A Transmit Power Control Algorithm for Data Acquisition Systems

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***Abstract*—Recently, wireless many-to-one networks have been attracting much attention and wireless sensor ad-hoc networks are applied to various applications. In ad-hoc networks using carrier sense multiple access with collision avoidance (CSMA/CA), the capacity is drastically decreased by the hidden node problem. In this paper, we assume a many-to-one network and propose a transmit power control (TPC) algorithm to avoid the hidden node problem. In our proposed TPC algorithm, a 1-hop area, a forced multi-hop area, and a multi-hop area are defined. All nodes in the 1-hop area adjust their transmit power as they can sense each other's transmit data, and all nodes in the forced multi-hop area and multi-hop area control their transmit power as they connect to a gateway (GW) with multi-hop and reduce the interference to nodes in the 1-hop area. The network capacity using the proposed TPC algorithm is evaluated by computer simulation. By this computer simulation, it is shown that the network capacity of TPC is better by about 2.6 times than that of No-TPC.**

Keywords—Transmit power control, Many-to-one network, Hidden node problem, CSMA

I. Introduction

Recently, wireless ad-hoc networks have been attracting much attention for the possibility of extending the wireless coverage area, improving the network capacity, and being able to optimally auto-configure networks with no infrastructure. Especially, wireless sensor ad-hoc networks are applied to various applications for monitoring the environment or metering electric consumption.

In ad-hoc networks, the collision avoidance technique is very important as each node transmits data automatically. Carrier sense multiple access with collision avoidance (CSMA/CA) [1, 2], which is adopted for IEEE 802.11 [2] or ZigBee (IEEE 802.15.4) [3], is the most popular collision avoidance medium access control (MAC) technique. In wireless ad-hoc networks using CSMA/CA, each node cannot transmit data when it senses other carriers. Therefore, a node's data and the data of the other nodes that are in its carrier sensing area do not collide. However, a data collision occurs because a node cannot sense the data from the other nodes that are outside its carrier sensing area. It is well known as the hidden terminal problem. Especially, in many-to-one networks such as sensor networks, data collisions by the hidden terminal happen frequently at a gateway (GW) because all nodes transmit data to the GW and the traffic at the GW increases drastically. Therefore, by preventing data collisions at the GW, the network capacity can increase.

CSMA/CA with request-to-send/clear-to-send (RTS/CTS) [2] is one of the most popular MAC techniques for data collision avoidance. Recently, a transmit power control (TPC) algorithm with RTS/CTS has been studied [4-9]. Although the collisions by the hidden terminal can be avoided by using CSMA/CA with RTS/CTS, the system capacity decreases as the overhead increases, and there is a possibility that the RTS/CTS signal collides with the hidden terminal.

By the way, recently, TPC algorithms using the game theory are proposed for peer-to-peer (P2P) networks [10-15]. In these TPC algorithms, it is assumed that each node connects with a different node. However, in many-to-one networks, the game theory cannot converge as all nodes connect with the GW. Therefore, these TPC algorithms cannot be applied to many-to-one networks.

In this paper, a TPC algorithm for many-to-one networks is proposed. We define three areas: 1-hop area, forced multi-hop area, and multi-hop area. In a 1-hop area, all nodes control their transmit power as they can sense each other. Nodes in a forced multi-hop area and multi-hop area control their transmit power as their signal cannot interfere at the GW.

The remainder of this paper is organized as follows. Section II describes our assumed system model. Our proposed TPC algorithm is explained in Section III. Section IV presents the computer simulation results for network capacity. Section V concludes this paper.

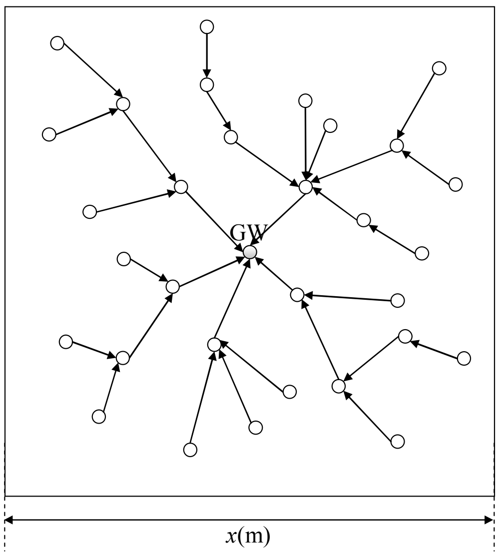

Figure 1 Example network

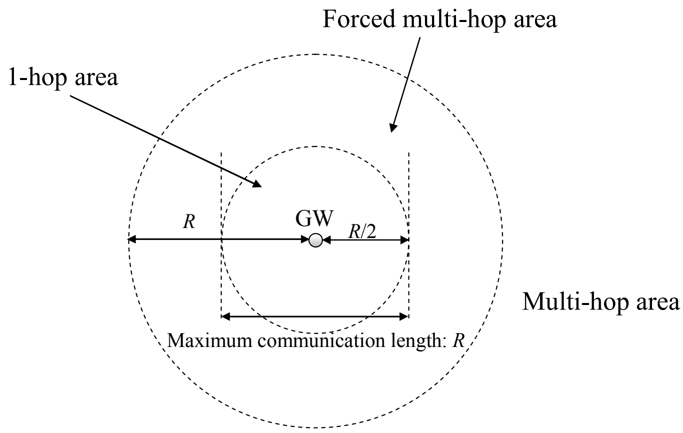

Figure 2 The definition of our proposed TPC algorithm

II. SYSTEM MODEL

Figure 1 shows our assumed system model. We consider a many-to-one tree topology's wireless network that consists of N access nodes (ANs) and one GW. ANs are uniformly distributed, the GW is set at the center of the area of a square with each side x (m), and all ANs connect to the GW via some relays by using CSMA/CA. By using CSMA/CA, each AN in the carrier sensing area can avoid a data collision. However, ANs with the relationship of hidden nodes cannot sense each other's transmit data. Therefore, many data collisions happen in the GW and the network capacity is drastically decreased.

III. PROPOSED TRANSMIT POWER CONTROL ALGORITHM

Figure 2 shows the schematic of our proposed TPC algorithm. To avoid hidden nodes around the GW, our proposed TPC algorithm divides three areas: the inner is a 1-hop area, the middle is a forced multi-hop area, and the outer is a multi-hop area. ANs in the 1-hop area control their transmit power as all ANs in the 1-hop area can sense each other. ANs in the forced multi-hop area control their transmit power, as they cannot interfere with the connection between the GW and ANs in the 1-hop area. The multi-hop area's ANs cannot connect to GW directly. However, if ANs in multi-hop area transmit their data with maximum transmit power, these data influence the link between ANs in the 1-hop area and forced multi-hop area. Therefore, these ANs should reduce their transmit power.

A. 1-hop area

When an AN transmits data with maximum transmit power $P_{\max}$ (dBm) the maximum carrier sensing range R (m), where the received power is equal to P_{cs} (dBm), can be expressed as

$$R = path\_loss^{-1}(P_{\max} + G_t + G_r - P_{cs}) \text{, (1)}$$

where G_r (dB) is the received antenna gain, G_t (dB) is the transmit antenna gain, P_{cs} is the carrier sense threshold, and path_loss (d) is the path loss function of the distance d (m). From Eq. (1), the ANs within R can sense each other. By defining a 1-hop area that is the inside the circle of radius $R/2$ from the GW, all ANs in this 1-hop area can detect signals from each other. Therefore, there is no hidden node in this 1-hop area.

Furthermore, if the transmit signal from a node in the 1-hop area reaches outside the 1-hop area, the transmission opportunity for nodes outside the 1-hop area decreases and the probability of a data collision outside the 1-hop area increases. Therefore, the transmit power in the 1-hop area should be controlled as AN_m, which is the node with which the distance is most separated from AN_i within the 1-hop area, can receive the data by P_{cs} from AN_i in the 1-hop area, where AN_m is an intersection of the half-line that connects the GW to AN_i and the boundary of the 1-hop area, like in Fig. 3. By carrying out like this, it is possible to prevent the signals from the nodes in the 1-hop area leaking out of the 1-hop area. When we assume that the distance between AN_i and the GW is d_i, the distance between AN_i and AN_m can be expressed as $d_i + R/2$. Therefore, the transmit power of AN_i in the 1-hop area $P_{t\_1hop,i}$ can be expressed as

$$P_{t\_1hop,i} = P_{cs} - G_t - G_r + path\_loss(d_i + R/2) \text{ . (2)}$$

B. Forced multi-hop area

There is an area where the signals from the nodes outside the 1-hop area with the maximum transmit power reach the GW and the nodes in this area are hidden to the nodes in the 1-hop area. This area can be defined by the distance d from the GW as $R/2 < d < R$. Therefore, by reducing the transmit power in this area as the signal cannot be received at the GW, the nodes in this area are forced to connect to the GW with multi-hop and there is no hidden terminal to the GW.

The transmit power is controlled as the transmit signals from the forced multi-hop area can be received at the GW with P_{rx} - P_1 (dBm), where P_{rx} (dBm) is the minimum received power and P_1 (dB) is a real value larger than 0. We assume that $P_{cs} = P_{rx}$ and the distance from AN_i, which is in the forced multi-hop area, to the GW is d_i (m), and the transmit power of AN_i, $P_{t\_forced,i}$, can be expressed as

$$P_{t\_forced,i} = P_{cs} - P_1 - G_t - G_r + path\_loss(d_i) \text{ . (3)}$$

By controlling the transmit power like Eq. (3), the GW cannot receive signals from AN_i in the forced multi-hop area. Therefore, ANs in the forced multi-hop area do not interrupt the communication between the nodes in the 1-hop area and GW.

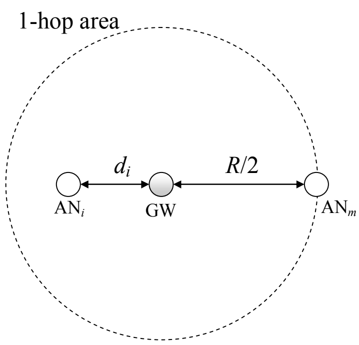

Figure 3 The relationship between AN_i and AN_m

C. Multi-hop area

The nodes outside the forced multi-hop area cannot directly communicate with the GW with $P_{\max}$. We define this area as a multi-hop area. In this area, all nodes can transmit data with P_{max} as the GW cannot receive their signals. However, these data influence the connection between ANs in the 1-hop area and ANs in the forced multi-hop area. Therefore, if we assume that P_2 (dB) is a real value greater than 0, the transmit power of AN_i, $P_{t\_multi,i}$, in this area can be expressed as

$$P_{t\_multi,i} = P_{\max} - P_2 . \quad (4)$$

Figure 4 shows a flowchart for our proposed TPC algorithm, where *i_Max* is the number of all nodes.

TABLE 1. Simulation parameters

Simulation area	4000 (m) × 4000 (m)
Transmitting time width	30 (s)
Carrier frequency	2.412 (GHz)
Data size	1566 (byte)
Data rate	1 (Mbps)
No. of retransmissions	6, 7, 8, 9, 10, 11, 12
Maximum transmit power	$P_{\max}$ = 100 (mW)
Antenna gain	$G_t = G_r$ = -2 (dB)
Minimum received power	P_{rx} = -96 (dBm)
Carrier sense threshold	P_{cs} = -96 (dBm)
Thermal noise power	-96.8 (dBm)
Required SINR	0 (dB)
Antenna height	2 (m)
Link threshold	96

IV. COMPUTER SIMULATION

In this section, we evaluate the performance of our proposed TPC algorithm by using NS-2. The simulation parameters are given in Table 1. We assume a 4000 (m) × 4000 (m) squarearea, and all ANs generate their data once randomly within 30 (s) and transmit their data to the GW. The MAC protocol is configured with IEEE 802.11b, and the thermal noise is set with -96.8 (dBm). In this simulation, it is assumed that each AN can know the distance from GW and the path loss between itself and GW. The path loss propagation model for transmitting data is the two-ray ground reflection model [16]. We can write the path loss at a distance d (m) as below

$$Path\_loss(d) = 20\log_{10}\frac{4\pi r D(d)}{\lambda} , \quad (5)$$

$$D(d) = \begin{cases} 1 & (if\ d \le r_{bp}) \\ \dfrac{d}{r_{bp}} & (otherwise) \end{cases} , \quad (6)$$

$$r_{bp} = \frac{4\pi h_r h_t}{\lambda} , \quad (7)$$

where λ (m) is the wavelength, r_{bp} (m) is the break point distance, h_r (m) is the height of the received antenna, and h_t (m) is the height of the transmit antenna. Dijkstra's algorithm [17] is employed to calculate the routing path from ANs to GW. In Dijkstra's algorithm, the average value of the downlink (DL) and uplink (UL) received powers is used as the cost value, and we select the route of the best cost value. If the received power of DL or UL is less than the link threshold value, it will not be cared.

First, we discuss the parameters of our proposed TPC algorithm. For our proposed TPC algorithm, P_1 and P_2 are the parameters, and these are optimal values. Therefore, we want to find these optimal values by using a computer simulation. Figs 5 and 6 show the packet reception rate (PRR) performances for P_1 and P_2, respectively. PRR is defined as the ratio of the no. of received packets at GW to the no. of all generated packets. In these simulators, we assume the number of retransmissions is six. In Fig. 5, we assume P_2 is 0 and the value of P_1 is from 1 to 10. From Fig. 5, it can be seen that the PRR performance decreases only a little when the value of P_1 becomes large. When P_1 is large, the interference between ANs in the forced multi-hop area, which cannot sense each other, becomes large. Therefore, the packet loss occurs at the link of an AN in the forced multi-hop area and an AN in the 1-hop area. Therefore, the optimal value of P_1 is 5. In Fig. 6, we assume P_1 is 5 (from Fig. 5) and P_2 is from 0 to 15. From Fig. 6, it can be seen that the PRR performance of P_2 = 10 is the best performance. When P_2 is very low, the received power from an AN in the multi-hop area to an AN in the 1-hop area is higher than that from an AN in the forced multi-hop area to a 1-hop area's AN. When P_2 is about 3, the received power from the multi-hop area's AN is the same as that from the forced multi-hop area's AN. Therefore, the PRR performance is the worst because signal to interference + noise ratio (SINR) is less than required SINR when these packets collide. The higher P_2 is set, the less the received power from the multi-hop area's AN becomes and the more the number of hop increases. When P_2 sets 10, PRR is the best and the number of hop counts can decrease. Therefore, P_2 = 10 is the optimal value.

Next, we discuss the effect of our proposed TPC algorithm. Figure 7 shows the PRR performance of No-TPC and our proposed TPC. The number of MAC retransmissions is 6–12. For the TPC algorithm, we assume P_1 = 5 and P_2 = 10. It can be seen that the PRR of TPC is superior to that of No-TPC. When the number of retransmissions is 6, the network capacity of TPC for PRR = 95% is better by about 2.6 times than that of No-TPC. This is because in TPC, the 1-hop area is defined to detect other nodes' signals within this area; thereby, there is no data collision at the GW, while in No-TPC, data collisions cannot be avoided because of hidden nodes around the GW. On the other hand, in No-TPC, the PRR decreases rapidly when the number of MAC retransmissions becomes bigger. However, in TPC, the PRR gets better if the number of MAC retransmissions is bigger. This is because in No-TPC, network congestion becomes more serious when the number of MAC retransmissions increases. In TPC, by increasing the number of MAC transmissions, the opportunistic ANs in the forced multi-hop area transmit their signals to ANs in the 1-hop area, and network congestion never happens at the GW because ANs in the 1-hop area can detect signals in this area from each other.

V. CONCLUSIONS

In this paper, we proposed a TPC algorithm for many-to-one network systems, which constructs three areas—a 1-hop area, a forced multi-hop area, and a multi-hop area—according to the distance between ANs and the GW. All ANs in the 1-

hop area can control the transmit power to make others sense this transmitted signal, and ANs in the forced multi-hop area can control the transmit power, which should not interfere the communication of the GW. The PRR was evaluated by computer simulations, which show that the PRR performance when using our proposed TPC algorithm is superior to No-TPC.

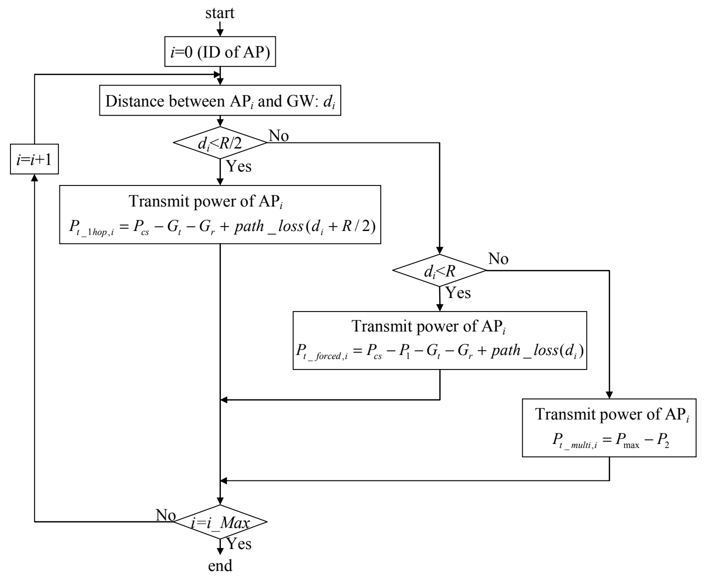

Figure 4 The flow chart of our proposed TPC algorithm

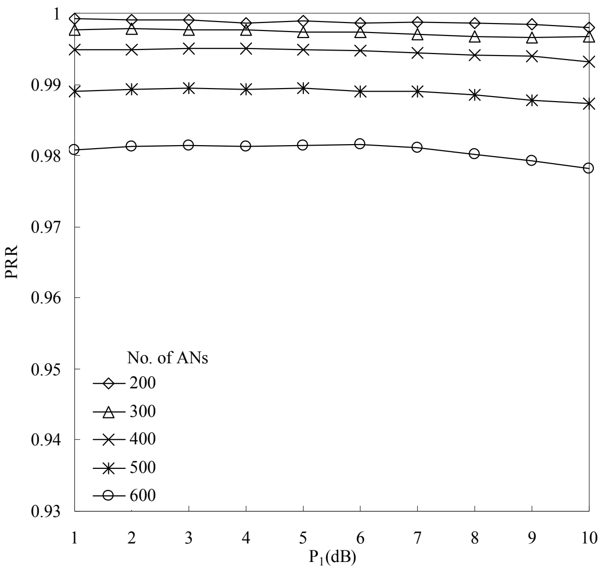

Figure 5 Optimal value of P_1

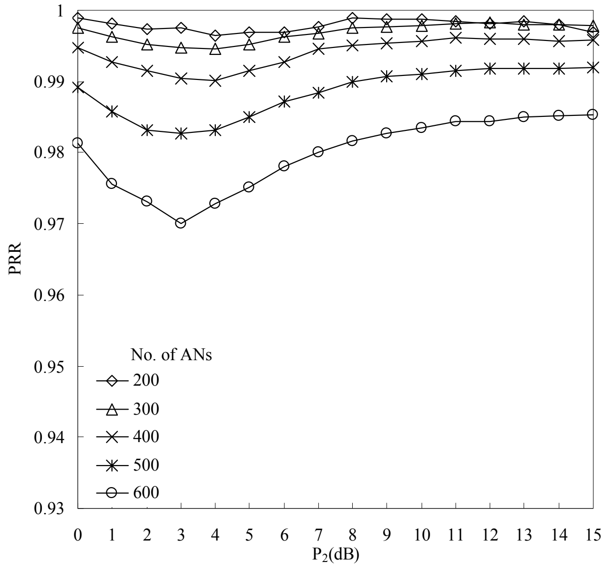

Figure 6 Optimal value of P_2

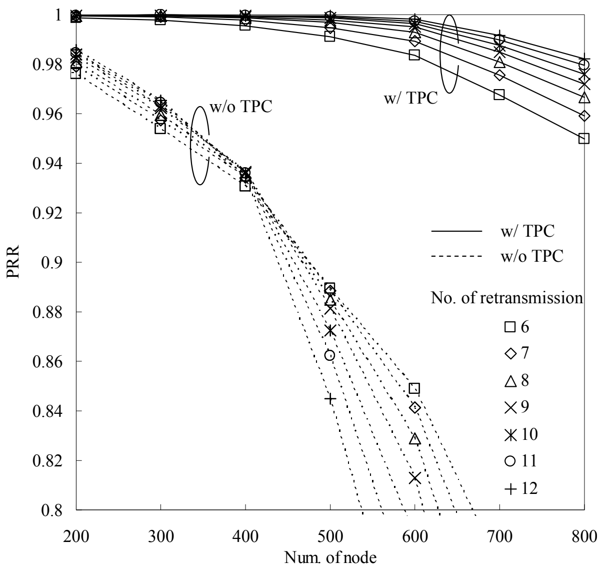

Figure 7 Packet reception ratio performances

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