AN SDN-BASED APPROACH TO REDUCE WIRELESS MOBILE DEVICES ENERGY CONSUMPTION

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ABSTRACT Wireless technology has become one of the most popular technologies in the human life. Moreover, the wireless access technologies are increasing heterogeneity, causing more and more wireless interfaces such as NFC, Bluetooth, Wi-Fi and LTE to be integrated into a wireless mobile device. The technologies co-exist in the same environment aiming for ubiquitous access. However, the energy cost for using multiple wireless interfaces simultaneously can cause the device to quickly run out of its battery. The main reason is each wireless technology commonly seeks for a good connection constantly, thus, it continuously consumes the power of the mobile device's battery. Therefore, it is important to efficiently manage those interfaces to provide power-efficient operation while maintaining the wireless connection in order to allow end users to enjoy the benefit of all available wireless technologies. In this paper, a software defined networking based approach is proposed to handle this issue. The conceptual idea is that all physical wireless network interfaces are managed by a virtual interface which is controlled by a software controller. Thereby, the wireless communication is controlled by the controller, hence, the energy spent on the interface is also being controlled by the software. As a result, a power efficient communication in the heterogeneous wireless network that consists of Bluetooth and Wi-Fi has been developed. The experiment results have proven the power controlled communication mechanism which maintains an on-going channel while seamlessly switching from one access network to another. Simulations have finally been performed to show the energy efficiency of the system.

1. INTRODUCTION

Wireless mobile devices bring users wireless connectivity, aiming for ubiquitous access. With the development of ICT, there are more wireless connectivity technologies being standard features of a mobile device, i.e., LTE, GPS, Wi-Fi, Bluetooth and NFC. However, the more wireless technologies is integrated into a device, the higher power consumption is or the shorter operating time is. This is because the operating time of a mobile device is dependent on battery power. Therefore, it is important to efficiently manage wireless interfaces to have a power-efficient wireless communication and to lengthen the operating time of the device.

There has been a number of studies for saving energy based on interface types, communication modes or interface states. For example, in [1], the author calculated the expected energy based on RSSI values when using Wi-Fi instead of cellular network to determine if the system should switch to Wi-Fi connection or not. Minji Nam [2] tried to save energy by treating the uplink and the downlink separately. Specifically, the mobile device receives through the UMTS interface and transmit through the WLAN one. Besides, several approaches agreed that turning off the WLAN interface during the idle state can save energy [3, 4 and 5]. In [3], the author used Virtual map of access points (APs) to enable the mobile to find available APs without checking any beacon frame. By doing that, the WLAN interface can be activated via GPS or 3G interface or by querying paging messages when necessary. Similarity, in [4], the author turned off the Wi-Fi interface after a certain time of inactivity without any periodic wake-up. A paging signal through the cellular network will wake it up when some data need to be sent or received reaches a certain threshold level. Lampropoulos [5] compared the energy consumption of the system where only one interface is activated at a time with one where both interfaces (WLAN/UTMS) are turned on. All the mentioned works above, however, pay attention to power consumption of a single device in a device-to-device communication rather than all devices in a group communication.

The operating time of mobile devices are commonly different depends on the battery life of the device. Additionally, in a group communication, the more member join the group, the more traffic is exchanged and the faster the devices runs out of battery. To help the low battery device in a group communication to maintain the connection with the others, the device needs to switch to another low power consumption connectivity technology, i.e., Bluetooth. Trivially, some other devices must also switch to Bluetooth to talk with the low battery device and at least one device must turn on two wireless interfaces serving as a relay node. Thereby, it requires a flexibility management of the physical interfaces as well as a vertical handover algorithm to maintain ongoing sessions. To this end, our SDN-based vertical handover proposal [6] is a potential solution. In the proposal, the local SDN controller was extended to collect the network state and then save them to a local database. The database is to help the controller to make a right decision in managing wireless connections without any support from outside. The performance of the proposed system was primary verified by maintaining an ongoing ICMP session while switching between Bluetooth and Wi-Fi network.

In this paper, a vertical handover algorithm between Wi-Fi and Bluetooth is proposed for prolonging the communication time for a low battery device. The handover occurs when the battery gets below a certain threshold, which is depend on how long the group want to communicate. The handover is executed by utilizing the SDN-based vertical handover system [6] with a new configuration. The system performance including packet loss has been evaluated in a real testbed. The power consumption as well as the communication time before and after handover occurs has been estimated.

The rest of the paper is organized as follows. In Section 2, the proposed vertical handover decision algorithm will be explained. After that, in Section 3, the proposed system will be evaluated. Finally, the paper will be concluded in Section 4.

2. VERTICAL HANDOVER ALGORITHM

Since Wi-Fi consumes significant power even with PSM and in idle state [2], it is potentially to help a low battery device to continuously communicate with the others by powering off its Wi- Fi interface and switch the ongoing traffic to a low power consumption connection, i.e., Bluetooth.

2.1 Handover decision algorithm

In this paper, four mobile devices are communicating via Wi-Fi with a topology which is depicted in Fig. 1. Each device is armed with the SDN-based vertical handover system [6] and is assumed to be able to join a Bluetooth piconet via a BLE interface. It is highly potential that a device, i.e., Node 1, has low battery than the others. The extended controller in the SDN-based vertical handover system on each node will exchange the node status to the others. Based on exchanged information

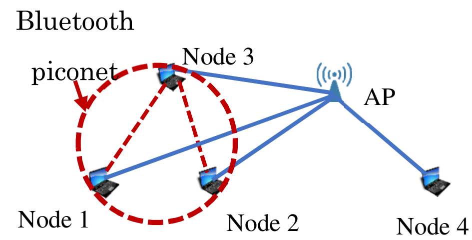

Fig. 1: Network topology

all nodes can understand how long Node 1 can continue to communicate when the connection is Wi-Fi. On Node 1, the controller can estimates how much power is consumed to switch from Wi-Fi connection to Bluetooth, how long to switch and the period of time in which Node 1 can continue to operate over Bluetooth. Based on the estimated values, the controller on Node 1 then is able to provide the decision about whether or not handover occurs. Based on exchanged information, volunteer nodes, i.e., Node 2 and Node 3, will give Node 1 a hand when necessary.

2.2 Handover execution procedure

When a low battery device decides to switch from Wi-Fi to Bluetooth to continuously communicate with the others, it needs support of nearby devices to form a Bluetooth piconet. In this work, the piconet has three nodes including the low battery node, a repeater and a master node namely Node 1, Node 2 and Node 3, respectively. Note that the master and the repeater nodes need to turn on both Wi-Fi and Bluetooth interfaces, hence, they are assumed to have enough power to be able to survive until the group communication ends. After selecting member for the piconet, the extended controller on each node wakes a program named “bluez” up for setting up the Bluetooth connection. The master nodes simply turns on the Bluetooth interface and wait for incoming Bluetooth slave connections. Meanwhile, the repeater node turns on the Bluetooth interface, and sends a slave request to the master node. The extended controller on the repeater node must control the physical interface to filter packets from known source via Wi-Fi interface to send over Bluetooth interface to expected destination and vice versa. This requires additional rules defined in the configuration in comparison to the configuration in [6]. At the same time, Node 1 performs vertical handover from Wi-Fi to Bluetooth to save energy. The vertical handover process uses the same procedure as in [6].

3. EVALUATION

3.1 Vertical handover evaluation

In order to evaluate the vertical handover from Wi-Fi to Bluetooth, we make a real testbed as illustrated in Fig. 1 and observe the network performance when vertical handover occurs on Node 1. The focusing parameter is the packet loss rate because the missing packets could be resent and cost more energy. Each node in the topology is equipped a Bluetooth 4.0 interface and a Wi-Fi 802.11g interface.

The evaluation was conducted by using the Iperf tool [8]. Node 3 starts an Iperf server and wait for incoming requests. Then, an Iperf client on node 1 sends UDP traffic at the rate of 100Kbps to the Iperf server. On both nodes, a vertical handover is triggered in 3 seconds after UDP traffic is being sent. The experiment has been repeated 30 times and the obtained results are shown in Fig. 2. The figure shows that the packet loss rate is mainly under 7%. The obtained results have confirmed that the system can perform vertical handover from Wi-Fi to Bluetooth while UDP traffic is sending.

Table 1: Wi-Fi power consumption.

State	Power consumption
Transmitting (P_{WTX})	1.8 W
Receiving (P_{WRX})	1.4 W
Idle (P_{WIDLE})	150 mW

Table 2: Bluetooth power consumption.

State	Power consumption
Wake up	15 mW
Transmitting (P_{WTX})	84 mW
Receiving (P_{WRX})	66 mW
Idle (P_{WIDLE})	25 mW

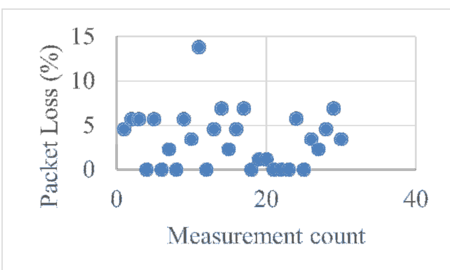

Fig. 2: packet loss rate when handover occurs from Wi-Fi to Bluetooth

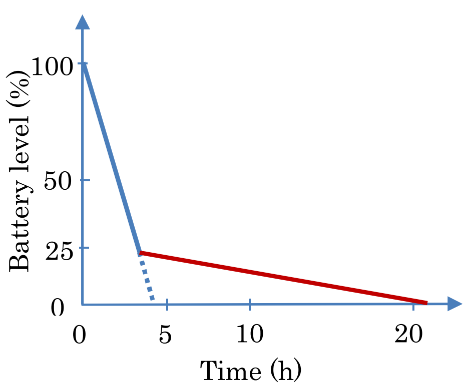

Fig. 3: Power consumption on Node 1 when handover occurs from Wi-Fi to Bluetooth

3.2 Energy consumption estimation

In this section, the theoretical lifetime of a mobile device is investigated. For the sake of simplicity, the Wi-Fi power consumption P_W is estimated based on the hardware specification [7] as shown in Table 1. The PSM enabled Wi-Fi interface is assumed to be in idle state by default. The period of time in which Wi-Fi is idle is denoted as t_{IDLE} and is assumed to be varied from 20s to 40s. The Wi-Fi interface wakes up to transmit data in t_{TX} seconds and receive data in t_{RX} seconds. The transmitting time and receiving time are also assumed to be varied from 40s to 130s. The power consumption of the Wi-Fi interface P_W in a cycle (IDLE, Transmit, Receive), which lasts t seconds ($t = t_{IDLE} + t_{TX} + t_{RX}$), is given in the following equation:

$$P_W = P_{WIDLE}*t_{IDLE} + P_{WTX}*t_{TX} + P_{WRX}*t_{RX}$$
$$= 0.15*t_{IDLE} + 1.8*t_{TX} + 1.4*t_{RX} \quad (1)$$

The average power consumption of the Wi-Fi connection using the equation 1 is 1.38W. The mobile device operates at V = 3V with a battery rated at I_B = 2000mAH. Thus, the device can run over Wi-Fi for 2000 / (1.38 / 3) * 1000 = 4.35h as depicted in Fig. 3.

This means if the battery is below 23%, the device could not communicate via Wi-Fi interface for 1h. To continue to stay in the group communication in 1h, the device may needs to switch the connection to Bluetooth.

The Bluetooth power consumption P_B is estimated based on the values given in [9] as shown in Table 2. To wake up and connect a Bluetooth salve to the Bluetooth master, it costs P_{BWU}=15mW. After being connected, the Bluetooth interface on either the slave or the master node spends P_{BTX}=84mW to send data and P_{BRX}=66mW to receive data. The interface spends only P_{BIDLE}=25mW while it is idle. Therefore, the power consumption P_B of the Bluetooth interface of the slave is drafty estimated as following equation:

$$P_B = P_{BWU} + P_{BIDLE}*t_{IDLE} + P_{BTX}*t_{TX} + P_{BRX}*t_{RX}$$
$$= 0.015 + 0.025*t_{IDLE} + 0.084*t_{TX} + 0.066*t_{RX}$$

Although BLE defines a protocol to allow the device to sleep for long durations, in this evaluation, for a fairness comparison, Bluetooth is assumed to behave as similar as Wi-Fi does. Thereby, the average power consumption of the Bluetooth slave using the equation 2 is 0.067W. Thus, the device with a battery level of 23% can continue to operate over Bluetooth for (2000*0.23) / (0.067 / 3) * 1000 = 20.59h as shown in Fig. 3.

The power consumption when both Wi-Fi and Bluetooth interfaces run at the same time is $P_{WB}=P_W+P_B$=1.447W. This means the master node and repeater node must have the battery level above 24% to be able to support the low battery node.

CONCLUSION

In this paper, a vertical handover algorithm between Wi-Fi and Bluetooth has been proposed. The algorithm triggers the handover process based on the battery level of the device and perform handover by utilizing the SDN-based vertical handover system. The estimated results show that, the low battery device can continue to communicate in a group for nearly 21 hours by switching the connection from Wi-Fi to Bluetooth. The results also point out that to support the low battery device, other devices only need to have the battery level above 24%. Besides, the experiment results on a real testbed has confirmed that when handover occurs, a 100 Kbps UDP traffic is maintained with a packet loss rate as low as 7%. In the future work, a more precise algorithm on estimating the energy consumption of Wi-Fi and Bluetooth in a variety of testbeds and protocols will be concentrated on.

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