Graduate School of Fundamental Science and Engineering
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博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

A Study on the Context-Aware Green Information-Centric Networking Model for Future Wireless Communications
将来の無線通信に向けたコンテキストアウェアグリーン情報指向ネットワークのモデル化に関する研究

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Nowadays, the Internet is shifting from host-centric to content-centric model as users are interested in content, instead of location. In this context, Information-Centric Networking (ICN) concept has introduced a new promising Internet architecture to solve the current host-centric Internet's severe problems of security and inefficiencies in content delivery. In detail, thanks to the in-network caching and naming schemes, ICN provides built-in security feature and focuses on content dissemination to decrease network load latency, response time, traffic load, and network resource usage, compared to the current host-centric Internet. The reason is that in ICN, the requested content data can be accessed from a replica instead of the only content source as in current IP-based Internet architecture. The innovative working mechanisms and ICN's merits then make it become a pioneer for the Future Internet (FI) architecture in the era of the Internet of Things (IoT) where the Internet is mostly used to access content. Even though ICN is regarded as a promising global-scale FI architecture, its in-network caching capability raises EE (Energy Efficiency) problems due to additional power consumption required for the caching capability of content routers.

However, little attention has been carried out to combine ICN concept and Green Networking, despite power consumption is a primary concern for the design and real-world deployment of future networks, due to its impact on economic and environment. In fact, the energy consumption of the Internet is estimated to be about 10% of total world energy, and this ratio keeps increasing as a tendency. One of the primary reasons for the high network system power consumption is that the current Internet Service Providers (ISPs) and existing Internet designs' working mechanism is typically operating with full power capacity due to over-provisioning for enduring peak traffic or the worst case, e.g., very high traffic load and fault protection cases. This policy produces a considerably unnecessary power consumption for redundant network resources as network nodes rarely operate at full-utilization. As a result, there are lots of wasteful/unnecessary power consumed by unused network devices and links. Also, as mentioned, in-network caching capability in ICN also raises new challenges, especially EE issue. Worse still, most of the current ICN work in the wireless environment do not consider EE and mainly deal with the mobility of content provider or consumer. The EE problem even becomes more challenging with the rapid increase in price for energy consumption, number of broadband wireless network users, as well as growing demand of the content users in the future network. These challenges emphasize the need for a wireless energy-efficient ICN-based platform for future communications.

Therefore, in this dissertation, we propose a novel Green ICN (Information Centric Networking) model which can adapt the power consumption of network nodes to the optimized utilization level proportionally. The cross-layer power adaption is conducted by adjusting the link rate dynamically according to the content popularity to reduce wasteful power consumption of Content Routers (CRs). Next, we introduce four different working power modes for Content Providers (CPs) to diminish their power consumption. We then apply the idea of the proposed Green ICN model, together with a proactive-caching based protocol and the introduction of a smart scheduler, for efficient and seamless communications in Intelligent Transport System (ITS). Moreover, to realize a more scalable context-aware optimized Green ICN model for future communications via wireless accesses, we propose an intelligent caching scheme, namely DCS (Distinguished Caching Scheme), in which the caching portion is adjusted based on the content popularity and available spaces of two customized caching partitions in each CR. By improving cache diversity considerably, this method realizes a power-proportional caching scheme because power is decreased when the traffic load is reduced via the proposed CRs' adaptive mechanism. We then formulate the

rigorous energy models of the proposal and existing network systems, considering practical insights for the feasible ICN infrastructure deployment. Finally, we show the economic incentives for implementing the proposed Green ICN system via our game-theory based case-study.

This dissertation consists of seven chapters and the detail of each chapter is described as follows:

Chapter 1 gives a brief introduction of Green networking in the context of scalable and sustainable network accesses for the feasible and efficient next-generation communications. Next, we stated our research motivations and main objectives. The outline of the proposed approach and its contributions, as well as the dissertation organization are also presented in this opening chapter.

Chapter 2 investigates the research background and surveys literature review on the new field of Green networking for the future Internet. The chapter firstly explains the fundamental concept of Green networking with Dynamic Power Scaling methods on a variety of greening methodologies, including sleeping mode, Adaptive Link Rate (ALR) and data center management scheme. Then, the ICN concept, its working mechanism, and various ICN platforms are indicated. Subsequently, the major challenges and research trends in ICN are analyzed, with a focus on recent research efforts addressed the EE issue in ICN.

Chapter 3 to Chapter 6 are the heart of this Ph.D. dissertation in which we elaborate overview of the fundamental framework of the Green ICN model (Chapter 3), the integration of the proposed model and caching scheme for efficient context-based content services in the application domains of ITS (Chapter 4) and scalable future wireless communications (Chapter 5), then verify the economic incentives for CAGIM deployment through a game-theoretical case-study approach in Chapter 6.

Chapter 3 gives an introduction to the general system concept and explains the working mechanism of the proposed Green ICN model. We define the system model and assumptions. Then, we use a cross-layer rate-adaptive scheme, and an optimized operating mode selection mechanism simultaneously for minimizing the power consumption from content routers (CRs), and content providers (CPs) in the ICN interconnections, respectively. By associating the power consumption of CRs and CPs with their operating mechanisms, we also build the analytical energy consumption models for EE evaluations of the proposed Green ICN model and other network designs (including conventional ICN design and existing IP-based architecture). This chapter is dedicated to lay down the foundation of optimizing the operating power consumed by both CPs and CRs so that the next chapters explain how this proposed Green ICN framework can be applied for efficient context-based content delivery in a wireless environment.

Chapter 4 extends the concept of the Green ICN model for the efficient communications in ITS. Typically, we apply the ALR-based operating for greening the communication in ITS. Also, we propose a new proactive-caching based communication protocol via the smart scheduler for seamless communications in ITS. The corresponding evaluation results based on the established energy model prove the efficiency of the proposed Green ICN system for ITS, in terms of both handover and EE performance (via analytical EE models).

Chapter 5 shows a scalable context-aware optimized Green ICN model (CAGIM) for feasible future wireless communications. We study the related ICN researches in a wireless environment and Wi-Fi technology with Wi-Fi Direct for Device to Device (D2D) Communications as the theoretical review to take the full advantages of the Green ICN model stated in Chapter 3. Specifically, besides the enhanced rate-adaptive operating scheme for CRs and the dynamic scheduling operating policy of CPs, we propose a smart popularity-based caching strategy (DCS) to improve the content diversity of the cache storage based on the content type and popularity level. DCS thus can further decrease the network system power consumption, thanks to its improved cache hit that reduces network traffic load. Toward the goal of realizing a context-aware green wireless network system with efficient content delivery, we also design a Wi-Fi Direct based scheme as an alternative approach to minimize power consumption and latency by sharing essential/important content objects via direct communications with a simplified priority-based caching scheme and power-saving mechanisms when wireless local area network (WLAN) connections are not available. The evaluation results corresponding to the enhanced mathematical energy models show that CAGIM can achieve high network efficiency by reducing both hop-count and power consumption considerably, compared to existing wireless network systems with different well-known caching schemes.

As a whole, Chapter 6 discusses the need for an efficient Green ICN model for FI. We also develop a game-theoretical case-study on the proposed Green ICN model to study the interactions between an ISP and a network equipment company, then analyze the economic incentives of players for deploying the proposal in the context of green networking. Moreover, we discuss ICN deployment and standardization challenges, then show that the established game-theoretical Green ICN approach is robust, easy to deploy, and practically relevant for the network players.

The final chapter (Chapter 7) summarizes all the content and major findings of the previous chapters. Though the findings of the research reported in this dissertation are critical in this new challenging networking field, this in-depth study still has its limitation and several questions that remain unanswered. The final chapter then also gives suggestions to the potential relevant future studies in the field of Green networking towards sustainable and scalable efficient future networks, not only limited to the author but also to all researches and scholars with similar areas of research interest. This dissertation acts as a practical effort to pave the way towards the realization of efficient and scalable green communications through promoting and shifting research and development (R&D) activities in ICN towards the sustainable real-world network infrastructure (deployment) for future networks.

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種 類 別 (By Type)	題名、　発表・発行掲載誌名、　発表・発行年月、　連名者（申請者含む） (theme, journal name, date & year of publication, name of authors inc. yourself)
Articles in Refereed Journals	○ [1] **Quang N. Nguyen**, M. Arifuzzaman, Y. Keping and T. Sato, “A Context-Aware Green Information-Centric Networking Model for Future Wireless Communications,” IEEE Access Vol.6, 2018. [2] Rungrot Sukjaimuk, **Quang Nguyen,** and Takuro Sato, “A Smart Congestion Control Mechanism for the Green IoT Sensor-Enabled Information-Centric Networking”. Sensors. 2018; 18(9):2889. [3] Cutifa Safitri, Yoshihide Yamada, Sabariah Baharun, Shidrokh Goudarzi , **Quang Ngoc Nguyen**, Keping Yu, and Takuro Sato, "An Intelligent Content Prefix Classification Approach for Quality of Service Optimization in Information-Centric Networking," Future Internet, Vol. 10, Issue No.4, April 2018. [4] Mohammad Arifuzzaman, Naheed NazneenTuli, Yu Keping, **Quang N Nguyen,** and Sato Takuro, “Integrated Caching and Routing Strategy for Information-Centric Networks,” European Journal of Advances in Engineering and Technology, ISSN: 2394 – 658X2018, VOL 5(2), pp.80-90, 2018. ○ [5] **Quang N. Nguyen**, M. Arifuzzaman, D. Zhang, K. Yu, and T. Sato, “Proposal for Standardization of Green Information Centric Networking based Communication utilizing Proactive Caching Intelligent Transport System,” Journal of ICT Standardization, Vol.4, Iss.1, pp35-64, July 2016. [6] Keping Yu, Battulga Davaasambuu, Nam Hoai Nguyen, **Quang Nguyen**, Arifuzzaman Mohammad, and Takuro Sato, “Cost-efficiency residential energy management scheme for Information Centric Networking based Home Network in Smart Grid,” International Journal of Computer Networks & Communications (IJCNC), Vol.8, No.2, March 2016.
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Presentation at International Workshops	[1] **Quang N. Nguyen** and Takuro Sato, “A Game-theory based Green Information-Centric Networking Model for Future Internet,” Korea, Japan, Malaysia Jointed IT Workshop, Seoul, Korea, December 2017. [2] **Quang N. Nguyen** and Takuro Sato, “Proactive-Caching based Green Communications in Information Centric Networking for Intelligent Transport System,” NTU (National Taiwan University) - Waseda Research Workshop, Taiwan, September 2016.
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