

# Future Mobile Network Management With Attractor Selection

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**Abstract**—Several task forces have been working on how to design the future Internet and it is high time for research work to move a step forward to networks on a large scale. In this paper, we propose a future mobile network architecture on a combination of OpenFlow and the attractor selection method to achieve scalability and energy conservation. In addition, we propose novel approaches to wireless network management by extending the attractor selection mechanism in route calculation and signaling cost for energy conservation. First, each mobile node selects the best suited interfaces in accordance with instantaneous live traffic volume. Then, network devices select the best cluster to join to reduce handover signaling cost. Through autonomous decision of each mobile node and network device, the whole wireless network can be managed in an energy efficient and robust manner.

**Index Terms**—Attractor selection; multi-interface selection; adaptive clustering; OpenFlow ; the future mobile network; energy conservation

## I. INTRODUCTION

Recently we are faced with a new era when future Internet infrastructure needs to be drastically changed from scratch in order to meet more variety of requirements from users. In the meantime, there has been an increasing number of research activities on future Internet infrastructures [1] applicable to the field of ICET (Information, Communication, and Energy Technology). All over the world, we can see many research task forces, such as the Future Internet Architecture (FIA) [2] of NSF (National Science Foundation) in the United States, the European Future Internet Assembly [3] under the European Seventh Framework Program (FP7), and AKARI [4] in Japan, working on future Internet research work.

From the viewpoint of user needs for our future society, the wireless communication environment is essential, and as research activities for wireless future network research, there have been several research activities such as the MobilityFirst Project [5] of the FIA program and POMI (Programmable Open Mobile Internet) 2020 of Stanford Clean Slate Program. In addition, there are several architectures suitable for the future mobile network with separated identifier and locator [6]. Among these activities, one of the most promising future Internet research activities is OpenFlow technology [7] to construct a programmable and environmentally-friendly ICET

infrastructure [8]–[10]. The OpenFlow technology has a potential to meet a wider variety of requirements from users due to its programmability and OpenFlow is available not only for wireless communication but also for wired. However, the above researches are limited within local sites such as campus networks and data center networks for the time being.

From another point of view, robustness is one of the keywords when talking about the future Internet infrastructure for coping with disasters like huge Tsunami or earthquakes. In addition, energy conservation for protection of the environment is also an important factor. To achieve the above targets, more reliable infrastructures based on theoretical background are desired instead of approaches based on empirical background. For instance, biological systems have evolved over a long period of time and have a robustness against environmental changes, which helps in the survival of the species. For this reason, there have been recently several mechanism based on biological systems applied to the future ICET [11]. Among biologically-inspired control mechanisms, attractor selection is one of the possibilities to formulate a mathematical model based on biological dynamics. Recently, there have been several research activities applying the attractor selection method to ICET management field in Yuragi Project [12] and in the Global Center of Excellence Program for Founding Ambient Information Society Infrastructure [13].

The future mobile network and the attractor selection method have so far been well-investigated independently. However, the combination of both is not mature enough. In this paper, we extend the above attractor selection mechanism in order to work on large-scaled mobile wireless network environments based on OpenFlow technology. First, we discuss the future mobile network on a basis of combination of OpenFlow technology and the attractor selection method. Second, we propose an method for a mobile node to select the best radio interfaces according to environmental conditions with attractor selection using an activity driven by real-time user traffic volume. Finally, we establish an appropriate clustering method to reduce handover signaling cost on the OpenFlow based future mobile network with the attractor selection using an activity driven by the difference of the flow directions between user traffic and signaling traffic.

The rest of this paper is organized as follows. In Section II we discuss related work. Then, in Section III we explain the basic mechanism of attractor selection mechanism in detail. In Section IV, we discuss an adaptation of an attractor selection method into the OpenFlow based future mobile network. In Section V, novel concepts to adapt attractor selection mechanism into the Future mobile network environment are proposed and discussed in detail. Finally, Section VI concludes this paper.

## II. RELATED WORK

One key technology for the future Internet is network virtualization established by programmable network components based on OpenFlow technology [8]. As an essential fraction of the future Internet, Yap et al. [9] draw a blueprint for future wireless mobile networks that can achieve handovers between WiMAX and WiFi environment. In addition, Yap et al. [10] deployed a testbed named as the OpenRoads to offer a slicing service in wireless infrastructure on a campus network.

In its original context within biological systems, Kashiwagi et al. [14] formulated a mathematical model of attractor selection to express an adaptive response system through differential equations. In addition, Furusawa et al. [15] introduced another attractor selection model based on adaptability between gene regulatory network in a cell and metabolic network. Based on the above models, Murata et al. [13] have developed and extended the ambient network management to give birth to future human life closely related to environmental adaptability, which is a part of the activities of GCOE (Global Center Of Excellence) program. Within the Yuragi Project [12] and the GCOE program, several research activities have been produced.

In addition, Leibnitz et al. [16] extended the above Kashiwagi-model into two-dimensional control mechanism and showed an instance of attractor selection application to multi-path routing in ad hoc networks. Wakamiya et al. [17] surveyed a wide variety of biologically-inspired systems and built a scalable architecture focusing on systems running in a self-organizing or autonomous manner based on the attractor selection. Leibnitz et al. [18] analyzed the perturbation effects in attractor selection based on observations of the system's responsiveness to inherent fluctuations.

## III. BASIC ATTRACTOR SELECTION MODEL

This section introduces a basic attractor selection model based on ARAS (Adaptive Response by Attractor Selection) [14]. The basic model is expressed as follows:

$$\frac{dm}{dt} = f(m) \cdot \alpha + \eta \quad (1)$$

where function  $f$  is defined by the potential and a function of the state  $m$ ,  $0 \leq \alpha \leq 1$  is an activity of the selected attractor, and  $\eta$  is noise term. At each time step, one attractor is selected based on the output of Eqn. (1). Here, the function  $f$  defines the attractors, e.g. if we would like to define an attractor  $m = 0$ , then  $f(m) = -m$  is one example of function  $f$ . The activity  $\alpha$  indicates suitability of the selected attractor

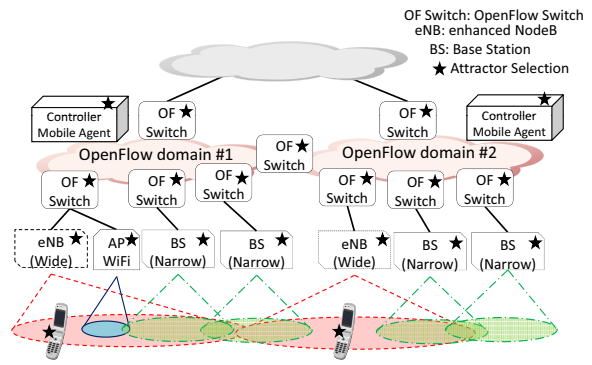


Fig. 1. An example of future mobile wireless network

to the current environment. The more suitable the attractor is, the larger the activity becomes. Hence, in case of larger  $\alpha$ , deterministic function  $f$  is dominant over noise to find an attractor. On the other hand, in case of smaller  $\alpha$ , the random term  $\eta$  becomes dominant. Changes of environmental conditions reflect on the change of activity  $\alpha$  appropriately for controlling the system. Hence, depending on the transition of activity  $\alpha$ , both deterministic dominant and random dominant states are switched over well suited for reducing unnecessary management cost and pursuing the utmost performance. In the end, this attractor selection procedure is an effective way to adaptive system construction against environmental changes.

## IV. PROPOSAL OF FUTURE MOBILE NETWORK ARCHITECTURE

In this section, we will discuss our vision of a future mobile network architecture. We focus on a network based on OpenFlow due to many of its strong points. However, OpenFlow also has some drawbacks. First, energy cost for path calculation increases in return for flexible path establishment. Second, traffic overhead caused by frequent handovers increases because an OpenFlow controller has its own local domain and is not suitable for a large scale network as it is. Hence, we introduce an attractor selection method to improve the above drawbacks.

Both OpenFlow and attractor selection have been innovated and evolved independently recently and we propose a hybrid system with both technologies. Attractor selection was explained in Section III. OpenFlow is a technology where centralized controllers can control user data paths of all network devices such as switches, routers, and base stations through an external standard API. In addition, data packets are handled on a flow basis, and therefore, flexible data path arrangement is possible. However, the centralized basis gives cause for worries of scalability.

Hence, we propose a future mobile network architecture taking into account both flexibility of OpenFlow and robustness of attractor selection. Our proposed architecture is shown in Figure 1. In this architecture, OpenFlow Controllers manage all the OpenFlow devices and simultaneously each device uses attractor selection in an autonomous manner to achieve his

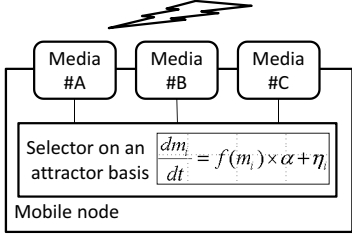


Fig. 2. An image of multi-interface selection

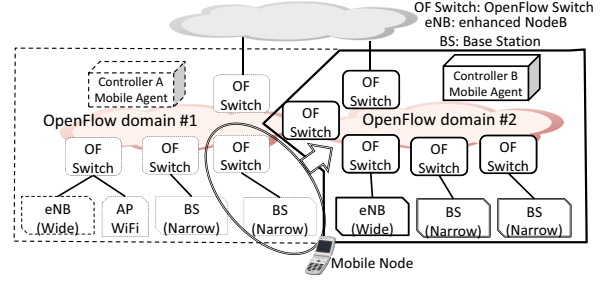


Fig. 3. An image of dynamic clustering

own targets such as reduction of energy consumption, end-to-end delay, and so forth. This combination of a strict control by OpenFlow and a loose control by attractor selection is useful to meet a variety of user needs for the future network.

## V. EXTENSION OF ATTRACTOR SELECTION MODEL

In this section, we will propose two approaches to enhance the future mobile network infrastructure discussed in Section IV by using the attractor selection method. One is the method of multi-interface selection operating on mobile node side and the other is the method of adaptive clustering method working on network side. Both of them are valid for energy conservation to protect environment.

### A. Multi-interface Selection of Mobile Node

In the future mobile network environment, different wireless medium are assumed to be arranged in a mobile node available on cognitive radio infrastructures [19]. The number of access media type, application type, and volume of traffic will increase in a large scale and this kind of explosion in diversity is expected that conventional centralized mobility management and mere distributed mobility management can not work properly and as a matter of fact, existing vertical handovers are not enough to live on the future mobile network. There needs scalable and robust mechanisms and therefore we focus on the attractor selection with the feature of biologically inspired mechanism. In the future mobile network, the performance of the best interface for a mobile node might be fluctuating according to environmental changes especially because of the diversity. It should be selected based on several aspects such as radio quality, traffic distribution, and required QoS. Handling all the conditions by the OpenFlow controller is inefficient and hence a kind of abstract control mechanism should be installed.

We chose the attractor selection model from [20] and the activity equation has been extended to work in a more effective manner by using live traffic information instead of passive pre-defined QoS information. Our proposed model is as follows:

$$\frac{dm_i}{dt} = \frac{s(\alpha)}{1 + \max(m_i)^2 - m_i^2} - d(\alpha) \cdot m_i + \eta_i \quad (2)$$

$$s(\alpha) = \alpha \left( \beta \alpha^\gamma + 1/\sqrt{2} \right), \quad d(\alpha) = \alpha \quad (3)$$

$$\alpha = \begin{cases} 1/(1 + \exp(-G_i \cdot m_i)) & (m_i > 0) \\ 0 & (m_i = 0) \end{cases} \quad (4)$$

where  $m_i$  indicates selection fitness of each radio interface of a mobile node and  $\eta_i$  is white Gaussian noise.  $\beta$  and  $\gamma$  are system parameters to design the depth of the potential at the attractor and the strength attracted by activity, respectively.  $\alpha$  ( $0 \leq \alpha \leq 1$ ) is activity to express suitability of the selected interface for the current environment, which is expressed as the outputs of sigmoid function of  $m_i$  and  $G_i$  is a gain parameter. This gain parameter is for the adjustment of sensitivity between activity  $\alpha$  and fitness  $m_i$ . The selection fitness on each interface,  $m_i$  is calculated by using real-time SNR (Signal-to-Noise Ratio) and available bandwidth calculated with the statistics of packet loss. Hence, fluctuating environmental information like packet loss is embedded implicitly on  $m_i$ . This  $m_i$  indicates the ratio of necessary QoS against live traffic volume on the radio media and closely related to the activity, which is equivalent to the satisfactory degree of media selection. This dynamics provides us with the selection of the best interfaces, which leads to energy conservation by avoiding unnecessary radio resource consumption and unnecessary signaling cost overhead.

### B. Adaptive Clustering of Controller Domain

In addition, in the future mobile network, several types of access edge devices are assumed to appear flexibly responding to user needs. Recently, base stations with small coverage like Femto cells [21] are expected to increase in number owing to the growing need for high data rate transmission for richer services. In addition, cognitive radio [19] is another promising technology to accomplish comfortable communication from the viewpoint of efficient frequency usage. Hence, the mixture of different access technologies is most likely to produce more and more opportunities for both vertical and horizontal handovers to cause large amount of signaling traffic between OpenFlow switches and controllers.

We would like to reduce the above signaling cost caused by handovers and utilize attractor selection in adaptively sustaining appropriate clusters according to environmental dynamics from the viewpoint of signaling cost reduction. Here, universality of attractor selection is one of the important features and hence the same basic model is used for this solution. On this issue, the same equations as Eqn. (2-4) described in previous Subsection V-A are used, where only  $m_i$  is replaced by  $s_i$  and  $s_j$  indicates selection probability

of a cluster group equivalent to each OpenFlow controller relative to a network device such as routers, base stations, and so forth. Parameters  $\eta_j$ ,  $\beta$ , and  $\gamma$  are kept the same as in Section V-A.  $\alpha$  ( $0 \leq \alpha \leq 1$ ) is activity to express suitability of the selected cluster equivalent to the OpenFlow controller that the device should join. This activity is expressed as output of a sigmoid function of  $s_j$  and  $K_j$  is a gain parameter. The selection fitness of each cluster  $s_j$  is calculated as the ratio of user data traffic volume against signaling traffic volume by using real-time traffic volume passing through the network device. The larger this value  $s_j$  is, the more likely the network device should stay at the current cluster. On the contrary, the smaller it is, the more aggressively the network device should change the cluster that belongs to.

According to attractor based dynamics, each network device selects the most appropriate cluster equivalent to OpenFlow controllers. As for attractor selection on OpenFlow controllers themselves, it would work if the OpenFlow network were established in a hierarchical manner. In addition, in the future era, popularity of always-on devices produces less signaling traffic caused by initial power-on procedure than those caused by handovers due to mobility. An example image of clustering is shown in Figure 3. The network is divided into clusters A and B surrounded by a dotted line and a straight line, respectively. According to the attractor selection model, some devices of cluster A within the oval are assumed to have a high possibility of handover and therefore are moved to cluster B. This dynamics are expected to formulate the most appropriate cluster distribution from the viewpoint of the optimal signaling cost by handover, in other words, energy cost. However, we should carefully grasp the tradeoff of reduction of handover cost and increase of cluster switchover cost.

## VI. CONCLUSION

In this paper, we discussed the future mobile network environment and proposed one of possibilities to combine OpenFlow with attractor selection. In addition, we proposed two novel concepts of mobile network management based on the application of attractor selection mechanism.

First, we proposed a concept to select the most appropriate interfaces for mobile nodes depending on instantaneous traffic volume. This method uses real-time dynamic information instead of preselected static information as a driving parameter of the attractor selection model, and therefore, the controlling function can be more sensitively operated. In the end, the network resources are expected to be utilized in an effective way at the right place and at the right moment. Second, a concept to build the most appropriate management domains was proposed. This is targeted to effectively reduce handover signaling cost. In the future, a wide variety of wireless access technologies will bring users more convenience, but bring operators additional management cost at the same time. Hence, we believe that our proposed concepts work and become one of the essential schemes.

Our future work is to evaluate each method based on our concepts by simulations to show advantages of our proposal

and to formulate specific attractor selection models especially on issues for the future mobile network.

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