On the Self-Healing Smart Grid Networks for Enhancing Transmission Reliability

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Abstract. This paper proposes a self-healing wireless network mechanism to provide efficient servicing in Smart Grid networks. Our proposed mechanism utilizes various wireless environment parameters to adapt to different conditions of the network, providing higher transmission delivery and real time service for the smart grid. We evaluate the performance of our mechanism via NS-3 simulator to verify the performance of the proposed scheme.

Keywords: Self-Healing Networks; Smart Grid Networks; Reliability

1 Introduction

The Smart Grid is a new paradigm of electrical infrastructure that is integrated with IT communication technologies to support various future electrical services. The integrated wireless networking technologies that support the smart grid are required to guarantee high reliability to provide high level of service to users [1]. However, due to the dynamicity of its nature, wireless networking systems have problems that prevent them from meeting the requirements of the smart grid systems.

One highly efficient method of alleviating these problems is utilizing the concept of Self-healing networks. Although active research has been made on self-healing network systems, only a few of them have their focus on Smart Grid. For example, [2] emphasizes on the requirement of self-healing in AMI based Smart Grid architecture, and surveys two methods by using C12.22 and SIP standards. However, these schemes are restricted on the specific protocols and cannot be adoptable for lower-layer protocol problems. Works on self-healing in sensor networks such as [3] may be of interest, but they cannot ultimately be the ideal case in Smart Grid environments because whereas sensor networks consider energy efficiency as the utmost importance, Smart grid environments must also consider reliability as another critical factor. To solve these problems, this paper proposes a mechanism utilizing various physical-level network parameters to detect and automatically heal the network to cope with the dynamicity and increase reliability of the smart grid network.

2 Proposed Scheme

For our network architecture, Neighborhood Area Nodes (NAN) inside the network form a multi-hop architecture and are controlled by multiple gateway nodes. The self-healing module is locally maintained by each NAN. **E**ach NAN must recognize the ID and hop count of all the gateways in the network. Also, each NAN retrieves the current channel information such as the MAC retransmission count, bit error ratio (BER), and the received signal strength (RSS). The MAC retransmission count can be utilized to decide that a certain problem is deteriorating the network. We have made a simple empirical experiment via NS-3 simulation to justify this statement, and found that when there are fading signals or interference from other nodes, MAC retransmission frequently occurs. Using this, we will define a new indicator, named as smart grid problem indicator sg_{pi}:

$$sg_{pi} = \sum_{i=low\_category}^{high\_category} (N_r(i) \times \omega_i) / (N_s + N_f) \quad \text{(1)}$$

,

where i = the category of the smart grid application, $N_r(i)$ = retransmission count of packet with category I, and ω_i = the weight of the category depending on its priority and importance. The N_s and N_f values will respectively represent the successful and failed delivery of the packets. Therefore, (1) will average the total amount of MAC retransmissions that has been attempted per every transmitted packet, with more penalties on the retransmission of more important smart grid data. Also, the moving average of RSS and BER values are calculated to sense the current status of the network. The moving average, $fade_{ci}$, is calculated as shown below,

$$fade_{ci} = \sum_{i=1}^{n} (RSS_j \times \omega_i) / n \quad \text{(2)}$$

.

j = 1 is the most recent RSS information that is acquired from the most recently received frame, and n = number of RSS considered in the moving average. The $intf_{ci}$ value that calculates the BER value is also calculated similarly to (2).

The indicator sg_{pi} of (1) will trigger a problem if sg_{pi} is larger than pre-configured threshold value N. If the problem is triggered, RSS and BER values are calculated at the time of trigger and are compared to $fade_{ci}$ and $intf_{ci}$ to pinpoint the exact problem. If the RSS value received while there is a problem trigger is lower than the moving average $fade_{ci}$ by more than the *trigger_threshold_value*, it is confirmed that the network is suffering from signal fading. The interference trigger is turned on instead when the BER values are higher than the $intf_{ci}$. Upon confirmation of fading problem, the self-healing module will attempt to increase the rate of successful data delivery. The module will process the data packet transmitted from the application layer, create multiple copies of it, and then apply different destination gateways to each copy of the data. Upon confirmation of interference, the module controls the back-off timers of the MAC layer. To control the back-off timer, formula (3) is used,

$$CW_{MAX\_adj} = CW_{MAX} \times \left(1 + \frac{N_f}{N_s + N_f}\right) \quad \text{(3)}$$

,

where CW_{MAX} = the default maximum setting of the contention window. The back-off timer and data redundancy will last until the calculation of the MAC level retransmission in (1) reports that the condition of the network is stable again.

3 Performance Evaluation

The performance of our proposed self-healing mechanism is evaluated using the NS-3 simulator. 34 general NAN nodes are placed randomly in a 400 * 400 network with 2 gateways placed on opposite corners of the network. Each node is equipped with two 54Mbps 802.11a radios, periodically sensing MAC retransmission count, BER, and RSS values [4]. Each node will transmit smart grid application data, which are Power quality data (ω_1), AMI(ω_2), and video surveillance(ω_3). The weight values are configured as $\omega_1 = 2$, $\omega_2 = 1.5$, $\omega_3 = 1$. In the future, we will consider various studies to optimize these weight values. In a simulation time of 500 seconds, each application is initiated at 10 seconds and continued until the end of simulation.

Fig. 1 shows the reliability of all applications. The acceptable delivery index is the threshold for deciding if a certain application was transmitted reliably. The reliable application ratio represents the percentage of the applications with delivery ratio over the index. With self-healing and acceptable reliability threshold configured as 90%, more than 90 percent of the applications have managed to be reliably transmitted. Even when the threshold is 96%, more than 70% of the applications exceed it. Without our self-healing mechanism, the reliability degrades more than 25% in the worst case.

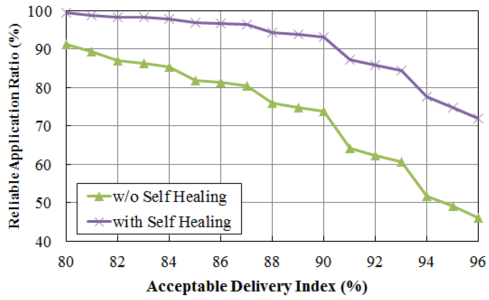

Fig. 1. Evaluation of Reliability

4 Conclusion

We have proposed a self-healing module for smart grid networking that can adaptively adjust to the current status of the wireless network. Via simulation, we have shown that our scheme can provide higher reliability to the smart grid. For our future work, we will attempt to organize our work into a complete self-organizing framework, accompanying it with more complex simulation studies.

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