Energy Aware Contention-Addressing Algorithm in WLAN Wake-Up Based Radio Network Uplink

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Abstract. The increased relevance of WLAN in upcoming wireless technology has made the efficient design of WLAN Medium Access Control an open issue of concern especially in terms of energy. Energy efficiency primarily focuses on carrier sensing, false wakeups, collision ad number of contention rounds. Research has proposed the use of low-power wakeup radio to perform carrier sensing operation which is has the potential of making WLAN have more energy and time for data transfer. However, the reduction of false wakeup and collision are still areas that consume node energy if not properly designed especially when contending stations are much. This work, proposes a IEEE 802.11 wake-up radio algorithm for uplink that employs a Hybrid Contention-Addressing to enhance energy in WLANs. Unlike other methods, the algorithm makes use of a distributed contention strategy to determine which station can wake up for data communication. Contention rounds are used to determine and queue up a set of stations chosen to transmit data. The algorithm greatly reduces false wakeups which arises from delay between sleep and wake up, by broadcasting the ACK frame after modulating the frame with a wake-up message (WuM) Piggybacking the address of the next station to transmit. Simulation results show that the by HCA-CSAM/CA algorithm is able to reduce energy overhead by 97%, which translates to 60hrs increase in battery lifetime and 68.3% reduction in latency as compared with ESOC..

Keywords: Wake-up radio, Medium Access Control, network uplink, IEEE 802.11.

1 Introduction

Typically, the contention-based IEEE 802.11 algorithm grants channel access to the lone station that wins contention while others that failed all wait for another session of contention before they can attempt data transfer [1, 2, and 3]. The down fall of this strategy (especially in large networks) is longer waiting periods and possible loss of buffered data. In addition, extended latency period between “sleep” of a station in a previous transmission and the “wake-up” of the next station (STA) has also been identified as an issue [2].

This work focuses on contention-based IEEE 802.11 enabled wake-up-radio (WuR) algorithm. Using using both addressing and contention techniques, there is the need of an algorithm which is effective in mitigating energy consumption of a wake-up-radio based IEEE 802.11 WLAN. The proposed algorithm enhances energy efficiency of the WLAN stations and as well, increase the wireless LAN battery lifetime. This in turn reduces data latency while ensuring that bandwidth is not reduced. And increases the number of connected devices. Obtained results from the developed hybrid contention-addressing (HCA-CSMA/CA) protocol were compared with that of WuR-ESOC [2].

After this introduction, a detailed literature review of relevant issues on the design is presented in Section 2. Methodology adopted in the design of the algorithm is presented in Section 3. In Section 4, results are discussed and the article is concluded in Section 5.

2 Literature review

In order to save energy, duty-cycling technique depicted in Fig. 1 was developed [4, 5] allowing WLAN modules only wakes up for data communication, otherwise it remains in the sleep mode [4].

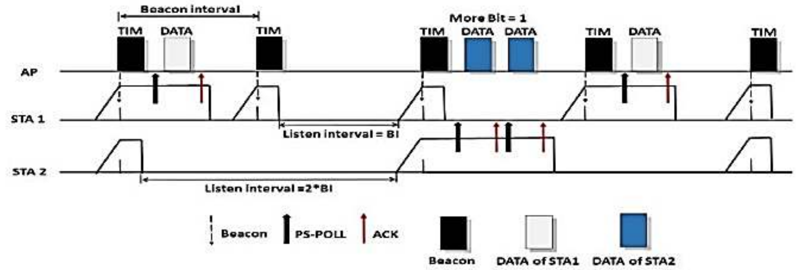
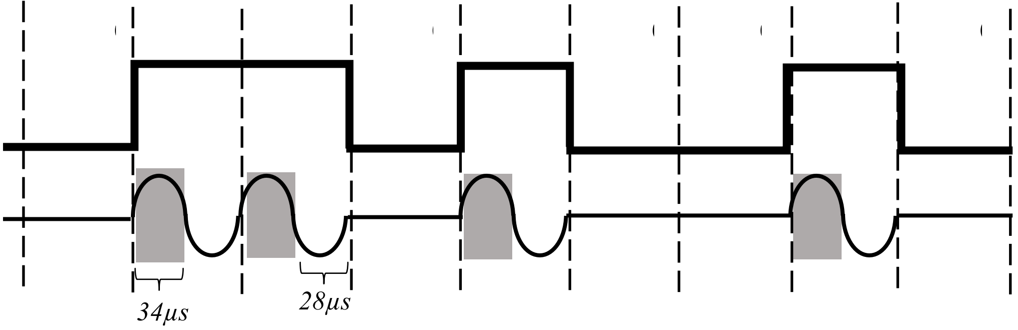


Fig. 1. Legacy Power Save Mode (PSM)

Traditional duty cycling which is used for power-saving in stations is composed of four (4) components which include; power save mode (PSM), Target Wake Time (TWT) mode, Transmission Opportunity Power Save Mode (TXOP PSM), Power Save Multi-Poll (PSMP) mechanism and the Automatic Power Save Delivery (APSD) [4, 6].

With IoT in focus, to increase energy efficiency of devices, the wake-up frontend developed by the task group on IEEE 802.11ba standard was designed as a low-power radio. This takes off the burden of uninterrupted channel sensing from the WLAN module, which translates to energy saving. Our detailed review on this topic can be found in [7].

In a bid to eliminate hardware modification in the module, a WuR system was proposed [9] to enable any IEEE 802.11-enabled device to act as a WuR transmitter via the subcarrier On-Off-Keying (OOK) Modulation scheme. As shown in Figure 2, this causes a high frequency 2.4GHz WLAN signal to emulate the low frequency 15KHz wake-up signal. Another work [3] used idea of varying frame lengths of WLAN signals to transmit wake-up IDs.



▮▮▮ 2.4 GHz envelope detection (IEEE 802.11 empty broadcast frames)

∿ 15 KHz envelope detection (Pseudo–Wake–up call signal)

▬ Bit rate ~ 1 Kbps (Demodulated OOK data)

Fig. 2. On-off-Keying scheme (Modulation)

In order to decrease collision probability in contention-based protocols, the contention Window method is used for scheduling channel access. Improved network throughput has been recorded via dynamic adjustment of Contention window [8, 10]. In [3] energy efficiency was enhanced by adjusting contention window using the WuR. Duty time for every packet was reduced by this. In the work, channel contention is initiated through inter-frame space measurement.

3 The Hybrid Contention-Addressing Algorithm

The **Hybrid Contention-Addressing Algorithm for Energy Efficiency in WLAN Waku-Up based Radio Network uplink (HCA-CSMA/CA)** which allows WLAN users to reduce power consumption is proposed. **HCA-CSMA/CA** maximizes power management by making use of the low-powered WuR for both carrier sense and control. Contention window (CW) is maintained constant while the WLAN transceiver is used only for data communication. The Algorithm is made up of the contention and Addressing Stages as shown in Fig. 3.

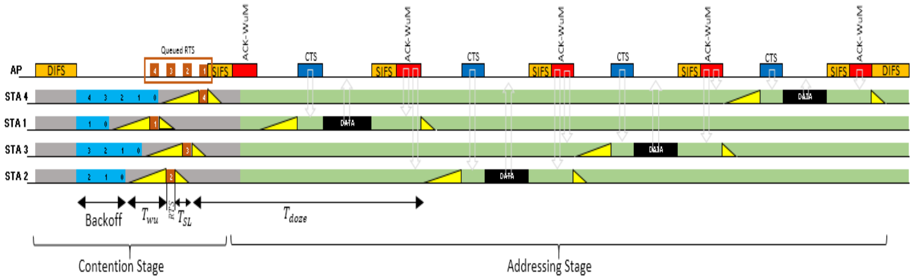


Fig. 3. The proposed HCA-CSMA/CA algorithm

3.1 The HCA-CSMA/CA Procedure

1. At the initialization stage, the size of the contention window is set to a value of CW=w by the AP. For this for work, CW values of 5, 10, 20, 50, 100, 200, 500, 370, 800 and 100 STA's were considered.
2. For every uplink session, the AP is only allowed to obtain a number of stations w from the stations in the cluster N. In order to obtain these w stations, Backoff values (BO) are randomly selected by WLAN modules of STAs. The also set their WuR counter values to BO=i values which is one of the contention window (where i is between 0 and w). This is illustrated in fig. 4. The WLAN module is only woken up by WuR when its count becomes zero. After then, the data transmission takes place.

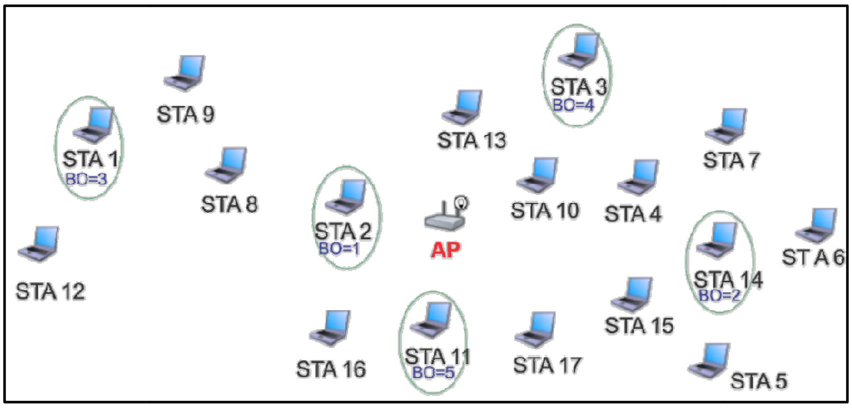


Fig. 4. Basic Service Area (BSA)

3. Since AP is modeled to accommodate a maximum of w STAs per session, only the w of N STAs are allowed to set their BO values to a value between 1 and w. During this period, the backoff counters of the unselected STAs remain idle.

4. When channel is sensed idle for DIFS value (TDIFS = 36µs or 4TSLOT. Where TSLOT = 9µs), the contending STAs starts decreasing their counters from BO=i to zero.
5. All selected w STAs are expected to perform two actions; first, counter decrement and secondly, wake-up. As depicted in Fig. 5, this action synchronizes their successive transmission of their RTS packets. Meanwhile, AP listens to STAs within SIFS before the next action is initiated.

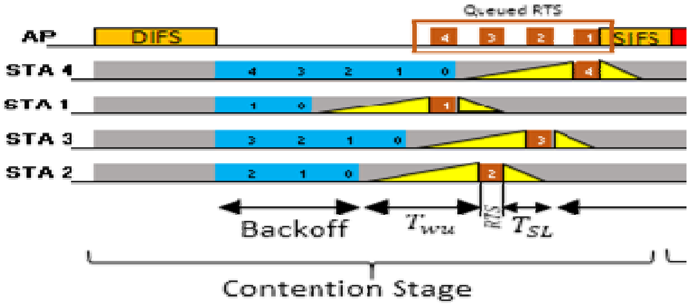


Fig. 5. Illustration of uplink transmissions at contention stage

6. Stations forfeit the opportunity to transmit RTS in an active session after it experiences collision during the active session. It can only try transmission after a fresh contention and selection session.
7. In order to prevent degradation of throughput because of excessive contention window when the network is idle [11, 13], contention windows are only modifiable before the initiation of the session of fetch. This will however be in accordance with the prevailing network condition and traffic.
8. After queuing the successfully received RTS packets, AP uses the collected addresses from the RTSs sent by STAs to sequentially address a CTS packets to the STAs.
9. As depicted in Fig. 6, addressing stage commences. After AP confirms zero channel activity within SIFS, AP addresses a WuM to STA number 1 on the queue. This is possible because of the previously harvested addresses it had from RTS packets sent in the contention stage. AP then observers a wait time of T_{wu} before sending CTS.

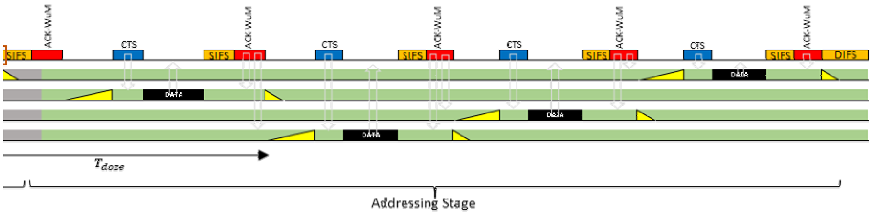


Fig. 6. Illustrating the Addressing Phase for four stations.

10. STA1 wakeup its WLAN module with duration T_{wu} of receiving WuM. It receives the CTS and then afterwards, transmits its data packet.
11. An acknowledgement-wakeup message (ACK-WuM) frame is broadcasted once AP senses the channel idle for a complete SIFS after successfully receiving STA1's packet. This signifies a successful transmission of the packet. The address of the active station is also stated in this broadcast.
12. This ACK also serves as a WuM for the next station on queue (STA2). This is possible, because ACK-WuM frame is OOK modulated with WuM.
13. This ACK-WuM OOK modulated technique creates a sleep/wake-up overlap between two succeeding stations (in this case, STA1 and STA2). This is a major factor that reduces overall network latency when added up.
14. The ACK-WuM frame a STA sends to indicate successful data transfer is also used to initiate data transfer permission for the next STA on the queue. This process continues on till all previously fetched STAs completes packet sending. The next contention cycle is initiated for another w set of selected STAs. The HCA-CSMA/CA flowchart is depicted in Fig. 7.

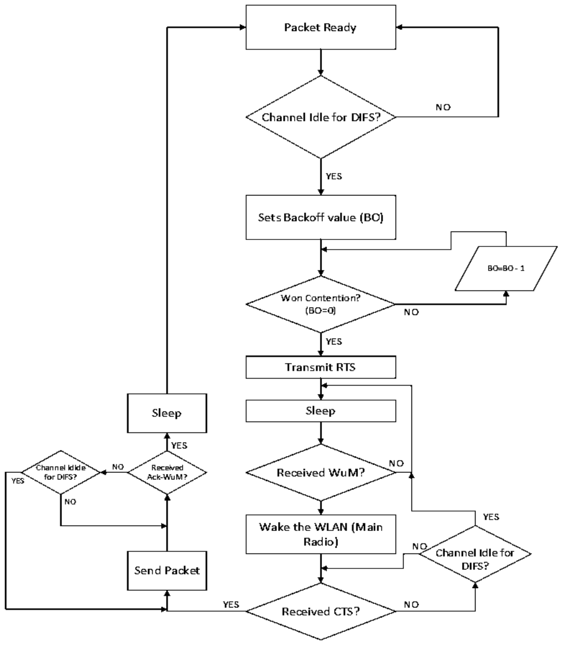


Fig. 7. The HCA-CSMA/CA algorithm Flowchart.

3.2 Simulation Setup Analysis

Using MATLAB simulation platform, the energy expended by HCA-CSMA/CA is studied for both contention and addressing phases. The WLAN modules posses wake-up latency (T_{wu}), WLAN radio cannot communicate during this period, but however consumes power. The considered WLAN for this work consist an AP, N stations. Contention window was set varying values of CW=w. Considering the work in [12] it takes about 139μs to switch from 1/4th clock rate to full clock rate and about 200μs to generate a stable carrier frequency. Hence in this work, latency for wake-up is computed as $T_{wu} = N_{wu} . T_{wu}$ this equals 200μs. This is derived by considering number of slots required for a complete WLAN module wake-up as $N_{wu} = 22$ while considering a slot duration as $T_{slot} = 9\mu s$. Table 1 outlines the definition of main notations used in the performance analysis.

4 Discussion of Results

The results were compared with CSMA/ESOC. The results were generated by from the parameters in simulation setup into the developed model. Performance of HCA-CSMA/CA was aimed to evaluate energy consumption, channel efficiency, and lifetime. The results for CSMA/ESOC were studied and compared with the results of HCA-CSMA/CA.

4.1 Energy Consumption and Lifetime

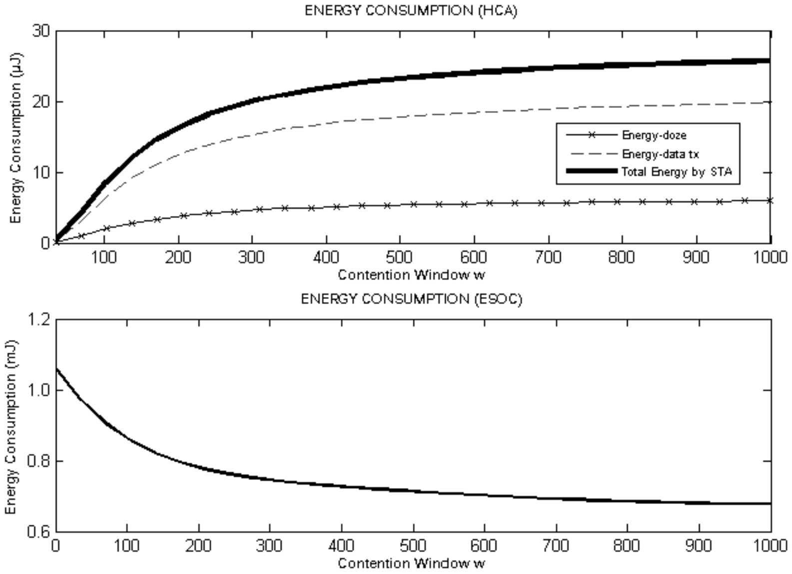
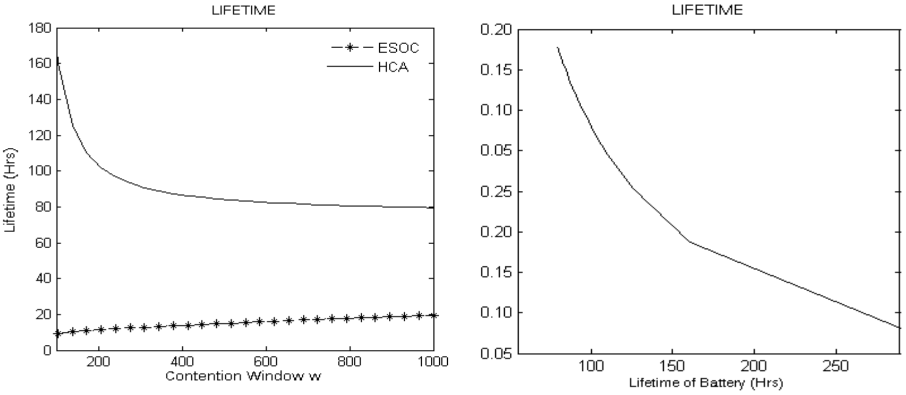


Fig. 8. Total Energy Consumption by STA

Total energy consumed by the STA's front-end (which comprises of the main radio and WuR) is plotted in Fig. 8 against the contention window for both algorithms. When compared with ESOC, HCA offers a 97% reduction in maximum energy cost. The energy utilization increases with the increase in contention window. More significantly, unnessesary period spent before stations send packets which is a characteristic of ESOC and similar protocols is responsible for the increase in energy cost. In the process, WuR does channel sensing which cost energy. At contention phase, energy cost consumed for RTS packet transmission and doze accounts for 30% of the overall energy consumed at the main radio. This is 23% of the total energy consumed by a STA on data packet transmission. About 77% of the total energy consumed is spent by stations for packet transmission. Thus, the minimal use of energy shows that energy is prudently utilized.

The improvement exhibited by HCA-CSMA/CA on energy consumption over traditional techniques is primarily due to the fact that false wakeup probability has been greatly reduced and the fact that STAs spend more time awaiting the reception of WuM packet.



(i) (ii)

Fig. 9. i. Lifetime versus Contention window ii. Power Consumption versus Lifetime

The time duration over which a 3.8V, 4000mWh rated battery rated is expected to fully discharge, also referred to as the "lifetime" is plotted against the power consumption in Figure 9(ii). As deduced from Fig. 9 (i) and (ii), a maximum power consumption of 190.9mW for a contention window of 1000 will result in a battery life of 79.62h (3.3175 days). At lower contention window of 102, the battery life is extended to 206.9hrs (8.62 days) due to the reduced power consumption resulting from lower STA-fetch size which translates to reduction in energy for processing their transmission. The lowest battery lifetime of the HCA exceeds the peak for the ESOC by approximately 60hrs (2.5 days) due to the reduced probability of false wakeup and longer time spent in sleep mode by the WLAN module.

4.2 Channel Efficiency

Fig 10 shows that the channel usage with respect to average time for data transmission (T_{avr}) increases with contention window size. At 1000 value for contention window, 83.86% channel efficiency is achieved. The time spent for queuing RTS packets and addressing the un-sensed CTS on the channel is responsible for the 6.14% reduction of channel efficiency with respect to ESOC.

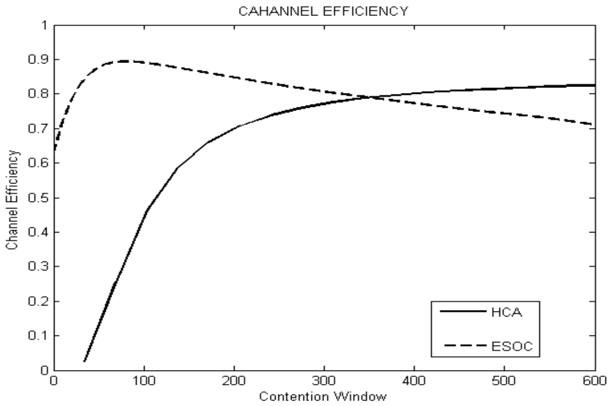


Fig. 10. Graph of Channel Efficiency

5 Conclusion

In this paper, presents how energy consumption of IEEE 802.11 WLAN can be greatly reduced by HCA-CSMA/CA. Ideal channel conditions and finite contention window value were considered in this model. Simulation results prove the efficiency of the algorithm in conserving energy. CSMA/ESOC shows 97% maximum energy consumption above ESOC in other words, approximately 60hrs the peak battery lifetime exceeds that of ESOC.

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