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The Power Conservation Scheme for Digital Picture Frames

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Abstract: Because of dynamic display feature and multimedia capability, a digital picture frame is quite popular by people and art gallery recently. A digital picture frame normally could be supplied with wall power. However, for more flexible placement or exhibition, a battery power is more suitable choice for a digital picture frame. In battery supply case, power save issue is the key consideration to prolong the exhibition duration. This paper presents an adaptive power control scheme for a digital picture frame and its wireless interface. The scheme was designed and functioned at the MAC layer of the IEEE 802.11 specification. The result of simulation showed that power consumption of the digital picture frame was obviously decreased and the operating period of it was greatly extended.

Keywords: digital picture frame, IEEE 802.11, power save, WLAN

1 Introduction

The wireless local area networks (WLAN) have been interested by academic researchers and industry experts in the past 10 years. Modern information appliances (IA) are usually networked to a control master, a PC server, over WLAN. The digital picture frames (DPF) are the typical products of IA and are one of the main applications of the flat panel displays (FPD). A DPF deployed at home or in a gallery may in high probability be supplied merely by pre-charged battery cells. Thus, the power saving scheme of a DPF to prolong the operation duration is very important to enable more flexible applications of the DPF in exhibitions.

The power consumption of a DPF during standby mode is typically less that of that of active mode. A DPF aggressively sets itself into standby mode to save the most of energy during the interval while fewer visitors are present nearby. With doze mode, the DPF could spend down to only 1% power of that of active mode. The DPF would set itself into sleep state during the middle rest interval. When it is required, the DPF can recover from standby mode in tens mini-second or can wake up from doze mode in less than a second. During the standby and doze mode, WALN is still synchronously networking to the control master for updating pictures, reporting the number of visitors and the residual power of the DPF for the statistics of preventive maintenance. A commercial WLAN modules consume about 1500 mini-Watts, this would be a dominant part compared to the power consumed by a DPF at standby or doze mode. Therefore, WLAN will also need to work in the power save mode as much as possible to reduce the total power consumption of the DPF under standby or doze mode, especially.

This paper proposes a power saving scheme for the infrastructure WLAN with directional antennas. Besides setting a DPF into sleep state, the scheme also forces the WLAN interfaces at idle state into doze mode, which consumes only 10% power of the WLAN module at idle state. Hopefully, near 90% of the energy consumption of WLAN could be conserved through the application of the scheme. Hence, the standby duration of the DPF is extended obviously and the battery replacement overhead is alleviated accordingly. A simulation will be conducted to verify the power saving effect of the proposed scheme for the infrastructure WLAN.

2 The IEEE 802.11 WLAN

The IEEE 802.11 specification includes MAC layer and physical layer. Firstly, we briefly introduce the terms defined in IEEE 802.11 standard. For the detailed description is described in the ANSI/IEEE standard [1].

A Wireless Medium (WM) is a medium used to implement the transfer of protocol data unit (PDU) between the peer physical layer (PHY) entities of WLAN. A Station (STA) is any device that contains IEEE 802.11 conformant MAC and PHY interface to the WM. Multiple STA working in either distributed coordination function (DCF) mode or point coordination function (PCF) mode form a basic service set (BSS). The BSS covered area is named the basic service area (BSA). A BSS can either be an infrastructure network or an independent ad hoc network.

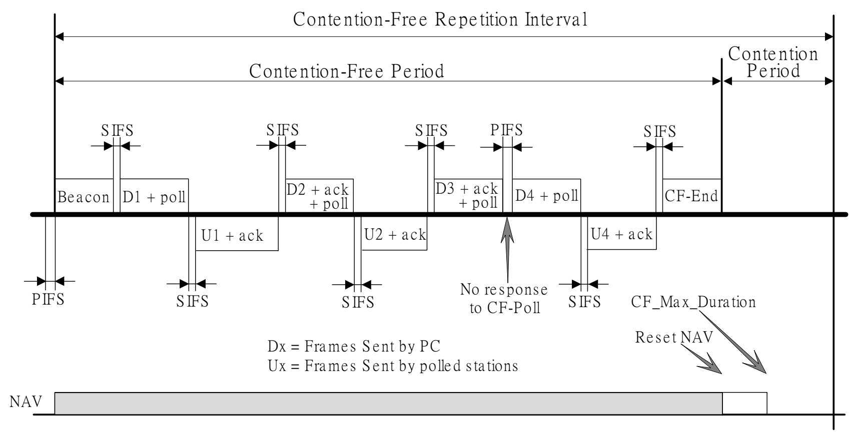

Figure 1: An example of PCF frame transfer

An ad hoc network composed solely of stations within mutual communication range of each other via the WM. An ad hoc network is typically created in a spontaneous manner. The principal distinguishing characteristic of an ad hoc network is its limited temporal and spatial extent. These limitations allow the act of creating and dissolving the ad hoc network to be sufficiently straightforward and convenient. In contrast, an infrastructure network consists of an access point (AP) and some STA. The AP acts as a point coordinator (PC) of a BSS. Typically, a STA connects to the Internet through the bridging or the routing function of the AP. Several AP forms an extended service set (ESS) via the wired network system. Thus, larger area can be serviced by the infrastructure WLAN.

There are two service control functions specified in the IEEE 802.11 MAC [7]. One is the PCF and the other is the DCF. The DCF provides contention based service, whereas the PCF provides a contention free service. In an infrastructure network, an AP utilizes the PCF function to become the PC to coordinate the communications of all STA. The rate of contention free period (CFP) and contention period (CP) can be defined in the beacon frame. At very beginning, the PC broadcasts a beacon frame with a time stamp and a contention free (CF) parameter set. The time stamp is used for the time synchronization between the PC and all mobile STA (MS). The CFPMaxDuration in the CF parameter set is used by all MS to preset their network allocation vector (NAV). This prevents the contention by the non-polled transmission. Thus, all MS can operate properly in the CFP when the PC is operating.

A STA indicates it CF-Pollability using the CF-Pollable subfield of Association and Reassociation Request frames. During a CFP, a PC is a polling master and all the MS, those are CF-Pollable and are included on polling list, act as slaves. The polling list is a logical structure sequenced by the association identifier (AID) of each STA and is used to force the polling of CF-Pollable STA. The PC performs a poll for each of the MS on the polling list. When polled by the PC, a CF-Pollable STA may transmit only one MPDU and may piggyback the acknowledgment of a frame received from the PC. The polled STA shall reply a NULL frame if there is no data frame to be sent. The PC can transmit data frame to a CF-Pollable STA and a non-CF-Pollable, a non-power-save STA. An example of frames transfer under PCF is illustrated in Figure 1.

CF-Pollable STA that are not on the polling list and did not request never to be polled, may be dynamically placed on the polling list by the PC to handle bursts of frame transfer activity by that STA. A CF-Pollable STA, which has no data to transmit, may operate in the power-save (PS) mode and shall normally exclude itself to the polling list. The STA shall synchronously wake up at the beginning per beacon frame to hear for the data frame indication in the beacon frame. The PC shall buffer data frames for those CF-Pollable STA with PS and shall inform those STA with the traffic indication map (TIM) in the beacon frame. Thus, the STA may put its radio into sleep mode for power save during CFP if there is no data indication to it in the TIM. The STA shall at least wake up until the end of CF-End if it finds a data indication for it.

3 Power Conservation Scheme

Advances in beam-forming technology have motivated current research to review some of the problems in wireless networking. Greater spatial

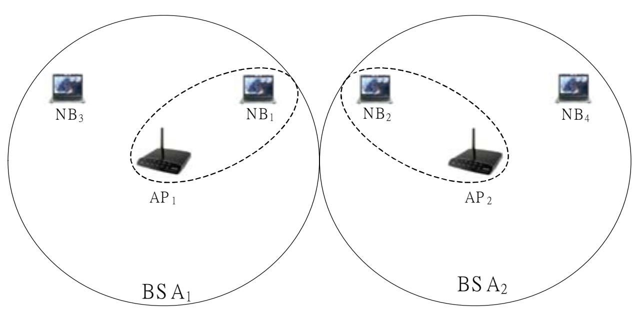

Figure 2: An example of beamforms in two BSA

reuse and longer communication range are potential benefits of utilizing directional antenna [13], [14], [18], [20]. Assume that the antenna system can offer two modes of operation: Omni and Directional. In addition, a node can operate only in one mode at a given time, but can toggle between modes with negligible latency. The gain of directional beamform is higher than that of Omni-directional one. Therefore, longer communication distance can be expected by the recipient STA or less power can be used to transmit a frame by the source STA.

An AP often uses the power source on the wall. Hence, there is no power shortage problem of the AP. The AP can freely operate its beamform in Omni-direction to transmit or receive frames. As for a mobile STA, the pre-charged power is scarce. To save energy, the STA tunes its beamform in the direction toward the AP. As mentioned previously, the STA will get higher signal to noise ratio (SNR) when receiving with directional beamform, and will consume less power when transmitting a frame to the AP. Besides power-save effect, it is also possible to reduce the co-channel interference to a nearby BSA.

In Figure 2, two nearby BSA are coordinated by the AP_1 and AP_2, respectively. The AP_1 and AP_2 send CF-Poll to their mobile STA in the corresponding BSA by Omni-directional transmission. During receiving, the NB_1 (STA_1) adjusts its radio beamform to the direction of the maximal receiving signal, which is the direction toward the AP_1. With the beamform, consecutive frames for the NB_1 will be received with better SNR compared to that of using Omni-directional beamform. Afterward, the acknowledgment or data frame to be sent to AP_1 can be transferred with less power over the directional beamform on the uplink. In the meanwhile, the NB_2 (STA_2) also uses the directional beamform to transfer/receive frames to/from the AP_2. With directional transmissions, the probability of interference between the two replies from NB1 and NB2 can be greatly reduced.

Without using power control, a pair of a source node and a destination node would normally use the maximal power to communicate. Many research results [6], [11], [15], [17] show that the power control not only saves power for the mobile nodes, but also increases spatial reuse and decreases co-channel interference to the neighboring wireless networks. Thus, the power control scheme was adopted in the directional MAC. Note that from the initial communications, the recipient can obtain the least required power P_{lr} from equation (1) [2]. Since power save is important to a mobile STA, the P_{lr} will be used for consecutive frame transmission from the STA. Let P_t be the maximal transmitting power level of the STA, P_r be the received power level at the AP, $R_{xthresh}$ be the necessary minimal receiving signal strength characterized by the recipient, and c be a comparison parameter to involve the gain effect from directional antenna, hence

$$P_{lr} = \frac{P_t}{P_r} \times Rx_{thresh} \times c \qquad (1)$$

During the initial communications, the AP calculates the P_{lr} for the STA and sends the value to the STA using the management frame. Upon receiving the frame with P_{lr}, the STA know the least required power to transmit a frame to reach the AP. Practically, the P_{lr} is much less than the maximal power P_t. Therefore, the power value of P_{max}-P_{lr} can be conserved by the power control scheme.

4 Performance Evaluation

To prove the effectiveness of the proposed method, we develop a simulation program to measure the energy consumption data for the performance evaluation of an infrastructure network with directional antenna worked under the IEEE 802.11 PCF. In the simulation, 10 DPF are randomly deployed in an indoor building with an area of 30m ∗ 30m. The display dimension of each DPF is 6 inches ∗ 8 inches. The DPF equipped with 2AH battery cells and it consumes 5W during normal operation, including a 1500mW WLAN interface card to communicate with an AP located at the middle of the indoor building. Assume that the WLAN has a directional antenna which can control its beamform toward a certain sector covering 120 degree scope. The duty rate of DPF was assumed to be 20% to represent the rate of visiting time. All the setting parameters were listed in Table 1.

Table 1: Simulation Parameters

Parameter	Value
Network Size	30m ∗ 30m
MAC Function	PCF
The number of DPF	10
DPF Dimension	6 ∗ 8 inches
Power	5W
Battery Cells	2AH
Input DC Voltage	12V
WLAN Power	1500mW
Visiting Duty Rate	20%
The Scope Degree of Directional Antenna	120°

The simulation was executed ten times to gather the averaged residual energy at all DPF. In each execution, the location of the DPF was dynamically deployed by a random function. Initially, all battery cells of the DPF were fully pre-charged. Assume that a DPF would put itself into sleep sate when there is no visitor in front of the DPF for 10 seconds. The DPF would wake up immediately if a visitor comes to the front of the DPF. This could be achieved by installing an approach sensor on the DPF to detect there is any visitor or not.

Several power saving methods were compared during the simulation. The SIM-1 represents the DPF was working all the time and there is no any power saving scheme and no power control function implemented on its Omni-directional WLAN. The SIM-2 denotes the sleep mode was enabled by the DPF yet the other conditions were the same as the SIM-1. Based on the SIM-2, the directional antenna controlled by the least required power was amended into the SIM-3 method. The SIM-4 added the PCF power saving scheme onto the SIM-3 to conserve more energy.

In Figure 3, the y-axis indicates the averaged residual energy of the batteries of all DPF. 100% means the battery is with full capacity. The residual energy was decreased when the simulation time was passing along. The x-axis describes how many hours were passing from the start of the simulation. One can read from the figure that the SIM-1 consumed the most energy among all methods. With SIM-1, the DPF would operate merely 5 hours in average. The operating lifetime is too short, so the replacement work would be too often for the host of the building. The residual energy of the DPF by the SIM-2 was greatly improved by putting the DPF into the sleep state. It can work more than two working days under normal visiting manner. After using the direction antenna, more energy can be saved in the SIM-3. With the SIM-3, a DPF could continuously operate about 4 days without the need to replace or re-charge its battery. Longer operation lifetime and less interference could be obtained by the SIM-4 because it adapted the PCF power saving scheme and the least required power by the power control. With SIM-4, it is possible to operate near 5 days and it could obviously relieve the overhead of replacement work by the host. If a little larger battery was choose instead of the original 2AH battery. The replacement period of the routine work would be extended to more than a week without difficulty.

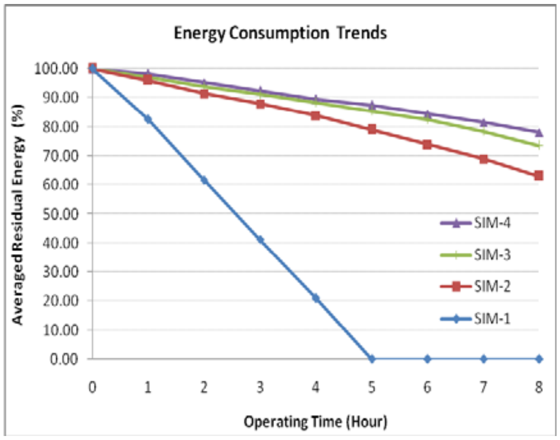

Figure 3: Energy consumption Trends

5 Conclusions

Recently, WLAN was embedded into many IA. A DPF is one of the examples. The power of a portable IA is usually furnished by the battery cells. Hence, the operating lifetime is limited by the capacity of the pre-charged battery cells.

To conserve energy for extending the working lifetime of an IA, several newer techniques for the power saving of the battery was proposed in our paper, including the directional antenna beamforming and the power control on the WLAN of an IA beside the sleeping scheme of the IA.

To evaluate the effectiveness of our proposal, we compared our proposal to the standard IEEE 802.11 by using the simulation. The result shows that around 80% of energy can be saved under normal operation style. The operating lifetime is tremendously prolonged.

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