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Review

A review of Internet of Things for smart home: Challenges and solutions

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ABSTRACT

Although Internet of Things (IoT) brings significant advantages over traditional communication technologies for smart grid and smart home applications, these implementations are still very rare. Relying on a comprehensive literature review, this paper aims to contribute towards narrowing the gap between the existing state-of-the-art smart home applications and the prospect of their integration into an IoT enabled environment. We propose a holistic framework which incorporates different components from IoT architectures/frameworks proposed in the literature, in order to efficiently integrate smart home objects in a cloud-centric IoT based solution. We identify a smart home management model for the proposed framework and the main tasks that should be performed at each level. We additionally discuss practical design challenges with emphasis on data processing, as well as smart home communication protocols and their interoperability. We believe that the holistic framework ascertained in this paper can be used as a solid base for the future developers of Internet of Things based smart home solutions.

Contents

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1. Introduction

With the expected growth in world population, the demand for energy will continuously increase. Current power grids were built decades ago, and despite the fact that they are regularly upgraded, their capability to fulfill future demands is uncertain. Existing reserves of fossil fuels are limited and impose harmful emissions, making social and environmental implications and impact inevitable. The result of this current state is the transition of the traditional centralized grid towards a distributed hybrid energy generation system that heavily relies on renewable energy sources, such as wind and solar systems (Lund et al., 2015), biomass, fuel cells, and tidal power.

Smart grid is a concept that integrates information and communication technologies (ICT) with grid power systems, in order to achieve efficient and intelligent energy generation and consumption (Iyer and Agrawal, 2010). It is characterized by a two-way flow of both electricity and information. Approaches in smart grid include novel solutions that would effectively exploit the existing power grid in order to reduce or eliminate blackouts, voltage sags and overloads. Utilities could benefit, as the load demand in critical situations would decrease. If demand is greater than the total generation, these systems could prevent the grid failure or major blackouts, and increase the reliability, quality, security and safety of the power grid.

Smart grid solutions can be applied in every part of the grid: production, transmission and distribution. Recently, a fourth part of the smart grid, i.e. the smart home has become a major (mainstream) research and application interest in smart grid. Smart home refers to the use of ICT in home control, ranging from controlling appliances to automation of home features (windows, lighting, etc.). A key element of the smart home is the usage of intelligent power scheduling algorithms, which will provide residents with the ability to make optimal, a priori choices about how to spent electricity in order to decrease energy consumption. Another term commonly used is smart house or home automation.

The combination of information technologies and advanced communication and sensing systems, creates a variety of new potential applications. New advanced concepts, such as pervasive or ubiquitous computing (Greenfield, 2006), where computing is made to appear everywhere and anywhere, hold a huge potential for application in smart grid (Parikh et al., 2010). Smart devices or objects, capable of communication and computation, ranging from simple sensor nodes to home appliances and sophisticated smart phones are present everywhere around us. The heterogeneous network composing of such objects comes under the umbrella of a concept with a fast growing popularity, referred to as Internet of Things (IoT).

IoT represents a worldwide network of uniquely addressable interconnected objects. According to Gubbi et al. (2013), IoT is an "interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework." Therefore, the Internet of Things aims to improve one's comfort and efficiency, by enabling cooperation among smart objects.

The standard IoT usually consists of many Wireless Sensor Networks (WSN) and Radio-frequency identification (RFID) devices. Wireless Sensor Network is a paradigm that was tremendously explored by the research community in the last two decades (Oppermann et al., 2014). A WSN consists of smart sensing devices that can communicate through direct radio communication. RFID devices are not as sophisticated. They mainly consist of two parts: an integrated circuit with some computational capabilities and an antenna for communication.

The concept of IoT, combined with smart metering, has the potential to transform residential houses, homes and offices into energy-aware environments. There is an increasing interest in the research community to incorporate the IoT paradigm in the smart grid concept, particularly in smart home solutions. The trends of web search popularity for the terms: Internet of Things, Smart Grid and Smart Home since 2004 are shown in Fig. 1. According to these statistics by Google, the trends will further increase for the terms Internet of Things and Smart Home.

In this paper, we present a holistic approach to the integration of state-of-the-art IoT (or near IoT) solutions into the smart home, taking into account both home energy management considerations and architectural challenges and solutions with emphasis on data processing issues, networking and interoperability features of smart home protocols. For this purpose, we surveyed the IoT frameworks present in the literature, analyzed these state-of-the-art solutions and defined challenges for future research. Section two presents the methodology used in this paper in order to select the most appropriate recent developments as published in the literature covering the topics of Internet of Things, smart grid, and smart home. The in-depth analysis of the results, as identified by our methodology, is given in Section 3. Our analysis is conducted in a threefold manner. Initially, possible and existing IoT and near IoT applications are analyzed in view of different parts of the smart grid where such solutions are and/or can be applied, with focus on the smart home. Afterwards, a generalization is given of the existing solutions in a new generic holistic framework that incorporates key features from the literature review as identified by our methodology. The analysis is concluded by overviewing a general smart home management model for the IoT based holistic framework by defining its integral levels and their main tasks as observed in the analyzed state-of-the-art solutions. The fourth section discusses challenges associated with IoT constrained resources (energy, memory capacity and processing capabilities), along with networking, interoperability issues, big data analyses, security and privacy. An overview of useful guidelines and solutions needed to face these challenges is given. Finally, this paper is concluded in the fifth section.

2. Review methodology

This section presents the methodology used in the paper in order to select the most appropriate recent developments as published in the literature covering the topics of Internet of Things, smart grid, and smart home. The literature was searched using the online service Google Scholar (GS) (https://scholar.google.com/). The main advantages of using GS as opposed to other similar resources like Scopus and Web of Science are freedom, ease of use,

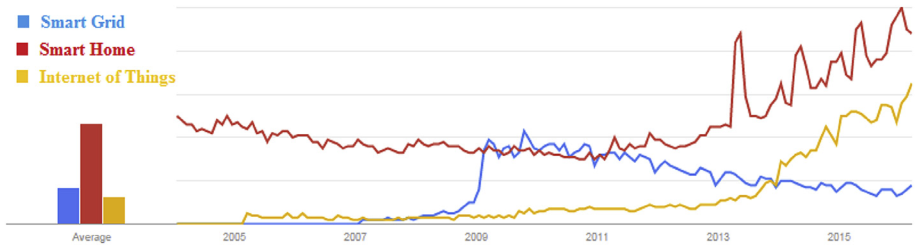

Fig. 1. Interest over time according to Google trends since 2004 for terms Internet of Things, Smart Grid and Smart Home.

and a broader universe of cited and citing items (Franceschet, 2010). Google Scholar has a high coverage for high quality studies, is highly sensitive and could be the first, and even more so a standalone choice for systematic reviews or meta-analysis (Gehanno et al., 2013). Only publications, excluding patents and citations were searched. All results provided by GS were sorted according to their relevance. Google Scholar's ranking algorithm relies heavily on an article's citation count, but also puts a high weighting on words in the title (Beel and Gipp, 2009). Currently GS does not search for synonyms of queried keywords; hence, all synonyms have to be rewritten and queried separately.

Only publications between years 2010 and 2016 were considered. Papers prior to 2010 were not considered since most of the advances in this area have happened within the last few years (GS retrieves 130 publications with keyword “Internet of Things” in the title published before 2010, and 7650 publication published after 2010), which is in line with the Google trends as shown in Fig. 1.

The following terms were allowed: “Wireless Sensor Network”, “Internet of Things”, “IoT”, “Smart Grid”, “Smart Home” and “Home Automation” to appear anywhere in the text of the publications. We consider the terms “Home Automation” and “Smart Home” to be synonyms, as well as the terms “IoT”, “Internet of Things” and “Wireless Sensor Networks” (since Wireless Sensor Networks together with RFID are the two main technologies which enable the development of IoT). Most of the research challenges in IoT have its origin in WSN; hence, some of the IoT solutions are simply borrowed from WSN (Mainetti et al., 2011). The general query form we use is “term1” AND “term2” AND “term3”, where term1 = (“Wireless Sensor Networks” OR “Internet of Things” OR “IoT”), term2 = (“Smart Home” OR “Home Automation”), and term3 = “Smart Grid”, and thus perform six searches. The queries and the total number of publications retrieved by GS are given in Table 1.

Only the first 100 results per query were considered for further analysis in this paper. There are overlaps between the result sets of the different queries so the final set of unique publications is around 150. For example, if we consider only the top 20 results there are a total of 74 unique publications, with multiple publications appearing in the results of more than one query. Fig. 2 shows the number of these overlaps, and additionally the average GS ranking for each group are given (e.g. papers that appear in the results of a single query have an average ranking of 12.54).

The unique set of publications was further filtered content-wise

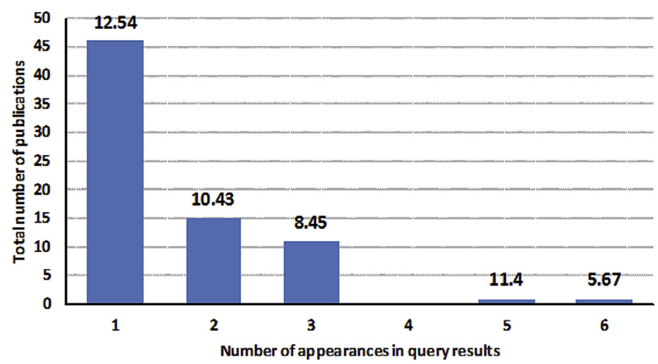

Fig. 2. Total number of publications appearing in the top 20 results for the six queries. The number associated with each bar refers to the average ranking of the publications in the group.

i.e. whether the publication has pertinent material regarding wireless sensor networks or Internet of Things solution/s for smart home and/or smart grid. First a number of papers were excluded based on the content of their abstract. Next, we considered the whole text of the remaining papers and retained only those in line with our review. The final remaining papers were analyzed in-depth. The finding is that the papers can be semantically divided in two main categories: WSN solutions and IoT concepts.

The first category includes papers that provide real-life working implementations of WSN in different domains like habitat monitoring, home monitoring, etc. They can be considered the seeds of future IoT applications.

The papers in the second category revolve around the IoT paradigm and provide concepts, frameworks, visions, and challenges of future “to be implemented” IoT solutions.

Hence, this work separately elaborates the papers in the two categories in the forthcoming Section (3). We firstly expatiate on papers in context of WSN implementations (3.1), then we survey papers in line with IoT solutions (3.2 and 3.3).

3. In-depth analysis of literature

This section presents the in-depth analysis of the results as identified by our methodology. The analysis is conducted in a

Table 1
Number of publications found by GS engine for different queries.

Query#	Term1	Term2	Term3	Total number of results
Query 1	“Wireless Sensor Network”	“Smart Home”	“Smart Grid”	919
Query 2	“Wireless Sensor Network”	“Home Automation”	“Smart Grid”	775
Query 3	“Internet of Things”	“Smart Home”	“Smart Grid”	1430
Query 4	“Internet of Things”	“Home Automation”	“Smart Grid”	1000
Query 5	“IoT”	“Smart Home”	“Smart Grid”	1050
Query 6	“IoT”	“Home Automation”	“Smart Grid”	747

threefold manner. Initially, possible and existing IoT and near IoT applications are analyzed in view of different parts of the smart grid where such solutions are and/or can be applied, with focus on the smart home. Afterwards, a generalization is given of the existing solutions in a new generic holistic framework that incorporates key features from the literature review as identified by our methodology. The analysis is concluded by overviewing a general smart home management model for the IoT based holistic framework by defining its integral levels and their main tasks as observed in the analyzed state-of-the-art solutions.

3.1. State-of-the-art (near) Internet of Things solutions in smart grid and smart home

The integration of IoT within the smart grid will bring a new perspective to electricity management, with benefit for all parties involved.

Table 2 differentiates the potential IoT applications regarding different aspects (parts) of the smart grid (Cardenas et al., 2014; Gungor et al., 2010; Parikh et al., 2010). Much of the pioneering research is hindered with a lot of challenges, especially when dealing with the first three aspects (generation, transmission and distribution) of the smart grid. The problems are mostly due to the harsh conditions in which sensor devices are deployed. Experimental results using IEEE 802.15.4-compliant sensor networks show that wireless links (including both line-of-sight (LOS) and non-LOS (NLOS) scenarios) in the smart grid have high packet error rates and variable link capacity due to electromagnetic interference, equipment noise, obstruction, etc. (Gungor and Korkmaz, 2012). Wireless nodes impose additional constraints, i.e. the memory and processing limitations of the sensor nodes and their limited power resources.

Fortunately, most of these challenges are not present in the fourth, consumer side of the smart grid, i.e. the smart home. For example, sensors are usually connected to home appliances and the battery life problem becomes superfluous as the devices have a steady power supply. Furthermore, strong electromagnetic fields are not associated with home grid infrastructure. Still, IoT for smart home is subject to challenges like reliability, privacy, and security (Iyer, 2011).

Modern homes equipped with smart meters, smart appliances, smart power outlets and sensing devices enable the development of energy-aware smart homes (Fig. 3). Although the smart home has been a dream for both utilities and consumers for a long time, such implementations are still very rare (Monacchi et al., 2013). On the other side, there are plenty of existing commercial solutions and advanced Demand Side Management (DSM) systems focused on large industrial consumers (Finn and Fitzpatrick, 2014; Palensky and Dietrich, 2011). Almost all of them fail to integrate small residential consumers.

IoT carries the potential to overcome this gap and to provide services that will foster the development of intelligent solutions for the common people. The main goal of IoT is to advance a better and safe society, where “Everything is a service” (public safety, environment, health care, production, etc.).

In this subsection we present relevant attempts from the literature as identified by our methodology. The papers discussed here semantically fall in a category regarding near IoT solutions for smart home, mainly from the neighboring fields of wireless sensor networks, home automation, and smart grid.

Novel architectures in terms of state-of-the-art software technologies with focus on domestic environments and habitat monitoring are proposed in Monacchi et al. (2013) and Stojkoska and Davcev (2009). In Monacchi et al. (2013) the authors promote design guidelines for collecting and integrating household data, thus enabling data interoperability. In Stojkoska and Davcev (2009), a web interface is developed in order to increase the interaction between the deployed WSN and its end users. Authors of Kamilaris et al. (2011) propose a solution for a Web-based energy-aware smart home framework that enables smart appliances to the Web. They have developed a graphical user interface to ease the interaction. The evaluation of their solution is done using a WSN organized in a star topology and also a multihop topology (up to three hops) for larger apartments (smart homes of around 100 m2).

VillaSmart (Caracaş et al., 2013) is associated with the ECOGRID EU (EcoGrid EU, 2015) project. The authors have installed a modular and extensible WSN in a test and reference household called VILLASMART. These authors are modeling the energy behavior of the building. These thermal models are improved using indoor and outdoor WSN readings (air and water temperature, solar radiation sensor, weather conditions and power consumption information), thus achieving more precise predictions of indoor temperature. Using the standard resistance-capacitance (RC) model, the maximum prediction error achieved is 1.790C. The IEEE 802.15.4 standard in the 2.4 GHz is used for indoor communication. The model parameter determination is done with the grey-box estimation method. In Srbinovska et al. (2015) a WSN is installed for vegetable greenhouse monitoring and a control system for agriculture is developed. This system helps farmers increase the crop production and quality by remotely controlling different parts of the greenhouse, like drip irrigation and fan facilities. In Risteska Stojkoska et al. (2014), the authors present a framework for temperature regulation inside commercial and administrative buildings, with focus on design and implementation of specific network topologies and node localization within the system.

3.2. Holistic IoT-based framework for smart home

It is expected that smart objects will be dominant on the market in the next few years and will become omnipresent in households, which will impose the need for new and improved services for smart homes (Karnouskos, 2011). For these reasons, the need for IoT based solutions will be incontestable.

Table 2
Potential IoT applications for smart grid.

Energy providers Energy generation	Transmission	Distribution	Consumers
Real-time generation monitoring	Transmission lines controlling	Underground cable system monitoring	Wireless automatic meter reading (smart metering)
Power plants controlling	Power monitoring	Transformers stations controlling	Home (Residential) energy management
Alternative energy sources controlling			Solar panels management
Residential (distributed) production monitoring			Predicting future solar panels and wind turbine production (using sensor data like temperature or humidity)

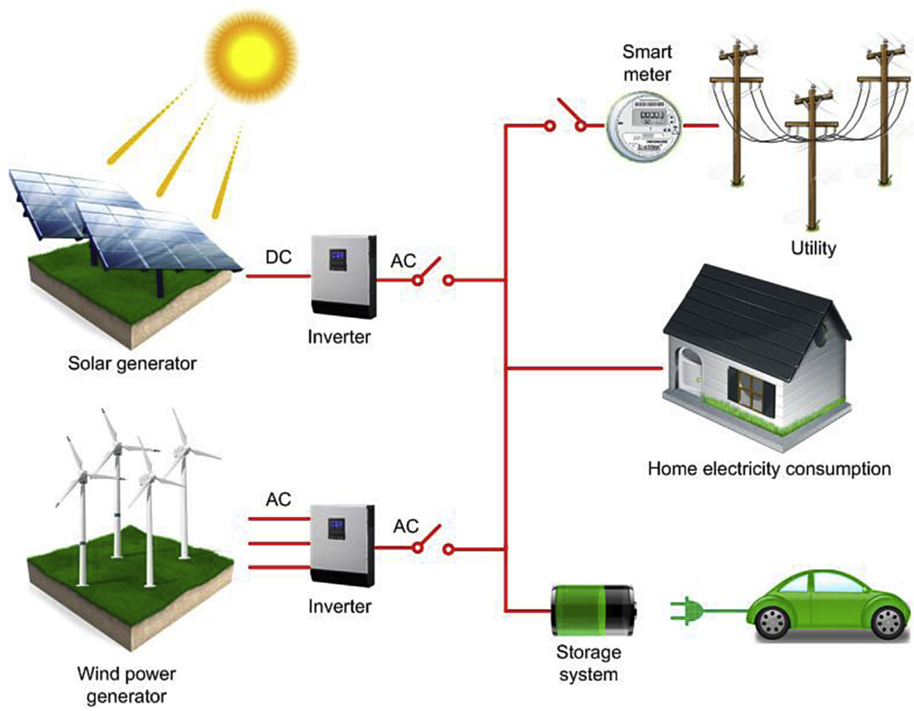

Fig. 3. Smart home.

Most recent publications focus on developing a general IoT framework that is suitable for broader range of application domains. In Lee and Lee (2015), the authors identity five IoT technologies as essential for building successful IoT solutions: radio frequency identification, wireless sensor networks, middleware, cloud computing and software for application development. They also identify three IoT categories for enterprise applications: monitoring and control, big data and business analytics, and information sharing and collaboration. In(Da Xu et al., 2014), the list of enabling technologies is enhanced with Near Field Communication, location based services and social networks. They suggest a four-layer architecture made up of: sensing, networking, service and interface. The role of the cloud is missing; therefore, it is not clear how services would be enabled. Liu et al. (2014) presents a middleware that supports naming, addressing, storage and look-up services. The idea is to develop a middleware at the top of the existing systems, thus to achieve easier integration of existing applications into IoT environments. Once again, the cloud is omitted as an enabling technology that should support all these services. The monitoring of production processes in industry using IoT is investigated in Shrouf and Miragliotta (2015). The authors propose a detailed framework that is focused on energy management, with possibilities for in-house or cloud-based data mining and decision making. The role of the third-party solution designers is not specified in the framework. Readers can also refer to (Gubbi et al., 2013; He et al., 2014; Xu et al., 2014) for interesting work regarding IoT architectures.

With respect to these publications, the framework presented in this paper can be considered a modified version of the most general model we found in literature (Da Xu et al., 2014), augmented with the cloud in the middle, and adapted to a particular application domain, i.e. smart home. This multi-level hierarchical holistic framework based on Internet of Things is used as a wrapper or generalization of all the key features of IoT solutions for smart homes identified in the literature. The graphical representation of the framework is given in Fig. 4. Within the framework data is sent wirelessly and is shown using dashed lines. The yellow lines correspond to a bidirectional electricity flow. The following paragraphs summarize each level of the framework.

3.2.1. Smart home

All household devices equipped with interfaces for wireless communication, make up the home WSN. Each home has a WSN, and the sensed data from each device is forwarded to a central station, which we refer to as *home sink* or *home hub*.

Each node in the home WSN is considered a smart device and has moderate computation and communication capabilities. The home hub can be any one device (smart meter, PC, tablet or smartphone) that has some data storage capacity, can perform local processing and can communicate with devices outside the home WSN. In the case of smart residential complexes or smart buildings, the counterpart of the home hub is identified as *residential sink* or *residential hub*. The residential hub needs to have an additional feature, as compared to the home hub, which is that it is responsible for managing data from/to shared distributed production sources. This is rather important, as renewable sources are usually shared among consumers, one example being a residential building with a PV system on the roof, where the PV system is used by all households in the building. Within the framework, each distributed renewable energy source is considered a smart device.

3.2.2. Cloud

All data from different sources is accumulated in the cloud (households' data, sensor measurements from the transmission/distribution lines or from the production sites, etc.). The cloud should provide massive data storage and processing infrastructure. It is the most advanced level of the framework (Da Xu et al., 2014; Lee and Lee, 2015). As stated in Gubbi et al. (2013), the cloud “promises high reliability, scalability and autonomy” for the next generation of IoT applications. The cloud is the central part of this system, hence our framework can be considered as “cloud centric” or “cloud based”.

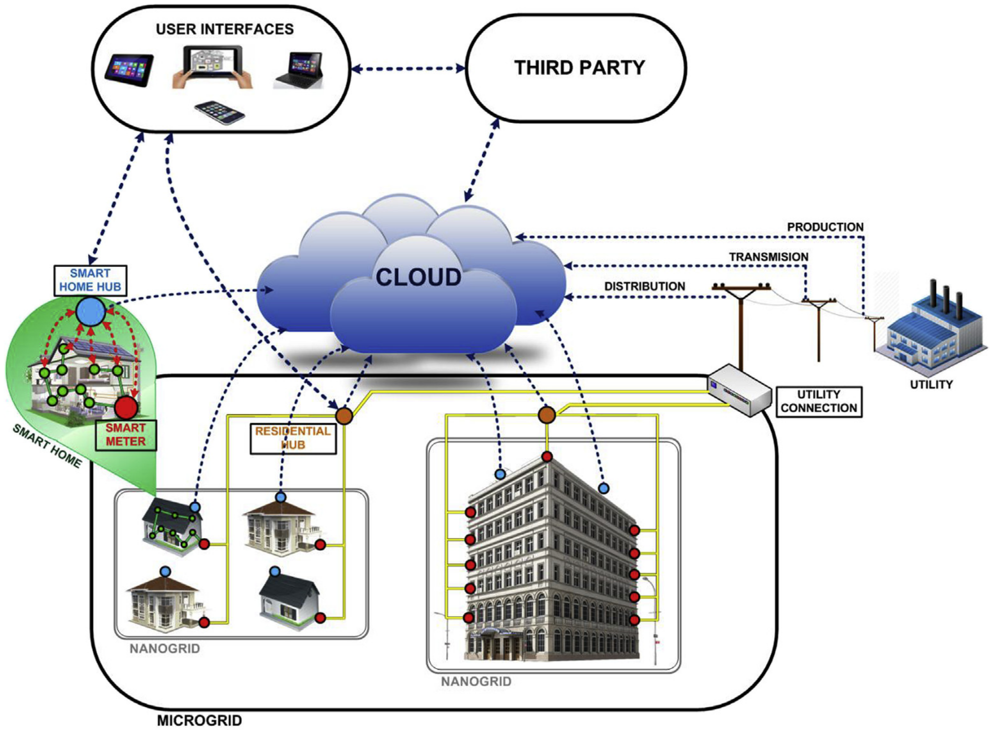

Fig. 4. Multi level IoT framework for smart home.

3.2.3. Utility

This level corresponds to the remaining parts of the smart grid, apart from the smart home: production, transmission and distribution. Each part independently sends data directly to the cloud. The typical information that can be exchanged with the utility is: price of electricity, weather forecast, distribution/transmission line status, current and future consumption of a microgrid, current and future production of the distributed production sources associated with a microgrid, etc (Sajjad et al., 2014).

3.2.4. Third party

Third party applications are developed using the cloud data (Gubbi et al., 2013). Other terms that are interchangeably used are business applications, industry oriented applications or user-specific IoT application. Namely, third party application developers get data from the cloud (private or public) and use this data to deliver solutions in the form of web based or mobile applications (Fan et al., 2010).

3.2.5. User interfaces

This level represents user interfaces that deliver data to the end users (notifications, recommendations, smart device controls, etc) (Da Xu et al., 2014). Raw tabular data referring to monthly (or even daily) household consumption is hard to be interpreted by the users. A more sophisticated visualization tool is needed to present not only the overall household consumption, but also the consumption at device/appliance level (Liu et al., 2014). This is particularly useful, since consumers will be able to learn more about different appliances in their home, especially ones that cannot be controlled automatically, like non-flexible devices, hence enabling the users to control them intuitively taking into account their consuming nature. Third party applications should put an effort toward developing intuitive visual user interfaces for the consumers and frequently evaluate those using Quality of Experience (QoE) metrics.

3.3. Smart home management systems

An energy management system is defined as an interface between a utility company and smart devices that consume power. It aims to provide benefits for both parties (utilities and consumers), somewhat biased towards the consumers.

Another term commonly used is Demand Side Management (DSM). It represents a set of technologies that enable monitoring and controlling the consumption/production at consumer level in order to perform power balancing in future energy systems (Atzeni et al., 2013; Rezvani et al., 2015; Siano, 2014).

In the context of IoT solutions for smart home, the traditional DSM model is shifted toward the cloud centric model. The cloud based approach offers centralized optimization that considers a huge set of parameters; hence it is expected to outperform the energy management as compared to a traditional approach.

Fig. 5 shows the general Smart home management model adopted for our holistic framework. The main tasks that should be performed at each level are presented as follows.

3.3.1. Smart objects/smart devices

Home appliances, lights, or sensors attached to production or transmission lines in a smart grid system can be considered smart objects. They can sense, actuate, process data and communicate. In order to sense and actuate, they need to perform A/D and D/A conversions (Byun et al., 2012).

These devices periodically perform sensing and send (wirelessly of wired) sensed data to the hub. Moreover, if protocols allow it, sensed data can be sent directly to the cloud. If possible, smart devices should perform basic data processing before they send the sensed data (Stojkoska et al., 2012; Viani et al., 2013).

Actuating can be also controlled remotely. In the context of DSM, home appliances can be divided in three categories: non flexible, flexible and dual nature appliances (Erol-Kantarci and Mouftah, 2010). The non-flexible appliances are those that are associated

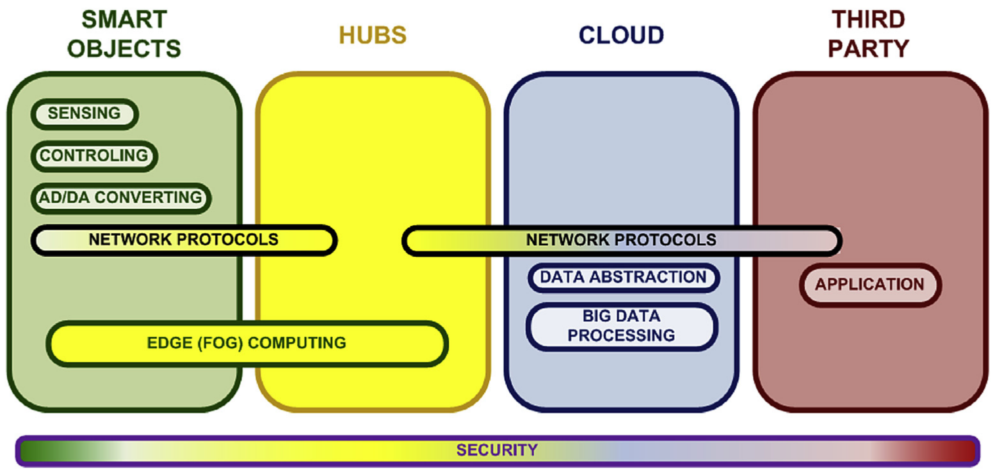

Fig. 5. General smart home management model.

with *baseline loads* or non-preemptive tasks (like light, TV, PC, hair drier) and cannot be controlled by the system (Ullah et al., 2013). The flexible appliances are associated with *regular loads* or pre-emptive tasks (like heating or air-conditioning) and can be automatically operated by the system. The dual nature appliances sometimes can act as flexible, but sometimes as non-flexible (like washing machine, dish washer or laundry). For example, sometimes the consumer does not care about the exact time the dish washer will operate, as long as it is within a predefined time frame. These appliances usually present *burst loads* (Khan et al., 2014; Ullah et al., 2013). The smart appliances (both flexible and dual nature) are equipped with smart power outlets that are able to measure their power consumption and to control their operation in real-time.

3.3.2. Hubs

The hub is a device that is responsible for collecting raw and/or processed data from the smart devices and forwarding them to the cloud (Zhu et al., 2010). Whenever possible, the hub has to perform local data processing (Viani et al., 2013), in order to reduce the data flow towards the cloud. Furthermore, in a smart home scenario, the hub can send commands to the smart devices acting as a local scheduler, regulator, or load balancer (Byun et al., 2012). In the case of a residential hub, it can send commands to the devices that regulate the electricity flow to/from the nanogrid, i.e. to manage the operations of buying/selling electricity from/to the grid.

The hub understands the communication protocols used by the smart devices. Hubs are needed to enable the interoperability between the smart objects, since the devices generally cannot communicate with each other (Gubbi et al., 2013; Heile, 2010). Hence, sometimes a household needs more than one hub.

In the future, when full interoperability among smart devices is achieved, it is expected that hubs will be superfluous in the model.

3.3.3. Cloud

The cloud is the most complex part of the home management. The main task of the cloud is to store the data (Zhou et al., 2013). Because of the high data volume, traditional approaches should be modified to meet the new requirements. New methods and algorithms based on machine learning techniques, time series processing and advanced analytics are to be employed (Da Xu et al., 2014; Gubbi et al., 2013).

Third-party applications typically assume that the data being used is unchanging i.e. the data is usable by applications on a non-real-time basis. In the cloud the event-based data is converted to query-based processing. This is a crucial step towards bridging the differences of real-time IoT networking and the third-party application world. The data should be stored persistently and abstracted at multiple levels so that they could be easily combined, recomputed and/or aggregated with previously stored data, with the possibility of some data coming from non-IoT sources (Da Xu et al., 2014). Even more importantly the different levels of abstraction will simplify the application access and usage since data will be presented in a manner required by applications.

3.3.4. Third party

Third party should develop applications for the end users in the form of schedulers, regulators, and load balancers (Fan et al., 2010).

A scheduler is a tool responsible for defining time slots in which the dual nature appliances will be active. A regulator is a tool responsible for the management of flexible devices, i.e. it will regulate the operation of air conditioners, heaters, dehumidifiers, etc. Load balancing should optimize energy consumption, considering current electricity price on the market and availability of electricity produced by the local renewable sources, if available.

All these tools need advanced algorithms that use much more parameters than those obtained by the home devices. They should perform the complex tasks of mining and knowledge extraction from the available data in the cloud in order to create consumer and household profiles, or in simpler words the available smart home data should lead to the creation of personalized recommendations for all users (Liu et al., 2014).

4. Challenges and solutions

In this section, some guidelines for future developers of IoT solutions on how to make good choices when dealing with different challenges associated with practical issues are presented.

4.1. Edge (fog) computing

Edge computing or fog computing is the process of data processing at the edge of the network. In this paradigm it is expected that the knowledge extraction process starts as early as the time the data is sensed i.e. at the sensor side. There are many reasons to employ this approach, but some of the more prominent ones are the energy saving, data volume reduction and latency reduction.

Each object/entity in the IoT can consume a huge amount of energy if its communication is not optimized. For smart objects, in terms of energy consumption, local computation is an operation cheaper than communication. Hence, the effort should be shifted toward developing lightweight algorithms for local data processing. This approach will decrease the data volume and will avoid sending huge portions of raw data. Instead, only metadata will be transmitted (data about the data). Reducing the number of transmissions among IoT devices is also very important in order to avoid latency issues and saturation of the wireless channels.

For these reasons, different data reduction techniques should be employed to minimize the communication overhead. There are three main techniques used for data reduction: data compression, data prediction and in-network processing (Stojkoska et al., 2012). For example, if data is not needed in real time, data compression (like delta compression) can be used. Otherwise, different filters can be used for real-time sensor data prediction, most of them based on adaptive filtering techniques, like moving average (MA), autoregressive (AR) model, autoregressive moving average (ARMA), least mean square (LMS), and LMS with variable step size (LMS-VSS) (Risteska Stojkoska et al., 2014; Stojkoska et al., 2012). Prediction is performed at each device and at the hub, i.e. predictions are made simultaneously on both sides. If the sensed value differs significantly from the predicted value (the difference is above a predefined threshold e_{max}), the smart device should send the measurement/data to the hub. Otherwise, the predicted value is considered to be "reliable" and is used to feed the filter for future predictions. This paradigm is known as "dual prediction scheme" (Santini and Romer, 2006). In-network processing is the process of consecutive data processing on their way to the destination. As data travel through intermediate nodes, some aggregating operations are performed.

4.2. Big data

The IoT-generated data come in big amounts, are variable in terms of structure, often arrive at real-time, and might be of uncertain provenance. This volume, velocity and variety (not to mention variable veracity) make the storing and analytics solution, which will generate useful insights, a very complex one (Zaslavsky et al., 2013). Traditional SQL-queried relational database management systems (RDBMSs) are unsuitable for the task, which is why big data solutions are needed. The IoT Cloud (Alamri et al., 2013; Botta et al., 2016) will enable the long-time storage and complex analysis of this data. The challenge of handling big data is a critical one, since the overall performance is directly proportional to the properties of the data management service (Dobre and Xhafa, 2014). A constellation of tools has evolved to service the market, most notably Apache's open-source Hadoop distributed data processing system, plus various NoSQL databases and a range of business intelligence platforms. There are multiple vendors that operate in different parts of the analytics pipeline (data integration, data storage, core analytics and data presentation), as well as 'full-stack' vendors like IBM, Microsoft, Oracle, SAP and Software AG. Both proprietary and open source solutions adopt alternative database technologies for big data (Copie et al., 2013): time-series, key-value, document store, wide column stores, and graph databases. However, to date there is no simple answer to the big data management question in the Cloud (Zaslavsky et al., 2013). The problem becomes even more cumbersome when the factor of data integrity is taken into account, not only because of its impact on the quality of service, but also for its security and privacy related aspects especially on outsourced data (Liu et al., 2015).

4.3. Networking

Networking protocols for Internet of Things solutions can be divided in smart device networks and traditional networks that are designed primarily for high data rates.

Smart home networking protocols are expected to adopt the protocols already established in Wireless Sensor Networks and Machine-to-Machine (M2M) communications, with no clear winner so far (Chen et al., 2012). Adding many advanced features to the protocol increases the cost, and reduces the ease-of-use. Designing an appealing protocol is not a trivial task, and is usually a tradeoff between the cost and the performances.

In perspective of the topology to be used, mesh is the most suitable choice of network topology for wireless communication due to the presence of obstacles in the home, like walls, furniture, etc. Dual-mesh, which means that the network operates as both wired and wireless, is an appropriate solution for households that have a previously installed wired home automation system.

There are many protocols designed for smart home solutions. Some of them dated back from the period when smart home was reserved for the wealthy households, and many new that try to combine the old design principles with the newly developed technologies. X10 is the oldest protocol that was initially wired, but new modifications make it dual-mesh. Insteon is another example of a dual-mesh protocol, which was recently integrated into Google owned Nest, Apple's HomeKit platform and Apple Watch (Darbee, 2013). The more recent protocols work only wirelessly (ZigBee, Z-Wave, 6lowpan, EnOcean, etc.).

There are different ways to classify protocols, and none of them is exhaustive enough. Using Google Scholar, we queried for publications that cover each of these protocols and the summary statistics for the number of publications is given in Table 3. This data is of November 2015.

Table 3 shows that ZigBee is the most popular protocol, but this is true only for the scientific research and academia (ZigBee, 2015). In practice, the Z-Wave is the one that has the most manufacturers, mainly due to their interoperability. According to Z-Wave Alliance, over 35 million Z-Wave products have been sold since they began selling in 2005 (Z-Wave Alliance, 2015).

The basic features of ZigBee, Z-Wave and Insteon are shown in Table 4. Theoretically, a Z-Wave network is limited to a maximum of 232 Z-Wave devices, but most vendors recommend using about 30–50 (Darbee, 2013). For example, MiOS LTD with their Vera products recommends 50 devices for Vera Lite, and 100 devices for Vera 3 (MiOS, 2015).

The price is another aspect that can be considered when choosing the right protocol. A ZigBee Licence costs $3500 per year, while Z-Wave charges $750 per device model for the logo (Darbee, 2013). A more detailed comparison of the smart home protocols can be found in Withanage et al. (2014).

Each level of the IoT framework should have particular features. We identify and summarize the required capabilities of IoT devices at each level in Table 5.

4.4. Interoperability

Currently, the main issue for the development of a generic smart home solution is the cost associated with integrating smart home devices (Ko et al., 2011). Interoperability is the key to open markets to competitive solutions in IoT (Lu et al., 2011; Misra et al., 2015). Leading companies in the world that are producing smart devices are working toward achieving full interoperability that will ensure easy integration with the existing Internet.

Z-Wave products are already interoperable with their previous versions, while ZigBee Allience with its Zigbee 3.0 has announced this feature to be implemented by the end of 2015. ZigBee has formed many committees that aim to define product properties required for different vendors to build interoperable devices for

Table 3
Number of publications according to Google Scholar.

	Zigbee	6lowpan	Z-Wave	Bacnet	X10	EnOcean	Insteon
Without patents	228000	9790	5770	6700	1840	1520	720
With patents	264000	9010	7650	7550	1890	2440	1080

Table 4
Basic features of ZigBee, Z-Wave and Insteon.

	ZigBee	Z-Wave	Insteon
Media	wireless (radio)	wireless (radio)	wireless (radio) and wired (powerline)
Frequency	2.4 GHz (worldwide), 915 MHz (Americas and Australia) and 868 MHz (Europe)	<1 GHz, (868.42 MHz Europe; 908.42 MHz United States; 916 MHz Israel; 919.82 MHz Hong Kong; 921.42 MHz Australian/New Zealand)	single frequency of 915 MHz
Network topology	mesh	Mesh	dual-mesh
Vendors	Texas Instruments, Atmel, Silcon Labs, Freescale, etc.	Sigma Designs	Smartlabs, Logitech
Maximum number of nodes	65000 (theoretically), 500 (in practice)	232 (theoretically), 50–100 (in practice)	16777216
Range	10 to 100 m line-of-sight	30 m open-air, < 30 m indoor	40 m
Modulation	Binary phase-shift keying (BPSK) for 868 and 915 MHz bands, or offset quadrature phase-shift keying (OQPSK) for 2.4 GHz	Gaussian, frequency-shift keying (GFSK) manchester channel encoding	Frequency-shift keying (FSK)

Table 5
Capabilities of IoT parts for smart home management system.

	Network topology	Communication protocols	Computational capabilities	Memory requirements
Smart Device	mesh/star	ZigBee/Z-Wave//Bluetooth/Insteon/X10, etc.	low	low
Hub	mesh/star	ZigBee/Z-Wave//Bluetooth/Insteon/X10, etc; LTE/optical fiber/Wi-Fi	intermediate	low to intermediate
Cloud	not applicable	LTE/optical fiber/Wi-Fi	very high	very high
Third party	not applicable	LTE/optical fiber/Wi-Fi	high	application dependent, from intermediate to high

different public application profiles, like Home Automation, Health Care, Remote Control, etc. Still, products are not necessarily interoperable across these profiles and across revisions within a profile. On the other side, X10 and Insteon are fully interoperable with each other (Darbee, 2013). Table 6 summarizes the interoperability features of these protocols.

4.5. *Security and privacy*

One of the most important issues of the emergent requirements facing the smart grid development is related to cyber security, both for the wireless and the wired parts of the systems (Ning et al., 2013; Schneps-Schneppe et al., 2012). The smart grid can be a target for cyber terrorists, which emerges as a critical concern for system designers.

Because of the way in which data is transmitted, IoT is inherently vulnerable to most of the common attacks of wireless networks. Hence, IoT requires a security policy, but the cost for providing it needs to be as low as possible. Different approaches that provide security lightweight crypto-primitives should be investigated (Altolini et al., 2013), in order to provide authenticity (the device is not a malicious object), integrity (transmitted data is identical with the received data) and confidentiality (make data unreadable to others) (Dimitrievski et al., 2006).

Table 6
Interoperability features of Insteon, X10, Z-Wave and ZigBee.

	Insteon	X10	Z-Wave	ZigBee
ZigBee	invisible to each other	No	No	No
Z-Wave	invisible to each other	No	Yes	
X10	Yes	Yes		
Insteon	Yes			

5. Conclusions

This paper addresses the vision that the residential buildings would shift themselves toward modern households that would be an evolution of the passive household. They would have their own solar panels and small wind turbines to produce their own energy, thus they would be able to buy/sell energy from/to the smart power grid. As it is expected for smart objects to become omnipresent on the market and respectively in consumers' households within the next few years, the need for IoT-based services for smart home will be inevitable.

In this paper, a methodology is developed using different search queries to select the most relevant papers from the literature that address this topic. Selected papers were semantically divided into two main categories: WSN solutions and IoT concepts. This was rather expected considering that WSN is the pivotal technology which enabled the development of IoT.

Although the WSN solutions are real life implementations that integrate devices inside a smart home, two disadvantages are identified, as they:

- work separately and the data is used only for local optimization;
- make an assumption of a fully (or near fully) automated home, which is a costly solution for most of the households.

The second category of papers concerning IoT mainly presents concepts, theoretical frameworks and visions for possible smart home/grid solutions. There is a lack of a unifying platform that would transform these separate individual applications into a single infrastructure, a platform that can be further used for advanced data mining and knowledge extraction. The desired solution should aggregate all available smart home data within a self-learning engine in order to create personalized recommendations for all users, regardless of the level of automation present at their homes. The solution should not entail any additional cost for the consumers, as it should not require any particular hardware.

The main contribution of this paper is the IoT based holistic framework, which incorporates different components from IoT architectures/frameworks proposed in the literature. This integral IoT framework is specific to the smart home application domain, with the cloud being the central element in the system that serves not only to collect and store data, but also as a gateway to third-parties interested in developing applications. In this context, we additionally survey the smart home management system, and we identify a model with a set of specific tasks that should be performed at each level in order to meet the system requirements.

As a second contribution, this paper discusses challenges for IoT based smart home solutions, with emphasis on practical issues like data processing, networking and interoperability of smart home protocols. Fog and edge computing are promising approaches for improving the energy saving inside the IoT network by reducing the number of transmissions between the IoT devices. Although there are some publications that investigate this potential, a lot of research and work still needs to be done. New big data solutions and algorithms are needed to deal with the potentially vast amount of data generated within the IoT. A constellation of tools has already appeared in the last few years, as there are multiple vendors that operate in different parts of the analytics pipeline. Another big issue is the interoperability, which is a prerequirement for opening the markets to competitive solutions in IoT. The current situation is that devices with different protocols cannot communicate, and, more important, the products with the same protocols are not necessarily interoperable across different profiles and across revisions within the same profile.

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