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A Novel Context Aware Power Management Model for Smart Grid Communication Networks

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Abstract

The advancements in the engineering trend and smart grid technologies made drastic changes in the power infrastructure rapidly. These emerging technologies enable the consumer and the power suppliers to improve the energy efficiency and reducing the greenhouse gas emissions by improving the power distribution models. This paper proposed a system architecture for power distribution called context aware power distribution model in smart grid communication networks. This model deals with domain grouping scheme which is an efficient approach for context aware services. This will monitor the user's conditions and surroundings as well as controls the home appliances. The context aware middleware architecture is introduced in the proposed model for efficient power distribution process.

Keywords: Smart grid, Context awareness, Domain matching, Pattern learning

1 Introduction

In the recent years, smart grid is the emerging technology in the power distribution with the combination of information technology. The smart grid follows the two way communication [7] from power suppliers to the consumers which lead to the grid reliability and energy efficiency [4] [5]. The smart grid contains the functionality of sensing the grid conditions, power reliability and controlling the appliances by two way communication. The communication in the smart grid provides the user privileges that dynamically respond to the changes in the grid condition and energy consumption. For instance, the user has the privileges to turn on the power consumption devices like washing machines at the time of low demand [4] [8], but at the time of high demand the user could turn off the appliances for power saving. Smart grid has the capacity to integrate with the renewable energy.

The recent studies on the distribution system have examined various aspects on smart grid and green IT which concerns to power distribution, monitoring, supply and demand. The ZigBee protocol is employed for the communication between user locations. The auto recovery distribution system is developed for improving reliability in the distribution system [2]. Smart grid employs the automated approaches for improving the computer networks. There has been a wide research is going on across the world for development of smart grids [1] [6]. Smart grid is a very efficient technology for utilization of power according to the demand. The power prices are reduced due to the smart technology by implementing the peak savings and service quality control [3].

The remainder of the paper is organized as follows. Section 2 deals with the domain grouping scheme for smart grid power distribution. Section 3 explains about the context aware middleware architecture for smart grid power distribution model. Section 4 deals with experimental evaluation of the proposed model and finally conclusion is in Section 5.

2 System Model

In this paper, we are presenting the system architecture for context aware information management in smart grid power distribution. We discuss methods and schemes for power distribution and context management in smart grids. The context aware information management is done through the intelligent control systems which are installed in the appliances in accordance with fixed and static values. The appliances with intelligent controlled system can be controlled according to the changing events and adopt to the user's situations and location characteristics. The intelligent controlled system is supported by a light weight middle ware. The small device with limited resources cannot manage complex events. The light weight middle helps in reducing the processing time and power consumption. As a first step, the model utilizes the domain grouping scheme for pattern generation.

The similarity among the domains is calculated as follows. The similarity function between domain A and domain C is represented as ϑ_{AC}, it is a comparision among persons, space and power. Where $\vartheta_{AC}^{Persons}$ the similarity between the persons, ϑ_{AC}^{Space} is the similarity between the space and ϑ_{AC}^{Power} is the similarity between the power consumption among the domain A and domain C. The similarity function of the of the $\vartheta_{AC}^{Persons}$ is calculated as

$$\vartheta_{AC}^{Persons} = \frac{1}{\{3 \times \max(\alpha,\beta)\}} \sum_{\mu=1}^{\max(\alpha,\beta)} \left| (I_{A.\mu} - I_{C.\mu}) + M(J_{A.\mu} - J_{C.\mu}) + N(K_{A.\mu} - K_{C.\mu}) \right|$$

Where $I_{A.\mu}$, $J_{A.\mu}, K_{A.\mu}$ are the Age, sex and job of person μ in domain A. α and β are the number of persons living in the domain A and in the domain C. M and N are the arbitrary constants. The similarity function of the ϑ_{AC}^{Space} is calculated as

$$\vartheta_{AC}^{Space} = \frac{1}{2}\{M(R_A - R_C) + N(S_A - S_C)$$

Where R represents the number of rooms in domain A and domain C and S represents the surface area of the domain A and domain C. M and N are the arbitrary constants.

The similarity function for the ϑ_{AC}^{Power} is calculated as

$$\vartheta_{AC}^{Power} = \frac{1}{P} \sum_{H=1}^{24} \left| Power_{A.H} - Power_{C.H} \right|$$

Where $Power_{A.H}$ is the power consumption from time (H-1) to time H at domain A, $Power_{C.H}$ is the power consumption from time (H-1) to time H at domain C. P is the arbitrary constant. We can group the domains according to the values generated by the similarity function ϑ_{AC}. The algorithm 1 explains about the domain grouping scheme for pattern generation in context aware power management. The SGPMM provides services according to the generated patterns.

Algorithm 1: Pattern Management

Begin
Step 1: Initialize all domains based on the environmental and residential situations
Step 2: Compute the similarity between the domains
Step 3: SGPMM collects the information about the domain characteristics
Step 4: Find the other domains with the equal similarity function
Step 5: Cluster the domains having the same similarity function
Step 6: SGPMM requests the other domains for the information convergence
Step 7: Generate the patterns based on the similarity function of the domains
Step 8: SGPMM provides the services according to the patterns generated
End

Domain Power Management:

Domain power management is very important factor in smart grid technologies. The smart grids are not concentrating on these issues due to their scalability. The power management is enabling by smart equipment which is fixed for every individual unit in the domain.

Domain power management scheme works as follows:

When a person in the domain starts the home appliance, the appliance establishes communication with the power manager and sends the START-REQ packet to the power manager. The REQ packet contains the format like sequence number, Time of request raised and the duration. The power manager made an analysis on the START-REQ and chooses the appropriate time for the staring of appliance. This analysis is based on the peak demand of the power consumption and pricing details at the time of request raised. Algorithm 2 shows the power management process with the waiting time function.

Algorithm 2: Power management with the waiting time function

```
Begin
Initialize the Threshold value τ
Initialize the appliance delay δ
Initialize the START_REQ
if START_REQ = peak then
        Introduce the delay δ up to off-peak ( )
        If δ> τ then
            Start the appliance immediately ()
        Else
            Start delay ( )
        End if
    Else
        If START_REQ = mid-peak then
        Introduce the delay δ up to off-peak ( )
        If δ> τ then
            Start the appliance immediately ( )
        Else
            Start delay ( )
        End if
    Else
        Start appliance immediately ( )
        End if
    End if
   End if
End
```

3 Middleware Architecture for Context Processing

The smart grid power distribution plays an important role in providing services and power distribution. The SGPMM is connected with the power grid and performs various functions like dynamic demand management, service provisioning, context aware services, power distribution and management, information convergence and pattern generation. The SGPMM is composed of three layers: A Context service layer, context management layer and context interface layer.

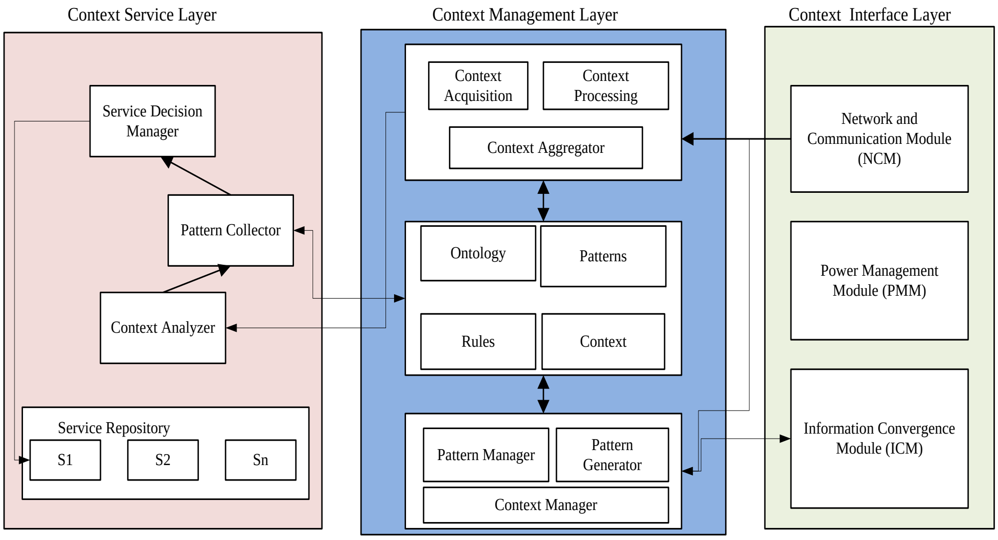

Fig. 1: Middleware Architecture for Context Processing

Context management Layer: The context management layer is responsible for managing the information regarding the user's activities and surroundings. This layer is subdivided in to three modules such as context management module, knowledge repository module and pattern generation module.
Context Management Module: The context management module consists of context acquisition which is responsible selecting the service based on the user condition. The context processing calculates the relation between the contexts and manages the correlation between the components. The context aggregator collects all the contexts after context processing.
Knowledge Repository: The knowledge repository module consists of ontology service patterns, association rules and context policies. The ontology updates the services automatically whenever the new situation arises. The association rules and context policies is managed by the ontology service which independently managed for the service maintenance and pattern generation.
Pattern Generation Module: The functionality of the pattern generation module is to generate the patterns by utilizing the information from the knowledge repository. The ontology service in the knowledge repository modifies the patterns according to the association rules and policies.

4 Experiment Analysis

The proposed architecture is tested with five different domains. Each domain contains the different home appliances, different age group people and different electric devices. The service requests and response time is taken as the parameter for measuring the efficiency of middleware architecture

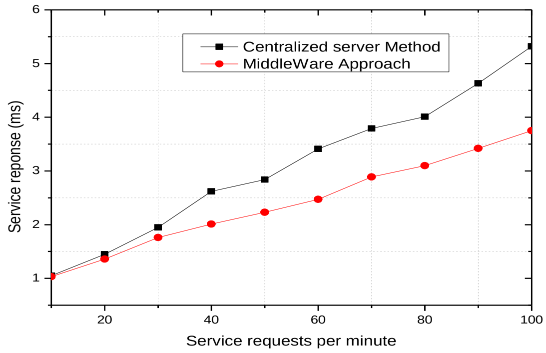

Fig. 2 Efficiency in terms of service request and response time

Figure 2 explains about the service response time of the context aware middle ware by handling the number of requests per minute. The proposed middleware architecture performs steadily at the time of increasing information requests by maintaining balance in between request and response time. Figure 3 shows the power consumption of the proposed middleware architecture for week days. The proposed model is compared with the centralized server model with different scenarios.

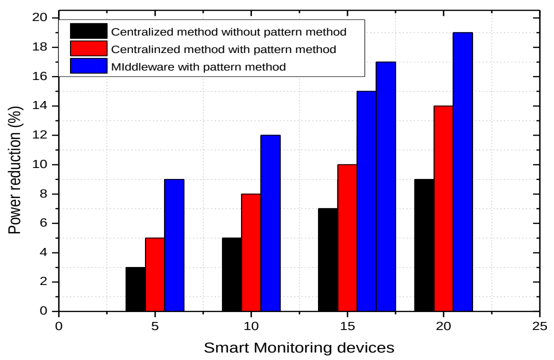

Fig. 3 Power Reduction with the pattern learning approach

The efficiency of the proposed middleware architecture model is nine to nineteen percentiles depending on the number of smart monitoring devices used for the smart grid. For achieving the context aware routing in smart grids, we are using the shortest path routing algorithm by considering the knowledge given below

$$Q = \{d_1, d_2, ..., d_n\}$$

Where Q is the domain and d is a device and n is number of devices presented in the group. The delay minimization problem is formulated as follows.

$$\min_{x} L \quad such\,that\;\; x = \{d_{i(0)}, d_{i(1)}, ..., d_{i(l)}\} \subseteq N$$
$$Z_{i(k)i(k+1)} \geq S,\; K = 1,...,L-1$$
$$P_{i(k)} \leq P_{\max}$$

The devices d_i and d_j are connected if the quality metric Z of the link is exceeds a minimum required value S. the maximum powered delivered by the communication devices is given as P_{max}. The device $d_{i(0)}$ is the source device and the $d_{i(L)}$ is the destination device and L is the delay, P_i is the power delivered by the device. The solution for the above stated problem is formulated using well known Dijkstra algorithm. Figure 4 shows the delay performance of the shortest path routing algorithm. The average delay of SPR algorithm is less when compared to the Beacon less routing and implicit geographical forwarding.

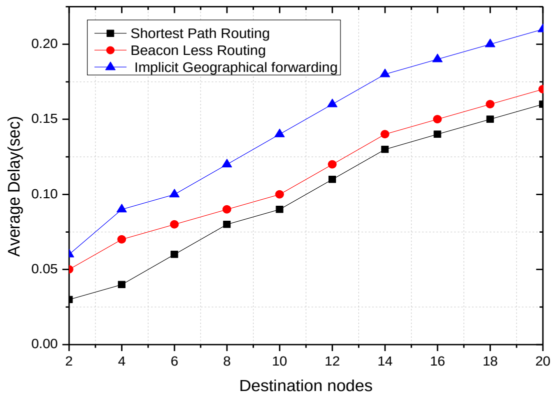

Fig. 4 Delay Performance in dynamic situations

5 Conclusion

The advancements in the field of smart grid made the changes in the distribution process of power to the world. Many studies and researchers are concentrating on the automation process for smart grids. This paper made a contribution for designing the smart grid power distribution model. It considers the domain grouping and pattern learning approach for the power distribution process. The context aware middleware was introduced for the intelligent management of power distribution over the residential areas. In order to evaluate our model, we carry out some experiments. The results show the efficiency of the proposed model.

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