



HAL
open science

Software-Defined Networking for Smart Buildings: Advances and Challenges

Zoubir Mammeri, Muhammad Usman Younus

► **To cite this version:**

Zoubir Mammeri, Muhammad Usman Younus. Software-Defined Networking for Smart Buildings: Advances and Challenges. 4th International Summit on Smart Cities 360° (Smart Cities 360° 2018), Nov 2018, Guimaraes, Portugal. pp.1-12. hal-02089292

HAL Id: hal-02089292

<https://hal.science/hal-02089292>

Submitted on 3 Apr 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Open Archive Toulouse Archive Ouverte

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible

This is an author's version published in:
<http://oatao.univ-toulouse.fr/22713>

To cite this version: Mammeri, Zoubir and Younus, Muhammad Usman *Software-Defined Networking for Smart Buildings: Advances and Challenges*. (2018) In: International Summit on Smart Cities 360° (Smart Cities 360° 2018), 21 November 2018 - 23 November 2018 (Guimaraes, Portugal).

Any correspondence concerning this service should be sent to the repository administrator: tech-oatao@listes-diff.inp-toulouse.fr

Software-Defined Networking for Smart Buildings: Advances and Challenges

Zoubir Mammeri¹ and Muhammad U. Younus¹

¹ IRIT – Paul Sabatier University, Toulouse, France
{zoubir.mammeri, Muhammad.younus}@irit.fr

Abstract. Last decade has witnessed a proliferation of work, both from the academic and the industrial sectors, to provide methods and technologies to support smart buildings. Due to advances in electronics and telecommunications, sensors and actuators maybe deployed and interconnected, at low cost, in buildings to make them smart, energy-efficient, and secure. Smart buildings (SBs) will redefine the way habitants live and interact in the future. SBs are among the dominant fields of Internet-of-things applications.

Software Defined Networking (SDN) is an emerging solution to make easier network management. This paper provides a brief state-of-the-art regarding networks used to support SBs and it addresses the benefits of SDN in the design and management of networks for SBs. As SDN-based SB roadmap is still at an early stage, this paper discusses some challenges to design and deploy SDN-based networks to fulfil SB requirements.

Keywords: Smart buildings, SDN, Software defined Networking, IoT.

1 Introduction

Due to advances in wireless and mobile networks and in microelectronics—including miniaturization of sensors and cameras—cities are becoming smart. As elements of smart cities, buildings also are becoming smart.

Smart devices, such as sensors and actuators are used to automate processes and improve efficiency and comfort of building occupants. Being composed of smart devices, smart buildings (SBs) are typical domain of application of IoT (Internet of Things) technologies [1], [2]. The killer application in SB field is energy saving, which should help the deployment of green cities and drastic reduction of pollution [3], [4], [5], [6], [7].

SBs are interdisciplinary and involve not only information and communication technologies (ICT), but huge skills, methods, tools, and products from mechanics, solar energy harvesting, electricity, electronics, chemistry, sociology, economy, etc. In this paper, SBs are only considered from a networking point of view.

The core of smart buildings is smart building management systems (BMS). All SBs are not expected to provide the same services. Thus, BMSs differ each from other depending on the nature and extent of services offered in buildings. In literature, one may

find *intelligent buildings* (IBs) and *Intelligent Building Systems* (IBSs) [8] instead of SBs and BMSs. IB and IBS terms are no longer (or rarely) used in recent literature.

SBs use multiple types of networks to collect data (i.e. measurements) from sensors and cameras and transmit commands to actuators. The first objective of this paper is to provide a brief state-of-the-art regarding networking aspects of SBs.

Software defined networking (SDN) emerged recently as a solution to facilitate the management of complex networks [9]. Status information about network devices—including routers, switches, and links—are centralized on an SDN controller, which has a coherent view of the network, and consequently, it is able to make the best decisions for managing the network devices to provide the required levels of QoS and security to SB applications. The second objective of this paper is to discuss the contributions of SDN approach to SB networks and highlight some challenges to address before SDN-based Smart-building networks become a reality.

The remainder of the paper is structured as follows. Section 2 overviews services provided to smart building users and presents networking technologies to support SBs. Section 3 briefly presents SDN architecture and reviews literature, which focused on SDN-networking for SBs. Section 4 highlights some challenging issues to address for making SDN-compliant the networks to support future SBs. Section 5 concludes the paper.

2 Smart buildings

2.1 Concepts and services

Before emergence of smart building, *building automation* and *intelligent building* were used. The objectives of all three terms is the same, only the approaches and technologies differ. Recently, SBs extended previous concepts with additional subsystems for managing and controlling energy sources, house appliances and energy consumption using most often a wireless networks and smart devices. SBs objectives are to provide new levels of comfort to the occupants with minimum possible energy consumption. Notice that *smart homes* are specific cases of smart buildings.

A huge variety of applications (services) are provided in SB context, including [1], [2], [10]:

Energy consumption. In almost countries, buildings account for more than 1/3 of total energy consumption and it is continuously increasing [3], [11]. Commercial, administration, and home/habitation buildings consume a huge amount of energy for lightening. Thus, reducing energy consumption (due to lightening, air conditioning, home electric and electronic devices) is one of the primary objectives of smart buildings. Building materials and ICT may contribute to reduce energy consumption. In addition, to SB services, many countries are encouraging their citizens to isolate their homes to reduce energy consumption.

Energy storage control. Electrical energy (such as electricity generated by solar and wind powers) in smart building can convert the electric energy directly into water heat energy, then the heat stored in water is released when needed.

Quality of life and comfort. Users can easily control a huge devices and machines installed at home in such a way that their comfort is improved.

Healthcare. Advances in medicine have significantly increased life expectancy of populations around the world. Smart buildings may provide assistance to elderly and avoid their placement at medical centers. In addition, using wireless technologies, any building occupant may be rescued in case of emergency.

Localization of people and devices. It is an SB service to quickly find objects at home, locate people, etc.

Security and surveillance. Cameras and infraction detectors provide powerful means to enhance security of buildings, and consequently, increases the quietude of individuals living there. SBs also may provide intelligent interconnections with medical centers, fire department, and police department to send emergency notifications.

Remote control. Monitoring homes and commercial buildings is made easy thanks to smart devices to which users can connect at anytime and from anywhere to see and monitor their homes, devices, and belongings.

Prediction of building operations. The objective is to detect abnormal consumption of energy, wears of installations, and so on, and then to recommend appropriate actions to maintenance staff.

Specific services. In case of commercial and company buildings, services such meeting room management, music broadcast, ovens control may be provided.

Overall, management system of SB is composed of three layers:

Sensor layer. It is composed of a set of sensor nodes deployed inside a building that periodically, or on-demand, measure specific phenomena (such as temperature, pressure, electricity consumption, space occupancy, etc.) and send measurements to the control layer. Huge types of sensor are available for measuring electricity consumption, luminance, temperature, humidity, air quality, carbon dioxide, carbon oxide, sound, motion, image, and so on.

Control layer. It receives measurements from sensors and instructions from management staff to take, in real-time, decisions regarding the control of physical devices. For example, reduce energy consumption by controlling electrical appliances such as air conditioning level and lights. A variety of building automation and control systems have been proposed. Their intelligence and complexity depend on the SB services to provide. Recent control systems are based on machine learning algorithms. SB control system proactively learn from occupants' behavior and adapt their operations based on the indoor and outdoor conditions.

Actuation layer. It includes huge variety of actuators such as comb drives, motors, servomechanisms, hydraulic cylinders, piezoelectric actuators, pneumatic actuators, and screw jacks. Actuators are deployed in SBs to lock/unlock doors, switch on/off lights, raise/ lower shutters, open/close valves, and start/stop air conditioning.

2.2 Networking technologies for SBs

SB should not be regarded as composed of islands, each associated with a specific service. Rather, it should be considered as composed of interconnected smart devices.

Thus, networking plays a vital role. Wireless sensor networks play a primary role for continuously sensing and monitoring the building energy, environment, and users behavior and interactions.

Communication requirements significantly vary from application to another. For example, temperature sensing requires much less bitrate than building halls monitoring through cameras deployed at each corner. Thus, bitrates span a wide spectrum from some kb/s to hundreds Mb/s. Also required transmission ranges vary from very short range (e.g. in centimeters to connect RFID readers) to long range (e.g. in km to connect to cloud through gateways and cellular base stations).

Today's dominant technologies in SB include Zigbee, Bluetooth, WiFi, UWB, 6LoPAN, LoraWAN, IPV6, cellular technologies (3G, 4G, and forthcoming 5G in few years), Power line communication, and Ethernet. Those technologies are ready to support internal (indoor) and external (outdoor) SB communications [12], [13], [14].

Data packet size, packet transmission frequency, latency, distance, environmental conditions (including walls), reliability, and cost are the main factors to select communication technologies to fulfil specific SB communication requirements.

In the last years, number of research works have been undertaken to deploy prototypes of experimental SBs over WSNs. In particular, the following SB services have been considered: electricity metering and energy saving [4], [15], [16], [17], light and fan speed control [18], ventilation system control [19], [20], temperature sensing [21], occupancy measurement, localization, and motion tracking [5], [6], [22], [23], building surveillance [24], and inhabitant wellness [25]. It should be noticed that Zigbee is the dominant technology used in the experimentations previously mentioned.

As the references below show, WSN have been intensively addressed in smart building context. However, as far as we know, WSNs have been addressed on per use case basis. In other words, published work showed deployment and performance analysis of WSNs to meet specific application requirements (e.g. monitoring indoor air quality in a specific building). Generic paradigms to address WSNs in SBs are still missing.

2.3 IoT and SB

IoT is a paradigm to enable interconnection of huge types of devices through sensors and actuators to the Internet. IoT enables a wide range of applications including energy saving, health, transportation, security, and leisure [26], [27], [28]. IoT application domains mainly include smart cities, smart grids, smart streets, smart buildings, and smart homes.

According to Ericsson's forecast [29], there will be around 30 billion IoT devices in 2022. Among that huge device number, a significant amount of smart devices would be used in smart buildings.

Some work addressed smart buildings from IoT point of view and suggested to consider SBs as applications of IoT. [30] proposed an IoT framework to enable smart building to communicate each with other (for example, in order warn the locals around in case of fire or critical situations). [7] proposed an IoT application for energy management in smart buildings on a university campus.

3 SDN for Smart buildings

3.1 Overview of SDN architecture

Networks and services they provide become more and more complex, which results in huge difficulties to managing them. Configuration of traditional networks to fulfil new requirements and demands takes time and comes at high cost. Recently, Software Defined Networking (SDN) emerged as a solution to ease network management and to reduce costs [9].

SDN is based on three pillars: i) softwarization of network device management, ii) centralization of decisions, and iii) separation of control plane from data plane of forwarding device. Softwarization provides a high level of flexibility and reduces manual efforts and human errors. Centralization provides a holistic view of the network, which enables making optimal management decisions. Decoupling control plane from data plane enables virtualization of networks (i.e. decoupling applications and services from physical network specificities). Broadly, SDN consists of three planes (also called layers): Application, Control and Data planes.

Application plane. It includes network management applications (also called *Network applications*) such as Routing, Traffic engineering, Load balancing, Mobility management, Security & intrusion detection, and Fault-tolerance. Application layer is still an open area.

Control plane. It centralizes the control tasks (i.e. configuring, monitoring, collecting forwarding statistics...) regarding how data packets are handled at network devices (i.e. routers and switches). Implementation of control plane tasks results in a *networking operating system* (NOS). NOS is a centralized system, but it may be supported by one or several interconnected machines. Today, huge commercial and open source SDN-controllers are available.

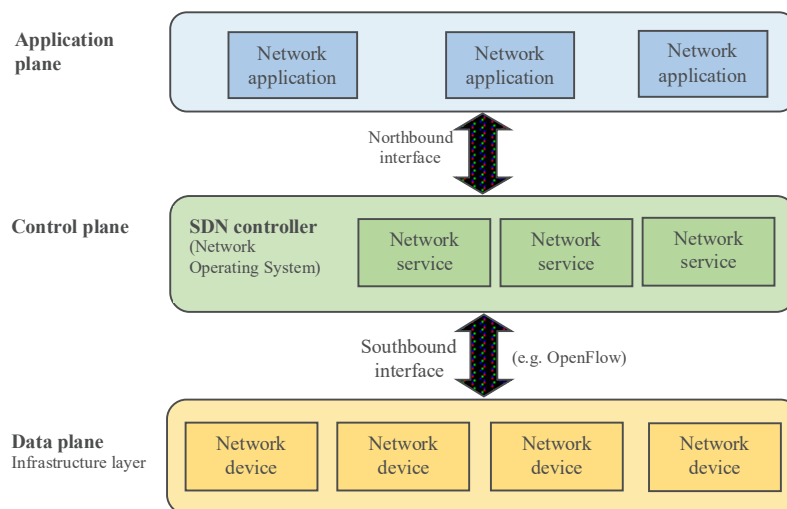


Fig. 1. Software Defined Networking architecture

Data plane (also call *infrastructure layer*). It is composed of forwarding devices (i.e. routers and switches), which forward data packets. At this plane, network devices are in charge of data packets-related actions—including receiving, forwarding, and dropping data packets—depending on the instructions from control plan.

Southbound interface—or API (Application programming interface)—defines the protocol of communication between Control Plane and forwarding devices. Northbound Interface is an API, which provides facilities for developing network applications.

Openflow is the standard specification of southbound interface provided by Open Networking Foundation (ONF) [31]. It is a protocol to allow SDN controllers deploy forwarding rules on switches and routers. OpenFlow was designed to work with existing products, without need of specialized hardware. Today, a number of OpenFlow-compliant forwarding devices are available.

OpenFlow-compliant forwarding devices maintain tables (called OpenFlow tables). Each flow table in a forwarding device contains a set of flow entries; each flow entry consists of three components: Match fields (including MAC and IP source and destination addresses, protocol type, port numbers, and other fields), Instructions to apply to matching packets (including forward, drop, and update packet...), and Counters (to keep track how many packets matched the rule). Flow entries are configured by SDN controllers through rules included in messages sent to forwarding devices. Controllers can add, update, and delete flow entries in flow tables, reactively or proactively, depending on network application requirements.

3.2 SDN for Smart buildings

In standard Internet, nodes are often autonomous and may connect to each other at unpredictable times to receive data with very different characteristics. Thus, each node is in charge of almost networking functions, which results in complex and expensive nodes. In SBs, the context is different: i) SBs are composed of objects (or smart devices) with limited resources, ii) data to/from objects is (often) known a priori in terms of characteristics and frequency of exchange, and iii) smart objects are deployed to participate to deliver services to building occupants. Thus, SDN approach is a good candidate, which offers a centralized view, to manage those objects and facilitate their deployment at low cost. Through SDN, it is easier to adapt (adding, moving, and removing nodes) the network topology to address new users' requirements.

As shown on Figure 1, basic application of SDN paradigm to SB networking results in an architecture composed of SB services, an SDN-controller, and switches to connect sensors and actuators. Management—including routing table configuration—of switches is made through OpenFlow, which is a *de facto* standard.

While SDN has been intensively addressed in huge types of networks to facilitate their design, management, and maintenance [32], there are few works, which considered SDN for SB networks. Below is a summary of state-of-the-art regarding SDN-based networks for SBs.

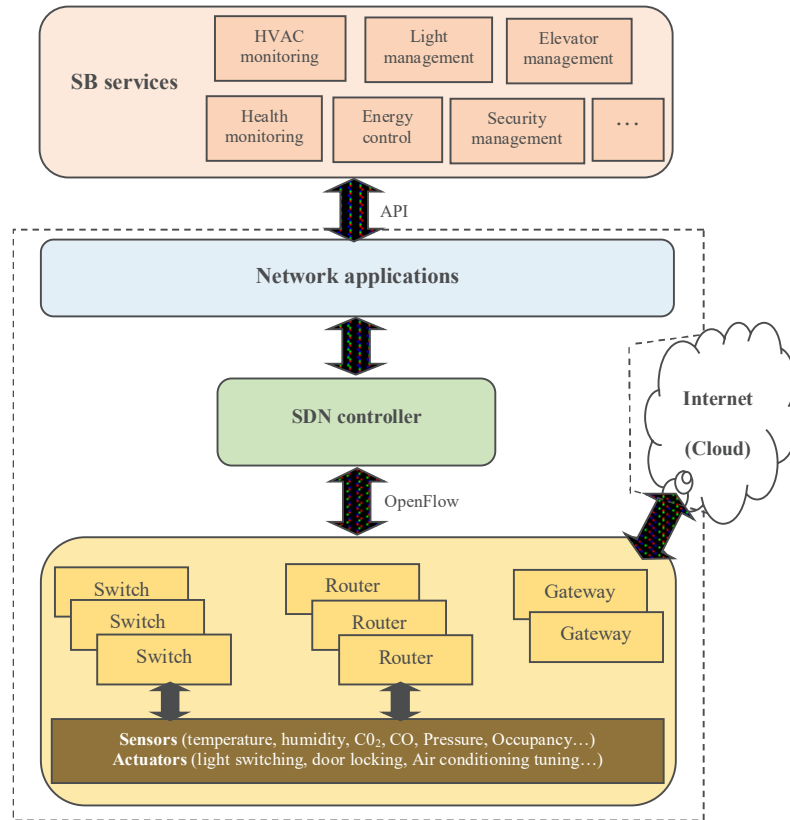


Fig. 2. SDN-based smart building architecture

[33] proposed a framework to manage forwarding tables of switches to collect data useful for context-aware service provisioning, while balancing load in building networks to receive a high level of QoS.

[34] and [35] provided an OpenFlow-based framework to address authentication between central controller and smart devices. OpenFlow is regarded as a powerful tool to implement security rules on smart devices.

[36] proposed a context-aware middleware to seamlessly connect smart devices to the SDN controller.

[37] proposed a SDN-based method for auto-configuration of home networks in cloud environments. Home smart devices are connected through OpenFlow-compliant switches.

[38] proposed an SDN orchestrator to coordinate adaptive allocation of uplink transmission bitrates according to smart gateways demands. Smart gateways interconnect smart devices to Long Term Evolution networks.

As discussed in next section, it is clear that more research work is needed before SDN-based networks would be capable of meeting communication requirements in SBs.

4 Challenges in SDN-based networking for SB

Roadmap of application of SDN architecture and interfaces for the design and deployment of SDN-compliant networks—to replace present networks used in different activity sectors—is still at its beginnings. The real world of operational networks is not easy to evolve, because of huge hardware, protocols, and applications that are already deployed. Co-existence of current networks and future SDN-based networks would take a long time before SDN-based networks would dominate. Fortunately, SB networking is a new field and real SB deployment is very scarce. Thus, it would be easier to adopt SDN in SB management systems without jeopardizing legacy automation infrastructures. Currently, general-purpose wired and wireless networks are used to support communications in SBs. Full compliance of networks with SDN and SB requirements requires further investigations. In particular, the following challenges deserve to be addressed.

Autonomous management. BS management systems should not be designed as ‘traditional’ computerized systems, which rely on frequent human administrator interventions. In case of SBs, once started, systems should function autonomously. In particular, networking aspects managed by SDN controllers should be autonomous. Adapting, reconfiguring, adding, and removing smart devices—without human intervention—to face any change in buildings is challenging.

Intelligent radiation control. As almost devices used in SBs communicate wirelessly, radiations occur, which impacts not only network throughput, but—more important—health of building occupants. It is of paramount importance that radiations are to be kept at a minimum level to preserve health of people. Signal strength may be collected by SDN controller and analyzed to either reduce transmission range of some devices or stop some of them, while limiting the overall QoS and not shutting down critical devices.

Robustness and availability of SB management system. Whenever some networking elements are unavailable, some SB services may become partially or totally unavailable. No users would agree on the installation of SB management system, which frequently enforces power shutdown or prevents them accessing their homes, offices or stores, because of network failures. Thus, SDN-networks for SBs should be redundant-based. Design and deployment of communication links and SDN controllers providing a given level of availability, at a reasonable cost, is challenging. SDN approach is based on centralization of decisions. How redundant SDN controllers may collaborate to make the whole system robust is challenging.

Quality of service guarantees. Some SB services (such as comfort service) have not tight QoS requirements. However, other services (such as electricity management, health emergency assistance, fire emergency, and intrusion detection) are critical and have QoS requirements in terms of delay and reliability. To provide real-time and reliability guarantees for SBs—where various types of traffic co-exist—new protocols and

algorithms, in particular dynamic and adaptive routing protocols and resource reservation, are required. Very few works addressed QoS guarantees in SDN-oriented networks in SB context.

Security and privacy. Security and privacy are aspects of paramount importance. In cyber context, attacks may affect any element of SBs. Today's physical keys to access buildings will be replaced by smart devices to lock and unlock doors. To avoid cyberattacks and prevent unauthorized people enter inside buildings or to intercept private data through cameras or other smart devices, efficient security mechanisms should be integrated. In case a single SDN controller is used to manage security, SBs become (very) vulnerable to attacks. Specification, verification, and distribution of security rules in SDN controllers and smart devices become a critical challenge. SBs could not be deployed in real world unless users trust them.

Collaboration of SB SDN-controllers. SBs, urban traffic monitoring systems, public lightening systems, water supply systems, and many other systems are all elements of smart cities. Thus, collaboration between SBs is required to coordinate actions in cities (such as electricity provisioning from smart grids and emergency in case of fire or water flooding). SBs' collaboration at application level, results in coordination at networking level. Design of SB SDN-controllers to allocate network resources and provide priority to urgent traffic, at city level, is a challenge to move from SB islands to collaborating SBs.

Hierarchical SDN control and evolvability. On one hand SBs provide services different in nature even if they share computing and networking resources. Networks used in SBs also are different each from other according to several dimensions (range, bitrate, protocols...) on the other hand. Combining together multiple networking technologies to support various services would result in complex management and SBs hard to evolve. One way to overcome complexity and facilitate evolvability, in case of technology evolution, is the design of hierarchy of SDN controllers.

Intelligent maintenance. In conventional buildings, some elements (such as light bulbs and locks) are replaced when they do not work or are likely to not work in the near future. SBs are composed of software and hardware elements. Software require updates and hardware may fail or become obsolete. Thus, preventive maintenance of smart devices is useful for SBs. From networking point of view, SDN design should consider smooth software updating and preventive maintenance using appropriate mechanisms to detect abnormal functioning of devices. In case some communication links are broken, SDN controllers should be designed to limit inconvenience to building users.

Machine-learning-based SDN for SBs. High quality SB services (e.g. keeping energy consumption at its minimum or privacy protection at its maximum) may be provided when SB management systems apply powerful learning models on collected data to derive behaviors that impact some indicators (e.g. high consumption of energy or vulnerability of some surveillance cameras). When networking is of concern, machine

learning techniques may be integrated in SDN devices and controllers to optimize network resources including sensor node energy, predict nodes (objects) mobility, provide better QoS, enhance security, and anticipate sensor battery replenishment. Machine-learning-based SDN networks for smart building are challenging.

5 Conclusions

To improve energy consumption and to provide comfort and assistance to building occupants—in case of emergency—buildings are becoming smart. In smart buildings, wireless technologies play a paramount role in smart device interconnection to enable the delivery of various services at low cost. This paper discusses some issues regarding networking technologies used as underlying communication infrastructures to support smart buildings.

SDN recently emerged as a promising solution to facilitate network management. Smart buildings are new applications of ICT and they are more likely to use SDN in their network management without the replacement of the existing hardware and software components being a barrier. Existing work on SDN-based networks for SBs is very scarce and focused on integration of some existing technologies, like Zigbee, in SBs. However, full compliance of networks with SDN and SB requirements requires to address much more challenges regarding methodology, protocols, optimization techniques, and standardization. This paper highlights some challenges regarding network management, radiation control, network robustness and availability, QoS, security and privacy protection, network maintenance, network control hierarchization, and integration of machine learning in SB-network management to put SDN at the core of SB networks.

References

1. M. Bajer: IoT for Smart Buildings - Long Awaited Revolution or Lean Evolution. In: IEEE 6th International Conference on Future Internet of Things and Cloud, pp. 149–154, IEEE, Barcelona (2018).
2. D. Minoli, K. Sohraby, B. Occhiogrosso: IoT Considerations, Requirements, and Architectures for Smart Buildings—Energy Optimization and Next-Generation Building Management Systems. *IEEE Internet of Things Journal* 4(1), 269–283 (2017).
3. L. Perez-Lombard, J. Ortiz, C. Pout: A review on Buildings Energy Consumption Information. *Energy and Buildings* 40(3), 394–398 (2008).
4. M. A. Hannan et al.: A Review of Internet of Energy Based Building Energy Management Systems: Issues and Recommendations. *IEEE Access* 6, 38997–39014 (2018).
5. C. Papatsimpa, J. P. Linnartz: Energy Efficient Communication in Smart Building WSN Running Distributed Hidden Markov Chain Presence Detection Algorithm. In: IEEE 4th World Forum on Internet of Things, pp. 112–117, IEEE, Singapore (2018).
6. G. D. Putra, A. R. Pratama, A. Lazovik, M. Aiello: Comparison of Energy Consumption in Wi-Fi and Bluetooth Communication in a Smart Building. In: IEEE 7th Annual Computing and Communication Workshop and Conference, pp. 1–6, IEEE, Las Vegas (2017).

7. P. Bellangente, P. Ferrari, A. Flammini, S. Rinaldi: Adopting IoT Framework for Energy Management of Smart Building: a Real Test-Case, In: IEEE 1st International Forum on Research and Technologies for Society and Industry Leveraging, pp. 1–6, IEEE, Torino (2015).
8. J. K. W. Wong, H. Li, W. Wang: Intelligent Building Research: A Review. *Automation in Construction* 4, 143–159 (2005).
9. D. Kruetz et al.: Software-Defined Networking: A Comprehensive Survey. *Proceedings of the IEEE* 103(1), 14–76 (2015).
10. M. R. Alam, M. Bin Ibne Reaz, M. A. Mohd Ali: A Review of Smart Homes—Past, Present and Future. *IEEE Transactions on Systems, Man, and Cybernetics* 42(6), 1190–1203 (2012).
11. N. Lior: Sustainable energy development: The Present (2011) Situation and Possible Paths to the Future. *Energy*, Elsevier 43(1), 174–191 (2012).
12. V. Gungor et al.: Smart Grid Technologies: Communication Technologies and Standards. *IEEE Transactions on Industrial Informatics* 7(4), 529–539 (2011).
13. M. Kuzlu, M. Pipattanasomporn, S. Rahman: Review of Communication Technologies for Smart Homes/Building Applications. In: IEEE Innovative Smart Grid Technologies Conference - Asia, pp. 1–6, IEEE, Bangkok (2015).
14. G. Lobaccaro, S. Carlucci, E. Lofstrom, A Review of Systems and Technologies for Smart, Homes and Smart Grids. *Energies* 9(348), 1–33 (2016).
15. Z. Zhou, X. Zhao, P. H. Chong: Optimal Relay Node Placement in Wireless Sensor Network for Smart Buildings Metering and Control. In: 15th IEEE International Conference on Communication Technology, pp. 456–461, IEEE, Guilin (2013).
16. N. K. Suryadevara, S. C. Mukhopadhyay, S. D. Kelly, S. P. Singh Gill: WSN-Based Smart Sensors and Actuator for Power Management in Intelligent Buildings. *IEEE/ASME Transactions on Mechatronics* 20(2), 564–571 (2015).
17. J. Byun et al.: An Intelligent Self-adjusting Sensor for Smart Home Services based on ZigBee Communications. *IEEE Transactions on Consumer Electronics* 58(3), 794–802 (2012).
18. C. Kaiwen, A. Kumar, N. Xavier, S. Kumar Panda: An Intelligent Home Appliance Control-based on WSN for Smart Buildings. In: IEEE International Conference on Sustainable Energy Technologies, pp. 282–287, IEEE, Hanoi (2016).
19. J. Brito et al.: An Intelligent Home Automation Control System based on a Novel Heat Pump and Wireless Sensor Networks. In: IEEE 23rd International Symposium on Industrial Electronics, pp. 1448–1453, IEEE, Istanbul (2014).
20. J. Taneja, A. Krioukov, S. Dawson-Haggerty, D. Culler: Enabling Advanced Environmental Conditioning with a Building Application Stack. In: International Green Computing Conference, pp. 1–10, IEEE, Arlington (2013).
21. X. Chen et al.: Energy-Efficient Wireless Temperature Sensing for Smart Building Application. In: IEEE International Conference on Solid-State and Integrated Circuit Technology, pp. 680–683, IEEE, Hangzhou (2016).
22. C. Brennan, G. W. Taylor, P. Spachos: Distributed Sensor Network for Indirect Occupancy Measurement in Smart Buildings. In: 14th International Wireless Communications & Mobile Computing Conference, pp. 1290–1295, IEEE, Limassol (2018).
23. P. Chen, K.-S. Ou, K.-S. Chen: IR Indoor Localization and Wireless Transmission for Motion Control in Smart Building Applications based on Wiimote Technology. In: SICE Annual Conference, pp. 1781–1785, IEEE, Taipei (2010).

24. S. Saha, S. Neogy: A Case Study on Smart Surveillance Application System Using WSN and IP Webcam. In: Applications and Innovations in Mobile Computing Applications and Innovations in Mobile Computing Conference, pp. 36–41, IEEE, Kolkata (2014).
25. H. Ghayvat, J. Liu, S. Mukhopadhyay, X. Gui: Wellness Sensor Networks: A Proposal and Implementation for Smart Home for Assisted Living. *IEEE Sensors Journal* 15(12), 7341–7348 (2015).
26. D. Uckelmann, M. Harrison, F. Michahelles: *Architecting the Internet of Things*, Springer (2011).
27. I. Ng, S. Wakenshaw: The Internet-of-Things: Review and Research Directions. *International Journal of Research in Marketing* 34(1), 3–21 (2017).
28. A. Al-Fuqaha et al.: Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. *IEEE Communication Surveys & Tutorials* 17(4), 2347–2376 (2015).
29. Ericsson: The Connected Future, <https://www.ericsson.com/en/mobility-report/internet-of-things-forecast>, last accessed 2018/10/30.
30. C. Carrillo, V. Benitez, C. Mendoza, J. Pacheco: IoT Framework for Smart Buildings with Cloud Computing. In: *IEEE 1st International Smart Cities Conference*, pp. 1–6, IEEE, Guadalajara (2015).
31. ONF: Open Networking Foundation - OpenFlow Switch Specification. Version 1.5.1 (2015).
32. I. Haque, N. Abu-Ghazaleh: Wireless Software Defined Networking: A Survey and Taxonomy. *IEEE Communications Surveys & Tutorials* 18(4), 2731–2737 (2016).
33. M. Tasic, O. Ikovic, D. Boskovic: SDN based Service Provisioning Management in Smart Buildings. *39th International Convention on Information and Communication Technology, Electronics and Microelectronics*, pp. 754–759, IEEE, Opatija (2016).
34. N. Xue, X. Huang, J. Zhang: S²Net: A Security Framework for Software Defined Intelligent Building Networks. In: *15th IEEE International Conference on Trust, Security and Privacy in Computing and Communications*, pp. 654–661, IEEE, Tianjin (2016).
35. R. Y. Xu et al.: Software Defined Intelligent Building. *International Journal of Information Security and Privacy* 9(3), 84–99 (2015).
36. P. Kathiravelu, L. Sharrifi, L. Veiga: Cassowary: Middleware platform for context-aware smart buildings with software-defined sensor networks. In: *2nd Workshop on Middleware for Context-Aware Applications in the IoT*, pp. 1–6, ACM, New York (2015).
37. M. Lee, Y. Kim, Y. Lee: A home Cloud-based Home Network Auto-Configuration using SDN. In: *12th International Conference on Networking, Sensing and Control*, pp. 444–449, IEEE, Taipei (2015).
38. A. S. Thyagaturu, Y. Dashti, M. Reisslein: SDN-based Smart Gateways (Sm-GWs) for Multi-operator Small Cell Network Management. *IEEE Transactions on Network and Service Management* 13(4), 740–753 (2016).