Proceedings of the International Conference , "Computational Systems for Health & Sustainability"
17-18, April, 2015 - byR.V.College of Engineering,
Bangalore,Karnataka,PIN-560059,INDIA

Internet of Things Architectures: Modeling and Implementation Challenges

Varun M Tayur
Department of Computer Science,
Jain University, Bangalore.

Dr.Suchithra R
Department of Computer Science,
Jain University, Bangalore.

Abstract: Internet of Things (IoT) encompasses a broad set of technologies, hardware and software stacks.The rapid evolution and broadened scope can be attributed to the inclusion of many existing mature technologies like the wireless sensor networks, RFID and a wide variety of custom solutions and newer smart devices.There is a growing need for devices to collaborate to provide the desired service.The heterogeneity coupled with theresource constrained nature of the devices seriously limits the choices in design. The capability to onboard billions of devices on to the existing infrastructure without degrading the quality of service is robust programming frameworks are in place more crucial. Automation enables devices to act independently which can be enabled only by ensuring.Architectural modelsaddressingthe challenges like scalability, distributiveness, interoperability and programmability are the need for the hour.

Keywords – IoTarchitectures; IoT programming challenges;IoT management; IoT modeling challenges

INTRODUCTION

The term Internet of Things represents arange of essentially low powered constrained devices connecting to the internet. Most of these devices are legacy custom solutions that were never designed to work over the internet. Adapting the IP protocol on such legacy systems may be technically infeasible or economically un-viable. Imagine devices that we use every day having embedded intelligence and being able to connect to the internet; if this happens, they could be managed from anywhere anytime. This can have wide range of applications in various aspects touching our lives in healthcare, transportation leading to a digitally assisted lifestyle. But, all these will stress the existing networking infrastructure as it is not ready to handle the scale that they provide.

Devices can be placed around in many environments where human habitation may be difficult like ex. Harsh terrains, cold temperatures etc.; it could also be that they are distributed geographically at different locations. Aggregating data and managing these devices as a single system while still being available all the time is a major challenge. A natural evolution of traditional computing with internet has given rise to a new computing paradigm called the cloud which provides the necessary environment and infrastructure to address the distributed management requirements.Once the devices are connected and suitable infrastructure is put in place, it needs to be efficiently managed. Faulty devices must be isolated so as to not hamper the functioning of the overall network. It should be possible to provision new devices, detect and replace faulty ones in the network, monitor the devices; all these non-intrusively with minimum overhead as most of all these devices are low powered and have lot of resource constraints.

RELATED WORK

The study is organized under the following broad areas namelyIoTReference Models – deals with standardization of the processes, Cloud Convergence and IoT–deals with architectures that offer the device as a service and its management, Programmable IoT – deals with programming and automation support in IoT environments, IoT management – deals with management aspects in IoT environment.

1.1. Reference models

The standard open IETF IoT stackenables connectivity of the devices into the internet, but the nature of low powered devices poses a challenge in keeping the network operative and secure. Other issues like ensuring backward compatibility, configuring and managing such devices is still a challenge. An intercepting intermediary is proposed in [18] which perform the initial heavy lifting on behalf of the devices by intercepting all the requests, transforming to and from Constrained Application Protocol (CoAP).Matching adapters in a sequence can be executed which handle the CoAP interactions non-intrusively providing security and other services which otherwise can strain the devices.

A mechanism for a scalable and automated deployment of things is proposed in [20] which removes' the need for human intervention for configuration and maintenance. A self-configuring Peer-to-Peer (P2P)-based architecture for large-scale IoT networks provides automated local and global service and resource discovery mechanisms. The P2P overlays namely the Distributed Location Service (DLS) and Distributed Geographic Table (DGT) provides the name lookup service and location information of a resource respectively. The main interface to the P2P overlay environment is via an intermediary IoT gateway which provides connectivity to the P2P infrastructure.A new loT Communication Model based on the OSI stack, with the vision of communications "anytime, anywhere, anyone, and anything" is proposed in [27], the two new layers: Quality of Service layer is classified as Layer 2 and the Security layer is classified as Layer 3. This architecture enables secure communications processes at all levels. Communication in the IoT environment requiresend to end Quality of Service which has to be adapted to run on small things based on the memory and resource requirements.

COMPOSE[14] and BUTLER [13] provides similar open and scalable platform infrastructure, where smart objects will be ingested and represented in the platform in a standardized manner ready to be consumed by applications. COMPOSE provides IoT platform as a Service to ease the development, deployment and consumption of IoT applications, developers portal provides environment for automatic provisioning and deployment, exposing the smart Objects as a Service enables standardized management of devices.IoT-A [15] group defines a Functional Model which contains seven functional groups complemented by two transversal functionalGroups for Management and Security. Management and Security are spread across layers end-to-end. The communication layer handles the QoS, routing and other functions, the IoT service layer provides service resolution and other services, virtual entity layer provides virtual entity resolution services, business process management layer provides the modeling and execution support, service configuration and organization enables automation.

1.2. IoT and Cloud Convergence

Convergence of IoT into Cloud computing as in figure 2 is another active area of research as cloud complements the compute and storage resources that are not in plenty within IoT. Open source cloud based platform [5] provides a generic platform that enables devices, RFID, NFC, M2M and sensor technologies and systems to be hosted in a decentralized architecture enabling interoperability amongst the many complementary technologies. Sensing and Actuation as a Service (SAaaS) approach proposed in [10] proposes an Infrastructure-oriented provisioning model for sensors and actuators. The SAaaS approach for is useful when field deployment of custom functionality is needed.

Figure 1: IoT and cloud Convergence [31]

Agent based [11]computing supports the development of decentralized, dynamic, cooperating and open IoT systems. A cloud-assisted and agent-orientedIoT architecture provides integration between IoT and the cloud based systems. Similar approach called as Agent of Things [24] proposes that every “thing” should have an internal reasoning and intelligence capability which enables the things to interact directly with other things in the same or different system types.

CloudThings architecture [17]proposes aunique service oriented online platform that allows system integrators and solution providers to use the Things application infrastructure for developing, deploying, operating, and composing applications and services. A cloud centric IoT architecture model [6] provides a virtual execution environment which is decentralized providing high reliability and accessibility. Applications can be built by composing services and deploying them into service platforms. Semantic technologies, open service frameworks and information models to support data interoperability in the design of the IoT and Cloud Computing are discussed in [21]. The inferences of data coming from physical and virtual objects needs to be interlinked so that individual data items and information objects to support semantic query can be carried out.

New services can be composed from existing services, using a mash-up [25]. The mash-up is made possible with existing web mash-up technology provided each thing exposes its functionalities as a web service. IoT Mash-up as a Service (IoTMaaS) proposes to address the problem connecting heterogeneous devices by following the model driven architecture principles and computational scalability based on cloud computing paradigm.

1.3. Programmable IoT

PatRICIAaims at providing an end-to-end solution for high-level programming and provisioning of IoT applications on cloud platforms [12]. It is based on the concept of intent and intent scope. The model handles runtime complexity, diversity and scaling IoT systems in the cloud by defining abstractions to enable easier, efficient and more intuitive development of cloud-scale IoT applications.

‘Drip-cast’ [22] uses techniques that require just a simple client-side program of withoutwriting server-side program or database code. The mechanismwas proven to be scalable for large set of devices on the cloud. Layered middleware controller based on the Universal Plug and Play (UPnP) has been proposed in [23]. The controller is based on the Linux Apache MySql and PHP (LAMP) server with UPnP support and RESTful extensions enabling programmatic access. The Master-Slave controller combination enables distributed handling of events and interactions with multitude of devices.

An embedded OData implementation on top of CoAP without requiring an intermediary gateway device is presented in [8]. Additional resources required for an OData/JSON implementation are justified considering the issues in interoperability in enterprise networks.

Machine to Machine interaction interfaces must be scalable as the number of devices that interconnect are huge, hence an integrated solution using a new kind of broker, named QEST that can bridge the two worlds, represented by their state-of-the-art protocols: MQTT and REST is proposed in [9]. MQTT provides asynchronous message delivery keeping in mind the nature of IoT low power constraints, while REST is a popular standard to expose the server resource. Combining the message delivery system with the RESTful service enables different kinds of devices to talk to each other via the REST, opening up opportunities to automate device deployment, and management.

A distributed, interoperable architecture for IoT based on smart control and actuation is proposed in [4] which aim to address handling heterogeneity of IoT devices by its layered structure. A middleware approach [7] hides the differences between ZigBee and RFID by defining the protocol conversion and mapping models. This allows applications to focus on the service level development and reduce the coupling with the underlying hardware and protocol.

1.4. IoT Management

A framework for managing the devices and configuring the network dynamically based on SDN System Architecture is presented in [3].The architecture consists of the control plane, having the controller andapplication platform, the other is data plane, whichmakes up devices and networks. An agentresides in M2M device or M2M gateway whichcorresponds to the Execution Framework (EF). The EFreceives the commands from the controller and programs the network. Due to the heterogeneity of devices and access protocols, IoT networks are becoming enormous and complex, the SDN allows devices to be treated as objects decoupling the control plane from the data plane and hiding the complexity.An OpenFlow implementation adapted for the wireless sensor networks is presented in [19]. It proposes two new abstract layers, a Common platform layer over the IoT devices and virtualization layer which be added at the top and bottom of a present Infrastructure. It proposes to utilize the OpenFlow protocol for providing a common management protocol and it concept borrowed from software defined networks to establish connectivity to the devices. Simulation results have shown that this architecture to scale very well for large network sizes and achieve upto 39% points more traditional sensor networks.

Higher level connection-technology-independent protocols are needed to shield different connection technologies in the integration requirements for things'. A management protocol which can be used to exchange information end-to-end is necessary. A SOAP-based [26] Things Management Protocol (TMP) is proposed which operates in the Application layer of the Internet stack. Operations like get/set similar to Simple Network Management Protocol (SNMP) operations enables uniform interface for communication between the things with things and things with the applications. TMP is a key technology for information integration and application based on connection-technology-independent protocols, SOAP-based TMP can take full advantage of HTTP, XML, SOA and other widely used technology with broad application prospects.

IoT integration intoIPv6 and its related protocols has been a major challenge considering the constrained capabilities offered by Wireless Sensor Networks, building automation, and home appliances. Integration of the existing management protocols in IPv6 into the emerging IoT networks based on protocols such as 6LoWPAN is discussed in [28]. The COnstrained networks and devices MAnagement (COMAN) Group from the IETF proposes solutions such as simplified MIB, new SNMP consideration, and CoAP-based management which could be the protocol to use for network management in IoT. LoWPAN Network Management Protocol (LNMP) is management architecture suited for the 6LoWPAN networks [29].LNMP architecture focuses on reducing the cost of communication and hence increases the lifetime of the network.The main objective of LNMP is interoperability with SNMP, butSNMP is considered large both in terms of communication and complexity for devices that have limited resources [16]. LNMP's operational architecture provides a distributed network discovery support with the help of co-ordinators which non-intrusively monitor and manage the devices. Theinformational architecture enables usage of SNMP based on the traditional IPv6 LoWPAN stack enabled by the adaptation layer for 6LoWPAN. SNMP being an Application layer protocol can be adapted to run over IPv6 with some modifications [28], a popular implementation NET-SNMP exists for use on both IPv4 and IPv6, the suite includes a full implementation of SNMP adapted for IPv6.

The devices deployed within the Internet of Things are resource constrainedwith respect to memory and processing capabilities and the low-power radio standards. An investigation on using existing management protocols like SNMP, NETCONF over Ipv6 to manage low powered devices is done in [16]. A lighter version of SNMP and NETCONF protocol implemented on the Contiki OS showed that SNMP was better suited over NETCONF with respect to resource utilization.

DISCUSSION

The reference models published by IETF, 6LoWPAN aims to provide a fully operational stack for IP based devices. Since, IoT includes an umbrella of technologies the adoption of IP has not picked up yet largely because of the low resource constraints on the devices. The adoption can largely increase if sufficient device abstractions are provided so that higher level applications can program them without the need to change. The reference model proposed by IoT-A group is a good example of a reference model which defines the abstractions in a nice way so that multiple kinds of devices can be managed and co-exist. Other reference models like COMPOSE and BUTLER and others give programmatic access models into the IoT world so that applications could be developed over them. Many models have been proposed to address the various challenges in IoT. Some of them are middleware based which enables them to be offered as a service on the cloud. One of the models also uses P2P for enabling automation of deployment while others have taken a traditional layered approach to segregate the functionality with each of the layers. Cloud convergence of IoT is another important area of active research where exploration has happened on providing the thing as a Service for ex. IoT controller as IaaS, Deployment runtimes as PaaS and management software as SaaS. Other forms of abstractions have been proposed which include use of semantics [1] to build a knowledge base of IoT so that it can be used in the composition of services.

IoT network management is another important area of interest as IoT presents unique challenges related to communication infrastructure. By using software defined network abstractions and Open-flow integration within wireless sensor networks, new applications have arisen. LNMP looks like a promising Network management protocols considering it has adopted the tried and tested SNMP protocol.CoMAN protocol again borrowing the good things from SNMP looks to be very promising for network management in IoT.

CONCLUSION

Large amount of work has happened in solving the challenges that has plagued IoT adoption. It is largely because of the absence of any standard based architecture and more so because of the adoption and embracing of different kinds of technologies wanting to connect to mainstream internet. Scaling the internet and associated infrastructure has been a more immediate problem, where lot of proposals suggests using IPv6 with cloud computing paradigms.Heterogeneous nature of the devices is an important characteristic of IoT, which could be addressed to some extent by using the asynchronous messaging platforms and platform independent models. The current communication infrastructure does not suit well for the Low powered constrained devices as they will be strained – which can be addressed by CoAP type protocols. Management and monitoring is another active area of research considering all the challenges that IoT presents to us. All these developments have led us to a more automated, device centric world where a device can talk to another device without an intermediary.

REFERENCES

[1] Nambi, S. N. et el., “A Unified Semantic Knowledge Base for IoT” inInternet of Things (WF-IoT), 2014 IEEE World Forum, vol., no., pp.575,580, 6-8 March 2014doi: 10.1109/WF-IoT.2014.6803232

[2] Gartner research (Dec 12 2013) [Online] Available: http://www.gartner.com/newsroom/id/2636073

[3] Hai Huang et el., “An SDN based Management Framework for IoT Devices” inIrish Signals & Systems Conference 2014 and 2014 China-Ireland International Conference on Information and Communications Technologies (ISSC 2014/CIICT 2014). 25th IET , vol., no., pp.175,179, 26-27 June 2013doi: 10.1049/cp.2014.0680

[4] ChayanSarkar et el., “A Scalable Distributed Architecture Towards Unifying IoT Applications”, in Internet of Things (WF-IoT), 2014 IEEE World Forum, vol., no., pp.508,513, 6-8 March 2014 doi: 10.1109/WF-IoT.2014.6803220

[5] George Suciuet el., "Generic platform for IoT and cloud computing interoperability study," in Signals, Circuits and Systems (ISSCS), 2013 International Symposium, vol., no., pp.1,4, 11-12 July 2013 doi: 10.1109/ISSCS.2013.6651222

[6] Yazid BENAZZOUZ et el.,"Sharing user IoT devices in the cloud," in Internet of Things (WF-IoT), 2014 IEEE World Forum, vol., no., pp.373,374, 6-8 March 2014doi: 10.1109/WF-IoT.2014.6803193

[7] Chunxiao Fan et el., "A middleware of Internet of Things(IoT) based on Zigbee and RFID," in Communication Technology and Application (ICCTA 2011), IET International Conference on , vol., no., pp.732,736, 14-16 Oct. 2011 doi: 10.1049/cp.2011.0765

[8] Matthias Thoma el el., "Rest-based sensor networks with OData," in Wireless On-demandNetwork Systems and Services (WONS), 2014 11th Annual Conference, vol., no., pp.33,40, 2-4 April 2014 doi: 10.1109/WONS.2014.6814719

[9] MatteoCollina et el., "Introducing the QEST broker: Scaling the IoT by bridging MQTT and REST," in Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium, vol., no., pp.36,41, 9-12 Sept. 2012 doi: 10.1109/PIMRC.2012.6362813

[10] S. Distefano et el., "Application deployment for IoT: An infrastructure approach," in Global Communications Conference (GLOBECOM), 2013 IEEE , vol., no., pp.2798,2803, 9-13 Dec. 2013 doi: 10.1109/GLOCOM.2013.6831498

[11] Giancarlo Fortino et el., "Integration of agent-based and Cloud Computing for the smart objects-oriented IoT," in Computer Supported Cooperative Work in Design (CSCWD), Proceedings of the 2014 IEEE 18th International Conference, vol., no., pp.493,498, 21-23 May 2014doi: 10.1109/CSCWD.2014.6846894

[12] Stefan Nastic et el., "PatRICIA -- A Novel Programming Model for IoT Applications on Cloud Platforms," in Service-Oriented Computing and Applications (SOCA), 2013 IEEE 6th International Conference, vol., no., pp.53,60, 16-18 Dec. 2013 doi: 10.1109/SOCA.2013.48

[13] BUTLER. (Jan 2015) [Online]. Available: http://www.iot-butler.eu/.

[14] COMPOSE. (Jan 2015) [Online]Available: http://www.compose-project.eu.

[15] IoT-A. (Jan 2015) [Online]Available: http://www.iot-a.eu/

[16] AnujSehgal et el., "Management of resource constrained devices in the internet of things," in Communications Magazine, IEEE , vol.50, no.12,

pp.144,149, December 2012doi: 10.1109/MCOM.2012.6384464

[17] Jiehan Zhou et el., "CloudThings: A common architecture for integrating the Internet of Things with Cloud Computing," in Computer Supported Cooperative Work in Design (CSCWD), 2013 IEEE 17th International Conference, vol., no., pp.651,657, 27-29 June 2013doi: 10.1109/CSCWD.2013.6581037

[18] Floris Van den Abeele et el.,"Fine-grained management of CoAP interactions with constrained IoT devices," in Network Operations and Management Symposium (NOMS), 2014 IEEE , vol., no., pp.1,5, 5-9 May 2014doi: 10.1109/NOMS.2014.6838368

[19] Arif Mahmud et el., "Deployment of Flow-Sensors in Internet of Things' Virtualization via OpenFlow," in Mobile, Ubiquitous, and Intelligent Computing (MUSIC), 2012 Third FTRA International Conference ,vol., no., pp.195,200, 26-28 June 2012 doi: 10.1109/MUSIC.2012.41

[20] Simone Cirani et el.,"A Scalable and Self-Configuring Architecture for Service Discovery in the Internet of Things," in Internet of Things Journal, IEEE, vol.1, no.5, pp.508,521, Oct. 2014 doi: 10.1109/JIOT.2014.2358296

[21] Martin Serrano et el.,"Open services for IoT cloud applications in the future internet," in World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops, vol., no., pp.1,6, 4-7 June 2013doi: 10.1109/WoWMoM.2013.6583487

[22] Ikuo Nakagawa et el.,"Dripcast -- Server-less Java Programming Framework for Billions of IoT Devices," in Computer Software and Applications Conference Workshops (COMPSACW), 2014 IEEE 38th International , vol., no., pp.186,191, 21-25 July 2014doi: 10.1109/COMPSACW.2014.35

[23] Hiro Gabriel Cerqueira Ferreira et el.,"IoT architecture to enable intercommunication through REST API and UPnP using IP, ZigBee and arduino," in Wireless and Mobile Computing, Networking and Communications (WiMob), 2013 IEEE 9th International Conference, vol., no., pp.53,60, 7-9 Oct. 2013doi: 10.1109/WiMOB.2013.6673340

[24] Mzahm, AnasM et el.,"Agents of Things (AoT): An intelligent operational concept of the Internet of Things (IoT)," in Intelligent Systems Design and Applications (ISDA), 2013 13th International Conference, vol., no., pp.159,164, 8-10 Dec. 2013 doi: 10.1109/ISDA.2013.6920728

[25] JanggwanIm et el.,"IoTMashup as a Service: Cloud-Based Mashup Service for the Internet of Things," in Services Computing (SCC), 2013 IEEE International Conference, vol., no., pp.462,469, June 28 2013-July 3 2013doi: 10.1109/SCC.2013.68

[26] Guiping Dai, "Design and implementation on SOAP-based things management protocol for internet of things," in Intelligent Control and Automation (WCICA), 2012 10th World Congress, vol., no., pp.4305,4308, 6-8 July 2012 doi: 10.1109/WCICA.2012.6359203

[27] Adel H. Alhamedi. et el., "Internet of things communication reference model," in Computational Aspects of Social Networks (CASoN), 2014 6th International Conference, vol., no., pp.61,66, July 30 2014-Aug. 1 2014doi:10.1109/CASoN.2014.6920423

[28] HananeLamaazi et el. "Challenges of the Internet of Things: IPv6 and Network Management," in Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2014 Eighth International Conference, vol., no., pp.328,333, 2-4 July 2014 doi: 10.1109/IMIS.2014.43

[29] Management of Networks with Constrained Devices: Problem Statement, Use Cases and Requirements (2013). [Online]Available: https://tools.ietf.org/html/draft-ersue-constrained-mgmt-02

[30] 6LoWPAN overview (Dec 2014). [Online]Available: http://projets-gmi.univ-avignon.fr/projets//proj1112/M1/p09/doc/6LoWPAN_overview.pdf

[31] Biswas, A.R.,Giaffreda, R., "IoT and cloud convergence: Opportunities and challenges," in Internet of Things (WF-IoT), 2014 IEEE World Forum, vol., no., pp.375,376, 6-8 March 2014 doi: 10.1109/WF-IoT.2014.6803194

