Innovation ***Challenge 2009***

Topic:
Intelligent Sensors

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Wireless Sensor Based Real Time Automated Electrical Meter Reading, Collection and Analysis for Electricity Theft Control

1. Abstract

Energy efficiency involves not just the efficient usage of energy but efficient management of energy consumption and distribution as well. Governments are time and again setting up energy saving targets and ensuring they are met. But various factors such as electricity thefts, wastage etc. are pulling their efforts down to attain desired goals. This paper discusses a solution using Wireless Sensor Networks to control the theft of electricity and also monitor the usage of electricity by an industry or household. A real-time measurement of power consumption directly from the electrical poles to the substations can not only reduce the human effort required to collect and feed the data but also alarm the individuals of wastage in power by comparison to the society as a whole. Apart from this, real-time measurements of power consumption when matched with distribution statistics can go a great deal in recognizing and minimizing the power theft in the region. The proposed system is capable of providing the operator with an exact consumption of electrical energy at any consumer installation at any point of time. An aggregate analysis of this data indicates points of mismatch in the distribution and consumption, locating its exact region.

2. Concept and Innovation details

2.1 Introduction

The increasing trends in electrical consumption and limited resources to suffice the need have made "Energy Efficiency" to become buzzword of today's era. Energy Efficiency not only includes the efficient usage of the available energy resources but also includes methods to prevent their wastage. Proper Management of the energy distribution and timely reporting of energy consumption can aid in quick estimation of consumption trends of a house, colony or industry. It can prevent inefficient usage of electricity which attributes to approximately 30% of T&D losses to the government [13].

The proposed system uses Wireless Sensor Networks for continuous collection, querying and analysis of electrical consumption measured by Automatic Meter Readers (AMR) installed at consumer sites. The Sensors are arranged in Cluster topology as shown in Figure 1. A sensor can act as a Full Functional Device (FFD) or a Reduced Functional Device (RFD) [8], with at least one FFD acting as a Coordinator.

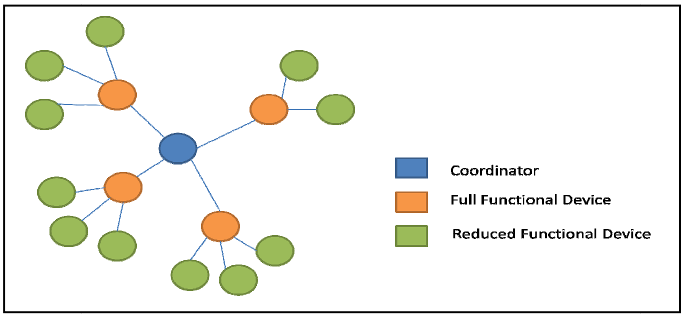

Figure 1: Arrangement of Sensors in Cluster Topology

This paper is organized as: Section 2 discusses concept and innovative idea including background and proposed system details. Section 3 discusses the applications of the proposed system and Section 4 concludes the paper along with the future scope of the proposed idea.

2.2 Background

Traditionally, to gather data from meters deployed in residential areas, technicians are sent. The data is recorded manually and fed into the database for further processing. The method is more cost-intensive and prone to human errors. Moreover, the theft of electricity often goes unnoticed. Various approaches have been proposed in this direction, improving meter data gathering to minimize costs and errors [11][12].

Direct Wire Connection, an approach using *M-bus* and *Power line link* [1][4] protocols, is based on the concept of using wired line connections to transfer data to a base station. Another approach involves transmitting data directly from meters to base station using Radio Frequency links. Mobile telephone network is another approach in which meter uses a cellular telephone network to send data via SMS or GPRS to a base station [5][6]. Though this method involves less human costs and easy data collection but equipments and calling services make this approach expensive.

Electricity theft has a significant impact on the nation's economy, thus its regulation and control is one of the major concerns of research [2][7][9]. As the electricity theft like any other commodity theft cannot be detected physically, its detection becomes more difficult. In several cases, the consumer denies electricity theft due to prior information about the checking and availability of no physical evidence. Various methods such as tapping the power supply, tampering with the meter reading [13] by slowing down the meter or causing permanent damage, or direct theft by connecting chords to LT distribution lines are used to consume more electrical power and show a lesser value. Various measures taken to reduce power thefts include regular checking of power supply lines, sealing of the meter, placement of meter outside the building to facilitate meter reading and ensure no harm is done to meter.

2.3 Proposed System

The system proposed here uses Wireless Sensor Networks and aims at Real Time Automated Electrical Meter Reading, Collection and Analysis of electrical distribution and consumption data of a region. Figure 2 provides an insight into the system proposed. The system uses a wireless sensor based AMRs which can be used to replace the currently used electronic meters. The power generated at power stations is distributed to substations of different regions. The distribution lines transmit the electricity to different regions (containing households, industries etc.). The AMR are installed on each consumer site (households, industries, etc.) and all the electricity consumption of that consumer is recorded by them. The sensors used in these meters are RFDs which are only capable of sending their data to the nearby FFDs. The FFDs, installed on all the poles, collect data from AMR and pass the information to the coordinators, present near the server at the substation. The Coordinators pass the information to the server placed at the substations. The information collected at these servers is then put to analysis which can be further used to monitor electricity distribution and consumption of a region, thus putting a check on electricity thefts.

This system is integrated with a web-based electricity consumption monitoring system where the end-user can keep a check on his consumption.

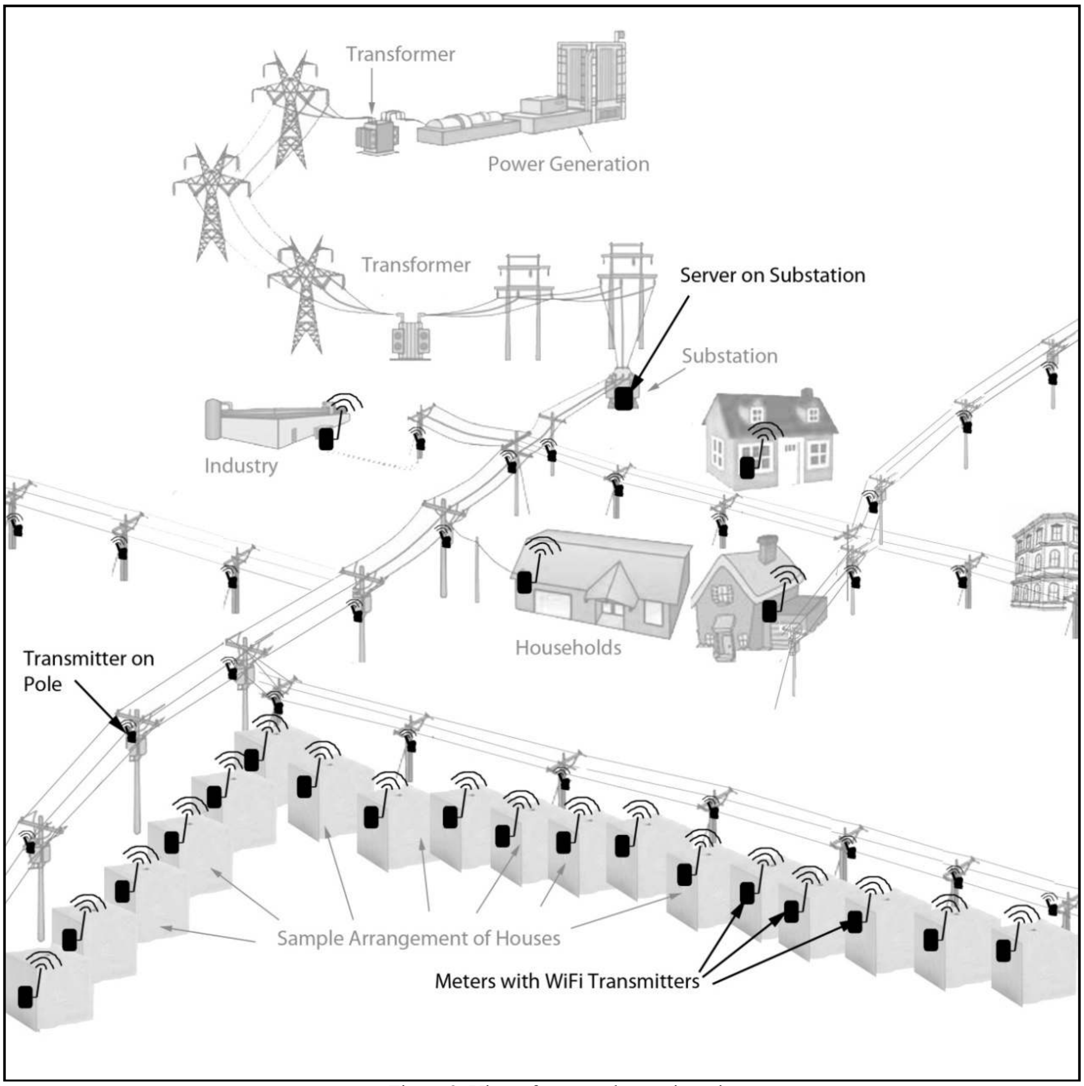

Figure 2: View of proposed setup in a city

2.3.1 Data Measurement

The FFDs are attached at each pole. Figure 3 shows the view of a pole. The data to be measured pertains to electrical distribution and consumption. This data can be measured across each pole. The difference of data across each pole gives the consumption of electricity by the consumer sites to which electricity is fed from that pole. This is compared to the readings provided by the AMR installed at those consumer sites (considering losses involved in transmission and distribution of electricity to consumer sites).

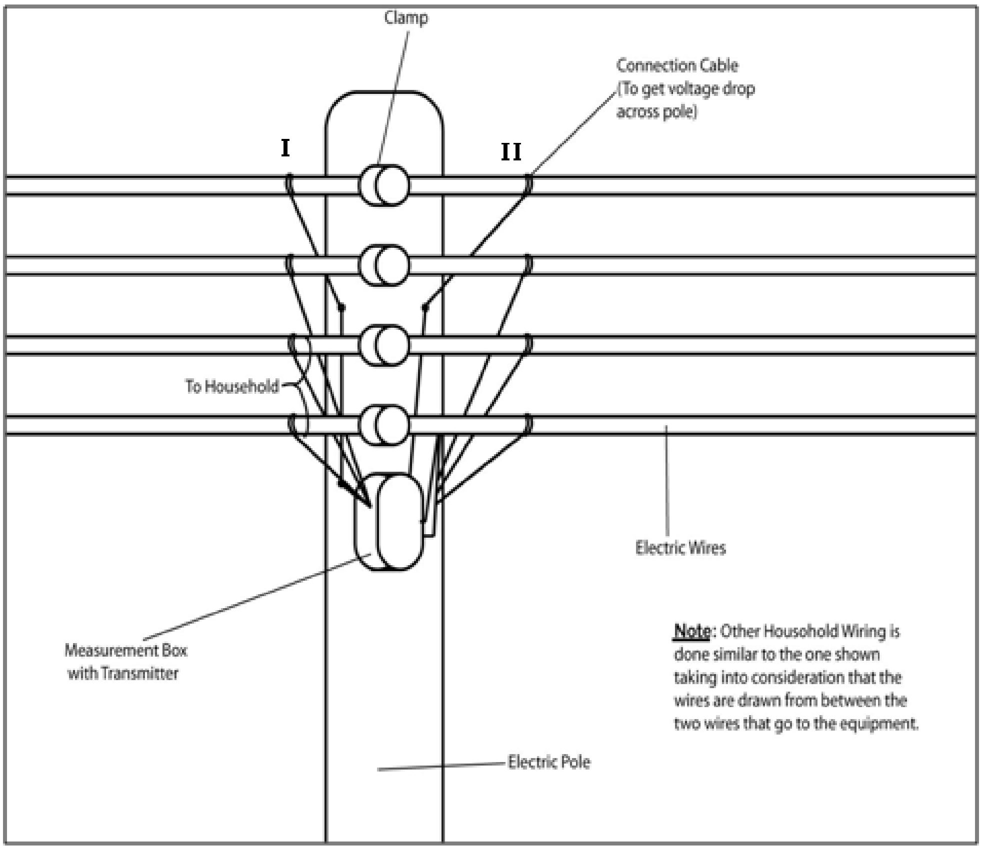

Figure 3: Detailed view of a pole

Let V be electricity consumption measured across each pole and C be the total electricity consumption read from AMR installed at the consumer sites which are fed from that pole. Let Ł be the losses involved in transmission of electricity from pole to consumer sites. The losses could be due to heating effect, magnetostriction, distance dependent etc. Based on above, the following equation can be formulated:

$$V=C+Ł \quad \ldots (1)$$

Since it is difficult to predict exact losses in real time environment, so we introduce a term η that determines the tolerance limits pertaining to losses, calculated statistically from the past and current consumption trends at consumer installations. So equation (1) can be reformulated as:

$$V=C+(Ł \pm \eta) \quad \ldots (2)$$

Let (V-(Ł ± η)), denoted by α, be the actual electricity available at consumer sites. Now comparing α with C can give us information about mismatch in electricity distribution and electricity consumed.

Case I: α>C: this shows that electricity available to the consumers is more than the consumption reading collected from AMR, thus shows the condition of electricity theft.

Case II: α=C: this shows that electricity available to the consumers is equal to consumption reading collected from AMR, thus shows an ideal condition.

Case III: α<C: this shows that electricity available to the consumers is less than the consumption reading collected from AMR, thus shows a hypothetical condition.

The thefts can also occur by unauthorized connections between two poles. Let V' be the voltage drop between point II of pole P1 and point I of pole P2 as shown in Figure 3. This voltage drop should equal the losses L' (where L' can be due to heating effect, distance dependent etc.) between the two poles. If there is a discrepancy, that means there is an illegal connection in between the two poles leading to theft.

2.3.2 Data Collection and Analysis

The data generated at AMR is converted into a set (or tuple) by RFD. The tuple, which is of the form <*loc id, timestamp, data*>, is sent to FFDs. The storage and processing of data becomes a major issue as the data is collected at regular intervals. The solution to this problem can be in-network aggregation [10]. The sensor, (any sensor capable of giving digital output can be connected to the processor {Resistive, Inductive or Capacitive}, including the present analog sensors with ADC) can be used here along with Berkeley mica mote [10] which supports various aggregation functions. In order to preserve the statistical details, Content-Sensitive Aggregation using histogram can be used [3]. This aggregation is performed at FFDs as shown in Figure 4. This aggregated data is sent to the coordinator where all the data from different FFDs is collected and is finally sent to the server. Due to continuous flow of data from RFDs to FFDs, some FFDs may get overwhelmed and become hotspots. This can be avoided by using multi-dimensional indices instead of one-dimensional indices [3].

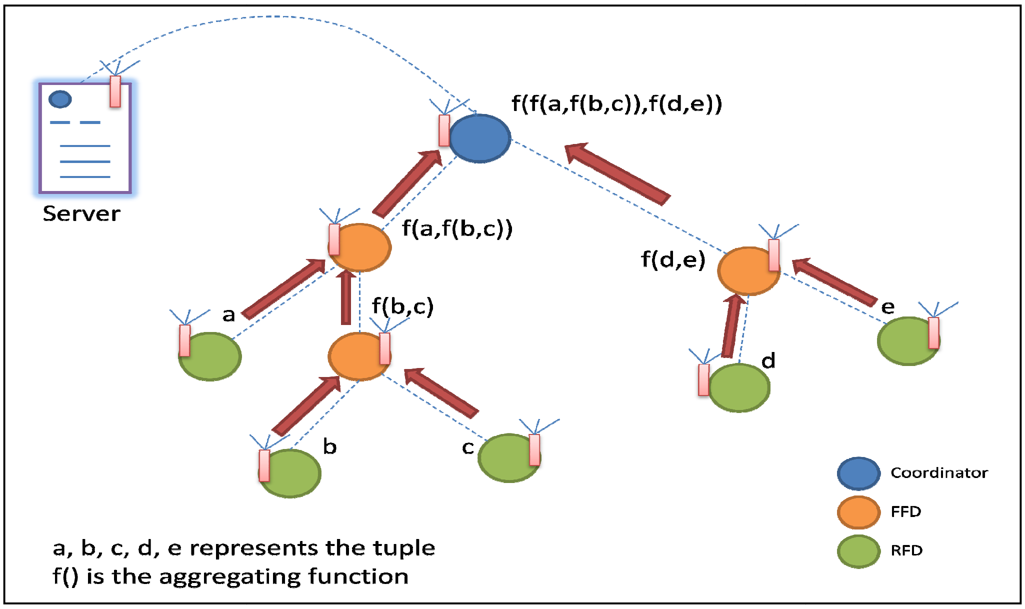

Figure 4: Data Flow and Aggregation

In case of failure of any node, the operator at the server is informed immediately. In case the failed node is a FFD, the connected FFDs ripple the information across the dependent network and all the nodes increase their measurement interval as a tradeoff between space and accuracy. The RFDs receiving no acknowledgement performs similar tasks which continue till a special command packet is sent indicating channel clearance.

2.3.3 End-User Electricity Consumption Monitor

The system is integrated with a web-based system by which end-user can monitor and keep a check on his electricity consumption trends. This system will also give statistical analysis of user consumption trends as compared to other users in vicinity. The end-users can limit their consumption by setting a threshold value. The system can alert the end-user when his consumption crosses this threshold limit.
The administrator at the server has software by which he can monitor the entire system including setting up the time intervals of data transmission from RFDs to FFDs, checking electricity consumption of consumers, detecting thefts etc.

2.4 Comparison with other prevalent methods

Table I shows the comparison of our proposed system for controlling electricity thefts with other prevalent methods.

Theft Method/ Solution	Direct LT cables with manual meters	Aerial Bunch cables with Manual Meters	Use of 11kV distribution Lines	Aggregation Meters at regular intervals	Our Approach
Meter Bypassing by shunt capacitors/ detouring	No protection is provided, this method is old and getting replaced.	No protection present, technology is coming up for other reasons like safety.	No protection is provided as such. Coming up for saving distribution losses, though implementation is costly.	Ability to detect thefts, but cannot pinpoint the exact location. Costly approach.	Gives instantaneous detection, cheaper than aggregate meters, can be coupled with Aerial bunch cables, 11kV lines for accumulating benefits**.
Unauthorized power connections	No protection is provided, manual checking is done.	Protection provided but fallible*.	No protection by itself, can be used alongside Aerial Bunch Cables.	Ability to detect thefts, but cannot pinpoint the exact location and time.	Instantaneous detection of connection point.
Meter Tampering	No protection is provided, manual checking is done.	No protection is provided. Left for manual checking.	No protection is provided.	Little to no protection is provided if the aggregate meter is tampered.	Instantaneous detection of tampered meter.

* It is possible to create a permanent cut in the wire for energy tapping at arbitrary times.
**Any given system can be upgraded to retain earlier benefits.

Table I. Comparison of different methods of electricity theft control

3. Application

The proposed system provides integrated data collected from every node and thus automates the process of meter reading, collection and bill generation; reduces the errors and human effort; and increases the overall efficiency. The real time collection and analysis of data is highly helpful in detection and control of electricity thefts. The system provides us with the exact details of input and output load at each node. On comparison of the available information, exact details of the location of discrepancy can be obtained, thus making theft detection easier with lesser human effort. The system can be used for data gathering and reporting as information available from each node is sent to the server for analysis. It provides a good solution when this task has to be carried out especially in remote areas. Also, the system aids in quick detection of failure of nodes in the network and thus helps in better management of the existing electrical connections. Further the proposed idea being utility independent can be extended with little modifications to other supply and distribution systems such as water and gas supply etc. Moreover, the indirect applications of the system include accident prevention because when the distribution system goes down, immediate information is available regarding the points of failure.

4. Conclusions and Future Works

The proposed system uses Wireless sensor based AMRs for recording the electricity transmission through the poles and also the consumption at consumer installations. As no complex wiring is required, the proposed system provides an efficient measure to monitor electricity transmission and consumption and control its wastage or any illegal consumption. Moreover, the integration of detection system with AMR makes it cheaper, faster, accurate and efficient over the current methods of theft detection.

The system has broad applications ranging from meter data gathering system to managing the distribution of load in the various areas and managing the data gathered to detecting and controlling the power thefts. The system can further be integrated with the distribution management system to cut-off the electricity distribution to consumers after fixed number of automated warnings. In future, instead of sending data using wireless media, it can be sent through the existing power lines, reducing cost and network interference.

5. Acknowledgements

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