Smart Architecture for Home Area Electrical Grid in India

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Abstract— **One of the major problems, which the Indian electrical grid faces, is the lack of an efficient power management scheme. The proposed communication terminology supports the management of power in the home environment. Real time awareness is provided to the customers regarding extra power consumption. In peak power consumption periods, the consumer can chose to incur the financial charges by using all their home appliances or be supported to operate any appliance they wish by switching off some other lower priority appliances. These smart electrical homes also support authorities to control the extra power requirement during peak hours.**

Keywords—Smart grid, Home Area Network, Power Management

I. INTRODUCTION

India's power demand exceeds its generated power, leaving many without power or only intermittent power, thus inflicting economic and standard of living losses. The implementation of a smart grid can be part of the solution as it can advance the efficiency, consistency, economics, and sustainability of the production and distribution of electricity. In order to constantly balance the generation and consumption of power and facilitate electrical energy being generated and transmitted instantaneously, the operation requires a power management scheme. A smart grid is an electrical grid offering a power management scheme that utilizes information and communications technology to collect and take action on information (such as information about the activities of suppliers and consumers). The power grid system is composed of distinct functions such as: generation, transmission, distribution, system control and operation [1].

As the current power grid system is maturing and technology is advanced utilities has begun taking steps to update the electricity grid by integrating new technologies and additional IT systems and networks which make the existing power grid system to operate as smart grid system. Transitioning from the traditional grid to the smart grid requires the integration of information and communication technologies (ICT) to the power grid. Advances in ICT [2] are being employed to increase automation, integrate distributed renewable resources, secure the grid infrastructure and enable efficient demand-side energy management. This is making it possible for energy suppliers to charge variable electricity rates thus varying the power demand and causing more power to be available. These variable charges need to replicate the large differences in the cost of generating electricity during peak or off peak periods. Appliance control switches have been implemented, that along with the consumer can control the usage of large energy consuming appliances such as Irons, Refrigerators, Air conditioners etc. so that they consume electricity when it is cheaper to produce.

Our contribution primarily aims to manage the consumer's appliances by designing the smart architecture for the consumer's home area electrical grid in India. Although there are many features of a smart grid, the consumer mostly only has direct contact with the smart meter, which along with other features serves the energy competence goal [2]. This architecture enables the consumer to choose when to cut short their own power usage and therefore charge on their electricity bill depending on peak hours and extra charges. This facilitates the proper management of India's existing power supply with the redistribution of power usage, thus leaving more power available to increase India's economy and standard of living. The proposed architecture enables consumer participation in electric power management actions using wireless communication devices. This architecture allows the consumer flexibility of appliance power usage. Consumers are enabled to switch on high priority appliances by switching off one or a set of low priority appliances and therefore not affecting the comfort/productivity level of the consumers. The communication terminology necessary for the proposed architecture demonstrates the type and packet structure of the communication packets that are sent by different wireless nodes in the smart home area electrical grid architecture.

The rest of the paper is organized as follows. The section II describes the related works. In section III, we propose the architecture for the smart home area electrical grid. In section IV, we explain the communication terminology for the proposed architecture. Finally, section V concludes the paper.

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II. RELATED WORK

The traditional grid has demand response [3] programs for large-scale consumers such as industrial plants or commercial buildings; however, it does not have a similar mechanism for the residential consumers mostly due to two reasons. First, it has been hard to handle the large number of residential units without communication. Second, the impact of demand response programs has been considered to be relatively small when compared with their implementation cost. Recently, residential energy management has become an active topic and several appliance scheduling schemes have been proposed.

Reference [3] describes a system where they control the residential power usage during the peak hours. They introduced a new interface called Residential Energy Manager (REM) which resides inside the smart meter itself. All appliances were interfaced with a ZigBee [3] module operating under an ISM band [4]. If a consumer wants to operate a certain appliance in a certain period; the particular appliance will be required to communicate with the REM and the smart meter all the time once the appliance is switched on. Smart meters enable two-way flow of information between the consumers and the utilities. With the installation of smart meters, utilities have been able to employ TOU [3] (Time of Use) pricing. In TOU pricing, the rate of electricity varies with on-peak, moderate-peak and off-peak hours. The grid informs the REM of the TOU, the REM calculates the operating time for each appliance as per the programmed algorithm.

Reference [5] describes three way handshake communications between the appliances and the smart meter and also illustrates the packet structure used for the communication. M. Erol-Kantarci and H.T.Mouftah only investigates controlling the usage of high power appliances by assuming that low power appliances do not make any difference in power [5]. In fact sometimes these low power appliances will cause serious issues in terms of power usage if the utility has no control of these appliances. Also all the appliances have to be able to communicate with the smart meter to receive the information regarding the time at which each appliance can operate. This requires considering appliances that may be out of the range of the REM. Managing this hectic communication between the REM and its command of numerous numbers of devices in a residency must be attended to.

III. ARCHITECTURE FOR SMART HOME AREA ELECTRICAL GRID

In today's Indian electrical grid, the wastage of power is been so high and the end consumers are unaware about the wastage. In order to prevent power wastage a monitoring system is being introduced, to coordinate the appliance operation and to control the energy consumption. This kind of system will have many additional benefits for the management of power in India. This paper introduces the design of a wireless device that when a consumer switches on a home appliance, the appliance informs the smart meter of this particular event and updates the smart meter on the amount power the appliance is using. In peak power consumption periods, the consumer can chose to incur the financial charges by using all their home appliances or be supported to operate any appliance they wish by switching off some other lower priority appliances.

The wireless devices are connected to each appliance, in a home, for monitoring and controlling the consumption [6]. The wireless devices and smart energy meter in a home, together, form a wireless network called Home Area Network (HAN) [7]. In our HAN, whenever an appliance is switched ON, it tries to communicate with the smart meter. If all wireless appliances attempt to communicate with the smart meter, congestion in the network will be created. To avoid this congestion, in the proposed architecture, we divide the HAN into different Room Area Networks (RAN) as shown in figure 1. This bifurcation depends on the amount of rooms available in each home. The maximum area that can be covered by RAN will be 30x30 square meters. All wireless appliances in a RAN are controlled by a head node (with additional processing capabilities than normal nodes) called a Room Energy Controller (REC). Therefore, every RAN should have at least one REC for efficient communication. The smart meter controls the functioning of all RECs.

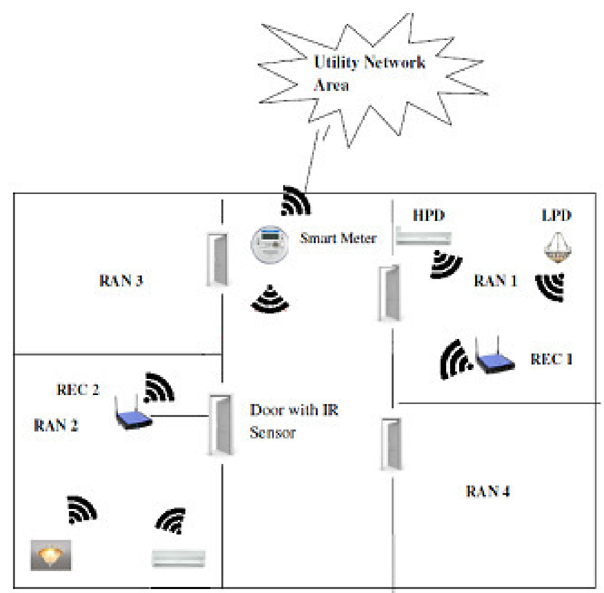

Figure 1: Architecture for smart home area electrical grid

The home appliances can be categorized into high power appliances and low power appliances. This categorization is based on the operating power value of each appliance. Those appliances having an operating power value greater than 120W are included in High Power Appliances (HPA) and those appliances having operating power value less than 120W are included in Low Power Appliances (LPA). The smart home area electrical grid architecture creates a lossless residential environment which prevents power wastage therefore making more power available for others, prioritizes needed appliances, takes into account all appliances using power in each home (whereas other systems have only paid attention to high power consuming appliances). Therefore scarcity of power is taken into consideration, which is particularly pertinent in India as there is a need for sharing scarce resources to keep up positive functioning of India's economy.

A. *Smart Meter*

In our home area network, the smart meter is working as a master node. The smart meter collects the power consumption demand from all appliances and calculates the total power utilized by the home. In the hardware, we use a smart meter attached to a node. The node consists of a processing unit of AT MEGA 128[5], a 16 Mb non volatile EEPROM[5] and an additional LCD screen to pop up the advisory messages for the user. Regarding communication, attaching a C2420 [5] wireless module to the node ensures the lowest power consuming transmission. The smart meter also functions as an interface between the home and the utility (the whole grid). As shown in the algorithm the smart meter will collect the information of current TOU (Time Of Use) of each appliance, and depending on the TOU, the smart meter will calculate the threshold power value for the RECs (Room Energy Controllers). After calculating the value, the smart meter will multicast this value to all RECs, and the RECs will set the value as their threshold and monitor the total power consumption in each RAN (Room Area Network) with reference to that threshold value. If any REC finds an appliance exceeding the threshold value, it will send a ready to act signal to the smart meter, and also shows a warning message in both the smart meter and Room Energy Controller (REC) display incoming messages and send control messages regarding abort mission, return to base station etc.

B. *Room EnergyController [REC]*

A Room Energy Controller (REC) is placed in each room of each home and acts as a fixed control node for each RAN. The REC collects packets from each appliance; these packets contain the value of power consumed by each Home Appliance's Interface (HAI) node and find the total power value for each room. The REC is attached to two IR door sensors to operate on context based automation. IR door sensors are placed in every room entrance and used to detect the human presence inside each RAN. The REC facilitates the users to adjust and personalize the scheduling of the functioning of each appliance, based on the user's needs. In the hardware, the REC requires a high processing potential, as it has to: collect and store the data received from its cluster, make decisions by processing the data and supervise the home automation. The REC's high processing potential is achieved by using AT MEGA 128[5], and a non-volatile EEPROM [5] memory (up to 16Mbit) for external storage. A LCD is also interfaced to show the warning messages and also for scheduling the appliances operational time for the user. For the communication between the REC and the High Power Appliances (HPAs), a 2.4 GHz module CC2420 [4] is used. For the communication between the REC and the Low Power Appliances (LPAs), a Nordiac[5] transceiver module is used.

C. *Home Appliance Interface (HAI) Node*

As we discussed the HAI nodes are divided into both HPA and LPA. The HAI will be attached to every home appliance. An HAI node will sense the current flowing through the appliance using a current sensor (FAN 4010) and calculate the total power consumed by its appliance and send this data to the nearby REC. The HAI contains a processing module, which is an ultra-low-power microcontroller MSP430F1611 [5]. The data acquirement modules each provide up to six 12-bit analog-to-digital channels[4], two 12-bit digital-to-analog channels[4], 16 general-purpose digital input/output channels[4], and up to 16Mbit of non-volatile EEPROM[5] memory. A relay module (present in the HAI) is used to switch ON and OFF each appliance as directed by the REC.

D. *IR Sensor*

Infrared (IR) Sensors will be placed in the entrance of the Room Area Network (RAN) so that the presence of people is monitored. This IR sensor is connected to the REC associated with the RAN. Whenever the sensor detects equality in the amount of people who have entered the room and the amount of people who have exited the room, then that information is sent to the REC. If any of the appliances are ON once all people have left the room, the REC will automatically turn OFF the appliance by sending a control message to the HAI node of that appliance (unless the user has registered for this not to happen). Thus by integrating IR sensors into the architecture, we are bringing some context aware responsive mechanisms to the home area electrical network. IR sensor is used to capture the context from the consumer.

IV. COMMUNICATION TERMINOLOGY

The optimal way to ensure a network remains error free and reduce its latency is to define a well structured transmission topology for the network. For the efficient working of the architecture presented in section III, we classified the time of consumption by the consumers into: HIGH peak time, LOW peak time and MIDDLE peak time. HIGH peak time is the time at which demand and cost of power is at its highest. LOW peak time is the time at which demand and cost of power is at its lowest. The MIDDLE peak time is the time at which demand and cost of power varies between that in the HIGH peak time and LOW peak time. The HAN communication terminology depends up on the demand of users to ON or OFF different appliances.

HAI_Node_ID	Dest_ID	Prv_pow_val	Check sum

0 16 32 40 44 bits

Figure 2: Home Appliance Interface (HAI) Packet Structure

Smart_Node_ID	Pow_thrshld_val	Check sum

0 16 24 28 bits

Figure 3: Smart Meter Update (SMU) Packet Structure

Whenever the customer switches on an appliance, the HAI node attached to that particular appliance becomes ON. Then the HAI node will broadcast a packet called a "HAI" packet to its surroundings to locate the nearby REC node. Figure 2 shows the HAI packet structure which contains the node ID, the information regarding the expected working time for the appliance and the previous consumed power value stored in the HAI node. In the proposed system the consumers have an option to set the approximated time of use of each appliance. Since the REC node is placed in each 30x30 square meter RAN area, all HAI nodes are expected to be in communication range with REC at times when the HAIs attempt to join the network. The REC will be responsible for calculating the total power consumed by the appliances in each RAN, and then compare those values with a threshold power value set by the smart meter using a Smart Meter Update (SMU) packet as shown in figure 3. The power threshold value field contained in the SMU packet varies with the HIGH/LOW/MIDDLE peak time and the current power consumption of that particular REC's RAN. By receiving the "HAI" packet from a HAI node, the REC will check the previous power consumption value of that HAI node. The REC will update the total power consumption value of is RAN and compare it with the threshold value of the RAN.

REC_ID	Dest__HAI_ID	Check sum

0 16 32 36 bits

Figure 4: Network Join Update (NJU) Packet Structure

Smart_Node_ID	HAI_Node_ID	Pow_thrshld_val	Priority_ flag	On_flag	Check sum

0 16 32 40 41 42 46 bits

Figure 5: HAI Node Update (HNU) Packet Structure

REC_ID	REC_Pwr_Val	Check Sum

0 16 32 36 bits

Figure 6: REC Power Update (RPU) Packet Structure

Case I: If the REC finds that it can accommodate the demand then it will send the network join update (NJU) packet, whose structure is shown in figure 4, back to the HAI node and up on receiving the NJU, HAI node will allow the load to operate at that time itself. The REC will send the HAI node update (HNU) packet, which contains the associated HAI node details, and the previous power value, a priority flag and appliance ON/OFF flag to the smart meter. The packet structure of HNU packet is shown in the figure 5.

HAI node ID	EM Flag	Check sum

0 16 20 24 bits

Figure 7: Node On Emergency (NOE) Packet Structure

HAI_Node_ID	Time_ stamp	OFF_flag	Check sum

0 16 32 36 40 bits

Figure 8: HAI Node Signoff (HNS) Packet Structure

Case II: In case the REC is not able to afford the operation of the appliance at that time, then it will send a REC Power Update (RPU) packet to the smart meter. The figure 6 shows the RPU packet structure that contains the REC node id, the HAI node ID, and the previous power consumption value. The smart meter database contains the list of HAI nodes with their power consumption values of the entire home. The smart meter will compare the previous power consumption values with the database power consumption values. By this comparison the smart meter will be able to select some appliances that can be switched OFF, depending on each appliance's power consumption and also on the priority value set to them. The smart meter will send these details, as an SMU packet, to the specific REC/s that is related to the particular appliances requiring targeting. The REC will forward the same SMU packet to the HAI node present in each appliance. The smart meter will send the SMU packets to the RECs, whenever a new appliance joins the network. By this communication procedure, the system is able to implement the limited user threshold but flexibility of appliance usage is preserved - a user is afforded the option to operate any appliance they wish by switching off some other lower priority appliances at that particular time. This supports the users to keep the power consumption of the residence within the stipulated value. This facility has not been taken into account in previous research, namely [8], [9] and [10], who also have investigated appliance management methods. The major advantage of this system is that although a limit is imposed, the user's comfort and productivity is not inhibited.

Following this particular imposition of a threshold limit is optional for all users; as the choice remains for the user to override the limiting/prioritizing appliance functioning system by incurring the financial charges of using all appliances throughout peak periods. If this is the case and the consumer wants to run all their appliances without attention to the thresholds, then the HAI node of each appliance, will initiate the sending of an emergency packet called Node On Emergency (NOE) packet to the REC. The NOE packet structure is shown in figure 7. After the reception of NOE packet the REC will send HNU packet to the smart meter.

The smart meter will then send an NJU packet back to the HAI node.

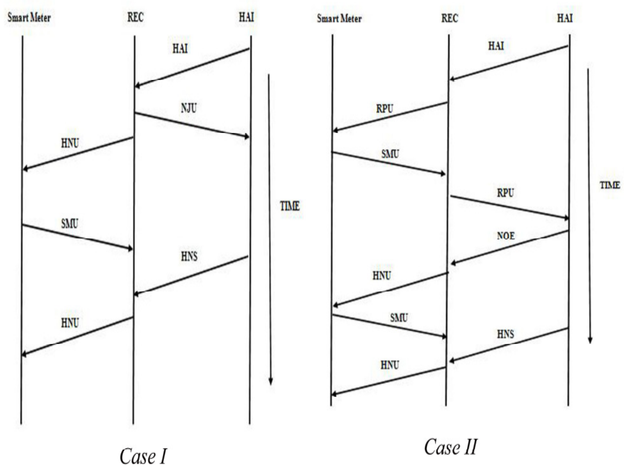

Figure 9: Communication terminology in *Case I & Case II*

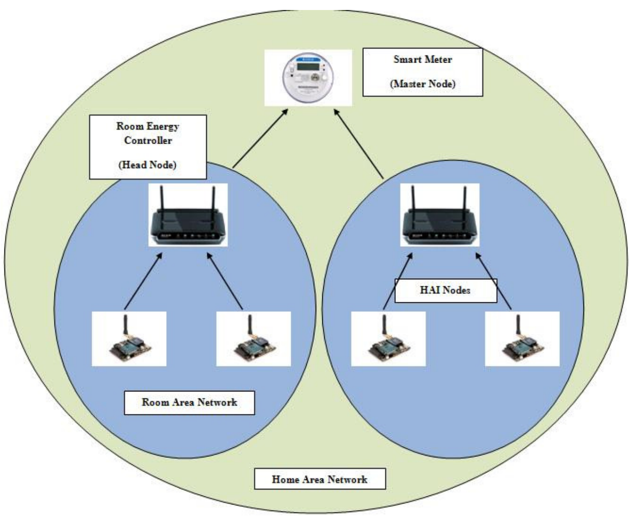

Figure 10: Hierarchical Communication Flow

The user can also switch off and on any appliance, as per their convenience, from any HAI node. The manually switch on appliances have higher priority than any other appliances. When any of the appliances are switched OFF, the HAI node associated with that appliance will send a packet called HAI node Sign off (HNS) to the REC. The packet structure of HNS packet consists of the HAI node ID, the time stamp, OFF flag and check sum as shown in figure 8. The REC node will intimate the sign off message to the smart meter with help of an HNU by setting the OFF flag. The smart meter also periodically sends SMUs when the TOU (Time Of Use) of each appliance changes. The communication terminologies in *Case I* and *Case II* are shown in figure 9 and figure 10 represents the hierarchical communication flow of the system.

V. CONCLUSION AND FUTURE WORK

The proposed smart architecture for the home area electrical grid for India which helps to manage the load in consumer side. The architecture and the communication terminology enable the consumer to reduce their amount of electricity bill by peak load management without affecting their comfort level. Also the architecture enables the utility to reduce the mismatch in the generated and demanded electric power.

The smart home area electrical grid architecture integrates the wireless technology with the existing grid and intelligently manages the operation of load in peak hours. However, the delay for communication and the security in communication haven't taken into account. These issues will be solved as future work.

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