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A Smart Positioning System for Personalized Energy Management in Buildings

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***Abstract*— Energy consumption in official buildings contributes to 42% of total energy generation in India. The key features in commercial buildings are usage of high energy consuming devices, long duration of usage of electrical equipments, large population density and large equipment density compared with the floor area usage in houses. Hence this problem has motivated to perform research on energy management in official buildings. The individuals in these buildings mostly have unique authority on most of the equipments they handle, and they have their own comfort level requirement based on the context and the equipment availability. Therefore, to devise an effective energy management solution it is required to consider personal requirements with highest priority than the community requirements. Hence in this research work we design and develop systems & solutions needed for Personalized Energy Management (PEM). Our proposed system is developed to capture the spatio-temporal data of context and electrical usage pattern for each individual with bare minimum sensors. To address this challenge, we proposed a smart positioning system (SPS) for personalized energy management. In SPS, we have developed an Real time Smart Positioning System (RSPS) algorithm for integrating electrical map and sensing coverage of electrical appliances inside a building to position the individual in real-time with respect to each of the electrical appliances. Using SPS, the current position of an individual inside the building is determined along with the position of nearby electrical appliances to automate the appliance usage. This is performed using the proposed RSPS algorithm where real-time mapping of electrical map, sensing coverage of nearby equipments, signal strength, and pattern of individual requirements are used to control usage of equipments related to individual's choice. Experimental analysis of the RSPS algorithm on our prototype has been performed and the results showed that it requires a minimum of 2 coverage and it is not required to have 3 coverage as in other localization algorithms. Under the above condition of 2 coverage this algorithm was able to achieve an accuracy of 90%.**

***Key words*—Smart building, RSSI, Zigbee, smart positioning, WSN, D2D Communication;**

I. INTRODUCTION

Energy is the fundamental factor to the quality of our lives. Nowadays, we are completely dependent on an uninterrupted and abundant supply of energy. Managing and conserving energy not only saves money but also helps in mitigating climate change and environmental degradation. In fact, energy management is widely acknowledged as the best solution for direct and immediate reduction of energy consumption. According to IEA, World Energy Outlook (2012) [1] major portion of the energy is consumed by buildings. Effectively managing energy in buildings either requires individuals who have energy awareness or a smart building, which monitors and regulates services that make the occupants comfortable [2]. The studies of Dr Kumar S on macro analysis of building population [3] show that the major type of building in India in urban area are office buildings. With in a building the energy consumption division is shown in Fig 1

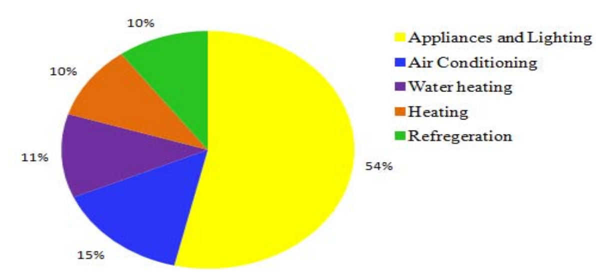

Fig 1.1 Energy consumption in office buildings

In urban areas the population density in an office or a commercial building is are very high compared to domestic usage for a specific area. The building services are achieved through wireless sensor networks (WSN). This WSN system tends to be either both complex and costly (using large number of sensors) or simple (limited application) efficient management of energy. This building experiences a major impact in usage of specific electrical equipments with the changes in climate variations like usage of AC, fan, etc with the change in temperature level. A common approach for controlling the electrical appliances based on the context aware system will not satisfy the comfort level of each individuals. A personalized low cost smart positioning system for energy management is proposed in this paper.

This paper is organized as follows: Section II discusses the related work in this area. In the next section, the Smart positioning system is explained followed by Electrical map generation and sensing coverage of the system. In the later sections, the RSPS algorithm is detailed followed by implementation, testing and performance analysis.

II. Related Work

Agarwal Y et.al, [4] deals with controlling of Heating Ventilation and Air Conditioning systems based on occupancy information, which was collected using a combination of sensors: a magnetic reed switch and a PIR (Passive Infra-red) sensor. The magnetic reed switch is used to sense the states of the door whether the door is open or closed. The detection of more than one individual in a room is not addressed in this paper. For a personalized controlling of the electrical equipment these two sensors will not give accurate information. Kumar N S et.al, [5] designed and developed a real time smart monitoring and controlling system for household electrical appliances. The measurement of electrical parameters of home appliances is done by interfacing with fabricated sensing modules. In essence, they provide manual controls which make the system ordinary, not smart. Every device in the home has two sensors which increases the number of sensors which is costly and more complex. Therefore, this is not an affordable solution in a commercial building.

Seco F, et al. [6] provides a survey of mathematical methods currently used for position estimation in indoor local positioning systems, based on radio frequency signals. This work gives an idea about different mathematical model used in localization techniques. These techniques are grouped into: geometry based methods, minimization of the cost function, fingerprinting and Bayesian techniques. Fingerprinting method [7] employs on measurement of received signal strength, RSS and consists two phases, the calibration phase and localization phase. In the localization phase, a test (target node) is moved through the grid, grid is a small area for the experiment, of sufficiently dense set of positions that cover indoor environment and records the signal strength from different base station. In the localization stage the system reads a set of signal which is most closely is chosen at estimation of location. Fingerprint methods make formal distinction between LOS and NLOS measurement, and are therefore inherently robust to the latter.

The existing systems do not provide solutions for personalized energy management since they are not equipped to track the usage of equipments by each individual. So they are commonly used for monitoring energy usage by a group of individuals. This will not provide us information necessary for understanding the individual usage of energy resources, which highly necessary for developing a personal energy management solution.

III. Smart Positioning System

This research work mainly focuses on official buildings. Currently some of these buildings use sensors for monitoring energy usage patterns. However the usage of sensors for effective energy management will be high in buildings that has large population density, long duration of equipment usage, large equipment density, and unique comfort requirements etc., compared to household requirements. In this research we have designed and developed a Smart Positioning System that consists of several modules that are capable to monitor and track the energy usage by each and every individual in a building. The different modules of a SPS are:

Wearable Device: Individual energy usage can be monitored and tracked only if we have a system that is capable to capture the equipment usage pattern per individual. To achieve this we have designed and developed a wearable device [8] that is capable to capture the equipment usage by each individual and also able to communicate the individuals presence at different locations inside the building.

Indoor Positioning System: To find the position of each individual in real-time, inside the building, we use the integrated approach based on the electrical map of the building, wearable device, and the sensing coverage of the electrical equipment. This method is explained in detail in Section IV.

Data Visualization and Analysis: The real-time data received from the wearable device will be used for finding the indoor location, electrical equipment in the vicinity, its current usage status etc. The visualization software will be capable to provide the real-time visualization of the electrical usage pattern of equipments and also the electrical usage pattern by each individual. This information will be fed into a learning module, which will help in developing a personalized energy management solution for the building.

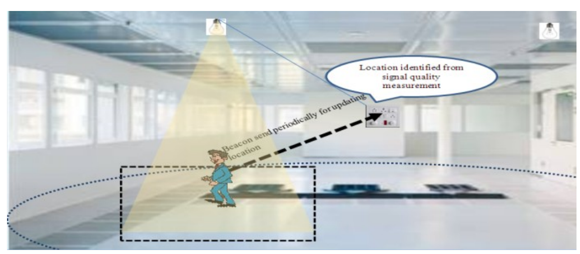

Fig 3.1 Architecture Diagram of Smart Positioning System

IV. Integration of Electrical Map and Sensing Coverage for SPS

The control of electrical appliance in a building for personalized energy management (PEM) System is based on the position of individual is proposed in the paper. The existing solutions for indoor localization method are costly. We need to find the location of the individual with respect to the electrical appliances in the room. Therefore, the location accuracy depends on the coverage area of the electrical devices. Area based localization is enough for the system. A low cost area based D2D (Device to Device) communication system is proposed in this paper.

The fingerprinting based method [7] is used for localization. The method has two phase Radio map preparation and localization phase. In Radio map preparation phase the whole area is divided into cell based on the coverage of electrical appliances and the received signal strength is stored in the data base as Radio map

A. Radio map preparation and RSSI measurement

In this experiment we assumed that the RSSI distorting signal is always the same for the area of study. The measured RSSI value needs to be converted to RSSI value in dBm form. Chipcon specifies the conversion formula to compute received signal power, P in dBm is shown in Eq. 4.1:

$$P = RSSI\_VAL + RSSI\_OFFSET \qquad (4.1)$$

where the RSSI_OFFSET is about -45 for a CC2420 radio in zigbee. As known, the signal strength will decrease with an increase in the distance between the anchor node and the target node. Due to indoor propagation effects, the data collected for radio map preparation had some unexpected values. In the conducted experiment, the RSSI value was observed to change between -50 and -90 dBm, and the variation was not linear. The RSSI values, which vary unexpectedly, can belong to different locations in one cell and also can belong to different cells. In other words, different cells may have the same RSSI value. Therefore, the algorithm must be written very carefully. Careful preparation of the radio map is also important.

B. Electrical map

The Smart positioning system works by integrating Electrical map and Sensing coverage of the building. The electrical map includes the position of all electrical equipments inside each room and the specification of each device. For a lamp the specifications are power consumption, Wattage, luminance etc. The electrical map is fetched from the server of the building which having the electrical map of each room in the building. We need to focus on the devices which consume more power in short time duration. The low power consuming devices for short time span is not considered since they do not have a contribution on total energy consumption.

C. Sensing coverage

The indoor area is divided into sensing coverage (cell). The area of one cell is calculated from the light coverage area of the electrical appliances. In this work we are only considering the lamp. The coverage of a lamp can be calculated. The equation 4.1is used to find the coverage area for a lamp

Consider a room having l meter length, b meter breadth, h meter ceiling to desk height is illuminated with a wattage of w and lumen of lu (depends on the utility [9]) using a lamp with efficiency e, maintenance factor m, utilization factor u and space height ratio (SHR) sh.

$$\text{Lumen per lamp} = e * w \qquad (4.2)$$

$$\text{No of lamps for the area} = (lu * l * b) / m * u * \text{lumen per lamp} \qquad (4.3)$$

$$\text{Light coverage area of lamp} = (m*u*le*w) / lu \qquad (4.4)$$

A cell has a maximum distance of $\sqrt{(l^2 + b^2)}$ (diagonal of the square) meters. Therefore, the maximum time an individual can walk in a cell is δ sec.

Smart positioning system integrates the electrical map and sensing coverage of electrical equipments for finding the position of the individual inside a room. A person with a wearable device can locate using wireless switchboard as an anchor node. The wearable device is capable of communicating (D2D Communication) with wireless switchboard to find position of the individual and controlling of nearby devices. The data collected from the wearable device is used to identify the location. This approach makes the system smart and energy efficient.

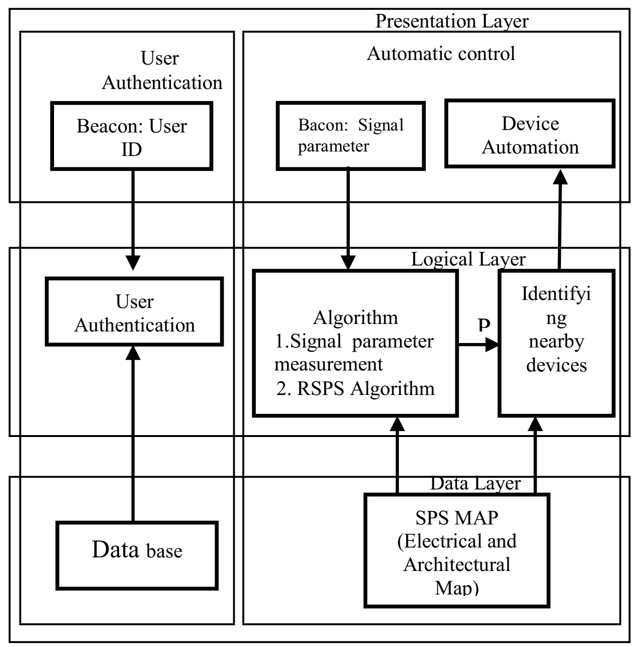

Fig 4.1 System Architecture (WSB)

A person with a wearable device is authenticated by the Wireless Switch Board (WSB) while he enters the room. The user ID for each wearable device is used for authenticating the individual .The details of authenticated individuals was stored in the data base. After authentication a periodic signal is transmitted from the wearable device to the WSB, to get the current signal parameter. The strength of a periodically received signal is estimated using WSB. According to signal parameter and RSPS (Real time Smart Positioning System) , the area that the person is in identified with the help of P and SPS map. SPS map is the integrated architectural and electrical map of the building. Then the nearby device of the individual is identified from the position and is automated. The system

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periodically checks the movement of the individual for turning of the devices when he moved to another device's coverage area. The system can efficiently work in the office where a number of people work in a large room, using cubicles. There are numerous electrical appliances placed for people to make themselves comfortable such as a light, a fan, and a computer. The control of the electrical appliances makes the building smart as well as energy efficient.

V. Real time Smart Positioning System (RSPS) Algorithm

The RSPS algorithm gives the position of the individuals with the help of electrical map and sensing coverage of each electrical appliance. The signal parameter for Region mapping is collected in data calibration phase, the personalization is achieved in personalization phase and the mapping of signal Parameter for position identification is done in Region mapping.

Algorithm 1 RSPS

1. Initialize all the variables
2. Call data calibration function
3. Call personalization
4. Call Region Mapping
5. Identify the position

Data calibration is a function for collecting the real time data of signal parameter and conversion of measured values to actual values of the parameters.

Algorithm 1.1 Data Calibration

Input TS = Time period

Output UserID,RSSI Value

1. Initialize all the variables
2. A periodic signal was sent to the WSB from wearable device
3. The User ID and RSSI is obtained from the signal
4. The register value is converted to power(in dBm) as per the equation in 4.1
5. Algorithms run when the anchor node receives a beacon
6. Send the identified cell to the main anchor node

Personalization is a function to identify the users and authenticating them

Algorithm 1.2 Personalization

Input UserID_D={1,2,3…}:Set of user id of authenticated person, stored as a database

UserID ={i}:Set of user id received from mobile node

Output User_presence = n; number of users.

1. If UserID (i) ∈ UserID_D then
2. Give permission to accesses RILSH
3. Store the user ID in temporary array.
4. search for second beacon
5. if the user id in the beacon is already exist in temporary array ignore it
6. else append to the array
7. else terminate the program

The cell is identified from algorithm, which works with the least mean square error method (LMSE), and the nearby electrical appliances are identified from the database. Then the appliances are controlled. The automatic controlling of electrical appliances based on localization makes the building energy efficient.

Algorithm 1.3 Region mapping

Input RSSI value of each cell for two anchor nodes (cell1_Anchor1) = Sets of RSSI values, stored as a database

Map of cell (cell_map)= set of all connected cell

User_presence = number of users.

Connected_cell = subset of cell_map,

Received RSSI data(Receive_RSSI_Anchor1) = set of recived RSSI values

Output Traversal_path = The path of individual.

1. Find the first cell near to door = identified_cell
2. Take the consecutive average number RSSI value from the Received RSSI data
3. Find out the connected cell of identified_cell
4. Read the data base for corresponding cell
5. Processed_data yk(i)= $\sqrt{(\sum (x(i)-y(j))^2)}$ i=1,…,sizeofcelldatabase
6. Find all yk's
7. Find the minimum of yk's
8. Find the cell corresponding to minimum yk
9. j number of cells are obtained
10. find the repeated cells from each anchor nodes
11. find the common cell obtained from the two anchor nodes
12. Common cell is the cell where the user in
13. Append the common cell in the traversal path file
14. Update the common cell as identified_cell

VI. Experimental setup and hardware implementation

The hardware for both the wearable device and wireless switchboard was developed. Wearable device consist of zigbee module and a micro-controller. Wireless switchboard consists of a zigbee module, relay, bulb voltage regulators and micro-controller.

For testing the area under experimentation is divided into cells. The area of one cell is calculated from the light coverage area of one lamp. In the experiment, we are considering an office area where each individual has one light, fan and electrical appliance per cabin, and we are considering only the lamp for this work. The equation 4.4 is used to find the coverage area for a lamp

In this experiment the area is considered is an office area has length 6 meter and width 6 meter and height 3 meter, the ceiling to desk height is 2 meters, the area is to be illuminated to a general level of 550 lux using twin lamp 32 watt CFL luminaries with a SHR of 1.25, each lamp has an initial output (efficiency) of 85 lumen per watt and the lamp maintenance factor is 0.63, utilization factor is 0.69 and space height ratio (SHR) is 1.25. From the equation 4.4 the coverage of lamp is 2 x 2 m^2.

Fig 6.1 Experimental area

Therefore, the maximum time an individual can walk in a cell is 2.03s. An average of 100 values is required for estimating the location, which is identified by repeated experimentation. Therefore, in each 20ms a beacon needs to be sent from a wearable device to the Wireless Switch Board (WSB). The RSSI value is checked in each 2 Sec to update the location.

The collected data is fed to the processing unit, which runs the RSPS algorithm on MATLAB.

VII. Performance Analysis

The Algorithm is tested for 80 times in the experiment area. Out of the 80 testing the algorithm shows correct position in 72 times. Therefore an accuracy of 90% is achieved with RSPS algorithm.

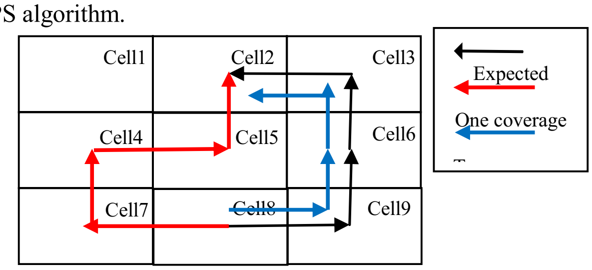

Fig 7.1 Cell structure and user path for one coverage and two coverage

One of the testing results and cell structure for testing is shown in Fig 7.1. In this setup the entrance to the room is in cell8 therefore the user path starts in cell8. The signal parameter for each cell has over lapped Therefore RSPS algorithm works for a set of consecutive signal strength values. The range of RSSI value for each cell under experiment is shown Fig.7.2.

TABLE I. Comparison between 1 coverage (1 anchor node) and 2 coverage (2 anchor nodes)

Path of the user (no of cell in user Path)	misclassification with One WSB	misclassification with Two WSB
8-7 (2)	½	½
8-5-2(3)	2/3	1/3
8-9-6-3-2(5)	3/5	1/5
8-7-4-1-2-3-6(6)	3/6	1/6

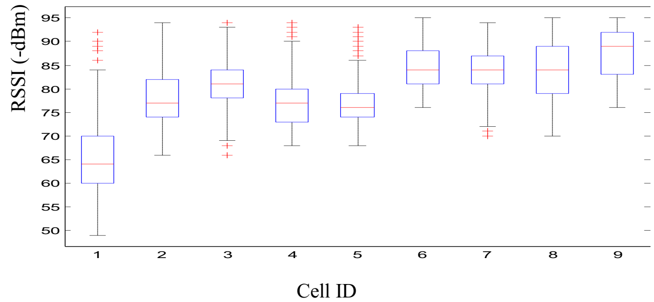

Fig 7.2 box plot for WSB1 (anchor node1)

The algorithm is evaluated using one WSB and 2WSB. The Table 2 shows the misclassification (error) with one coverage and two coverage. It should be noted that if only one anchor node was used, there was a misclassification (more than a 50% error) where the points are at an equal distance from the anchor node. Therefore a minimum of 2 coverage (2 anchor nodes) is necessary to find exact position. From the analysis it is seen that even if the no of cells in the user path increases the algorithm able to identify the current cell of the individual.

VIII. Conclusion

A Smart system for positioning of individuals inside a building was developed. A wearable device and a wireless switch bored were designed to get the position of the individual and controlling the nearby electrical appliances. In this work the system was tested multiple times for several days and various times. From the result, it is proved that the received signal strength with the RSPS algorithm could efficiently determine real time localization of individuals inside a room with minimum number of anchor nodes. By determining the individual's exact location, we can appropriately control the nearby electrical appliances, thus saving energy. The algorithm was evaluated with respect to accuracy, coverage, and cost. As a future work, the electrical usage pattern of each individual for a group having more than two individual is to be identified and the electrical devices are control without affecting the comfort level of each individual.

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