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LETTER

Feasibility study of Ethernet energy harvesting in an IoT beacon system

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Abstract Beacon systems for Internet of Things (IoT) services require frequent battery replacement and costly maintenance. To resolve these issues, we developed a novel beacon system. This system does not require Power over Ethernet (PoE) to supply power because it uses Ethernet energy-harvesting technology via the RJ45 port of the router and switching hub. We experimentally confirmed that the power produced through the Internet TCP/IP network signals activated the beacon dongle to transmit signals, and that a smartphone then received these signals.
Keywords: energy harvesting, Ethernet, IoT, beacon system
Classification: Energy harvesting devices, circuits and modules

1. Introduction

Recently, a variety of omni-channel services using Internet of Things (IoT) and Online-to-Offline (O2O) technologies have been in the limelight [1, 2, 3]. These approaches employ a beacon signal that communicates with nearby smartphones to provide Location-Based Services (LBSs) or Geo Fencing Services (GFSs) [4]. Beacon systems can also be used in O2O technology to provide various other services, such as offering discount coupons through smartphone applications [5, 6, 7, 8]. After a smartphone has received a unique ID and short messages transported through the broadcasting signals of a Bluetooth Low Energy (BLE) device operating at 2.4 GHz [8, 9], an application receives mapped information in a corresponding universally unique identifier (UUID) from the GFS [10, 11]. In addition, information regarding indoor locations can be provided based on the Received Signal Strength Indicator (RSSI) of the signals, so Indoor Positioning Systems (IPSs) are possible [12, 13, 14, 15].

The downside of beacon technology is that if a beacon signal is transmitted every second or every 10 seconds at periodic intervals, a large amount of battery energy will be wasted and the battery will need to be replaced biannually or annually [16, 17]. Even though the intervals at which beacon signals are emitted can be extended to reduce power consumption, if this is done, some moving devices will be passed by and unable to detect the beacon signals because of the long interval times [18, 19]. Therefore, the signal interval and transmission output level should be designed based on the service scenario and application.

A regular power supply for a semi-permanent beacon system is required to resolve this issue. However, this approach has two problems: first, cost-effectiveness may be reduced because of maintenances of charging battery and labor costs. Second, for a transmitter that cannot be controlled remotely, it may be impossible to alter the setting conditions, or an operator may have to visit the site in person to change the configuration for system maintenance.

In this work, we propose an Ethernet Energy-Harvesting (EEH) technology for a networked beacon system in which sequence energy can be supplied as a binary signal through data wire lines, unlike in existing environments where PoE is supplied from a traditional wired/wireless router or wired networked router [20]. The proposed EEH beacon system is based on a networked device structure, enabling the device management server to conduct monitoring and remote control.

2. System descriptions

A beacon system can be operated in an advertisement mode in which it does not require devices to be connected. In other words, if a service is based on a packet composed of a prefix of 31 bytes, Universally Unique Identifier (UUID), major/minor and RSSI, then various application services can be operated in the "central" applications (smartphone) [21]. To match the beacon data to the assigned and designated information, the system is given access to the database (DB) server of the Content Management System (CMS), which provides the product information and website link URL for a location-based coupon service. When it operates in the advertisement mode of BLE communication, in which the system can communicate with multiple devices simultaneously, this broadcasting communication type is appropriate for services that detect the occupation of a device or send a small amount of data (31 bytes or less). It can also be used as a reference point for fingerprinting to achieve localization in indoor environments where GPS signals cannot be detected [22]. The GFS, for example, is currently being expanded. Under this service, if a user device of the beacon system approaches a service area that

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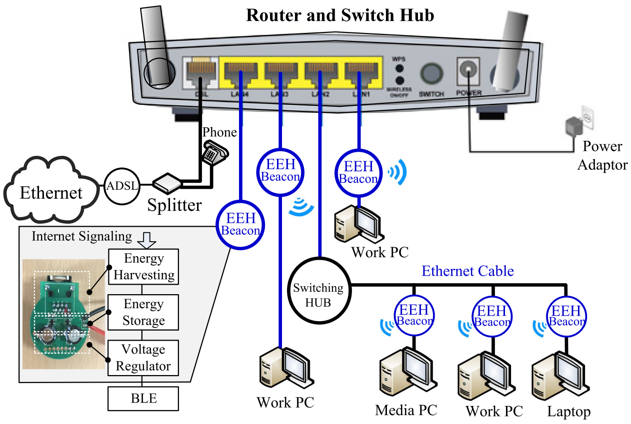


Fig. 1. Diagram of the networked beacon system with EEH technology.

can detect the corresponding beacon signals, the operation of the user service starts or stops immediately.

Fig. 1 displays the beacon system concept and a schematic diagram for manufacturing the EEH technology proposed in this work. For manufacturing, the RJ45 port has been designed to be used compatibly so that extra devices are not required for the existing network devices. The EEH beacon is made up of the following components: a full-wave rectifier (BAS3007) [23] that transfers Ethernet signals (Tx+, Tx−) into a DC voltage that can be recharged by stored energy, a supercapacitor (5.5 V/0.22 F) that stores energy to deliver output power to the load, and a DC/DC converter (LTC3105) [24] that constantly supplies the voltage (1.8 V) needed for the beacon dongle load. For the beacon communication, we used a 2.4-GHz BLE SoC (nRF51822) from Nordic Semiconductor. We designed the EEH beacon dongle to send dummy signals from a PC to a corresponding module for energy conversion. This enables such signals to be used to send power to the designated UUID using the EEH dongle. Hence, a batteryless beacon system can be used. This system could be applied to a customer check-in service that allows customers to receive a stamp or coupon through an application when they visit a store.

3. Experimental results

Fig. 2 displays the measured result of current consumption from an event current profile for the power characteristics of the beacon module, which will be used to apply EEH power to the beacon. The nRF51822 set the supply voltage to 1.8 V and the RF output power to +0 dBm. The result shows that a 40 µA of current is consumed at a standby event, while 14.7 mA and 12.2 mA are consumed at a receiving event (point E) and at sending event (points G), respectively [25]. When the beacon is operated at certain intervals, the EEH module is controlled to charge in real time for 80% of the transmission time, when the maximum power is consumed.

To apply the beacon to Internet devices through EEH technology, we used a commercial Internet product wired router (Q504) [26] and wired switching hub (H605) [27].

The specifications of the two devices used for the experiment were compared to determine energy harvesting

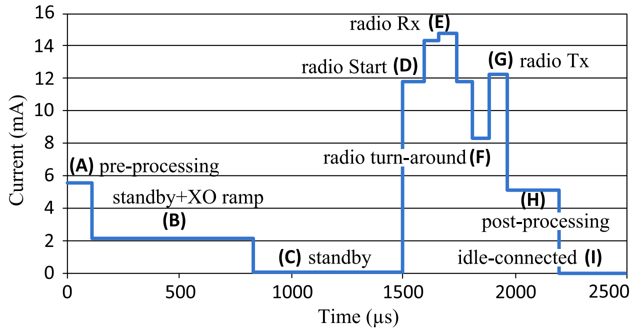


Fig. 2. Measured results of an event current profile after comparison of the BLE basic currents and the time characteristics.

Table I. Comparison of hardware specifications between the wired router and the wired switching hub.

	Wired Router	Wired Switching Hub
Model	ip TIME Q504	ip TIME H605
Main chipset	IP3210 NAT/NAPT Router Chipset, 32 bit RISC CPU 32 MB SDRAM, 15 MB Flash	IP175C Ethernet Integrated Switch MAC, PHY chipset
Operating layer	L3, Network layer, Internet Protocol, NAT, S/W Routing engine	L2, Data Link layer Ethernet
Clock	25 MHz clock frequency Transmit clock period 40 ns/400 ns @100 M/10 M	25 MHz clock frequency Transmit clock period 40 ns/400 ns @100 M/10 M

differences due to their hardware performances. The comparison shows in Table I.

Fig. 3 displays the experimental design diagram for measuring EEH power in Internet signals and examining whether the developed EEH dongle applies a beacon. To compare and measure EEH power, we configured the experiment with a Sony Vaio laptop with a Marvell Yukon 88E8059 model, as well as the switching hub [28]. The router and Internet devices were connected to the backbone network. The laptop and devices were connected point-to-point through a Cat5e UTP cable, and the rectifier was used to convert binary Internet signals that were transmitted to the Cat5e UTP cable to direct current (DC).

The voltage transmitted to a load was measured by an oscilloscope (TPS200B), which changed the converted DC voltage to the load impedance from 1 kΩ to 10 MΩ. The power was then calculated (power = V^2/R). The power generated from EEH across different loads is shown in Fig. 4. In the load impedance range of 75 kΩ to 2 MΩ, a high level of power was measured, ranging from 107 to 190 µW in the switching hub and from 38 to 72 µW in the router. An EEH power comparison between the two devices revealed that the switching hub exhibited more power than the router.

As demonstrated in the hardware performance comparison of the internet devices in Table I, it is important to convert energy through the effective conversion of binary signals. This means that the data transmission timing should be rapid, because the data conversion speed in the physical layer [29] affects the performance. Since H605 is

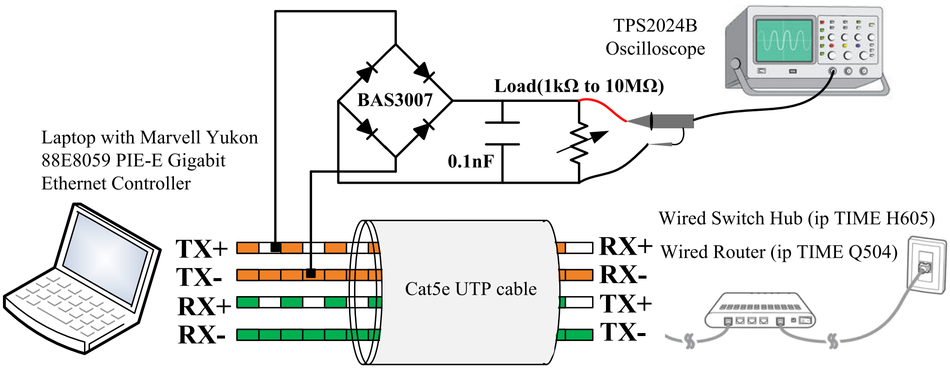


Fig. 3. Configuration for measuring EEH power.

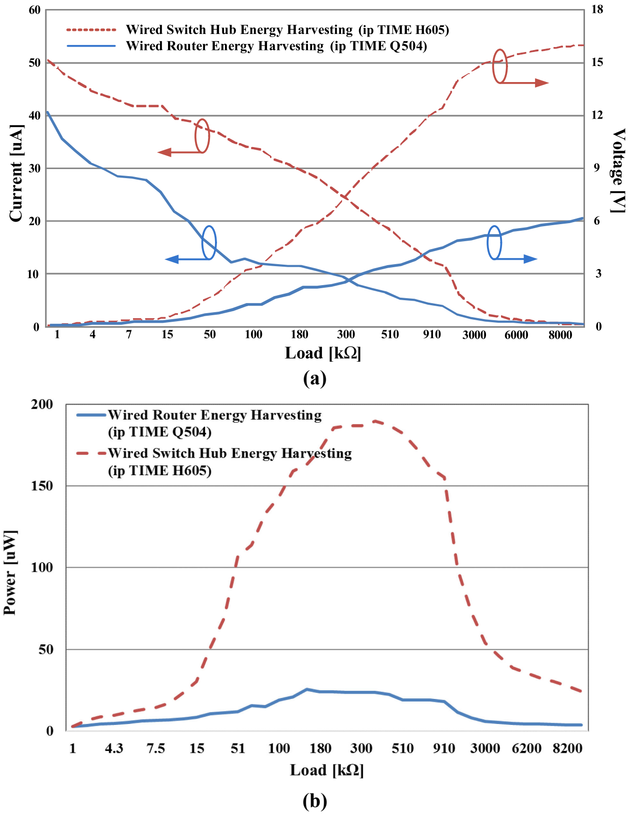
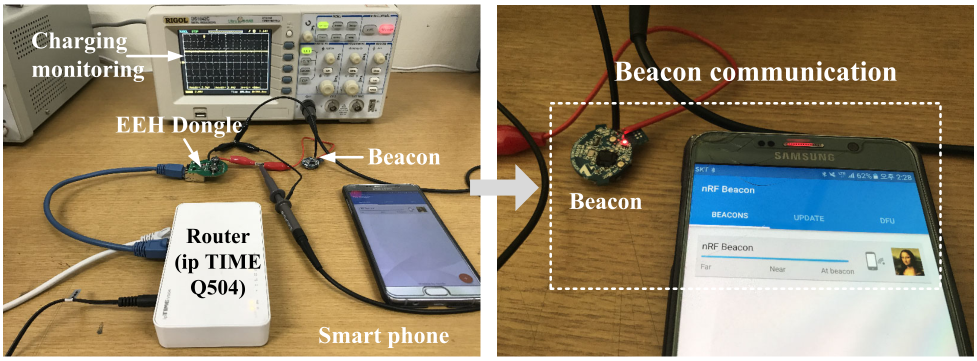


Fig. 4. Measuring power generated across Internet energy harvesting loads.
(a) Measuring voltage and current across changing Internet energy harvesting loads
(b) Measuring Internet signal energy harvesting power and maximum load in accordance with changing loads.

the L2 switch that processes data in the PHY and MAC layers, this device processes the L2 data frame. As the router (Q504) processes L3 packets in the software and embeds the CPU inside, this device provides routing support with software. Hence, the router (Q504) inevitably has data processing latency compared to the switch hub (H605), so its energy efficiency is lower.

The EEH power of the two internet devices was not sufficient to handle beacon operation power in real time without a charging function, as demonstrated by the beacon power consumption (Fig. 2). There was little to no power consumption in ranges other than the beacon signal transmission range, which consumed a large amount of power. Therefore, it is necessary to have a power level that extends the battery life through charging control or the use of an alternative power source. As shown in Fig. 2, the equivalent average current consumption by the BLE chip for 2500 µs was approximately 5.83 mA. However, assuming that power is charged to the capacitor for 650 µs in the standby (C) range and for 300 µs in the idle connected (I) range in a signal cycle, it should be able to be used as a self-powered beacon device. Therefore, for 650 µs, enough power should be charged to the electrolytic capacitor that it can be consumed to operate Tx/Rx signals in the (D) to (H) range and then used for 300 µs in the (A) to (B) range. However, as the capacitor had a slow charging speed, it did not have enough time to obtain power to consume in a cycle. Therefore, an algorithm that charges the capacitor in advance is required to operate the beacon device.

To examine whether the beacon device could operate and transmit signals when charged with EEH power, we established the system shown in Fig. 5 and conducted an integration test. When the charging voltage of 3 V required for beacon signal transmission was detected, the power of the beacon device was connected to operate the beacon. When the charging voltage was 1 V or lower, the device was charged again. Beacon signals from the beacon device were received successfully through an application that scanned the BLE signals of the smartphone when the device operated (Fig. 5(b)) [30]. The beacon device was configured to transmit 0 dBm power, so it could transmit signals at a distance of 30 to 40 m indoors and more than 100 m outdoors.



(a) (b)

Fig. 5. Photograph of the test set used for the EEH dongle-based beacon communication.
(a) Configuration to verify beacon signal transmission.
(b) Demonstration beacon signal transmission.

4. Conclusion

This paper has suggested EEH technology, which converts Ethernet signals into electrical energy. We implemented EEH power in a self-powered IoT beacon service. EEH technology provides the power required for the beacon by converting binary signals from the RJ45 port in the wired switching hub or wired router into direct current voltage and charging power.

This technology can provide a beacon service without any additional power supply, and the RJ45 dongle design has made it easier to use in IoT-related devices. To measure and analyze EEH power, we used a commercial wired switching hub (H605) and a wired router (Q504). The measured results indicated that power was generated from 107 to 190 µW in the wired switching hub, and from 38 to 72 µW in the wired router. The switching hub displayed a higher power level than the router across a wider range of loads. Although the power generated from EEH was not sufficient to power the beacon in real time, the present study confirmed that the beacon device (nRF51822) functioned and transmitted beacon signals through charging.

Based on these findings, we plan to implement a charging algorithm in accordance with the beacon operation cycle and apply it to a self-powered beacon service through continued research on EEH technology in the future. We expect that this work will reduce the operation and maintenance costs arising from battery replacement, one of the problems with existing beacon services. Furthermore, as the beacon can be connected to the RJ45 port, transmit Internet signals to existing Internet devices without any additional device, and be applied to a networked beacon system, it can also be used for wired network communications and remote control for a variety of additional online to offline (O2O) services.

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