Ad Hoc Networks 22 (2014) 13–26

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Interference-aware QoS multicast routing for smart grid

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A R T I C L E I N F O

Article history:
Received 18 October 2013
Received in revised form 31 March 2014
Accepted 13 May 2014
Available online 27 May 2014

Keywords:
Smart grid
Multicast
Wireless interference
Wireless mesh network
QoS

A B S T R A C T

In the smart grid Wide Area Control Systems (WACS), controller sends command & control message (C & C) messages to remote devices. The reliability and stability of WACS heavily depends on whether the remote devices react promptly. In other words, the end-to-end transmission delay of the C & C messages plays a significant role in ensuring the performance of WACS. Multihop wireless mesh networks are considered as suitable networking infrastructure for providing data communication in smart grid. Nevertheless, due to the interference nature of wireless networks, identifying paths with minimum end-to-end delay is not trivial. This paper deals with the issue of identifying the multicast tree with minimum end-to-end transmission delay for multicasting a C & C message from the controller to a set of remote devices. Our proposal particularly considers the specific communication requirement from smart grid. The contributions of this paper are: (1) we formulate the problem of calculating multicast tree delay as an integer linear programming; (2) we propose a delay estimation method; (3) we propose a new routing algorithm to identify a multicast tree with the minimum delay. Through extensive numerical experiments, we demonstrate that the proposed routing algorithm outperforms the existing multicast tree routing algorithm.

1. Introduction

Smart grid (SG) is considered as an efficient way to improve the efficiency of a power system through utilizing information technology in power grid. In SG, home appliances, smart meters, and control center are interconnected with each other through wired or wireless networks. Smart grid can be seen as a hierarchical network composed by Home Area Network (HAN), Neighborhood Area Network (NAN), and Wide Area Network (WAN) [3]. Fig. 1, adopted from [3], shows a multi-tier smart grid communications network with HANs, NANs and WANs. HAN provides connections from home appliances, such as phone chargers, stoves, air conditioners, electric vehicles, to smart meters. Generally, HAN is implemented by one-hop WLAN with the open wireless standards, such as IEEE 802.15.4 or IEEE 802.11. NAN connects smart meters to local access points. Both wired and wireless technologies can be used to provide the communication infrastructure. For reducing deployment cost, multihop wireless mesh network is considered as the candidate for providing high-speed and easy-to-deploy wireless backbone in NAN [6]. In this case, the data of a smart meter is transmitted to an access point in a multi-hop manner. WAN provides communications links between the grid and core utility systems, which is typically supported by the fiber network.

Referred to [3,4], in Wide Area Control System (WACS), the control action initiated by a controller must be communicated to the distant devices. We refer to the network message that carries the action instruction, such as turn off voltage breaker, and travels in the communication network

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http://dx.doi.org/10.1016/j.adhoc.2014.05.008
1570-8705/

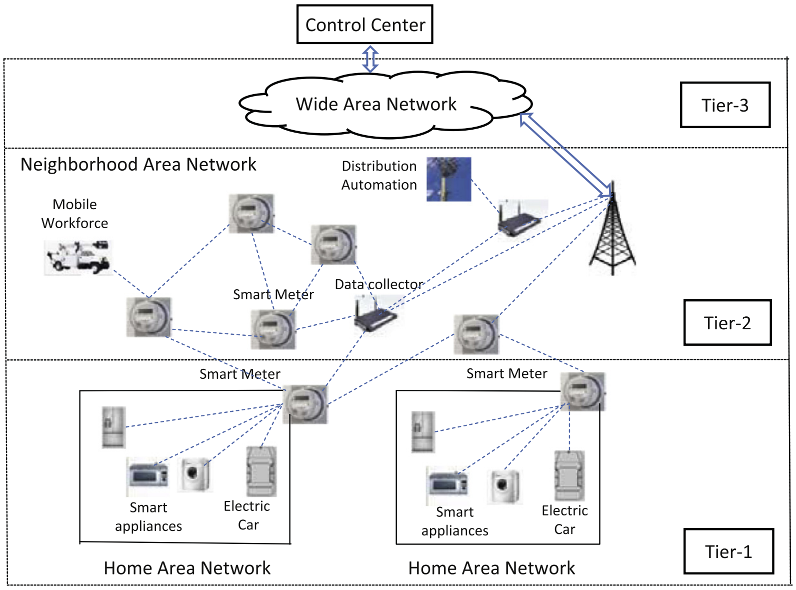

Fig. 1. Multi-tier smart grid communication network.

as *controlling message*. Controlling messages normally are of the highest priority that each device would first schedule transmitting the controlling messages. Therefore, the latency is mainly composed by the end-to-end transmission delay from source to destination. According to [3], multicast is expected to be a common need in the future given that WACS may deal with a group of residents in a neighborhood. The control action is considered successful only if all the controlled devices perform the specified actions within a certain time limit. For instance, the system may blackout due to the breaker not turning off timely. If the controlling message traverses inefficient routes so that some devices receive the message late, undesirable events may happen even the controller makes a correct control action. In order to provide the physical layer power system stability, the communication delay should be limited. It is thus necessary to develop efficient multicast routing algorithms in NAN. We first use an example to illustrate the importance of an efficient multicast routing algorithm.

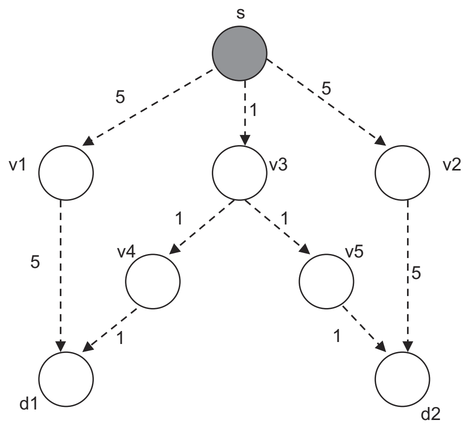

Fig. 2. An illustration for different multicast trees.

Fig. 2 shows a simple multi-hop wireless network. s is the source node and it aims to transmit a message (or a packet) to d_1 and d_2. The number besides a link is the transmission rate in terms of the number of time slots needed to send the message. The transmission rates of different links differ because of channel and distance diversities. For example, (s, v_3) can transmit the message in 1 slot, while it takes five slots to transmit on (s, v_1) and (s, v_2). The end-to-end delay of a multicast tree is the time needed for all intended receivers to receive the packet. We now develop the end-to-end delay of the multicast tree consisting of paths $\langle s, v_1, d_1\rangle$ and $\langle s, v_2, d_2\rangle$. In a single transmission, s can send a packet to both v_1 and v_2 at the same time. It takes 5 time slots. We assume that both (v_1, d_1) and (v_2, d_2) can transmit concurrently. Thus, it takes another five time slots to transmit a packet on each of both links. That is to say, it totally takes ten time slots for a packet from s to arrive both d_1 and d_2. We then consider another multicast tree composed by paths $\langle s, v_3, v_4, d_1\rangle$ and $\langle s, v_3, v_5, d_2\rangle$. It takes one time slot for s to transmit a packet to v_3, and then v_3 transmits the packet to both v_4 and v_5 in the next time slot. Afterwards, (v_4, d_1) and (v_5, d_1) transmit concurrently, which takes one time slot for a packet arriving at d_1 and d_2. Thus, it totally takes three time slots for s transmitting a packet to d_1 and d_2. If a routing algorithm unfortunately selects the first tree, the control action would be delayed unnecessarily that the system stability may not be guaranteed.

In order to provide an appropriate multicast tree for delivering controlling messages in WACS, we need to study the following issues.