SMART X: A DESCRIPTION FOR SMART ENVIRONMENTS

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ABSTRACT

In the Internet of Things, various terms are used to describe smart environments. These include Smart City, Smart Home, Smart Grid, Smart Industry and many more. However, they are often missing concrete definitions, which makes their use seem indiscriminate. The problem of horizontal integration describes that the different smart environments of the Internet of Things need to be brought together in order to gain a common advantage. But because we use a great abundance of terms describing smart environments, achieving horizontal integration between all of them seems almost impossible. Fortunately, the terms used for smart environments are often redundant, making the problem of horizontal integration more manageable. This theoretical study gives an overview of the current state of horizontal integration in smart environments. Its most well-known solutions and projects are presented and common problems of those solutions are discussed. After that, a new term is described based on the technological foundations prevalent in the smart environments in question. This term is *Smart X* and will be explained with some examples. Smart X as a concept is supposed to reduce the complexity of horizontal integration that arises from the inflationary vocabulary of smart environments that is currently used. Finally, further problems with existing projects and possible solution pathways are discussed.

KEYWORDS

Internet of Things, Horizontal Integration, Interoperability, Smart X, Smart Home, Smart City

1. INTRODUCTION

In recent years, the Internet of Things (IoT) has become a buzzword that extends into most areas of information technology. It consists of a wide variety of smart environments that are responsible for automating processes in their respective areas of application and are intended to make life and work easier for their users. New smart environments are constantly appearing in the literature, such as *Smart City*, *Smart Home*, *Smart Grid*, *Smart Infrastructure*, *Smart Health* and many, many more. A firm definition of these environments is often not given and *smart* mostly serves as a buzzword for modern communication systems. To better address the technological realities of our smart lives, we need a new way to talk about our connected world.

There is plenty of reason for this, as the economic impact of the IoT is immense, with the most significant areas in manufacturing and health care (Al-Fuqaha et al., 2015). Despite this, it is mostly impossible to share data efficiently between different smart environments, which poses a market risk, according to (Manyika et al., 2015). New technologies such as Thread are already trying to solve interoperability problems in their respective application areas, but are not able to cover them for the entire IoT domain.

This lack of interoperability is noticeable in various ways because end users are often confronted with multiple smart environments. For example, a lot of information is collected and processed in the Smart Home. Furthermore, municipal utilities are equipped with smart energy networks that enable more efficient use of resources. And last but not least, more and more Smart City initiatives exist, offering various functions for their residents. What is meant by “lack of interoperability” here is that there are no uniform interfaces between these environments and information is not aggregated.

This paper presents several options from the literature to address this lack of interoperability. It is also shown that the terms currently used to describe smart environments are inadequate to address the technological issues that arise with horizontal integration. A new term - *Smart X* - is elaborated to focus the discussion on the technological realities. Finally, some of the previously mentioned problems are identified and briefly discussed.

Smart X has one primary purpose: to reduce the complexity of horizontal integration. In the course of this theoretical study, a variety of smart environments will be highlighted. Connecting them for a common benefit is known as horizontal integration (Al-Fuqaha et al., 2015) and is a significant task due to the currently vast number of terms used in the literature. Smart X represents a subset of the terms used in the literature, which is limited to the main technological differences of each smart environment. The vocabulary currently used, which is partly redundant, mainly creates the impression that connecting all subsets of the IoT is an unattainable goal. Horizontal integration of the subsets of Smart X, on the other hand, seems more achievable.

2. RELATED WORKS

Interoperability of smart environments is a big problem of IoT and the process of connecting them is known as *horizontal integration* (Al-Fuqaha et al., 2015). This circumstance has developed because the requirements for the application areas of IoT differ significantly. For example, different promises are made regarding reliability, latency, jitter, and bandwidth (Qin et al., 2014), which is reflected in the respective protocols. Dave et al. describe in (Dave et al., 2020) that this interoperability is noticeable on different abstraction levels. It is shown that not only different protocols are problematic, but also the use of different network layers, platforms, and syntactic and semantic differences.

Technologically, this results in a variety of smart environments, which are mostly disconnected from each other. In the literature, these are often referred to as *vertices* or *vertical markets*, whose horizontal integration is a major problem (Filipponi et al., 2010; Prazeres and Serrano, 2016; Noura, Atiquzzaman and Gaedke, 2019). How these vertices are defined depends on the consideration of the respective authors. An overview can be seen in Table 1, although for some publications, the categorizations were adjusted. For example, a search for “smart” in (Stübinger and Schneider, 2020) yields 559 hits, but a generalization was also made within the publication itself, which is reflected in Table 1. Also, very similar categories were renamed. In other cases, single terms such as *Smart Garden* in (Noura, Atiquzzaman and Gaedke, 2019), which were used only once throughout the reviewed literature, have been omitted.

Table 1. Overview of different verticals mentioned in the literature

	(Al-Fuqaha et al., 2015)	(Noura, Atiquzzaman and Gaedke, 2019)	(Stübinger and Schneider, 2020)	(Hui, Sherratt and Sánchez, 2017)	(Marksteiner et al., 2015)	(Sidorov et al., 2019)
Home	X	X		X	X	X
City		X	X	X	X	X
Health	X	X	X	X		X
Grid/Energy	X	X		X	X	X
Vehicles	X					
Industry	X	X		X		
School	X					
Infrastructure	X		X			
Transportation	X	X			X	X
Sustainability			X			
Economy	X		X			
Agriculture	X					
Technology			X			
Office/ Buildings				X		X
Production					X	X
Factory				X		X

The sources used for Table 1 are mainly works that deal directly with horizontal integration (Al-Fuqaha et al., 2015; Noura, Atiquzzaman and Gaedke, 2019) or other literature that each provides overviews of the IoT and enabling technologies (Marksteiner et al., 2015; Stübinger and Schneider, 2020). Furthermore, in the case of (Sidorov et al., 2019), a paper was used that provides a broad overview of technologies of the IoT despite its focus on the project presented in it. Also, the available sources were selected because they each deal with a variety of smart environments. In this way, an overview that addresses a large number of terms used in the literature can be provided.

In addition to the categorization of Table 1, other possible classifications exist. For example, (Filipponi et al., 2010) uses a generalized representation of smart environments, where infrastructure and shopping are grouped as *smart city space*, home and office as *smart indoor space*. Marksteiner et al. also sees the above environments as parts of the Smart City (Marksteiner et al., 2017). Another category is *smart personal spaces*, which includes vehicles and presumably other technologies such as smartphones. Also, a variety of proposals exist to enable horizontal integration between the aforementioned vertices (Filipponi et al., 2010; Collina, Corazza and Vanelli-Coralli, 2012; Qin et al., 2014).

It is evident that there is to be a vast number of smart environments for which horizontal integration is desirable. The industry already combines Smart Grid functions with those of Smart Industry, so certain processes are only carried out when electricity prices are favorable. However, a stricter coupling to the power grid can also be useful for private individuals (Komninos, Philippou and Pitsillides, 2014). In corporate building automation, complicated and expensive solutions are met with acceptance if a financial incentive is present. This is particularly the case if installation and maintenance can be outsourced to external experts.

In the consumer market, however, solutions must be developed that are easy to implement and bring clear advantages. A complex configuration of gateways between each environment is only reasonable for very few end users. In addition, the number of environments to be linked seems so enormous that complete horizontal integration hardly seems possible. However, one thing the definition of Smart X in Section 3 is meant to show is that many existing smart environment definitions are essentially redundant and that the problem of horizontal integration might in fact be simpler than one thinks at first glance.

In the following, some approaches and projects are presented that deal with the topic of horizontal integration. Most of them use the MQTT protocol as the underlying technology, but there are also projects that propose more complex architectures. The present distinction is mainly based on the importance of MQTT in the proposed solutions.

2.1 MQTT Based Approaches

MQTT is a well-known publish-subscribe protocol for machine to machine (M2M) communication that is applied in many IoT architectures (Collina, Corazza and Vanelli-Coralli, 2012; Prazeres and Serrano, 2016; Gavrila et al., 2018; Dave et al., 2020). Information processing is organized around so-called *topics* to which clients subscribe and on which information can be published. It is particularly suitable for use in IoT systems and smart environments due to its low resource requirements and broad support. For these reasons, MQTT is the focus of many researchers studying horizontal integration.

In (Collina, Corazza and Vanelli-Coralli, 2012) two different concepts are combined: On the one hand, MQTT as a publish-subscribe protocol for energy-efficient M2M communication, and furthermore REST as a component of the Web of Things. The so-called QEST broker developed here thus makes it possible to provide REST resources as MQTT topics. This approach connects the concepts of the Web of Things with that of the Internet of Things and provides their resources in a unified way. The Ponte project (Dave et al., 2020) builds on QEST and extends it, among other things, with a CoAP interface.

2.2 Architecture Approaches

The area of the IoT is also characterized by the large number of technologies used, which can be seen just by looking at the Smart Home and the large number of wireless standards used there. For this reason, the more abstract approaches based on MQTT are always dependent on gateways taking over the translation into suitable formats and protocols. Complicated mesh network structures, as for example with ZigBee (Ondrej et al. 2006), are hidden from the higher layers of the MQTT service by these gateways.

The project SOFIA (Filipponi et al., 2010) proposes an architecture that loosely couples various producers and consumers of messages in so-called *smart spaces*. These producers and consumers are called *knowledge processors*, which in turn publish their information on, and consume information from, several interconnected publish-subscribe services - *semantic information brokers* - respectively. In this approach, applications each implement knowledge processors with which they can access the network of semantic information brokers.

A similar concept is that of the self-organized *Fog of Things* (FoT) (Prazeres and Serrano, 2016). Here, much of the information processing is shifted to the boundaries of the network to the FoT gateways, which receive it from sensors - the FoT devices. These gateways are also responsible for translating between different protocols and technologies or have advanced functionalities such as persistent storage of data (FoT servers). Again, MQTT-based Message Oriented Middleware is used for the connections of the devices.

Some approaches focus directly on the physical layer. One possibility here is the use of software-defined radios (SDR), as Gavrila et al. show in (Gavrila et al., 2018). Here, the authors developed an SDR gateway that supports various wireless protocols using a Universal Software Radio Peripheral. A similar project has also been developed by Lin et al. (Lin et al., 2013).

3. SMART X

In Table 1 different verticals are presented and ordered by the literature in which the corresponding terms are used. It should be emphasized here that depending on the literature used, authors come to very different conclusions regarding the respective categories. Although the research deals intensely with smart environments, it is apparently not possible to find a uniform vocabulary for it. The concrete problems that lead to this circumstance include the following:

- Depending on the nature of the underlying work, the interpretation of smart environments may vary. For example, a broad literature review by Stübinger and Schneider comes up with different keywords than one would have expected from a purely technological interpretation (Stübinger and Schneider, 2020). Technical surveys, on the other hand, usually map a variety of verticals (Al-Fuqaha et al., 2015; Noura, Atiquzzaman and Gaedke, 2019; Stübinger and Schneider, 2020).
- The choice of and focus on the level of abstraction is also relevant to the interpretation of the verticals. In (Collina, Corazza and Vanelli-Coralli, 2012) and (Dave et al., 2020), which present the MQTT solutions presented above, the terms of Table 1 are not mentioned at all. Instead of smart environments, they are using the term smart *objects* here. Similarly, this is also the case in the work of Gavrila et al., which in a sense deals with the other extreme of levels of abstraction: Here, too, the terms do not occur (Gavrila et al., 2018).

In order to deal with this circumstance, we propose to define a new term that does justice to the technical perspective. This term is *Smart X* and is based on the different technologies used in the respective smart environments or verticals. Smart X is thus a smart environment that is technologically distinct from other smart environments (Smart Xs). Horizontal integration between different Smart Xs is still a major problem (Noura, Atiquzzaman and Gaedke, 2019). However, a unified vocabulary here is intended to sharpen the problem definition and help overcome the boundaries of different Smart Xs. Some examples of this concept are discussed below.

3.1 Smart Home

First of all, the term *Smart Home* describes a network of sensors and actuators designed to assist its occupants in their daily lives (Bugeja, Jacobsso and Davidsson, 2016). They further target a user base that does not necessarily have sufficient technical skills to set up complicated home networks, which has implications on their design. For this reason, usability is a key factor when it comes to selecting a system for one's Smart Home. Other factors include security, privacy and, in particular, acquisition costs, since Smart Home devices are typically not critical services (Hui, Sherratt and Sánchez, 2017).

Due to their availability and user familiarity, protocols such as WiFi and Bluetooth are sometimes used for home automation. However, they involve considerable computational overhead, which makes them unsuitable for battery-powered devices. This problem is solved by technologies such as ZigBee, Z-Wave and

Homematic. Since the transmission power of especially the battery-powered devices is usually weaker and collision-avoidance methods would also mean a higher overhead, the respective networks are mostly organized as a mesh (Ondrej et al. 2006; Ondrej et al. 2006). Wired systems such as KNX on the other hand are very rarely used in homes due to their installation costs.

A requirement that arises of using specialized Smart Home protocols is that certain gateways must be used for interacting with the network. These are usually provided by the suppliers of the respective devices. However, community solutions such as *Home Assistant* (https://www.home-assistant.io/) or *OpenHAB* (https://www.openhab.org/) can also be used with adapters for the respective protocols. The use of Thread and Matter should make it easier to integrate Smart Home devices into IPv6 networks in the future (Unwala, Taqviand and Lu, 2018).

3.2 Smart Grid

The Smart Grid is closely related to the Smart Home because of the locality of data collection and communication. However, the interaction between these two Smart X often does not extend beyond the boundaries of the energy grid. Komninos, Philippou and Pitsillides show in (Komninos, Philippou and Pitsillides, 2014) several reasons why closer collaboration between Smart Home and Smart Grid is beneficial. Mainly discussed in the literature are the potential electricity savings (Hui, Sherratt and Sánchez, 2017). Among the technologies most often discussed are 5G, Narrowband IoT (Neagu and Hamouda, 2016) and WiMAX (Neagu and Hamouda, 2016; Marksteiner et al., 2017). However, the standardization of this Smart X is mainly through government specifications (U.S. Department of Commerce, 2020).

Since power grids are critical infrastructure, there is also interest from the government in securing and defining the Smart Grid. The National Institute of Standards (NIST) has launched an initiative to drive forward the standardization of Smart Grids. Among other things, it describes criteria by which industry standards will be considered for use in Smart Grids and a list of standards that meet those criteria. Some of the better-known protocols include MODBUS, BACnet, and DNP3. This detailed elaboration serves as the basis for the definition of this Smart X.

3.3 Smart City

In the literature, Smart City is often understood as a superset in which many other smart environments can be found (Marksteiner et al., 2017; Stübinger and Schneider, 2020). However, it is so differentiated from other smart environments by the requirements placed in and the technologies used by it that it is understood to be a Smart X in this paper. For example, Smart Cities often use wireless technologies that enable information exchange over many kilometers (Sidorov et al., 2019). Battery-powered devices are also used in some cases, which require low power consumption. One example is sensors that check soil moisture near urban greening to enable more efficient irrigation.

Relevant technologies that enable energy-efficient communication over many square kilometers include Narrowband IoT, LoRa and SigFox, which belong to LPWANs. Unlike Smart Home networks, here end devices connect to public base stations. In LoRaWAN, for example, high availability is ensured since messages can be received from several base stations.

While technologies such as ZigBee, Bluetooth and WiFi are also discussed as Smart City technologies in some publications (Jaloudi, 2015; Jawhar, Mohamed and Al-Jaroodi, 2018), they are not generally suitable for Smart City deployment due to high installation costs and short radio distance (Mekki et al., 2018; Sidorov et al., 2019). A concrete example of Smart City implementation is the Datenplatform Darmstadt (https://datenplattform.darmstadt.de), which can be used to query various information such as traffic status and particulate matter levels, and to track Corona infection events. In related publications such as (Poppe, 2021), 5G and LoRaWAN are mentioned as concrete technologies, but also WiFi as hotspots for citizens.

3.4 Further Smart X

This paper considers only the three mentioned Smart Xs in detail. However, a larger number of other Smart Xs is conceivable, which are defined by their technologies. Examples of these are partly given in Table 1. It should be noted, however, that these environments found in the literature do not have to be technologically delimited at all, and thus do not represent Smart X. It is likely that similar technologies will be used for Smart Industry, Building, Office, and School. In this sense, *Smart X* is intended to serve much more as a basis for discussion than as a fixed definition of already mentioned smart environments.

A specific example of the redundant categorization as a smart environment is the Smart Garden mentioned in (Noura, Atiquzzaman and Gaedke, 2019). Among others, ZigBee (Al-Ali et al., 2015) and WiFi (Hadi et al., 2020) can be used here, which are technologies that focus on the Smart Home domain. In addition to the work mentioned above, sensors for monitoring soil moisture and actuators for automated irrigation based on Smart Home technologies are now also available for end users. So from this perspective, Smart Garden is no additional Smart X, as it is not technologically different from the Smart X of Smart Home. Based on this information, Smart Garden is essentially the same as Smart Home.

This paper aims to introduce the term Smart X and to show examples of its usage. However, classifying the various terms shown in Table 1 into different Smart X will require further quantitative literature research.

4. FURTHER PROBLEMS AND PROPOSED SOLUTIONS

In Section 2, some projects have already been presented that offer solutions to the problem of horizontal integration. However, how existing technologies can be integrated into these solutions is often not considered. Underlying architectures, protocols, and management entities often do not allow for easy information exchange. Specifically, to the best of the author's knowledge, there is no architecture for gateways that can interconnect a large number of different Smart Xs.

Designing a gateway for a multitude of different Smart X is difficult because the respective technologies make certain tradeoffs due to their requirements (Qin et al., 2014) and representing this in a uniform system is presumably very complex. In environments with many battery-operated devices, it may not be possible to guarantee that telegrams reach their destination since acknowledgments are not defined in the respective protocol. Also, various network properties such as jitter, latency and reliability must be taken into account by a unified system. If information such as temperatures is made retrievable beyond the original publishing as in (Collina, Corazza and Vanelli-Coralli, 2012), expiration dates must also be considered. A careful examination of these properties and more must be the content of further work addressing the problem of horizontal integration.

In addition to the uniform representation of semantic information such as the coding of temperature or wind speed, it must also be known which devices can in principle be represented in IoT systems. Similar concepts are already used in ZigBee (Ondrej et al. 2006) and Bluetooth, where devices have a type that determines their role in the network. Again, a detailed definition of all possible devices in IoT applications is a tremendous task, but relevant to enable horizontal integration across Smart Xs. This can also be seen as a concretization of various concepts such as *semantic information brokers* (Filipponi et al., 2010) or *FoT devices* (Prazeres and Serrano, 2016), as these do not yet define tasks or device classes themselves.

However, the possible solution to the problem of horizontal integration must also adhere to certain quality parameters. For example, such systems are expected to be responsive enough for their tasks. Therefore, it is most likely necessary to have a decentralized architecture so that certain tasks can also be processed locally and at short notice. However, similar to blockchain concepts, it should be ensured in the long term that the overall system approaches a consistent state.

Last but not least, user privacy rights must also be taken into account in a unified system. According to (Hui, Sherratt and Sánchez, 2017), the Smart Home is the best opportunity for the Smart City to obtain personal information about its users. On the one hand, this personal information is of great value to other smart environments, but for the same reason, it does not necessarily want to be shared by the user. An attacker who can derive from Smart Home information, whether a user is at home or not, can generate great value for criminal their activity. However, for example, while an attacker might be able to derive certain information from a users Smart Home, it might still be advantageous to offer some of that information to the smart city's public transport system in case the user arrives late at the bus stop. A rights and privacy system must therefore be created that only allows certain parties access to sensitive information. Side channel attacks should also be considered in this context. An example of this could be that a Smart Home that does not transmit any information indicates that the user is not currently present.

Another special case is when information obtained in a smart environment does not belong to the actual user of the environment. This is the case, for example, when the landlord or municipal utilities read a tenant's consumption values to determine the electricity and heating costs. Here, too, a rights system must determine whether a user should still have access to consumption information.

5. CONCLUSION

This paper introduced Smart X: A description for different smart environments that are technologically distinct from each other. Previously used terms for smart environments were mostly historical and defining them precisely is difficult or even impossible. Therefore, the proposal was made to use a concept instead, which is aligned with the technological realities of smart environments. This refers to Smart X, which has been explained in this paper using three examples: Smart Home, Smart Grid and Smart City.

Also, various architectures were presented from the literature to solve problems in IoT systems, particularly horizontal integration. These are mostly based on MQTT and function as middleware for exchanging information from sensors and sending instructions to actuators. Although the presented proposals are quite relevant for unifying the IoT, they do not address the technological specificities of the underlying systems enough. Furthermore, issues such as privacy, information ownership, and semantics of information are often not addressed.

Smart X offers the possibility of reducing the complexity of the horizontal integration of a wide variety of smart environments. This is made possible by the fact that many smart environments can be grouped together by taking a technological view, since similar technologies characterize them. Horizontal integration of the remaining Smart X is thus a more manageable task than that of the more arbitrary smart environments mentioned in the literature. We hope that, on the basis of Smart X, the discussion will be further aligned with the technological foundations of such systems in the future.

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