Aura Minora: A user centric IOT architecture for Smart City

Talal Shaikh
School of Mathematics and Computer Science
Heriot Watt University
Dubai, U.A.E.
t.a.g.shaikh@hw.ac.uk

Salih Ismail
School of Mathematics and Computer Science
Heriot Watt University
Dubai, U.A.E.
si8@hw.ac.uk

Joseph D Stevens
School of Mathematics and Computer Science
Heriot Watt University
Dubai, U.A.E.
js78@hw.ac.uk

ABSTRACT
For a typical smart city many IoT (Internet of Things) architectures have been proposed to integrate the various ICT Solutions. Since there are many perspectives, the emphasis and the design of each architecture vary. So at the moment there is no standard architecture. The best approach is to adapt architecture for its intended use. Most of the current IOT architectures are service centered. After surveying literature, there exists a gap in a user centered approach with intelligent edge devices. We propose Aura Minora: a novel architecture for IOT based on a bottom-up approach. Our approach in this paper is to see, how this user centric architecture would help end users as well as the smart city governing body to use existing Internet infrastructure to provide services. We also focus on user privacy and security aspect within this architecture. We further discuss the various views like informational, functional and deployment view of our architecture.

CCS Concepts
• Computer systems organization → architectures → other architectures.

Keywords
IOT Architecture, Edge Networks, Bottom Up Approach, Smart City.

1. INTRODUCTION
The world urban population is projected to grow upto 60% at least, by 2030. This increased population would bring about increased constraints on energy consumption and other infrastructure services that a city would be providing to its inhabitants [1]. The city officials would balance this by heavily relying on smart city based infrastructure and services. This would be done by incorporating several complex systems of infrastructure, human behavior, technology, socio-political structures and economy.

The currently available architectures look into this from management point of view and have a top down approach to solving this. The users' perspective is often overlooked and this becomes a negative catalyst towards an optimal solution.

With the decrease in cost of electronics and more functionality available to Wireless Senor Network (WSN) nodes, users generally invest on devices for personal use. This would in turn provide a more efficient use of resources on a dynamic level. Rather than having a fixed IoT Architecture that looks into a way of managing general city concerns like health, energy, transport, dwellings and the environment, it would be interesting to see many different services that arise, based on how people interact with the system both on a personal level with the devices around them and understanding how the interaction has an impact on a larger scale of the city they live in.

In this research we propose a bottom up view from a users' perspective, as this is more holistic in nature. Our main area of focus will be from an individualistic perspective and his/her use of IoT devices and how to efficiently enable it using the existing environment and modification to it. We would discuss on how to create a smart home environment for an individual within a city. Every individual home/office would be a tiny technological drop creating a fully-fledged IoT based city.

We first explain the various architectures proposed for an IoT enabled smart city. We have categorized them based on our understanding of the topologies of IoT architectures. This enabled us to fairly try to fill the gap in other architectures and provide a more comprehensive architecture. We move on to examining the flaws and advantages of each architecture. The critical analysis lays foundation to our architecture. The next section moves onto the explanation of the layers of our architecture to provide a skeletal view of the architecture. Once the main purpose and functionality of each layer is explained, we move onto providing a fully-fledged explanation of the architecture fitting a user's perspective in a smart city. The purpose of this section is to provide a snapshot of our architecture in a bottom-up approach and how every layer of the proposed architecture would fit in a smart city. Finally, we conclude this paper by providing a comprehensive analysis of our own work and the possible work to be done on our architecture on a government level.

2. RELATED WORKS
2.1 Approaches to Internet of Things Architectures
There are number of architectures that have been proposed for the IoT. Each of these proposed architectures are grounded in different perspectives of the IoT. As a result the emphasis and design of the architecture vary. There is no standard architecture to fit all implementations of IoT. Until there is an adopted standard architecture, it appears the best approach is to adopt an architecture

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that is best suited for its intended use. In this section we will discuss a range of architectures and categorize them based on their approach.

There are two approaches to the Internet of Things according to [2] an internet oriented approach or a thing oriented approach. The internet oriented approach addresses the internet technologies needed to implement the IoT. While the things oriented approach focuses on the integration of sensors that collect data. These two orientations have affected the way architectures are designed [3]. Depending on the priority of the architecture it will influence overall design. Another factor that influences overall design is the perspective of the model.

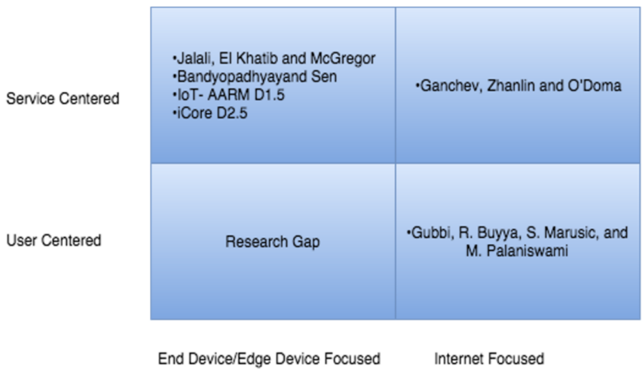

Figure 1. IoT approaches in Literature.

There are two distinguishing perspectives for architectures: service centered or user centered. Most architectures have adopted the existing Service Oriented Architecture (SOA) for ease of dealing with large systems across disparate infrastructures. It focuses on how the service interacts and benefits from the architecture. The contrasting perspective is a user centered approach that allows the users to interact with the system which they choose. This opens up flexibility and helps users to benefit and participate rather than be a part of.

We have combined these concepts to make better sense of the evolving landscape of IoT architecture and show where there is a specific need for the architecture proposed here in. Architectures have two features, they have an orientation and a perspective, and we have adapted these to focus and center respectively. The architectures below have been evaluated and placed in the appropriate quadrant according to their focus and center. It is agreed that the majority of architectures are service centered [3] [4], due to the existing SOA model. After surveying the literature a gap appears in the user centered approach that is device focused. This is what we propose.

The Gubbi, R. Buyya, S. Marusic, and M. Palaniswami architecture [3] is a designed as a user centered model that places the cloud at the center, which provides all of the resources to for the application to run. The data is collected from the sensors, which are specified as either wireless sensors or RFID chip, then connected to the cloud through the appropriate network protocols, the cloud can be public, private or hybrid. The cloud will be responsible for aggregation, distribution, analytics and visualization. The goal of this architecture is to put the cloud at the forefront in order to provide flexibility and cater to end user. This design is scalable and can exploit the vast computational power of the cloud to reason through the large amount of sensor data in an economic way but it may not be suitable for all industries especially ones that need human intelligence.

However the model also has some room for improvement. There is no gateway specifically defined although the functionality and protocols are discussed in the paper the device is not included in the framework and only appears in the illustration of the interaction. Because it's all done in the cloud it may not be ideal for a city where the data will be highly localised. Finally there is little to no mention of privacy and security. This is an example of a user centered, internet focused architecture.

Ganchev, Zhanlin and O'Doma [5] introduces a new high level service oriented IoT Architecture that is focused top down specifically for a smart city and is not intended as a generic model. It begins with all services and divides them into 4 basic platforms: eGovernment, Enterprise Based, Company Based and Business Oriented. Each of these sectors will have specific platform that is located on the city infrastructure, which is later proposed to be any IoT provider.

The cloud is only a part of the service provider infrastructure. The premise of this proposed architecture is instead of using generic cloud services to underpin the architectures, independent IoT service providers will emerge to provide specific platforms to the appropriate sector. There is a heavy emphasis on the individual devices needed to implement the infrastructure, such as switches, routers, IPS devices, servers, firewalls. It doesn't account for any type of user devices or the types of devices that would be connected to the platform. Because it focuses on the importance of devices to support the service platforms, it is a good example of a service centered, device focused architecture.

Jalali, El Khatib and McGregor, [6] this architecture is from the perspective of solving the ever growing concentrations of city populations and the strain it will cause on the resources. A generic IoT architecture is the proposed solution to "manage and control the resources of the city". The architecture uses three layers: Sensing Layer, Networking Layer, Control and Services Layer. The sensing layer is described in detail, grouping sensors in to three categories and describing how they collect data and connect to the network. The Network Layer is brief and implied to be the Internet. The cloud is considered part of the service layer where the data is then mined, or converted to knowledge, using suitable algorithms. Finally and most importantly it is delivered to the service.

Providing data to the service is the driving factor of the architecture. There is no mention of security or privacy here or of the user's involvement. Additionally the authors do not discuss who consumes the services. This is an example of a service centered, device focused architecture.

Bandyopadhyay and Sen, [4] this architecture is very general and is designed to be open enough to apply to any industry, enterprise or government. The layers are divided into two groups, data capturing and data utilization. The data capturing group has three layers: Edge Technology layer, Access Gateway layer and Internet layer. Similar to Jalali the edge layers have 3 categories of sensors but the protocols are not prescribed to maintain generality. Once the data has been collected through the sensor and passes through the gateway to the internet it reaches the data utilization group layers.

The utilization group layers are made of the Middleware layer and the Application layer. The Middleware is based on SOA and provides data filtering, data aggregation, semantic analysis, access control and knowledge discovery. This is described as the most critical as it is the interface between the networking hardware and the application service where the data feeds to. This is an example of a service centered, device focused architecture.

2.2 Practical Architecture Applications

The proposed architectures examined thus far are not currently deployed. The next architectures examined are a result of project implementations from the European Research Cluster on the Internet of Things (IERC). The IERC addresses the issue that there is no one single architecture to address all of the needs for IoT. [7]. There have been a large number of IoT architectures designed to fit the specified need and this has resulted in "the balkanization" [8] of solutions and will make it more difficult to integrate these heterogeneous systems in the future.

In an effort to address this siloization the Internet of Things-Architecture (IoT-A), funded by the European Union, has published it's Architectural Reference Model (ARM). The ARM is a publicly available, non-proprietary, fully developed architecture. It's most recent version is D1.5, and is encapsulated in a 482 page reference manual. The IoT-A breaks the architecture into five models that interact with each other.

It focuses on representing physical entities and representing them virtually through a device or sensor [7]. A domain model is used as the grounding of the architecture to provide a basis for the multitude of IoT applications to be integrated. Once the physical entity has been converted to a virtual entity it then enters to the information model. Here the information is "stored and processed and in an IoT system." [9]. The next step is to utilize the information for selected service; this is referred to as the Functional model.

The ARM D1.5 is end device focused. It provides a flexible model to accommodate many different end devices and their domain applications. It treats these end devices as physical entities that are being monitored and makes them virtual so as to feed into the services in the functional model. The aim of this architecture is to enable interoperability between the many different types of domains and their devices in order for them to supply information to the services. Thus making it end device focus and service centered.

The Internet Connected Objects for Reconfigurable Ecosystem (iCore) Project builds on the IoT-A ARM D1.5. It main objective is to speed up the deployment of IOT services and applications [10]. The iCore has three levels in its architecture. The Virtual Object Level (VO) is similar is the representation of the physical object participating in the system. It supplies its data to the next level up called the Composite Virtual Object Level (CVO).

The CVO is the middle layer and enables different types of devices to be aggregated together in a service. This aggregated data and utilizes semantics to improve the accuracy of the services offered at the top level, called the Service Level (SL). The CVO uses end user feedback collected at the SL and other outside sources to deepen the System Knowledge that is used in the system optimization. The SL then uses semantic queries and inference engines to assist the user in understanding the situation presented by the system [7].

This architecture is the closest to user centered and end device focused that has been examined so far. In the SL the end users give feedback on the system and this allows the system to adapt to user's needs. However this is different than allowing the user to interact directly with end device and modify how the end device interacts with the system. In the iCore the user interaction is used to build System Knowledge to improve the service, thus making it service centered rather than user centered.

Both the IoT-A and the iCore architectures do not utilize cloud capabilities in their design instead they focus on getting the end devices integrated into an IoT system to be utilized in a service. There is a need to explore an IoT architecture that will be end device focused and user centric. This will allow the users to better understand the potential of the IoT and give them greater control over the data provided by the end device sensors.

3. AURA MINORA IOT ARCHITECTURE

We have looked at our architecture from the viewpoint of different stakeholders. To accommodate all this we have looked into the different architecture models that encompass all the stakeholder views. We have approached the development of our IOT Architecture model with the principles from Krutchens "4+1 view architecture development model" and from Rozanki and Wood's holistic enterprise architecture (entarch) strategy[11] [12].

This allowed us to expose information assets that usually is packed in silos in a city-wide infrastructure services. It further aided us to design an architecture that supports an efficient and secure IT architecture that sufficient meets a growing smart city's goals. We have further focused on the three view which is common to every architectural model, i.e., functional, informational and control

Aura Minora can be classified into mainly six essential layers in the architecture. Figure 2 below depicts the various layers of Aura Minora. Each layer has been designed with the outlook of an easy transition from the existing infrastructure.

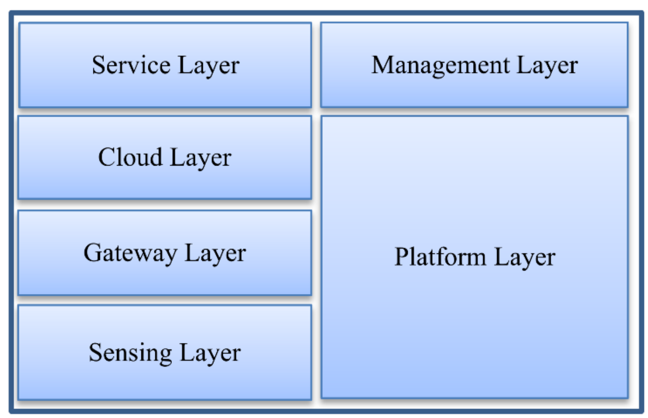

Figure 2. Aura Minor IOT Architecture

Sensing Layer – This layer includes all the inputs from the sensors, RFIDs, etc. This facilitates the data sensing and input. The main functions are data creation. The sensing layer would entertain heterogeneity to accommodate the wide variety of devices and sensors.

Gateway Layer – This layer includes the switches, hubs, routers, all devices that could be used to collect the output of the data from the sensing layer. The essential function of this layer would be data collection. However there are some data creation as well after the processing.

Cloud Layer – This layer is essentially the link between the private network of the user to the cloud services on the internet for different IoT service provided by the government. An all IP platform would ensure the smooth transition of an existing infrastructure.

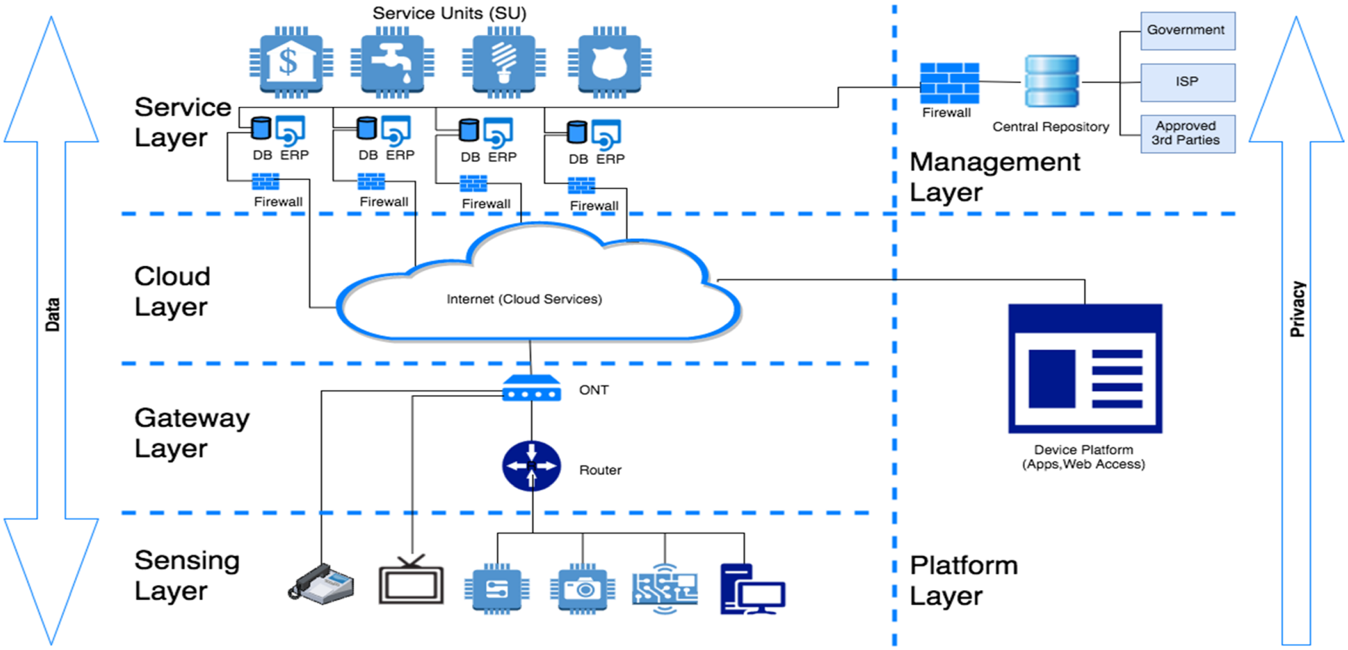

Figure 3. A snapshot of detailed Aura Minora

Service Layer – This layer helps to utilize the data through front-end applications which are integrated to the user's home. This would be individual units of services that a user is subscribed to. Every service unit (SU) will have its own individual database to store its data and ERP systems to manage the business functionalities.

Platform Layer – The platform layer provides substantial application power to the users to remotely access their IoT network from anywhere. This would include the user applications, web services and other user centric information retrieval. An individual perspective of the data analysis and visualization is provided to the user to better comprehend the usage of resources. This data would be pulled from the cloud. This layer could be fully residing on the cloud layer, however to provide an individual perspective to end user, it would require collecting data from the sensing and gateway layers.

Management Layer – This layer is a central repository providing access to all the databases' of the service units. The access would be required by the government, Internet Service Provider (ISP) and other approved third party agents. A controlled user access policy needs to be applied this layer. A copy of the individual databases could be kept to provide a backup that would enable a fail-safe system.

3.1 The Architecture

A bottom up approach and its advantages have been clearly emphasized in the introduction. Our approach would allow for a smooth transition from the existing infrastructure of a city into an IoT enabled architecture.

In the sensing layer, the user sets up the house/office or personal area with the required sensors, devices and other devices that generates the required data. All this devices are connected to one or multiple routers that support various protocols such as IPv4, IPv6, 6LoWPAN, ZigBee, Z-Wave etc. in the Gateway Layer. There has been various routers that support such wide variety of protocols to accommodate and control the heterogeneity of sensors and other devices. The router/s are generally connected to an ONT (Optical Network Terminal) which is provided by the ISP to distribute Internet services, telephony services and other services.

The cloud layer tries to ensure the usage of the existing cloud services over the internet. Thus reducing the need to design the services to control the sensing layer of users remotely. This would also provide individual users the ability to access their devices from home or remotely. This is done through a platform layer which connects the users' smart devices like phones, tablets to the application which is hosted on the cloud.

The cloud services are created and controlled by their respective service units like water authority, electricity, fire and safety etc in the Service Layer. The private database of each service units are connected to the cloud to manage the data and their ERP-CRM system to manage the users. Every individual service unit's database would be connected to a central repository providing efficient backup and control options to the city authority. This would fall under the management layer which also would provide the data analytics and statistics on a city level. The ISP and other approved third party authorities can have access

3.2 Security and Privacy

The gateway layer could have custom firewalls made to protect the individual network (home/office) of the user. However the need for this is less because the users are preauthorized. So if the users are really concerned they could use a router that provides firewall services. This would allow the flexibility of cost to the user. However, the data resides collectively in the individual service units. Every SU needs to connect to the cloud services on the Internet behind a firewall to offer maximum protection. The connection between the individual SU and the central repository, though it is a private network it needs to ensure that the data is protected. A firewall is the minimum that needs be implemented. The communication link between the SU and Central Repository can be encrypted to offer better security. However it would be a costly decision to make.

The data of the individual user that is generated at the sensing layer cannot be altered by the user and needs be sent to respective SU. However, the privacy of the user lies in how secure the individual SU and the central repository is designed. If users add sensors that are custom to their private network, the data will be kept private. Any custom addition to the network, the user will be given the choice to protect the data. This would ensure privacy on a very basic level. Based on the sensitivity of the data the user will be allowed to change the access policy of the data within their network and outside their network.

5. CONCLUSION

It is clear that IoT implementation would be the way forward to have smarter cities. However, the number of full or partial implementations has been negligible even though benefits are immense. This is due to the lack of an architecture that has the quality to rather transform an existing infrastructure of a city. A complete alteration of an existing infrastructure of a city would be costly and illogical. Aura Minora provides an IoT enabled architecture that would allow for a city to phase out into a fully IoT oriented smart city. Transformation capability is key to our architecture.

Furthermore, we have seen that most of the architectures that are available are service oriented or device focused approach. This would limit to the flexibility of an architecture widely. Our approach is more user centric as we believe a bottom up approach would enable a smooth transition from an existing technological infrastructure. The skeletal view of the layers and further the placement of a smart home and city infrastructure around it shows how we could phase out the transformation.

The next part of our research would be Aura Majora which would be ideally focusing on the finer details of providing control and management of the current architecture to the government and ISPs. Further it would include the M2M platform that would be an essential parallel to any IoT based architecture.

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