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Methodology for the Analysis of Electrical Consumption

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Abstract. A demand system is designed in order to analyze and control the way in which electricity consumption occurs in a scenario, this type of system has four objectives to reduce consumption, reduce costs, reduce peak average to ratio and maximize the comfort of the users. The design of these systems can be based on the implementation of IoT. When using IoT for the development of demand systems, a layer of information is integrated which generates a multi-objective optimization problem. Metaheuristics are used to solve multi-objective problems. This paper introduces a proposed methodology to develop demand systems and the first products implemented.

Keywords. Demand system, internet of things, metaheuristic.

1 Introduction

Until now, a methodology for analyzing electric consumption has not been developed from the perspective of the implementation and use of data in an IoT architecture.

Internet of Things (IoT) has been implemented in the way to develop different application areas, like Smart Warehouse, Smart grid, Smart City, Smart meter, Smart Healthcare and Smart Home [1]. There is a common objective to accomplish between the Smart grid and Smart home that is to develop systems that make an efficient electric consumption. This kind of systems is called Demand Systems (DS).

The works focused in the search of the improvement of the electric consumption are about devices or control variables [2-5] buildings consumption [3], houses [6], costs [2,7-10] sensor infrastructure [3] and control algorithms [4,10]. Few works focus on the current challenge of developing solutions supported by IoT.

Demand Systems analyses how the electric energy is used, their objectives could be one or more from these: low Peak Average Ratio (PAR), minimize costs, minimize consumption and maximizer user´s comfort [11]. To develop DS requires: define objectives, variables and what kind of factors needs to be considered. When DS works with consumption data needs to handle a big quantity of data [12] that could use to make decisions [13, 14] and converts into a multi-objective optimization problem [15]. A metaheuristic is used to find a solution to the multi-objective problem.

So, according to the characteristics of the problem, it requires to search for alternative solutions that are appropriate to the context of the problem, which consider the source of the data, the variables and the implementation of a metaheuristic to search the optimal consumption.

Rest of the paper is organized as follows, in Section 2 describes the state-of-the-art work. A description of the layers that make up the methodology proposed to develop projects that implemented Internet of Things is given in Section 3. In Section 4, a brief discussion is carried out. Both conclusions and work to be done in the future are announced in Section 5.

2 Related Work

Many researchers around the world worked to make an optimal electric consumption system in different research lines smart meter, smart grid, neural network, metaheuristic, IoT, Genetic algorithm and big data. Nadeem et al. in [16] considered to develop a DS to reduce consumption under a predefined level, costs and waiting time using hybrid metaheuristics schemes based on Teaching-Learning techniques. The metaheuristics used were Optimization Stopping Rule (OSR), Genetic Algorithm (GA) and Firefly Algorithm (FA); in this work is combined OSR-GA, OSR-TLBO, and OSR-FA. This work considered three electric devices (fridge, dishwasher, and dryer), the variables that were considered for every device: costs average per month, the cost reduction, the priority and the delay per hour per day. It is simulated by the implementation of every technique and their hybrids to each of the devices.

Yao et al. in [17] said that the energy management problem consists in to solve appliance load scheduling and grid power dispatching under a single optimization framework of a utility grid with dynamic costs, a photovoltaic module and the household appliance with three different types: interruptible, uninterruptible and time-varying; in this work was implemented a simulation of a mixed integer linear programming framework. His future consists of two stages, first to implement a genetic algorithm, second to implement a multiobjective optimization framework.

Rahim et al. in [11] described the goal of implementing a demand system, which is reduced to the following to reduce the costs, minimization of Peak to average ratio and maximize comfort. In this work is proposed a generic architecture for a demand system, it models the electric consume in a house, here was considered three algorithms genetic algorithm (GA), binary particles swarm optimization (BPSO) and ant colony optimization (ACO). The GA was more efficient than BPSO and ACO in term of consumption reduction, minimizing PAR while is considered user comfort. In this work was concluded that is still an open problem to Minimize PAR, cost, consumption and maximize comfort.

Javaid et al. in [5] focused over to control electric consumption and maintenance the comfort taking into consideration the user preferences. Was implemented four algorithms: genetic algorithms (GA), teaching-learning base on optimization (TLBO), enhanced differential evolution (EDE) and enhanced differential teaching-learning algorithm (EDTL). The consumption model took two types of devices flexible and inflexible, device, consumption and schedule of use, this model is implemented in a microgrid context.

Jon the other hand, Avaid et al. in [3] presented an electric consumption model that consider houses and devices mount; the kind of devices are interruptible, not interruptible and regular application use. This model is for a demand-side management to reduce peak average to ratio, costs and renewable energy that are considered tariff and time of use. The algorithms that were analyzed are bacterial foraging optimization algorithm (BFOA), genetic algorithm (GA), binary particle swarm optimization (BPSO), wind-driven optimization (WDO). In this work, a genetic binary particle swarm optimization (GBPSO) is proposed. Results showed that GA is better than others in term of PAR reduction and execution time, BPSO is better than the others in term of cost reduction. GBPSO is more efficiently than the others in terms of cost and PAR.

Complementary work, is presented by Hao and Wang where they proposed a demand-side management (DSM) in [10], this DSM reduced cost in terms of tariff and costs, devices identified are interruptible and not interruptible. This DSM implemented a game theory which one can reduce costs and help to increase load demand at the off-peak time. The peak time hours were between 8 to 24 hours. Mohsin et al. developed a demand-side management in [13] with the main purpose of reducing costs, PAR and time, maximize comfort in applying a harmony search algorithm (HSA). This work compared his algorithm with binary particle swarm optimization (BPSO), differential evolution (DE), genetic algorithm (GA), ant colony optimization (ACO), Hybrid Differential Evolution – Harmony Search (DE-HS), immune artificial hybrid algorithm, genetic hybrid algorithm, teaching-learning base on optimization (TLBO) and Shuffled Frog Learning (SFL). Devices considered in this works were defined as interruptible, not interruptible, flexible and inflexible. The results showed that HAS is better in terms of costs, PAR and consumption.

In addition, Huang et al. in [14] where a set of models of demand response was used, using a gradient (PSO) based on particle swarm optimization, the main objective was to schedule the operation of appliances to save energy and reduce cost considering user convenience. The model is simulated and compared to hybrid PSO algorithm and cooperative PSO algorithm. The proposed algorithm shows better results in a real-time application. Similarly, Matei et al.in [18] described an IoT architecture, that consist of four layers sensors, physic, digital and meta through that the data flow. In this work were proposed two times of data process, first in the physic layer and second in meta-layer. The first process to select data and reduce computational cost, and in the second process could be implemented in any algorithm or technique, the choice of it depends on objectives.

Finally, Mohsin et al. concluded in [13] that a deterministic optimization is inefficient and impractical to handle a big problem. A heuristic optimization is better to implement in big data problems. Also, Silva et al. conclude in [19] that the electric consumption varies according to an hour of the day, the day of the weak and season.

Hoon et al. explained in [2], IoT let to monitor, handle and control devices WEB way. The IoT implementation let to get information from data that are generated in real time. There is a challenge for smart meters to develop an intelligent environment (AmI).

Table 1. Goals of systems developed in literature.

Reference	Kind of System	Reduce cost	Reduce Consumption	Comfort	Reduce PAR	Algorithms
Tsai and Lin [20]	DRS	X	X			Sorting genetic algorithm
Yao et al. [17]	DS	X	X			GA
Nadeem et al. [16]	DS	X	X	X		OSR-GA, OSR-TLBO, OSR-FA
Rahim et al. [11]	DRS	X	X	X		GA, BPSO, ACO
Tushar et al. [21]	DRS					Game theory
Javaid et al. [5]	DS	X	X			GA, TLBO, EDE, EDTL
Javaid et al. [3]	DS	X			X	BFOA, GA, BPSO, WDO, GBPSO
Hao and Wang [10]	DS	X				Game theory
Mohsin et al. [13]	DS	X		X	X	HAS
Huang et al. [14]	DRS	X				PSO
Chen et al. [22]	DS	X			X	PSO

Table 2. Kind of appliances in literature.

Reference	Interruptible	Non-Interruptible	Flexible	Not-Flexible
Hao and Wang [10]	X	X		
Mohsin et al. [13]	X	X	X	X
Kakran and Chanana [7]	X	X	X	X
Javaid et al. [3]	X	X	X	
Yao et al. [17]	X	X	X	

In Table 1 is summarized the articles in which demand system and demand-response system (systems that not only take into account the consumer but also the electricity suppliers) developments are presented, identifying for each one of the systems, the implementation objectives to be fulfilled, as well as the metaheuristic algorithms implemented. It is observed in the table that one of the first techniques to be implemented for a demand system is a genetic algorithm and hybrid algorithms. In Table 2 shows the types of appliances in which the household devices can be located.

For the accomplishment of this work were consulted and analyzed 69 articles, that articles were classified according to the areas of development identified; there were 3 articles of smart meter, 29 of smart grid, 1 of nerual network, 5 of metaheuristics, 1 of learning alfgorithm, 12 of IoT, 3 of genetic algorithm, 13 of data minig, 2 of corpus, 3 of bioinspired algorithm and 2 of big data

According to the analysis of 63 articles, the application objectives that could be for the control of processes, big data analysis, behavioral modeling, consumption control, including renewable energy and to form part of a Smart home were identified.

From the reviewed articles it was observed that 73% focus their proposals for the implementation of a demand system from the Smart grid area, 11% from the implementation of a metaheuristic, 4% from the use of the internet of things, 4% implements genetic algorithm and 8% use Smart meters.

3 A methodology for Analysis of Electronic Consumption

A demand system (DS) analyze and control the electric area consumption. The DS objectives [11] are to reduce costs, reduce consumption, reduce PAR and maximizer user comfort. IoT implemented a control and monitoring infrastructure through the web to devices that are in the same red, so it´s possible to develop a DS using this concept. The IoT data flow, its obtained from [18] where describes IoT architecture and [22] describes cyber-physic behavior (see Fig. 1).

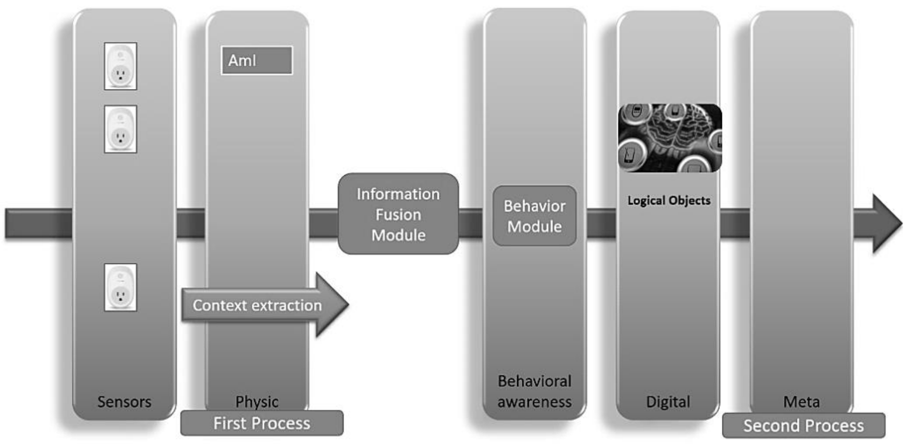

Fig. 1. DS data flow in IoT.

The IoT data flow, flow through five layers called sensor, there is a sensor architecture; physic, here is implemented an ambient intelligent (AmI), AmI extracts the context and in this stage is made a first process whit sensor and user data; the data extracted pass to information module, where all the context data are gathered; behavioral awareness is processed the data and found a behavior; digital, here is created a logical object that represents the real objects; in the meta-layer all the logical objects data are processed according to particular objectives of the problem to be solved.

When is developing a DS and is integrated an information layer, which happens when IoT is implemented, the problems became a multi-objective optimization problem and are solved using metaheuristics [23]. Also, is necessary to identify all variables that determine the electric consumption, to know the types of devices, to identify a meta-heuristic algorithm and to propose an electric consumption model.

The methodology feasibility is going to be illustrated with a case study with a real case scenario of electronic consumption corresponding to every identified device that is frequently used in an office, house, and classroom.

3.1 Consumption and Context of Use

Context of use is a triple composed by the identification of electric consumption device, the environment where the device is used, house, office, classroom, and user's particular needs or preferences. For each device, a set of common characteristics have been identified. Accordingly to the following list:

- *Minimum power* corresponding to the minimum electrical power needed for the device to operate. This value was estimated from public lists of electronic devices publicly available on their websites.
- *Maximum power* corresponding to the minimum electrical power needed for the device to operate. This value was estimated from public lists of electronic devices publicly available on their websites.
- *time of use*. The average daily usage time measured in hours.
- *kind of device.* The devices are classified according to the most common appearance. For example, office supplies, video games, household appliances, electronics, lighting and security devices.
- *The type of devices* corresponding to the a category proposed in related works [4,24,25] that are: interruptible (I), non-interruptible (NI), flexible (F) and not-inflexible (NF). An Interruptible system refers to a system that can be turned on and off without any particular constraint. Interruptible devices are defined like devices that could be used in anytime, and the time of use varies according to the user needs [5, 7,10,13,17]. Not-interruptible devices stop their function once they are finished, their consume could be variable or constant [7,10,13,16,17]. Flexible devices, their functions could be stopped and continue at another time, could be on standby too [3,7,13,17] Not-flexible devices, they could not be turned off because is necessary that they have a constant function [7,13].

3.2 Sensor Layer

Sensor Layer stores sensors raw data, also known as primary data, corresponding to the sensors consumption readings. In a particular context the set of devices may vary and the corresponding arrangement as well, we call this setup the Sensor Architecture. So, from this layer the output is a data base with the consumption readings, consumption meters, of each device that is connected to the sensor architecture of the electricity facility under a specific context.

Data acquisition nowadays could be the result of using IoT devices, or we could even built a no-invasive potentiometer using Arduino Uno and SCT-013 sensors, or any related technology. Data consumption files are obtained and stored in a DB, a sample set is listed as follows in Table 3:

Table 3. Consume list from a laptop.

Current (Amperes)	Power (Watts)
6.4871	1423.1668
3.9958	878.9938
4.4403	976.8803
4.7000	1059.5591
12.5839	2768.4433
9.4061	2009.3459
8.5427	1894.3894
4.9717	1059.7808
3.8485	846.6782
6.0309	1327.0713
18.2753	4020.5761
6.7826	1492.1634
6.0730	1336.0534
6.6512	1409.5651
3.1939	702.6623

This is an input fusion layer and the classifier. The current work just consider data from a specific context which every household device monitored by a non-invasive smart meter that represents a specific consumption that is determined by the occupants' behavior.

In our example, we implemented a database (DB) using MySQL Workbench, DB is in a local server. The DB has 268 registers. Every register is stores: <id_device, device_name, min_ power, max_power, freq_time, shut_down, kind_device>, some registers are showed in Table 4.

Table 4. Consume list from a laptop.

ID device	Device_name	Min power	Max_power	Freq_time (use Hrs/day)	Shut_down	Kind_device
OF1	Cannon (three light)	6.4	400	1.5	Yes	I
OF2	Cannon (three light)	6.4	1000	1.5	Yes	I
OF3	Cannon (one light)	6.4	220	1.5	Yes	I
OF4	Cannon (one light)	6.4	236	1.5	Yes	I
OF5	CPU	14.1	250	4	Yes	F
OF6	CPU iMac 3.06GHz	129.6	365	4	Yes	F
OF9	Digital decoder	55	55	24	Yes	I
OF10	Scanner	65	275	1	Yes	I
OF11	Fax	65	150	1	Yes	F

3.3 Physical Layer

The physical layer corresponds to the composition of the primary data and a particular user data that corresponds to a set of constraints. For this purpose an interactive systems is recommended. a human-computer interface.

The external data is the readings obtained from the room sensors. In a demand system it is identified that the user data have to do with the preferences and times of use of the electrical devices that are monitored through the sensor architecture; and the external data are the data obtained from the environmental conditions (temperature, humidity, presence, etc.), that is, all those data that result in a high degree of importance to be considered for the conditioning of the use of electrical devices within the area you want to control. In our case, we have built a website (see Fig. 2) where users select their devices, graphically, and coherent with the proposal of building better Legos [26].

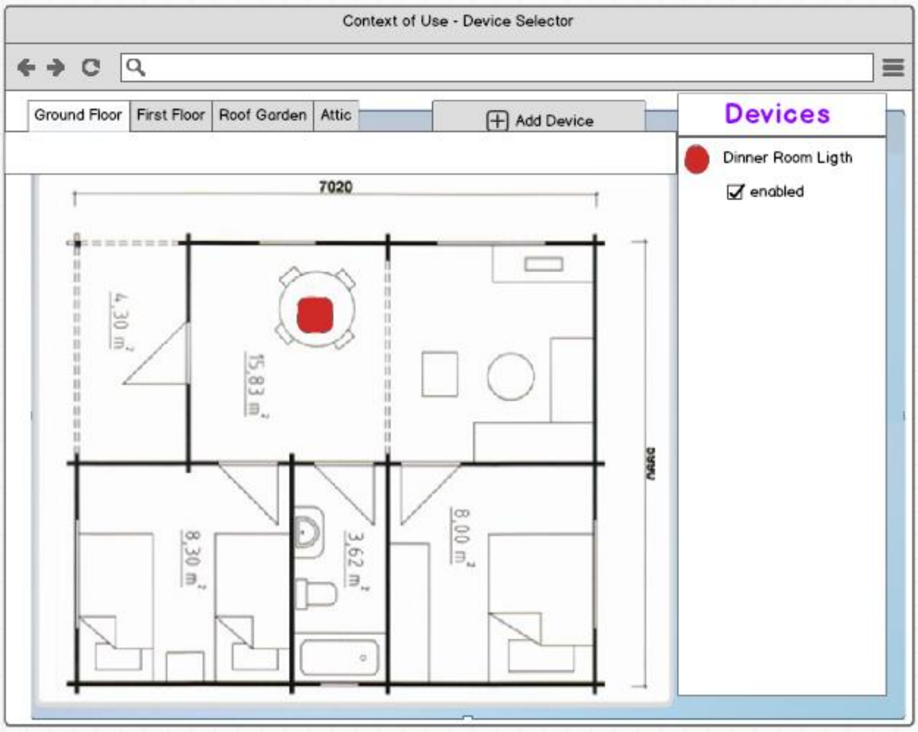

Fig. 2. A web site used to help users to select the physical set of devices available at their facility.

3.4 Fusion Layer

It works as a repository of all the data that must be considered (primary, external and user data) to solve the problem that is being studied; to later be able to group them according to the needs of solution. The output resulting from this module is grouped data.

3.5 Behavioral Layer

A behavioral module is in the behavior layer, in which methods or procedures can be implemented to generate the necessary parameters according to the problem to be solved, this module includes both the user's data (which determines the restrictions to consider) as environmental data (which are the conditions for decision making).

Demand System in the behavior module, a behavioral model can be implemented that identifies the probability and time of use of the devices, giving as output the on and off schedule, and the operating time of each device; and integrate, a module capable of generating the actual consumption data that each device can have. All the resulting data pass in vector form to the next layer.

3.6 Digital Layer

The digital layer is where the data from the previous layer arrive and a space is formed with the vectors that represent the possible behavior scenarios of all the objects that are in the real world. The vector space is sent to the next layer. In a demand system, we have a set of vectors formed from the combinations of possible consumptions that each of the devices that are being monitored may have.

3.7 Target Layer

In the target layer, procedures are implemented that seek proposals for solutions to the objectives that are to be achieved according to the proposed scenario. A demand system is a multi-objective problem and to implement it, a metaheuristic is implemented.

4 Discussion

From the methodology described in the previous section it is possible to identify how the flow of the data is carried out when it is integrated into IoT to solve a problem. In the case of implementation of a demand system consists of selection of devices for reading consumption data, the development of an intelligent environment that serves as an interface to user and serves to read the consumption data to perform a context extraction, develop a module to merge the data received, develop a behavior model that will be implemented in a behavior module, obtain logical objects that emulate the real object, and implement a metaheuristic whose definition of objective function is based on the objectives (objectives of DS system) to meet the original problem.

Has been identified a methodology to identify consumption variable, which consists to identify the devices that are the most frequently are in a house, office, and classroom; the maximum and minimum power: the frequently time of use according to the area in which demand system is going to be implemented; and the classification to which the device belongs (I, NI, F, NF). With the database, devices are possible to simulate N different scenarios with d devices each one.

With the non-invasive data acquisition system, it has been possible to acquire the consumption of devices found in a house (oven, television, phone charger, laptop, charger, washing machine, and refrigerator).

Have been identified metaheuristics to be implemented in a DS to make an efficient consumption, genetic algorithm, particle swarm optimization, teaching-learning based on optimization and optimization stopping-rule.

The data flow in demand system was obtained from two different ideas, one that talks about an architecture that would be considered when is implementing an IoT project, and another one when is talking about a context where is necessary to take in a count the information. The selection of metaheuristic to be implemented is based on what has been identified in the literature, in which the constant of selecting a genetic algorithm is identified against whose results are compared to another metaheuristics implementation.

5 Conclusion and Future Work

This methodology was developed after having analyzed articles that have as objective the development of demand systems, where it is appreciated that the development layers in which they focus only cover one or two of the methodology proposed in the present work. It is appreciated that if the methodology proposed in the present work that uses IoT as part of the implementation process is followed so could be to identify and to comply with every one of the requirements to be met.

The proposed methodology is used as the basis to develop a demand system, where the appliances were identified as their consumption variables too.

As future work, the creation of an intelligent schedule is left to foresee with the probability of use both the schedules and the time of consumption of each device that are contemplated in the scenario. As well as, the implementation of a metaheuristic to analyze and identify the recommendation that is appropriate according to the needs of the user, the reduction of consumption and voltage peaks.

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