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Effective Energy Management IOT Framework for Smart Metering System

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Abstract: A smart city always concern about effective energy consumption in order to save energy as possible. A smart meter display result of consumed unit in specific time frame (real time result). Internet of things and advance metering infrastructure both enables more reliable smart city. Many countries have already deployed smart meter since early 2000s. This provides social, economic and environmental benefit in smart grid technologies. In this paper we have proposed control and monitoring IOT technology for effective energy management in smart metering system.
Keywords: IOT, NILM, MDM, smart meter, smart grid.

I. INTRODUCTION

The energy consumption has been increased in remarkable rate of 2.7% in every year. Most report shows that 72% of total energy consumption is by commercial building and residential building [1] and around 30 % of energy usually wasted building and corporate park [2]. For energy management in such built in environment, research have been made in smart building and smart grid technology.

Our primary concern is energy efficient control strategy and monitoring the real time on/off of electrical appliances. The monitoring provides needed information of smart control devices and wireless senor network gives advantage to them. In building [12] where broadly distributed smart electrical devices in each floor requires a smart meter, which increase the cost of smart meter deployment, system maintenance and data collection. Then building got a major task to manage the cost of smart meter deployment and auditing the real time accuracy of working of devices [13].

A. Related work

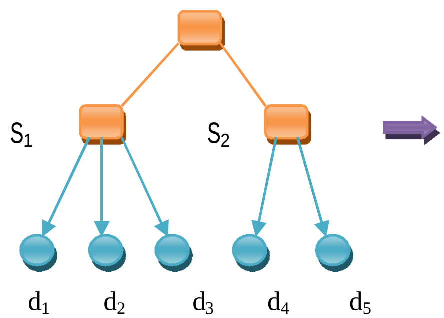
For this huge amount of smart meter deployment where energy auditions become a large problem for both industry and academia. There are two main part of this related literature.

The first one is NILM (non-intrusive load monitor) based on on/off state disaggregation. Deploying cost of smart meter is been reduce by this approach because it focus on deploying only one high frequency smart meter at power load tree. And disambiguate the on/off states of appliances by transmitting a signal and pattern recognition. Hart proposed reactive load signature detection with this approach [3]. Patel et al. introduced event detection and performed the preconisation by electrical noise in [4]; and end use detection addressed by Farinaccio et al [5]. The Wang [6] proposed a technique for track on/off states of massive electrical appliances by light weight compressive network. In [7] paper, they introduced a light weighted low cost smart meters that can work in relatively low frequency. They also introduced the energy monitoring, tracking of efficiency and optimization of smart meter development.

The second one literature is about fidelity energy auditing system. Such as in [8], Jiang et al. provided high-fidelity monitoring electrical usage in built in environment by utilization of contextual metadata for development and design of a wireless sensor network. The PowerNet introduced by Kazandjieva [9] that was hybrid sensor network used for monitoring the utilization and power of smart devices in large scale. The development of wireless plug-load electric meters in built in environment by Dawson-Haggerty [10]. Instead of making on/off state of appliances by RFID sensor and amount energy consumption, the [7] considering relation between smart meter deployment cost and state tracking accuracy.

They [7] consider electrical network as a tree form where leaf act as electrical appliances and nodes are the outlets. And smart meters are placed at every node for monitoring the real time electricity consumption by appliances. The on/off states of every appliance are unknown variable that provide vital state for smart meter technologies. We will have 2^n number of possible on/off state for n number of appliances. For such network and real time state we require large amount of smart meters. The key challenges were to deploy minimum amount of smart meter with high accuracy of state tracking. These challenges have following contribution.

1) *Load tree Decoding:* In this load tree are splits into set of single root tree where efficient decoding methods decode the state of leaf appliances by smart meter root. This condition provides necessary high-accuracy decoding.
2) *Hardness Proof And Algorithm Design:* The problem of minimum smart meter deployment cost while satisfying necessary condition for state decoding is an NP hard problem. So [11] consider the appliances have bounded power consumption and load trees have only bounded node degree.
3) *Simulation Assessment:* There were an assumption that [12] decoding algorithm and smart meter deployment scheme with field data. It has been determine that there algorithm reduces 70% of power load networks in simulation.



$$P = \begin{pmatrix} p_1 & 0 \\ p_2 & 0 \\ p_3 & 0 \\ 0 & p_4 \\ 0 & p_5 \end{pmatrix}$$

Figure 1: smart meter deployment mapping to observation matrix.

B. Our Contribution

As above approximation algorithm consider [16] about minimum smart meter cost and high accuracy state decoding by assumption electrical appliance as in tree form. In our proposed algorithm we also consider the same but instead of greedy algorithm we use the dynamic algorithm.

In rest of our paper is arranged as follows. Section II introduces about model of system and vector decoding. We proposed out optimization algorithm in section III. Simulation result in Section IV. And finally conclusion at section V.

II. PROPOSED METHODOLOGY

The typical energy distribution in building can be represented in form of tree, which is hierarchical load tree. Power entrance in building is recognized as root of tree. The outlets are non-leaf nodes which are connected smart meter. And leafs are the actual electrical appliances. We provide total consumptions of appliances by smart meter in the sub-tree rooted at monitored node shown in figure1.

The energy consumption value when any turn on is represented in power pattern. The statistical power of each i appliances are denoted a by (Pi, θi) where θ is power deviation and P is power consumption value. In the real time $[(1 - \theta i)Pi, (1+ \theta i)Pi]$ bounded power consumption with high probability by various training methods.

We assume the n appliances and m meter on a loaded tree in my $aP \approx z$ model. We formulated the model between smart meter and appliance states where:

1) $P \in N^{nXm}$ is pattern matrix. Here P is smart meter deployment power and setting for n appliances.
2) $a \in \{0,1\}^n$ is sector vector (indicates on/off)
3) $z = (z_i \,|i = 1, \ldots, m) \in N^m$ is observation vector where each zi indicates the power measurements of smart meter i.

Our main goal is determine the state of appliances and reading by m deployed smart meter. Our task is make effective pattern by understanding relationship between smart meter deployment and state of appliances.

A. State vector Decoding

Here we explore the relation between state accuracy and smart meter deployment. We must find the state of vector on a given matrix in each time slot.

$$\text{Minimize } \|aP - z\|_2 \qquad (1)$$

$$\text{Subject to } a_i \in \{0,1\}, \text{ for all } I = 1,\ldots..n.$$

Least square estimation (LSE) is approach of this problem which can solve by various algorithms such as Tibshirani algorithm [10]. In decode phase power load tree are decomposed into sub-tree which also called mono-meter tree. For explaining this, let consider an environment where v is a load tree which is monitored by smart meter. In this, smart meter ST(v) is value of power consumption by appliances in sub-tree. Here load tree T = (V,E) is decomposed into m mono-meter tree shown in figure 3. As we know on/off state of appliances are independent o each other. So meter of such appliances also be distributed and solved parallel.

LSE algorithm is directly applied on each mono-meter tree and these mono-meter trees can be decoded in parallel. The n number of node in mono-meter tree is n_v << n and running time could be reduce sharply. However, there is only single observation value from mono-meter tree and corresponding state in map table. Offline pre-process mode are applied to make mapping table where we sort them according to their power consumption in time $O(n_v 2^n{}_v)$. At each interval of time, online decode running time be $O(n_v)$. In general, users always desire to minimize the number of smart meters in building. So we need to connect many appliances to a mono-meter tree and mean while must disambiguate the on/off state.

III. PROPOSED ALGORITHM

In our methodology, we define that our main goal to reduce smart meter deployment cost and also provide good accuracy for monitoring electricity consumption by appliances. The algorithm1 define the smart meter deployment problem with following input and desired output.

1) *Input:* T = (V,E) is a load tree with N nodes. And L set of leaves in T. Each leaf have power pattern (pi,)
2) *Output:* The minimum deployments of smart meters with accuracy in monitoring appliances.

We need to utilize the all smart meter useful, for reducing the number of smart meter. In the algorithm1, we consider smart meter can only be place which ST(Father(v)) is not clear where v is child of father(v). And then apply the dynamic algorithm got optimal result. Here we use bottom up approach for retrieval of father node by child node. Let Tree v have n number of node such as v1, v2, v3, ….., vn. To make mono-meter tree generated from visited node to clear, we make cut-off original tree into sub-tree in iteration.

If ST_i (v) is not clear, then we deploy smart meter at child node v to make it clear. Here in iteration, we search for sub of sub-tree to C*min* sub set load tree and generate new sub-tree with mono-meter.

Even if ST_i (v) isn't clear than there is no need of smart meter to be deploy in child v.

This algorithm reach to root when all the node are visited because smart meter always want the root.

Algorithm 1: Dynamic algorithm for SMDP

INPUT : Tree T =(V, E) with integers on the leaves
OUTPUT: Set D ⊆ V to deploy smart meters
D = Ø
  for all i ← 1 to n do node when searching from bottom to the root
      if ST(v) is "Not clear" **then**
    let v be the i
    Cmin= Childof(v)
      for all C ⊆ Childof(v) **do**
          ST_(v)=ST(v) \ (_ST(u))
          if |Cmin| > |C| and STu∈C(v) is "Clear" **then**
          C min← C end if
      end for D ← D ∪ Cmin
      T ← T \ ST(u), ∀u ∈ C
    end if
  end for
return D

The algorithm2 will provide us the state of leaf or appliances connect to a network. If we get mono-meter tree not clear than there must be some overlapping in observation ranges. In mono-meter tree, any appliances may have only two states. The process of checking weather mono-meter is clear or not clear, we have following steps:

a) Number all possible expect observation values and expected power consumption of all appliances.

$$S^j = \{a^v | a^v \epsilon \{0,1\}^{nv}, \text{ and } a_i^v = 0, \text{ for all } i > j\} \quad (2)$$

b) Detect overlapped observation segments existence between each two successive observation range.

Algorithm 2 has detection of state of appliances and further iteration to get state of child node. This clear and not clear judgement with running time $O(Bn_v^2)$ needed for each subset.

Algorithm 2: State of vector detection

```
INPUT : A tree ST(v)
RETURN: "Clear" if ST(v) is clear;"Blurry" otherwise.
for all ˆz ← 1 to n B do
Uv[ˆz]=0, θv[ˆz]=0
end for
Uv[0] = 1
for all pi, i =1...nv do
    for all ˆz ← nv B downto 1 do
        if ˆz - pi^v >= 0 and Uv[ˆz - pi^v ] = 1then
            if Uv [ˆz] = 1 then
            return "not clear"
            else
                Uv[ˆz] = 1
                θv[ˆz] = max{ θv[ˆz], (θv[ˆz]( ˆz-pi^v)+ θi^v pi^u)/ ˆz }
            end if
        end if
    end for
end for
ˆz1 ← 0
For all ˆz2 ← ˆz1 + 1 to nvB do
    If Uv [ˆz2] = 1 then
        If ˆz2 - ˆz1 <= θv [ˆz1] ˆz1 + θv [ˆz2] ˆz2 then
        return "Not clear"
        else
        ˆz1 = ˆz2
        end if
    end if
end for
return "clear"
```

IV. SIMULATION RESULT

Our algorithms were theoretical analysed and numerical evaluated for provide performance and effectiveness. We performed simulation on our algorithm in different appliances power distribution, different scale and different node. We proving the dynamic algorithm's performance on cost saving and compare with greedy algorithm's and optimal smart meter deployment.

A. Performance In Deployment Cost

Under different setting, our algorithm provide cost saving performance even in error-free state on load tree. We evaluate our algorithm preformation under three kinds of power distribution, such as uniform distribution, exponential distribution and power distribution. The number of meter deployed divided by number appliances is known as cost ratio.

B. Performance Monitoring

We provide error-free monitoring guarantee through our algorithm. Normal distribution has been used for simulating real time consumption. Over all decoding accuracy of our algorithm is 92%. Thus it prove that our algorithm provide efficient power performance than greedy and optimal algorithm.

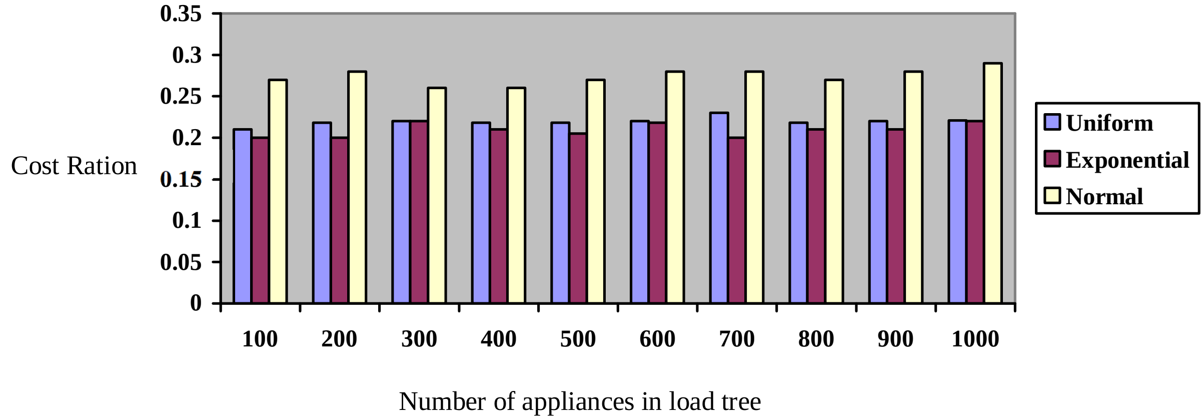


Figure 2. Cost ratio with respect to monitoring the load tree

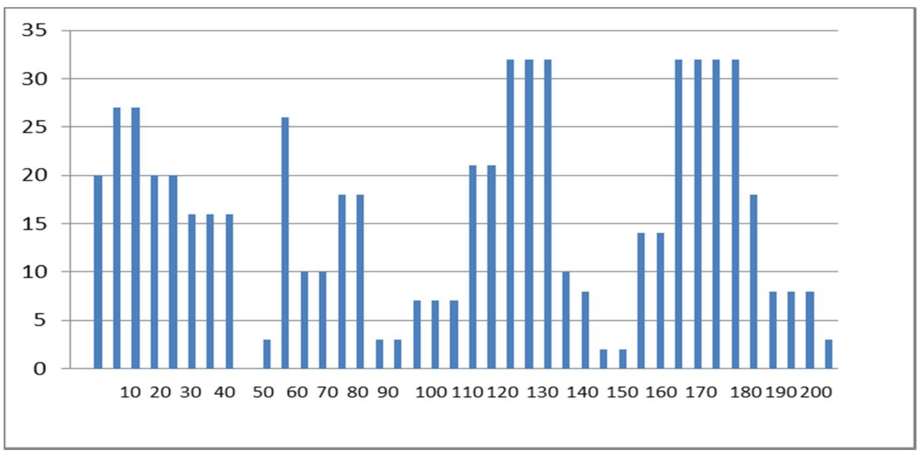


Figure 3. state detection result by decoding algorithm

Table I

Performance of our proposed dynamic algorithm for SMDP

Appliances in load tree	8	12	16	20	24	28
Meter (Dynamic algorithm)	2.3	2.3	3.1	4.1	4.5	5.4
Meter (Greddy algorithm)	2.2	2.3	3.2	4.2	4.8	6
Meter (Optimal algorithm)	2.2	2.2	3.2	4.1	4.6	5.5

C. Comparison of Dynamic Algorithm with Greddy and Optimal Algorithm

We made an analysis were dynamic algorithm, greedy algorithm and optimal algorithm in tabular format. In our simulation, we consider brute force algorithm to optimal solution on random generated power by 8 to 28 appliances. As in give solution, we getting average performance closer to 1, which determine dynamic algorithm can find solution accurately.

V. CONCLUSION

The optimal smart meter deployment and accuracy in state of appliance are been the two main concern of this paper. The decoding of state determines error-free condition for appliances. After [15] then optimal smart meter deployment strategy has necessary condition of NP-hard and approximation algorithm to solve the problem. Simulation result show the reduction in smart meter deployment over various power loads.

There are many ways to extend our work. For example working with [14] multi-mode and distributed patterns. And time dependency of state of appliances, more number of energy can be saved.

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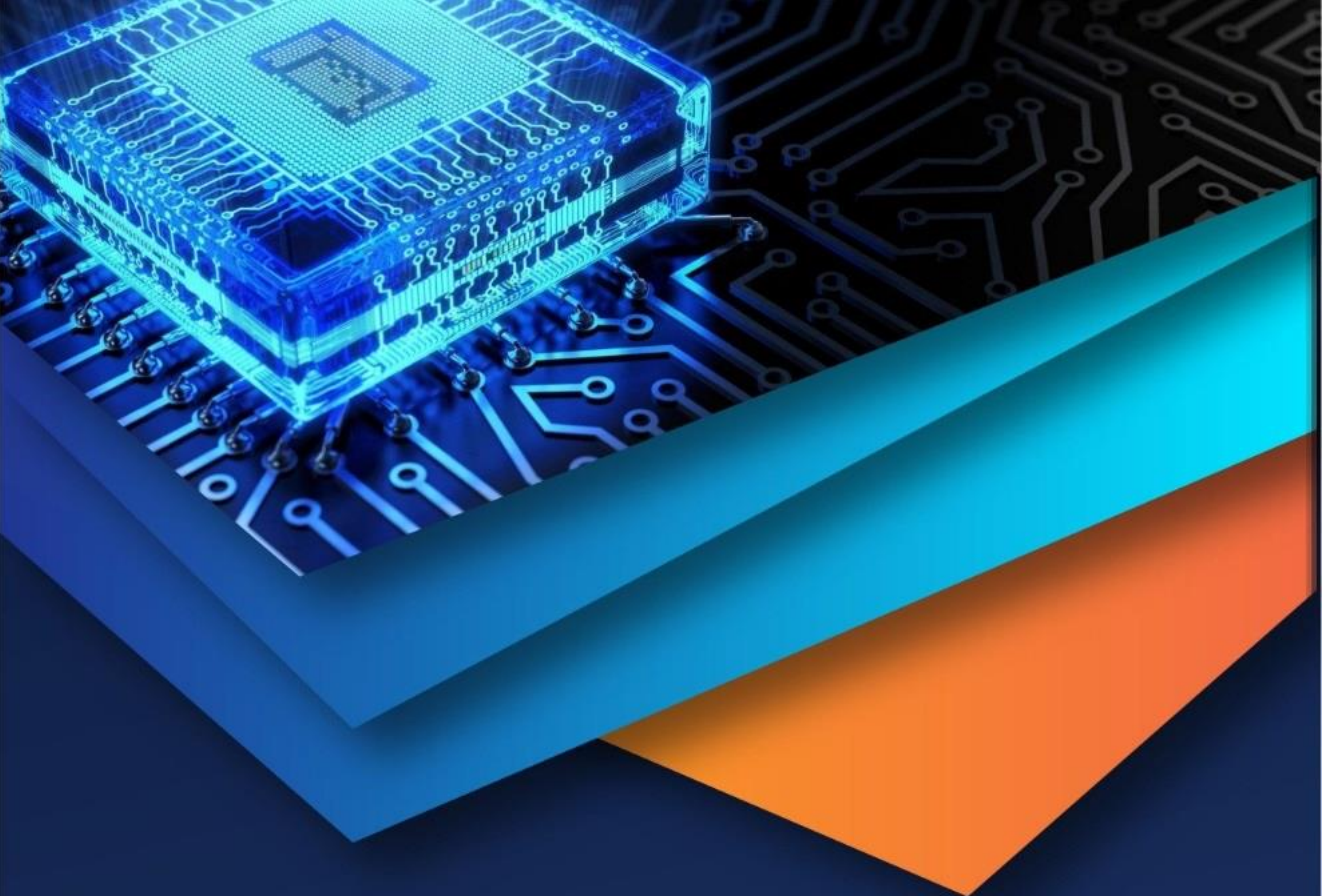

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