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Comparison of Delay Distributions of Responses in a Home Area Network using Wi-Fi with and without in-network Data Aggregation

N. S. Weerakoon *, M. A. M. Manaz, and K. M. Liyanage

Department of Electrical and Electronics Engineering, Faculty of Engineering, University of Peradeniya , Sri Lanka

E-Mails: n.s.weerakoon@gmail.com; mohdmanaz@gmail.com; kmliya@gmail.com

* Tel.: +94-71-682-8030

Abstract: Smart Grid is divided into seven sub domains by NIST. The customer domain refers to the end users of electricity. In addition to the traditional role of consumer, they will also participate in generation as well as storage of energy. They would respond to signals coming from the grid and reduce or increase consumption and/or generation accordingly. For this purpose the customer premise should be equipped with an information network, which is called a Home Area Network. Architecture of a Home Area Network needs to be optimised in terms of time and energy. In this research the behaviour of a HAN in terms of time is studied. Delays of responses from the devices for the requests made by the central controller were measured for two most popular architectures, with and without in-network data aggregation. When the probability mass functions were plotted, it was evident that the delays in the two cases do not differ by much.

Keywords: Smart Grids; Home Area Networks; Delay; Wi-Fi.

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1. Introduction

Smart Grid (SG) is an automated, widely distributed energy delivery network that is reliable, affordable, globally competitive, accommodates renewable energy sources along with the traditional energy sources, reduces carbon footprint, and very efficient [1]. SG will be characterised by two-way flow of electricity and information. For this it is necessary to bring the philosophies, concepts and technologies that enabled the Internet to the electric grid [2]. In brief the idea is to bring Internet to the electric system.

Designing the massive information system for Smart Grid requires a piecemeal approach. For this purpose, National Institute of Standards and Technology (NIST) provided a conceptual reference model, in which SG is divided into seven sub-domains as Customer, Markets, Service Provider, Operations, Bulk Generation, Transmission, and Distribution

Out of these seven sub-domains, the customer domain is defined as, "*The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial*" [3]. In situations of emergency, rather than being a passive consumer, a customer can actively participate in supplying energy to the grid in case of an emergency. For this, a special programme called Demand-Response (DR) is introduced. In a DR programme, the grid communicates its status to the customer so that the customer can actively respond to them [4]. A HAN is required for the customer to control all his devices. When a DR signal arrives at the customer premises, the HAN controller needs to be aware of the status of each device in the premise so that it can decide how it is going to respond to the request from the grid. It can then dispatch its decision to each device so that the devices can respond. For better controllability the HAN controller needs to decompose a complex DR signal into a simple request of load, storage, or generation.

Usually, a DR signal has a ramp period allocated for the devices to respond and to accommodate any delays. This delay depends on the actual arrangement of nodes in the HAN. The other contradictory factor that needs to be considered is the energy consumption of the communication devices, which has a significant footprint in energy usage. In-network data aggregation is proposed to reduce the energy consumption by reducing the communication distance [5]. Therefore, in this research the two delay distributions are compared with a view to arriving in the optimal architecture.

2. Method

Matlab® Simulink® models were built for simulating the two scenarios. In each model, a central controller analogous to HAN controller is designed. This controller broadcasts requests and in the model without in-network data aggregation (model 01), each device can hear it and then respond. In the model with aggregation (model 02) only the cluster heads can hear it. Any device receiving this broadcast signal retransmits it so that any hidden node (a node that cannot hear from the central controller) would also hear it.

The central controller will send three types of requests. The type of the request is randomly selected from the set {1, 2, 3}, which represents load, storage, and generation respectively. When a node receives a request it send an acknowledgement.

After sending the acknowledgement, the node rebroadcasts the request once without modifying the source address. Then the node processes the request and checks whether the request is of its own type. If it is then the node will generate data requested. The node will hold the data for a short period depending on its serial number to ensure that the nodes below it have sufficient time to send in their responses. Higher the serial is (the node is in a higher level) the longer the holding period. If the request is not relevant to the node it keeps on listening to the nodes below it and aggregates the data sent by them after a timeout. Once the data is aggregated the node will create a data packet and send it to the next hop.

When a node has data to be sent it senses the carrier in two ways, physically and virtually. In physical carrier sensing the node listens to the carrier whereas in virtual sensing, it uses the size field of the packet being transmitted. Then the node will back off for that period and starts listening to the channel. If the channel is free it again backs off a random time and will start transmitting its data. When the destination node receives data it will generate an acknowledgement and send it back. If a collision occurs, the destination node discards the packet and there will not be an acknowledgement. If the sender does not receive the acknowledgement within a timeout, it will retransmit the data packet in the same manner as before.

There were 25 nodes in both models. Each of these devices was designed to simulate a simple device of one type and they respond to requests of their type. This is essentially comparative to a load responding to a load request. In model 02 there were 05 more nodes acting as cluster heads. In fact, these heads will add up the data arriving in from their leaf nodes and send the result as a single response to the central controller. Moreover, they may have their own data provided that the type of the request is same as their type and these data will also be added to the total.

The network of both models simulated Wi-Fi with a data rate of 56 Mbps. During simulation, the central controller generated 100 requests. The delay between sending a request and receiving acknowledgements and responses was measured.

3. Results

In the model 01, there were 2500 acknowledgements and 818 responses. The minimum delay was 6.7ms while the maximum was 380.6ms. The mean and the standard deviation of the distribution were 161.4ms and 56.2ms respectively.

With in-network data aggregation (model-2), there were 500 acknowledgements and 402 responses. The minimum delay was 28.1ms while the maximum was 577.9ms. The mean of the distribution was 207.4ms with a standard deviation of 102.1ms. The probability mass functions

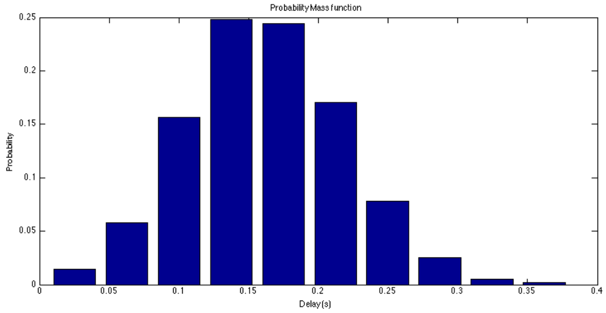

Figure 1 - Probability Mass function of Delays without Data Aggregation

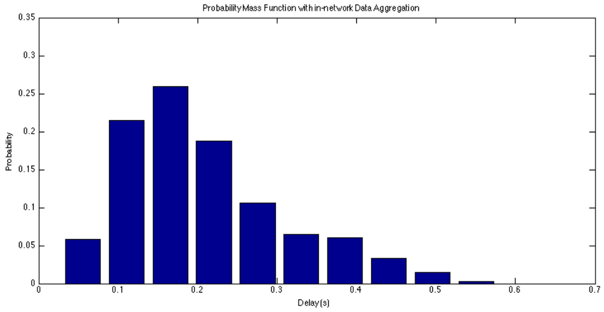

Figure 2 - Probability Mass function of Delays with Data Aggregation

of the two cases are shown in Figure 1 and 2 respectively.

4. Conclusions

Both delay distribution are skewed. However, these distributions need to be statistically tested to confirm that they are actually Poisson distributions. With the simple Chi-square goodness-of-fit test, they do not prove to be Poisson, and hence needs more through analysis. The parameters of the two distributions are not significantly different. Therefore, it can be argued that data aggregation does not make the system slow to respond. However, the added delay due to data aggregation plays a major role when data aggregation is done. Therefore, the waiting time of the aggregators need to be optimised to ensure a reliable measurement without hindering the performance.

These distributions can be used in modelling real-time communications after establishing their validity with a physical network model. However, it is also necessary to study the total energy consumption in each case to conclude the best architecture.

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