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IoT – Principles and Paradigms

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ABSTRACT

Every industry in the world is getting equipped with smart devices. The healthcare industry is enhancing its services via various smart wearable devices. The transport industry is developing customer satisfaction and goods security with the use of the intelligent transport system. The agriculture industry is pressing towards smart farming, like using sensors to improve the irrigation system and farm monitoring, and many more such domains are aiming towards an automated and smart environment. The education system is also leaping forward by introducing the concept of a smart university. Internet of Things (IoT) will play a crucial role in the pursuit of worldwide connectivity. In this paper, we have broadly discussed the basics of IoT, its applications, and various protocols and databases used. We have provided a brief insight into myriad of IoT applications, namely Smart cities, Smart security, Smart agriculture, Home automation, Smart health, Industrial control, Smart cars, and Smart university. Also, a comparison of protocols-CoAP, XMPP and MQTT - has been highlighted. For database connectivity, comparison among MongoDB, SQLite, and Firebase has been discussed. We aim to provide a succinct survey to all those who want to use IoT predominantly and specifically according to their requirements.

Key words: Applications, Databases, IoT, Protocols, Survey.

1. INTRODUCTION

IoT- a network of interconnected devices and services which adhere to specific and standardized protocols - is a paradigm, which contributes the ideology enabling any device possessing cognitive skills, irrespective of its spatial and temporal arrangements, to share and analyze data and perform some intelligent task, say to improve and/or aid our lifestyle. It has made access to information and communication among devices easier, with minimal and optional human intervention as well.

IoT is comprised of smart devices—generally sensors, actuators, and gateways—inter-communicating with each other using their UID (Unique Identifier), and sending the data collected to the cloud. Once it gets to the cloud, it is processed to perform some rule-based action, to improve and/or achieve the goal. It provides a wide platform of usage in different domains like healthcare, education, agriculture, automotive, transportation, logistics, environment, energy, business, and government. IoT is expected to occupy all major service domains, improving the quality of consumers' life and the enterprises' productivity [1]. IoT is set to change fiction to reality soon and enable us to drive into efficiency. The concept of 'IoT' dates back to 1970 under the term "embedded internet" or "pervasive computing"- coined by Kevin Ashton in 1999 during his work at Procter and Gambler [2]. The earliest model of an internet-connected appliance was Carnegie Mellon University's Coke machine, in the early 1980s, which allowed the programmers to check the status of the coke in the vending machine [3].

IoT is gaining a big focus in the development of various small entities of the smart world and is widely accepted due to its useful impact on the daily life of human beings [1]. IoT Smart connected objects are expected to reach 75.44 billion by 2022, and its economic impact will be between 2.5 trillion dollars to 6 trillion dollars by 2025 according to report by Statista. According to McKinsey's survey, the internet-connected devices have grown 300% in the last 5 years and M2M (Machine-to-Machine) traffic in the United States has grown 250% in the last 5 years. It present unique and new market opportunities for a variety of business such as manufacturing units, application developers, etc. It has been successful in securing an important position in the government's priority tasks, and also admitted to the central government's 15 priority technologies. The biggest economic impact is expected to be observed in healthcare and manufacturing industry.

In our survey, we noticed that due to the inherent heterogeneity of the devices, as well for supporting a myriad of services, there has been extensive research resulting in the development of various communication protocols as well as storage mechanisms and structures for efficient analytics. But an underlying issue is- there is not sufficient documentation to support standardization of the interfaces as well, say rules regulating or directing their usage, etc. hence a novice might get lost while trying to comprehend the concept, even for some specific application or service development based on IoT. We have made an effort to alleviate the problem, and for the same, have extensively referred major research papers on

IoT concerning protocols and applications, from the year 2010 to the present such as [5],[14], etc. Our paper aims to provide a step towards approaching the concept with relative ease, by providing a simple and concise scope of the tools and technology, for beginners and alike.

Table 1: Comparison of widely used protocols

Property	CoAP	MQTT	XMPP
Transport	UDP/IP	TCP/IP	UDP/IP
Interaction Model	Request-Reply (REST)	Publish-Subscribe	P2P
Scope	D2D	D2D, C2C	D2D, C2C
Interoperability level	Semantic	Foundational	Structural
Security	DTLS	TLS	TLS/SSL
Fault Tolerance	Decentralized	Broker SPOF	Server SPOF
Standard	IETF	OASIS	IETF
Message Pattern	R/R	Publish/Subscribe (P/S)	P/S by extension
Address	DTLS	Topic only	JID
RESTful	No	Yes	Yes
2G, 3G, 4G suitability	Excellent	Excellent	Excellent
Low power	Excellent	Good	Fair
Compute Resources	10Ks/RAM Flash	10Ks/RAM Flash	10Ks/RAM Flash
Architecture	Tree	Tree	Client-Server
Header size	4 bytes	2 bytes	-
Target devices	Very constant	Generic	High memory consumption
QoS(Quality of Service)	Yes	Yes	No

The rest of the paper is organized as follows: Section 2 deals with core application layer protocols for communication, namely CoAP, MQTT, and XMPP, and their comparison. Section 3 provides an insight into the databases and/or cloud services for analytics and decision-making. Section 4 deals with applications of IoT, with their brief comparison. Section 5 concludes the paper.

2. PROTOCOLS

IoT pervades across a giant array of domains, encompassing single system to multiple-platform deployments to real-time cloud systems [9], wherein the components communicate with others (Device2Device), and the collected data will be sent to the server infrastructure (D2S), which will consequently share device data (S2S) to devices or people [10]. Hence, we need standardized communication protocols for effective integration among heterogeneity of sensors and devices operating in the network. A comparison among the following protocols has been depicted in Table 1, namely, CoAP (Constrained Application Protocol), XMPP (Extensible Messaging and Presence Protocol), and MQTT (Message Queuing Telemetry Transport).

3. DATABASES

With the current advent in IoT, Cisco estimates that 5 exabytes of data is being produced every day, and approximately 500 zettabytes of data would be generated per year by the end of 2019, and will further continue to grow so exponentially. The data generated would be so humongous that even a lifetime would be insufficient to manually analyze the data produced by a sensor in some automotive industry. This vast store of data presents a plethora of opportunities to everyone for feature extraction and analysis, and to provide those as services to the consumers. As estimated by Statista, the global IoT market will hit 8.90 trillion, owing to the vast growth rate and generation of data, subsequently being used for analytics. But the problem, as found out by Harvard Business Review, is that hardly 1% of the data is being analyzed or used at all, while less than half of the structured data is being used for analytics and decision making.

The main problem faced in analytics is the maintenance and storage of the data being generated, and lack of standard methods for mining the knowledge from the data. Data is at the core of IoT; its handling and utility extraction is of great value for the companies, hence it needs to be focused on [19]-[21]. Firstly, determine the exact functionalities required, and analyze the data requirements for the same, and the information needed from the data [12],[22]-[24]. Some such factors for choosing a database are size, indexing of data, portability, querying, transaction and process modeling, aggregation, archiving, security and cost. Then split the functionalities according to the services provided by the software to be used for data processing [23],[24]. The following Table 2 compares some of the various widely used databases:

Table 2: Comparison of widely used databases

	MongoDB	SQLite	Firebase Real-time Database
Type of database	It is a free and open-source cross-platform document-oriented NoSQL database platform, which stores all the records called documents, in BSON format.	It is an open-source embedded relational database, having a serverless transactional database. SQLite is one of the most widely used Relational databases for IoT.	It is a cloud-hosted fully-managed NoSQL document database which allows to store and sync data, even at a global scale, in real-time.
Usage	Very fast and powerful database supporting unstructured data. It is an unstructured database, allowing different data types to be stored and to be processed in real-time, hence suitable for IoT.	SQLite database engine is present at the center of the network and the edge too thus capable of providing fast reliable services to applications with reduced overhead. Vast applications in IoT for an easy and resource-constrained computing environment.	It comes to the rescue for complex protocols like HTTP (Hyper Text Transfer Protocol) and MQTT, and acts as a communication medium for IoT sensors and interconnected devices. The major advantage is the fact that they have a powerful APIs [12], and also provides support for offline services.
Data Storage format	Document-oriented BSON notation for easy read, store, transmit and web-interfacing	ACID-compliant transactions Uses B-tree pages	Documents and collections with powerful querying, does not follow any structural database rules and constraints. When network connectivity is established, such operations are synchronized with the database[13]
Compliance with services	Services/API are linkable to dynamic apps via some UI.	Linkable to dynamic applications but services/API have to be built along with UI.	Provides iOS, Android, and Web SDKs, even offline data access. It helps users in working freely and independently with databases.
Core features	Efficient RAM caching, Time-to-Live collections for data, Reliability, Accessibility, Highly scalable.	Portable and efficient, Reliable, Cross-platform Small code/memory footprint	Automatic, multi-region data replication with strong consistency. It is a cross-platform client platform, wherein the clients access the same resource from Firebase server, and automatically updates when any data is stored or changed [13].
Real-time Operability	Sharding for automatic load balancing on servers	Operable in serverless environments and No administrative authentication required No dependencies	Provides cross-platform functionality which will allow sharing of the same resource to all clients from the server. Enables serverless development

4. APPLICATIONS

A. Smart Cities

A smart city is an area where humongous data is collected from the region to provide information which can be used to manage its resources efficiently. Major cities like Seoul, New York, Tokyo, Shanghai, Singapore, Amsterdam, and Dubai are already working towards smart city projects [4]. To convert a traditional city into a smart city implies engaging with the data exhaust produced from the city and its neighborhood [16]-[18], by equipping devices with smart sensors, and using it to automate and operate tasks efficiently on physical and virtual levels.

B. Smart security

The prime reason why IoT is going boom is due to its ability to secure things since the security invasions and emergencies can be notified to the user immediately. Some of the aspects are Surveillance and Perimeter Access Control which involves detection and control of people in unauthorized and restricted areas, especially for usage in military and other defense forces where non-authorized people or citizens are strictly prohibited. Also, Smart security can be used for the safety of equipment such as Fluid Presence and Detection in sensitive building grounds, huge data centers and warehouses to prevent breakdowns and corrosion. Also, Radiation Level Monitoring in nuclear power station surroundings, wherein distributed sensing of radiation levels is used for indicating leakage alerts. Similarly, the gas leakages detection and levels in industrial environments, surroundings of chemical factories and mines can also be made possible by IoT.

C. Smart environment

There have been many research efforts focusing on the solving environmental pollution and wastage of resources [6]. A healthy environment is difficult to maintain, especially in today's era, due to industrial and transport wastes, irresponsible human activities, etc. [7]. IoT would help in tracking the amount of water, quality and amount of fertilizers needed and the level of toxic elements found. Quality Enhancing- monitoring soil moisture and trunk diameter to control selective irrigation- and Weather Analysis- for forecasting ice formation, rain, and various precipitation changes and controlling humidity and temperature levels in alfalfa, hay, straw, etc. to prevent fungus and other microbial contaminants- are also some of the useful aspects of IoT in agriculture.

D. Home Automation

The main objective is to control all the home appliances from anywhere and anytime. Wi-Fi technology is used especially due to the networked nature of deployed electronics [6]. By using the IoT system remotely inside the houses, it can monitor and manage our home appliances and also help cut down on monthly bills and resource usage as well as make it secure and detect intrusions [26]. Many big corporations are developing platforms which can integrate automation across various technologies, such as entertainment, healthcare monitoring, energy monitoring and wireless sensor monitoring in the home and building environments [7]. Some of the major aspects are Energy and Water Use Control, Remote Control of Appliances, and Intrusion Detection System.

E. Smart Health

Keen attention is to be given to hospitalized patients for continuous observation of their vitals and physiological status, which can be done via IoT. In smart health, sensors gather comprehensive physiological information and the cloud analyzes and store this information, and these analytics are sent to caregivers for further analysis and review. Few examples include assisting and monitoring patients inside hospitals, especially elderly or disabled people, Medical Fridges for monitoring and controlling freezers which store medicines, vaccines, and organic elements- and Ultraviolet (UV) Radiation Measurement of UV sun rays to warn people not to be exposed in certain hours.

F. Industrial Control

Industrial Internet of Things (IIoT), or Industry 4.0, presents a plethora of smart practices for product designing principles as well as data-driven automation, to enhance remote monitoring and maintenance capabilities. There are many strategic benefits of IoT for industrial automation apart from time and cost savings [13], such as Machine to Machine Applications (M2M) [13], Indoor Air Quality (Monitoring of any toxic gas presence) and Overall Auto-diagnosis (such as product process control, industrial environment monitoring, manufacturing supply chain tracking, and manufacturing safety and energy savings).

G. Smart Car

IoT has proven to be a great disruptive change for the automotive industry, creating huge opportunities in the market such as Intelligent Vehicles. 1.3 million people are killed in traffic accidents annually and most of these are caused by human error based on physical and emotional factors [15]. Smart cars would continuously monitor themselves and their environment and would be alert and responsive to changing conditions thus minimizing casualties as well as efficient movement, since vehicles communicate about their locations on roads so they can maintain perfect spacing and reduce traffic congestion. Also, it can greatly reduce massive pollutant emissions into the air and save fuel otherwise burnt during traffic jams [16]. The major concerns with parking, which arise due to inverse proportionality of the number of vehicles and space, can also be solved [25].

H. Wearables

Smart wearables are the most ubiquitous IoT implementation. Various smart wearables like wrist wear, clothes, and medical wearables are highly efficient in data processing. While most of them are connected to the cloud, they are considered a subset of IoT. Wi-Fi and ZigBee are used for communications among IoT devices. It enables the users to continuously monitor their body and vitals and to keep them healthy and active. The major concern about smart wearables is data protection and security since data is prone to attacks since wireless devices always provide the facility of connecting everywhere.

I. Smart University

University campuses are an ideal place to impart a smart environment. Very few researchers have contributed to integrating IoT with education, which would be a fruitful present to future generations. In Smart university, the following modules have been considered:

• **Smart Classroom**: Equipped with Smart Energy Management, Smart Lighting, Smart attendance management

• **Smart Campus**: Equipped with Smart inventory tracking, Smart lighting, Smart Environment monitoring

• **Smart Parking**: Equipped with Smart sensors and gateways for better and efficient handling of parking space

• **Smart Event Monitoring**: Monitoring of logistic and other requirements for events organized on the campus

In [11], the concept of Smart University is discussed. In this, the authors have discussed smart classroom, smart parking, and smart inventory management. Its implementation can enhance teaching-learning environment inside the campus. Advantages of a smart university are as follows:

• Electricity consumption inside campus will be reduced
• Inventory tracking will become easy
• Parking system will be fully manageable
• Constant monitoring of smoke and temperature will help in an early identifying disaster
• Reuse of the complete model and can be established in another part of the campus and other universities.
• Enhancement in the teaching-learning environment and the campus-surveillance system

5. CONCLUSION

The overall objective is to showcase the importance of the proliferation of IoT solutions for its adoption of low power communication technologies, and minimizing the risk of excess energy footprint. There is an effort to compare applications and protocols of IoT simplistically.

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