Energy Efficiency for IoT Devices in Home Environments

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***Abstract*— The Internet of things (IoT) is a conceptual grouping of technological capabilities that enable not only the interconnectivity of useful devices but also the environmental control of useful experiences. The IoT may be viewed as a multiplicity of connected environments in which a user can control and be controlled by experiences. Environments are populated by sensors, controllers, and other objects, which are principally powered by electricity. As a consequence the growth of the IoT impacts the requirement for renewable energy and energy consumption efficiencies. In this paper we discuss optimizing energy consumption in the IoT smart environment of a home. Optimization by simple design is adopted as the best strategy for planning and regulating energy consumption.**

Keywords— IoT; Sustainable energy; Energy consumption; Smart homes; Renewable resources

I. INTRODUCTION

Many research publications approach IoT energy problems from the point of view of putting in an IoT system to the control function of electricity, and consequently reporting consumption efficiencies and the optimization of loadings [1],[2],[3]. These IoT systems often concern heating and ventilation systems for industrial plants and the energy savings can be shown to be up to 50%. However, in this paper we are concerned with the IoT itself and its components in terms of energy consumption. The global expansion of the IoT has proliferated sensor networks and their control systems to a degree that the power requirements are impacting national grids with increased and variable demands. Whereas previously consumer homes had relatively static energy requirements that were determined by simple service constraints and seasonal variation, IoT has added extra layers of energy requirements and demand cycles. The consumer's behavior was usually conditioned by cost benefit reasoning, and the resource consumption moderated by the consequences of learned feedback. Today however, homes are populated with sensors that feed and expand expectations for service, and the appetite for services. The consumer has a self-important expectation that the often-invisible sensor and multisensory systems will deliver satisfying human experience. Consumer reach may be extended by remote or locally automated commands, and consumer experiences controlled by voice, text, programming, and other means of communication. [4] says, "Our energy calculations show that in 2015, wireless cloud will consume up to 43 TWh, compared to only 9.2 TWh in 2012, an increase of 460%. This is an increase in carbon footprint from 6 megatonnes of CO_2 in 2012 to up to 30 megatonnes of CO_2 in 2015, the equivalent of adding 4.9 million cars to the roads. Up to 90% of this consumption is attributable to wireless access network technologies, data centers account for only 9%."

The rapid expansion of automation in the home has brought with it new energy costs and associated risks for energy supply. The IoT services are promoted by providing the consumer with simplistic access both locally and remote control of fundamental service requirements in the home. The consequence has been multisensory networks that are coupled to actuators, information sinks, and automated balancing systems; some of which operate automatically and have self-balancing and regulating systems, and others that the consumer may communicate and control. In this paper, strategy for the optimization of energy requirements in a smart house is developed, and the necessity of optimizing the resource requirements for the IOT infrastructure, human experience, and environmental costs presented.

II. THE INTERNET OF THINGS (IOT) ARCHITECTURE

IoT is envisioned to be an ecosystem that will evolve for connectivity of environments and the services required for sufficing human life expectations [5]. It is to facilitate the interaction of smart objects with smart environments in order to facilitate real-world human interaction and to break down the barriers between humans and machines. At present, the IoT architecture is yet to be standardized, but a number of consistencies [6] characterizes it.

Application Layer
Network Layer
Perception Layer

Figure 1. IoT Architecture

For example, it is generally deemed to have three layers in a hierarchical structure, with an application layer; a network layer; and, a perception layer (figure 1). The perception layer is an innovation that describes the sensor network elements which provides the network and the applications with its data. The perception layer gathers information and recognizes objects systematically structured so that the environmental items of interest or objects are monitored. This layer includes RFID tags, readers, terminals, GPS units, cameras, and a wide variety of other sensor nodes that take and process selected data from the environment.

The perception layer uses the network layer to communicate the data collected from a targeted environment. The network layer is responsible for creating and managing information, building and processing intelligence, connecting the Internet network systems, and running a network management center. The network layer then makes available to the application layer useful information that may be utilized for the execution of processes. For example, industrial control, energy control, work distribution, motor vehicle control, and so on. The IEEE has been working on standards for IoT architecture and has differentiated descriptions of IoT fields, IoT domains, and IoT similarity/dissimilarity exceptions. The proposed reference architecture defines basic building blocks and the integration schema [7]. The intention is to be able to document and to limit architectural deviations so that standardization will be possible and the consequential boost for interoperability between the different IoT systems that are available today. The implications of interoperability in a smart home is that there may be fewer sensors required in order to support the required functionalities of the home. This will mean that where today several systems are implemented for different environmental monitoring and control purposes then a single node will be able to multitask and communicate seamlessly within the design architecture.

One of the current open source architectures that has been made available by [8] proposes the definition of generic enablers which give reusable functionality for commonly shared tasks across different environments. The generic enablers are categorized into an architectural reference model with six main groups. These are:

- The computational, storage and network resources which services require and manage.
- The management of the big data streams into useful information
- The ecosystem and delivery framework that provides infrastructure for handling technical and business concerns
- The service enablement that manages resource requirements
- The connectivity requirements for services that interfaces networks and devices
- Secure services that meet the protection requirements of the consumer's expectation

The International standardization organization (ISO) has also published an IoT reference architecture and model. The *ISO/IEC 30141 Internet of Things Reference Architecture* International standard defines IoT systems, service, and component characteristics. It specifies architecture, roles, and the model for definition of relationships and terms, with the aim of enhancing interoperability between different aspects within the IoT, and between different IoT systems. The central concern of the standardized reference architecture is to cut across the different ecosystems in which the IOT has functionality, services, and communications; and to establish consistency in referal. At a similar time to the ISO standardization publication the European Union also produced an architectural reference model (ARM). It consisted of defining aspects of architectural view and the creation of models that would classify IOT concepts such as the physical, the virtual, the augmented, devices, resources, services, and the relationships between these various concepts. Central to the construct was the information model in relation to the communication model, and the functional model. In addition, guidance was provided for the processes to be followed in the use of the reference model, and the implementation of the reference architecture. The purpose of the guidance was to enable the development of systems qualities that any IOT system could be identified by the architectural benchmarks and service design satisfaction.

III. IoT Wireless and sensor Energy Requirements

The energy requirements of wireless networks are greater than those of wired networks. The energy in wireless network is consumed by maintaining the network whereas in a wired network the energy consumption is driven by use. The IoT is dependent upon wireless networks for data coverage and sensor communication. In the bigger picture, the IoT has four major energy consumption points:

- data centers
- communications
- the devices
- obsolescence

A data center provides the information intelligence and data storage for the IoT. Data centers require large amounts of energy to support their business activities. In 2017 it was estimated that data center cloud services energy consumption was equivalent to the energy requirements for the fifth-largest nation on earth. The expansion of the IoT in the ways that are projected has a significant impact at the data center with regard to increased energy consumption. The communication element of the IoT concerns the maintenance of the machine to machine transmission of data and the maintenance of the systems and in dependable states. As the volume of communication increases then so does the energy requirement. The IoT is a more complex multilayered networking than the traditional internetworks that have supported the Internet. The IoT adds extra layers before the Internet layer that require energy resources. In addition, these layers have many elements within them, each of which have significant energy demands. The overall picture is that the data centers and their communication requirements are significantly greater for the IoT in comparison with the more traditional Internet service provision.

IoT devices can be more energy efficient and ready for alternative energy supply such as from solar power. It may be argued that the devices component of the IoT is an area for energy cost reduction, but then the counter arguments have to be reviewed. In the first instance if the example of a mobile phone is taken, then the energy use of a mobile phone is less than that of a PC. However, there is a tendency for people to carry their mobile phone 24 x 7, and to expect seamless access to wireless networks wherever they go. This new utilization of technology in terms of mobility and continuous usage accentuates the demand for extensible networks and the subsequent energy requirements. Consideration is also required for the number of mobile devices in use in relation to the more traditional PCs and laptops, which they outnumber. The scope of IoT devices is also far greater than PCs and laptops. IoT devices are seen as growing in number and diversity, and occupying necessary services that are the requirements for critical infrastructure and life experiences. Subsequently, the numbers of IoT devices will continue to grow and be much greater than any other previous energy consuming digital device.

Obsolesce of IoT devices and infrastructures has an energy cost that needs to be calculated in terms of retirement, replacement, recycling, and disposal. The components of an IoT system are brittle and susceptible to defects. The larger components such as a surveillance camera may have a live of 5 to 10 years but the smaller components such as a sensor on a wall oven or magno vision on a vacuum cleaner, have months depending on environmental conditions and usage. Retiring an IoT system requires the considerations of operational and service energy costs for the replacement. In addition, the costs associated with recycling and disposal must be factored. The replacement of an IoT system incurs the full range of energy expenditure found in any system implementation. These expenditures can be in terms of electricity, primary fuels, production energy costs, distribution energy costs, marketing energy costs (including wireless communication networks), and the related environmental impact. The size and projected growth of the IoT will progressively stage the obsolescence impact with an increasing burden as the year's progress.

IV. Alternative Energy Supplies

The case for increasing energy supplies to satisfy the demands on energy consumption of the IoT is a convincing case based on comparisons with the current energy requirements for the Internet. The projected growth of IoT energy requirements is reasonable given the architectural design and the increased uptake of the technology opportunity. Traditional electrical energy supply by coal, gas, fossil fuels, nuclear, and hydro sources has more recently been substituted by solar, wind, and mechanical alternatives. Each source of energy has a trade-off between cost, availability, and its impact on the environment. Table 1 summarizes these concerns. Hydro generated energy requires significant capital investment to establish the generating facility but thereon after can maintain a near zero environmental impact providing water levels are managed appropriately. This would appear the best alternative energy supply but in many jurisdictions suitable water resources may not be available.

The traditional sources of energy in coal and gas have been highly criticized and shown to have an impact on the carbon content of the surrounding atmosphere, and the raising of temperature levels. Carbon has a short and long-term detrimental effect on life and life cycles, and the heat around generating plants a lesser but detrimental effect. The availability of coal is generally high around the planet and transportation has assured its availability. Gas is less plentiful and requires developed infrastructure for transportation. Attempts at the mechanical generation of electrical energy are prolific throughout history. More recently, the waves in the sea and the general movement of water in the oceans have been harnessed by mechanical means for electrical energy generation. These facilities have a low environmental impact but generally deliver variable and periodic amounts of energy, and tend to be limited in size and availability.

Nuclear electrical energy generation has been efficient but costly, and consequently limited in availability. Initially the infrastructures are highly specialized and expensive to implement, but once established are efficient generators. The environmental impact is significant both in terms of the energy emissions and the disposal of waste. The solar generation of electrical energy appears a viable and desirable alternative for locations where there is an excess of solar energy. These facilities have both a visual and a disposal impact on the environment. Consequently, the adoption of alternative generating sources of electricity have to be chosen carefully to meet the demand of the rapidly expanding IoT requirement.

Table 1. Energy source evaluation

Energy source	**Cost**	**Availability**	**Environment impact**
Coal	Extraction and infrastructure	High	High carbon and heat emissions
Gas	Extraction and transportation	Low	Low carbon and high heat emissions
Hydro	Infrastructure	High	Water levels
Nuclear	Extraction and Infrastructure	Low	Heat and energy emissions Waste disposal
Solar	Infrastructure	High	Disposal of panels and batteries
Wind	Infrastructure	Medium	Visual impact on landscape
Mechanical	Infrastructure	Low	Visual and physical impact

V. OPTIMIZATION OF SMART HOME ENERGY REQUIREMENTS

The control and optimization a smart home energy requirements is at two levels. First the system itself requires control whereby the consumption of energy resources is minimized against the demand from the consumers, and behavioral controls are monitored in order to minimize energy consumption. For example, the simple night day controls on lighting, infrared controls for room lighting, load balancing for heating, and so on. The other level of control must come at the sensor node level where by design, the use of consumer services are optimized. For example, the duplication of sensor nodes through non-standardized reference models may be considered insignificant, but when a smart home may have in excess of 10,000 sensors, the summative energy consumption becomes significant. Similarly, the duplication of wireless networks and wireless network services delivers an unnecessary burden on energy requirements. These issues when taken across whole suburbs of the homes becomes a significant cost to the energy system as mentioned by [4]. Each of the four major energy consumption points by the IoT (outlined in section III) contribute to an escalation of energy requirements for a single smart home that is then multiplied by the number in a smart city.

The optimization of energy requirements has four main components:

- life-cycle management
- behavioral modification
- standardization
- simplicity in design

The optimization of energy consumption starts with the management of sensor life cycles. The power consumption of the different sensor phases depends on the attached peripherals, such as a surveillance camera or a light detector, and the times each is activated. The system itself is stable and hence the sensor nodes are dependent upon the phases of life cycle, the optimal settings, and the relevancy the data transmitted. For example, when a sensor node is sleeping, the energy requirements are minimal. As soon as sensing or transmitting are initiated then the largest amounts of energy are consumed. However, for the sensor network to be effective the sensor nodes must transmit relevant data at an opportune time. For this to happen the availability of power to a sensor must be trigger sensitive and the performance monitored against expected information requirements. The optimization compares data quality against the deliverable values set for system performance. The information management iteratively adjusts life-cycle performances to be in keeping with the requirement. The consequence is that the sensor network and its wireless connectivity are powered to an optimal level in order the functionality of the design is delivered. In the design phase of the system architecture the power consumption and the load balancing of each component of the system has to be calculated, and duplications removed. In addition to phase analysis, compensorary analysis also has to be undertaken that in the event of failover an alternative energy resource is available.

In a traditional home, the users have been conditioned by the payment of fees for services over periods of time. The capacity of the home to deliver specific services and the condition interaction of humans with relatively fixed experiences generates a predictable environment for energy consumption. In this way, the energy consumption in a standardized traditional home can be predicted with the seasonal variation modelling and occasional outliers for exceptional circumstances. However, in a smart home energy consumption is driven by expectations and the experience of services. In this situation the human may demand more or less of a service but not be in a position or even want to assess the cost of that service. For example, the cost of powering the smart fridge and recharging the motor vehicle each night may be acceptable as value-added services that enhance living experience. Previously the motor vehicle was powered by other means and the fridge consumed less electricity before the IoT connectivity. The extra energy consumption is justified by behavioral experiences that in themselves set new expectations for consumption. In this sense the IoT is a vendor's dream where the consumer demands more and more service in order to satisfy rising expectations. Consequently, modification of human behavior is required to optimize energy consumption.

The IoT is yet to be standardized by any international organization (see section II for current initiatives). Consequently, many IoT devices duplicate the work of others, and many components of the IoT are proprietary so that two or more components may be used for one functionality when only one may be required. The purpose of standardization is to establish interoperability within a system and between systems. The energy cost savings can be considerable. Standardization is a key component in the simplicity of design. Today IoT systems are complex systems that are multilayered, have unnecessary redundancies, have design incompatibilities, and are yet to address fully the question of energy optimization. The objective of providing the end user with a consistent experience across multiple environments is an example of multiple duplicities in wireless networks. While it is not conceivable to have one unified global wireless network, standardization has achieved portability between networks and connectivity for information experiences. However, at present there are many unresolved barriers to seamless human experience. For the IoT to achieve the intended globalization and satisfaction of human experience than standardization must follow negotiated global agreements. A significant beneficiary of such an initiative will be reduction in energy requirements.

VI. DESIGN SOLUTIONS

The IoT consists of six fundamental elements that connect to deliver the end user experience. In the first instance devices are connected with sensors (perception layer) and communication capability (network layer). There is then intermediation where data analytics occurs to select appropriate data values that initiate actions. These actions are then communicated to the end user for their experiential satisfaction (application layer). In figure 1 the IoT reference model shows that inevitable relationships occur between the six fundamental elements that deliver end user experience. In this fashion devices are connected to human value by the intermediation of facilitating functionality. The IoT is no different than any other information technology opportunity. It requires the deliverables from one layer to be passed to another and the elements of each layer to interact seamlessly for the end user experience. At present there are many unresolved intermediation issues that are costly for the end user experience and also the optimization of energy resources. Our advocacy is for the resolution of issues by design simplicity that includes agreed reference models, standardization, and interoperability agreements.

Simplicity in design requires the many of the current obstacles to energy consumption reduction in the IoT be removed by design. The contribution of standardization for achieving this objective has been outlined in section V. The 10 tenants of design simplicity are:

- Reduce Duplication [Re-use one unit/algorithm not many]
- Reduce Phases in Lifecycle [Context Adaptation]
- Reduce Transmit Time [Optimize Parodicy]
- Reduce Sense Scope [Target Stimuli]
- Reduce Data [Management Algorithms]
- Reduce Resistance [Choose Materials]
- Reduce Complexity [System and Circuit Design]
- Reduce Components [Optimise Work System]
- Reduce Loads [Optimise Load Balancing Algorithms]
- Standardize architecture [Have consistent reference model]

At present, the IoT appears overly complex and underdeveloped in many areas. The objective of allowing objects to be “sensed or controlled remotely across existing network infrastructure”, and hence “creating opportunities for more direct integration of the physical world into computer-based systems”, appears possible, but only within specific environments. The claims for “improved efficiency, accuracy and economic benefit” have been achieved in an industrial environments but the general adoption across all environments is yet to occur. In this sense the IoT is still developmental and experimental in its constituency. As a result the attainment of a generalized cyber physical system that encompasses technologies such as smart grids, virtual power plants, smart homes, intelligent transportation and smart cities; appears theoretical in nature. Further research is required into the development of artificial intelligence, data analytics, and data value selection that will satisfy human experience.

Design solutions start by conceptualizing the relationship between design, production, and use (figure 2). In the IoT general architecture and reference models are available in a multiplicity of formats. The designer must take these additions to knowledge and formulate improvements that reflect a more integrated and seamless environment for development. At present many actions may be taken but the evaluation criteria for quality improvement based on risk and environmental impacts may be absent. In these situations, it is up to the developer to take responsibility for assessing and optimizing simplicity in design that will deliver, for example, optimal energy usage and minimal environmental impact.

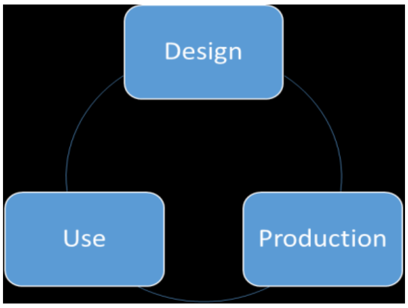

Figure 2. The dependent relationship

The design cyber physical systems requires consideration of both machine and human factors (figure 3). The machine requires specification of market, components and requirements, whereas the human requires specification of variation, expectations and tolerance. Each attribute brings different metric and quality to the system design. One requires an engineering approach and the other an experimental approach, but each approach must inform the other for robust modelling. The mediation of the different worlds occurs between interoperability and experience. The machine requires optimization for maximum functionality, and the human minimum quality loss. It is up to the developer to take these design guidelines and to operationalize the implementation of cyber physical systems that maximize the human experience while minimizing the environmental, social, and future harm that may result from the relationship. The present state of the IoT leaves scope for the innovative implementation of designs that are responsive to unresolved issues; and to balance the demands of human experience against the energy requirements, the costs, and the potential environmental harm. Redesign for the Smart home can maximize potential benefits while minimizing infrastructure costs.

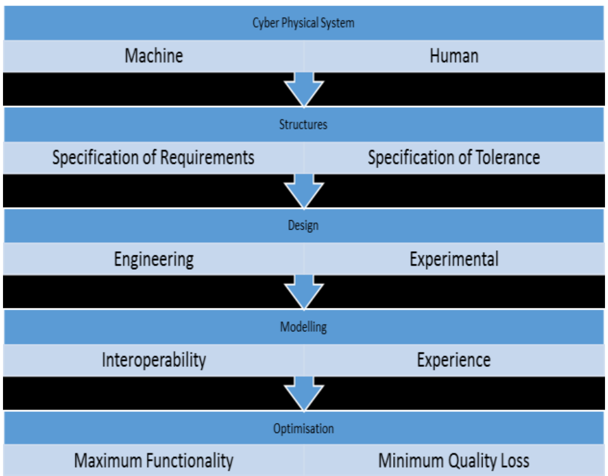

Figure 3. Design of cyber physical system

VII. CONCLUSION

As a conceptual grouping the IoT is a compelling information artefact that promotes the possibility of greater seamless human computer interaction for better services and end user experiences. However, the energy demands have to be addressed by better balancing of not only supply and demand, but also better estimation of the total cost of use. In this paper, we have acknowledged the use of the IoT for optimizing resource control as one aspect of resource management, but advocated for greater attention to be paid to design for the optimization of the IoT infrastructures. Clean renewable energy sources with the optimization of a reduced energy footprint by design is the ideal Human Computer Interface. In this paper, we have presented strategy for optimizing energy requirements in a smart house through device efficiency, and emphasized the necessity of balancing the resource requirements for the IOT infrastructure, human experience, and the environmental costs.

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