

IMPROVED BACK-PRESSURE SCHEDULING TECHNIQUE in AMI DISTRIBUTION NETWORK

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ABSTRACT

In this paper, we provide an objective function (OF) on a mesh network architecture, consisting of multiple gateways that will ensure high performance and reliability of the grid network in emergency situations. Some incidences like power outage generate large number of data packets and cause congestion. Thus in order to manage the traffics we introduce a multi gateway scheduling algorithm based on Back-Pressure method and propose a distributed objective function. The simulation results confirm the superiority of the proposed objective function.

INTRODUCTION

One of most important issue in smart grid is providing a reliable communication system for AMI. In fact AMI system is created with the goal of notifying consumers with the amount of energy that they consume. It is also used to monitor and control the electrical system components. Although there have been many progress in computer technology and network systems but smart grid is facing with reliability and security challenges in wired and wireless communication environment. For instance, smart appliances, a major part of the smart grid in order to improve efficiency of energy, forced to communicate with intelligent network elements in other areas of smart grid through the home and neighbor networks. In order to make compatible networks, the proper use of wireless and wired technologies is the main issue of smart grid communication networks at the last miles.

For instance, PLC is noticeably used in home network applications. At the same time, wireless LAN techniques such as the IEEE 802.11 due to technological development and the benefits of their cost have become standard for wireless access and have been used widely in home entertainment.

Generally AMI network should be designed in a way that be able to guarantee high degree of reliability, self-configuring and self-healing. Achieving these requirements do not depend just on selecting a mesh routing protocol. For example, MAC and physical layer protocols also depend on the nature of application layer traffics.

In particular outage management is an important example in this context. In such a situation, the system

is expected to receive outage notifications, and also exchange information among all meters. This situation can lead to increase traffic and consequently severe congestion in the network.

In the case of an ordinary neighborhood network, a residential area is divided into separate areas (for example, mesh nodes) that normally meters communicate with AMI, through their local gateway.

Under such circumstances, meter which are close to local gateway are expected to experience more congestion than those are further away. This can cause bottleneck especially at power outages. Thus it is beneficial to combining all these networks with multiple gateways to a larger network in which each meter can access any of gateways according to local traffic activity.

According to the above description proposing a suitable scheduling algorithm in multi gateway AMI network can greatly affect the reliability and the performance of the networks. This is due to handling the traffic and proper scheduling of packets in the case of congestion situation. In the following sections we describe the back pressure technique which we propose our new objective function (OF) based on this method. Ultimately we will discuss about our new OF, the simulation process and the results.

BACK-PRESSURE ALGORITHMS FEATURES

The basic concept of back-pressure algorithm for a multi-hop network was first introduced in [1]. It will schedule any packet through a specific route according to the queue-length difference of each single-direction single hop link. Backpressure routing is an algorithm for dynamically routing traffic over a multi-hop network by using congestion gradients. The algorithm can be applied to wireless communication networks, including sensor networks, mobile ad hoc networks (MANETS), and heterogeneous networks with wireless and wire line components. Attractive features of the backpressure algorithm are:

- I. It leads to maximum network throughput.
- II. It is robust in comparison with time-varying network conditions.
- III. It can be implemented without knowing traffic arrival rates or channel state probabilities.

IV. A numeric value that maximize or minimize the objective function, and plays a major role in routing.

The objective function specifies how much each variable contributes to the optimization problem. In this case the optimal routing in multi-hop wireless networks is the problem and variables include queue length, the quality of the links and etc. The scheduling and routing of Back-pressure guarantee the optimal throughput performance and is a promising technique for improving throughput in a wireless multi-hop mesh network. In the classic Back-pressure, each node makes queue for each flow. Each node makes decision for routing and scheduling based on the existing congested packets in the queue and the status of the network [2].

In order to explain the difference between the routing and scheduling in back-pressure there is an example. Consider topology shown in figure 1 for backpressure operation. The topology consisting of three nodes; i, j, k , and two flows; 1,2. Note that this small topology is a zoomed part of a large multi-hop wireless network. The source and destination nodes of flows 1 and 2 are not shown in this example, *i.e.*, nodes i, j, k are intermediate nodes which route and schedule flows 1 and 2. At time t , node i makes routing and scheduling decisions for flows 1 and 2 based on the per-flow queue sizes; $U_i^1(t), U_i^2(t)$, as well as the queue sizes of the other nodes, *i.e.*, node j and k in this example, and using the channel state of the network $C(t)$. In particular, the backpressure determines the flow that should be transmitted over link $i-j$ by $s^* = \arg \max \{D_{ij}^1(t), D_{ij}^2(t)\}$ such that $s^* \in \{1, 2\}$. The decision mechanism is the same for link $i-k$. Note that this is joint routing (*i.e.*, the next hop decision) and scheduling (*i.e.*, the flow selection for transmission). The scheduling algorithm also determines the link activation policy. In particular, the maximum backlog differences over each link are calculated as; $D_{ij}^*(t) = D_{ij}^{s^*}(t)$ and $D_{ik}^*(t) = D_{ik}^{s^*}(t)$. Based on $D_{ij}^*(t), D_{ik}^*(t)$ and $C(t)$, the scheduling algorithm determines the link that should be activated. Note that the decisions of routing and scheduling (also named as max-weight algorithm) are made jointly in the backpressure framework, which imposes several challenges in practice.

NETWORK TOPOLOGY AND ROUTING PROTOCOLS

There are different routing protocols in AMI network such as DADR, Hydro and etc. Figure2 shows the current routing protocol classification in AMI networks. A bunch of these protocols that support load distribution, reliability and multi-path routing protocols are called Timer Based Multi Path Diversity Routing that Back-Pressure is a one of most important algorithms in this type.

Due to the lack of bandwidth in wireless networks, efficient use of resources to achieve high throughput and

high quality communications on multi-hop wireless networks is important. In this context, routing and scheduling algorithms for wireless resources is necessary to dynamically allocate network in order to maximize the throughput. Back-Pressure routing is an algorithm for dynamic routing traffic over a multi-hop networks using a gradient of heavy congestion. This algorithm can be used in wireless networks such as Sensor Network, MANET (Mobile Ad-Hoc Network), a network of heterogeneous wireless and wired components. A routing algorithm works in scheduled time slot. At any time slot, algorithm chooses the route which causes the maximum difference in traffic between the neighbors to transmit the data.

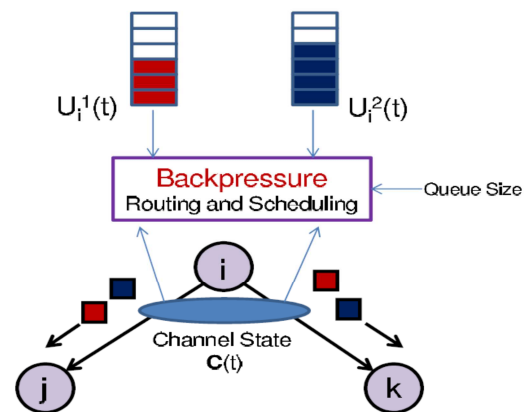


Figure1- Routing and scheduling in Back-pressure protocol

MULTI GATEWAYS ROUTING

A neighborhood network may consist of several sub-networks that the mesh nodes indicating meters in each subnet and are able to have access only to local gateways. The gateway, which is referred to a DAP (Data Aggregation Point) is connected to the main gateway through a wireless or wired link. Due to the variable nature of traffic, some gateways may be more congested and the nodes belonging to neighbor subnets are unable to participate in routing to reduce traffic load. Therefore, to allow public participation in the routing, aggregation of all these networks into a larger network with multiple gateways (DAPs) in which all meter can have access to any gateway can be useful, as in figure3. With this type of arrangement if some gateways and nodes in the network fail or new node added we expect promotion in self-healing and self-configuring. Designing such a network needs to develop a flexible routing protocol so any node can have a separate path to each gateway. As mentioned earlier in emergency situations such as power outages and some applications, the exchange of packets at the network becomes very large, therefore the network traffic can be increased

rapidly and causing a bottleneck. One way to solve this problem and to distribute network load is to use multi gateway network. This means that these networks will be combined into a larger network with multiple gateways (see Fig.3)[2]. Therefore, by using multiple gateways routing we can assume that all nodes have an active route to any of the gateways.

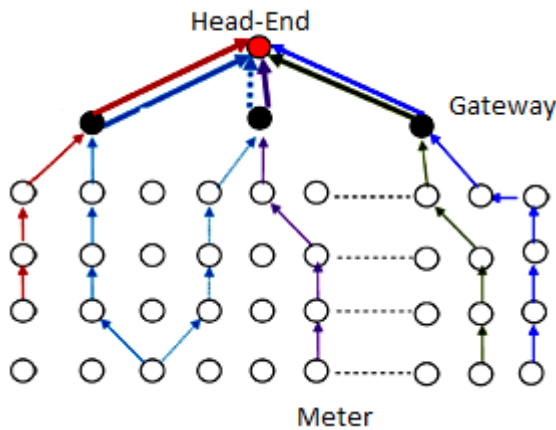


Figure3- A NAN with multi gateway

PROPOSED METHOD

In the current study, we use multi gateways routing protocol which already is presented in figure3. Thus each node should have a specific path to each gateway, so if necessary, traffic can move out from each gateway and not necessarily the local gateway. To achieve this purpose, each node must have a separate route in its routing table to each gateway.

These paths are obtained as follows: each gateway broadcasts its information (as root) periodically. All nodes that receive this message insert the gateway address into routing table as root and broadcast this message plus the address of itself as parents. This process is repeated until all available nodes find a specific path to all gateways. Ultimately each node in upward direction chooses the next hop based on the objective function.

NEW OBJECTIVE FUNCTION

We propose an objective function in a way that reliability and congestion is well managed. The proposed OF is as follows:

$$R(N_{h,T})(t+1) = \min_{\dot{N} \in \mathbb{B}(N_{h,t})} \{ \hat{H}(\dot{N}) \cdot Q(\dot{N}, t) \cdot ZO(\dot{N}, t) \} \quad (1)$$

where $R(N_{h,T})$ is the receiving node with a distance h from the nearest gateway that is selected as the next hop in time T , $\mathbb{B}(N_{h,T})$ is the set of all neighbors of a sender node, $Q(\dot{N}, t)$ is the queue length for the neighbors of sender node, $\hat{H}(\dot{N})$ is the number of hops to the nearest gateway, Z is a coefficient between 0 and 1 that controls the impact of queue length path between a leaf node and the root and $O(\dot{N}, t)$ is the minimum queue length multiplied by its distance from the nearest gateway node on the path from a leaf to the corresponding gateways.

SIMULATION RESULTS

In this section we use the Opnet software package [3] to simulate the network architecture which is shown in figure 3. We have developed a multi gateways routing protocol base on constructing a tree. This routing scheme, is an extension of the HWMP protocol for wireless mesh networks. As we noted earlier in this network, each mesh node in a tree not only generate its packages but also should relay the packets from the child node (excluding leaf nodes). As a result, the traffic is aggregated at the upstream link will reduce the tendency to increase the number of hops. As it can be seen in figure 3, each gateway as the root of a tree is periodically broadcast root message to construct its tree. It is important to note that a gateway node in the network represents the last hop. The MAC address of the node G_1, G_2, \dots, G_n are used as a unique feature. Every node in the network topology has several gateways. So several entries in the route table represents a separate path to the gateways. Due to the implementation of the proposed Back-Pressure, the main objective will be selecting the next hop.

To compute the OF, only the parent nodes are used in calculations. Every node must have an active route to all gateways. When a mesh node generates a packet or receives a packet, the node will check its neighbor list and compare any desired metric, and then chooses the best node as a next hop.

The topology in our simulation model includes four gateways and 48 nodes that are uniformly distributed. Figure 4 shows the end-to-end delay diagram in comparison with the OF used in [4]. The red curve is the average end to end delay for our objective function and the blue curve is that of given objective function in [4]. The results show that our objective function improves the end-to-end delay with respect to [4]. The main reason that cause the supremacy of our OF is that we consider the minimum hop count and queue length through the path from the node to root when choosing the next hop.

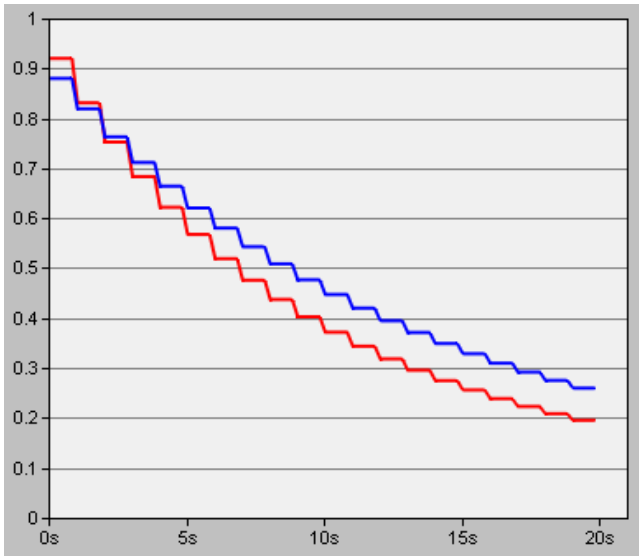


Figure4- Comparison of end-to-end delay

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CONCLUSIONS

In this paper, we offer an objective function in a multi gateway network in order to create a reliable two-way communication between meters and DAPs in AMI networks. Simulation results confirm that the proposed objective function by considering different parameters like hop counts and queue length reduce the overall end to end delay. Note that low latency is a critical factor in some applications like delivering an outage message through network.

Routing protocol	Reliable	Secure	QoS	Point-to-point routing	One-to-many routing	Many-to-one routing	Multi-path	Low latency	Scalable	Energy efficient	Load balancing	Application
DADR [43]	✓				✓	✓	✓		✓			Wireless AMI
Hydro [44]	✓			✓	✓	✓	✓		✓		✓	Wireless AMI
Timer based multipath diversity routing [46]	✓				✓	✓	✓				✓	Wireless AMI
Jung et al. [47]	✓			✓		✓	✓					Wireless AMI, status management and monitoring
Wang et al. [45]	✓				✓	✓		✓	✓			Wireless AMI
Li et al. [48]		✓			✓	✓			✓			Wireless AMI
Bartoli et al. [49]	✓	✓				✓				✓		Wireless AMI
Li et al. [53]			✓	✓					✓			DR
PMR [54]	✓				✓		✓					AMI-PLC

Figure2- Routing protocol classification