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Investigation of an Improved Adaptive Power Saving Technique for IEEE 802.11ac Systems

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Abstract

Background/Objectives: Recent advances in IEEE 802.11ac based wireless networks have made them potential enough to be used for Voice over Wireless Local Area Networks (VoWLAN). The main requirement in the design of such network is to minimize the energy consumption to maximize the network lifetime of user equipment's. **Methods/Statistical Analysis:** For such energy conservation, the IEEE 802.11ac networks make use of power saving protocols, where the wireless radio is turned on and off periodically. In this paper, a group based adaptive power saving mechanism is suggested that dynamically utilize the contention and transmission opportunity parameters of user equipment. **Findings:** The design of the power saving is unique as the grouping is based on the current power level of user equipment's, type of service, channel status and the number of services to a user equipment. **Application/Improvements:** Simulation results shows that proposed grouping technique provides an improvement of 46.25% and 47.29% in terms of energy consumption and delay, respectively compared the existing power saving protocol for delay sensitive and VoWLAN applications.

Keywords: IEEE 802.11ac, Medium Access Control, VoWLAN, Wireless Networks

1. Introduction

Due to the increased advancement of devices having wireless networking interfaces such as smart phones, media players, and many more, Wireless Local Area Networks (WLANs) are growing rapidly and are deployed widely in many areas. In these places using WLAN enabled laptop and portable devices mobile users having wireless internet connectivity is provided through WLAN hotspots. As power saving scheme is discussed in IEEE 802.11 standard, wireless devices which are based on IEEE 802.11 works in two modes: active mode and other one is Power-Saving Mode (PSM).

In active mode, as wireless node is always switched on, data transmission and data reception can be performed by wireless users at any time. However, in terms of energy conservation, this mode is inefficient. As in WLANs a node is wirelessly connected to the backbone network. As these networks consist of IEEE 802.11 standard most of the applications which are based on voice are delay sensitive[1]. Here nodes are switched off to low power sleep mode to save energy. If sleep time is not properly scheduled, delay may occur. In order to satisfy the delay constraints, sleep-scheduling protocols are used.

In order to minimize energy consumption as well as maximize data throughput, a specific protocol is designed. In order to use the WLAN in real time applications it is very challenging. However, radio can be turned off by staying in sleep mode. This can reduce the energy consumption but delay above a threshold may get lost[2]. Hence, it is very much necessary to design an algorithm in such a way that should have proper sleep or wake-up schedule.

The rest of the paper is organised as follows: In Section 2, the works related to the design of the power saving in WLAN system is presented. Section 3 describes the proposed adaptive power saving technique based on grouping of users. Section 4 details the calculation of contention window and transmission opportunity. Section 5 describes the simulation results for existing and proposed

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power saving mechanism. Finally, Section 6 concludes the major findings.

2. Background

In WLAN, as battery life is important, various power saving mechanisms are introduced. In this mechanism the station has to wake up at every beacon interval. However, if the station has low battery power it cannot wake up at every interval which results in loss of packets. Hence, a Broadcast/Multicast Double buffering scheme is introduced for such situation in WLAN systems[3]. IEEE 802.11 WLAN has been widely used for broadband wireless access. In order to fulfil these requirements, it should have high bandwidth utilization and throughput. Energy- efficient multipoll scheme has been proposed which lowers the energy consumption as well as provides higher bandwidth utilization[4]. In addition; this technique solves the overhearing problem.

To analyse delay insensitive traffic mobility aware power save mode which is lightly loaded has been proposed[5]. It adjusts the sleep time interval for this traffic rate reducing wakeup overheads. Hence, it conserves more energy in an efficient manner. However, when the traffic is heavily loaded, performance is limited. Sleep-Optimal Fair-Attention scheduler (SOFA) has been proposed which reduces the energy consumption during heavy traffic[6]. Here the PSM clients stay awake for a very less time. In addition, the packets are sent to these clients in a desirable sequence. This results in energy fairness.

In order to reduce unbounded delay, a scheme known as PSM with Adaptive Wake-Up (PSM-AW) is end users-side clarification which permits the end user device to doze for a determined time interval prevents varying server delay. This technique is applicable when in PSM devices negatively impact delay when the node is in sleep mode[7]. Applications having technique such as Delay-Intolerant Uplink Traffic (DIUT) is used for organization IEEE 802.11 WLANs. The scheme known as Enhanced Timer-Based Power Management (E-TPM) is used in these applications where radio transceiver of station in sleep mode wakes up when station generates outgoing frame so that transmission of DIUT takes place in a timely manner. This scheme does not outcomes extra delay when the station is in sleep mode. Similarly, the delay for traffic for downlink station is controlled within a given certain amount of time.

Packet transmission that depends on packet size is one of the important parameter to define energy consumption. Since frequent packet retransmission leads to energy waste, energy efficiency of wireless networks is saved by EEFA (Energy Efficiency Frame Aggregation) technique[8-11]. This is an energy-efficient scheduling algorithm, which is based on frame aggregation which changes the size of accumulated frame depending on error rate of frame. Due to this the transmission of data is completed during the given TXOP which reduces consumption of energy.

In order to decrease power consumption and enhance energy efficiency, a scheme known as Adaptive-Transmission Power Control Mechanism (A-TPCM) is proposed. The performance is measured in terms of multi-factors. This technique reduces power consumption of WLAN devices in varying conditions. A novel Delayed Wakeup (DW) scheme is suggested which targets at saving battery power without affecting delay performance[12-14]. Here the excess stations are identified by AP, which goes in sleep mode instantaneously and awaken up at non-congested beacon interval. Maintaining lower energy consumption and lower delay should also improve the quality performance of wireless network. Hence, a QoS Definite Energy Improved Packet Transmission Technique for the IEEE 802.11 WLAN is proposed. Significant energy saving in high traffic load is achieved by this technique.

3. Proposed Adaptive Power Saving Technique based on Grouping of Users

The power in WLAN stations is saved by various groupings based on multiple parameters. Then sleep parameters are estimated based on every grouping. Specific parameters are calculated to for packet transmission here the main idea is to compute the Transmission Opportunity (TXOP) duration and contention window size. When a single data packet is transmitted, TXOP is reserved for that single packet. Contention window controls the size of random backoff.

Figure 1 shows the flowchart for proposed transmission technique. As shown in flow chart, packet transmission starts with initializing general parameters. As here power saving is done based on grouping, these groups are divided based on power comparing with its threshold value. As group 1 is based on current power level, packet transmission is assigned to group 1 if power is less than threshold power. If not, it is assigned to group 3, which is based on channel status. Then both groups individually update their sleep parameters and calculate specific parameters as shown in Figure 1.

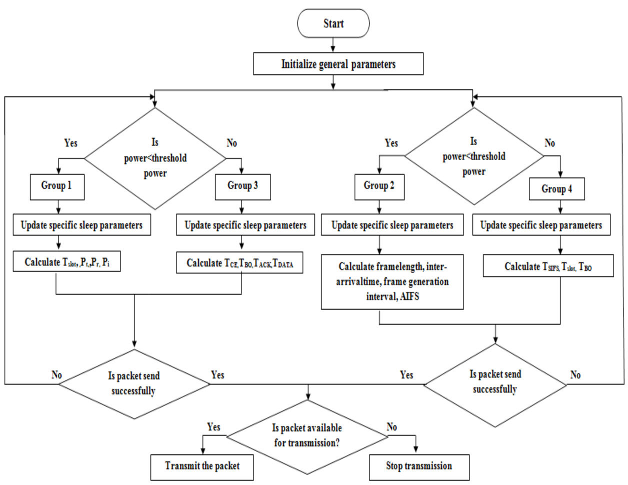

Figure1. Flowchart of proposed algorithm.

After calculating these parameters, then the packet is send. As in group 2, it consists of grouping of users based on type of service therefore it depends on power level which is less than threshold value. If power is greater, packet transmission is assigned to number of services per user. Thereafter, both groups update their sleep parameters and calculate specific parameters. Next if the packet is send successfully it is made available for transmission, otherwise it has to initialize the transmission. Packet is transmitted if it is available for transmission otherwise transmission is terminated. Based on these groupings, contention window and transmission opportunity has been calculated depending on its individual parameters.

3.1 Mathematical Analysis

Let Pi be the likelihood that there is no transmission in given slot time. Meanwhile each station communicates with probability τ, then

$$P_i = (1-\tau)^n \tag{1}$$

Assuming that exactly one station transmits in channel, the probability that transmission is successful is given by

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}} \tag{2}$$

Then the probability that a transmission going on the channel is unsuccessful (collided) is given by

$$P_c = 1 - P_s \tag{3}$$

$$P_c = 1 - \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \tag{4}$$

Average slot duration is given as

$$\sigma_{avg} = (1-P_{tr})\sigma + P_{tr}P_sT_s + P_{tr}(1-P_s)T_c \tag{5}$$

$$\sigma_s = \frac{P_{tr}P_sT_s}{\sigma_{avg}} \tag{6}$$

$$\sigma_c = \frac{P_{tr}(1-P_s)T_c}{\sigma_{avg}} \tag{7}$$

$$\sigma_{bo} = \frac{(1-P_{tr})\sigma}{\sigma_{avg}} \tag{8}$$

Here, Ts and Tc are periods of a transmission which is successful and a collision.

The energy consumption is given as

$$E(P) = (1-P_{tr})\sigma_s + P_{tr}P_s\sigma_c + P_{tr}(1-P_s)\sigma_{bo} \tag{9}$$

Where σ_s, σ_c, σ_{bo} are the portion of time the network occupies for a successful transmission, failed transmission and decrementing the back-off transmission.

The delay is a total time when station begins to transmit a frame competes for the channel till the contention is successful.

The average length of slot time is given as

$$d = P_{tr}(P_sT_s + P_cT_c) + P_i\sigma \tag{10}$$

A station transferring a frame evenly selects an integer in the series (0, W–1) as the backoff slot and then starts the backoff procedure. When the backoff counter reduces to zero, the frame is transmitted. When the frame gets transmitted successfully during its first broadcast, the average waiting time for this frame to communicate the channel is estimated to calculate delay

$$D = E[backoff\_slots].d \tag{11}$$

$$D = \frac{CW-1}{2}.d \tag{12}$$

3.2 Grouping of Users based on Varying Constraints

3.2.1 Grouping of users based on Current Power Level

As we are using here IEEE 802.11 ac, a maximum of four stations are there in each user group. Since these users operate at different power according to the specific requirements, the proposed technique resembles to DCF procedure. Here first the user station transmits the frame initial transmission rate to the access point. It then estimates Quality of Service (Qos) value and appropriate rate selection. The access point calculates new transmission rate and received power. It then passes the feedback packet to user. The user then assigns the optimum date rate and power adaptation is obtained. Here the data frame is transmitted using Distributed Coordination Function. Random backoff number is generated between zero and contention window is determined which is minimum. Then for a Distributed Inter-Frame Space (DIFS) interval, it waits until the channel is free and begins to decrement backoff number.

3.2.2 Grouping of users based on Type of Service

As the users use different types of service, energy efficiency depends on type of service. The types of service used can be voice, video, web and email. The technique used here is Enhanced Distribution Coordination Function. As per the type of service, it has different inter frame spacing, CW_{min} and CW_{max} values. When one station is transmitting a frame, other stations should define that they must transmit a frame. Each station concedes as the frame is now being transmitted and produces a random backoff value. Each service has different Arbitrated Inter Frame Space (AIFS) value and CW_{min}; this generates a random backoff number according to these values. As voice has the shortest backoff value as it has a minimum $CW_{min.}$ Therefore, it starts transmitting first and all other stations defer.

As voice finishes transmitting, all other stations wait for their corresponding AIFS value and begin to decrement the random backoff counter. The configuration of applications are given as voice has data rate of 64 kbps and frame length of 20 ms. Video has target rate of 64 kbps and frame generation interval of 40 ms. Whereas web page has inter-arrival time having mean 60s and distribution is exponential. Email also has inter-arrival time which is exponentially distributed with mean 120s. Here TXOP duration is calculated when it transmits one data frame when gain is accessed to the medium.

3.2.3 Grouping of users based on Channel Status

on channel status grouping of users is done and the technique Adaptive Modulation Coding (AMC) is used. Here the transmitted frame is arranged in such a manner that transmission of higher modulation symbols takes place first and then lower transmission symbols. Transmission of modulation scheme with lower code rates takes place following incremental bits. Since these techniques are used for since these techniques are used for reliable communication and maximize throughput. The transmitted and receiver PHY is estimated in the system. The link adaptation is placed on receiver side. Then based on status of channel, modulation scheme is selected and fed back to the receiver. The modulation scheme used is QPSK, BPSK, 16-QAM and 64-QAM. The modulation techniques are used depending on the code rate. As here the Power Coordination Function (PCF) procedure is used to transmit the packets, it has a different value of data packet, poll packet and back packet depending on the modulation scheme. Also the energy consumption depends on energy of packet transmitted, received packet and idle packet. Depending on control packet and data packet, contention window and TXOP value varies for each modulation scheme.

3.2.4 Grouping of users based on Number of Services per User

Here we group the users depending on number of services per user. Suppose a user is using voice and video traffic at the same time, therefore it has less contention. Here we use a Binary exponential backoff algorithm where node doubles its contention window to $CW_{max.}$ Then after the successful transmission it resets to $CW_{min.}$ However, the traffic load is high here. If one station has higher backoff counter and other has lower, it resets to zero and then reaches to maximum contention window. There after packets are transmitted. Since more than one service is used by the same user, traffic load is high in this case. Therefore the value of traffic rate is high in this case as compared to other cases.

4. Calculation of Contention Window and Transmission Opportunity

Depending on the grouping of users, based on different specific parameters, contention window and transmission opportunity is analyzed for each group. Here the size of contention window depends on type of grouping of users. Transmission opportunity is a constrained time period which defines a start time and a maximum period. Where as its duration depends on data transmission rate and data length. In group 1, CW value depends on power values i.e. Pt, P_r and P_i values. In group 2, it depends on type of service and all its packet and frame length. In group 3, it depends on type of modulation used whereas in group 4, it depends on traffic rate of the system. There after we calculate the energy consumption and delay of the system. Here objectively user experience is compared of power saving techniques considering energy consumed and delay obtained. The user is concerned by power consumption and communication delay depending on the requirements. Power is consumed while transmitting and receiving the packets, station stays in sleep mode for power saving. Main aim is reduce the power as sleep parameters are taken into account. Also the technique optimizes the sleep timer and sleep duration such that sleep mode do not cause any extra delay.

The main factor to be taken into consideration is proper transmission control while transmitting the packet. High transmission power wastes energy whereas less transmission power outcomes packet loss and retransmission. The time that is needed to transmit all the packets to user during a given service interval is defined as TXOP duration which is estimated at minimum rate R. If Ni denotes the number of packets of mean length Li which arrives during given service interval,

$$N_i = [S_i * \frac{\beta}{L_i}],\ i = 1,2\ldots\ldots n \qquad (13)$$

Therefore, TXOP for each service interval is denoted for ith duration given as

$$TXOP_i = N_i \cdot \left(\frac{Li}{R} + 2.SIFS + ACK\right), \quad i = 1,2\ldots\ldots n \qquad (14)$$

5. Performance Analysis of Existing and Proposed Power Saving Techniques

The performance of the proposed grouping mechanisms has been analyzed in this section. Energy consumption

Table 1. Calculation of CW and TXOP

Groups	Parameters	CW(BI)		TXOP
1	T_{slot}, $CW_{min,}$ $CW_{max,}$ $P_{t,}$, $P_{r,}$ P_i	$2^m - 1$ m= retry limit		$k_j U_j$
2	Frame length, inter-arrivaltime, frame generation interval, AIFS	Voice	aCW_{min}	$N_i L_i/R$
		Video	aCW_{min}	
		Email	$(aCW_{min+} 1)/2-1$	
		Web	aCW_{max}	
3	$T_{CE,}$ $T_{BO,}$ $T_{ACK,}$ T_{DATA}	BPSK	$2^m CW_{min}$	L_p/L_i
		QPSK	$2^m CW_{min}$ -1	
		16QAM	$2^m CW_{max}$	
		64QAM	$2^m CW_{max}$	
4	$T_{SIFS,}$ $T_{slot,}$ T_{BO}	CW_{min}= aN -B		$L_p/r(x)$

and delay has been calculated with respect to varying parameters, namely, nodes and message inter-arrival time. The stations set their contention window as shown in Table 1. In addition, its performance is compared to protocols such as standard IEEE 802.11 and S-MAC. The TXOP duration and contention window decides when the packet is transmitted. This also decides the throughput of system. Also these parameters are taken with respect to IEEE 802.11 ac. The Figure 2 shows average energy consumption for varying message inter-arrival time gives the comparison of different protocols for varying message inter-arrival time. From graph, it is clear that proposed technique with grouping has lower energy consumption than technique without grouping. Also these techniques possess lower energy consumption in comparison with S-MAC and IEEE 802.11. Percentage decrease in energy consumption of proposed technique with grouping compared to IEEE 802.11 is 46.25%.

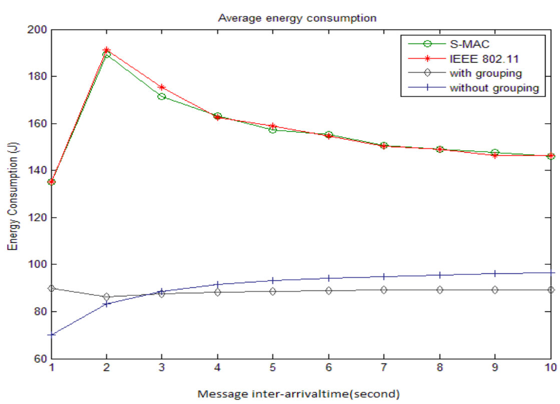

Figure 2. Average energy consumption for varying message inter-arrival time.

The Figure 3 shows the average energy consumption for varying number of nodes. From graph, it is evident that energy consumption first increases as number of nodes increases and then gradually decreases. Here the proposed technique has lower energy as compared to other protocols. Percentage decrease in energy consumption number of nodes which are of grouping technique with respect to IEEE 802.11 is 69.04%. From Figure 4, it could be inferred that the delay increases with varying number of nodes. The increase is rapid in S-MAC and IEEE 802.11. On the other hand, the proposed technique with grouping, delay marginally decreases as number of nodes increases. Percentage decrease in delay of proposed technique with grouping as compared to IEEE 802.11 is 47.29%.

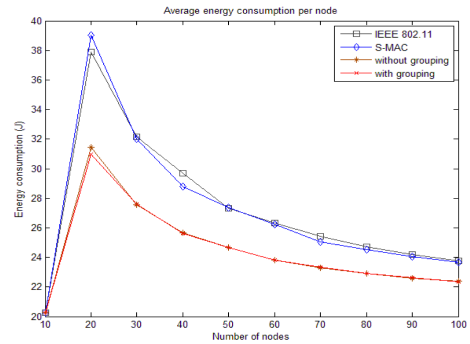

Figure 3. Average Energy consumption for varying number of nodes.

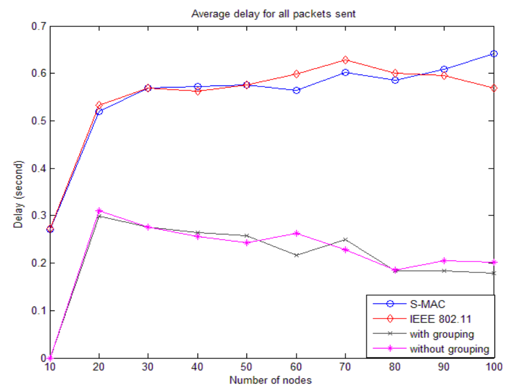

Figure 4. Average Delay for varying number of nodes.

In Figure 5, average delay for varying message inter-arrival time, delay is measured for message inter-arrival time which is varying. The delay for technique with grouping has minimum delay as compared to without grouping. Here, the S-MAC and IEEE 802.11 has higher delay. Percentage decrease in delay of proposed technique with grouping as compared to IEEE 802.11 is 30.84%.

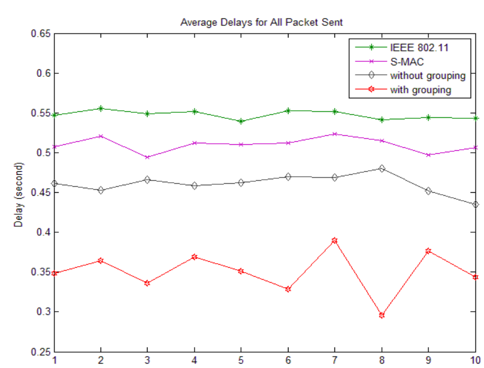

Figure 5. Average Delay for varying message inter-arrival time.

6. Conclusion

This paper suggests a group based adaptive power saving technique for IEEE 802.11ac systems and the results display lower delays compared to systems without grouping. Moreover, the proposed power saves technique helps to improve the lifetime of the user stations by consuming minimum energy as compared to the standard and recent power saving protocols.

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