KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS VOL. 6, NO. 1, Jan 2012

RESTful Architecture of Wireless Sensor Network for Building Management System

Ngoc-Thanh Dinh and Younghan Kim[†]
School of Electronic Engineering, Soongsil University
Dongjak-gu, Seoul, 156-743, Korea
[e-mail: ngocthanhdinh@gmail.com, yhkim@dcn.ssu.ac.kr]
*Corresponding author: Younghan Kim

Received September 18, 2011; revised November 24, 2011; accepted December 26, 2011; published January 31, 2012

Abstract

The concept of an “intelligent building” received significant attention from academic, industry and standard development organizations when technically termed a building management system (BMS). Wireless sensor networks (WSNs) and their recent development enhanced monitoring and control applications for the building’s areas. This paper surveys and analyzes advantages of the main current and emerging approaches that may be fit for BMS. Specifically, we discuss challenges including interoperability, integration, overhead, and bandwidth limitation of WSNs in BMS. Based on analyses, we highlight the advantages of an IP-based and RESTful architecture approach as the most suitable solution for BMS using WSNs (BMS-WSN). The paper also describes our future direction and design for BMS-WSN based on these advantages. The purpose is to enable interaction of users with BMS-WSN in the same way as with any website while ensuring energy efficiency. A test-bed implementation and evaluation of a BMS application is also introduced in this paper to demonstrate the feasibility and benefits of IP-based and RESTful architecture for BMS.

Keywords: Building management system, IoT, REST, CoAP, 6LoWPAN, RPL

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the “program for CITG” support program supervised by the NIPA(National IT Industry Promotion Agency).

DOI: 10.3837/tiis.2012.01.003

1. Introduction

Building management system (BMS) provides efficient control function for maintaining building condition (e.g., temperature, humidity, air cleaning, light control, and reducing unnecessary energy consumption as well as building security). An example is shown in **Fig.1**.

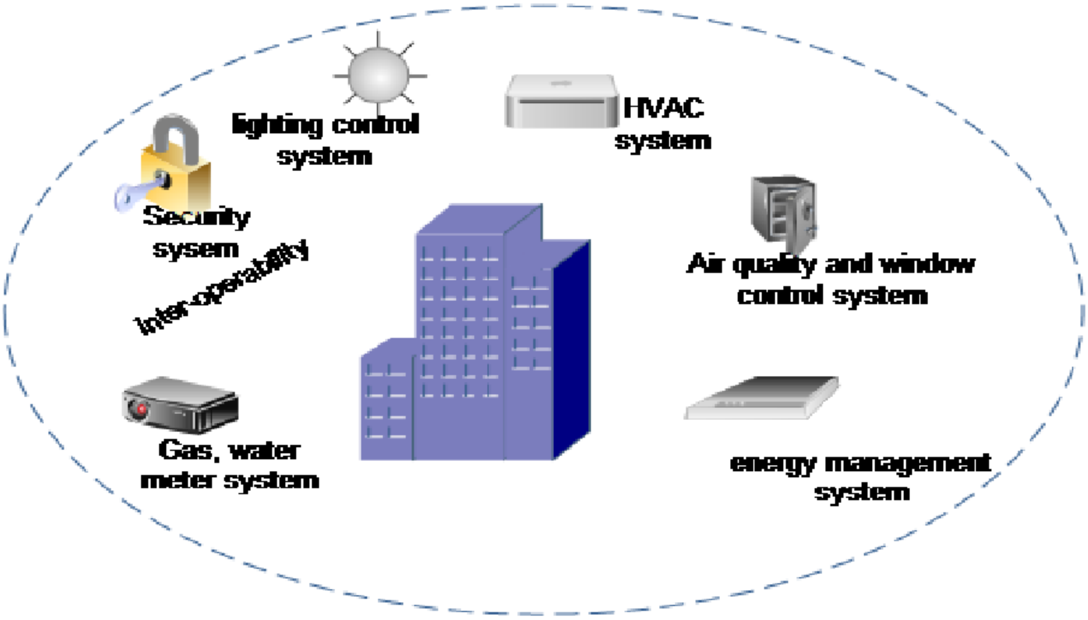


Fig. 1. BMS subsystems example

Hard-wired networks have long been used in BMS. However, this approach is an expensive and inflexible design. Recently, a new approach for BMS based on wireless sensor networks (BMS-WSN) appeared [1][2][3]. Recent researches on this topic, such as protocols and architecture experiments [1][2][3][4], have demonstrated the strength of wireless sensor networks (WSNs). Specifically, WSNs can provide environment monitoring and device controls that are suitable for BMS requirements. This technology will open up the potential of the Internet of Things (IoT) for BMS.

In this paper, we focus on the development and application of BMS-WSN. Even though there are many advantages of WSNs, challenges still exist to the development of an efficient BMS-WSN. An overview of current and emerging approaches for BMS-WSN is covered in this work. Specifically, we analyze and discuss challenges including interoperability, integration, overhead and low bandwidth problems of constrained environment WSNs for BMS. Based on analyses of different mechanisms, we highlight advantages of an IP-based and REST architecture approach as the most suitable solution for BMS-WSN. A direction and design for BMS-WSN is also described to benefit from this approach. The purpose is to enable interaction of users with BMS-WSN in the same way as with any website, while ensuring energy efficiency to meet the requirements of BMS. A simple prototype implementation of BMS application is also introduced in this paper to demonstrate the feasibility and benefits of IP-based RESTful architecture for BMS.

The rest of the paper is organized as follows. Section 2 discusses current trends of development in BMS. The analysis of RESTful and SOAP architectures are highlighted in Section 3. In Section 4, we propose the solution of BMS-WSN using IP-based REST architecture. A test-bed is described in Section 5. Finally, Section 6 concludes the paper.

2. Existing Researches in BMS-WSN

In this section, we review the literature and ongoing researches into BMS-WSN, which are based on technologies for improving energy savings, user comfort, and security functions of the building. Different technologies are currently employed for BMS with different benefits and evaluations. In the next step, we analyze the advantages and disadvantages of these technologies and discuss which approach is the most suitable for future BMS.

Hard-wired networks have long been used in BMS [5]. However, this approach is an expensive and inflexible design. Recently advances in WSNs, including hardware [6], software [7][8] and emergent standards [9][10], have demonstrated the strength of WSNs. WSNs as a key solution are alternatives to a wired approach in the BMS field [11][12][13]. WSNs are used in many kinds of application in BMS, including HVAC, lighting, air quality and window controls and security and safety systems, which use different types of sensors such as light sensors, gas sensors, movement, motion sensors and more.

Recently, a large amount of research has studied modeling, design, and implementation for BMS [14][15][16][17][18]. Kastner et al. introduced the basic requirements, services and application model for BMS [19], and Ploennings et al. [15] analyzed a network in BMS and proposed an automated model. A fuzzy logic control is implemented for building illumination and temperature control in [17]. A novel multi-agent control system for managing the comfort level of the building environment is proposed in the research of Dounis and Caraiscos [20]. Nakamura et al. proposed a sensor/actuator network with collaborative sensing and actuation for lighting control [21]. The BMS area also received much attention from different groups such as BACnet [14] and Local LON [16]. Most of these groups highlighted and used ZigBee as an approach for BMS.

ZigBee is a wireless networking technology developed by the ZigBee Alliance based on the IEEE 802.15.4 standard for low data rate and short-range applications. The protocol stack of ZigBee is shown in **Fig. 2-(c)**. ZigBee building automation standards [22] and two related profiles [23][24] are defined for description, attributes and practices of ZigBee for BMS.

Other researchers have focused on IP-based approach. Recently proposed IPv6 stacks are available for WSNs environments [25] to satisfy the large address space needed for WSNs. The IETF 6LoWPAN standard [9] has recently been proposed to adapt IPv6 into WSNs. IP-based WSNs potentially help extend the capability of the Internet. 6LoWPAN specification [9] provides a way for IPv6 packets to be transmitted over 802.15.4. The main techniques provided by 6LoWPAN include: 1) Header compression; 2) IPv6 address auto-configuration; 3) IPv6 Neighbor discovery for constrained environment; and 4) Fragmentation.

In this environment, a routing protocol is needed. There are two approaches for routing in LoWPAN: mesh-under and route-over. In the mesh-under approach, routing is performed using a link layer address **Fig. 2-(a)**. In the route-over approach, routing is performed at the network layer **Fig. 2-(b)**. The IETF ROLL working group has been carrying out the IPv6 Routing Protocol for low-power and lossy networks (RPL), which supports point-to-multipoint, multipoint-to-point, and point-to-point communication in WSNs.

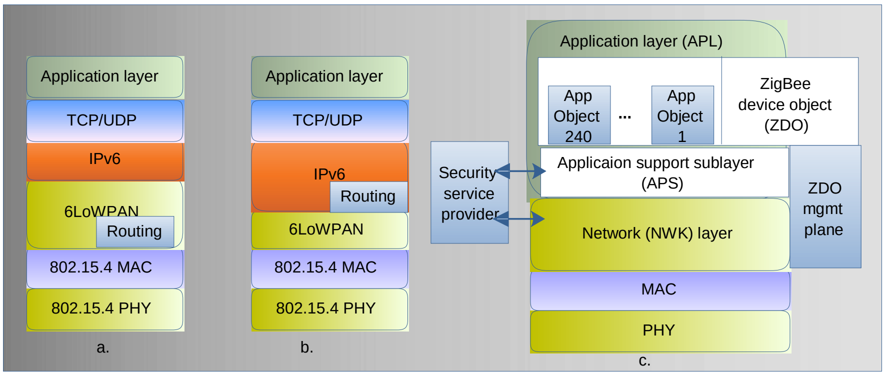


Fig. 2. Protocol stack for BMS-WSN: a. 6LoWPAN-mesh under; b. 6LoWPAN route-over; c. ZigBee

IP-based and ZigBee are two typical approaches for BMS. Each approach for BMS has different benefits. In the next step, we analyze the advantages and disadvantages of the approaches by comparing them in terms of technical requirements of BMS. Some comparisons of the main characteristics of each approach are shown in **Table 1**.

Table 1. A Comparison between ZigBee and 6LoWPAN

Class	6LoWPAN	ZigBee
Devices types	6LoWPAN border router (6LBR), 6LoWPAN router (6LR), host	Coordinator, router, end device
Hop limit	255	30/10/5 (mesh routing/ tree routing/ source routing)
Routing	RPL	Mesh routing, tree routing, source routing
Supporting reliability	TCP/UDP	ACKs and retransmission
Requiring translation gateway for Internet connectivity	No	Yes
Implementation size	24 Kbytes (ROM), 3.6 Kbytes (AM)	45-128 Kbytes (ROM), 2.7-12 kbytes (RAM)

Considering the Internet connectivity requirement, many existing WSNs use specialized protocols with a special gateway to connect the WSNs with the external IP network. This approach may lack flexibility, take more time and be more complicated to develop new applications by requiring specialized modifications. To avoid the use of a specialized gateway, 6LoWPAN was designed to be operable with the Internet. Therefore, sensors in BMS can be natively addressed and connected through the IP protocol without requiring the use of a specialized protocol translation gateway. Running IP in BMS-WSN also has the benefit of interoperability at the network layer.

Considering the reliability side, to improve the reliability of communication, 6LoWPAN uses UDP augmented with sequence numbers, acknowledgements and retries, while ZigBee offers simple acknowledgements and retransmission.

In implementation size, ZigBee requires larger resources because it has a large number of complex mechanisms for different applications. In addition, current 6LoWPAN implementation requires fewer resources (ROM/RAM) than ZigBee.

The emergency and advances of IP-based approach will improve standard protocols, quality, and interoperability for operations of BMS-WSN.

For enhanced quality, interoperability, integration and extended service of BMS, the application architecture approaches are also very important. In the next section, we discuss the main approaches of application architecture for BMS.

3. Architecture Approaches of IP-based WSNs for BMS

3.1. Existing issues of BMS-WSN

Wireless sensor networks are generating potential chances for BMS. They would be more efficient, convenient, safe and less costly than traditional networks. However, there are some existing issues we will discuss in this section.

Energy efficiency: Energy efficiency is generally one of the main important issues in WSNs, including BMS-WSN. Sensor devices and actuators need to be as energy efficient as possible because they are powered by batteries.

Inter-operability and integration issue: There are many kinds of subsystems in BMS, including HVAC, lighting, air-quality monitoring and others, so a practical issue of BMS is cross-function. In the conventional operations, these systems still remain isolated. It leads to high operational costs and complex management. The valuable data should be shared among systems to improve BMS with a larger service and intelligent monitoring system. It is therefore beneficial to consider a model for integrating BMS subsystems to improve management under a unified system.

Additionally, the building managers and users may not always be inside the building to use BMS services. Therefore, supporting ubiquitous accessing service is also needed. These issues require an optimal design of application architecture to support inter-operability and integration as well as their energy efficiency. In the next section, we discuss approaches for the application architecture of BMS-WSN.

3.2. Architectural approaches for BMS-WSN

One of the major benefits of an IP-based approach is to make it possible to use the standard Web service architecture. Web services are a common technology for developing interoperable distributed applications. Web services have previously been proposed for connecting WSNs with other networks [26][27][28][29]. In this section, we analyze advantages and disadvantages of Web services approaches for BMS and show how Web service can adapt into the BMS-WSN.

First, we highlight the advantages of Web services for BMS-WSN. Using Web services on sensor nodes has the following significant advantages. The greatest advantage of using Web service is interoperability and supports the network cross-function of deployed sensors to be shared across different applications. The existing applications can benefit from new deployed sensors. New applications can also benefit from available deployed sensors to reduce cost efficiently, as shown in the example in **Fig. 3**.

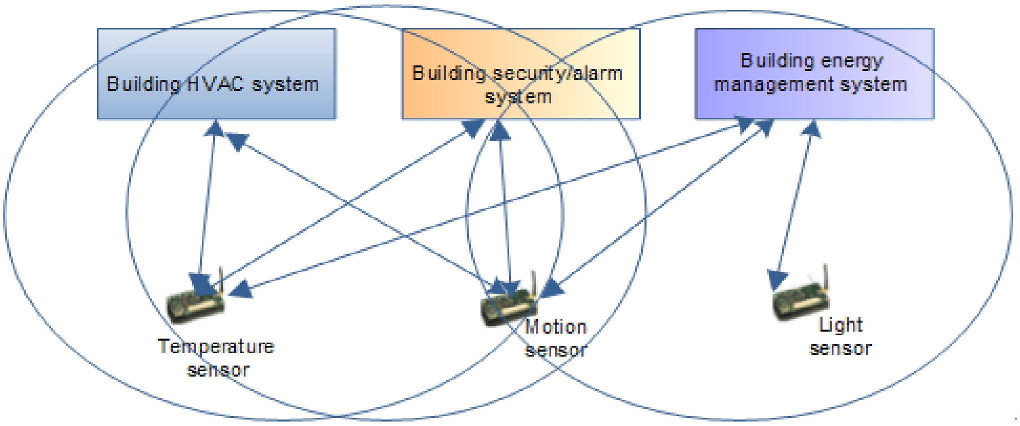


Fig. 3. An example of shared sensors across different systems.

A Web services approach brings a solution for the integration issue among many Web services applications. A Web services approach also helps improve user interface between sensors and end users.

A key challenge in using Web services on resource-constrained sensors is energy and bandwidth overhead. So redesigning protocols should optimize message formats and complexity. Next, we compare Web services architectures for BMS-WSNs to find the most suitable one.

The architectures of Web services could be classified into two categories: SOAP-based and RESTful-based mechanisms. SOAP-based Web services use the Simple Object Access Protocol standard (SOAP). RESTful-based Web services use Representational State Transfer (REST) [31]. Recently, studies have demonstrated that both of these application approaches can be used for WSNs [29][30][31]. From implementation of SOAP and REST for WSN [30][31][32], a comparison of SOAP-based and RESTful-based approaches is shown in **Table 2**.

Table 2. A comparison of SOAP-based and RESTful-based mechanisms

Class	REST-based	SOAP-based
XML Parser RAM footprint	Not required	4
REST Engine RAM footprint	4	Not required
SOAP Engine RAM footprint	Not required	36
Power Consumption	~ 3.5 mW	~ 9 mW

We see that a REST-based mechanism is much lighter and more energy efficient than a SOAP-based mechanism. Therefore, we suggest using the REST paradigm. For more detail, we analyze the advantages of RESTful-based mechanisms for BMS-WSN.

Lightweight: RESTful-based mechanisms use standard HTTP protocols and avoid unnecessary XML and extra encapsulation. The application can also give better performance and energy savings because of its lightweight mechanism.

Scalability: RESTful-based systems provide a very simple and effective way to support load-balancing and flexible URI-partitioning. They also support caching to achieve better scalability.

Resource description and accessibility: RESTful-based Web services (WSs) use URIs and take advantage of a declarative approach [33] for the representation of resources that are self-descriptive. This makes RESTful-based Web services easy to access.

4. RESTful Architecture of WSNs for BMS

From the many benefits of IP-based approach demonstrated above, we recommend using a 6LoWPAN approach for BMS-WSN. Additionally, BMS-based knowledge also needs for the architectural design. We design a BMS-WSN architecture based on the logical structure of real buildings and 6LowPAN approach, as shown in **Fig. 4**.

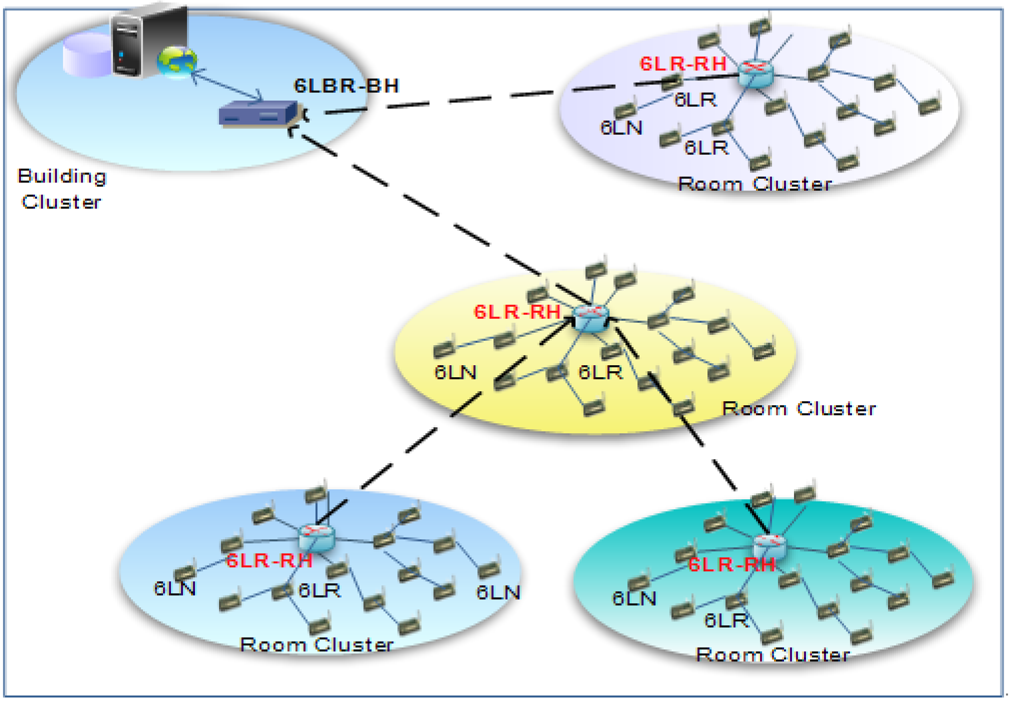


Fig. 4. BMS-WSN architecture design

In our design, we classify each room as a Room Cluster in the Building Cluster. There are four types of sensor nodes in this model: 6LN, 6LR, 6LR-RH and 6LBR-BH. A 6LoWPAN Node (6LN) is any sensor participating in a LoWPAN. A 6LoWPAN Router (6LR) is an intermediate router. In each room is inserted a 6LoWPAN Router Room Head (6LR-RH), which receives data from other nodes in the room and can communicate with other 6LR-RHs. Each building has a 6LoWPAN Border Router Building Head (6LBR-BH) to collect sensing data from all rooms in the building. 6LBR-BH sits at the boundary of 6LoWPAN and other building IP networks. 6LBR-BH is also responsible for IPv6 prefix propagation for the BMS-WSN. Because data from nodes in the same room are highly correlated, we suggest implementing data aggregation functions in 6LR-RH. 6LBR-BH is connected with a Web server. A Web server provides Web services for BMS-WSN application, which includes a database to store and link between the physical infrastructure data and the Web services. Sensors populate their data and resource services to the database. From the many advantages of RESTful architecture as analyzed above, we suggest using RESTful architecture for BMS-WSN. We design an appropriate model for BMS-WSN as shown in **Fig. 5**.

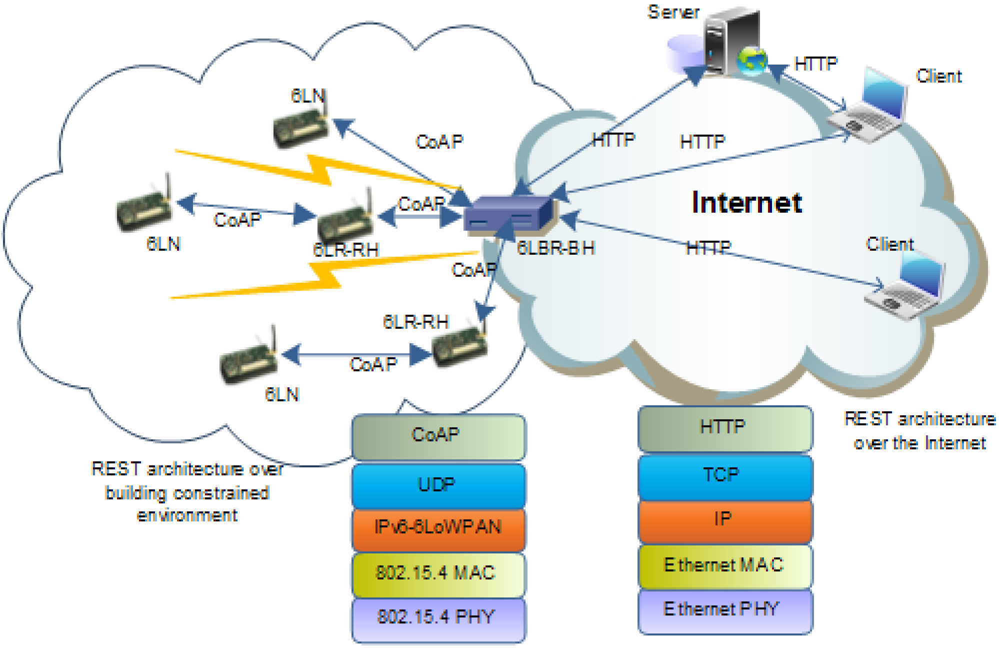


Fig. 5. RESTful communication model of BMS-WSN

We typically use 802.15.4 MAC/PHY. The two upper layers use IPv6-6LoWPAN with RPL routing protocol and UDP. We analyze the approach for the application layer in the next step.

As analyzed above, even though RESTful Web services are simple, the overheads and protocols were not suitable for BMS-WSN for several reasons. Therefore, a more efficient way to realize the REST architecture for BMS-WSN is needed.

Recently, the IETF Constrained RESTful Environment working group (CoRE) [7] has formed to develop a REST-based framework for constrained devices. The CoRE has proposed the Constrained Application Protocol (CoAP) [7], including a minimal subset of REST and stateless mapping with HTTP. Hosts using CoAP support a solid communication framework to connect sensor nodes to the Internet and offer flexible services with following main features:

Compact header: CoAP is designed to keep the message overhead as small as possible with a short fixed header size of 4 bytes followed by extensible binary options. CoAP includes a minimal subset function of HTTP to take into account the low processing and energy efficiency.

URI: CoAP also supports URI. The resources can be manipulated using request methods GET, PUT, POST, and DELETE.

Transport layer: CoAP is built on top of the UDP to reduce overhead and multicast support. It also supports a simple stop-and-wait reliability mechanism [7].

Supporting asynchronous communication: A major inappropriateness of HTTP for M2M communication is the use of pull-model interaction, which means the transactions are always client-initiated. CoAP supports asynchronous communication, which is common in Sleep/Wake-up sensor of M2M application. CoAP uses asynchronous communication to support the push of information from servers to clients using subscriptions to request a response of resource each time it changes, as shown in **Fig. 6**. In this example, the CoAP client sends a subscription message as confirmable type (CON) to the CoAP server to require providing up-to-date temperature data with lifetime of 120 seconds.

Resource discovery: To support interoperability between CoAP endpoints, CoRE proposes a technique for discovering and advertising resource descriptions. They define the well-known resource path /well-known core for resource discovery.

Caching: CoAP supports caching for resource representations to optimize for the performance of WSNs.

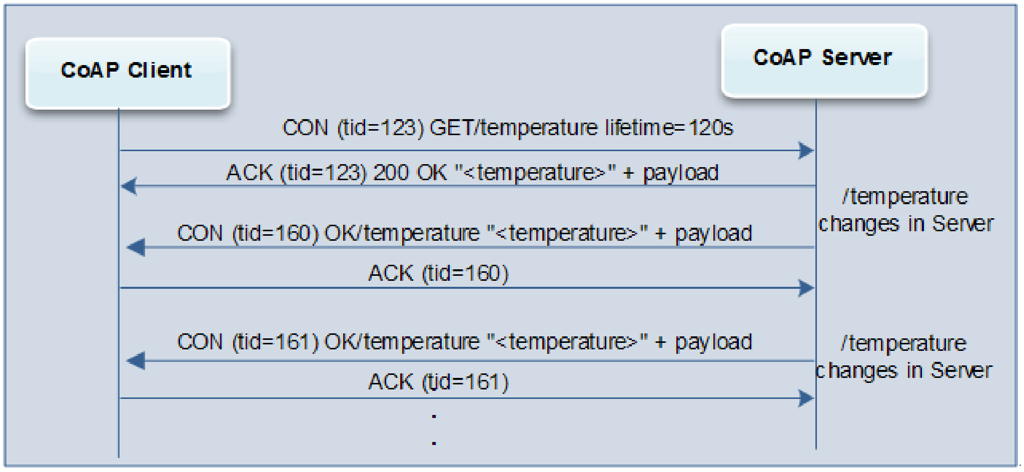


Fig. 6. An example of CoAP subscription message exchange

The benefits of CoAP/6LoWPAN in our BMS architectural design realize resource services at each sensor node. To meet inter-operability and integration requirements of BMS-WSN, a Building Service Provider (BSP) is designed, as shown **Fig. 7**. BSP receives data pushing from CoAP nodes and provides building data service for demands. It supports different subsystems to access shared sensing data and provides a building data service for clients through the Internet or integrates with other applications so they can inter-operate together to extend services and make an efficient BMS.

Consequently, our BMS-WSN supports inter-operability and integration requirements based on REST architecture on top of CoAP/6LoWPAN. Furthermore, to make BMS widely deployable in the real market, a semantic model of BMS is needed for management and user-friendly interaction. Next, we discuss our view in developing a semantic model for a BMS framework that focuses on device naming, resource and service naming and configuration, as well as resource discovery for BMS.

BMS device naming: BMS includes a large number of resource-constrained devices. For management and user-friendly interaction, a semantic model for naming and discovery is needed. Based on BMS knowledge, the naming of building devices should be based on devices' logical location in the building. For example, a semantic device name like "temperature-sensor2.room24.floor4.building05" means that a CoAP server with name temperature-sensor2 exists in room 25, floor 4, building 05. This is an understandable name for the management location of a sensor device in BMS without using other expensive mechanisms such as GPS. From an organizational or global perspective, this approach includes the organization domain with local device name. For example, if the organization's domain is "ssu.ac.kr," we could have a global device name such as "temperature-sensor2.room24.floor4.building05.ssu.ac.kr."

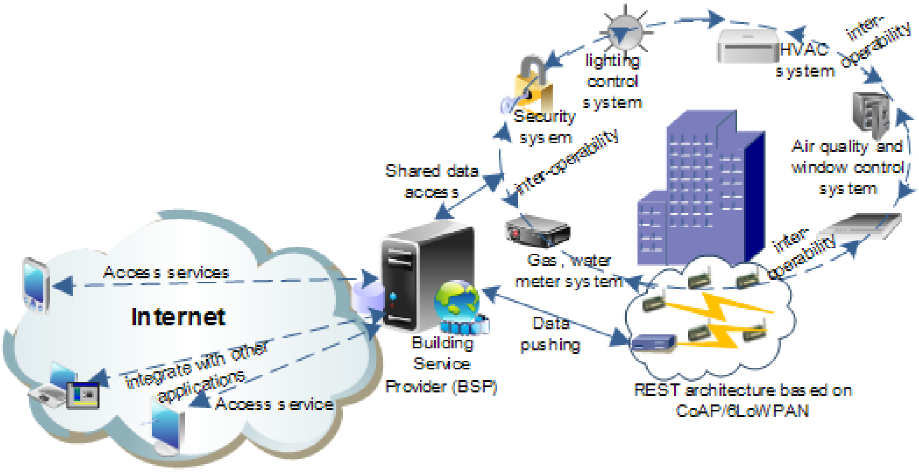


Fig. 7. Inter-operability, integration model for BMS-WSN

BMS resource and service naming: We also suggest that a semantic URI naming convention of services and resources in BMS application be investigated. For example, a GET method URI is used to get the temperature resource of a sensor in a building like "temperature-sensor2.room24.floor4.building05.ssu.ac.kr/temperature." This message means that a CoAP server with the name temperature-sensor2 in room 2, floor 4, building 05, provides a temperature sensing service, which is expressed using the readable resource attribute "temperature." This approach can be simply solved using DNS services [34], which have the ability to efficiently resolve an instance name to the required information that a client needs to actually use a service, (e.g., IP address and port number), as shown in the example in Fig. 8.

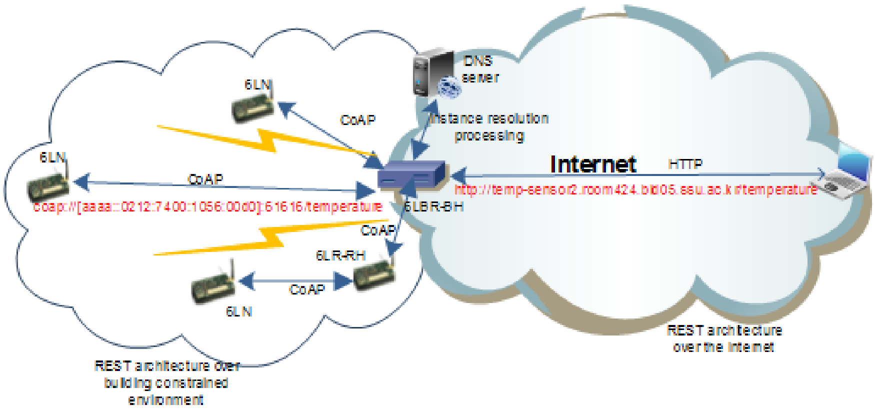


Fig. 8. A semantic model of BMS-WSN

BMS configuration and service discovery: In our BMS-WSN, stateless auto-configuration of IPv6-6LoWPAN is very important because of a large number of IP devices. After setting up, a new node sends a router solicitation request (RS) using link local multicasts address. A router receives the RS message and replies with a router advertisement message including configuration information. After a sensor finishes its configuration, it executes service advertisement to other nodes and registers with the DNS server with information including domain name, resource name, service type, and more. A DNS server or 6LBR-BH can also detect a new device plugged in the network and then execute service discovery for the functionalities offered by the new device. The DNS server stores this information as an instance for resource, service discovery, and resolution. Other devices can use the DNS service to learn about their communication-targeted device information, as shown in Fig. 9.

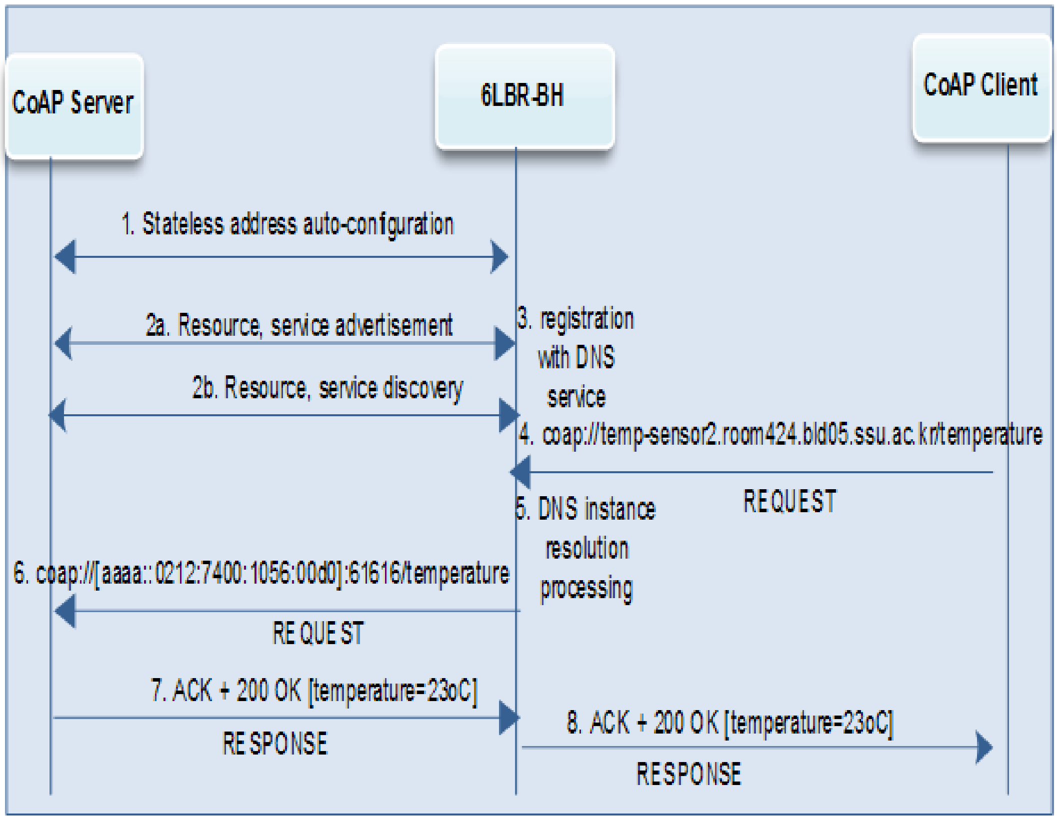


Fig. 9. An example of semantic operations for BMS-WSN

5. Evaluation

We developed a simple test-bed with one 6LBR-BH, two 6LR-RH, and 10 sensor nodes in two rooms with logical topology, as shown in Fig. 10.

6LBR-BH is necessary to forward the packets to and from the WSN. To achieve this function, on the WSN side, 6LBR-BH handles routing logic (RPL) and IPv6 (6LoWPAN). On the Internet side, the PC's kernel handles IPv6 forwarding between the WSN and the Internet. They communicate to each other using serial communication over USB (SLIP). The architecture of 6LBR-BH is shown in Fig. 11.

The platform is based on a MSP430 16-bit CPU running at 3.9 MHZ. It has a CC2420 radio chip, 48 kB program flash and 10 kB of RAM. The Contiki REST engine provides macros to define and instantiate RESTful Web service resources [7]. Taking advantage of the Contiki REST layer abstraction, these sensors are implemented in a simple CoAP server application using RESOURCE and PERIODIC_RESOURCE abstractions with ContikiMAC and protocol stack, as described in **Fig. 5**.

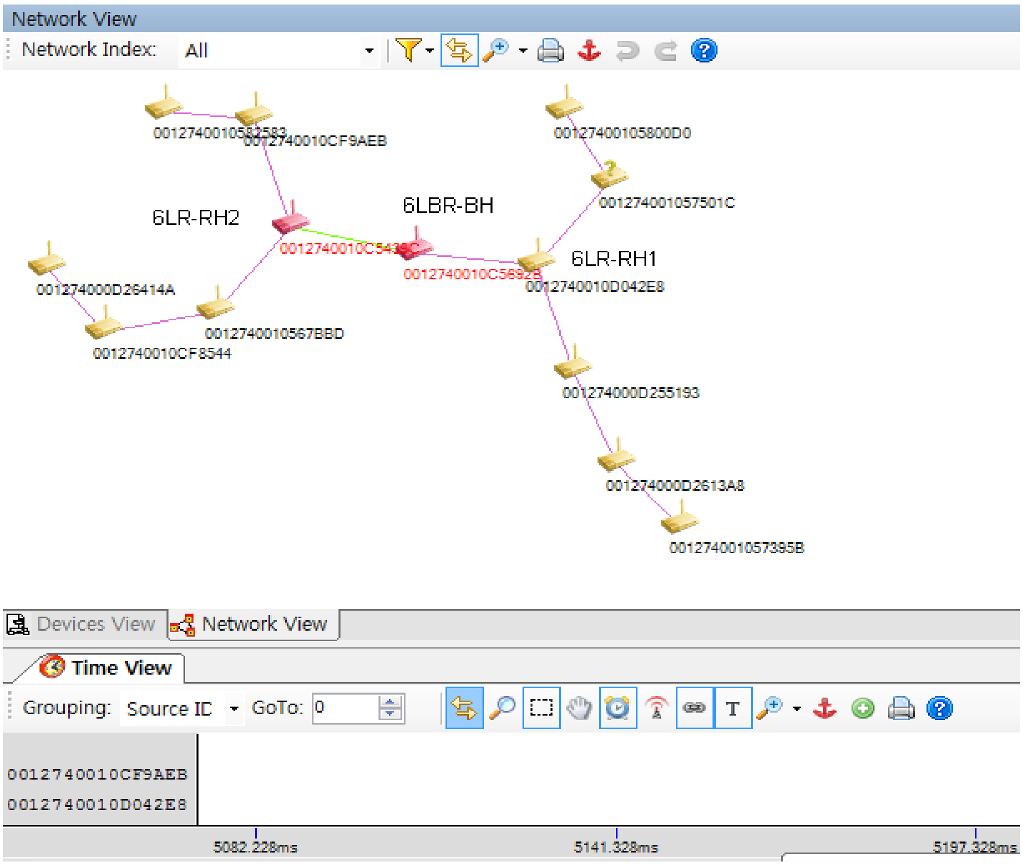


Fig. 10. Experiment's logical topology

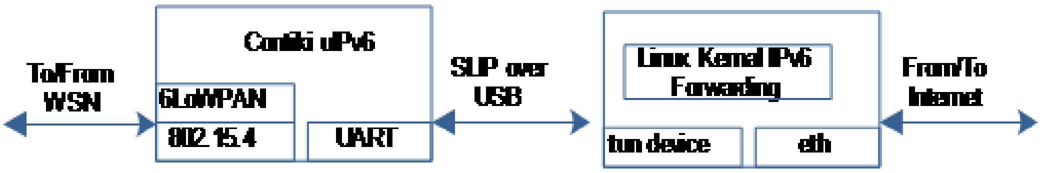


Fig. 11. The architecture of 6LBR-BH

Each CoAP server node provides two kinds of resource services: temperature and humidity information services with sensing interval equals 60 seconds. In BMS, there are various subsystems that require different values of Max_Age of CoAP message. So the default value of Max_Age parameter, as defined in the draft [10], is not suitable for all BMS subsystems. For example, in fire alarm system, the Max_Age must satisfy the real time constraint. On the other hand, data can be valid until the next required sensing report, such as few minutes in HVAC system. We set Max_Age equal sensing interval. For example, in the test-bed of temperature sensing for HVAC system, the sensing interval is five minutes; then we set Max_Age equal 300. Bornmann and Shelby [35] define the block size to pertain the CoAP payload. The default value of the block size is zero, indicating that the actual block size is 16 bytes. By our observation, the sensing data of BMS application is not too large, but 16 bytes seems too small. It can lead to too much CoAP message exchanges in an inefficient way. Furthermore, the maximum packet size of IEEE 802.15.4 is only 127 bytes. So the size of 128 might be already large for fragmentation at adaptation layer. From 256 bytes, it results in demanding the IP fragmentation in every hop. Therefore, after considering the header overhead, we select 64 bytes block size of CoAP payload as a good choice for BMS application to avoid loading the lower layers and fragmentation.

We test accessing the CoAP resource service using the Web interface through the Internet and build a simple BMS application using CoAP resource services in a remote site. With the Web interface testbed, CoAP requests are sent through the IPv6 network for accessing sensing data of a node with the address aaaa::0212:7400:1058:00d0. The response message is shown in **Fig. 12**.

coap://[aaaa::0212:7400:1058:00d0]:61616

200 OK

Header

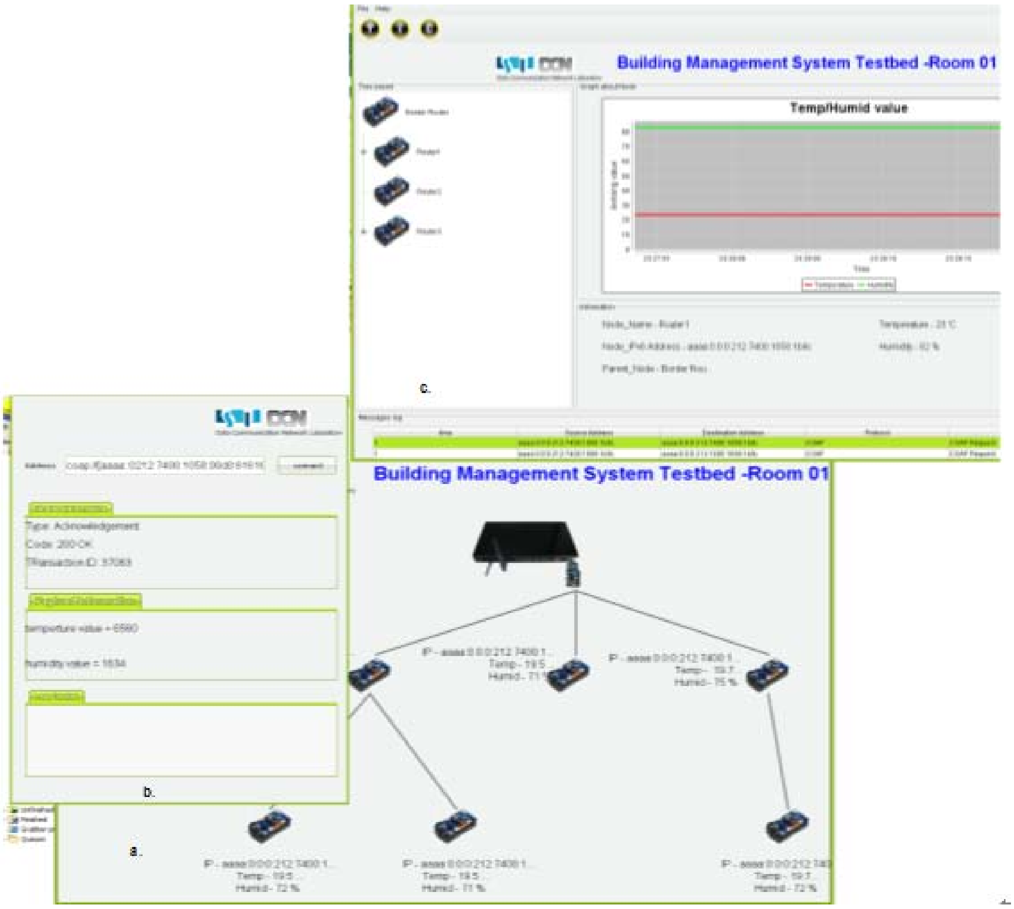
```
Type: Acknowledgment
Code: 200 OK
Transaction ID: 61363
Options: Content-type: [int] 0 (1);
```

Payload

```
6560;1630
```

Fig. 12. An example of accessing CoAP resource service through Web interface

Based on the resource services of a CoAP server sensor, our BMS program in the remote site supports both periodic and query sensing services. The network topology of WSN in room 01 is displayed as **Fig. 13-(a)** for building networks and devices management. The building manager can check the condition of a room in the building (temperature, humidity) through the condition control window, as shown in **Fig. 13-(b)**. A CoAP browser window is also implemented to support irregular sensing data query from remote site as shown in **Fig. 13-(c)**.



Type: Acknowledgement
Code: 200 OK
TRansaction ID: 37063

temperature value = 6580

humidity value = 1634

Node_Name : Router1
Parent_Node : Border Rou

Fig. 13. An example of BMS-WSN application in a university building

The Web and window application interfaces provide a user-friendly way to interact with sensors. Additionally, CoAP servers can inter-operate with others by exchanging CoAP requests/responses. Finally, we evaluated the measurements to demonstrate that the system offers an acceptable performance given the constrained devices. We measured the completion time of CoAP request in our 4-hop network, as shown in **Fig. 14**. The completion time stays under one second over 4 hops. The average power consumption of CoAP server nodes is provided in detail in **Fig. 15**. The battery capacity is 2850 mAH. Dividing this value for the average power consumption of a node, we estimate the least expected lifetime of 276 days. The above results demonstrate the feasibility of applying RESTful architecture for BMS-WSN.

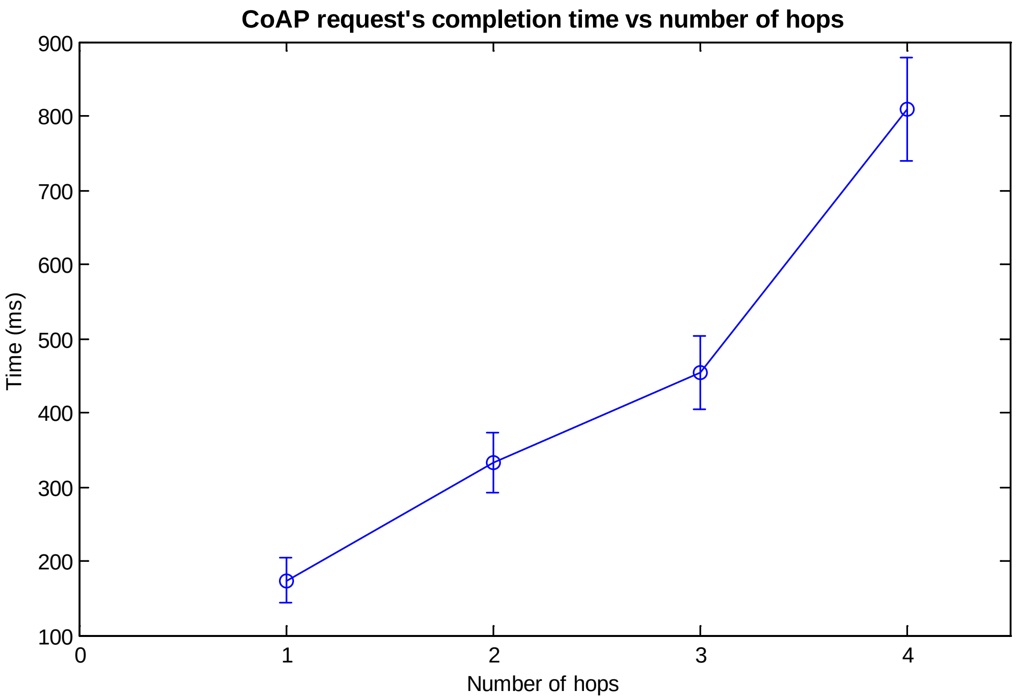


Fig. 14. CoAP request's completion time vs. number of hops

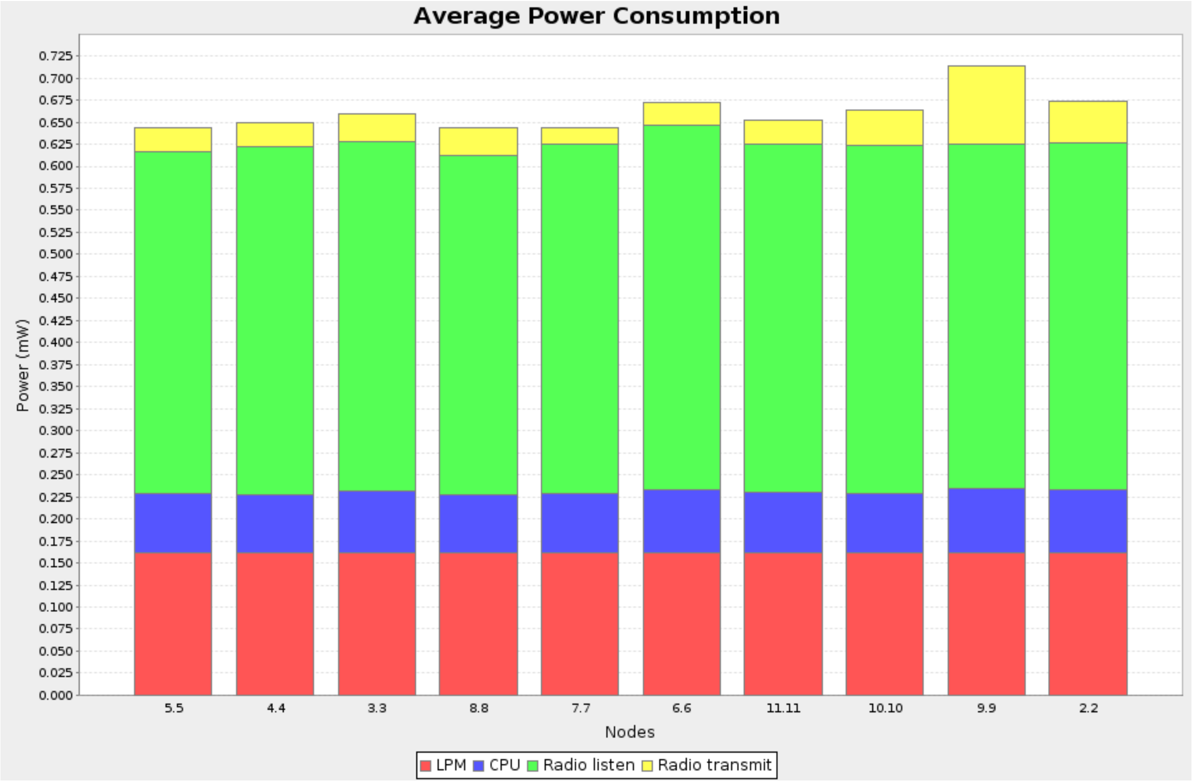


Fig. 15. Average power consumption of CoAP server nodes

6. Conclusion

This paper analyzes the advantages of the main current and emerging approaches that may be fit for BMS. Based on these approaches, we highlighted an IP-based approach with 6LoWPAN solution for IPV6 over LoWPAN and RPL routing protocols. A comparision of REST architecture and SOAP architecture is analyzed, revealing many advantages of REST architecture for BMS-WSN. The IETF CoRE working group is developing CoAP, an application layer protocol for a RESTful architecture in a constrained environment. CoAP offers the same methods for resource manipulation as HTTP and supports additional functions for M2M application. The paper also describes a direction for BMS-WSN relying on the advantages of the IP-based and REST architecture approach, which is expected to enable the interaction of users with BMS-WSN in the same way as with any website, while ensuring energy efficiency to meet the requirement of BMS. For future work, a detailed design and implementation will be investigated.

References

[1] C. Adam and W. Jakub, “On applications of wireless sensor networks,” Journal *of Internet--technical development and applications*, pp. 91-99, 2009.

[2] A. Willing, “Wireless sensor networks: concept, challenges and approaches,” in *Proc. of Elektrotechnik & Informationstechnik*, vol. 123, no. 6, pp. 224-231, Jun. 2006. Article (CrossRef Link).

[3] S. Thomas, D. F. Henri and V. Martin, “Sensor scope: experiences with a wireless building monitoring sensor network,” in *Proc. of the Workshop on Real-World Wireless Sensor Networks*, 2005. Article (CrossRef Link).

[4] J. Y. Chang, J. Y. Kim and O. Kwon, “Demo abstract: control city – integrating wireless sensor networks and building management systems,” in *Proc. of the 2009 International Conference on Information Processing in Sensor Networks*, pp. 421-422, Feb. 2009.

[5] C. Wong and A. So, “Building automation in the 21st century,” *in Proc. of The Fourth International Conference on Advances in Power System Control, Operation and Management*, vol. 2, pp. 819-824, Nov. 1997. Article (CrossRef Link).

[6] http://www.xbow.com, 2009. Article (CrossRef Link).

[7] http://www.contiki-os.org/, 2010. Article (CrossRef Link).

[8] http://www.tinyos.net, 2009. Article (CrossRef Link).

[9] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler, “Transmission of IPv6 packets over IEEE 802.15.4 networks.” Article (CrossRef Link).

[10] Z. Shelby, B. Frank, and D. Sturek, “Constrained application protocol (CoAP),” Nov. 2011. Article (CrossRef Link).

[11] M. R. Brambley, M. Kintner-Meyer, S. Katipamula, and P. J. O’Neill, “Wireless sensor applications for building operation and management,” *Web based energy information and control systems: case studies and applications, B. Capehart and L. Capehart, Eds. Boca Raton, FL: The Fairmont Press/CRC Press*, pp. 341–367, 2005. Article (CrossRef Link).

[12] M. Kintner-Meyer and R. Conant, “Opportunities of wireless sensors and controls for building operation,” *Energy Engineering Journal*, vol. 102, no. 5, pp. 27–48, 2005. Article (CrossRef Link).

[13] Siemens , Sustainable buildings–*Smart meters: stabilizing the grid*, Article (CrossRef Link).

[14] http://www.bacnet.org/, 2009. Article (CrossRef Link).

[15] J. Ploennigs, P. Buchholz, M. Neugebauer, and K. Kabitzsch, “Automated modeling and analysis of CSMA-type access scheme for building automation networks,” *IEEE Transaction on Industrial Informat*ation, vol. 2, no. 2, pp. 103–111, May. 2006. Article (CrossRef Link).

[16] Lon: Local operating network, http://www.echelon.com, 1990

[17] M. T. Lah, B. Zupan, and A. Krainer, “Fuzzy control for the illumination and temperature comfort in a test chamber,” *Journal of Builing Environment*, vol. 40, no. 12, pp. 1626–1637, Dec. 2005. Article (CrossRef Link).

[18] Qifen Dong, Li Yu, Huanjia Lu, Zhen Hong and Yourong Chen, “Design of building monitoring systems based on wireless sensor networks,” *Journal of Computer and Communication*, vol. 2, no. 9, pp. 703-709, Sep. 2010. Article (CrossRef Link).

[19] W. Kastner, G. Neugschwandtner, S. Soucek, and H. M. Newman, “Communication systems for building automation and control,” *Proceddings of the IEEE*, vol. 93, no. 6, pp. 1178–1203, Jun. 2005. Article (CrossRef Link).

[20] A. I. Dounis and C. Caraiscos, “Advanced control systems engineering for energy and comfort management in a building environment—a review,” *Renew. Sustain. Energy Rev.*, vol. 13, no. 6/7, pp. 1246–1261, Aug./Sep. 2009. Article (CrossRef Link).

[21] M. Nakamura, A. Sakurai, S. Furubo, and H. Ban, “Collaborative processing in mote-based sensor/actuator networks for environment control application,” *Signal Process.*, vol. 88, no. 7, pp. 1827–1838, Jul. 2008. Article (CrossRef Link).

[22] ZigBee Alliance, “ZigBee Building Automation Overview,”. Article (CrossRef Link).

[23] ZigBee Alliance, “ZigBee Home Automation Public Application Profile,” *Revision 25*, *ver. 1.0*, Oct. 2007. Article (CrossRef Link).

[24] ZigBee Alliance, “ZigBee Smart Energy Profile Specification,” *Revision 15*, Dec. 2008. Article (CrossRef Link).

[25] J. Hui and D. Culler, “IP is dead, long live IP for wireless sensor networks,” in *Proc. 6th ACM Conf. Embedded Net. Sensor Sys*tems, pp. 15-28, Nov. 2008. Article (CrossRef Link).

[26] A Malatras, A Asgari, T Bauge, “Web enabled wireless sensor networks for facilities management,” *IEEE System Journal*, vol. 2, no. 4, pp. 500-512, 2008. Article (CrossRef Link).

[27] D. Guinard and V Trifa, “Towards the web of things: Web mashups for embedded devices,” in *Proceedings of WWW (International World Wide Web Conferences)*, 2009. Article (CrossRef Link).

[28] T. Luckenbach, P. Gober, S. Arbanowski, A. Kotsopoulos, and K. Kim, “TinyREST - a protocol for integrating sensor networks into the Internet,” in *Proc. of REALWSN*, 2005. Article (CrossRef Link).

[29] B. Priyantha, A. Kansal, M. Goraczko, and F. Zhao, “Tiny web services: design and implementation of interoperable and evolvable sensor networks,” *in Proc. of ACM SenSys*, Nov. 2008. Article (CrossRef Link).

[30] D. Yazar and A. Dunkels, “Efficient application integration in IP-based sensor networks for emerging energy management systems,” *in Proc. of ACM Buildsys*, Nov. 2009. Article (CrossRef Link).

[31] R. Fielding, “Architectural styles and the design of network-based software architectures,” *PhD thesis*, 2000. Article (CrossRef Link).

[32] A. Sleman, and R. Moeller, “SOA distributed operating system for managing embedded devices in home and building automation,” in *Proc. of IEEE transaction on Consumer Electronics*, vol. 57, no. 2, pp. 945-952, 2011. Article (CrossRef Link).

[33] E. Wilde, “Declarative web 2.0,” in *Proc. of the IEEE International Conference on Information Reuse and Integration*, pp. 612-617, 2007. Article (CrossRef Link).

[34] ftp://ftp.ietf.org/internet-drafts/draft-cheshire-dnsext-dns-sd-10.txt, 2011. Article (CrossRef Link).

[35] C. Bornmann and Z. Shelby, “Blockwise transfer in CoAP,” *draft-ietf-core-block-04*, 2011. Article (CrossRef Link).

Ngoc-Thanh Dinh received his B.S degree in information technology from University of Science – Vietnam National University in HoChiMinh city, Vietnam. Since September 2010, he has been pursuing a M.S degree at the Graduate School of Electronic and Telecommunication in Soongsil university, Seoul, Korea. His current researching interests include wireless sensor and actor network, P2P, mobility and next generation network.

Younghan Kim received the B.S. degree in electronic engineering from Seoul National University, Korea in 1984. He received the M.S. and Ph. D. degrees in electrical engineering from KAIST, Korea in 1986 and 1990, respectively. From 1987 to 1994, he worked in Digicom Institute of Telematics as a senior research engineer, where he developed ISDN and packet switching systems. Since 1994, he has been a professor in the School of Electronics at Soongsil University in Korea. His research interests include wired and wireless networking, QoS, mobile computing and ubiquitous networking. He is a member of IEICE and IEEE.