Wireless Power Transmission in Smart Cities: The wIshood
Wireless Smart Neighborhood

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Abstract: Wireless power transmission (WPT) of scale is the next step in power electronics. In this paper, we propose the Wireless Smart Neighborhood (wIshood). The idea presented serves smart city planners and developers to consider the future societal impacts of current and expected technological advancement. The wIshood merges ICT, IoT, CC, SDN and WPT to propose a solution to foster the creation and growth of the building blocks of modern societies. We outline the architecture and challenges of wireless smart neighborhoods. The wIshood is a solution to electricity congestion and deployment costs of transmission and distribution infrastructure.

1 INTRODUCTION

In the recent past, city planners have been busy resolving the best trade-off among mobility, green zones and residential and commercial expansion. To address these conflict-of-interest problems, technological breakthroughs will be fundamental for future smart city planning. At a careful but steady pace, modern cities are embracing the information and communication developments. Products and services, from technological innovations, will become ubiquitous in future smart cities. From rural to urban, industrial to residential and the overlap, Wireless Power Transmission (WPT), the Internet of things (IoT) and Information and Communication Technologies (ICT) will become a cornerstone in the design of new and growth of human settlements.

The evolution towards smart environments is being welcomed by society. Nowadays it is commonplace for cities to be equipped with free WiFi hotspots, real-time traffic information and safety surveillance, to mention a few. In this respect, creativity driven and farsighted governments are playing a crucial role to speedup the technological evolution of the city. For example, *Pervasive Nation*, a public funded initiative, is empowering academia and entrepreneurs to develop and implement an IoT testbed of scale in Dublin city (PervasiveNation, 2016). With the ever-increasing services and cloud connectivity, IoT devices are set to pervade all aspects of our daily lives. Thereby revolutionizing a broad range of applications in a variety of domains, such as healthcare, home automation, transportation, intelligent energy management and smart grids (Bellavista et al., 2013).

Neighborhoods form an important building block of every city. Nevertheless, presently they have a passive rather than active role in the progress of the city. In a top-down manner, technology is percolating into neighborhoods. In smart cities, legislation is requiring a change of old practices towards an efficient use of resources. Nevertheless, electricity distribution still relies on cables for its delivery.

In this paper we propose the wireless smart neighborhood: The wIshood[1]. The novelty of the wIshood is that households use WPT for electricity supply. The energy is wirelessly supplied from a local renewable power station (RPS). Although, still in an early stage, wireless power transmission is gaining momentum. Both, industry and academia know that WPT will be the solution to a variety of problems. With WPT, the wIshood has three major advantages to positively contribute to the smart city. Firstly, the increase of renewable electricity integration decreases fossil-fuels dependence. Secondly, city growth will have a lesser impact on the distribution and transmission capacity. Lastly, the wIshood will promote industrial investment by reducing transmission congestions hence lowering marginal energy prices. The wIshood exploits the edge cloud paradigm. The distributed architecture supports heterogeneous IoT devices, scheduling, information, processing and control of energy supply and demand for households.

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[1] Pronounced as *wiz-hood*

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The reminder of the paper is organized as follows. In section 2, we do a brief outline of related literature. In section 3, we present the architecture of the wIshood. In section 4, we outline the challenges to be addressed by the research community. Lastly, section 5 summarizes the work presented.

2 RELATED LITERATURE

The Smart city is a green field for research. Although, there are ingenious attempts of materializing some of the conceptual designs, technological progress is constantly and at a faster pace widening the possibilities. For the reader interested in a survey of Smart City architectures, Kyriazopoulou recently presented a thorough literature review on the topic (Kyriazopoulou, 2015).

The work of Akcin *et al.*, describes passive and active solutions to problems associated with population expansion and urbanization. Among the active methods, they comment on improving traffic flow with road-side sensors. On the passive approach, e.g., they presented a Swedish study on natural ventilation of cities to reduce the power for cooling buildings (Akcin et al., 2016).

Reducing the peak-to-average ratio (PAR), hence balancing the load curve, is one of the main goals of demand side management (Cakmak and Altas, 2016), (Yoon et al., 2014), (Liu et al., 2014), (Zhu et al., 2015). For instance, Cakmak and Altas, developed an Cuckoo search algorithm (CSA) to address the problem of appliance scheduling in a neighborhood. The approach is oriented to increase the efficiency of electricity supply and demand. The algorithm minimizes the objective function of the tradeoff of shiftable loads scheduling and consumer satisfaction by means of financial benefits. They showed the CSA scheduling reduced the PAR from 3.27 to 2.53 (Cakmak and Altas, 2016).

Smart metering of electricity, in smart homes, was described in the work of Pingle *et al.* They used an Arduino mote to gather data from the IoT equipped appliance. The raw data, in amperes, was processed in the cloud to output watts and finally sent to the user's mobile phone. They commented on the implications and advantages for the end user of real time information on energy bill savings (Pingle et al., 2016).

Presently, the four most common technologies for wireless power transmission are: 1. Electromagnetic radiation; 2. Inductive coupling; 3. Magnetic resonant coupling; and 4. Acoustic waves (Shinohara, 2014). Antennas alignment is one of the major concerns in WPT applications. A Planar Archimedean Coil was proposed to overcome misalignment between transmitter and receiver (Feenaghty and Dahle, 2016). Imura *et al.*, summarized the WPT requirements for electric vehicles (EV) charging in Japan. They described a road infrastructure for WPT to provide a solution to the problem of long-distance traveling with EV (Imura et al., 2016). Recently, Jian *et al.*, presented a proof of concept of WPT with inductive coupling. In their laboratory setup, they wireless transfered electricity from a renewable source to a load with a pivoting antenna (Jian et al., 2016). Although, long distance WPT over free space is feasible (Ma et al., 2016), WPT over long distances among obstacle rich environments is currently a topic of research.

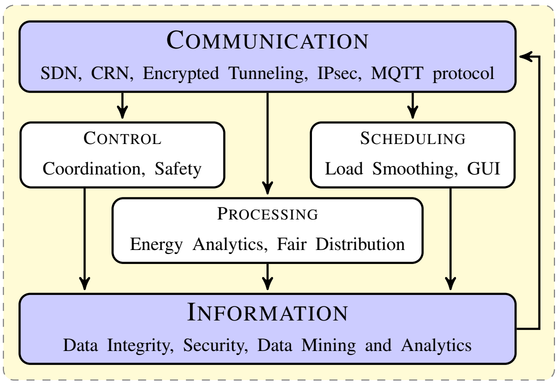

Figure 1: Layered architecture of the wIshood.

3 ARCHITECTURE

The layered architecture of the wIshood is shown in Fig. 1. It is composed of five layers: scheduling, information, communication, processing and control. Each household has IoT deployments of metering sensors, actuators, appliances and power switches. The functions of the IoT devices is to provide the hardware for data collection and communication. Machine learning and control theory will serve as the foundations of the Processing layer (Tobar et al., 2014). Finally, the control layer manages the energy distribution infrastructure; which is composed of the RPS transmitter antenna and the households' receiver antennas.

3.1 Communication

The fundamental task of the Communication layer is to ensure that the two way transfer of data from heterogeneous IoT motes and the edge-cloud is done in an efficient and secure way. We propose a Software Defined Network (SDN) and Cognitive Radio

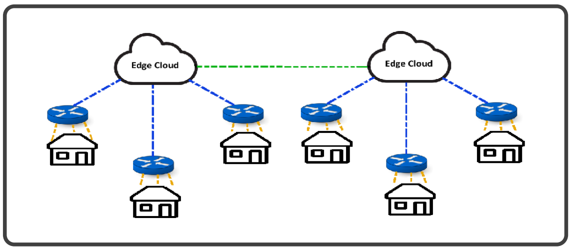

Figure 2: Communications are between IoT to gateways, gateways to edge-clouds and between edge-clouds.

Networks (Khan et al., 2016) to manage and transfer data from gateways (e.g., switches and routers) at each household to the edge-cloud; where the processing and decision making takes place.

The control of the queueing networks is done with a Lyapunov optimization algorithm (Samarakoon et al., 2016). To account for bandwidth bottlenecks and latency we adopt the Message Queue Telemetry Transport protocol (Jo and Jin, 2015). Figure 2, represents a high level communication view of the architecture. The data generated by the smart houses, RPS, weather forecast module and storage is channelled through gateways to the edge-cloud. *IPsec* tunneling is the cryptographic protocol of the communications network.

3.2 Information

The acquisition of the sheer amount of high-speed data, constantly generated from smart homes, is a significant task upon storage and analysis (Beckel et al., 2014). The Information layer resides in the edge-cloud, we adopt the integrated IoT Big Data Analytics framework (Bashir and Gill, 2016).

The principal functionality is to make the data accessible to the Scheduling, Processing and Control layers. A major task is to assure data integrity and security. At this layer, a first phase of data mining is implemented to eliminate redundant and non useful values. Thus, reducing the strain upon and bandwidth required by the Communication layer.

The stored data is fetched by the algorithms in the Processing phase. Figure 3, shows the flow of information among the IoT devices, cloud, Processing and Control layers. Dashed lines symbolize the WSN; red lines, power transmission and black lines, wired communication.

3.3 Scheduling

The scheduling layer positively exploits the flexibility of load shifting. The work of Liu *et al.*, categorized appliances as: 1. Shiftable; 2. Throttleable; and 3. Essential (Liu et al., 2014). Appliances such as dishwashers and laundry machines can be assigned a time slot to run. HVAC (heating, ventilation and air condition), although have rigid operation periods, are flexible to power adjustments within predefined ranges. A graphical user interface (GUI) is implemented for individuals to submit their desired scheduling of shiftable and operation ranges for throttleable devices. The output of the Scheduling layer is sent to the Processing layer (see §3.4). The latter analyzes the available resources and the energy demand. In case of mismatches, alternative scheduling arrangements are feedback to the households.

3.4 Processing

The processing layer, addresses the competing necessities of each household, proposes alternative scenarios to conflict-of-interest problems and determines tradeoff solutions between divergent goals. The functions of this layer are to perform the energy analytics and provide feedback when supply cannot meet demand. We use a ”divide and conquer” methodology to approach the non-linearity, uncertainty and highly coupled interactions in the wIshood.

The input, is the data from the information layer. Feedback is sent back to the scheduling layer. The processing unit integrates demand side management, energy generation and storage to optimize energy dispatch to the neighborhood. This layer provides a solution to the task of fair distribution of a scarce resource in a heterogeneous demand environment. To address this challenge, the functionalities of the processing layer include machine learning, optimization and forecasting algorithms.

A Kohonen self-organized network is used to reduces the dimensionality of the data. Then a Hidden Markov Model serves to classify the massive amount of sensor data; to be gathered and transfered by the IoT infrastructure. The HMM function is to determine clusters and patterns in the data. The output of the HMM is sent to the optimization module (OM).

The functions of the OM, are twofold: 1. Minimize the cost function of the wIshood energy distribution; and 2. Operate the RPS and storage infrastructure. The cost function takes into account individuals satisfaction, energy availability, weather forecast and storage levels. The feedback to the scheduling layer is the output of the optimization module. The algorithm is composed of two phases: 1. Optimization with given and foreseen conditions; and 2. Search of alternative scheduling scenarios whenever the demand surpasses the local supply. The feedback is sent back to the household individuals to accept the proposed changes or proceed with the original scenario; albeit requiring to buy electricity from elsewhere, e.g. the national grid. The latter functionality of the OM is to operate the RPS excess energy generation. This is done mainly through management of the centralized and distributed storage devices.

The weather forecast module objective is to provide support to the OM tasks. It is composed of two parallel processes. Firstly, an artificial neural network (ANN) algorithm performs fast, real-time and on-demand estimations of short-term (i.e., hours to a couple of days) weather conditions. Secondly, the forecast layer is connected to a national weather forecast system. This second process provides the necessary information for decision-making of long-range (i.e, weekly) estimates.

3.5 Control

The control layer principal tasks are: 1. Coordinate the commands sent from the processing layer; and 2. Guarantee the safety operation of the RPS, electricity distribution and storage infrastructure. The control layer receives input from the processing and communication layers. The output is the dispatch of energy from the RPS and central storage to the households appliances, storage facilities, centralized storage and into the national grid.

The backbone of the control layer are Adaptive Robust Control Theory and Kalman filtering. The design of the controller takes into account the uncertain events occurring in the wIshood, e.g., trucks blocking wireless communication or infrastructure failure. The metering devices constantly update the controller of the electricity distributed over the wIshood. The Kalman filter is a final preprocessing phase of the metering data before the control adapts to the changes of the environment.

4 CHALLENGES

The wIshood ecosystem (see Fig. 3) poses a myriad of challenges to be addressed by the research community. In the following we mention a few of the vast possibilities and from different domains of expertise.

4.1 Wireless Power Transmission

Electricity transmission of domestic scale is by far the most complex aspect to be addressed. Although successful attempts of long distance WPT have been accomplished, they have been based on a free space environment (Ma et al., 2016). WPT attenuation is due mainly to obstacles between source and destination and atmospheric losses. Frequency spectrum can be selected to minimize the latter although it should also take into account interference with existing communication bands (Imura et al., 2016).

The design of transmitter and receiver coupling systems is highly dependent of the material of the core. Presently, the core is made of composite ferrite materials such as Mn-Zn and Ni-Zn. The former is mostly employed because of its electric properties. Nevertheless, a mayor concern of core manufacture is scalability. Firstly, ferrite material are brittle and prone to breakdown as size increases. Secondly, the high permittivity of Mn-Zn leads to intense electric fields in discontinuities. Thus, arching or discharge occurs even in the presence of high dielectric materials. Lastly, frequency selection has a direct impact upon the permittivity of the ferrite material and hence the ability to guide the electric flux (McLean and Sutton, 2016).

4.2 Heterogeneous IoT

It is common to employ IoT motes from a variety of vendors. Hence, the data gathered, from these devices, cannot be used directly and must be converted into a standard form. Moreover, employing IoT in large sets can also result in spectrum scarcity. IoTs often employ unlicensed spectrum. To account for band saturation smart IoT should have cognitive capabilities i.e., dynamically switch between different frequencies.

Efficient bandwidth allocation techniques are of paramount importance (Khan et al., 2016). Dense deployment of IoT motes in a specific area can result in severe bandwidth constraints. This is due to the fact that IoT motes are, at a high-speed, continuously transmitting data to a shared infrastructure and using same unlicensed spectral bands. Bandwidth allocation, to the massive number of devices, poses stringent constraints to current communication protocols.

4.3 Security

The lessons learned from recent IoT hacks makes security of utmost importance. Coordinating security mechanisms (e.g., software updates, malware detection and identity management) present real constraints in highly federated environments. Security orchestration in the wIshood must incorporates threats aware mechanisms from IoT but also from cloud computing and SDN perspective.

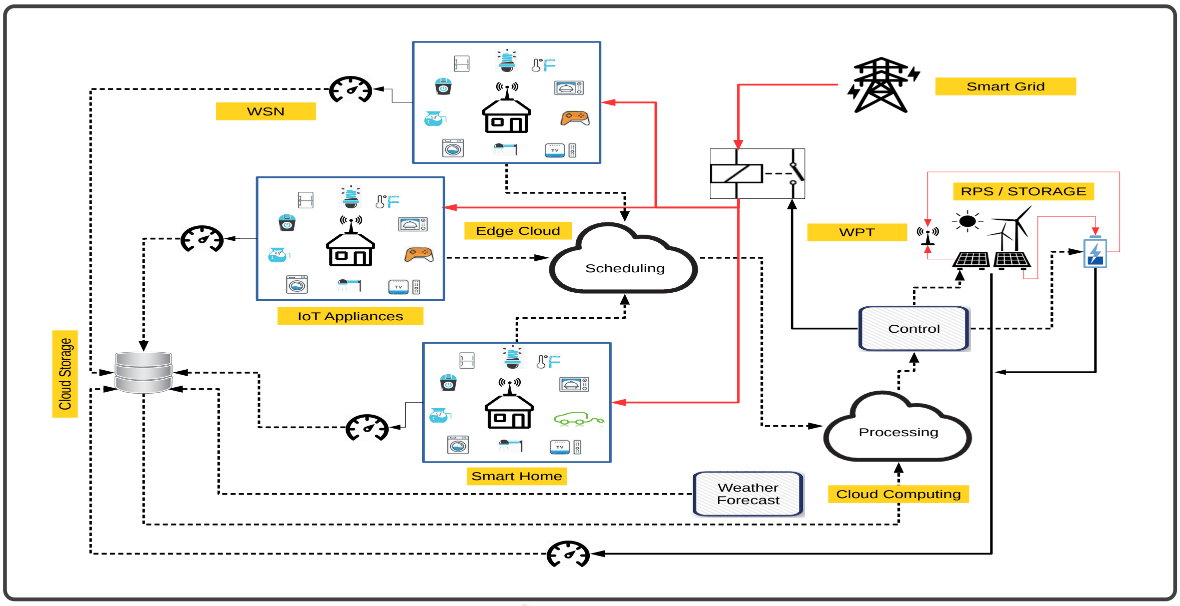

Figure 3: Topology of the wIshood's architecture. It is formed by the scheduling, information, communication, processing and control layers. The RPS supplies energy to the households using WPT technology.

4.4 Energy-Harvesting-Aware Robust Protocols

To efficiently exploit energy sources, robust communication protocols are also vital. Although such protocols have been thoroughly explored for conventional energy-harvesting sensor networks, they cannot be adopted for smart homes because of its unique challenges. Exclusive communication protocols and standards must be designed (Hou et al., 2016) for commercialization of reliable and customizable implementations.

4.5 Efficient Power Management

Scavenged energy requires effective power management among household appliances. We considered two cases 1. Energy generated by RPS is less than real-time demand; and 2. Power production is greater than demand. Thus, to address these scenarios, efficient utilization and fair distribution of energy algorithms need to be designed.

In the former, the energy should be fairly distributed among the households. A key aspect of power orchestration is the time allocation for running different appliances. For any excess power requirements the energy could be obtained from the smart grid (see Fig. 3). In the second scenario, if the energy produced is more than required, the excess energy could be stored for later use or re-routed toward other areas, e.g., sold to the smart grid. Thus, research effort should go into coupling wake-up scheduling schemes with harvesting schemes to ensure quality of service requirements.

Apart from dispatch specific issues, energy trading with third parties must be taken into consideration. This implies a *Credits* scheme for energy trading between neighborhoods in different periods of time. The dispatch algorithm should also take into account the best time for selling electricity to the smart grid.

4.6 Appliances Management

A principal challenge of the processing layer is to provide an optimized schedule of energy consumption. The cost function of the optimization algorithm will also take into consideration the users defined parameters for the shiftable, throttleable or essential appliances. The unsupervised learning algorithm proposes better scheduling based on previous data and recent consumption trends. The complexities of the non-linearities among IoT devices, household preferences and uncertainties call for adaptable models, faster learning and optimization algorithms.

5 CONCLUSIONS

This work presented a new framework of future smart neighborhoods, the wIshood. The wIshood advances the state-of-the-art of smart cities with an infrastructure for wireless transmission of electricity for residential needs. Within the wIshood, the energy is generated, stored and dispatched to the households. We envision, an intensive deployment of IoT devices, cloud computing and a wireless power transmission of scale. This paper outlined the architectural foundation and algorithms to address the challenges of such an ecosystem.

Future work intends to simulate components of the wIshood architecture. We plan to develop two algorithms. Firstly, a reduction of household data to stream to the Information layer. Secondly, a Recurrent Neural Network for energy demand forecasting.

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