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論　文　要　旨

Thesis Abstract

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主論文題名　（Title）

Energy-Efficient Heterogeneous Wireless Communication with Extended SDN-Controller

内容の要旨　（Abstract）

In the next generation of wireless networks such as the fifth generation (5G), different radio access technologies (RATs) will be integrated into each mobile device as a fundamental feature, aiming to connect any person using any device at anytime, anywhere. To allow the users to enjoy the ubiquitous connectivity, RATs are generally activated simultaneously. Therefore, the mobile device has to consume higher energy for the simultaneous activation of multiple wireless interfaces as well as the continuous connectivity. Although RATs co-exist in the same environment, they are designed heterogeneously. The technologies that offer high data rate are generally energy-consuming ones while low-energy technologies commonly provide low data rate. When the services run on the device do not always require high data rate, it is not an energy efficient way to keep using high-speed technology. If a low energy technology, i.e., Bluetooth, can be used in replacement of the energy-consuming one, i.e., Wi-Fi, the energy consumption of the wireless communication can be saved. It is obvious that the consumed energy will be saved most when the unused technology is turned off. To migrate between different technologies without disrupting any ongoing services, the network-layer connectivity must be maintained, or a vertical handover (VHO) is required.

The VHO process is generally controlled by a centralized control. In many occasions, the centralized control center does not function properly affecting the mobility management's execution. For instance, in catastrophic disasters like the East Japan Earthquake, crucial network infrastructures were destroyed, causing the centralized control to be isolated. Thereby, the VHO should be controlled by the mobile device itself to be aware of the environment. The mobile device typically navigates traffic through the firmware of the wireless network interface cards (WNIC) using their drivers, which are typically dependent on the vendors. To be aware of the vendors, the control of the traffic navigation between WNICs should not

be relied on any modification of the WNICs' drivers.

Not to modify WNICs' driver, network traffic should be under control of software as introduced by Software-Defined Networking (SDN). Unfortunately, the control in existing SDN architecture ends at the network switches or routers. When applying the SDN architecture in a mobile device, a traditional SDN-controller (traditional-SDNC) become a local controller. The traditional-SDNC still directly controls a virtual OpenFlow switch, which turns WNICs into its ports. However, traditional-SDNC is deployed locally, it lacks the global view of the network topology and cannot navigate the traffic correctly. To support the traditional-SDNC in controlling traffic, an extended SDN-controller (extSDNC) is proposed.

To control the switch, a traditional-SDNC needs at least information of the network such as the network topology. To learn the network topology, the network information including IP and MAC addresses must be exchanged among the devices. Therefore, the first feature that needs to be enhanced for the traditional-SDNC is a controller-to-controller (C2C) communication. Since the traditional-SDNC's design is to talk only with the networking devices, i.e., OpenFlow switches, the messages exchanged in a C2C communication must go through the switches. Unfortunately, in the OpenFlow specification, there is no option to allow a traditional-SDNC to send any messages through switches to another traditional-SDNC. The traditional-SDNC needs a network application (nwApp) to instruct the switches to forward and receive a message to another traditional-SDNC. Note that nwApp in SDN architecture is mainly to steer the switches through a traditional-SDNC. Therefore, it is recommended to use a non-SDN software, or an extended SDN controller (extSDNC), to play the role of exchanging C2C's messages.

To perform a VHO smoothly, the VHO must be triggered properly. For this purpose, different VHO trigger algorithms are introduced for a different context. For instance, in disaster scenarios, VHO can be triggered based on speech pattern recommended by ITU-T to prolong the communication time for victims. In wireless multi-hop networks, VHO between an energy-consuming technology, i.e., Wi-Fi, and a low-energy one, i.e., Bluetooth, can be used to reduce unnecessary energy intermediate nodes spent to relay messages. In this case, VHO is triggered based on bandwidth utilization, i.e., Bluetooth's capacity. In any case, experimental results have confirmed that data traffic was migrated smoothly from any direction between different wireless access technologies.

When using the extSDNC, mobile devices can control data traffic between wireless network interfaces (WNICs) with ease and flexibility. When all WNICs are activated, the traffic will be navigated simply by modifying OpenFlow rules. However, when there is only one WNIC is activated and the others are disabled, to migrate traffic from the activated WNIC to a disabled WNIC, the disabled WNIC firstly is enabled. After that, the enabled WNIC is configured. Although the WNIC is configured, new OpenFlow rules must be installed to navigate traffic to the newly configured WNIC. To reduce the time, the WNIC configuration and OpenFlow installation can be executed in parallel. However, it is not easy to complete two processes at the same time, thus, the difference between the end time of configuring network and that of installing OpenFlow rules is one of the sources of handover delay. To eliminate this delay, the VHO process should be executed after both processes finish. Besides, the VHO execution processes on a device utilizing the link layer event to reduce the handover delay as well as the number of packet loss. However, when both communicating devices have to change the access technology, the different of when they finish the VHO process is another source of handover delay. To reduce this delay, a VHO timing adjustment mechanism is introduced to insure the VHO processes to complete at the same time. Two mentioned solutions are integrated in a proposed framework named esVHO. The esVHO framework executes VHO after the destination WNIC is configured and assigned an IP address, hence, the handover delay as well as the number of packet loss is reduced. Experimental and simulation results have confirmed that esVHO saves energy for the wireless communication with a small number of packet loss.