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Passive power control routing for wireless mesh networks

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Abstract. This paper proposes an energy-aware routing method, P-AODV. Based on the AODV routing protocol, this study designed a Passive Power Control (PPC) algorithm to enhance energy efficiency. The proposed method includes signal detection and power setting phases. During the signal detection phase, the source node broadcasts the route request packets (RREQ), and the downstream intermediate node calculates the optimum power level at the upstream intermediate node according to the Received Signal Strength Indicator (RSSI) after receiving the RREQ. During the power set phase, the destination node returns the RREQ packet to notify the power level of the upstream nodes to the source node. After that, all nodes from the source node to the destination node, engaged in transmission, will transmit data at a coordinated power level. As indicated by the computer simulation results, P-AODV could have 30% higher energy efficiency than traditional AODV. This PPC algorithm could also be used in Wireless Mesh Networks (WMNs).

1. Introduction

As intelligent terminals develop vigorously, wireless networks have brought forward the whole WLAN industry, from the original 802.11 b, 802.11 g/a, and 802.11 n to the current 802.11 ac, which focuses on a high transmission rate. Existing WLAN technology can meet the Quality Of Service (QOS) needs of general users, compared to 802.16 or 3G, except for consideration of usage in a fast moving environment. Hence, it plays a practical role in wireless network solutions.

Wireless networks can be divided into infrastructure basic service sets and independent basic service sets, with regard to their framework. An Access Point (AP) is needed for the wireless network in an infrastructure basic service set, which can provide stable service and frequency width under perfect infrastructure conditions. However, once there is a lack of infrastructure or sparsely populated environments, there is a high cost in establishing the AP, including the backhaul and power supply, of a wired network.

Under the environment of a lack of infrastructure, Wireless Mesh Networks (WMNs) are self-configurable service networks that are able to provide solutions [1]. Existing wireless networks all apply WLAN wireless solutions plus ad hoc networks, which utilize the accessibility, high efficiency and low cost of WLAN. In combination with the multi-hop function of ad hoc networks, they connect in a peer to peer form and expand the service scope of WLAN greatly to form a whole mesh network, and connect to private backhauls or the internet through a gateway.

Data transmission in existing wireless mesh net-

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works is completed through multiple intermediate nodes. In the case of too many mesh network nodes or too much data throughput, the entire network will be clogged up, leading to decreased efficiency, which can be solved through a load balancing routing algorithm. In addition, excessive wireless power between all nodes will lead to co-channel interference of the power signal with the same frequency in the physical layer design, and energy waste.

In the ad hoc routing protocol, numerous methods to reduce energy consumption have been proposed, e.g. minimizing the consumption of transmission energy, maximizing the residual energy, and RF transmission power control. Literature [2] proposed a PMPR routing protocol in which each node uses GPS or other location methods to find out its relative position, and selects optimum routing through estimating minimum transmission energy consumption and maximum residual energy.

In literature [3], besides routing selection through the use of transmission energy and residual energy, link-stability was taken into consideration. Transmission energy and residual energy were combined into an equation for simultaneous consideration to enable the routing to take linkage stability into consideration, along with energy consumption.

In literature [4], parameters such as path loss of electromagnetic waves, receiving sensitivity and data transmission rate, were taken into consideration to optimize energy consumption in node transmission, according to the relative distance between output power and receiving sensitivity, as well as the relationship between the data transmission rate and throughput. In literature [5], under the same transmission power, due to short distances and better SNR, the data transmission rate was higher. Although this mode was not the shortest path and the number of node paths might increase, a large frequency width, due to a high data rate, shortened the transmission time. Analog results can also reduce the efficiency of energy consumption.

The deployment of WMNs is relatively slow; however, there are some small scale implementations, which are based on different protocols. This is the reason why some modifications to original protocols have been proposed in WMN implementation. In [6], the authors evaluate the influence of AODV and OLSR on the lifetime of battery-powered nodes when subjected to different transmission power levels and payload sizes. In [7], a wireless mesh network has been considered as a viable solution to offer broadband connectivity to rural communities, due to its ability to provide extended coverage and scalable deployment. In its contribution, investigation into a suitable routing protocol, in the context of providing rural broadband communication, is presented by evaluating performance analysis for an ad hoc on-demand distance vector (AODV), Optimized Link State Routing (OLSR), and a Hybrid Wireless Mesh Protocol (HWMP) was simulated.

Wireless mesh networks are becoming increasingly common and popular as they have important advantages over competing technologies. In [8], the authors introduce a new routing protocol which is an extension of the AODV algorithm called AODV-Mesh. It evaluated the AODV-Mesh algorithm in two cases for recovering broken routes, using the local repair mechanism (AODV-Mesh) and not using the local repair mechanism (AODV-Mesh NoLR). The results show that the AODV-Mesh NoLR algorithm improves performance and efficiency. In [9], a Quality-of-Services (QoS) aware AODV routing protocol in wireless mesh networks with node authentication schemes has been discussed. In [10], a new routing protocol, named Adaptive Ad hoc On-Demand Distance Vector (AAODV), is presented. Unlike AODV, this protocol is able to establish routes using any of the routing metrics calculated per link, due to its ability to separate path quality monitoring from routing. In [11], the authors designed a cooperative routing algorithm, which takes active radio electronic power consumption into consideration when constructing a minimum power route from source to destination. The paper introduces the concept of a supernode with improved power efficiency, and proposes a power aware cooperative routing algorithm.

In consideration of the same frequency interference and saving node power consumption, this paper proposed an energy-aware routing protocol, P-AODV, for wireless mesh networks, combined with routing layer and physical layer designs to create an algorithm for PPC based on the AODV protocol. The proposed system can control the radio output power for data transmission at the network nodes effectively, under the premise of not increasing the number of routing control packets, so as to reduce overall energy consumption and system interference.

The rest of this paper is organized as follows. Section 2 proposes the P-AODV based on a wireless mesh network and introduces the PPC algorithm. Section 3 describes the simulation environment and discusses the results of energy loss, and Section 4 provides the conclusions.

2. Energy-aware routing protocol

2.1. AODV routing protocol

Routing protocols for existing wireless networks are mainly divided into two categories. The first category is proactive-table driven, based on the distance vector and shortest path. The shortest routing table between nodes should be maintained to establish real-time, fast and effective routes. However, the routing table of the whole topology must be maintained at regular intervals. Periodic broadcasts will increase the network load largely for packet transmission. Relevant routing protocols include DSDV [12] and OLSR [13].

The second category is reactive source-initiated and on-demand driven. The largest difference from table-driven routing is that on-demand routing will send out RREQ to search for routing only when data transmission is required. Thus, on-demand routing has more effective frequency width use than does table-driven routing. However, it has a longer delay time than table-driven routing. Relevant routing protocols include AODV [14] and DSR [15].

AODV is reactive source-initiated and on-demand driven. AODV will establish routing only when data transmission is required, and it will not continue maintaining routing after transmission is completed. The AODV routing protocol is mainly divided into the two phases of route discovery and data transmission.

The route searching phase includes the route reply phase and route request phase, as shown in Figure 1(a). When node 1 intends to transmit data to node 5, node 1 will broadcast an RREQ; at this time, node 2 and node 3, which are within the wave receiving range, will receive the signal from node 1. Node 2 and node 3 will add the RREQ from node 1 into the completed route signal for forwarding. However, if there are no other nodes adjacent to node 2, because node 2 cannot maintain the data of the whole topology (due to AODV being a reactive route), it will also forward the RREQ signal. The RREQ signal forwarded by node 3 will be received by node 4 and then forwarded to node 5. Accordingly, destination node 5 will have the route number of the source nodes and the data of the previous node.

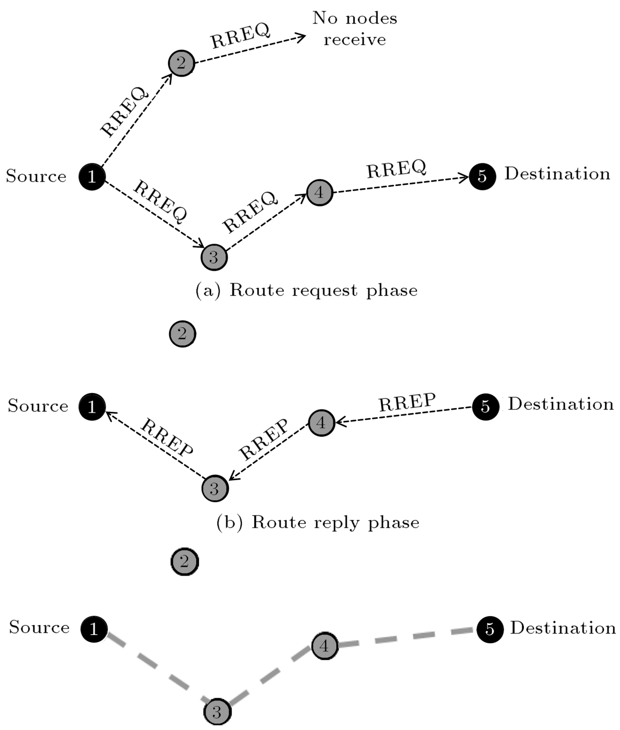


Figure 1. AODV routing example.

In the route reply phase, node 5 will select the shortest path through which to pass back the RREP after receiving multiple route data, as shown in Figure 1(b). Node 5 will pass back the RREP packet to the intended intermediate upstream node 4, intermediate upstream node 3 until the source node 1 in the form of a unicast. During the data transmission phase, node 1 will transmit data to destination node 5 using this routing information, as shown in Figure 1(c).

2.2. P-AODV routing protocol

The P-AODV routing protocol is designed based on the existing ADOV protocol. This study proposed a PPC algorithm to reduce power loss. This design is divided into signal detection and power setting phases. During the signal detection phase, the receiving node will detect the signal strength of the transmitting node when receiving an RREQ packet. During the power setting phase, the receiving node will give the accurate power level of the transmitting node when replying to the RREP packet. During data transmission, the transmitting node will transmit data to different downstream intermediate nodes using various transmission powers against different destination nodes.

As shown in Figure 2, when implementing route searching, the node receiving the RREQ will implement the PPC algorithm and measure the RSSI of the upstream transmitting node. When replying to the RREP packet, it will inform the upstream node about the calculated power level. The upstream node will measure the RSSI of the downstream transmitting node when receiving the RREP and then adjust the transmission power and notify the next node about the accurate power level when transmitting data. In this way, all transmitting nodes can adjust to the optimum power level when transmitting data and all receiving nodes can also adjust to the optimum power level when transmitting ACK data.

Figure 3 shows the implementation methods of P-AODV routing using PPC. At the beginning, node i will send the RREQ using the largest amount of power when searching for the route. If the RSSI received by node j from node i is -58 dBm, a level 2 output power can meet the requirements of -59 dBm at the receiving end. Therefore, node j will inform node i through the RREP signal, and the node will lower the transmission power level from level 3 to level 2. At the same time, node i will calculate and validate the channel status when receiving the RREP. If the power level calculated by node j is the same as that of node i, the power level

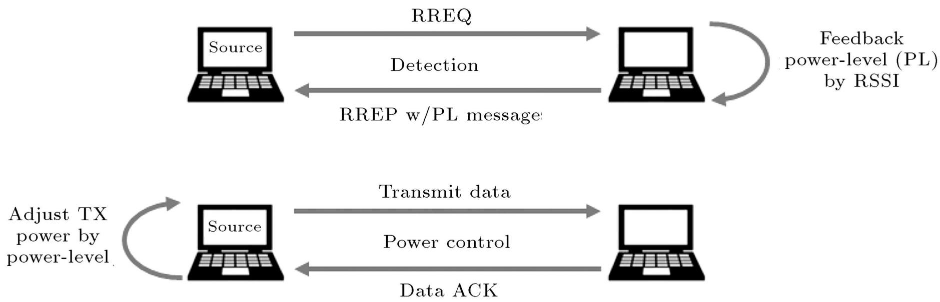


Figure 2. P-AODV design concept.

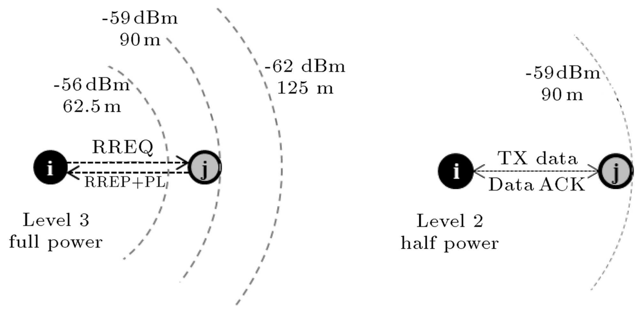


Figure 3. Power level decision example.

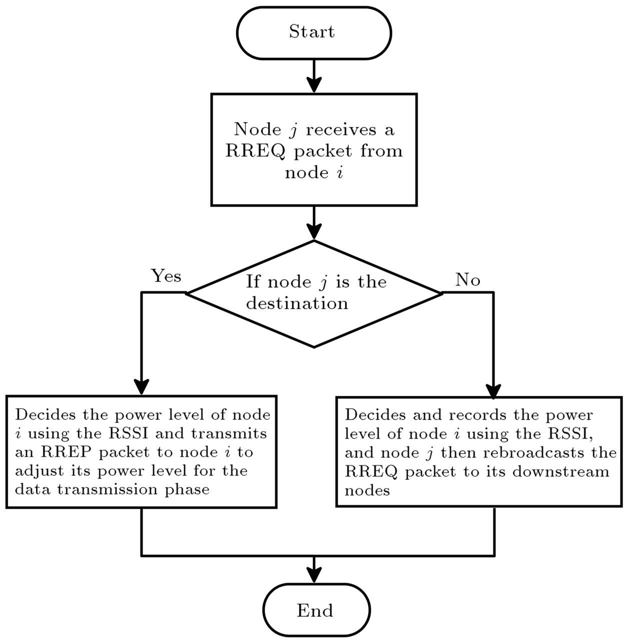


Figure 4. Flowchart of RREQ in P-AODV.

of node j will not be adjusted during data transmission, but if the power level calculated by node j is different from that of node i, the power level calculated by node i shall prevail.

Figure 4 is the flow chart of the P-AODV RREQ. Node j will check whether it is the destination node when receiving an RREQ packet from node i. If so, node j will calculate the power level of node i using the RSSI and supply the power level of node i using the RREP packet. If not, node j will calculate and record the power level of node i using the RSSI, and node j will broadcast the RREQ to the adjacent downstream node until the destination node is found.

Figure 5 is the P-AODV RREP flowchart. The destination node will send the RREP packet through a unicast. Node i will check whether it is an intermediate node to the source end when receiving the RREP packet from the downstream intermediate node. If node i is the source node, it will adjust the transmission power level and transmit the data packet to node j; if it is an intermediate node, it will transmit the power level to the upstream node until it reaches the source node. Thus, when the source node finds the transmission path, the power level of all nodes on the entire path will be adjusted. During the data transmission phase, each node can transmit using the most applicable power level to achieve an energy-saving effect.

3. Computer simulation

3.1. Simulated scene

The simulated scene was based on the framework of a wireless mesh network, and a gateway was used to connect the wired network and the wireless node to simulate the power consumption of P-AODV and AODV against the proposed PPC method. To estimate network efficiency, sampling nodes 16, 25, 36, 49, 64, 81, 100, 121, 144, and 169 were distributed uniformly in the form of a chessboard, with each node generating 10 packets per second, and each packet spending 10 power units. Figure 6 shows the simulated scene and power level setting.

3.2. Power consumption efficiency

Figure 7 shows the average power consumption efficiency. The power consumption using P-AODV was significantly better than that of traditional AODV, mainly because the P-AODV routing protocol does not increase the original AODV communication packet; it only increases the power level transmitted by the RREQ and RREP packets after adding the PPC algorithm. Only one field needs to be added to the route table, and this allows a 30% energy saving, as seen from the average energy consumption indicated by

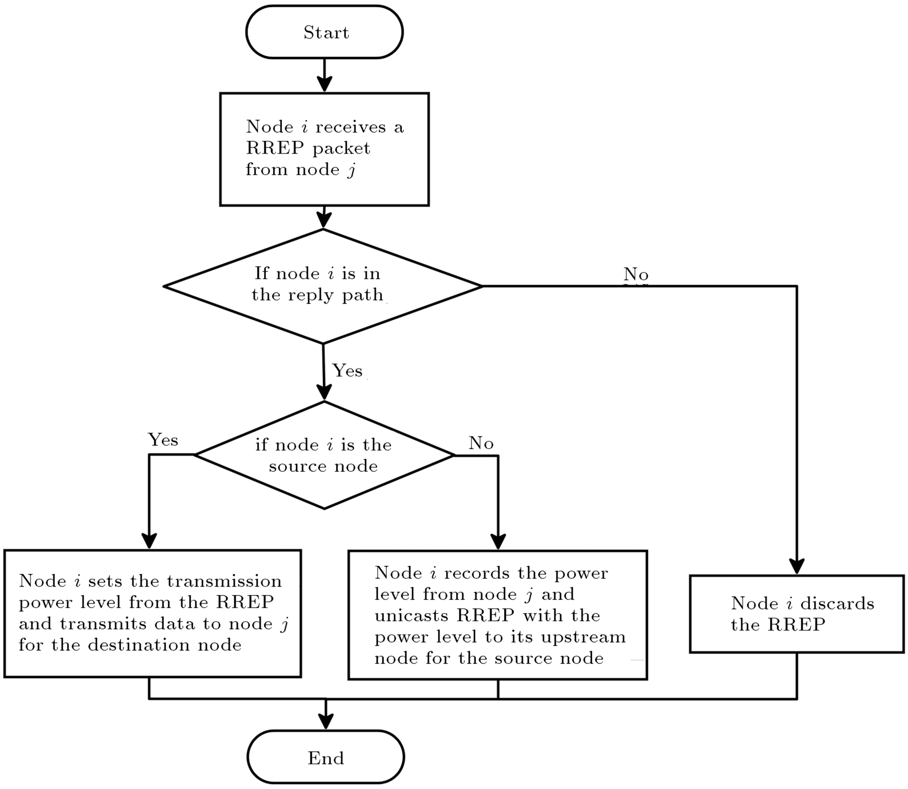
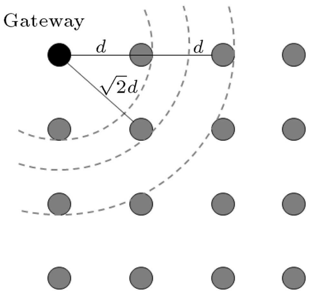


Figure 5. Flowchart of RREP in P-AODV.



Power level	Distance	Power consumption
Level 3	$2d$ (120 m)	100
Level 2	$\sqrt{2}d$ (90 m)	50
Level 1	d (62.5 m)	25

Figure 6. Computer-simulated scenes.

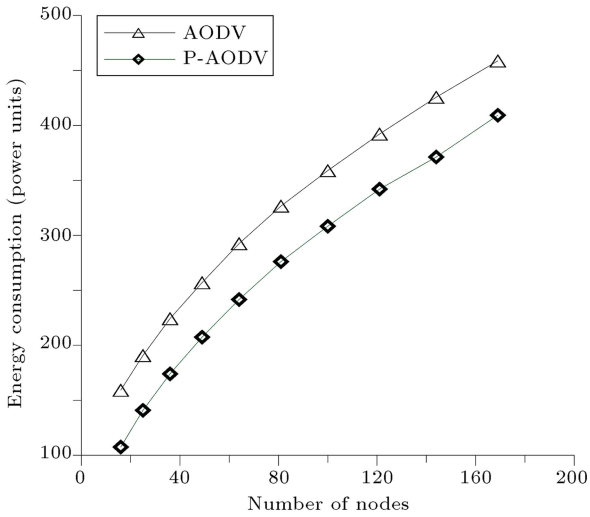


Figure 7. Average energy consumption of P-AODV.

the simulation data. Thus, the P-AODV is an effective method of reducing power consumption.

4. Summary

This study proposed the P-AODV routing protocol and a PPC algorithm to promote energy efficiency in WMN networks. During the signal detection phase of the P-AODV, the RREQ packet will enable the downstream nodes to calculate the power level of the upstream nodes. During the power setting phase, the RREP packet will enable the upstream nodes to adjust to the optimum power level of the downstream nodes. Therefore, during the data transmission phase, meaningless power loss can be avoided and the signal interference of adjacent nodes be reduced. As indicated by the simulation results, P-AODV can reduce more than 30% of the energy consumption of traditional AODV; thus, the PPC algorithm of P-AODV can reduce the transmission power loss of the entire network.

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Biographies

Chih-Min Yu was born in Taiwan. He received a BS degree in Electrical Engineering from Chung-Cheng Institute of Technology, in 1989, and MS and PhD degrees in Telecommunication Engineering from the National Chiao Tung University, in 1997 and 2006, respectively. In August 2009, he joined the Faculty of Chung Hua University, Hsinchu, Taiwan, where he is currently an Associate Professor with the Department of Communication Engineering. Prior to that, he was Assistant Researcher at the Chung-Shan Institute of Science and Technology, Taiwan (1989-2007), and Assistant Professor with the Department of Information and Communication Engineering, Asia University, Taiwan (2008-2009). His research interests include mobile communications, ad hoc networks and wireless sensor networks.

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