Feasibility Evaluation of 6LoWPAN over Bluetooth Low Energy

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ABSTRACT
IPv6 over Low power Wireless Personal Area Network (6LoWPAN) is an emerging technology to enable ubiquitous IoT services. However, there are very few studies of the performance evaluation on real hardware environments. This paper demonstrates the feasibility of 6LoWPAN through conducting a preliminary performance evaluation of a commodity hardware environment, including Bluetooth Low Energy (BLE) network, Raspberry Pi, and a laptop PC. Our experimental results show that the power consumption of 6LoWPAN over BLE is one-tenth lower than that of IP over WiFi; the performance significantly depends on the distance between devices and the message size; and the communication completely stops when bursty traffic transfers. This observation provides our optimistic conclusions on the feasibility of 6LoWPAN although the maturity of implementations is a remaining issue.

Keywords
Internet of Things, IPv6 over Low power Wireless Personal Area Networks, Bluetooth Low Energy, MQTT

1. INTRODUCTION
The Internet of Things (IoT) is an IT system based on a network of smart objects embedded with a sensor, software, and connectivity to exchange data with service providers. In the vision of Trillion Sensors Universe [3], for example, a tremendous amount of smart objects will be deployed everywhere on the earth, and each of them has connectivity to the Internet, either directly or indirectly through gateways. To provide such a ubiquitous connectivity with several restrictions to power, memory space, network bandwidth, and processing resources [2], IPv6 over Low-power Wireless Personal Area Network (6LoWPAN) [6], which is standardizing by IETF, is a promising technology.

*This work was done during an internship at AIST, Japan.

In terms of the link layer, several low-power wireless technologies, including ZigBee/IEEE 802.15.4, Bluetooth Low Energy, and Wi-SUN, have been developed for supporting IoT applications and services. Bluetooth Low Energy (BLE) [1] or Bluetooth Smart aims at enabling low-cost sensors to exchange data for short distance, and it has a wide range of applications, including smart watches, home electronics, location-based services such as Apple’s iBeacon and Google’s Eddystone. The Bluetooth specification version 4.1 or newer is required for IPv6 over BLE links [2]. Although the standardization process is ongoing, some operating systems have already supported it in advance.

In this paper, we demonstrate the feasibility of 6LoWPAN over BLE through conducting experiments on a commodity hardware environment. Our contribution is a preliminary performance evaluation of 6LowPAN over BLE, including the power consumption comparing with both wired and wireless Ethernet technologies, the impact of the distance between devices and the message size on the throughput, and the application performance based on MQTT.

The rest of the paper is organized into the following sections: Section 2 presents the overview of a network protocol stack supporting IoT services, Section 3 shows our experimental results in a commodity software and hardware environment, Section 4 demonstrates a simple MQTT application as a use case of IoT services, and finally Section 5 summarizes the paper and briefly mentions future work.

2. IOT PROTOCOLS
Figure 1 shows a typical 6LoWPAN protocol stack from the physical layer to the application layer. Though 6LoWPAN is originally designed for IEEE 802.15.4-based networks [6], currently 6LoWPAN over BLE is under the process of standardization at IETF [7]. The physical bit rate of BLE is up to 1 Mbps, and the effective throughput is about one-third of it. BLE has two roles of devices: a master and a slave. A slave device broadcasts advertise messages until a master detects it. After the link layer connection establishment, 6LoWPAN initialized the network interface, and IPv6 communication between them is ready to start.

6LoWPAN is an adaptation layer protocol in the middle of a link layer and a network layer, and it allows the transmission of IPv6 datagrams over IEEE 802.15.4 or BLE net-
works. Precisely speaking from the viewpoint of the BLE network, 6LoWPAN works on top of the Logical Link Control and Adaptation Protocol (L2CAP) layer. IPv6 requires to transmit datagrams of 1280 bytes or larger, and the minimum header size is 40 bytes. However, the physical packet size of BLE is up to 47 bytes. 6LoWPAN fills the gap by employing several features including header compression and fragmentation. Several header compression schemes are defined, and the proper scheme is used for each IPv6 address type such as a link-local address and a unique local address. At network interface initialization, a link-local address based on the 48-bit BLE address is automatically assigned to the device. In this case, IPv6 header can be compressed to only 2 bytes. However, applications cannot use a link-local address, and a non-link-local address have to be assigned to the network interface. In this case, IPv6 header can be compressed to 12 or 20 bytes.

Application protocols layer on top of transport protocols. Table 1 briefly compares three popular application protocols suitable for communication in machine-to-machine (M2M) and IoT: MQTT [9], MQTT-SN [11], and CoAP [10]. Message Queuing Telemetry Transport (MQTT) [9] is a publish/subscribe messaging transport protocol. An MQTT system contains three roles: broker, publisher, and subscriber. A broker is a medium for message exchanging among clients. A publisher transfers the message that be referenced by topic. A subscriber waits for messages that related to the topic. If the topic that a subscriber attend was changed, the message is distributed to the subscribers. MQTT also provides three-level QoS for delivering messages between clients and brokers: “at most once”, “at least once”, and “exactly once”. MQTT for Sensor Network (MQTT-SN) [11] is a lightweight variant of MQTT for low bandwidth and high failure networks, and devices with significant resource constraints. It does not require TCP and security features. Usually, MQTT-SN gateways transfer MQTT-SN messages to an MQTT broker. Constrained Application Protocol (CoAP) [10] is an HTTP-like transport protocol based on the Representational State Transfer (REST) model. Servers make resources available under a URL, and clients access these resources using methods such as GET, PUT, POST, and DELETE. Unlike HTTP, CoAP is based on UDP and the encoding is binary form.

The rest of the paper shows MQTT over 6LoWPAN because we can use several well-designed and open source MQTT implementations as shown in Table 1.

3. EXPERIMENT
To demonstrate the feasibility of 6LoWPAN over BLE, we have conducted two experiments. This section shows the performance evaluation including the power consumption and the application-level performance using MQTT while the next section demonstrates a use case of MQTT over 6LoWPAN.

3.1 Experimental setting
We have built a minimum 6LoWPAN environment which consists of ThinkPad X230t (X230) and Raspberry Pi model B+ (RasPi). Table 2 summarizes the specifications. Linux operating system is running on both X230 and RasPi, where the kernel 3.18 and later have already supported 6LoWPAN over BLE.

To evaluate the performance of MQTT on a 6LoWPAN environment, MQTT version 3.1 compliant implementations were used as follows. Mosquitto [4] is an open source broker implementation written in the C language. We used the version 3.1. Paho [5] is an open source client library and supports multiple programming languages such as C, Java, and Python. We used version 1.1 and, both our benchmark and application programs were written in C.

We used unique local IPv6 addresses in MQTT experiments. After establishing 6LoWPAN connection, a link-local IPv6 address is automatically assigned to the BLE device as described in Section 2. We also assigned a unique local IPv6 address to each device because Paho C library cannot use a
### Table 2: Hardware and Software Specifications

|                | ThinkPad X230t                              | Raspberry Pi model B+                      |
|----------------|---------------------------------------------|-------------------------------------------|
| **CPU**        | Intel Core i7-3520M@2.90 GHz                | Broadcom BCM2835 (ARM1176JZF-S)@700 MHz   |
| **Memory**     | 16 GB                                       | 512 MB                                    |
| **Disk**       | SSD 256 GB                                  | microSD Card 32 GB                        |
| **Ethernet**   | Intel 82579LM                               | Microchip LAN9512                          |
| **BLE**        | I-O DATA USB-BT40LE                         |                                           |
| **WiFi**       | I-O DATA WN-G150UMK                        |                                           |
| **OS**         | Ubuntu 14.04.2 LTS 64bit                    | Raspbian GNU/Linux 7                      |
| **Kernel**     | 3.18.0-031800-generic                      | 3.18.14+                                  |

### Table 3: Comparison of power consumption among a combination of network devices and workloads [mA]

| device          | workload  | observed | diff. |
|-----------------|-----------|----------|-------|
|                 | idle      | 0.20     | -     |
| wired Ethernet  | idle      | 0.24     | 0.04  |
|                 | ping      | 0.24     | 0.04  |
|                 | iperf (58.3 Mbps) | 0.27     | 0.07  |
| WiFi            | idle      | 0.29     | 0.09  |
|                 | ping      | 0.30     | 0.10  |
|                 | iperf (32.2 Kbps) | 0.32     | 0.12  |
| BLE             | idle      | 0.21     | 0.01  |
|                 | ping      | 0.21     | 0.01  |
|                 | iperf (5.84 Kbps) | 0.21     | 0.01  |

link-local IPv6 address to transfer messages.

### 3.2 Benchmark

#### 3.2.1 Power Consumption

We measured the power consumption of RasPi on several conditions, that is, the combination of three network devices (wired Ethernet, WiFi, and BLE) and three workloads (idle, ping, and iperf benchmark program). The distance between devices is 0 meter. RasPi is supplied 5V power from USB cabling. To measure the power consumption, we observed current on a USB power line by Sanwa PC700 multimeter.

Table 3 shows that the absolute power consumption of each case and the increase over the baseline, that is idle without any network devices. The power consumption of 6LoWPAN over BLE is one-tenth lower than that of IP over WiFi. BLE takes lowest power consumption among three devices, and the increase over the baseline is only 0.01 mA. On the other hand, WiFi takes the highest power consumption. In terms of the transferred per Joule, however, BLE is not efficient because the throughput is quite small comparing with the theoretical link bandwidth, which is 1 Mbps. We consider the implementation may not be mature enough.

#### 3.2.2 Distance between devices

We measured the impact of the distance between 6LoWPAN devices on the application-level performance, that is, how many MQTT messages can be published from a client to the broker for one second, where the distance is varied from 0 to 20 meters. Each benchmark trial takes 10 seconds. This experiment was conducted in a corridor without any blind spots and devices were put on the floor.

Figure 2 shows results of the round trip latency and the MQTT throughput. The MQTT throughput linearly decreases as the distance increases. Finally, the communication failed where the distance is over 20 meters. It is because that MQTT runs on top of TCP and TCP performance degrades as the round trip time increases. We observed a few TCP retransmissions during this experiment, where the number of TCP retransmissions does not depend on the distance. Note that we obtained each result separately, and the latency fluctuated; therefore the correlation between them is not so evident from Figure 2.

### 3.2.3 Message size

We also measured the impact of the message size on the MQTT throughput where the message size is varied from 1 to 256 bytes. The distance between devices is 0 meter. Each benchmark trial ran in the period of 10 seconds.

Figure 3 presents the relationship between the throughput and the message size. The message size is a significant factor for the performance. The throughput decreases in proportion to the message size, and it suddenly drops between 16-byte and 32-byte messages. It can be caused by fragmentation, where the message is fragmented into multiple BLE packets. This result leads that application programmers should keep the message size as small as possible to get better performance.
This topic is used to get the status of the light. It returns “on” or “off”.

Table 4: Topics of USB-powered light application

| Topic     | Description                                                      |
|-----------|------------------------------------------------------------------|
| light/control | This topic is used to turn the light on and off. The message should contain “on” or “off”, otherwise the client returns an error. |
| light/status  | This topic is used to get the status of the light. It returns “on” or “off”. |

4. USE CASE: USB-POWERED LIGHT APPLICATION

We have implemented a simple MQTT application as a use case of IoT services. This application allows the users to control the USB-powered light from remote computers, and it is quite simple but enough for demonstrating the usability and the functionality of MQTT.

This application consists of two clients: device and controller. A device client is running on a computer that has a target device, e.g., USB powered-light, and controls it. On the other hand, a controller client controls the target device and get the status remotely. These clients exchange the MQTT message via a broker, and they act as sometimes subscribers and at other time publishers. We define two topics: “light/control” and “light/status”, as shown in Table 4. The former is used to turn the power on and off; the latter is used to get the power status. Besides, to keep the latest power status on the broker, we set messages for topic “light/status” to be retained.

This application is written in Python with the Paho Python library. To control the power supply of each USB port, we use hub-ctrl [S] on a controller client. In this experiment, device and controller clients ran on RasPi and X230, respectively; the broker ran on X230.

We found a critical problem that hub-ctrl turns off all of USB ports on RasPi. Therefore, the “light/control off” message turns off not only the light but also the BLE USB dongle. By using GPIO instead of hub-cntl, we can control AC power supply to external electronics products like this application.

5. CONCLUSION AND FUTURE WORK

6LoWPAN is a promising technology in the IoT era. To demonstrate the feasibility, we have conducted a preliminary performance evaluation of a commodity hardware environment, including Bluetooth Low Energy (BLE) network, Raspberry Pi, and a laptop PC. Our experimental results show that the power consumption of 6LoWPAN over BLE is one-tenth lower than that of IP over WiFi; the performance depends on the distance between devices and the message size. Since this evaluation is limited, a comprehensive evaluation will be shown in a future publication.

Besides, we have observed that the implementation on the Linux is not mature enough. Although our MQTT benchmark generates a none realistic workload, we found a serious issue as described below. Our MQTT benchmark have often failed, and any packets do not go through the network after that until rebooting machines. This issue was not observed with wired and wireless Ethernet. To pursue the cause, we have updated the Linux kernel from the version 3.18 to 4.0. However, the situation does not change. A stable implementation of 6LoWPAN over BLE is a future work.

Privacy is another big concern for IoT services. We plan to develop MQTT services using homomorphic encryption that allows computations to be carried out on encrypted user data. Such technology can extend the range of application of IoT and 6LoWPAN.

6. REFERENCES

[1] Bluetooth SIG. Bluetooth specifcation version 4.0. http://www.bluetooth.org
[2] C. Bormann, M. Ersue, and A. Keranen. Terminology for Constrained-Node Networks. RFC 7228, May 2014.
[3] J. Nieminen, T. Savolainen, M. Isomaki, B. Patil, Z. Shelby, and C. Gomez. IPv6 over BLUETOOTH(R) Low Energy. Internet Draft draft-ietf-6lo-btle-16, July 2015.
[4] E. Foundation. Mosquitto: an open-source implementation of an MQTT broker. http://www.eclipse.org/mosquitto/
[5] E. Foundation. Paho: an open-source client implementations of MQTT and MQTT-SN messaging protocols. http://www.eclipse.org/paho/
[6] J. Hui and P. Thubert. Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks. RFC 6282, September 2011.
[7] J. Nieminen, T. Savolainen, M. Isomaki, B. Patil, Z. Shelby, and C. Gomez. IPv6 over BLUETOOTH(R) Low Energy. Internet Draft draft-ietf-6lo-btle-16, July 2015.
[8] Y. Niibe. AC Power Control by USB Hub. http://www.gniiibe.org/development/ac-power-control-by-usb-hub/index.html
[9] OASIS. MQTT Version 3.1.1. October 2014.
[10] Z. Shelby, K. Hartke, and C. Bormann. The Constrained Application Protocol (CoAP). RFC 7252, June 2014.
[11] A. Stanford-Clark and H. L. Truong. MQTT For Sensor Networks (MQTT-SN) Protocol Specification Version 1.2. Technical report, November 2013.
[12] T. Yamaguchi. MQTT-SN Gateway & Client over XBee and UDP. https://github.com/ty4tw/MQTT-SN.