From the Internet of Things to The Web of Things - Enabling by Sensing as-a Service

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***Abstract*—Sensing as a Service (SenaaS) is emerging as a prominent element in the middleware linking together the Internet of Things (IoT) and the Web of Things (WoT) layers of future ubiquitous systems. An architecture framework is discussed in this paper whereby things are abstracted into services via embedded sensors which expose a thing as a service. The architecture acts as a blueprint to guide software architects realizing WoT applications. Web-enabled things are eventually appended into Web platforms such as Social Web platforms to drive data and services that are exposed by these things to interact with both other things and people, in order to materialize further the future social Web of Things. A case study is discussed to illustrate the integration of SenaaS into the proposed WoT architectural framework.**

***Index Terms*—Internet of Things, Web of Things, Sensors, Web services, smart grid, cloud computing.**

I. Introduction

Wireless networking infrastructures like Wi-Fi and Bluetooth are increasingly ubiquitous, providing pervasive access and control to people, places, and things from anywhere and at anytime. In the last ten years, networking technologies have been coupled with sensing technologies to provide seamless and remote access to a variety of sensory data that support Web applications to deliver ambient, sustainable, healthy, and safe living solutions [1]. These technological advances lay a promising foundation for new Web of Things (WoT) applications and services that are enabling the lives of people everyday. WoT emerged as the application platform for Internet of Things (IoT). As the Web is to the Internet, so WoT is to IoT. The maturity of Web services propelled the Web platform to host services exposed by real-world things. These new WoT services and related applications are continuously bridging the physical and virtual worlds. Today, the increasing number of WoT services substantiates what Tim Berners-Lee said, "*If you are not on the Web, you will have problems accessing services*"[1].

The Web as we know it today has evolved over the years. It has matured from an information portal to a virtual community that sets and leads social trends. Advances in Web services are abstracting specific technicalities and enhancing global interoperability across enterprise systems. The transformation of raw Internet protocols enabling IoT, into Web protocols enabling WoT involved a major milestone contributed by the semantic Web in the evolution trajectory of the Web. The semantic Web creates structured and meaningful content on the Web which led to analytical inferences that scaled up Web intelligence to deliver smarter applications. A major vision for Web-enabled real-world things (WoT participants) is to utilize the capability of physical objects to make dynamic decisions by sensing and reacting to changes in their respective environments. An increasing number of devices have embedded sensors which support the outcomes of this vision.

SenaaS is a concept [2], in which sensor-enabled devices are seen as data collectors and the device owners participate in the sensing process by offering their device's sensory data collection capabilities as services to other users or applications. These recent technological advances, create opportunities for innovative WoT solutions for future enterprises and management applications such as smart grid operations[3], [4].

There are a number of enablers for sensor-enabled-Web services. First, the availability of cheaper sensors is driving user experiences and promoting the development of third-party applications that respond to sensor data such as future energy-service providers proliferating across smart grid platforms. These applications persuade users adopting new behaviors to better balance supply and demand by engaging power-sensor owners via data analytics rendered by Web applications, at a global scale. Secondly, embedded sensors within Web servers are now easily programmable [5],.and a Web of sensors are modeled via standard methodologies to described complex applications [6]. Software development kits (SDKs) and visualization tools for programing sensors are enabling young students to develop creative and innovative systems for everyday use. Well-defined and time-tested Web protocols and practices are reducing the learning curve to access and program sensors-enabled Web services. Thirdly, many of these sensor-based apps are actually open source allowing reuse of existing programs and not re-invent the wheel. The availability of these programs on the pervasive Web increases the possibility of remotely deploying software updates and patches to sensors. Fourth, the cloud computing platform enables sensors to offload their payload to the backend, and moreover the dearth in sensor-capabilities that is made up for. This provides an extraordinary scale for the dissemination, collection, and clustering of sensor data. Finally, pairing sensors and mobile phones have created a unique paradigm for social participation in continuous sensing, recognizing the role of people in tagging sensed data. The concept of mobile-phone sensing opens up avenues for seeding a knowledge-base for a community of smart-things and people, seamlessly interacting with each other.

[1]Tim Berners-Lee. (n.d.). BrainyQuote.com. Retrieved May 4, 2016, from BrainyQuote.com Web site: http://www.brainyquote.com/quotes/quotes/t/timberners444487.html

These innovations are rightly poised to enable WoT to present and disseminate valuable sensory information. However, the challenges are many. There is a wide variety of sensing devices, like proximity, light, temperature, electricity. and video. These sensors generate varied formats of data and of different quality. Most modern sensors are mobile and therefore the data generated are susceptible to spatiotemporal changes. Sensors that are candidate to evolve into Web resources are often constrained in capabilities like identity, processing, communication, and storage [7]. These challenges make the discovery, access, process, integration, and interpretation of these sensory data a viable research challenge.

In this paper, we first discuss some background, and reveal some related work. Then, we described a scalable framework to access sensor data via standard Web pathways. In doing so, we propose a semantic model to to harness the variety and volume of sensor data. Finally, we illustrate our model through a use-case and suggest applications that would display the benefits of adopting the proposed framework to transform sensor data services into information and then to usable knowledge.

II. Background and Related Work

Ubiquitous computing is experiencing radical changes with the Internet bridging the gap between the physical and the virtual worlds. Many appliances, machines, and devices (things) around us are becoming Internet enabled or could be Internet-augmented. The exponential changes in information technology, computing capabilities, and seamless communication protocols are pushing technology into the very fabric of our everyday environments. The motivation towards Internet of Things (IoT) and the requirement for a standard application platform birthed the research focus on the Web of Things (WoT). The research and development of WoT is set to take ubiquitous computing to unprecedented heights because it allows people and devices to have access to information and knowledge in real-time on the widely accepted and scalable platform of the Web [8], [9].

WoT focuses on using the platform of the Web to connect sensor-enabled devices on the Internet [8]. The protocols and tools for creating Web-based applications are widely used and understood for many years. Web technologies have proven to be scalable and the provisioning of services using Cloud technologies is being rapidly adopted in all domestic, business, and industrial applications [10], [11]. The advent of cloud computing introduced the concept of providing resources as services. Infrastructure-as-a-service, Platform-as-a-service, and Software-as-a-service were service models that were introduced to efficiently disseminate and use resources on the scale of the Web [12], [13]. WoT research initiatives makes it possible for real-world things to communicate, collaborate, and make autonomous decisions where the lack of capabilities of real-world things are substituted by cloud-based services [7]. As a result, researchers have built and modeled platforms and applications for collecting and processing valuable information using Web technologies like HTTP, RESTful Web services, and CoAP increasing the availability of real-world sensory data as Web resources [14], [15], [16]. Similar to HTTP protocol, the CoAP protocol uses a request/response model for communication between client and server. In addition to HTTP features, CoAP includes IP multicast, resources discovery, and it also provides a server-push model for asynchronous exchange of messages [17].

While sensors attached to smartphones have much less restriction to computing power, a major constraint that needs to be handled for Wireless Sensor Network (WSN), is the capability constraints of the sensor nodes. Embedding a tiny Web server to the sensor, or to the sink node of a WSN allows for the efficient processing of data from the sensors [5]. To cope with the constraints of the embedded Web servers, the authors of [18] suggested a browsing architecture. Here, the user requests are redirected to another Web server that is capable of communicating with sensors and populating rich Web content. Therefore, a major design component of WoT applications for sensors is the inclusion of the backend server-side processing of data [19]. In more recent works [20], [21], [17], everyday things have been embedded with tiny Web servers that receive and process HTTP requests to control and access these things. The use of simple HTML content populated with sensor data, is sent to backend cloud infrastructure to generate Web-based profiled user interface.

While the technology is advancing towards the Web-enablement of sensors and the embedding of these sensors into everyday things, there are research challenges that are yet to be addressed. A major issue not addressed in many of the research approaches is the representation and modeling of the wide variety and large numbers of these sensors and the data that is generated. We present the SenaaS architectural framework and propose a semantic model for subsuming the variety of sensing entities.

We present a scenario to explain the various possibilities of realizing the merging of SenaaS and the WoT in the context of a smart grid application.

III. Sensing as-a Service Architectural Framework

A generic framework for SenaaS architectures is presented in Figure 1. The physical layer comprises of two sub-layers. The bottom layer consists of different types of sensors and actuators (*Sensing Devices*) that are embedded into the environment. These sensors gather data from their surroundings through respective communication standards presented in the *Communication Protocols* layer and then transfer it to the *Sensing as-a-Service Platform*. Within the platform, information and knowledge are assimilated from the sensory data using various *Data Management Functions* and exposed as services using *Service Oriented Architecture (SOA) Integration functions*. These services seed the functions and intelligence of various smart applications like Smart City (shown in Figure 1), Smart Grid, and Smart Home.

The success of smart applications depends not only on the capability of utility companies to gather and analyze data but on the active participation of *informed consumers*. For example, the electricity grid is an engineering marvel but

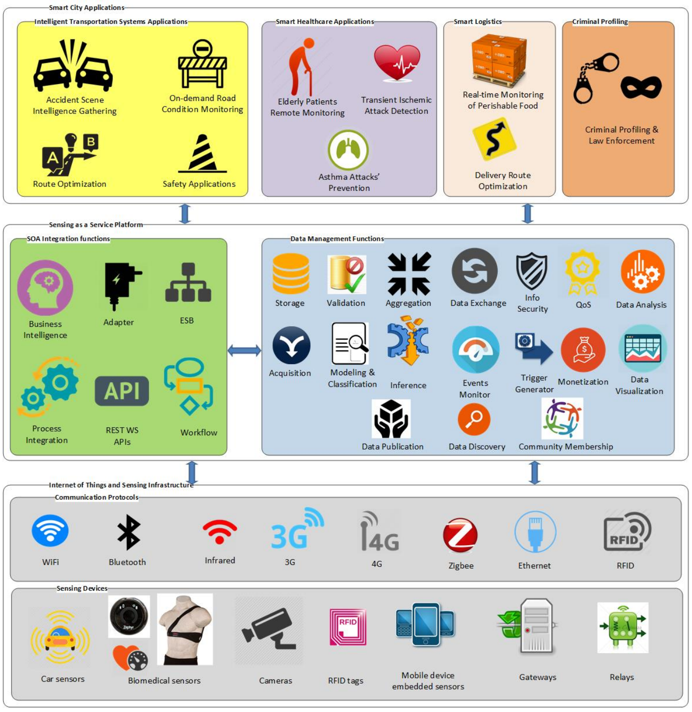

Figure 1. A Generic Architectural Framework for Sensing as-a Service Platforms

with increasing demands for electricity the urgency to use sustainable methods to harness and preserve electricity is the need of the hour. This requires the participation of *informed consumers* to provide information and the utility providers to regulate the demand and supply to meet consumer demand in an efficient manner. The realization of a smart grid application where the consumer makes intelligent choices for their energy consumption would require a two-way communication between the consumers and the utility companies.

The challenges of realizing the smart grid application include:

1) How would utility companies draw maximum participation from their consumers?
2) What standard platform would be used to reach and educate all the consumers to participate (platform independence)?
3) Can the participation of consumers be incentivized?
4) How is scalability issues addressed?
5) How is security and privacy ensured for remote access and monitoring?
6) What strategy can be used for efficient backup and recovery?

To address the above listed challenges we propose the integration of the Social Web of Things layer to the SenaaS platform. We also provide a refinement to the platform to clearly differentiate between requirements that enable intelligent inferences and focus on essential services for a smart application.

IV. WoT Enabling Sensing as-a Service (SenaaS)

The inference of knowledge and an intelligent decision making process needs to be included in the SenaaS platform to deliver services to the consumers. The inclusion of knowledge based value-added services requires the platform to be scalable, easily deployable, secure, easily accessible to both sensor data producers and consumers (people and things). Moreover, knowledge based services require participatory sensing and therefore the SenaaS platform needs to be incentivized. To meet these requirements we propose the adaptation of the SenaaS platform with the Web Based Social Networking Platform.

A. Architectural Framework for Integrating the WoT and Sensing as-a Service

Here, we propose a more detailed architectural framework in Figure 2 for bridging the WoT and SenaaS platform. Our proposed framework addresses the questions raised above in the previous section in three ways. Firstly, we clearly differentiate the knowledge representation and service provision layers from the data acquisition and analytics layers. Secondly we introduce the Web based social networking layer to propagate and integrate the relationship between people and things (sensor enabled devices) as friends which ensures security and privacy. Thirdly, we propose the use of RESTful service oriented interface to create Web services which increases scalability and reduces the time for technology adaptation. The different layers of our framework as shown in Figure 2 are explained next.

1) Sensor Data Providers: Here we identify three types of sensory data providers,

- Legacy sensors like industrial sensors that have proprietary interfaces and have no Web based integration capabilities e.g. parking sensors.

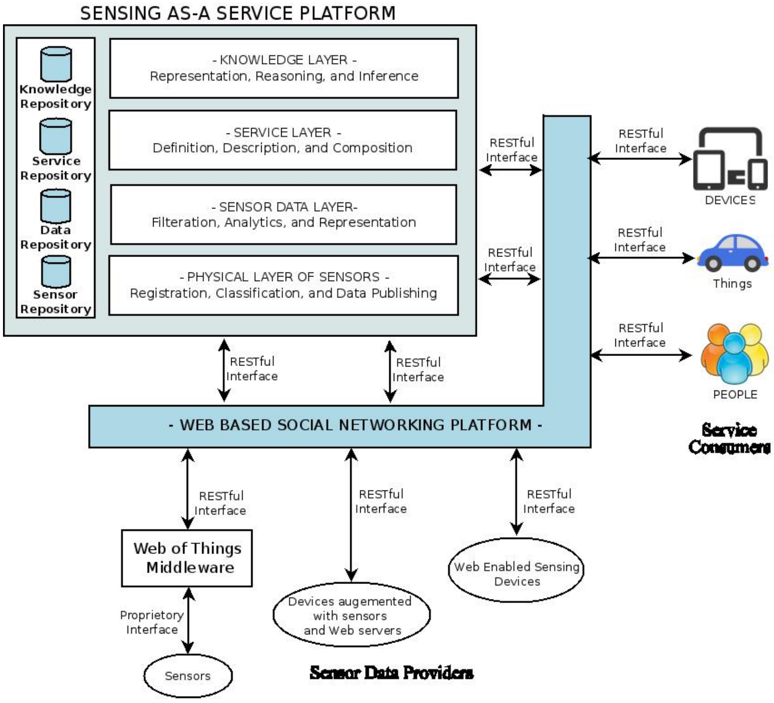

Figure 2. Framework for bridging the WoT with Sensing as-a Service Platform

- Devices that are augmented with sensors and Web servers e.g. vending machines augmented with Flyport[2].
- Web enabled sensing devices e.g. smart phones that have various sensors and are capability of hosting Web servers.

These providers would ideally produce different types of data. The types of data that are:

- Physical Data: Data generated by sensors, e.g. locations, temperature, and pollution rate.
- Participatory Data: Data generated by people on social media e.g. photographs and videos taken by people.
- Cyber Data: Data generated by devices connected on the Internet e.g. IP addresses, mobile phone numbers, packet routing data, and protocols.
- Web Resident Data: Data generated from Web sites like Wikipedia, and also Cloud based data e.g. youtube videos, Amazon, and eBay.

Incentivizing participation creates a win-win situation for data providers. This model is especially useful where data providers are mobile phone users. The incentives will motivate the participation and increase the possibility of getting accurate and relevant data.

2) WoT Middleware: The WoT Middleware, provides the necessary adapters and interface to Web enable the transfer of sensory data. With plugins for various proprietary protocols and standards this module would glue the proprietary interfaces and data standards into HTTP packets and transfer it using RESTful interface via the Web Based Social Networking Platform.

3) Web Based Social Networking Platform: People, places, and things congregate as friends on the Web based social networking platform. Adopting an existing social networking platform, like Facebook, or Google+, that provides service oriented RESTful interface ensures the quick propagation of relationships between people and things in a secure manner. Communities of people and things are formed where privacy levels are maintained and intelligent services are exposed [22]. The platform of the Web over HTTP has the scalability factor already tested and used for many years making it easy for all stakeholders to quickly adopt the technology. This platform would interface with all layers of the SenaaS platform using the RESTful interfaces, allowing services to be generated from each layer. To its benefit, REST provides a decoupled architecture, and light weight communication between service producer and service consumers. This make REST a popular building style for cloud-based APIs, like those provided by Amazon, Microsoft, and Google. Since RESTful interfaces take advantage of HTTP methodologies, they are the logical choice for building APIs that allow end users to easily connect and interact with the Web and cloud based services.

4) Physical Layer - Sensing Infrastructure: All physical sensors register themselves to the SenaaS platform through services exposed through the physical layer. The sensors will go through moderations and verifications to ensure SenaaS platform level regulations and security [23]. The sensors are also classified based on their capabilities and the provision to be augmented with additional capabilities is made available [7]. The services provided at this level is the streaming of raw data where the data published is without any filtration or cleaning.

5) Sensor Data Layer: While raw data is available from the Physical layer, this layer filters and cleans the large amount of data that is streamed in from the sensors. Erroneous, duplicate,

[2]http://www.openpicus.com/flyport.html

and repetitive data are removed. The data is analyzed for relevancy and converted into predefined representations. The representations may vary from standard protocol representations like SyncML or Linked Data representations that is established for an ad-hoc project. These representations are made available through RESTful interfaces, for consumers that are registered with the platform.

6) Service Layer: All services provided by the SenaaS platform is defined in this layer. This layer functions as a portal for SenaaS service discovery. Service descriptions using RESTful Service Description Language (RSDL) is designed to provide structured descriptions of all RESTful API that is comprehensible for both human and automated machine processing. Service composition methods are adopted which enables the composition of multiple services based on consumer request ensuring operation signatures, semantics, and service level agreements.

7) Knowledge Layer: The need for targeted contextual information is the primary need for the SenaaS platform. The Knowledge layer uses machine learning to reason and intelligently derive contextual content and provide recommendations. This layer makes use of best practices, rules engine, and prior learning to infer the contextual significance of sensory data.

8) Service Consumers: Through the Web based social networking layer both men and machines are eligible participants of the SenaaS platform. These participants request and receive services from the SenaaS platform to make contextual decisions based on the changing environment they find themselves in. The consumers are registered with the platform and the amount of their service usage is recorded and monitored.

9) The Repositories - Data Management Functions: The main data storage and management are:

- Knowledge Repository: This is mainly used by the knowledge layer to support its machine learning functions of creating contextual information based on predefined rules and sensory data.
- Service Repository: This is mainly used by the service layer to manage all the services provided by the SenaaS platform.
- Data Repository: This is mainly used by the data layer to filter and clean the raw data stream that is provided by the sensors.
- Sensors Repository: This is mainly used to store details of all physical sensors that are registered with the SenaaS platform.

V. A Case Study on Smart Grid

Consumers form an integral part of the smart grid. Their engagement in utilizing new information and adopting new behavior is crucial for the successful deployment of the smart grid to better balance energy supply and demand. Passive end-users are transformed into active smart-grid engaged-players using the transformative power of data analytics. To collect data insights that influence consumers' involvement into smart-grid operations, this scenario brings together peer users and Energy Service Providers or ESPs into contemporary social

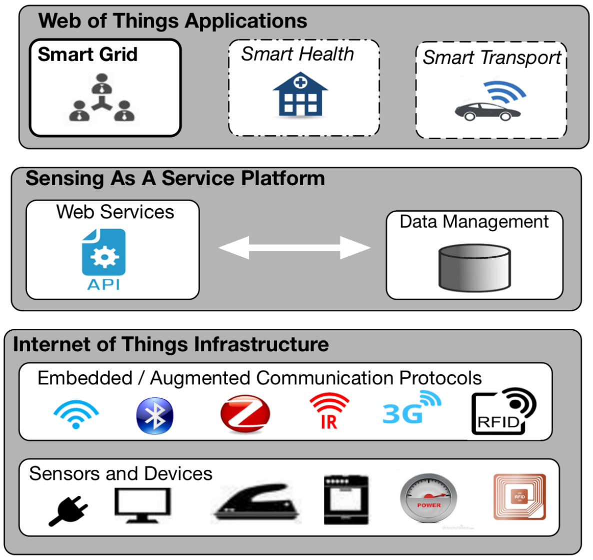

Figure 3. Web of Things virtualization framework

platforms. The intimacy of this relationship is bridged by the integration of power-consuming appliances augmented by power-sensing devices. Our WoT-enabled SenaaS approach creates a data stream channel exposing the Energy Service Interfaces or ESIs of these sensors that provide sensory data to our proposed social Web platform. These data streams feed social Web platforms with sensory data which could be utilized to drive desired smart-grid user behaviors. This social framework is based on a mashup of IoT based SenaaS services and social media to instill further intimacy between users and energy suppliers via a direct integration of power-consuming appliances. New communities are formed at various energy-related grain levels (i.e. energy type, users type, etc.) which are used to drive and evaluate individual engagement to manage "Personal Energy Meter" to personalize user's engagement towards smart-grid operations. Social interactions naturally drive competitive instincts based on energy patterns that involve both users and connected devices [24]. We collect engagement data before and after our experiment to observe and report any behavioral change towards hypothetic smart-grid scenarios augmented by smart electricity-sensing outlets attached to energy consuming utilities within an office space. The experiment may uncover social correlations and data-pattern indicators that could be instrumental to stimulate user's engagement towards smart-grid services. In addition, we deliver an evaluation of the dissuasive potential of Social IoT to bridge between consumers and future smart grid service providers.

VI. Conclusion and Future Work

The Web of Things empowers future ubiquitous applications with new sources of data and innovative services. We discussed the realization of WoT following an SenaaS based middleware to "glue" together Inetrnet-enabled things and Web-enabled object counterparts. The proposed blueprint architecture illustrates things' enablement in terms of connectivity and logical abstractions as services delivered data or operations. A case study centered around the prominent smart grid is discussed, whereby Web-enabled objects are given a social profile, and woven into people-community to drive behavioral changes towards smart grid operations. Future works could extend the proposed blueprint architecture with a "visualization" layer to browse WoT across inter-connected things on the Web.

REFERENCES

[1] Charith Perera, Arkady Zaslavsky, Peter Christen, and Dimitrios Georgakopoulos. Sensing as a service model for smart cities supported by internet of things. *Transactions on Emerging Telecommunications Technologies*, 25(1):81–93, 2014.

[2] Arkady B. Zaslavsky, Charith Perera, and Dimitrios Georgakopoulos. Sensing as a service and big data. *CoRR*, abs/1301.0159, 2013.

[3] A R Al-Ali and R Aburukba. Role of internet of things in the smart grid technology. *Journal of Computer and Communications*, 2015.

[4] Kelly T. Sanders and Sami F. Masri. The energy-water agriculture nexus: the past, present and future of holistic resource management via remote sensing technologies. *Journal of Cleaner Production*, 117(Complete):73–88, 2016.

[5] D. Raskovic, V. Revuri, D. Giessel, and A. Milenkovic. Embedded web server for wireless sensor networks. In *2009 41st Southeastern Symposium on System Theory*, pages 19–23, March 2009.

[6] Terence L van Zyl, Anwar Vahed, Graeme McFerren, Petrus Shabangu, and Bheki Cwele. Using SensorML to Describe Scientific Workflows in Distributed Web Service Environments. *IGARSS*, 2009.

[7] S. S. Mathew, Y. Atif, Q. Z. Sheng, and Z. Maamar. Web of things: Description, discovery and integration. In *Internet of Things (iThings/CPSCom), 2011 International Conference on and 4th International Conference on Cyber, Physical and Social Computing*, pages 9–15, Oct 2011.

[8] Dominique Guinard, Vlad Trifa, Thomas Pham, and Olivier Liechti. Towards physical mashups in the web of things. In *Networked Sensing Systems (INSS), 2009 Sixth International Conference on*, pages 1–4. IEEE, 2009.

[9] Vlad Stirbu. Towards a restful plug and play experience in the web of things. In *Semantic computing, 2008 IEEE international conference on*, pages 512–517. IEEE, 2008.

[10] M. Zhou, R. Zhang, D. Zeng, and W. Qian. Services in the cloud computing era: A survey. In *Universal Communication Symposium (IUCS), 2010 4th International*, pages 40–46, Oct 2010.

[11] Yacine Atif, Ding Jianguo, and Manfred A. Jeusfeld. Internet of things approach to cloud-based smart car parking. *The 7th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN 2016),*, 2016.

[12] Prith Banerjee, Richard Friedrich, Cullen Bash, Patrick Goldsack, Bernardo Huberman, John Manley, Chandrakant Patel, Parthasarathy Ranganathan, and Alistair Veitch. Everything as a service: Powering the new information economy. *Computer*, 44(3):36–43, 2011.

[13] S. Patidar, D. Rane, and P. Jain. A survey paper on cloud computing. In *2012 Second International Conference on Advanced Computing Communication Technologies*, pages 394–398, Jan 2012.

[14] Rajeev Piyare, Sun Park, S Yeong Maeng, and S Hyeok Park. Integrating wireless sensor network into cloud services for real-time data collection. In *Proceedings of the International Conference on ICT Convergence (ICTC)*, pages 752–756, 2013.

[15] Erik Wilde. Putting things to rest. *School of Information*, 2007.

[16] M. Blackstock and R. Lea. Iot mashups with the wotkit. In *Internet of Things (IOT), 2012 3rd International Conference on the*, pages 159–166, Oct 2012.

[17] L. Mainetti, V. Mighali, L. Patrono, P. Rametta, and S. L. Oliva. A novel architecture enabling the visual implementation of web of things applications. In *Software, Telecommunications and Computer Networks (SoftCOM), 2013 21st International Conference on*, pages 1–7, Sept 2013.

[18] S. Bae, D. Kim, M. Ha, and S. H. Kim. Browsing architecture with presentation metadata for the internet of things. In *Parallel and Distributed Systems (ICPADS), 2011 IEEE 17th International Conference on*, pages 721–728, Dec 2011.

[19] M. Kovatsch, M. Lanter, and S. Duquennoy. Actinium: A restful runtime container for scriptable internet of things applications. In *Internet of Things (IOT), 2012 3rd International Conference on the*, pages 135–142, Oct 2012.

[20] Katie Derthick, James Scott, Nicolas Villar, and Christian Winkler. Exploring smartphone-based web user interfaces for appliances. In *Proceedings of the 15th International Conference on Human-computer Interaction with Mobile Devices and Services*, MobileHCI '13, pages 227–236, New York, NY, USA, 2013. ACM.

[21] N. K. Giang, M. Ha, and D. Kim. Buddy thing: Browsing as a service for the internet of things. In *Services Computing (SCC), 2015 IEEE International Conference on*, pages 122–129, June 2015.

[22] Dominique Guinard, Mathias Fischer, and Vlad Trifa. Sharing using social networks in a composable web of things. In *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on*, pages 702–707. IEEE, 2010.

[23] Ezedine Barka, Sujith Samuel Mathew, and Yacine Atif. Securing the web of things with role-based access control. In *International Conference on Codes, Cryptology, and Information Security*, pages 14–26. Springer, 2015.

[24] Antonio J Jara, Yann Bocchi, and Dominique Genoud. Social Internet of Things: The Potential of the Internet of Things for Defining Human Behaviours. In *2014 International Conference on Intelligent Networking and Collaborative Systems (INCoS)*, pages 581–585. IEEE, 2014.