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Evaluation of sensor network capability in a practical problem

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A B S T R A C T

A wireless sensor network (WSN) has important applications such as remote environmental monitoring and target tracking. This has been enabled by the availability, particularly in recent years, of sensors that are smaller, cheaper, and intelligent. These sensors are equipped with wireless interfaces with which they can communicate with one another to form a network. The design of a WSN depends significantly on the application, and it must consider factors such as the environment, the application's design objectives, and cost, hardware, and system constraints. The availability of low-cost hardware such as CMOS cameras and microphones has fostered the development of Wireless Multimedia Sensor Networks (WMSNs), i.e., networks of wirelessly interconnected devices that are able to ubiquitously retrieve multimedia content such as video and audio streams, still images, and scalar sensor data from the environment. The age span of elder people is increasing and this trend may continue in near future. Elder people wish to stay as independently as possible and are keen on fulfilling lives, but self-regulating ways of life involve with risks, such as weakening, memory loss or impaired judgment and falling that limit mobility. A intelligent, robust, less cost, flexible and real time home monitoring system has been developed to record the basic home activities and respond immediately when there is a change in the regular daily activity of the elder person.

1. Introduction

Provision of reliable energy services in context of increased environmental concerns will become possible in future smart grids 1. Various technologies are being developed by researchers for realization of smart grid including: Advance Metering Infrastructure (AMI), Home Area Networks (HANs), Distribution Automation (DA), etc. 2. Services of the traditional grid have been used by the humanity since decades. Global population and the dependency level of humans on electricity are increasing exponentially. Recent advances in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short distances. These tiny sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of sensor networks based on collaborative effort of a large number of nodes. The position of sensor nodes need not be engineered or pre-determined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an on-board processor. Instead of sending the raw data to the nodes responsible for the fusion, sensor nodes use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data. One of the most important constraints on sensor nodes is the low power consumption requirement.

Sensor nodes carry limited, generally irreplaceable, power sources. Therefore, while traditional networks aim to achieve high quality of service (QoS) provisions, sensor network protocols must focus primarily on power conservation. They must have inbuilt trade-off mechanisms that give the end user the option of prolonging network lifetime at the cost of lower throughput or higher transmission delay.

2. Sensor networks applications

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Sensor networks may consist of many different types of sensors such as seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic and radar, which are able to monitor a wide variety of ambient conditions that include the, temperature,

humidity, vehicular movement, lightning condition, pressure, soil makeup, noise levels, the presence or absence of certain kinds of objects, mechanical stress levels on attached objects, and the current characteristics such as speed, direction, and size of an object (Estrin et al., 1999).

The developed system consists of two basic modules. At the low level module, Wireless sensor network of mesh structure exists capturing the sensor data based on the usage of house hold appliances and stores the data in the computer system for further data processing. Collected sensor data is of low level information containing only status of the sensor as active or inactive and identity of the sensor.

Fig. 1: The fabricated home monitoring system based on wireless sensors network

To sense the activity behaviour of elder in real time, the next level software module will analyze the collected data by following an intelligent mechanism at various level of data abstraction based on time and sequence behaviour of sensor usage. Fig. 1 shows the newly developed zigbee based wireless sensor home monitoring network which can be used to track the uses of appliances used by the person for day-to-day activities.

Fig. 2 shows the necessary electronics inside a sensing unit. The current system consists of 6 electrical appliances monitoring unit used to monitor and four force-sensors based monitoring unit. The electrical appliances such as hot water kettle, microwave oven, toaster, television, room heater and washing machine are monitored. The force sensor based units are used to monitor bed, toilet, sofa, and chair which are used by the elderly person. Other than those sensors, a panic button for emergency help and a temperature cum humidity sensor has been used in the system. The system has been continuously used for five consecutive days to collect data.

Current state-of-the-art sensor technology provides a solution to design and develop many types of wireless sensor applications. A summary of existing sensor technologies is provided in Appendix A. Available sensors in the market include generic (multi-purpose) nodes and gateway (bridge) nodes. A generic (multi-purpose) sensor node's task is to take measurements from the monitored environment. It may be equipped with a variety of devices which can measure various physical attributes such as light, temperature, humidity, barometric pressure, velocity, acceleration, acoustics, magnetic field, etc.

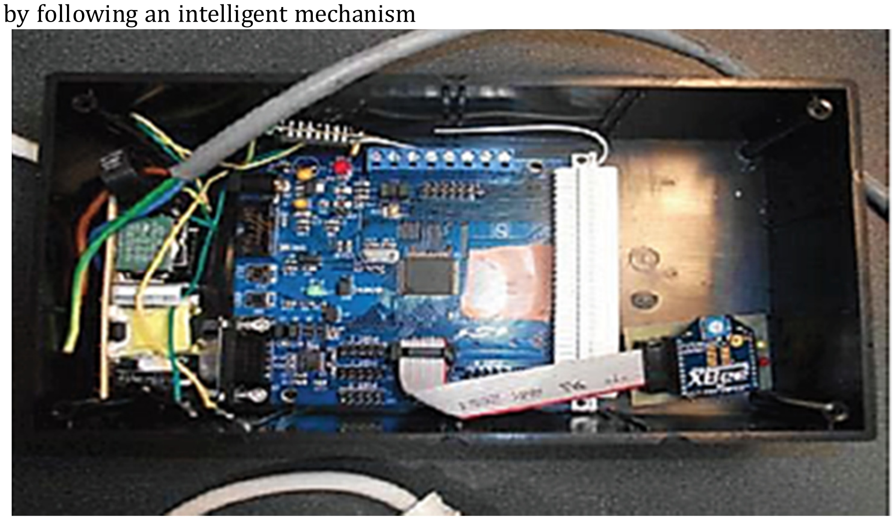

Fig. 2: The electronic details of a sensing unit

Gateway (bridge) nodes gather data from generic sensors and relay them to the base station. Gateway nodes have higher processing capability, battery power, and transmission (radio) range. A combination of generic and gateway nodes is typically deployed to form a WSN. To enable wireless sensor applications using sensor technologies, the range of tasks can be broadly classified into three groups as shown in Fig. 3.

3. Military applications

Wireless sensor networks can be an integral part of military command, control, communications, computing, intelligence, surveillance, reconnaissance and targeting (C4ISRT) systems.

The rapid deployment, self-organization and fault tolerance characteristics of sensor networks make them a very promising sensing technique for military C4ISRT. Since sensor networks are based on the dense deployment of disposable and low-cost sensor nodes, destruction of some nodes by hostile actions does not affect a military operation as much as the destruction of a traditional sensor, which makes sensor networks concept a better approach for battlefields. Some of the military applications of sensor networks are monitoring friendly forces, equipment and ammunition; battlefield surveillance; reconnaissance of opposing forces and terrain; targeting; battle damage assessment; and nuclear, biological and chemical (NBC) attack detection and reconnaissance.

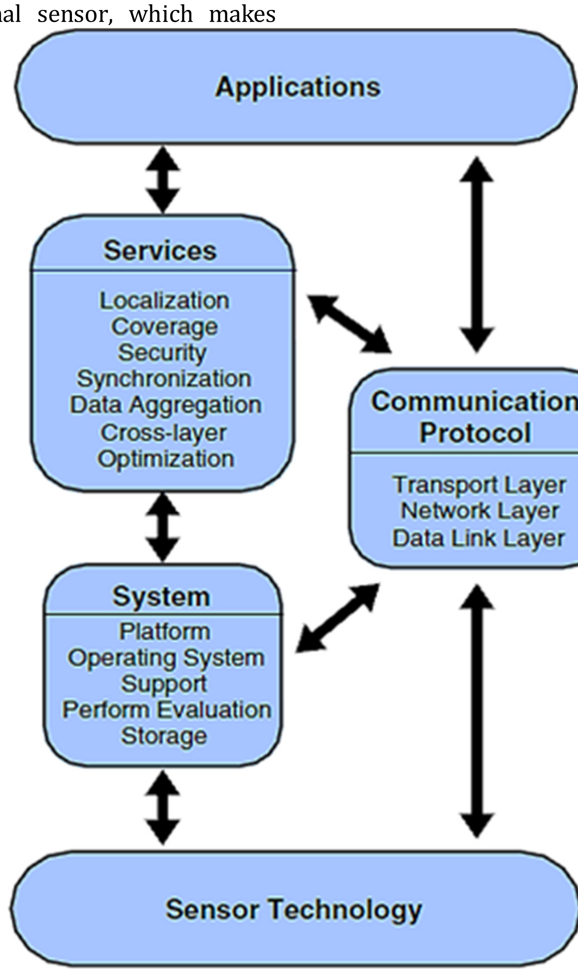

Fig. 3: Broad classification of various issues in a WSN

3.1. Environmental applications

Some environmental applications of sensor networks include tracking the movements of birds, small animals, and insects; monitoring environmental conditions that affect crops and livestock; irrigation; macro instruments for large-scale Earth monitoring and planetary exploration; chemical/ biological detection; precision agriculture; biological, Earth, and environmental monitoring in marine, soil, and atmospheric contexts; forest fire detection; meteorological or geophysical research; flood detection; bio-complexity mapping of the environment; and pollution study.(Agre et al., 2000; Cerpa, 2000; Cerpa et al., 2001; Cho, 2000; Halweil, 2001; Warneke et al., 2001)

3.2. Health applications

Some of the health applications for sensor networks are providing interfaces for the disabled; integrated patient monitoring; diagnostics; drug administration in hospitals; monitoring the movements and internal processes of insects or other small animals; telemonitoring of human physiological data; and tracking and monitoring doctors and patients inside a hospital (Kahn et al., 1999; Noury et al., 2000; Rabaey et al., 2000; Petriu et al., 2000)

3.3. Home applications

Home automation: As technology advances, smart sensor nodes and actuators can be buried in appliances, such as vacuum cleaners, micro-wave ovens, refrigerators, and VCRs (Abowd et al., 2000). These sensor nodes inside the domestic devices can interact with each other and with the external network via the Internet or Satellite. They allow end users to manage home devices locally and remotely more easily.

4. Smart environment

The design of smart environment can have two different perspectives, i.e., human-centered and technology-centered (Herring, 2000). For human-centered, a smart environment has to adapt to the needs of the end users in terms of input/ output capabilities. For technology-centered, new hardware technologies, networking solutions, and middleware services have to be developed. A scenario of how sensor nodes can be used to create a smart environment is described in (Essa, 2000). The sensor nodes can be embedded into furniture and appliances, and they can communicate with each other and the room server. The room server can also communicate with other room servers to learn about the services they offered, e.g., printing, scanning, and faxing. These room servers and sensor nodes can be integrated with existing embedded devices to become self-organizing, self-regulated, and adaptive systems based on control theory models as described in (Essa, 2000). Another example of smart environment is the ''Residential Laboratory'' at Georgia Institute of Technology (Akyildiz et al., 2002). The computing and sensing in this environment has to be reliable, persistent, and transparent.

5. Types of sensor networks

Current WSNs are deployed on land, underground, and underwater. Depending on the environment, a sensor network faces different challenges and constraints. There are five types of WSNs: terrestrial WSN, underground WSN, underwater WSN, multi-media WSN, and mobile WSN (see Appendix B).

The table 1 shows a comparison between the different types of wireless sensor networks:

Table 1: Comparison between the different types of wireless sensor networks

	Terrestrial WSN	Underground WSN	Underwater WSN	Multi-media WSN	Mobile WSN
Definition	A network consists of hundreds to thousands of sensor nodes deployed on land	A network consists of wireless sensor nodes deployed in caves or mines or underground	A network consists of wireless sensor and vehicles deployed into the ocean environment	A network consists of wireless sensor devices that have the ability to store, process, and retrieve multi-media data such as video, audio, and images	A network consists of mobile sensor nodes that have the ability to move
Challenges	– In-network data aggregation to improve performance across communication, energy cost, and delay – Minimizing energy cost – Reduce the amount of data communication – Finding the optimal route – Distributing energy consumption – Maintaining network connectivity – Eliminating redundancy	– Expensive deployment maintenance, and equipment cost – Threats to device such as the environment and animals – Battery power cannot easily be replaced – Topology challenges with pre-planned deployment – High levels of attenuation and signal loss in communication	– Expensive underwater sensors – Hardware failure due to environment effects (e.g., corrosion) – Battery power cannot easily be replaced – Sparse deployment – Limited bandwidth – Long propagation delay, high latency, and fading problems	– In-network processing, filtering, and compressing of multi-media content – High energy consumption and bandwidth demand – Deployment based on multi-media equipment coverage – Flexible architecture to support different applications – Must integrate various wireless technologies – QoS provisioning is very difficult due to link capacity and delays – Effective cross-layer design	– Navigating and controlling mobile nodes – Must self-organized – Localization with mobility – Minimize energy cost – Maintaining network connectivity – In-network data processing – Data distribution – Mobility management – Minimize energy usage in locomotion – Maintain adequate sensing coverage
Applications	– Environmental sensing and monitoring – Industrial monitoring – Surface explorations	– Agriculture monitoring – Landscape management – Underground structural monitoring – Underground environment monitoring of soil, water or mineral – Military border monitoring	– Pollution monitoring – Undersea surveillance and exploration – Disaster prevention monitoring – Seismic monitoring – Equipment monitoring – Underwater robotics	– Enhancement to existing WSN applications such as tracking and monitoring	– Environmental monitoring – Habitat monitoring – Military surveillance – Target tracking – Underwater monitoring – Search and rescue

Terrestrial WSNs (Toumpis et al., 2006) typically consist of hundreds to thousands of inexpensive wireless sensor nodes deployed in a given area, either in an ad hoc or in a pre-planned manner. In ad hoc deployment, sensor nodes can be dropped from a plane and randomly placed into the target area. In pre-planned deployment, there is grid placement, optimal placement (Yick et al., 2006), and 2-d and 3-d placement (Pompili et al., 2006; Akyildiz et al., 2006) models.

In a terrestrial WSN, reliable communication in a dense environment is very important. Terrestrial sensor nodes must be able to effectively communicate data back to the base station. While battery power is limited and may not be rechargeable, terrestrial sensor nodes however can be equipped with a secondary power source such as solar cells. In any case, it is important for sensor nodes to conserve energy. For a terrestrial WSN, energy can be conserved with multi-hop optimal routing, short transmission range, in-network data aggregation, eliminating data redundancy, minimizing delays, and using low duty-cycle operations.

Underground WSNs (Li, 2007; Akyildiz et al., 2004) consist of a number of sensor nodes buried underground or in a cave or mine used to monitor underground conditions. Additional sink nodes are located above ground to relay information from the sensor nodes to the base station. An underground WSN is more expensive than a terrestrial WSN in terms of equipment, deployment, and maintenance. Underground sensor nodes are expensive because appropriate equipment parts must be selected to ensure reliable communication through soil, rocks, water, and other mineral contents. The underground environment makes wireless communication a challenge due to signal losses and high levels of attenuation.

Underwater WSNs (Heidemann et al., 2005) consist of a number of sensor nodes and vehicles deployed underwater. As opposite to terrestrial WSNs, underwater sensor nodes are more expensive and fewer sensor nodes are deployed. Autonomous underwater vehicles are used for exploration or gathering data from sensor nodes. Compared to a dense deployment of sensor nodes in a terrestrial WSN, a sparse deployment of sensor nodes is placed underwater. Typical underwater wireless communications are established through transmission of acoustic waves. A challenge in underwater acoustic communication is the limited bandwidth, long propagation delay, and signal fading issue.

Multi-media WSNs (Akyildiz et al., 2007) have been proposed to enable monitoring and tracking of events in the form of multimedia such as video, audio, and imaging. Multi-media

WSNs consist of a number of low cost sensor nodes equipped with cameras and microphones. These sensor nodes interconnect with each other over a wireless connection for data retrieval, process, correlation, and compression. Multi-media sensor nodes are deployed in a pre-planned manner into the environment to guarantee coverage. Challenges in multi-media WSN include high bandwidth demand, high energy consumption, quality of service (QoS) provisioning, data processing and compressing techniques, and cross-layer design. Multi-media content such as a video stream requires high bandwidth in order for the content to be delivered.

Mobile WSNs consist of a collection of sensor nodes that can move on their own and interact with the physical environment. Mobile nodes have the ability sense, compute, and communicate like static nodes. A key difference is mobile nodes have the ability to reposition and organize itself in the network. A mobile WSN can start off with some initial deployment and nodes can then spread out to gather information. Information gathered by a mobile node can be communicated to another mobile node when they are within range of each other. Another key difference is data distribution. In a static WSN, data can be distributed using fixed routing or flooding while dynamic routing is used in a mobile WSN. Challenges in mobile WSN include deployment, localization, self-organization, navigation and control, coverage, energy, maintenance, and data process.

6. Internal sensor system

For a sensor to operate in a wireless sensor network, there are several internal system issues that need to be addressed through the system platform and operating system (OS) support. In addition, supporting standards, storage, and physical test beds are reviewed in the following subsections. System platform and OS support Current WSN platforms are built to support a wide range of sensors.

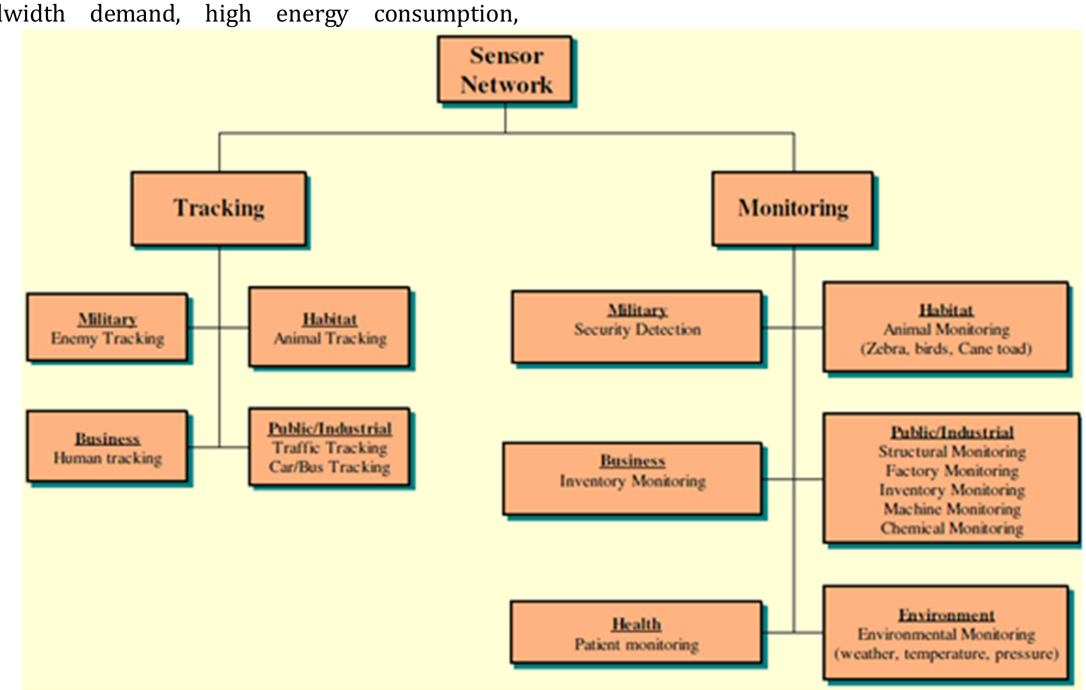

Fig. 4: Overview of sensor applications

Products that offer sensors and sensor nodes have different radio components, processors, and storage. It is a challenge to integrate multiple sensors on a WSN platform since sensor hardware is different and processing raw data can be a problem with limited resources in the sensor node.

System software such as the OS must be designed to support these sensor platforms. Research in this area involves designing platforms that support automatic management, optimizing network longevity, and distributed programming. Below we discuss two platforms: a Bluetooth-based sensor system (Leopold et al., 2003) and a detection-and-classification system (Gu et al., 2005).

Bluetooth-based sensor networks: Howitt (2003) reported a study to determine if a Bluetooth-based sensor node is viable for a WSN. Typical radio components used in a WSN are based on fixed frequencies where sensor nodes within communication range compete for a shared channel to transmit data. But Bluetooth is based on spread-spectrum transmission where separate channels are used to transmit data.

Detection-and-classification system developed in VigilNet (Mulligan , 2007) can detect and classify vehicles, persons, and persons carrying ferrous objects. It targets objects with a maximum velocity error of 15%. The VigilNet surveillance system consists of 200 sensor nodes which are deployed in a preplanned manner into the environment. Their locations are assigned at the time they are deployed. Each sensor node is equipped with a magnetometer, a motion sensor, and a microphone.

6.1. Standards

Wireless sensor standards have been developed with the key design requirement for low power consumption. The standard defines the functions and protocols necessary for sensor nodes to interface with a variety of networks. Some of these standards include IEEE 802.15.4 (Montenegro et al., 2007), ZigBee, Wireless HART, ISA100.11 IETF 6LoWPANIEEE 802.15.3 Wibree. The following paragraph describes these standards in more detail.

6.2. Storage

Conventional approaches in WSNs require that data be transferred from sensor nodes to a centralized base station because storage is limited in sensor nodes. Techniques such as aggregation and compression reduce the amount of data transferred, thereby reducing communication and energy costs. These techniques are important for real-time or event-based applications, but they may not suffice. Applications that operate on a query-and-collect approach will selectively decide which data are important to collect. Optimizing sensor storage becomes important in this case when massive data is stored over time. Given that storage space is limited and communication is expensive, a storage model is necessary to satisfy storage constraints and query requirements. In this subsection, we evaluate several storage methods in terms of design goals, assumptions, operation models, and performance.

7. Scheme for energy management

In this section we propose our scheme for energy management: the Home Appliances Coordination Scheme for Energy Management (HACS4EM). HACS4EM is a communication based domestic energy management scheme which is primarily aimed at reducing home electricity consumption charges. The scheme involves communications among smart appliances, a central EMU and WSHAN.

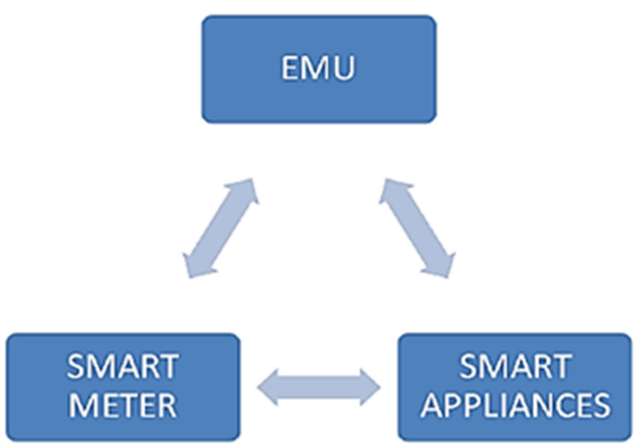

Fig. 5: Interaction among major entities of HACS4EM

When EMU receives the AVAIL-REP packet, it schedules a convenient start time for the appliance according to the HACS4EM algorithm and notifies it to consumer by sending a START-REP packet. The consumer, at this stage may be willing to negotiate with EMU, through the NOTIFICATION packet. The message flow is shown in Fog. 6.

8. HACS4EM Algorithm

Proposed algorithm consists of nine steps which are depicted in Fig. 7 and are elaborated as follows:

Step-1: In first step of the proposed algorithm, the consumer turns on his ith appliance which generates and sends a packet to the EMU. In our simulation we have generated these packets randomly.

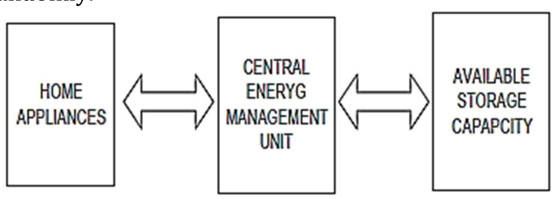

Fig. 6: Message Flow in HACS4EM Application

Step-2: On receiving the START-REQ the EMU communicates with smart meter and storage through AVAIL-REQ to know about the time of use (ToU) prices. The ToU prices tell the EMU the corresponding energy consumption prices at that particular moment. The EMU can easily find whether the current time lies within peak hours. EMU checks the starting time of the appliance S ti. If it lies outside the peak hours, the EMU replies to the appliance through a START-REP packet and the appliance is started immediately, otherwise the algorithm moves to the next step.

Step-3: This step is taken if S ti is found to be in peak hours. In this step the EMU checks for all the standby appliances in home and turns off all irrespective of their requests to be switched on, as it has been reported that standby appliances have played a reasonable role in energy wastage.

Step-4: If the starting time of appliance S ti falls inside the peak hours the EMU communicates with the local energy storage (solar, wind, PHEV, UPS battery etc.) inside the home to inquire about the locally generated or stored energy in the system. If there is enough energy in the storage system for the appliance, it is started immediately without any delay otherwise the algorithm moves to the next step.

Step-5: After switching off all the standby appliances in home and in accordance with storage capacity, the EMU checks the power ratings of ıth appliance Pi. Here we set a threshold value of power Pmax. After the standby appliances are switched off and for every appliance requests its power ratings are compared with the threshold value Pmax. For all Pi ≤ Pmax the appliance is directed to start immediately otherwise the algorithm moves to the next step. In our simulation we have set the value of Pmax to be 1 kWh.

Step-6: This step is taken if the power ratings of ıth appliance is greater than the threshold value i.e. if Pi ≥ Pmax. If the condition is true the appliance operation is shifted from peak hours to off peak hours. Hence a delay is introduced in the operation of appliance cycle. Different techniques of DSM have already been discussed in our work and we have selected the load shifting technique in our proposed HACS4EM scheme.

Step-7: As the appliance operational cycle has been delayed, and it is shifted from peak to off peak periods, a delay di is introduced which is equal to the difference of the scheduled time suggested by EMU and the request start time. This delay is inversely proportional with comfort level of consumer. They are never satisfied with large delays so we have introduced a threshold value of delay called Dmax. If di is greater than Dmax the appliance is directed to start immediately otherwise the operation cycle of the appliance ı is shifted.

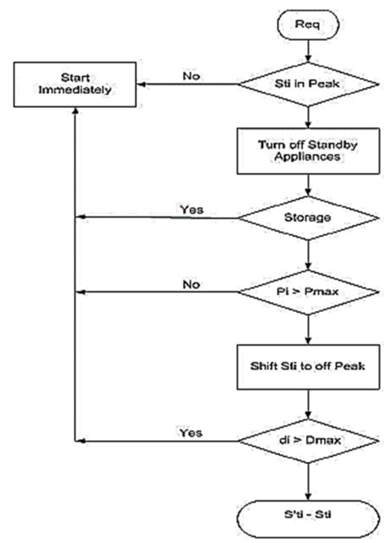

Fig. 7: HACS4EM Flowchart

Step-8: If the condition di ≥ Dmax is not satisfied for any appliance request, appliance cycle is shifted to hours where electricity prices are comparatively low. To let the appliance know about its starting time the EMU calculates the delay in appliance cycle and sends it to appliance. The scheduled delay can be found from the following difference.

(1)

Where

S'ti is the starting time of appliance ı scheduled by EMU.

Sti is request start time by appliance ı. This value is returned to appliance ı and notified as its delay.

Step-9: At this point the consumer may be willing to negotiate with the EMU. The consumer may deny or accept the schedule provided by the EMU. EMU informs storage unit and smart meter about the consumer's decision through UPDATE-AVAIL packet.

9. Conclusion

The flexibility, fault tolerance, high sensing fidelity, low-cost and rapid deployment characteristics of sensor networks create many new and exciting application areas for remote sensing. In the future, this wide range of application areas will make sensor networks an integral part of our lives. However, realization of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, hardware, topology change, environment and power consumption.

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