2018 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE)

The Internet-of-Things and Integration with Wireless Sensor Network Comprehensive Survey and System Implementation

1st Moez Altayeb
Ph.D student, dept of Electrical and Electronic Engineering
University of Khartoum UOFK
Khartoum, Sudan
tayebhajj@gmail.com

2nd Sami m.Sharif
Prof at dept of Electrical and Electronic Engineering
University of Khartoum
Khartoum, Sudan
sam.m.sharif@gmail.com

3rd Suliman Abdella
A.Prof at dept of Electrical and Electronic Engineering
University of Gazira
Wadmadani, Sudan
suliman2003@hotmail.com

***Abstract*— in this paper we introduce the concept of the Internet of Things technology (IoT) and its network stack and protocols, utilizing new emerging computation system, as well as the method that interconnect with Wireless Sensor Network (WSN). A special state-of-the-art paradigm for WSN node is designed and implemented from ARM Cortex computation system and Programmable System on Chip (PSoC). The node drive the data to the internet using special network stack, depending on IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) protocol, which integrates novel effectiveness and solutions for sensors issues. In addition, the cloud computing technology is used to reduce the amount of data in resources constrained devices and simplify the surveillance from any device support internet.**

***Keywords*— IoT, Cloud Computing, WSN, 6LoWPAN, PSoC Resources Constrained device, Embedded Systems.**

I. INTRODUCTION

The massive progress in the very large scale integrated circuits VLSI introduce new type of embedded system that has the capability to perform sensing, communicating and networking, and the most best advantage of low power consumption, this advantage make it relevant devices to be involved as wireless sensor network node. However the WSN application such as environmental monitoring and surveillance aggregated the node with a numerous data which perform a drawback with resource constrain device with a limit storage capacity intended for data acquisitions. On the other hand processing complicated environmental data while the progress of collecting and transmitting information will fatigue the node and decline its performance, therefore the segregation of processing and the storing data out off the WSN is needed. To solve this we need to deliver data to the internet in order to be stored and processed. The development of the internet of things (IoT) motivate a tremendous device to relay data to the remote internet resources for processing, storing and surveillance, moving device data to large scale high storing, computation power located in the data center such as the concept of cloud computing allow remote users or IoT devices to store and process massive data. Numerous applications migrated to the internet producing and consuming data as a result explosive expansion of connected devices. This requires scalable resource management, new processing models and infrastructures to support its main dimensions data volume, velocity, and variety [1]. Both of data processing and storing can be accomplished closed to the field device or user whereas huge data and application that cannot perform locally at the edge of the network can be relayed to the cloud data center that can cope with these types [1]. Most of recent research focuses on the ability to process store data at the edge of the network such as fog computing, unfixed clouds, vehicular networks, are which examples considered as newly emerged concepts that have an ability edge capacity near to data production [2]. Fog computing concept performs a distributed infrastructure at the edges of the network, as a result of low latency access and high response to application requests when compared to data center cloud computing system [3]. The fog concept, yield to novel services and applications innovation for the internet future [4].

II. WSN AND INTERNET OF THINGS IOT

Wireless sensor network and sensing devices will make a big influence in the internet of things *(IoT)* [5][6][[7]. Since they represent the main way through which any computational system can interact with the physical world. In a WSAN several physical sensors and actuator devices are deployed in the physical environment in order to achieve monitoring and control operations. Physical events and quantities, like radiations, temperature, pressure and light intensity are continuously measured by sensor devices. Then, the collected information data are transferred by a wireless link to the remote monitoring center. When this data arrived at the monitoring center it processed and an action is taken according to the analyzed data. The WSANs are commonly used in wide application domains, ranging from normal environmental event monitoring and location/tracking applications to advanced applications such as those in the industrial, smart grid and healthcare domain. The applications area of environment networking is growing and new applications for sensing emerging rapidly. The Internet of Things (IoT), sometimes named as an Internet of everything [8] [9] is defined as a paradigm in which objects provided with sensors, actuators, and computing communicate with each other in order to serve a specific purpose[10]. The Internet of Things (IoT) provides a new approach. It allows devices to relays the data thru infrastructure. This can support many advanced applications. Utilizing the new protocols such as 6LoWPAN [11] over IPv6 [12]. Connectivity is accomplished thru border routers, which joins end device with the network. This allows the end device to join the data center and perform which called cloud computing that allows tremendous data to be relayed to the cloud. As mentioned in the survey in [13], the IoT paradigm has incorporated three main aspects: Things-oriented vision, Internet-oriented vision, and Semantic-oriented vision. All mentioned properties and new efficient protocols of IoT made the possibility to realize integration with WSN where sensor data relayed, processed and monitored on the internet. A new world of advanced IoT devices is emerging [14]. The traditional the Internet as infrastructure joining end user's terminals will change, and a new innovation of interconnected "smart" devices constitutes wide advanced computation environments will emerge [15].

III. Cloud Computing

The phrase "Cloud" describes the data center, which collects networks and services in the form of a cloud to present a large area network. On cloud there are tremendous numbers of connected computations system and routers [16]. The concept of Cloud computing is to perform integration and sharing between different resources networks, storage, applications, servers, and services to realize coherence and economies of scale and find a way to optimize the effectiveness of utilization of the shared resources [17].

IV. Cloud Computing Models

Cloud computing divided into three main types that user can choose: Private, public and hybrid. Each type of has special contracture [18]. There are specific services models in Cloud computing:

A. *Cloud Software as a Service (SaaS)*

This type of cloud service is introduced to the user as a software on the internet (cloud), the architecture of this service depended on both of service-oriented as well as component oriented [19]. The user of this service will not a configuration or manage the hardware, operating system or the servers storage media.

B. *Cloud Platform as a Service (PaaS)*

This cloud service requires from the consumer to implement his software program using any software supported by the provider, the user then can upload his software in the service infrastructure. The user did not concern the administrating of other infrastructures.

C. *Cloud Infra Structure as a Service (IaaS)*

The third type of cloud services IaaS, supply the user with computation and storage [20], the user has to take care about the applications, data, runtime, middleware, and the operating system also. This type of services is the minimal level of cloud computing [21]. It only offers networking, computing, and storage while other requirements shod be provided and administrated by the user.

V. IoT Protocol Architecture

A. *6LoWPAN*

The 6LoWPAN is a Low-Power wireless Area Networks protocol allows any tiny device to have its own routable internet protocol IP. This simplifies the administration to be easier, moreover It also makes security more important as a result standard tools can be used to administer small devices. 6LoWPAN has a minimal use of code and memory and enables a standard socket API, Direct end-to-end Internet integration. Multiple topology options 6LoWPAN Device type can be a host, Router or ER Edge router.

VI. 6LoWPAN Layers Protocol Stack

The 6LoWPAN has special stack layers, figure (1) shows the 6LoWPAN layers and the main TCP/IP stack layers.

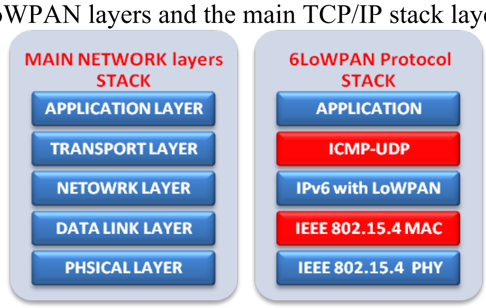


Figure 1: 6LoWPAN and TCP/IP stack layers.

1) *Physical and Data Link Layer*

In most IoT devices, both of physical and data link layer equipped with the IEEE 802.15.4 protocol which designed for low power consumption as well as low data rate (250 Kb/s), this impressive protocol pertaining for devices that suffering from severe battery depletion.

2) *Adaptation Layer*

The great features of the IPv6 are its flexibility and capability to scalability, consequently, it considered the appropriate protocol provide data communication for the internet of things. Whoever low power wireless personal area networks 6LoWPAN use the integration between the IPV6 and the protocol IEEE 802.15.4 [26]. To perform this integration an adaptation layer between the data link layer and the transport layer is added. The wireless communication between 6LoWPAN and the internet accomplished over the gateway device. The adaptation layer makes the wedge of IPv6 into 802.15.4, IPv6 contains a very large header that cannot fit with IEEE 802.15.4 which only has 127 byte MTU of the standard. Therefore, the necessity to carry out the important information and ignore the rest is required. The adaptation layer dedicated to finding an appropriate incorporation between IPV6 and IEEE 802.15.4 by compressing and fragmenting the packets this can be performed by [27]:

A. Header compressor

The IP6 has a maximum overhead to avoid this 6LoWPAN minimize the overhead using data compressing by skipping some of the fields and leave the link layer to drive it or can be shared across packets figure (2)

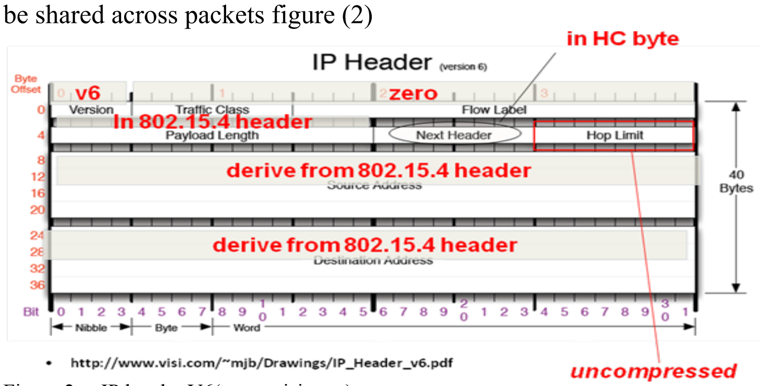


Figure 2.a: IP header V6(www.visi.com)

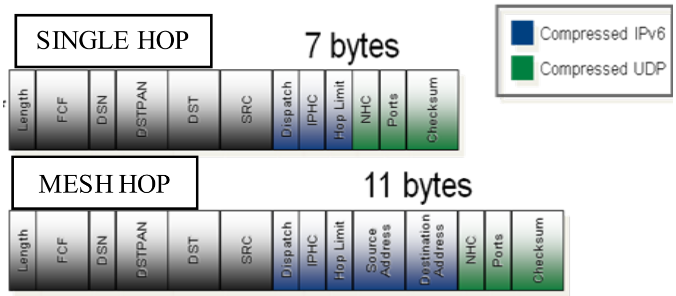


Figure 2.b:6LoWPAN compressor.

B. Fragmentation

The internet protocol IP6 has 1280 bytes of MTU whereas the Zigbee IEEE 802.15.5 only require 172 bytes. Hence the internet protocol IP6 should be fragmented. The adaptation layer, figure (3), derives the operation of fragmentation.

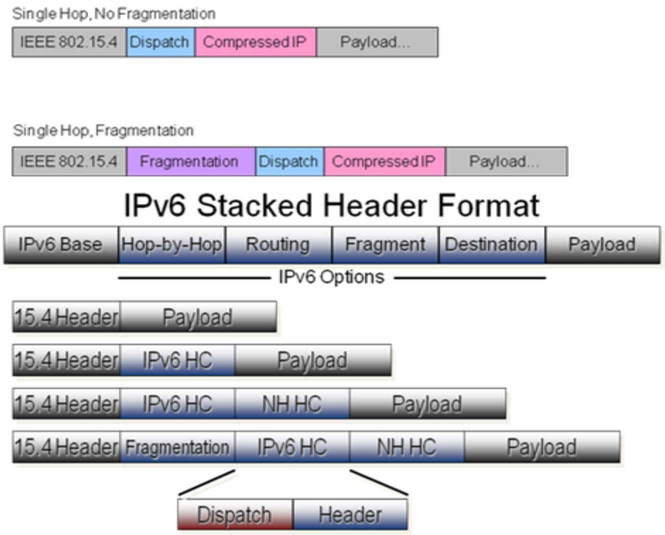


Figure 3: Fragmentations.

3) Transport Layer

Embedded system has a specially limited resource as an application requirement, due to the resource constrain the sophisticated network protocol such as transmission control protocol (TCP) implementation on the node has an influence on the system application such as maximizing the latency, contention to take tremendous memory size. Moreover TCP is a connection-oriented which has a large overhead. To avoid this, a pure UDP can be used instead of TCP or a lightweight implementation of the transport layer protocol suite (lwIP) can be used**.** The focus of the lwIP implementation is to minimize the use of the embedded system memory as well as providing powerful network transport protocols. This making lwIP suitable for use in embedded systems with limited memory size about 40 kb of code ROM**.** In addition**,** a fast data transmission can be achieved by using connectionless user datagram protocol UDP that supported in lwIP.

4) Application layer

Presentation and formatting the data is the main issue of the application layer. Most of the internet applications depend on the hyper terminal text protocol HTTP which is unsuitable with restricted resource constrained, in confirming with this a new novel protocol for the internet of things is emerged such as MQTT (Message Queue Telemetry Transport) and CoAP (Constrained Application Protocol).

A. Constrained Application Protocol:

Instead of using HTML or XML text format which is used in commonly used in the HTTP protocol. The CoAP protocol comprises a binary data which form the EXI (Efficient XML Interchanges) this led to more neat efficient constrained application environments, figure (4) [50]. For this reason, it is widely spread on IoT [22, 23]. Beside this CoAP protocol can perform automatic configuration, exchanging of the asynchronous message, resource detection and solve congestion problems. Multi-message types were supported such as non-confirmable, confirmable, reset (nack), and acknowledgment. In order to drive reliable data communication over user datagram protocol, confirmable messages are the best selection [24]. The response can be piggybacked in the acknowledgment itself. On the other hand, when security in mind DTLS (Datagram. Transport Layer Security) is used.

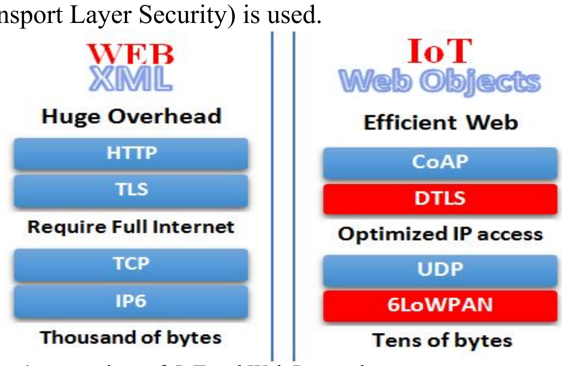


Figure 4: comparison of IoT and Web Protocol

B. Message Queue Telemetry Transport

The Message Queue Telemetry Transport MQTT protocol is a publish/subscribe working on transmission control protocol. The IBM Corporation is the developer of this protocol [25]. MQTT is a lightweight protocol, which is somewhere suitable for IoT applications, but Still, depend on transmission control protocol it is not preferable in most IoT applications in which the overhead is a bottleneck.

C. File Transfer Protocol FTP

Despite the surveillance of live data, the necessity of invoking data from storage media is required. Therefore the application layer includes the FTP service in order to allow the user request a file that contains aggregation sensors data with events and its accurate time. The data can be stored as long as the storage media capacity allows, or it can be programmed to start storing at a specific time interval.

VII. WSN PLATFORM DESIGN AND IMPLEMENTATION

The WSN Platform is a pivotal primarily part and considered as the core of the WSN network that performs variant issues such as: data acquisition, data processing and communication protocol.

The networking protocol incorporates special stack layers discussed in section 2.1 the main protocol used is 6loWPAN for data communication and transmission.

A. Data Acquisition system

1) Programmable System on Chip PSoC

Wireless sensor network platform contains analog parts which perform the sensor and data acquisition tasks. These sections consist of general purpose sensors and many different types of electronic devices like operations amplifiers and components such as resistors, transistors and capacitors. In addition there are also some others digital devices like counters and registers and logical gates, all of each working in integration to perform a complete continues data acquisition system. This type of constructing require a large area and an independent power supply for each device, this yields to a complicated platform design and reduce the power of the system and overall extend the platform area. To overcome this problem a programmable system on chip (PSoC) is integrated into the system instead of using a group or collections of electronic devices. The Cypress Semiconductor PSoC3 figure (5) is an advanced programmable embedded system-on-chip, which contains a reconfigurable digital and analog device such as computing system, memory, operations amplifier, general porpoise I/O ports, all embedded on one single chip. The PSoC has an advanced architecture that integrates the reconfigurable digital and analog device with a microcontroller. The single PSoC embedded system can drive more than 100 electronic functions reducing design time, board area (small space), power consumption, and system cost while improving system quality.

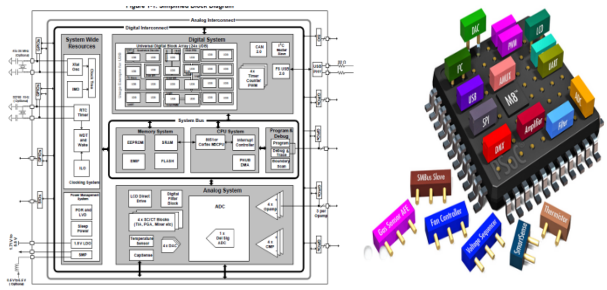


Figure 5: diagram of PSoC.

The PSoC embedded system introduce new electronic connection concept. The designer can perform the join and connections between the on-chip internal devices systems with full software control, this reduces the time and simplifies the design. PSoC Creator is a free Windows-based Integrated Design Environment (IDE). The software contains more than a hundred components, the designer can drag the component, code the design, configure the design, and review the hardware.

B. *Processing and Computing System*

1) *ARM Cortex*

The *Broadcom BCM* Cortex-A53 processor is a low-power consumption processor that implements the ARM architecture. The Cortex-A53 processor has one to four cores (quad-core), each with an L1 memory system and a single shared L2 cache. The most useful properties for this embedded system in addition to the low power is a small size, very fast processing and cheap (low cost) which make it suitable to use in the WSN node. This ARM chip is compacted in different evaluation boards with additional Peripherals and devices to perform ultra-small computers very similar to the normal personal computers and can perform the most tasks as they do figure (6). The system is configured and derived by operating system and can interface with other electronic hardware such as GPS for location services via USB, serial port, general I/O ports and Ethernet. The communication in the network is done by either an external transceiver or an internal build in 802.11 Wi-Fi. In addition to sensing the environmental critical phenomena, the system can be used as a communication web server on the network to display and exchange the wireless sensor network data for the remote monitoring and control clients in high-speed processing supported with high-level networking protocols.

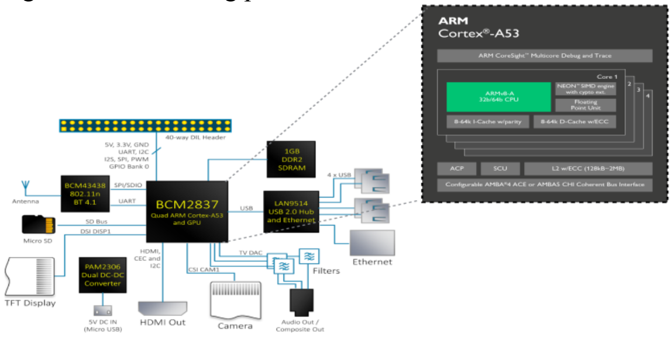


Figure 6: microcontroller internal block diagram**.**

2) *The Operating System*

The operating system is a resource manager for the nod embedded system, the task of the operating system is to manage the allocations of the resources to the system in an orderly and control manner. many types of kernel can support the embedded system such as UCLINUX, µC/Probe from Micrium, FreeROTS and others.

a) *Open source ARM Linux (Rh/Debian)*

The development and manufacturing of advanced small low power ARM microprocessor are spread wildly and are commonly used on more than millions of electronic systems including WSN platforms because of its powerful computing, small size, and overall a very low power consumption. Consequently, most of the biggest LINUX operating system corporations' providers and developer strives to introduce their own OS that supports this type of ARM CPU architecture. The most commonly ARM CPU that is supported with many types of open source Linux distributions is the ARM Cortex –A53 MP Core processor. The RedHat Company has a Fedora distribution optimized to support this architecture, most of the packages that work on the fedora can work in this platform which makes it useful to use in WSN node. The most important features of this distribution are that it supports wide LINUX networking packages and tools for Ethernet and wireless protocols, network management, network administrating, and server with file sharing. All this make it suitable for WSN developing.

C. *Communication system Protocols in IoT and WSN*

1) *Zigbee*

The Zigbee protocol is widely used in WSN and PAN due to its power efficiency and neat networking rout. This communication protocol depends on the IEE 802.15.4 on both of the physical layer and data link layer [28]. The main issues of the Zigbee protocol are to drive communication connecting low-cost low power resources constrained devices for a long time within a small area utilizing the IEEE 802.15.4. in addition, the protocol provides special networking and applications in both of top layers (network and applications layers). On the other hand, communication between the WSN node and the internet is another demand. There are many communications protocols schemes used in this field but the popular data transmission types dominated in the IoT are, low power Wi-Fi, LoraWAN, RFID, Sigfox, IEEE 802.15.4, NFC. In this work, we focused on both of WiFi and 6LoWPAN with WSN.

2) Low power Wi-Fi

The community of Wi-Fi introduces the new (WiFi HaLow). This type has very low power consumption as well as far propagating distance approximately double the ordinary Wi-Fi and depends on the original communication protocol 802.11 these advantages make it an appropriate communication technology for the IoT. The properties of this developed protocol [29, 30] intended to fit with WSN such as low power consumption, which makes it a use full device to integrate WSN with the Internet of Things.

VIII. METHODOLOGY

To implement data relay from WSN to the internet through the designed platform, two platforms is used:

A. ARM and 6LoWPAN Transceiver system

Normal TCP protocol has massive overhead and case maximize latency. The alternative solution is to use 6LoWPAN transceiver for small continues data transmission such as satellite tracking system. The 6LoWPAN use UDP protocol to inject data on the internet. The design uses the AT86RF233 SPI transceiver interfaced with the platform thru SPI figure (7). The operating system kernel is configured for 802.15.4, 6LoWPAN protocol and WPAN tools where build to configure the 802.15.4 devices. The sensor is connected to the PSOC device which performs the analog amplification and noise filtering then the PSoC send the converted data to the ARM computation system, in addition to the computing and analysis the ARM system the software network protocols to drive the AT86RF233 in order to relay the data to the internet. Any cloud service can be used to serve the application such as Windows AZURE, which has a special service to support the ARM devices.

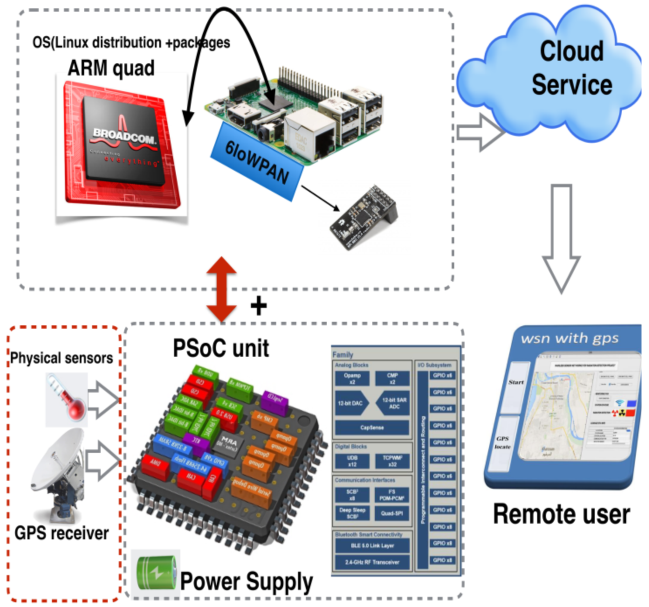


Figure 7: integration between PSoC, ARM cortex, 6LoWPAN

B. Digi XBee system

1) Wi-Fi system

This design intended to drive continues sensor data to the internet cloud, the system uses the XBee Wi-Fi module. That offers communication to remote point based on 802.11 bgn networks utilizing 802.11 proprieties. The device interfaced with the platform using SPI communication protocol. In order to drive the data from the platform over the device special package software is used, this package contains all AT command supported by the device.

2) Distance Measuring Equipment (DME)

The system incorporates an ultrasound sensor in order to check the fuel tank level. The ultrasound level is oriented to face the tank liquid surface and send pulses to that direction when the pulse reaches the liquid surface it bounced to the reverse direction toward the receiver the microcontroller compute and calculate the time between traveling and reflecting and determine the tank level. The level information is sent via serial port to the XBee device.

3) Actuators and valves

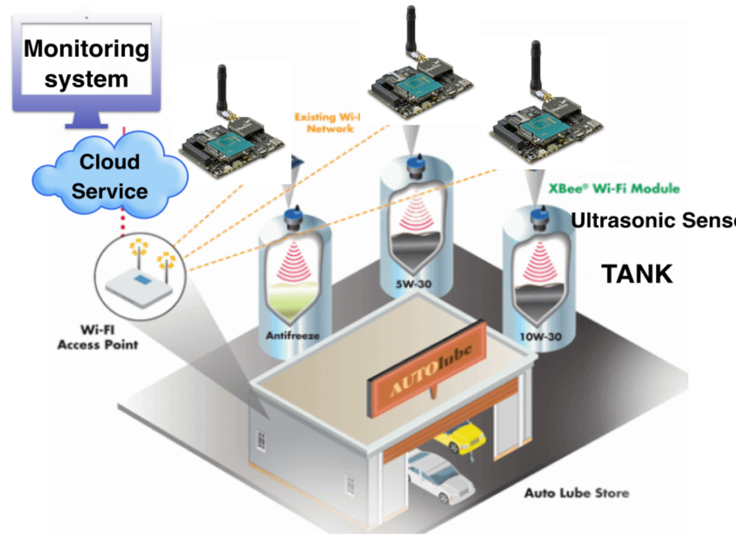
When the tank level exceeds the adjusted limit, the microcontroller sends an order to the stepper motors to close the feeding valves to prevent overflow, and when the tank level falls to end level the microcontroller gives an order to the pump to start work as well as the valve to open.

4) Temperature system

The fuel station is saturated with dangerous gases and liquids which my case explosion. To prevent this, a fire detector allocated and incorporated with firefighting system to eradicate any fire action. The detectors connected to the microcontroller and its state transferred to the XBee device.

VII. RESULT AND DISCUSSION

To simplify the surveillance of the system from each device support the internet. The DiGi internet cloud services for XBee device utilized to monitor and control the whole system. The benefit of the Device Cloud is to store system data as well as process it and display the data in advanced graphs. The user can start to monitor operation from any place where an internet service is available. Figure (8) shows the application system and figure (9) shows the cloud service monitoring application service.



Figurre8: fuel station controlled by XBee and sensors. (www.digi.com)

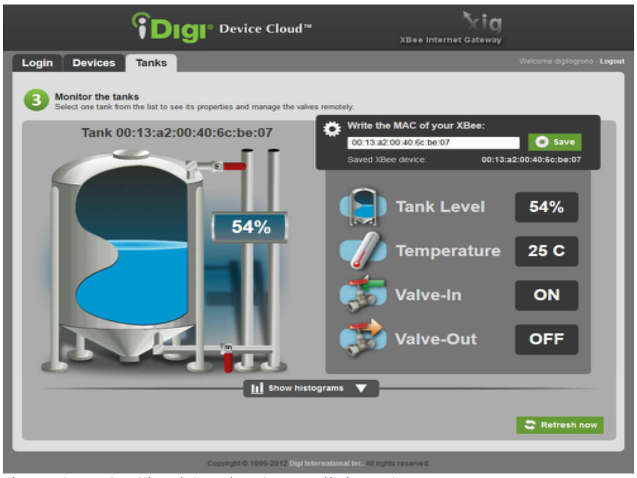


Figure 9: DIGI Cloud Service (www.digi.com).

VIII. CONCLUSION

This work introduce the concept of IOT and its novels protocols and network stack such as 6LoWPAN and communication device as well as the methods interconnects it with WSN, utilizing the concept of Cloud Computing for simplifying the storage of tremendous WSN data in the cloud and using its computation power to process and monitoring WSN applications.

REFERENCES

[1] M.Arul Mozhi Pradeepa, B.Gomathi "Towards Fog Computing based Cloud Sensor Integration for Internet of Things". International Journal of Computer Science and Engineering Communications, Volume.5, Issue.6 (2017): Page.1761-1773 www.ijcsec.com.

[2] L. F. Bittencourt, O. Rana, and I. Petri, "Cloud computing at the edges," in Cloud Computing and Services Science, M. Helfert, V. M´endez Mu˜noz, and D. Ferguson, Eds. Springer International Publishing, 2016, pp. 3–12.

[3] Luiz F. Bittencourt, Member, IEEE, Javier Diaz-Montes, Senior Member, IEEE, Rajkumar Buyya, Fellow, IEEE, Omer F. Rana, Senior Member, IEEE, Manish Parashar, Fellow, IEEE "Mobility-aware Application Scheduling in Fog Computing".

[4] Bonomi, Flavio, et al., "Fog computing and its role in the internet of things," Proceedings of the first edition of the MCC workshop on Mobile cloud computing. ACM, 2012.

[5] E. Borgia, "The internet of things vision: key features, applications and open issues, Comput. Commun. 54 (1) (2014) 1–31.

[6] L. Atzori , A. Iera , G. Morabito , "The internet of things: a survey, Comput. Netw. 54 (15) (2010) 2787–2805

[7] L.A . Grieco , A . Rizzo , S. Colucci , S. Sicari , G. Piro , D. Di Paola ,G.Boggia, "IoT-aided robotics applications",technological implications, target domains and open issues, Comput. Commun. 54 (1) (2014) 32–47.

[8] Andrea Zanella, Nicola Bui, Angelo Paolo Castellani, Lorenzo, Vangelista, and Michele Zorzi. "Internet of Things for Smart Cities". *IEEE Internet of Things Journal*, 1(1):22–32, 2014, doi:10.1109/JIOT.2014.2306328.

[9] Daniele Miorandi, Sabrina Sicari, Francesco De Pellegrini, and Imrich Chlamtac. "Internet of Things: Vision, applications and research challenges. *Ad Hoc Networks"*, 10(7):1497–1516, 2012, doi:10.1016/j.adhoc.2012.02.016.

[10] Pallavi Sethi and Smruti R. Sarangi "Internet of Things: Architectures, Protocols, and Applications". Hindawi, Journal of Electrical and Computer Engineering, Volume 2017,, Article ID 9324035, 25 pages, https://doi.org/10.1155/2017/9324035.

[11] G. Montenegro, J. Hui, D. Culler, and N. Kushalnagar, Transmission of IPv6 Packets Over IEEE 802.15.4 Networks, document RFC 4944, Oct. 2015. [Online]. Available: https://rfc-editor.org/rfc/rfc4944.txt

[12] S. Deering and R. Hinden, Internet Protocol, Version 6 (IPv6) Speci_ cation, document RFC 2460, Dec. 1998. [Online]. Available: https://rfceditor.

[13] Luigi Atzori, Antonio Iera, and Giacomo Morabito. The Internet of Things: A survey. *Computer Networks*, 54(15):2787–2805, 2010, doi:10.1016/j.comnet.2010.05.010.

[14] Maarten Botterman. Internet of things: an early reality of the future internet. In *Workshop Report, European Commission Information Society and Media*, 2009.

[15] Daniele Miorandi, Sabrina Sicari, Francesco De Pellegrini, and Imrich Chlamtac. Internet of things: Vision, applications and research challenges. *Ad Hoc Networks*, 10(7):1497 – 1516, 2012.

[16] J.M. Reddy, J.M. Monika, "Integrate Military with Distributed Cloud Computing and Secure Virtualization," IEEE Computer Society, pp. 1200-1206, Nov. 2012.

[17] Ahmed Mohamed Gamaleldin "An Introduction to Cloud Computing Concepts "Practical Steps for Using Amazon EC2

[18] Sun Microsystems, Inc."Introduction to Cloud Computing architecture", White Paper 1st Edition, June 2009.

[19] Mustafa Gamal, Ass. Prof. Manal Ismail, Dr. Hesham Kesk "SaaS-Flow: Software as a Service Workflow Management System". Faculty of Engineering, Helwan University, Helwan, Egypt.

[20] D. Nurmi, R. Wolski, C. Grzegorczyk, G. Obertelli, S. Soman, L. Youseff, and D. Zagorodnov, "The Eucalyptus open-source cloud-computing system", in Proceedings of IEEE/ACM International Symposium on Cluster Computing and the Grid (CCGrid 2009), Shanghai, China, pp. 124_131, University of California, Santa Barbara.(2009, Sep.)Eucalyptus [online].

[21] D. Nurmi, R. Wolski, C. Grzegorczyk, G. Obertelli, S. Soman, L. Youseff, and D. Zagorodnov, "The Eucalyptus open-source cloud-computing system", in Proceedings of IEEE/ACM International Symposium on Cluster Computing and the Grid (CCGrid 2009), Shanghai, China, pp. 124_131, University of California, Santa Barbara.(2009, Sep.)Eucalyptus [online].

[22] W. Colitti, K. Steenhaut, N. De Caro, B. Buta, and V. Dobrota,"Evaluation of constrained application protocol for wireless sensor networks," in Proceedings of the 18th IEEE Workshop on Local and Metropolitan Area Networks (LANMAN '11), pp. 1–6, IEEE, Chapel Hill, NC, USA, October 2011.

[23] Z. Shelby, K. Hartke, and C. Bormann, "The constrained application protocol (CoAP)," Tech. Rep., IETF, 2014.

[24] B. C. Villaverde, D. Pesch, R. De Paz Alberola, S. Fedor, and M. Boubekeur, "Constrained application protocol for lowpower embedded networks: a survey," in Proceedings of the 6th International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS '12), pp. 702–707, Palermo, Italy, July 2012.

[25] D. Locke, "MQ telemetry transport (MQTT) v3. 1 protocol specification," IBM developerWorks Technical Library, 2010, http://www.ibm.com/developerworks/webservices/library/wsmqtt/ index.html.

[26] D. Culler and S. Chakrabarti, "6lowpan: incorporating IEEE 802.15. 4 into the IP architecture, IPSO Alliance," White Paper, 2009.

[27] J.W. Hui and D. E. Culler, "Extending IP to low-power, wireless personal area networks," *IEEE Internet Computing*, vol. 12, no. 4, pp. 37–45, 2008.

[28] P. Baronti, P. Pillai, V. W. C. Chook, S. Chessa, A. Gotta, and Y. F. Hu, "Wireless sensor networks: a survey on the state of the art and the 802.15.4 and ZigBee standards," *Computer Communications*, vol. 30, no. 7, pp. 1655–1695, 2007.

[29] B. Shanmuga Sundaram, "A quantitative analysis of 802.11ah wireless standard," International Journal of Latest Research in Engineering and Technology, vol. 2, 2016.

[30] W. Sun, M. Choi, and S. Choi, "Ieee 802.11 ah: a long range 802.11 wlan at sub 1 ghz," Journal of ICT Standardization, vol. 1, no. 1, pp. 83–108,2013.