Wavelet Applications to the Internet of Things: A Smart Parking System

Pankaj Chhetri, Cajetan M. Akujuobi, Matthew N. O. Sadiku, Smriti Bhatt, Paras Bhatt

Roy G. Perry College of Engineering, Prairie View A&M University, Prairie View, TX 77446

Abstract The concept of a smart world has gained popularity in recent years. The idea of a smarthome, smart parking and smart cities have become a reality through the evolution of the Internet of Things (IoT). The continual efforts being made in the field of IoT directly contribute towards maximizing the productivity and reliability of urban infrastructure. The problems faced by big cities, such as traffic congestion, limited car parking areas, pedestrians and road safety are being managed by IoT today. However, to support a very large infrastructure within a nation and at a global scale, we need to utilize other applications in addition to the competences of IoT.

In this paper, we initially discuss the evolution and history of IoT and explore different IoT application domains. We then introduce a novel method of using Wavelet technology to enhance the effectiveness of the Cloud-supported Internet of Things applications. For this purpose, we present a conceptual use case of a smart-parking system employing the Wavelet and develop a design architecture based on Cloud-supported IoT architecture. The Smart-parking use case is designed to leverage the capabilities of a real-world cloud-supported IoT platform, viz. Amazon Web Services (AWS) and its IoT platform, AWS IoT. In our smart parking use case, we depict the applicability of Wavelet applications and present the implementation design utilizing AWS IoT. We also discuss the associated challenges and future avenues to develop our use case into a real-world deployment.

Keywords Internet of Things, Wavelet Applications, IoT Security, Smart Parking, Smart Devices

1. Introduction

Internet of Things (IoT) has received a considerable attention in both industry and academia in recent years. IoT, in simple words, can be realized as interconnection of smart objects or things. These things/devices are capable of autonomously gathering data and information from its surroundings which can be used in accomplishing a specific task. Recently, IoT has gained rapid momentum and is being explored in every field, such as commerce, government, academia, and industrial applications. There is tremendous growth of IoT devices and applications in the industry. Consequently, significant research on IoT including state-of-art surveys [1-3], and IoT applications in various application domains, such as healthcare [4], wearable [5], and smart home and smart communities [6-8], is being conducted.

The advancements in the Internet technologies and connected smart objects have contributed in making IoT a widely pervasive concept. IoT applications and services are tremendously enhancing our lives and will continue to do so in the future. However, there are many challenges associated with IoT, naming a few here are limited resources (e.g., power, storage, etc.), scalability, heterogeneity, and security and privacy. While many researchers and industry players are addressing these challenges with research and innovative initiatives, there is still a significant gap between current IoT applications (rapidly being developed and not widely adopted) and effective and secure IoT applications required for the continued success of IoT.

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In this paper, we focus utilizing Wavelet technology in assisting today's IoT applications for enhancing the quality of users' lives. This paper presents the application of Wavelet in context of Internet of Things. Our main objective is to explore Wavelet application and its consideration for IoT in a specific IoT paradigm, viz. Cloud-supported Internet of Things. Cloud computing is one of the most essential enabling infrastructure for IoT which abstract the heterogeneity involved with IoT devices and provide virtually unlimited resources, such as storage, computation, and analysis to IoT [9, 10]. We demonstrate a smart parking use case scenario in a Cloud-supported IoT environment. For our conceptual use case, we consider one of the largest Cloud services provider, Amazon Web Services (AWS) [11] and its Internet of Things (IoT) service, AWS IoT [12]. We present the architectural components of the smart parking use case utilizing Wavelet and AWS IoT. Finally, we also discuss implementation challenges involved as well as future directions.

The rest of the paper is organized as follows. Section 2 provides a brief introduction to Internet of Things and its evolution and history. Section 3 discusses current state-of-art of IoT and its application domains and infrastructure including some examples. Section 4 presents introduction to the Wavelet technology and its application to IoT scenarios. In Section 5, a Smart Parking use case utilizing Wavelet-based application in Cloud-supported IoT architecture is presented. Lastly, Section 6 provides a summary of our work and discusses future directions to be investigated in context of our use case and innovative methodology of employing Wavelet application.

2. Background

Due to the diverse and dynamic nature of IoT, different definitions and descriptions of IoT are available. The Internet of Things (IoT) is a network of Internet enabled devices, machines, objects, and people which work together autonomously by gathering surrounding data, performing analysis on it, and providing valuable information to the IoT stakeholders along with accomplishing a specific task or function [13]. In other words, IoT is network of sensors and actuators embedded into physical objects which has the ability to connect to the Internet(the core of IoT), and gather and exchange data with other objects/things, people, machines, and systems in the network[14, 15].

Internet of Things: History

The concept of IoT has been around for more than two decades now. One of the early implementations of IoT was found at Carnegie Mellon University in 1982, where a coke vending machine was connected to the Internet and was queried to know about inventory, i.e. coke is available in the machine or not, and if the drinks were cold. Similarly, in early 1990s, seminal research and publications in ubiquitous computing by Mark Weiser's, and concept of automated connected home appliances by Reza Raji started to appear. However, the term Internet of Things was first coined by Kevin Ashton of Procter & Gamblein 1999. Around the same time, IoT started to gain momentum when Device-to-Device communication was first introduced by Bill Joy as a part of his "Six Webs" framework. Later during the same year, Kevin Ashton identified Radio-Frequency Identification (RFID) technology as the foundation of Internet of Things, and promoted this concept by Auto-ID Center at MIT [15].

Another milestones in the history of IoT was achieved when the number of connected devices surpassed the human population between 2008 and 2009. In 2011, Gartner introduced the term "Internet of Things" in their hype cycle for emerging technologies, which reached around the peak of the cycle in 2014. Along the timeline, IPv6 launch, commercial presence of Arduino and other hardware platforms, and recently introduced IoT platforms are major parts of the IoT history and growth over the years [16]. Today, major Cloud services providers, naming a few, Amazon Web Services (AWS) [11], Microsoft Azure [17] and IBM Watson [18], have introduced their own Internet of Things (IoT) platforms.

Evolution of Internet of Things

The evolution of the IoT converges from the development of wireless technologies, micro-controllers and micro-electromechanical systems (MEMS), machine-to-machine technologies, and the Internet. Another factor to support the evolution of IoT is the large Internet addressing space achieved through the advancement in IPv6

[13]. It is required to identify each object uniquely in the physical and virtual space, and for billions of connected devices it will be made feasible by large addressing space provided by IPv6. The evolution of IoT has also been maintained based on basic IoT architectures, where a simple IoT architecture comprise of three layers: i) *Object or perception layer* where the devices and physical objects are present, ii) One or more *Middleware layer(s)* where virtual objects (digital counterpart of physical objects) and Service-Oriented Architecture (SOA) management services and Cloud services reside, and iii) *An application layer* is at the top of the architecture where users and administrators can directly access these applications [1, 9]. An access control oriented (ACO) architecture for Cloud-enabled IoT with four layers is presented in [9]. Similarly, other layered IoT architectures including three basic layers and additional layers have been developed in [1, 3].
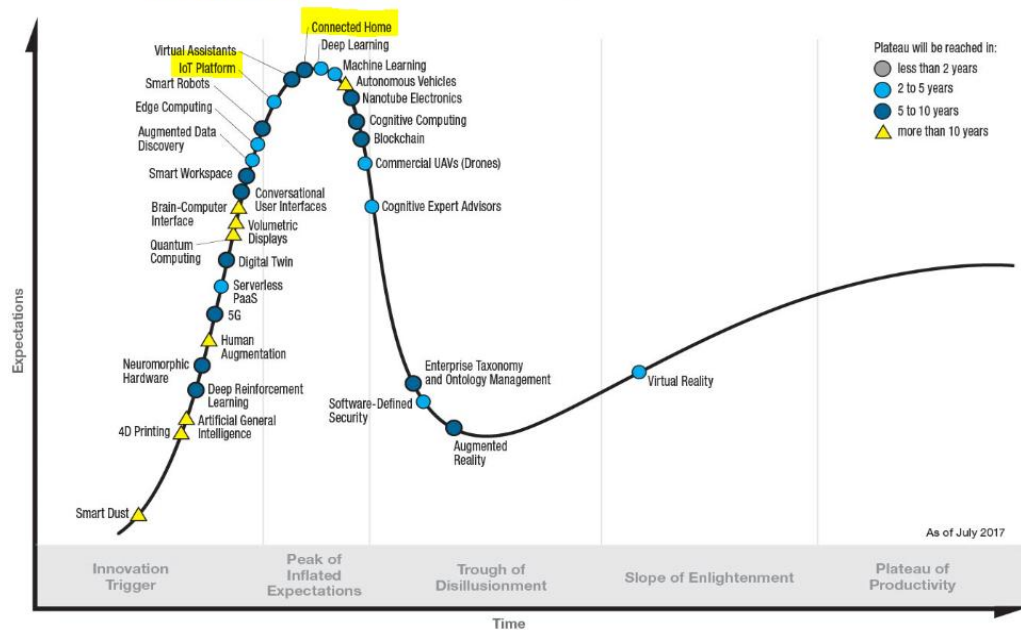

Figure 1: The Gartner Hype Cycle for Emerging Technologies, 2017[19]

IoT is evolving with "anything" and "everything" being connected to the Internet as well as becoming smarter with support of technologies like Cloud Computing, Artificial Intelligence (AI), Big Data Analytics, and Machine learning. According to Gartner hype cycle for emerging technologies as of July of 2017, IoT Platforms are towards the peak of the cycle and are expected to reach the plateau within next two to five years [19]. Moreover, the number of connected devices is growing exponentially and has been estimated to reach more than 20 billion devices by 2020 [20]. Influenced by these predictions and advancements in the IoT arena, numerous IoT applications and services are being developed and deployed in different sectors, such as industry, government, education, transportation, infrastructure, healthcare, and military. Some of the common examples of IoT today are: connected smart homes, connected appliances (e.g., thermostats), smart cities, connected cars, smart grids, smart medical devices and applications, wearable devices, etc.

3. IoT Application Domains and Infrastructure

IoT has shaped into a very diverse and broad concept. Through a combination of IoT enabling technologies, various IoT applications and services are put forward and deployed in commercial and domestic environments in different parts of the world. In [1], Atzori et al. discusses some of the application domains where IoT is enriching the quality of our lives: i) Transportation and logistics (supply-chain); ii) Healthcare; iii) Smart environment (home, office, plant); and iv) Personal and social domain; also a special "Futuristic domain" where IoT will play an important role in the future. Similarly, a holistic view of IoT application domains is shown in Figure 2, which is presented by Bhatt et al. in [21]. Here, the authors depicted the IoT domains space as continuously expanding arena and implied other domains to be added in the near future through a dotted blank oval. In each of these domains, many IoT examples are being applied and installed.
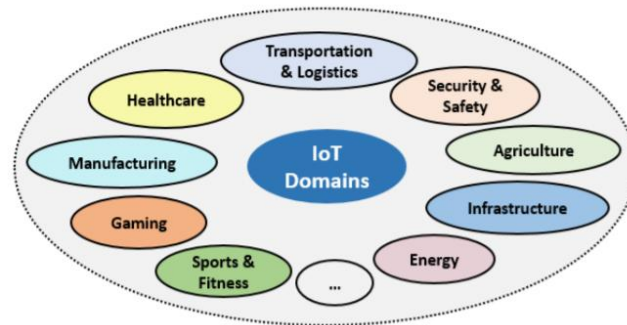
Figure 2: IoT Application Domains [21]

IoT Application Domains:

Some of them are discussed as follows.

- **Transportation and Logistics:** Autonomous smart cars, connected busses with real-time information and location data, traffic management with smart lights, sensors, and cameras, RFID [22] enabled toll tags, sensor-enabled parking, are some of examples in the transportation domain. In logistics, IoT is applied to manage supply-chain in different scenarios with real-time information sharing [1]. For example, in an IoT based supply-chain scenario, any product shipped from Amazon that has RFID enabled labels can automatically update its tracking status.

- **Healthcare:** IoT is playing a major role in healthcare with smart medical devices and wearable IoT devices for providing quality care to the patients. Ambient assisted living, chronic disease patients' care, and remote patient health monitoring are a few examples of IoT in the healthcare domain. A range of wearable IoT devices, such as glucometer, heart rate tracking device, are available in the market to measure vital body parameters and monitor user health [21].

- **Infrastructure:** This domain includes the smart environment and infrastructure enabled by the IoT, for example smart homes, smart cities, smart grids, etc. As per Gartner hype cycle for emerging technologies, we will be seeing connected homes within the next five to ten years. In many parts of the world, smart cities are being setup and employed to benefit human kind [23].Currently, many of the things in homes are connected, such as thermostat (e.g., NEST), light bulbs, refrigerators, smart window blinds, etc.

- **Security:** IoT applications are also being explored in security arena. An interesting example is a wearable band, named Nymi Band [21, 24], which can be used to authenticate to applications and services within a range of user proximity. The band authenticates the user based on its heart rate. Similarly, safety domain includes IoT examples which ensures the safety of the users. For example, smart cameras monitoring homes and surroundings to protect against adversaries.

Similarly, other IoT domains comprise of their own examples and applications. For instance, in agriculture domain, a common example is a plant watering system based on moisture sensor monitoring the moisture level of the soil. For energy preservation, IoT sensors are utilized to monitor energy usage and data. These are some of the many examples of IoT that have already been realized in different sub-fields of IoT. Wearable Internet of Things (WIoT), Vehicular Internet of Things (VIoT), and Medical Internet of Things (MIoT) are sub-fields of IoT.

IoT Infrastructures and Services

IoT includes smart devices (e.g., sensors, actuators), it's enabling technologies (e.g., networking protocol, M2M communication protocols), and an IoT framework that supports its operations, an example of it is the Cloud-enabled IoT framework [1, 9]. Smart IoT devices, such sensors, actuators, smartphones, are basic element of the IoT infrastructure. They collect relevant data and perform some specific functions to provide services to the end users. The enabling technologies of IoT comprise of Internet, wireless technologies – Zigbee, Light-weight Bluetooth, 6LoWPAN, secure communication and networking protocols – MQTT (Message Queue Telemetry

Transport), CoAP (Constrained Application Protocol), Cloud Computing, and Big Data and Analytics [2]. These technologies enable a viable infrastructure for IoT and allow to provide IoT services to the customers.

A popular IoT paradigm is Cloud supported or Cloud-enabled Internet of Things. IoT devices are generally small in size and are resource constraint with limited storage, computation, and analytics power. Cloud provides unlimited resources to IoT. The huge amount of data collected by IoT devices can be stored and analyzed in the Cloud. Major Cloud services providers are utilizing their cloud services to provide IoT services and solutions built upon their cloud infrastructure. AWS IoT [12] by Amazon Web Services [11], MicrosoftAzure IoT Suite [17], and IBM Watson Internet of Things [18] are among currently available IoT services. These services allow users to connect their IoT devices to the Cloud, and enable secure bidirectional communication between devices and Cloud services to perform desired IoT functionalities.

4. Wavelet and IoT Applications

A wavelet is a mathematical function used for digital signal processing and image compression. It is a tool that enables the analysis of several timescales of the local properties of complex signals. Wavelets can be used for wide range of application in various fields, such as Geophysics, Astrophysics, Video coding, Image compression, IoT applications etc. [25]. It is the foundation for new techniques of signal analysis and synthesis and its applications are used to solve various problems in the area of compression and de-noising.

The advancement of wavelets in the both academia and industry is astounding. The usage of application of wavelet is not limited as the technological development has no physical barriers and expands in different directions so does the wavelet application advances. Relating application of Wavelet to IoT is being used amongst different IoT sectors: manufacturing industry, automobile, construction and building, smart homes and cities and so on. The different types of wavelet such as: Haar, Daubechies, Symlets, Morlet, Mexican Hat, etc. are being used in the area of IoT in terms of various applications including Image, Video, Data compression, and Big Data Analytics.

Now, even the agricultural sector is not left behind in technological enhancement of Internet of Things by improving the productivity and quality of crop yields, and farms. The application of wavelet is used for image and data compression and to analyze the big data collected from the sensors installed in the farms. Wavelet application plays a vital role in the enhancement of IoT for Agriculture (IoT4Ag) [26], it provides the extremely productive ways to cultivate soil, raise livestock, higher production, crop health, automated machinery in use, energy and water consumption level. IoT4Ag ensures the higher level of accuracy and timely communication of real time data collected through sensors and applications of plantation, harvesting, water level, soil quality, and weather forecast to the farmer's before-hand. Wavelet application, particularly, is used to compress and analyze the collected data, the data is then processed and becomes available to the farmersas real time information in advance which helps them to plan their course of action pre-hand and take necessary steps for future occurrence [26].

Similarly, the capabilities of the Wavelet can be explored in various IoT application domains as discussed earlier. There is huge amount of data associated with IoT applications. A smart parking use case employing Wavelet is presented in next section.

5. A Smart Parking System

Wavelet has been heavily used in image and data compression and analysis techniques. Utilizing the capabilities of Wavelet, many different IoT applications can be designed efficiently. Mostly IoT data comprise numerical data, however, with everything being connected to the Internet and large number of surveillance cameras and smart phones generate Big Data of images and videos. In such scenarios, Wavelet tools and models can be utilized to process huge amount IoT data (e.g., still images and video frames). Video analytics is also used for cognitive assistance, for example Google glasses capture user environment data and provides cognitive feedback to users regarding different operations to assist them.

In this paper, we present a conceptual use case scenario of Smart Parking system where real-time data of parking lots and available spaces can be provided to the users through a mobile App. This application shows different analytics based on the data (images, video frames) collected by cameras and sensors installed at

various parking lots inside the parking complex/area. Based on the information available through the app, people can decide which parking lot has space and are closer to their location for parking their vehicle. It is very useful in saving time and energy, which otherwise is wasted, in finding parking. This scenario could be used for any parking where IoT devices can be deployed.
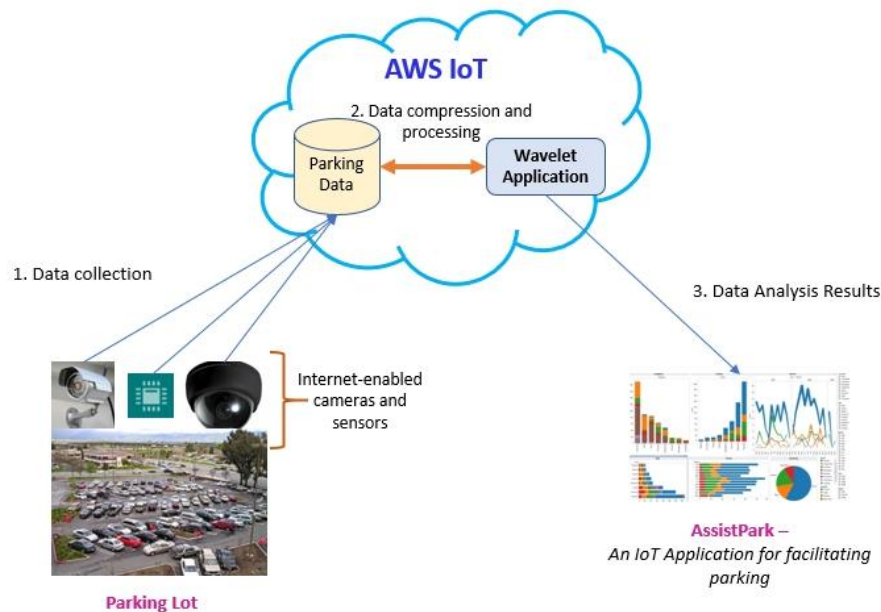

Figure 3: A Smart Parking Use Case Utilizing AWS IoT Platform

In this paper, we present a conceptual use case scenario of Smart Parking system where real-time data of parking lots and available spaces can be provided to the users through a mobile App. This application shows different analytics based on the data (images, video frames) collected by cameras and sensors installed at various parking lots inside the parking complex/area. Based on the information available through the app, people can decide which parking lot has space and are closer to their location for parking their vehicle. It is very useful in saving time and energy, which otherwise is wasted, in finding parking. This scenario could be used for any parking where IoT devices can be deployed.

The Smart Parking System, named as *AssistPark*, consists of an on-site deployment of IoT sensors, actuators, cameras, connected to the AWS IoT and cloud services. These devices collect data which is processed and analyzed and then used to monitor and signalize the availability of parking space to the users by assisting in parking and saving their time. The implementation components of the use case are considered to be hosted on the AWS Cloud employing the Wavelet applications for data compression. The data, images, and videos collected by sensors, actuators, and cameras are processed and compressed using the Wavelet signal processing technique. Wireless Sensor Networks (WSNs) are another vital architectural component of the use case. The cars and sensors deployed at each parking space are connected to the internet and would form multiple WSNs where different cars and sensors can communicate with each other. If there is a parking space available nearby, then the cars in that area would get notification about available parking. Using the shortest path algorithms and available data in the Cloud, the cars who have allowed notification alerts for parking assistance will get alerts or notification on the nearest vacant parking space. The sensor data, images and videos captured by cameras are transmitted to the AWS cloud server where wavelet applications will be used for data compression and analysis; shortest path algorithm and data analytics and visualization will provide the user the status of subscribed parking lots duringcontinuous time interval.

In Figure 3, a sequential view of the use case where multiple smart cameras and sensors deployed at a parking lot collect data associated with the parking availability and push it to the AWS IoT Platform [12]. The security of data transfer is managed through SSL/TLS and AWS inbuilt support for devices. A formal access control model for AWS IoT, known as AWS-IoTAC, is developed by Bhatt et al. in [6], where the authors also presented ABAC enhancements to the AWS-IoTAC model. In the Cloud, there is a data storage and a Wavelet

application which allows to process and analyze data by compressing it and extracting required information from the data. Other AWS services, such as Simple Notification Service (SNS), can be utilized to send alerts and messages to users regarding updates in parking availability. Wavelet application and tools, as shown in [27] where the authors presented a Gamma Modulated Wavelet Model for IoT traffic data analysis in scenarios like smart hospitals, smart homes, smart shopping center, and smart grid, can be employed in the AWS IoT platform for data analysis and processing. The final results of the analysis are forwarded to the parking assist application, *AssistPark*, which does predictive analysis to find parking trends and availability of parking space over the time of the day and presents the results and information in form of figures and graphs on the application dashboard. This use case is a conceptual idea of how Wavelet techniques and applications can be applied in context of the Cloud-supported IoT. Due to the involvement of various architectural components and diverse applications, the real-world implementation of the use case includes several challenges. Some of them are, security and privacy of the users, IoT devices, and cars; application of efficient Wavelet model and techniques; and development of a mobile application for different users (iOS and Android).

Implementation Considerations and Challenges

Cloud computing and Internet of Things (IoT) are two totally different domains which are brought together with industrial developments and academic research and has now become a part of our daily lives. The implementation, adoption and use of these two technologies together are expected to be more widespread, which will make them vital components of the future IoT technology. There are an array of technical terms involved when Cloud computing and IoT collaborate together. Cloud computing enables data storage and management collected through different IoT devices and provides back-end infrastructure by providing data servers and endpoint SDK and API components. The SDKs are embedded into the internet connected devices and exchange real-time two way data with the remote server. The cloud server/back-end server provides all the back-end functionality needed to operate even large scale and critical IoT solutions. The cloud server manages secure two way communication across all the connected objects, including data consistency, device interoperability, and security and privacy concerns.

As mentioned earlier, Wavelet is a mathematical function used to digitize signal processing and data compression. It is considered as a tool which is implemented at the back-end of Cloud server to analyze, process and compress the data collected by different IoT devices. The volume of data being collected by millions of IoT devices will be very huge and to support this volume of data the need for a stable environment is crucial. Implementation of Wavelet technology is a novel model for IoT supported by Cloud infrastructure and enables a large number of application and use case scenarios in this domain. Therefore, the Cloud-supported IoT platform that we have considered for our future proof-of-concept prototype implementation is AWS Cloud and AWS IoT services.

One of the major concerns for Cloud-supported IoT application is security and privacy, especially users and devices authorizations and communications. There is foundational research being done in the areas of IoT access control and authorization. A comprehensive survey on access control models for IoT is presented by Ouaddah et al. in [28]. For the *AssistPark* where numerous users, cars and IoT devices will be communicating with each other, we plan to apply a combination of Role-Based Access Control (RBAC) [29, 30] and Attribute-Based Access Control [31, 32] models for securing the authorizations and communications in the Smart Parking system architecture. A Role-centric ABAC model that combines the advantages of RBAC and ABAC has been developed by Bhatt et al. in [33]. The authors also presented an ABAC model with the user and object groups, group attributes, and hierarchical relationship between groups and attributes of theusers and the objects [34]. The concept of grouping IoT devices and cars based on similar characteristics is applicable in our use case scenario where sensors and actuators can be grouped together to assign attributes as well as defining authorization policies.

Our combinational approach allows to combine user roles and attributes of users, devices, cars, and application to be used in the access control framework where only user with specific roles and attributes will be authorized to communicate with the devices, Cloud, and AssistPark application. Similarly, the devices and cars would be

able to communicate messages with each other based on their attributes (e.g., owner of device or car, location of device and car, time of the day, etc.) and ABAC policies defined by the administrator in the system.

6. Conclusion

Wavelet application for IoT seems promising, especially when IoT data is growing at an exponential rate. Wavelet based statistical models and applications will directly contribute towards analyzing and visualizing the IoT data and its results. It will help in making critical decisions for improving the quality of our lives, be it in any IoT application domain and significant research applying Wavelet technology to different IoT domains is essential to realize its full potential. The Cloud-supported IoT architecture provides a framework with all the essential resources and enables an environment for future research and application of Wavelet in different IoT domains. In this paper, we presented a conceptual smart parking use case and its architectural and implementation components. In the future work, we plan to implement an operational proof-of-concept prototype utilizing the Wavelet application and AWS IoT platform. Another future research direction in the same context is to develop an access control mechanism employing RBAC and ABAC which can best address the security and privacy issues in Cloud-supported IoT architectures.

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Authors

Pankaj Chhetri is an IT Professional and a doctoral student at Prairie View A&M University, Texas. He is a student member of IEEE. His research interests include: Cloud and IoT Security, Access Control Models on IoT devices and IT Management and security.

Cajetan M. Akujuobi is the vice-president for Research, Innovation and Sponsored Programs at Prairie View A&M University, Texas. He is the author of two books and several papers.

Matthew N.O. Sadiku is a professor at Prairie View A&M University, Texas. He is the author of several books and papers. He is an IEEE fellow. His research interests include computational electromagnetics and computer networks.

Smriti Bhatt is an Assistant Professor at Texas A&M University- San Antonio. Her research interest is in the area of Cloud and IoT Security, Access Control models.