CHAPTER 4

AN APPROACH FOR POWER MANAGEMENT IN SMART GRIDS

4.1 INTRODUCTION

Smart grid is an emerging technology that helps in providing efficient power management for existing power systems. It is mainly used to control the power load via price signaling. The communication between the power supplier and power customers is a key issue in smart grid. Present power systems expect to provide quality of service for various demands of consumers. In this paper, an efficient power management scheme is prescribed and it implements an effective communication method for smart grid environments.

The proposed method is evaluated through simulations and proved that it provides better performance when compared to other existing methods. In recent years, power grids are experiencing revolutionary changes through technological transformation. One important development of smart grid is that electric appliances can receive real-time power price via communication networks and optimize their power consumption level according to the current power price. Then, the power utilization efficiency (it is the ratio between the output power utilized by the system to the input power applied to the system)
is significantly improved and the global energy consumption is reduced to meet the demands of global challenges.

In smart grid, a key challenge is how to adapt the communication network to the context of power price transmission. Obviously, the data flow of power price cannot be elastic since it should be real-time; otherwise, it may incur a significant loss if the expired power price is used. Therefore, the data transmission of power price must be equipped with QoS guarantee.

The basic power control protocol uses maximum power level for various data communications over smart grid environments. In this paper, a power management protocol called as SPAM is put forth it allows smart meters dynamically to power level for transmitting DATA/ACK according to the distance between the transmitter and its neighbor nodes.

In addition, the power level for transmitting RTS/CTS is also adjustable according to the power level for DATA/ACK Packets. The approach is based on an RTS–CTS handshake in the context of IEEE 802.11. Different power levels among different nodes introduce asymmetric links. Therefore, RTS and CTS are transmitted using the highest power level and DATA and ACK are transmitted using the minimum power level necessary for the nodes to communicate. IEEE 802.11 standard defines two mechanisms to access a channel: DCF and PCF.

The DCF is contention-based scheme, which uses CSMA/CA as the access mechanism and is a fully distributed protocol. The PCF is a contention-free scheme, which uses an Access Point (AP) as the coordinator and is a centralized protocol. In this paper the power saving mechanism of the DCF method is considered.
A power control mechanism that can be incorporated into the IEEE 802.11 RTS–CTS handshake is proposed in Jung et al. 2002 on A Power Control MAC Protocol for Ad-hoc Networks. The scheme allows a node A, to specify its current transmit power level in the transmitted RTS, and allows receiver node B to include a desired transmit power level in the CTS sent back to A. On receiving the CTS, node A then transmits DATA using the power level specified in the CTS. This scheme allows B to help A choose the appropriate power level, so as to maintain a desired signal-to-noise ratio.

A similar protocol is utilized in the work of P. Venkata Krishna et al. 2008. An Efficient 802.11 medium access control method and its simulation analysis, where in the RTS and CTS packets are sent at the highest power level. The DATA and ACK may be sent at a lower power level. This scheme is referred the BASIC power control MAC protocol. It is found that the BASIC scheme has a shortcoming that can degrade the throughput. Furthermore, the BASIC scheme may potentially increase the energy consumption, instead of decreasing it.

The power control protocol presented is also similar to the BASIC scheme. It maintains a table for the minimum transmitted power necessary to communicate with neighbor nodes. This scheme allows each node to increase or decrease its power level dynamically. However, different power levels among nodes result in asymmetric links, causing collisions. A power control protocol proposed in Gomez et al. 2006 conserving transmission power in wireless ad hoc networks uses one control channel and multiple data channels. A control channel is used to assign data channels to nodes. An RTS, CTS, RES and broadcast packets are transmitted through the control channel using the highest transmit power.
By an RTS–CTS handshake, the source and destination nodes decide which channel and what power level to use for data transmissions. On the reception of CTS, the source sends an RES to the destination to reserve a data channel. Then, DATA and ACK transmissions occur on the reserved data channel using the negotiated power level from the RTS–CTS handshake. Transmit power is controlled according to packet size in P.Venkata Krishna et al 2008. Design of sequencing medium access control is used to improve the performance of wireless networks.

The proposed scheme is based on the observation that reducing transmission power can result in energy savings, but it can also result in more errors. A higher bit error rate can lead to increased retransmissions, consuming more energy. Thus, all the referenced protocols choose an appropriate transmission power level based on the packet size. An adaptive scheme is also presented by some authors to choose MAC frame size based on the channel conditions.

4.2 BACKGROUND

In smart grids, many business cases of fair electricity transaction have been created. However, the existing methods of agent-based control and event-based control cannot always guarantee an optimized power flow in the electric power distribution networks, if there are renewable energy resources and fluctuated loads. Smart power management system modeling is based on a variety of factors according to regulation policies, grid management requirements and operation rules.

A network is a self-configuring network of wireless links connecting mobile nodes. These nodes may be routers and/or hosts. The mobile nodes communicate directly with each other and without the aid of
access points, and therefore have no fixed infrastructure. They form an arbitrary topology, where the routers are free to move randomly and arrange themselves as required.

Each node or mobile device is equipped with a transmitter and receiver. They are said to be purpose-specific, autonomous and dynamic. This compares greatly with fixed wireless networks, as there is no master slave relationship that exists in a mobile network. Nodes rely on each other to establish communication and each node acts as a router. Therefore, in a mobile network, a packet can travel from a source to a destination either directly or through some set of intermediate packet forwarding nodes.

Mobile networks became a popular subject for research as laptops and 802.11/WiFi wireless networking became widespread in the middle to late 1990s. Many of the academic papers evaluate protocols and abilities assuming varying degrees of mobility within a bounded space, usually with all nodes within a few hops of each other, and usually with nodes sending data at a constant rate. Different protocols are then evaluated based on the packet drop rate and the overhead introduced by the routing protocol.

IEEE 802.11 specifies two medium access control protocols, PCF and DCF. PCF is a centralized scheme, whereas DCF is a fully distributed scheme. In this paper, DCF is considered and the terms transmission range, carrier sensing range and carrier sensing zone which are used in the rest of the paper need to be defined.

**Transmission range:** When a node is within transmission range of a sender node, it can receive and correctly decode packets from the sender node. The simulations, the transmission range is 250 m when using the highest transmits power level.
**Carrier sensing range:** Nodes in the carrier sensing range can sense the sender’s transmission. Carrier sensing range is typically larger than the transmission range, for instance, two times larger than the transmission range. The simulation, the carrier sensing range is 550 m when using the highest power level.

Note that the carrier sensing range and transmission range depend on the transmit power level. Since carrier sensing range includes the transmission range, carrier sensing zone which excludes the transmission range from the carrier sensing range is defined.

**Carrier sensing zone:** When a node is within the carrier sensing zone, it can sense the signal but cannot decode it correctly. Note that, as per the definition here, the carrier sensing zone does not include transmission range. Nodes in the transmission range can indeed sense the transmission, but they can also decode it correctly.

Therefore, these nodes will not be in the carrier sensing zone as per the definition. The carrier sensing zone is between 250 m and 550 m with the highest power level in the simulation.

Figure 4.1 shows the transmission range, carrier sensing range, and carrier sensing zone for node C.1 when node C transmits a packet. B and D can receive and decode it correctly since they are in transmission range. However, A and E only sense the signal and cannot decode it correctly because they are in the carrier sensing zone.
The DCF in IEEE 802.11 is based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). Carrier sensing is performed using physical carrier sensing (by air interface) as well as virtual carrier sensing. Virtual carrier sensing uses the duration of the packet transmission, which is included in the header of RTS, CTS, and DATA frames.

The duration included in each of these frames can be used to infer the time when the source node would receive an ACK frame from the destination node. For example, the duration field in RTS includes time for CTS, DATA, and ACK transmissions. Similarly, the duration field for CTS includes time for DATA and ACK transmissions, and the duration field for DATA only includes time for the ACK transmission.

Each node in IEEE 802.11 maintains a NAV (Network Allocation Vector) which indicates the remaining time of the ongoing transmission.
sessions. Using the duration information in RTS, CTS, and DATA packets, nodes update their NAVs whenever they receive a packet. The channel is considered to be busy if either physical or virtual carrier sensing indicates that the channel is busy. Figure 4.2 depicts how nodes in transmission range and the carrier sensing zone adjust their NAVs during RTS–CTS–DATA–ACK transmission. SIFS, DIFS, and EIFS are Inter Frame Spaces (IFSs) specified in IEEE 802.11.

Note that in Figure 4.2 the lengths of RTS, CTS, DATA, and ACK do not exactly represent the actual sizes. IFS is the time interval between frames. IEEE 802.11 defines the IFSs – SIFS (Short Inter Frame Space), PIFS (PCF inter frame space), DIFS (DCF inter frame space), and EIFS (extended inter frame space). The IFSs provide priority levels for accessing the channel. The SIFS is the shortest of the inter frame spaces and is used after RTS, CTS, and DATA frames to give the highest priority to CTS, DATA and ACK, respectively. In Distributed Coordinated Function DCF, when the channel is idle, a node waits for the DIFS duration before transmitting any packet.

In Figure 4.2, nodes in transmission range correctly set their NAVs when receiving RTS or CTS. However, since nodes in the carrier sensing zone cannot decode the packet, they do not know the duration of the packet transmission. To prevent a collision with the ACK reception at the source node, when nodes detect a transmission and cannot decode it, they set their NAVs for the EIFS duration. The main purpose of the EIFS is to provide enough time for a source node to receive the ACK frame, so the duration of EIFS is longer than that of an ACK transmission.
As per IEEE 802.11, the EIFS is obtained using the SIFS, the DIFS, and the length of time to transmit an ACK frame at the physical layer’s lowest mandatory rate, as the following equation.

$$\text{EIFS} = \text{SIFS} + \text{DIFS} + (8 \times \text{ACKsize}) + \text{Preamble Length} + \text{LCP Header Length} / \text{BitRate},$$

where ACKsize is the length (in bytes) of an ACK frame, and Bit Rate is the physical layer’s lowest mandatory rate. Preamble length is 144 bits and PLCP header length is 48 bits. Using a 1 Mbps channel bit rate, EIFS is equal to 364 µs.

![Timing Diagram](image.png)

**Figure 4.2 Timing Diagram for Transmitter and Receiver Node in IEEE 802.11 MAC Protocol**

Recently, some power control MAC protocols that can be incorporated with the IEEE 802.11 protocol have been proposed. A typical scheme uses the lowest possible power level for transmitting data packets
where as to use the maximum possible power level for control message packets. Those protocols are referred as Basic Power Control Medium Access Control MAC Protocol (BPCMP). Next, BPCMP needs to be focused and their limitations have to be discussed.

The power control for the MAC protocols chooses the right transmit power levels for different packets in MANET. The transmit power levels affect the radio range, battery life time, and capacity of the network. Some power controlled MAC protocols that can be incorporated into the IEEE 802.11 protocol have been suggested. The basic scheme allows a node to specify its current transmit power level according to different packet types.

Such protocols are called the BPCMP. Unlike IEEE 802.11 which sends all packets at the same power level, BPCMP sends RTS/CTS packets using the maximum possible power level but sends DATA/ACK packets to the lowest acceptable power level.

Figure 4.3 illustrates the timing of sending RTS/CTS using the maximum power level, $p_{\text{max}}$, and DATA and ACK packets using the lowest possible power level, desired. Figure 4.4 shows an example of radio range, where the transmit power level for RTS/CTS is 30mW and the lowest acceptable transmit power level for DATA/ACK is 1mW.

In BPCMP (see Figure. 4.4), the desired power level for transmitting DATA/ACK is determined after RTS/CTS handshake. The procedures for a complete transmission cycle are described as follows.

1. The transmitter sends RTS packets using the maximum possible power level $p_{\text{max}}$. 
2. The receiver receives the RTS at signal power $p_{\text{rec}}$, and calculates the minimum desired transmit power level $p_{\text{data}}$ for transmitting data packets as follows:

$$P_{\text{data}} = \frac{P_{\text{max}}}{P_{\text{rec}}} \times R_{\text{thresh}}$$

(4.1)

Where, $R_{\text{thresh}}$ is the lowest acceptable received signal strength. Then, the receiver marks the minimum desired transmit power level in the control message field of CTS and sends CTS back to the transmitter.

3. Once CTS is received, the transmitter begins to transmit data packet using the power level $p_{\text{data}}$.

4. The receiver sends back an ACK as soon as it receives DATA. The transmitting power level for sending ACK is determined in a similar way as done for DATA.

There are several problems with BPCMP. (1) Using the fixed transmitting power level, $P_{\text{max}}$, for RTS/CTS is not energy efficient since the distance between the transmitter and the receiver may change. (2) The transmission at maximum possible power level causes interference with other existing radio applications. (3) Different transmitting power levels result in asymmetric topologies, and thus may consume more energy.

Furthermore, the BPCMP was put forth under the assumption that signal attenuation between transmitters and receivers is kept the same in both transmission directions.
Finally, the BPCMP adopts the maximum possible transmitting power level for sending RTS/CTS packets and the minimum desired transmitting power level for sending DATA/ACK packets for implementing power control. As indicated by the simulation results, it does not work so well in terms of energy efficiency.

In addition, it degrades the overall network capacity. Hence, in this paper an efficient power management protocol is offered and it is developed on the concept of BPCMP for smart grids.
Figure 4.4 BPCMP’s Different Power Level

4.3 SYSTEM MODEL

The smart power adjustment method is developed based on the information and its corresponding communication in smart grids as shown in Figure 4.5. It is very important for smart grids to achieve efficient data communications between various components of smart grids such as energy providers, power distributors, smart meters and consumer devices.

With the deployment of SPAM in smart grid, it is possible not only to achieve power saving data transfer mechanism but also develop an efficient power management system due to the fact that SPAM ensures timely communication amongst various components of smart grids.
The system design is specifically defined in six interrelated elements or domains, and all the domains are connected using two way communication system. It is more crucial for the smart grid power system. The domains of the system model can be defined as power management, demand response analysis, energy providers, power distribution, smart meters and consumer devices and the model design is profiled in figure 4.5.

4.3.1 Power Distribution

The power distribution domain plays a crucial role and it distributes the electricity to and from the end customers in the smart grid. The distribution network connects the specifically designed smart meters and all intelligent field devices by managing and controlling them through a two-way wireless communications network. It may also connect to energy storage facilities and alternative distributed energy resources at the distribution level.
4.3.2 Smart Meter

Smart metering systems allow interval metering for both active and reactive components of electricity consumed and injected into the network, so contributing to more accurate balancing, losses and power factor calculation, to promoting peak and off-peak prices and to discouraging bad practices in the use of the network.

Smart metering technologies may further provide information on quality of electricity supply at each connection point, thus contributing to more effective investments and renovation plans of the grids, thereby increasing security of supply. The most important benefit is that, due to the accurate information and two-way communication that smart meters can provide on actual time of use, customers could be encouraged to modify their load profile.

Figure 4.5 shows the simple outer look of smart grid management in which the smart meter is connected with the gateway, using two way communications used to exchange price, energy, time, support and various types of messages. Smart meters measure and record at 30 minute intervals how much electricity a household or business is using. There are different smart meter models, but the basic functions are the same.

Smart meters communicate meter readings directly to electricity distributors, eliminating the need for someone to come out and read the meter – whether that is for each quarterly bill, to change one’s electricity retailer or to reconnect power when one moves house. Not only does this reduce fees, but electricity bills will also be more accurate – virtually eliminating estimated bills. Smart meters will also provide consumers with more accurate information and bring an end to estimated billing.
4.3.3 Demand Response Analysis

Demand Response Analysis (DRA) entails the control of energy demands and loads during the peak level to achieve the balance between energy supply and the demand. So the effective utilization of the available energy in peak time enables the good quality of experience. Customers can participate in the energy market competition by changing their energy consumption approach instead of being passively exposed to fixed prices; these steps are quit likely to get profits for both end users and company.

Demand response provides an opportunity for consumers to play a significant role in the operation of the electric grid. They may reduce or shift their electricity usage during peak periods in response to time-based rates or other forms of financial incentives. Demand response programs are being used by electric system planners and operators as resource options for balancing supply and demand. Such programs can lower the cost of electricity in wholesale markets, and in turn, lead to lower retail rates.

The methods of engaging customers in demand response efforts include offering time-based rates such as time-of-use pricing, critical peak pricing, variable peak pricing, real time pricing, and critical peak rebates. It also includes direct load control programs which provide the ability for power companies to cycle air conditioners and water heaters on and off during periods of peak demand in exchange for a financial incentive and lower electricity bills.

The electric power industry considers demand response programs as increasingly valuable resource option whose capabilities and potential impacts are expanded by grid modernization efforts. For example, sensors can
perceive peak load problems and utilize automatic switching to divert or reduce power in strategic places, removing the chance of overload and the resulting power failure. Advanced metering infrastructure expands the range of time-based rate programs that can be offered to consumers and smart customer systems such as in-home displays or home-area-networks can make it easier for consumers to change their behavior and reduce peak period consumption from information on their power consumption and costs.

These programs also have the potential to help electricity providers save money through reductions in peak demand and the ability to defer construction of new power plants and power delivery systems -- specifically, those reserved for use during peak times.

One of the goals of the Smart Grid R & D Program is to develop grid modernization technologies, tools, and techniques for demand response and help the power industry design, test, and demonstrate integrated, national electric/communication/information infrastructures with the ability to dynamically optimize grid operations and resources and incorporate demand response and consumer participation.

To attain this goal, OE is supporting research, development and deployment of smart grid technologies, distribution system modeling and analysis, consumer behavior modeling, and analysis and high speed computational analysis capabilities for decision support tools.

4.3.4 Energy Providers

Energy providers are the organizations which provide energy services to the consumers or electrical users and utilities. This is the main domain to concentrate more on QoE. The energy providers should maintain a good quality of service as well.
One of the distinctive characteristics of the electric power sector is that the amount of electricity that can be generated is relatively fixed over short periods of time, although the demand for electricity fluctuates throughout the day.

Helping to try and meet this goal, electricity storage devices can manage the amount of power required to supply customers at times when the need is the greatest, which is during peak load. These devices can also help to make renewable energy, whose power output cannot be controlled by grid operators.

The domain of bulk generation is categorized into: 1) non-renewable, non-variable, 2) renewable, non-variable and 3) renewable, variable generation. The first two categories represent traditional generation that can be dispatched when needed. The third category represents a new challenge for the grid.

Within the bulk generation domain, large quantities of renewable generation need to be integrated into the grid. The ideal generation would be in the form of renewable, non-variable. This would permit the generation source to be dispatched by the regional balancing authority. Renewable, variable generation such as wind and solar require fast-responding reserve generation such as spinning reserves or natural gas turbines to take over when the wind stops blowing or the sun becomes blocked by clouds.

This requirement adds significant costs and impedes the growth of variable renewables, even if the occurrences are rare. Renewable generation on the grid currently amounts to 4% of the overall generation. The goal of
increasing this to 30% will result in a grid that has significantly more variability than the current grid.

4.3.5 Consumer Devices

Consumer devices can effectively utilize the power in the sense of consumption and saving. These devices contained by the customers or consumers of electricity may also store, generate and manage the use of electricity. Traditionally, three types of customers are discussed, each own domain: residential, commercial, and industrial. The consumer devices may be varied based on the specified customer type and the usage strategy.

4.3.6 Power Management

Power management has the central control of all the other domains. This is very crucial for the smart grid to communicate effectively in both the directions. The transmission of electricity over long distances in bulk quantity is also required to manage the storing and generation of electricity. The SPAM can adjust the transmitting power for DATA/ACK packets as well as signal RTS/CTS packets according to the current network condition in order to reduce the energy consumption whereas the performance of the whole network should not be sacrificed. Hence quality of service needs to be increased.

4.4 SMART POWER ADJUSTMENT METHOD

The proposed Smart Power Adjustment Method (SPAM) can adjust the transmitting power for DATA/ACK packets as well as RTS/CTS packets according to the current network condition in order to reduce the energy consumption. But the performance of the whole network should not be much
sacrificed. The main idea for the protocol is to use appropriate power levels for transmitting DATA/ACK packets and the RTS/CTS packets.

Through simulation it is easy to show that the new protocol is more energy efficient than BPCMP and at the same time it is simple to be implemented. The transmitting power level should be adjustable depending on the distance. Existing BPCMP adjusts the transmitting power for sending DATA and ACK packets to a minimum required level. However, it still needs a fixed maximum possible power level to transmit RTS and CTS packets. Since the network topology changes dynamically, the power level for sending RTS and CTS also needs to be adjusted according to the current node density.

![Diagram](image)

**Figure 4.6 System Overview**

The appropriate power level brings in several advantages, such as energy saving and collisions reduction. Here there is an attempt to adjust the transmitting power level locally within a local neighboring smart meter group and to have an approximately similar power level for all the neighboring nodes. In the designed protocol, transmitting power level for a smart meter
group is adjusted to an approximately similar value in two ways one is to adopt an appropriate power level for transmitting DATA/ACK, depending on the average distance from the transmitter to all the current neighbors. The other one is to adjust the power level for transmitting next RTS/CTS to a value proportional to the DATA/ACK power level.

![Diagram](image)

**Figure 4.7 Next Transmission to Same Node**

The main design methodology and basic concepts about the designed method are that the transmitting power for sending RTS/CTS packets should be adjusted to a level just slightly higher than that required for transmitting DATA/ACK packets. On the other hand, to guarantee connectivity of the network, the transmitting power level has to be increased gradually if it is too low to reach any other node.

While in the first time the node wants to transmit data to the neighbor node it sets the power level and sends the RTS. If the receiver is in that range, it sets the exact power level for data in CTS. So during the DATA transmission, the transmitter adjusts to receiver level and sends the data. If it
is not in the range transmitter increases the power level and continues the same and maintains the table for that node based on that power level.

4.5 CONCLUSION

The focus of this paper is on the design of power control MAC protocol for smart grids. A system model for smart grid is presented and the same is evaluated for power management. The efficient use of dynamic MAC helps the smart grids in conserving energy and for better management of power resources.