section (Section 4).

A. Network Topology and Assumptions

Our ICN system topology is shown in Fig. 1. We propose the tree based network topology including of a server/content provider and N distinguished routers. The server/content provider is connected to the aggregated content router. This tree topology has N+1 level and can be described as follows: server/content provider acts as the root node (level N+1) and all the content routers are allocated into N levels of the tree (the Aggregated content router is at level N). Each "parent" node (content router) has the same number of "children" node.

We assume that the ICN system consists of different content c and C is the set of contents (i.e. c ∈ C). Then every content is stored at the server/content provider. Let S is maximum number of contents (assume that all content have same size) that each ICN content routers can cache. The detail of our dynamic algorithm and working mechanism of our proposed Green ICN architecture is stated in part B and part C of this section.

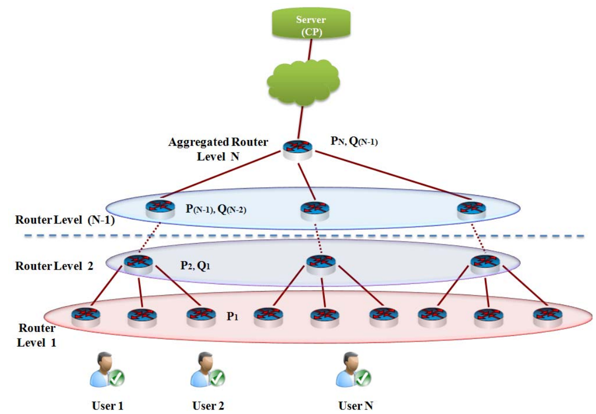

Figure 1. Network topology for the proposal ICN system.

B. Content router working strategy

We assume that ICN content routers in our proposed network are equipped with aforementioned ALR technique. Then we determine dynamic content router working strategy to adapt the link rate to the real router's utilization based on the content popularity.

For this objective, we define p_k as the probability that one content user can find a specific content c (c ∈ C) at a level k router node. We also assume that every router at the same level of the tree network topology share the same value of p_k. Then, in ICN, for a content c ∈ C, we have:

$$\sum_{k=1}^{N+1} p_k = 1 \quad (1)$$

In ICN system, current IP-based network system, a content request/interest only comes to a server in case no content router contains that content whereas in current IP-based network system, it is the only way to get a content/data (i.e. $p_k = 0 \ \forall k \in \text{ set } (1,2,\ldots,N)$ and $p_{N+1} = 1$. The more popular a content is, the more possible an user can find it in the lower level, then we deduce (2) for non-popular content and (3) for more popular content:

$$p_1 \ \leq \ p_2 \ \leq \cdots \leq \ p_{N+1} \quad (2)$$
$$p_1 \ > \ p_2 \ > \cdots > \ p_{N+1} \quad (3)$$

Let Q_k is the probability that a content user have to traverse k-level (or k hops, where k ≥ 1) of the tree topology to find a interested content c ∈ C, then:

$$Q_k \ = \ p_{k+1} \ \prod_{l=1}^{k}(1 - p_l) \quad (4)$$

Different Q_k and p_k are shown in the Fig. 1. Similar to p_k, the number of levels (hops) that content user traverse is expected to be lower with more popular content.

From this ICN model, we adapt the operating power of ICN content router to its real utilization depend on the popularity of the contents that the ICN router serves. Let R_k is the incoming link rate to content router level-k and R_{ICN} is the link rate for the conventional ICN system. Since a popular content has higher tendency to be found at the first levels, we determine the maximum link rate for the level 1 router:

$$R_1 = R_{ICN} \quad (5)$$

Then R_k will adapt to the operating link utilization of ICN router for every interest for content c $\in$ C come to it. Let $E_{R2\text{-}ICN}$ and E_{S3} are the operating energy consumed by a ICN content router and server, respectively (more detailed explanation is presented in Section 4). Considering the case when a single or multiple interests come to a router level k but only ask for a single content c $\in$ C, then the new optimized value for $E_{R2\text{-}ICN}$ in case we use ALR-support content router for our proposal is:

$$New\ E_{R2-ICN,k} = E_{R2-ICN}\ \alpha\ (1 - p_1 - \textstyle\sum_{l=1}^{k-2} Q_l) \quad (6)$$

where α is the proportional coefficient of link rate and power consumption of ICN content router (1 ≤ α ≤ 1.3 and α = 1 implies the ideal case when the link rate is directly proportional to the power consumption). Let S_k is the set of content come to a level k content router, then optimal operating energy of a level k-ICN router is identified by following formula:

$$Optimal\ E_{R2-ICN,k} = E_{R2-ICN,k}\ \{1 - \min\,(p_{1c} + \textstyle\sum_{l=1}^{k-2} Q_{lc})\} \quad \forall Content\ c \in S_k\ and\ |S_k| \le S \quad (7)$$

Equation (7) can be deduce from (6) because the ICN system should guarantee that a content router need to adapt its utilization to satisfy all the interests for the different contents (with different popularity) which come to it (i.e. assure sufficient link utilization for interest of the content with highest required link rate come to a content router).

C. Optimal operating modes for Server

We design 4 different working modes for server with different upper limit power consumption threshold values (assume that proposed ICN system uses servers with suitable function, e.g. Intel Intelligent Power Node Manager [12]). The server can be in either one of the following 4 distinguished power modes as follows:

- Full-mode (F), denotes that the server working with the full power-capacity as threshold power consumption.
- Adaptive mode (A), denotes that the server working with the adaptive saving mechanism based on interest traffic to the server.
- Save mode (SM), denotes that the server in this mode will work with maximal power consumption equal to half of its power-capacity.
- Idle mode (I), denotes that the server in this mode will be put in the idle state to maximize the energy saving. Note that Idle mode is different from the sleep mode: "idle" means maintaining the low-operating state of the server, not "sleep", as stated before.

TABLE I. Optimal power mode decision model for the server.

Input Variables		Output Variable
Number of content request (interest)	***Number of different content user***	***Optimal Power mode***
L_1	L_2	SM/I
L_1	H_2	A/I
H_1	L_2	
H_1	H_2	F/I

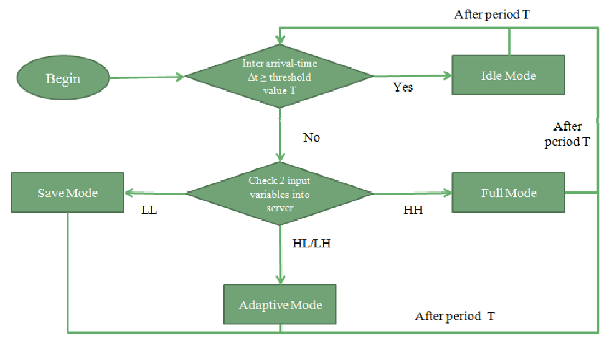

Figure 2. Flowchart of optimal operating power mode decision algorithm for the server.

We then schedule the server with its optimal working mode dynamically based on the current state of the server and interest traffic send to server for a period of time *T* to cut down the server energy consumption. In more detail, the upper limit of power consumption of I, SM and F mode are: 25%, 40% and 100% of maximum power performance of server, whereas the threshold power consumption for Adaptive mode (A mode) is identified dynamically based on interest traffic to server. Firstly, to determine the current state of the server, we define inter arrival-time Δt as the arrival-time difference between 2 consecutive content requests sent to server. If the value of $\Delta t \geq T$, the system put the server into the I mode (i.e. we also choose T as the threshold value for Δt), otherwise our proposed algorithm selects the optimal power mode for server (1 out of 3 remained power modes: SM, A or F mode) by taking into consideration the interest traffic to server for a period of time *T*.

The interest traffic (content request) is identified by 2 input variables: the number of content request (interest) and number of distinguished content users/clients send request to server during a period of time *T*, together with their respective threshold values. The rule block defines the optimal power mode decision model for the server is shown in Table 1. The following notions and parameters are used:

- T_1, N_1 are the threshold value and the number of the content requests (interests) send to server for a period of time *T*, respectively. If $N_1 < T_1$ then N_1 is defined as L_1, otherwise it is determined as H_1.
- Similarly, T_2, N_2, L_2, H_2 are the respective values for the second input variable, which is the number of

different content users/clients of server during period T.

- SM/I (A/I, F/I): The Save Mode (or Adaptive/Full mode) is selected unless the case that the server does not get a new content request (interest) during period T (i.e. $\Delta t \geq T$) then the dynamic algorithm activated the server's I mode instead of SM (or A/F mode).

In particular, Let P_A is the upper limit of the power consumption for the A mode then it can be calculated by the following formula:

$$P_A = 1 - (x_1 \frac{T_1 - N_1}{T_1} + x_2 \frac{T_2 - N_2}{T_2}) \quad (8)$$

where x_1 and x_2 are 2 weighted values of 2 input variables: the number of content request and the number of different users send request to the server for a period of time T, and $x_1+x_2= 1$. In Equation (8), if $T_1 < N_1$ then let $(T_1 - N_1) = 0$ whereas if $T_2 < N_2$ then let $(T_2 - N_2) = 0$.

The detailed flowchart of operating power mode decision algorithm for the server is shown in Fig. 2. The objective of this decision algorithm is to make decision for the optimal power mode of the server in ICN system, then minimize the overall energy consumption of server. This working mechanism much improves the energy-consumption efficiency of the server, compared with the conventional ICN system or the current IP-based network system, which can be considered as: the server only work in F mode (since server always work in the full-power capacity mode, or Full mode in every case).

IV. Mathematical Models for Energy Consumption Evaluation

In this section, we assume that total energy consumption of a network system comprises of two main components: the energy consumption of all routers and energy consumed by server. We also assume that each network system comprises N routers and a server. In this way, we present the mathematical models for energy consumption of IP-based network system and conventional ICN system, referred to [13]. Then we build our proposed ICN system model for energy savings evaluation compared to the power consumption of these 2 mentioned systems.

A. IP-based network system energy consumption

The energy consumed by a IP-based system is:

$$\begin{aligned} E_{IP} &= N\ E_{R-IP} + E_S \\ &= N\,(P_{R1-IP}\ T_w + P_{R2-IP}\ T_w) \\ &\quad + (P_{S1}\ T_w + P_{S2}\ T_w + P_{S3}\ T_w) \end{aligned} \quad (9)$$

where E_{R-IP}, E_S are the energy consumed by a IP router and energy consumed by the server; P_{R1-IP}, P_{R2-IP} are the embodied power and working power of a IP router; and P_{S1}, P_{S2}, P_{S3} are the embodied power, power for server storage and operating power of a server (same value for both ICN and IP based network system), respectively. Besides, T_W is the working time of the whole network system.

B. Conventional ICN system energy consumption

The conventional ICN system energy consumption can be calculated as:

$$\begin{aligned} E_{ICN} &= N\ E_{R-ICN} + E_S \\ &= N\,(P_{R1-ICN}\ T_w + P_{R3-ICN}\ T_w + P_{R2-ICN}\ T_w) \\ &\quad + (P_{S1}\ T_w + P_{S2}\ T_w + P_{S3}\ T_w) \end{aligned} \quad (10)$$

where P_{R1-ICN}, P_{R2-ICN}, P_{R3-ICN} are the embodied power, working power and power to cache memory of a ICN router, respectively.

C. Proposed ICN system energy consumption

In order to optimize the value of total energy consumed by energy consumption as a combination of two optimal values:

$$E_{ICN-Proposal} = \sum_{k=1}^{N} Optimal\ E_{R-ICN,r_k} + Optimal\ E_{S-ICN} \quad (11)$$

where optimal energy consumption of all routers is:

$$\sum_{k=1}^{N} Optimal\ E_{R-ICN,r_k} = N\,(P_{R1-ICN}\ T_w + P_{R3-ICN}\ T_w) + \sum_{k=1}^{N} Optimal\ P_{R2-ICN,r_k}\ T_{Or_k} \quad (12)$$

and optimal value of the server:

$$Optimal\ E_{S-ICN} = (P_{S1}\ T_w + P_{S2}\ T_w) + Optimal\ P_{S3}\ T_{O_s} \quad (13)$$

where T_{Or_k} is the operating time of router r_k with proposed ALR design, and T_{O_s} is the operating time of the server with optimal power mode.

In our proposed ICN system, the dynamic algorithm produces the optimal values for the operating power of servers and routers. As a result, the ICN system is expected to maximize the energy savings and environmental protection.

V. Result and Evaluation

We simulate our proposed green ICN system with ndnSIM, which is a scalable emulator of Named Data Networking (NDN) [14] under the NS-3 framework. The network topology used in the simulation is tree topology as depicted in Fig.1. There are 13 ICN content routers and the aggregated node at level 3 is connected to the repository (server/content provider) to form a 4-level tree network topology. Total number of objects/different contents is 10,000 and we assume that a content user does not generate any interest for the objects/contents which are not stored in the repository. The content users/clients are connected to a node level 1. Each "parent" node is connected to 3 "child" nodes. The Zipf distribution is used for the content popularity distribution. Cache object eviction policy is LRU (least recently used). We simulate with 20 content users/clients and we also assume that every content has the same size of 1 GB (with payload size of 1KB). The link capacity/bandwidth we use for simulation is 1 Gbps and all the ICN nodes have the functionalities of PIT, FIB and CS as described in [1]. Under the assumption that we have 2 similar network systems with same characteristics: one follows conventional ICN and the other has IP-based architecture. Then we make simulation and make comparisons between these 2 systems and our proposed Green ICN system, in terms of average power consumption with the above parameters.

The following metrics are evaluated in our simulation:

- The ICN content router caching size: From our simulation result as shown in Fig. 3, the average power consumption does not seem to be directly affected by the ICN content router cache size though the energy of both conventional ICN and our proposed ICN model increase when we increase the size of the content cache of each content router (in this case, we simulate with 3 different ICN content router cache sizes: 64 GB, 128 GB and 256 GB).
- Threshold value T_1: T_1 is identified as the threshold value of the number of interests/content requests send to server for a period of time *T*. Therefore, when we increase the value of T_1, it is higher possibility that the server will work on other modes rather than the F mode. As a result, energy consumption of system is also expected to decrease because the server power consumption is high. This is verified by simulation as shown in Fig. 4.
- Alpha value (α): As can be seen in Fig. 5, the value of α and average power consumption of the network system have a linear relationship. Therefore, when we increase the value of α (i.e. let $\alpha > 1$), as expected, the energy saving of the proposed Green ICN system is also decreased. In detail, with $\alpha = 1$ (the ideal case with ALR-enable content router), our proposed ICN model can save about 28.66 % and 29.42 % energy compared to the IP based model and conventional ICN in the same scenario, respectively (with 128 GB for content router cache size), whereas these ratios are decreased to 25.57 % and 26.36 % with $\alpha = 1.3$.

In general, for all of the discussed metrics, though the conventional ICN system consume slightly more energy than the current IP-based system, simulation with topology proves the efficiency of our proposal Green ICN model compared to current IP-based model, in terms of energy saving performance. This is because when many contents already cached in routers then as a result, at that time, other routers and servers may get into adaptive or idle state, hence optimize the energy saving of the whole network system.

VI. Conclusion and Future Work

In this paper, we propose a novel Future Green ICN Model with adaptive power consumption ability based on the interest traffic to the server to optimize the working power of servers/content providers to deal with over-provisioning network system (for the worst case). We design 4 different power consumption modes (Idle, Save Mode, Adaptive and Full Mode) to save the power consumption of server as well

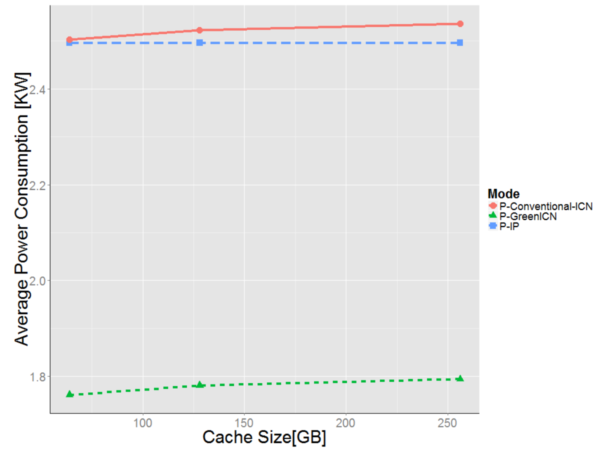

Figure 3. Average power consumption of different network systems versus the different cache size of ICN content router.

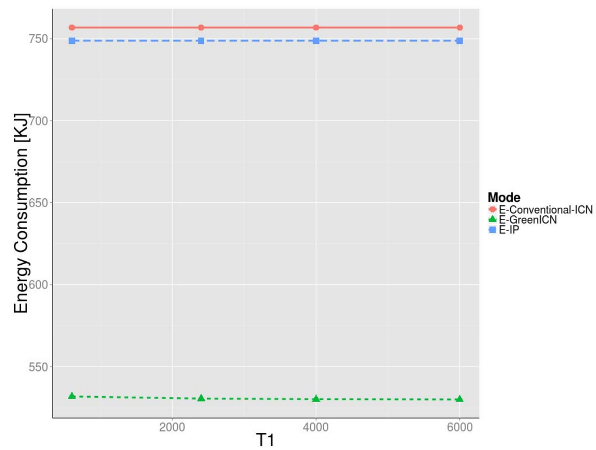

Figure 4. Energy consumption of different network systems versus threshold value T_1.

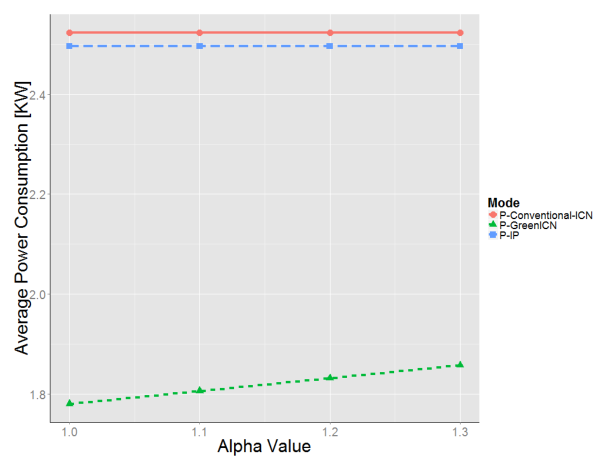

Figure 5. Average power consumption of different network systems versus α value.

as we adapt the power consumption of the content router to the real-time link rate by considering the content popularity and utilizing ALR. The simulation results in ndnSIM prove the efficiency of our proposal scheme in terms of power consumption compared to both current IP-based network and the conventional ICN. Hence, we show that, with the appropriate hardware support, our proposal ICN architecture can offer substantial savings for the future Internet.

As a scope of future work, we will expand our proposed model's scalability by considering the case of cluster of distinguished servers. Since a server consumes a lot of energy, this is expected to improve the energy efficiency of our current optimal ICN model presented in this paper. We also plan to extend our study for the case of Wireless/Mobile Network for our future work. Besides, we intend to apply the proactive caching theory into our proposal.

Acknowledgment

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