A Standardizable Network Architecture Supporting Interoperability in the Smart City Internet of Things

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Abstract. An increase of 2.5 billion people is expected in urban areas by 2050, when 66% of the world population will reside here. It is therefore reasonable to assume a parallel growth in the smart city Internet of Things (IoT). A challenge, however, is presented in the interoperability between the devices deployed, limited due to the ad hoc and proprietary ways which systems have been rolled out to date. A standardized network infrastructure specific to the IoT can work towards resolving the challenges. This approach to operation, however, raises questions with regard to how an architecture may support different devices and applications simultaneously, and additionally be extensible to accommodate applications and devices not available at the time of the framework's development. In this paper, these questions are explored, and an IoT infrastructure which accommodates the interoperability communication constraints and challenges today is proposed.

Keywords: Internet of Things (IoT) interoperability · Context data
Network protocols · Quality of Service (QoS) · Smart city · Standardization

1 Introduction

An increase of 2.5 billion people is expected in urban areas by 2050, when 66% of the world population will reside here. Parallel growth in the smart city Internet of Things (IoT) may subsequently also be anticipated. A challenge is presented, however, in the limited interoperability between solutions currently deployed, which is restricted due to the ad hoc and proprietary ways which systems have been rolled out to date. This is a well-recognized problem and different solutions have previously been proposed to support interoperability, as in [1, 2], for example; the work in these papers explores the use of gateways to facilitate interoperability. In this paper, on the other hand, a contrasting approach is presented with the argument that a standardized network infrastructure for the IoT can work towards resolving interoperability challenges by facilitating a common approach to communication between devices and data repositories. This builds on the promise of the INTER-IoT concept, which is working on the principle that, "*Open interoperability delivers on the promise of enabling vendors and developers to interact and interoperate, ..., the INTER-IoT voluntary approach will support and make it easy for any IoT stakeholder to design open IoT devices, smart*

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objects, services, and complex systems and get them to be operative and interconnected quickly, ..." [3]. While recognized by a body of researchers as necessary, the interoperable approach to operation raises questions with regard to how an architecture can simultaneously meet the requirements of different devices and applications: Can a 'one-size-fits-all' architecture support all operations anticipated in a smart city IoT? Can a common protocol support data transfer from all devices to a centralized cloud repository? To what extent will operation of the smart city be application-agnostic and therefore encourage interoperability? In this paper, these questions are explored, and a future smart city IoT network infrastructure which will overcome interoperability communication constraints and challenges is proposed.

2 Smart City IoT: The Need for a Standardizable Architecture

The need to develop a smart city IoT infrastructure is dependent on the scope with which we consider smart cities to exist: The term 'smart city' has recently evolved and, due to the fact that a single standardized architecture has not been made available by the Internet Engineering Task Force (IETF), the term is open to variation in its interpretation. A smart city is considered, for example, by the European Smart Cities to be one, "*performing in 6 characteristics built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens*" [4]. This takes into account smart economy, mobility, governance, environment, people and living. Their concept agrees with a definition from the Department for Business Innovation & Skills (BIS), which defines a smart city as, "*an environment in which the citizen is a more active and participative member of the community, providing feedback on the quality of services*" [5]. These definitions agree in that the smart city focus is on the empowerment of its citizens. The BIS take this concept further, with the idea that the smart city, as a result of empowering the human population, becomes a dynamic environment in which the city becomes more livable and resilient, and therefore more able to respond quickly to challenges [5].

Other parties consider the smart city from a technical perspective: For the European Commission, for example, "*A smart city is a place where the traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and businesses*" [6]. The Innovation Cities Program also considers the technical perspective, with 'smart city' being a, "*term commonly used to refer to the creation of a knowledge infrastructure*" [7], where it is the data collected from the network and connected devices that drives intelligent operation as opposed to any role played by humans. In this view, the technology influences the role played by people in smart cities, and is provisioned with an assumption that users desire specific capabilities.

While these definitions each focus on a distinct perspective (i.e., from the technology or human viewpoint), other perceptions of smart cities recognize the role to be played simultaneously by both humans and technology. One definition which includes both contributors comes from Smart City Networks, for which a smart city, "*provides technologies that make our destinations smarter places to visit, live, and play*" [8].

This definition accommodates the idea that, as the ease with which solutions can be made available improves through more supportive technology, the extent to which smart technologies meet the desires of citizens grows in parallel. Both citizens and technology are therefore seen as essential in facilitating a successful infrastructure: "*Without Smart, Connected People, There are No Smart Cities*" [9].

It is interesting that, as technologies within the IoT become less focused on health, safety or government-oriented objectives (e.g., as in [10–12]) and move towards having more socially-aligned goals such as retail or leisure, it becomes more challenging to identify *show-case* deployments. Of course they exist, through the applications developed by individual users, but they are less likely to be advertised as *exemplar* solutions by city-wide working groups such as EuroCities [13] or Future Cities [14]. This confirms the early stage of evolution at which the smart city IoT is, through the fact that it is bodies with high levels of technical expertise who are developing solutions which are attractive to large user groups. To fulfil the visions of smart cities described above however, it will be necessary to develop an infrastructure that motivates the general public to engage, with the assumption that it will be them, and not industry, who will contribute solutions so that, "*the citizen is a more active … member of the community*" and cities are "*smarter places to visit, live and play*".

Given that the technologies have, in general, been deployed by major technical players, IoT capability today requires that a city has a level of IT intelligence to use the data collected from connected devices, to integrate software solutions to meet smart city objectives, and to develop applications supported across a range of devices. As a result, we live within a smart city IoT where solutions are vendor and application-specific (e.g., as in [15–17]), and are not readily deployable by parties without a technical skillset. It can be assumed, however, that the majority of people who will want to use smart city technology have expertise beyond IT. There is therefore an opportunity that groups participating in the smart city can contribute their knowledge to facilitate wider goals of the IoT in solutions which meet the needs of users in an ad hoc manner. Current network architectures are missing capabilities which fulfil these expectations of the IoT, and as a result rapid application roll-out and intelligent data use is not possible by a user base with a wide range of expertise.

3 State-of-the-Art IoT Technology

In recognition of the limitations of technical solutions provided by industry in terms of their ability to achieve the envisaged perspective of the IoT, individual bodies are contributing solutions in an attempt to open the environment to allow implementation by a wider group than at present. The Smart Cities Council, for example, is working towards 2030 [18] with their vision of smart cities. Their framework consists of technology enablers (instrumentation and control, connectivity, interoperability, security and privacy, data management, and analytics) to facilitate perceived smart city responsibilities in the areas of the built environment, energy, telecommunications, transportation, water, health and human service, public safety, and payments. With partners which include Mastercard, IBM, Microsoft, Mercedes-Benz, Cisco, Verizon and Qualcomm, the Council is working on citizen engagement strategies and tools, financing and procurement tools, and policy frameworks and tools. Their concepts and ideas are far-reaching, but their solutions remain to be standalone.

As another example, AllSeen Alliance [19] is a consortium whose mission is, "*To enable widespread adoption and help accelerate the development and evolution of an interoperable peer connectivity and communications framework … for devices and applications in the Internet of Everything*". The technology makes use of the *AllJoyn* open source project which enables devices in the IoT to work together. The peer-to-peer communication facility is defined as part of their base services, which include: Onboarding; Configuration; Notification; Control Panel; and Audio Streaming. The Configuration capability, for example, allows one to configure device attributes, such as a name, while the Notification functionality enables all devices to communicate.

As an exemplar system, its scope is also more limited than the novel applications anticipated in the IoT, as outlined in the previous section. The standard involves device discovery, device pairing, message routing, and user notifications. This does not suggest a solution significantly more novel than others available, nor does it suggest a particularly original use of IoT technology. Furthermore, while this architecture facilitates peer-to-peer communication between devices, it does not support the delivery of collected context or application data to a centralized repository. Instead, the functionality is limited to a restricted set of services. The envisaged perspective of the smart city is therefore unlikely to be achieved using such a technology alone, and a gap in the solutions available can consequently be considered to exist.

4 Research Proposal: A Standardizable Architecture for the IoT

In response to the limitations of state-of-the-art solutions to date, and the envisaged perspective of the future smart city, a proposal is made in this paper of a generic network architecture which supports interoperability in the future IoT, and which opens the technical environment to a wider set of participants than at present. The intention is that it will not be necessary for developers to create ad hoc protocols to integrate their technology within the IoT. The architecture is based around the potentially simultaneous support of multiple domains within any smart city IoT, such as the smart home, smart building, or smart vehicle, all of which may populate data fields in a supporting repository for use within or across the domain. The model, together with a selection of supporting comments which reveal how its specific mechanics will be designed in the near future, is shown in Fig. 1.

To explain the framework in more detail: It is assumed that context and application data will be collected from devices operating within the IoT, which enable citizens to become '*smart*' and '*connected*'. To support this technically requires that the devices generating data have functionality to enforce that this information is transported with each packet leaving IoT devices, functionality which belongs in the *Context Layer* proposed in this model. A *Data Repository* will therefore support operation within the IoT, within which data will be organized into one of two repository types, either one in which data can immediately be defined and organized, or one in which the data is not classifiable in relation to a specific device or application. In the latter, the data can be

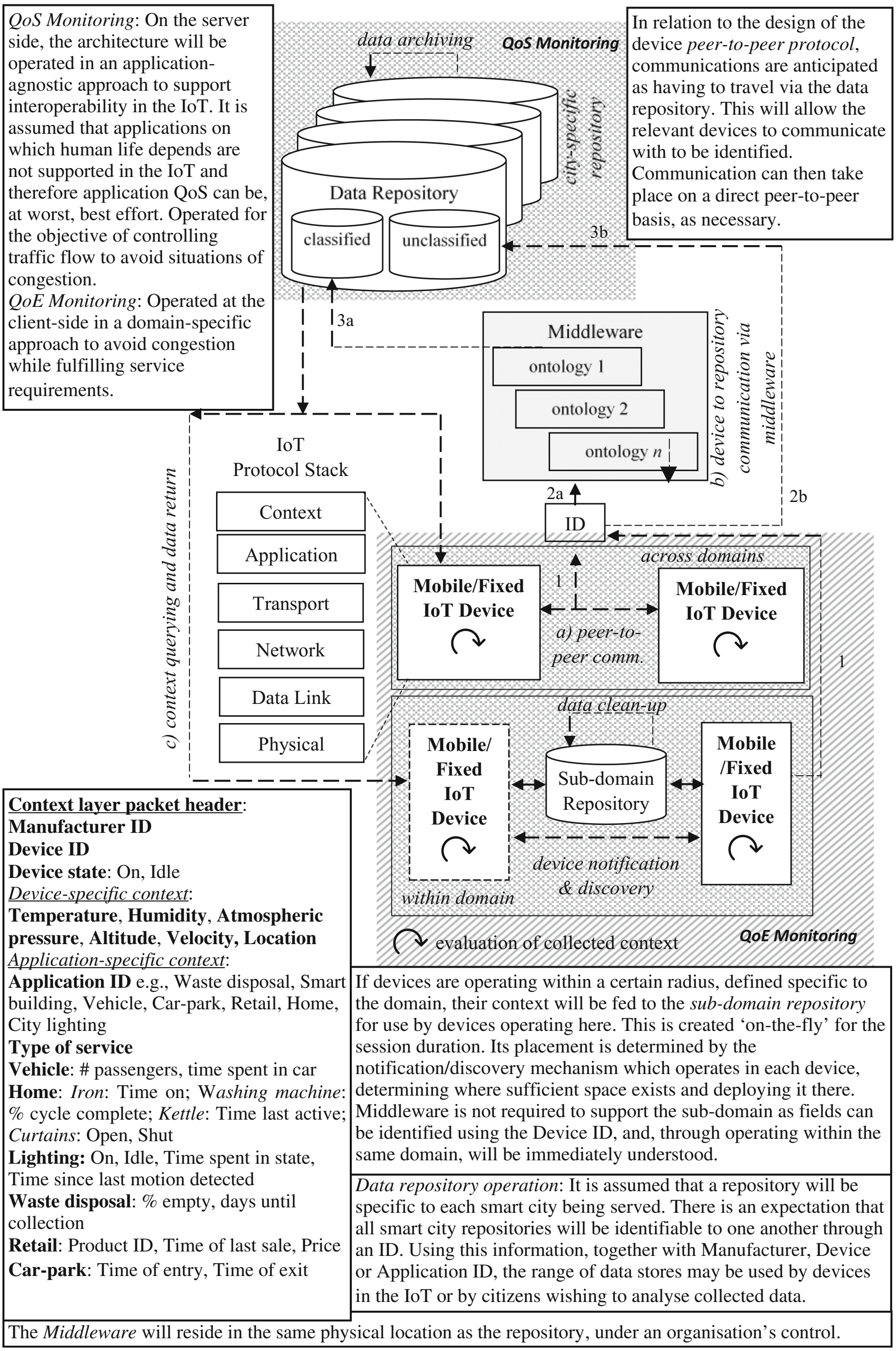

Fig. 1. End-to-end architecture facilitating Interoperation across the IoT

captured, but will be usable in a less autonomous way. The *Middleware* is crucial to facilitating organization and operation of the repository and, indeed, influencing the extent of interoperability achieved by the architecture overall: While the system's objective is to be generic, this being a core requirement to fulfil the IoT's diversity and desired interoperability, the middleware will have system-specific components, such as manufacturer, device and application ontologies. Using ontologies, context can be classified according to the device and manufacturer identifier, and then be passed for storage within the organized repository (Fig. 1, steps 2a, 3a). In the event that the device and manufacturer identifier is not represented (i.e., data is this field is not available or the ontology is not present), data will pass directly into the unclassified repository (Fig. 1, steps 2b, 3b). *Repository management* depends on the type of repository involved: In the organized repository, clean-up activities will involve data archiving, which will be important with a potentially large volume of data collected across the smart city IoT. In *sub-domain repositories*, on the other hand, it is less important that data is retained for long periods of time, it most likely being used on a short-term basis. A sub-domain in the context of this work refers to data relevant to an individual domain, and which is unlikely to have any purpose outside the domain. *Quality of Serivce (QoS)* and *Quality of Experience (QoE) monitoring* are also important within the IoT at both client and server sides of the network. The objective of QoS monitoring on the server side is to facilitate a solution which is scalable and ready to accept data when it arrives for storage, and to return the collected or processed context accurately when requested. The objective of QoE monitoring on the client side is to facilitate the operational requirements of clients.

5 Challenges of a 'One-Size-Fits-All' Approach in the IoT

It is a challenging proposal to develop a 'one-size-fits-all' architecture which supports all applications and devices in the IoT. The design of the framework proposed in this work demonstrates a system-specific approach, to a certain extent. This may not be expected, given the objective of supporting interoperability in the future IoT, where an awareness of any specific aspect may suggest limited ability to respond to new developments and therefore overall restricted interoperability. Attention has been given in the design however, to support extensibility and therefore interoperability for developments not existing at the time of the framework's creation through the provision of a middleware. This design choice depends on the participation of manufacturers and developers, and their provision of ontologies which may be uploaded to the middleware. While an end-to-end network infrastructure is proposed in this work, the protocols intended to operate in each section of the architecture are currently under development. Operational challenges are being taken into account in their design: For example, how will data be organized when an ontology has not been provided in order to achieve any utility from it? In relation to context data collection from the IoT network and devices operating within, how will the rate of packet generation vary depending on the application, device and real-time network state? Furthermore, how can operation across domains be supported, such that context generated in one is recognized and usable in another? Protocol designs which respond to these questions will be explored in future work.

6 Conclusion

It can be concluded that current network architectures are missing capabilities which fulfil expectations of smart cities, restricting the ease of rapid application roll-out and intelligent data use by a user base with a range of expertise. The infrastructure proposed in this paper involves a generic yet standardizable framework, with device and application-specific aspects which allow a greater level of utility to be exploited, and avoiding a situation where operation is restricted based on a vendor or application type. It is proposed in this paper that application- and device-specific aspects must exist in the IoT framework to achieve the full utility required, and manufacturers must take responsibility by make ontologies available for incorporation within the framework's middleware. There are challenges to overcome, and the evolution of a single smart city IoT technology which meets the requirements of all applications and devices is an ambitious goal. Future work involves development of the protocols which will support the IoT framework proposed in this paper.

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