A Review on Energy Saving Techniques for Wireless Local Area Networks (WLAN)

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***Abstract*—Energy efficiency issues is becoming paramount important with the increasing number of internet based application deployment. With the growth of internet application deployment, there is a huge increase in the number of WiFi enabled devices which leads to increased deployment of WLANs. Increased energy consumption has several detrimental effects. In general, it leads to a rise in greenhouse gases as well as contributes to higher cost of business operation. Specifically, for WLANs since the user devices are mostly battery operated which limits the useful lifetime of a terminal, thus managing energy efficiently is extremely important in such devices to prolong the battery life. This paper presents a comprehensive review for energy saving approaches proposed for the WLAN.**

***Index Terms*— Energy Efficiency; Energy Saving Approaches; WiFi; WLAN.**

I. INTRODUCTION

Wireless communication has witnessed an explosive growth towards applications and diversifications, leading to a significant evolution in its usage and deployments. This is due to increases in the deployment of network infrastructure in parallel with the rising demands of Information and Communication Technology (ICT) services, which in turn increases the traffic volume and applications in a network. This is supported by statistics provided by the International Telecommunication Union (ITU) which show a significant increase in ICT usage over 15 years since 2000 until 2015, as depicted in Figure 1[1]. Based on this figure, with an increasing trend in customer traffic levels, the need for operating energy is growing at a rapid pace.

These increases in demand of wireless services contribute to higher energy consumption as well as an increase in carbon footprint. SMART 2020 from The Climate Group [3] claims that currently, The ICT contributes to almost 5% of the whole power consumption and due to this, Energy Efficiency (EE) has significant economic benefits. This paper discussed a comprehensive study of state the art solutions for energy efficiency in WLAN networks. In this paper, energy saving techniques for WLAN can be categorized based on physical and MAC layer techniques.

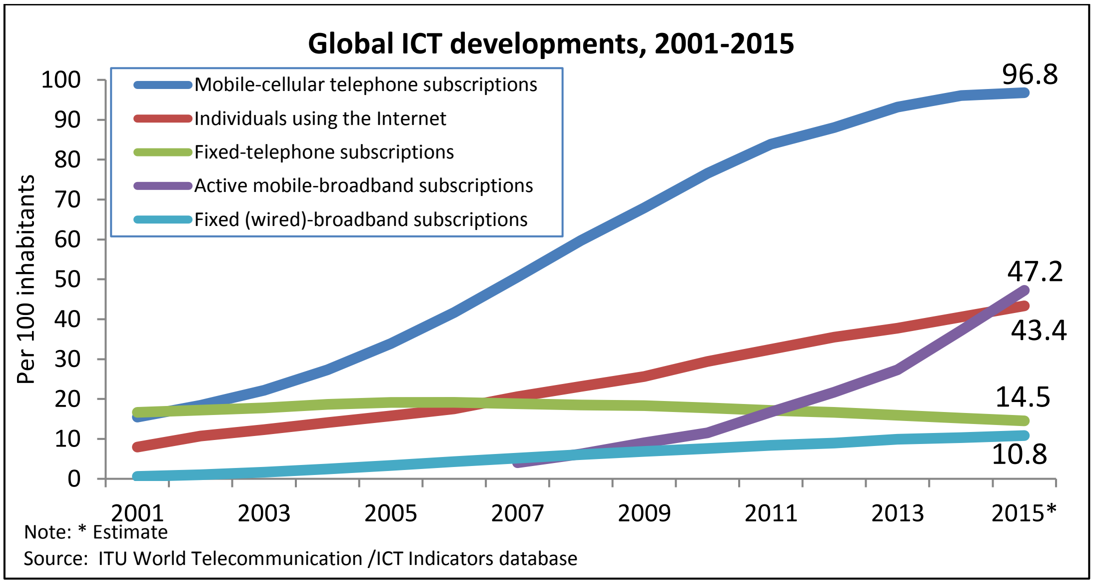

Figure 1: Information Communication Technology (ICT) growth over last 15 years [2]

II. Energy Efficiency Issues In WLAN

Reducing the energy consumed by wireless communication devices is perhaps one of the important operational issues for the widely deployed IEEE802.11 WLANs. Thus, managing energy efficiency is extremely important in such devices in order to prolong the battery life. Different researchers have studied the energy efficiency issue and based on their research outcomes, various Physical and MAC layer techniques have been proposed. Some of the techniques were developed to optimize the current algorithm uses in the above layers, whereas other techniques propose new radical changes. Figure 2 shows taxonomy of the energy saving techniques designed for WLANs.

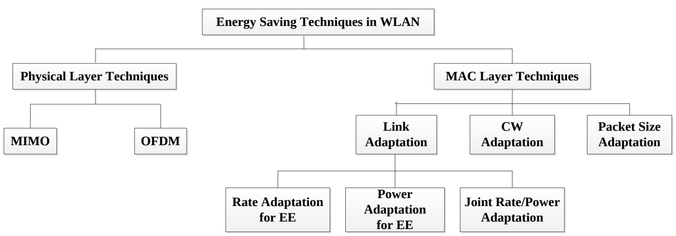

Figure 2: Classification of energy saving techniques for WLANs

Numerous energy saving techniques has been proposed for WLANs. These techniques can be broadly categorized into PHY and MAC layer techniques. The physical layer provides functions such as modulation, channel coding, power control, etc. The MAC layer manages or allocates the wireless resources to all users. The MAC layer perform multiplexing, as well as scheduling tasks, and to some extent handling the Quality of Service (QoS). Therefore, both layers are considered for energy efficiency approaches. The following section gives a detailed explanation of each class.

III. Physical Layer Approaches

The PHY layer represents the electrical and physical parts of a wireless device. Specifically, it defines the relationship between the device and the transmission medium. One of the roles of PHY layer is performing the modulation of the digital data in user devices and the corresponding signal transmitted through the wireless channel. Physical layer techniques can be further classified into two basic types, based on their functions as discussed in the following section.

A. Multiple Input Output (MIMO)

Advanced signal processing technique uses by MIMO devices, which is spatial multiplexing, increases the capacity or spectral efficiency by sending independent information streams in parallel over different spatial channels. This technique improves throughput and reducing the energy consumed. Increases in spectral efficiency leads to smaller transmission duration, which decrease the circuit and transmit power consumptions. To balance both circuit energy and transmission energy, adaptive modulation can be applied, together with the MIMO technique.

Qiang et al [4] provide a framework which is a combination of cooperative MIMO and frame aggregation for an energy minimization approach. Communication is split into two parts, which are local communication (among nodes in a cluster) and long haul communication (between central nodes and the AP). Data aggregation is applied in both communications. During long haul communications, the data is compressed using a space time block coding (STBC) technique. There are two approaches during long haul communication. Firstly, the transmit power is reduced by using the cooperative MIMO (grouping of several nodes and the AP which represents the multiple input single output). Secondly, the data aggregation technique applied reduces the amount of transmitted data. The results demonstrate that the energy efficiency is significantly improved due to the joint technique, as compared with either the cooperative MIMO system without data aggregation or the data aggregation system without cooperative MIMO.

B. Orthogonal Frequency Division Multiplexing

The OFDM technique uses large number of subcarriers transmitted in parallel. The carrier waveforms are spaced orthogonally to each other in order to avoid crosstalk or interference among subchannels. The OFDM technique offers high spectral efficiency. Multiple accesses are attained by allocating dissimilar sets of orthogonal subcarriers to every user. The advantage is that a subcarrier could be adaptively assigned to the users which experienced high signal to noise ratio (SNR) (good channel). Thus, system capability could be increased, which is identified as multi-user diversity. In OFDM, multi-user variety can be used not only to increase network capacity but also to reduce energy consumption. This is because when a good channel is assigned to the specific user, the transmit power can be extremely decreased. According to this observation, an optimal resource allocation (subcarriers and channel gain) scheme and link adaptation is exploited for an energy efficient OFDMA system, as presented in the following papers [81-84].

The research is drawn-out to the case of a frequency selective channel, as presented by Miao et al. [5, 6]. It is proved that greatest energy efficiency can be attained by adjusting the overall transmission power based on channel conditions. The work as proposed in [6] developed an iterative procedure to gain optimal link adaptation solutions which adjust the power transmission as well as its allocation (subcarriers and channel gain) with the key goal of decreasing the energy consumed. This link adaptation according to channel state information to adjust the transmission data rate, transmit power and resource allocation. From the analysis, they determine three ways to expand the energy efficiency. The simulation analysis depicts that at least a 15% enhancement in energy efficiency is attained when applying this concept and the improvements depend on how much frequency diversity occurs within the channel. The link adaptation technique for MIMO-OFDM which could reduce the energy consumed with respect to the QoS constraint is proposed in both studies [7].

IV. MAC Layer Technique

The MAC layer manages the functions and procedures for transmission of data between network entities by providing access to a transmission channel using either contention based and contention free techniques using different types of physical layers. The MAC layer can reduce the energy using several approaches. Optimization or adaptation of several MAC layer variables, for example the combination of power with transmission data rate via link adaptation, contention window adjustment, packet size adaptation, fragmentation threshold and other MAC layer parameters leads to conserving the energy consumption [8-10]. Another solution is applying a scheduling technique where the energy saving can be achieved by shutting down system components during inactive period [11-13]. The subsequent section discusses each technique and provides the works in literature related to those approaches.

A. Link Adaptation Techniques

Link adaptation was able to adapt the MCS and transmission power as stated by the channel environments on the radio link. Power adaptation is a method used for selecting relevant transmission power level to match the channel condition for the correct reception of a data. By taking advantage of good channel conditions, the link adjustment mechanism usually is applied to increase the throughput [14]. The transmitter adapts its MCS value to improve the data rate based on channel SNR values.

An energy aware rate adaptation model to choose the data rate for next following transmission has been develop by Muhammad et al [15] with aim to minimize the energy. As result, their protocol selects MCS according to lowest energy consumption. Li et al [17], propose CARLA (Cooperative Relaying and Link Adaptation), an algorithm which join link adaptation and supportive relaying technique to enhance both the throughput and reduce energy. CARLA use RTS/CTS exchanges and predicted packet transmission time to estimate current congestion level. Jinglong et al [16, 17] come out with transmission power adaptation technique for energy saving. The power control mechanism of transmission power adaptation proposed two phases which are initialization and the updating phases. During updating phase, the PDR and level of transmit power correlation is updated. Minimum energy consumption can be achieved with optimal transmission power as been suggested.

The work in [20] using a scheme as a power control mechanism for many-hop different rate 802.11 networks. The transmit power is increased to improve quality of the signal. To estimate the upper power bound of the link, the method is based on the acknowledgement (ACK) information exchange. Regarding queue length observation, the transmission power is greater than before which is based on estimated power bound and at the same time switches to a high level of modulation pattern if traffic demand is not met. Simulation analysis indicates that, this scheme could track and expand the traffic requirement compare to Automatic Rate Fallback (ARF) scheme. A Signal Interference Noise Ratio (SINR) (STPC-MAC) was proposed by Duc Ngoc et al [18]. The approach allows the nodes transit to doze mode whenever no packet transmission executes. By applying this technique, energy will be conserved. The proposed scheme main idea is to use the Traffic Indication Message which is called (ATIM) window. The ATIM message is exchanged with information of transmission power.

B. Energy Efficient Contention Window Adaptation

Reducing the number of collisions can be one of the approaches towards improving energy efficiency. It can be related to the number of retransmissions required for packet transmission. This is because lower numbers of collisions reduces the congestion in the network which contributes to a greater packet success rate, thereby reducing the number of retransmissions required which also decrease energy consumed. Most of the methods involve enhancements of DCF protocols.

Numerous studies have introduced efficient collision resolution algorithms based on CW adaptations to reduce collision levels. Shakir et al [19] present a mechanism to reduce the global collision rate as well as time delay. To reduce the collision rate, the algorithm mechanism measures the congestion rate of the channel as a guide before determine the initial size of the CW[i]. The primary CW[i] size of the corresponding AC is updated dynamically. The work proposed by Krishna et al [20] come out with a method known as algorithm of virtual backoff which is an efficient MAC according to sequencing approach. Level of collisions and delay are reduced during the backoff times. For this scheme, un-biased distributed technique is used to access the channel where each node uses a counter. The approach set a boundary to limit the total number of packet transmission. Simulation analysis confirmed that the proposed scheme maximize the bandwidth utilization where the throughput is increased up to 75%. Besides that, level of collisions decreased to 65% as compared to the legacy protocols. Rathanakar et al [21] demonstrate the scheme which adaptively alter the size of CW according to priority value. The scheme provides two main objectives which are take full advantage of higher throughput and decreasing level of internal collisions. To maximize the throughput and reducing level of collisions, all stations share the resources equally. Two different stages is provided and for all stages, assumed that station with access categories of AC2 and AC3 is applied. The simulation results show that the proposed algorithm performs better in terms of channel throughput and collisions level than the other prominent algorithms.

C. Packet Size Adaptation

Other efforts taken to enhance energy saving for wireless transmission is by analyzing the effect of packet size. The optimum packet size depends on the channel conditions. This has been the basic principle behind packet size optimization, especially in poor channel conditions. Packet size adaptation focuses on collision reduction to reducing energy consumption. Analysis of CW and packet size which give effects towards energy efficiency was carried out by Xiadong et al [22]. The work come out with analytical model with goal of reducing energy consumed under an ideal channel and error prone channels. The main focus of the work is to investigate on how the CW and packet size gives effects towards reducing energy consumed. Besides that, the trade-off between lowering the protocol overheads via using of larger packet size and decreasing the packet error rate by applying smaller size of the packet. From the analysis, it is shown that the Distributed Coordination Function (DCF) with ready to send/clear to send (RTS/CTS) reduces more energy as compared to the basic scheme. The research concludes that a shorter packet is preferred as the channel conditions deteriorate and under ideal channel conditions, adapting to a bigger packet size, DCF which applies RTS/CTS results in much lower energy consumption. The research in [23] using a distributed adaptation algorithm of packet length where individual node adaptively changes their packet size according to the estimation of probabilities for each significant packet loss. In this technique, an AP acts as a main controller which periodically broadcasts channel occupancy information. Based on this information, each station adjusts the packet size accordingly, together with its own local observations.

V. CONCLUSION

Energy saving mechanism can be classified based on layer approaches which are physical and MAC layer schemes. For the physical layer techniques reviewed in this chapter, the link adaptation is used to deals with channel condition for maximizing the throughput based on several channel indicator parameters. According to the channel indicator, the transmitter adapts the Modulation and Coding Scheme (MCS). For MAC layer approaches, it is observed that the main insufficiency of most distributed contention MAC procedures emanates from packet collisions. Thus basic principle of the reviewed techniques is collisions reduction. Most of the reviewed techniques of CW adaptation proposed an aggressive adaptation of CW either based on consecutive successful packet transmission or congestion rate as discussed. The reviewed techniques in this paper can be extended to develop an energy saving techniques as will be proposed in future works.

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