

Efficient MAC protocol for IEEE 802.11 wireless LANs with obstructing objects

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Previous experimental studies show that the performance of IEEE 802.11 wireless LANs can be significantly degraded when obstructing moving objects and humans are present in the service area of wireless LANs. We propose the efficient MAC protocol based on the multipolling method to mitigate the interference from obstructing objects.

Keywords: wireless LAN, MAC, obstructing object, polling

1 Introduction

As wireless LAN technology becomes prevalent in hotspot areas where densely located devices interchange information via Internet, IEEE 802.11 wireless LANs are susceptible to the interference from obstructing objects. According to the experimental studies in [1, 2], obstructing moving objects and humans in the service area of wireless LANs can significantly degrade the performance of wireless LANs.

For dealing with the interference from obstructing objects, wireless LANs can use CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol based on the PHY and MAC carrier sensing information [3]. However, when the uplink signals of some wireless LAN devices are interfered from obstructing objects so that AP (Access Point) is outside the transmission range of the devices in a persistent manner, CSMA/CA is ineffective for the uplink transmission. This is because, even though wireless LAN devices find for their transmissions idle transmission time slots using the PHY and MAC carrier sensing information, the transmission signals cannot be properly decoded by AP, which is located outside the transmission range of the devices.

In this paper, to mitigate the uplink interference from obstructing objects, we compose the multihop shortest path from each wireless LAN device, the transmission signal of which is interfered from obstructing objects, to AP using the connectivity information among wireless LAN devices, and propose the new MAC protocol based on the multipolling method, which efficiently grants the transmission opportunities to wireless LAN devices on shortest paths. The connectivity information among wireless LAN devices were also employed in [4]. In this paper, we assume that the hidden node problem does not exist in wireless LANs. However, when the hidden node problem exists in wireless LANs, the approach in this paper can be

easily extended to mitigate both the uplink interference from obstructing objects and the hidden node problem by applying the proposed MAC protocol to each cluster of wireless LAN devices obtained by [5].

2 Proposed MAC protocol

Every wireless LAN device should carry out the authentication and association processes between AP and itself before it is allowed to transmit MAC data to AP [3]. The uplink data transmissions of some devices, which are located near the boundary of the service area of wireless LANs, can be interfered by obstructing objects so that the transmission signals of the devices cannot be properly decoded by AP, which is located outside the transmission range of the devices. Even though the uplink signals of the devices are interfered by obstructing objects, AP is very likely to be within the carrier sense area of the devices because the carrier sense range is at least twice the transmission range [6].

When AP detects that it cannot properly decode the uplink signals from some devices, we want to compose the shortest paths from the devices, the transmission signals of which are possibly interfered from obstructing objects, to AP using the connectivity information among wireless LAN devices. When AP detects that it cannot receive from some devices the ACKs corresponding to its downlink signals, which is possibly interfered by obstructing objects, AP can boost the downlink transmission power to overcome the downlink interference from obstructing objects. Wireless LAN devices cannot boost the uplink transmission power to overcome the uplink interference from obstructing objects due to the limited battery power.

At the initial time when AP does not have the connectivity information among wireless LAN devices, AP should collect the connectivity information using the PCF

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(Point Coordination Function) polling protocol during CFPs (Contention Free Periods). We want to briefly review the method for AP's collecting the connectivity information among wireless LAN devices using the PCF protocol [4]. The connectivity information $C_{i,j}$ between nodes i and j is equal to 1, if device j properly decodes the PHY signal transmitted from device i , and is zero otherwise.

While AP polls the devices associated with itself in a round robin manner, each device k maintains the set S_k of the devices of which the transmission signals are decoded by device k , and piggybacks the change of S_k on the polling response. If during a polling cycle, AP physically senses a polled device not to respond to transmit a signal, AP proceeds to poll the next device a PIFS (PCF Inter-Frame Space) period after the end of the previous transmission.

From the connectivity information among wireless LAN devices, AP can construct a directed graph G of devices and AP where edge (u, v) exists if $C_{i,j} = 1$ for devices u and v that are not AP, and edge (w, AP) exists if AP can decode the transmission signal of device w during the previous polling cycle. If AP cannot decode the transmission signal of device x , however, can physically sense the transmission signal of device x , AP tries to find the shortest path from device x to AP using Dijkstra's algorithm. If the shortest path from device x to AP is found, at the next polling cycle, AP multipolls sequentially the devices on the shortest path by multicasting a single multipolling frame including the MAC addresses of the devices on the shortest path as the recipient MAC addresses beside the MAC address of AP. If AP cannot find the path from device x to AP, AP carries out single polling for device x for obtaining the connectivity information related with device x .

Receiving a sequential multipolling frame, the first recipient device x should transmit its response data frame an SIFS (Short Inter-Frame Space) period after the reception of the multipolling frame, the next recipient devices in the multipolling sequence should sequentially relay the response data frame of the first recipient device x an SIFS period after the end of the previous transmission. If AP physically senses any recipient in the multipolling sequence not to transmit a signal after the end of the previous transmission, AP initiates the next polling operation to poll the next device in the original PCF polling order a PIFS period after the end of the previous transmission. If AP physically senses all the recipients in the multipolling sequence to transmit after the end of the previous transmission, AP can successfully receive the response data frame from device x even though AP is outside the transmission range of device x . The ACKs of the uplink transmissions can be piggybacked on the next polling or multipolling frames for the efficient use of bandwidth. The updated connectivity information among wireless LAN devices is continuously delivered to AP as piggybacked on the multipolling or polling response frames from wireless LAN devices.

3 Simulation results

We assume that in a hospital five hundreds of IEEE 802.11n wireless LAN sensors are associated with an AP, which is located at the center of the circular service area with radius of r , and the sensors, which are uniformly located over the service area, continuously attempt to transmit the data frames with payloads of 10 000 bits in a real-time fashion.

Without the interference from obstructing objects, each sensor is assumed to have the transmission and carrier sense ranges with radii of r and $2r$, respectively. However, the transmission signals of sensors are obstructed from moving medical equipments and people to the degree $d = 0.05, 0.1, 0.15, 0.2, \dots, 0.4$, which means that the transmission and carrier sense ranges of each sensor are shortened to $(1-d)r$ and $2(1-d)r$. Note that the signal obstruction makes the AP to be outside the uplink transmission ranges of some of the sensors that are near the boundary of the service area, however, the AP is always within the carrier sense ranges of all the sensors despite of the obstruction. The AP is assumed to boost the downlink transmissions to overcome the downlink interference from obstructing objects so that all the sensors are located within the transmission range of the AP.

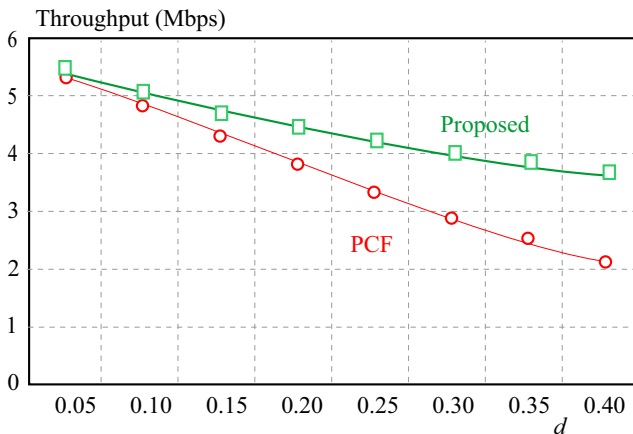
Considering that wireless LAN sensors are usually configured to have much lower transmission and reception rate than that of conventional wireless LAN devices, we assume that the uplink data frames are transmitted with 6.5 Mbps [7]. Furthermore, the transmission rate of the downlink multipolling and polling frames is assumed to be 6 Mbps, which is included in the set of rates with which all the devices should receive. Due to the multicasting nature of the multipolling frames, the multipolling frames should be transmitted with one of the rates with which all the devices can receive. The transmissions of all the multipolling and polling frames, on which no data frames are piggybacked, are assumed to be successful, and the transmissions of other frames are assumed to be unsuccessful with probability of 0.01 % when the recipients are within the transmission range of the senders. For simulations we used the values of the parameters as presented in Tab. 1.

The PCF protocol is the basic MAC protocol targeted for real-time service in IEEE 802.11 wireless LANs [3]. The PCF protocol or the modified PCF protocol, which is proposed in the previous section of this paper, is assumed to be employed to transmit the uplink data frames from the sensors to the AP. At the start of simulations at least ten thousand data frames were generated for each sensor, and simulations were conducted until all the data frames of the sensors, of which the transmission ranges the AP is located within, were successfully transmitted to the AP. In Fig. 1, for the degree $d = 0.05, 0.1, 0.15, 0.2, \dots, 0.4$ to which the uplink signals are interfered from obstructing objects, we compare the performance of the PCF protocol and the protocol proposed in the previous section of this

Table 1. Values of simulation parameters

Parameter	Value
Data frame transmission rate	6.5 Mbps
Multipolling and polling frame transmission rate	6 Mbps
SIFS	16 μ s
PIFS	25 μ s
Time slot	9 μ s
PHY header trans. length	20 μ s
Transmission error probability	0.01%

paper in terms of the number of MAC payload bits that are successfully transmitted from the sensors to the AP per unit time.

**Fig. 1.** MAC throughput comparison

As we can see in Fig. 1, the MAC protocol proposed in the previous section of this paper significantly improves the MAC performance as compared with the PCF protocol. The main reason for the improvement is that the wireless LAN devices, of which the transmission ranges the AP is located outside, cannot transmit their uplink data frames to the AP by the PCF protocol, however, can transmit their data frames to the AP using the shortest paths composed by the proposed MAC protocol. Actually, each wireless LAN device, of which the transmission range the AP is located outside, was indirectly connected to the AP via an intermediate node, of which the transmission range the AP is located within, for all the values of d . As the interference degree d becomes greater, the MAC performance of both the PCF and the proposed MAC protocol worsens. However, the decreasing rate of the MAC throughput of the proposed MAC protocol for the increasing interference degree d is significantly smaller than that of the PCF protocol. Because it is evident that the significant increase of MAC throughput leads to the significant

reduction of transmission delay, we can see that the proposed MAC protocol improves real-time QoS (Quality of Service) of IEEE 802.11 wireless LANs where the interference from obstructing objects exists.

4 Conclusions

We proposed the new MAC protocol to mitigate the interference from obstructing objects in IEEE 802.11 wireless LANs. By the shortest paths found by the proposed MAC protocol, and the multipolling method, the wireless LAN devices, of which the uplink transmission signals are severely interfered from obstructing objects, can be indirectly connected to AP to transfer their uplink data frames to AP safely. Numerical examples were also presented to show the MAC performance improvement by the proposed MAC protocol.

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