# Cognitive Radio-based Power Adjustment for Wi-Fi

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*Abstract*—**In this paper the idea of using Cognitive Radio (CR) techniques to optimize the access point (AP) configuration for IEEE 802.11 WLAN was exploited. In particular, we address the issue of optimizing AP transmission power and channel allocation within the network. The aim is to optimize the overall network performance by adjusting the transmission power of the APs and minimizing the non-adjacent co-channel interference in an extended service set (ESS) area. The goal of CR is to use the heuristic approach in sharing the spectrum among the active nodes without degradation in the network performance. In order to have a successful data transmission among the active nodes, an efficient transmission power adjustment algorithm is needed. The algorithm considers the overall power distribution between an AP and another co-channel non-adjacent AP using CR techniques as well as control the switching to other APs to optimize the overall network performance.**

***Keywords-Wi-Fi, ESS, cognitive radio, power adjustment***

## I. Introduction

Wi-Fi (IEEE 802.11) is a renowned technology deployed in most of the places such as campuses, offices and some public areas. The rapid increasing of the wireless communications requires some solutions to enhance the network performance and avoid any bottleneck that occurred during data transmissions. This WLAN is a flexible data communication technology that enables users to move in this infrastructure network. Due to this reason, the number of WLAN installation is increasing and they actually share the same frequency spectrum which is in fact a scarce resource. This type of network is created by placing a set of APs in a geographical area and it is connected to the Ethernet. But blindly placing the APs might cause interference.

Interference is the main reason why the capability of network cannot be fully utilized. Two types of interference can be distinguished: adjacent channel interference where it is produced by its transmissions on adjacent or partly overlapped channels; and co-channel interference which is caused by the same frequency channel.

Interference is minimized using three basic methods; AP placement, adjusting the transmission power and optimizing the AP frequency channel [1]. This work will be focusing on adjusting the transmission power of the APs by taking into consideration the co-channel non-adjacent AP. Transmission power affects directly the transmission range of an AP and cannot be simply adjusted.

According to IEEE 802.11 standard [2], the node will be associated to the AP that has the highest received signal strength indicator (RSSI) at the receiver. Consequently, more nodes will be connected to the highest RSSI that resulted in overloading at the particular AP. Beside this problem, for AP that uses the same channel or different overlapping channels, interference may occur among them. Pre-allocating the channels to each AP and adjusting the transmission power are the possible solution to the stated problem.

This research proposed a new model for Wi-Fi (IEEE 802.11) network to improve the overall network system performance by adjusting the transmission power based on the estimation of the distance between the AP and the associated WS. Some heuristic approach using cognitive radio techniques may be feasible in order to better utilize the AP transmission power among the WSs in an ESS. A heuristic algorithm is proposed at the initial stage that only focusing on the static WS.

The paper is structured as follows: first, is a brief description of the two main topics of the paper: IEEE802.11 architecture and cognitive radio in an infrastructure network. Section III describes some related works and Section IV describes the proposed solution based on the heuristic approach of CR. Finally, the conclusion in Section V.

## II. Theoritical Background

### A. IEEE 802.11 Architecture

It is well known that the IEEE 802.11 MAC can be modeled based on the CSMA protocol for radio wireless. A CSMA/CA (carrier sense with collision avoidance) is used as a medium access control scheme. The access mechanism is based on the 'listen before talk' approach, i.e. each station that is willing to use the shared resource listens to the channel for the ongoing communication before attempting its own access. If the channel is sensed busy the station refrains from transmitting. Beside the above mentioned mechanism, the specification also contains a four-way frame's exchange protocol called RTS/CTS mechanism. A station will send a control frame called Request-to-Send (RTS) and received a Clear-to-Send (CTS) frame as a response to the station. Then the actual data frame is send to the corresponding station and will receive an acknowledgement if the transmission is successful.

RTS/CTS mechanism can ideally eliminate most interference faced by the WSs. However, in an open space environment, RTS/CTS cannot function well when the distance between the transmitter and the receiver is larger than 0.56 times the transmission range [3].

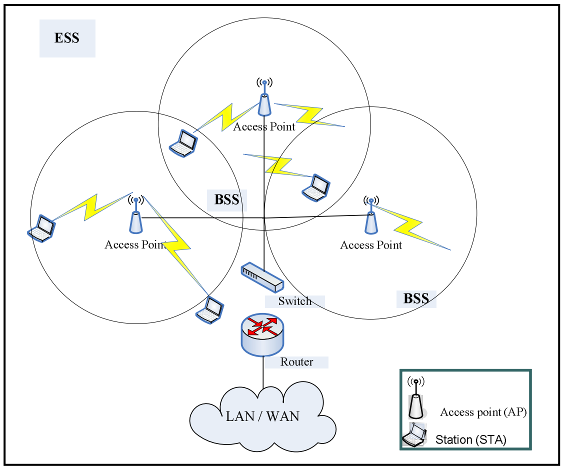


Figure 1. IEEE802.11 Architecture

As defined in IEEE 802.11 standard [2], the protocol supports the architecture that comprises of several components that interact to provide WS mobility in WAN. The architecture of IEEE 802.11 is shown in Fig. 1. The most basic type of IEEE 802.11 LAN is the independent basic service set (IBSS). It is also known as ad hoc network where the communication is among the WS.

In an infrastructure mode or known as basic service set (BSS), the basic network components consists of the WS, the wired stations and an AP conveying the bridging function. A connection with more than one BSS is an extended service set (ESS). In an ESS deployment, where multi-APs are deployed, there will be a high possibility of overlapping coverage areas.

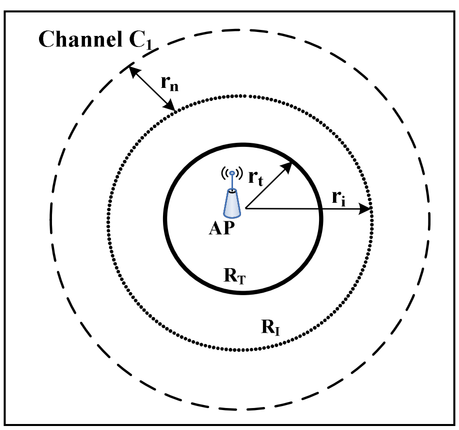


Figure 2. Transmission range and interference range

In wireless network, each AP is associated with a transmission range, $R_T$ and interference range, $R_I$. $R_T$ and $R_I$ are directly depends on the node's transmission power [4]. Fig. 2 shows the specified $R_T$ with a radius of $r_t$ and $R_I$ with a radius of $r_i$. $R_T$ represents the range within which all transmissions are successful if there is no interference from other nodes. Whereas, $R_I$ is the range within which the receiving nodes will be interfered with other transmitters and might suffer a loss.

An additional no-talk radius, $r_n$, is also defined to indicate that no transmission in that area. Under the so-called protocol model [4], a transmission is consider successful if and only if, the receiving node is in the transmission range and out of the interference range of all other transmitting nodes. Prateek and Ahmed have proposed an algorithm for transmission power assigned to AP under interference constraint [5]-[6]. Their solutions assume a protocol model similar to this work.

### B. *Cognitive Radios*

Cognitive radio refers to wireless architecture where the communication system does not operate in a fixed assigned band but rather searches and find an appropriate band to operate [7]. It can adjust its configuration based on the radio environment, so that other WSs can efficiently share the limited spectrum resources.

Basically, cognitive radio network consist of a set of nodes; secondary transmitter, secondary receiver, primary transceiver and primary receiver. The primary users are the user with license; whereas the secondary users are the unlicensed users. In order to find spectrum holes, the CR will dynamically adapt its transmission while minimizing the interference that may occur to the primary users. In a cognitive radio network, the secondary user (unlicensed user) will find an opportunity in sharing the spectrum without causing any interference to the primary user.

CR will be employed according to a cognition cycle that was originally described by [8] as the fundamental activities in order to interact to the environment. Fig. 3 shows the activities that a CR should perform: observation, orientation to determine its importance, creation of alternative plan, decision making and implementation of the actions.

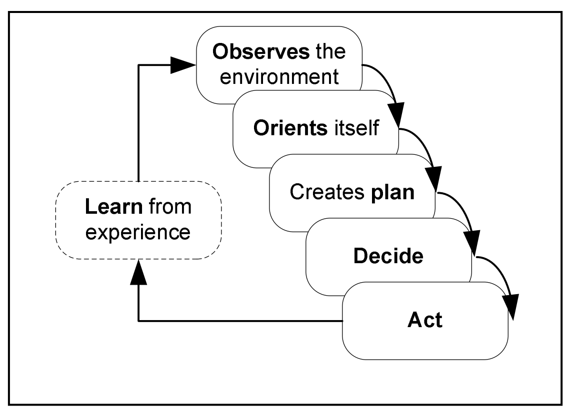


Figure 3. Mitola's simplified cognitive cycle

Cognitive radios merge artificial intelligence (AI) and wireless communications [9]. The research adapts the idea of using CR techniques that can intelligently decide on the transmission power level based on its environment. However, it only apply CR techniques heuristically in the AP without physically implements the cognitive radio network. Some related works is describes in the next section.

## III. RELATED WORK

Implementing a wireless communications with an optimal power adjustment has been widely studied. Transmission power and channel allocation are important to define the coverage range for each AP in IEEE 802.11 WLAN [4].

A lot of work has been done to adjust the transmission power of the transmitter to the active nodes in a wireless network. This paper focuses on adjusting transmission power in an ESS of an infrastructure network by pre-allocating channels to the APs. As mentioned earlier, the work adapts cognitive radio techniques as the solution.

Previous researchers have done some work on adjusting the transmission power of the AP in a WLAN using cognitive radio network [4], [10]-[13]. The main challenge of cognitive communication lies on how to balance between the conflicting goals of maximizing the performance of secondary user, which is the cognitive radio (unlicensed) and minimizing the interference to the primary user (licensed).

Hoven [10] in his research work uses received SNR as a proxy for distance to prove that a cognitive radio can vary its transmission power while maintaining a guarantee of service to primary users. Nevertheless, [13] focuses on quantifying the impact of the transmission power of secondary user on the occurrence of spectrum opportunity, i.e. the transmission power of a secondary user does not only determine the communication range but also affects the availability of spectrum opportunities. The work done by [11] focuses on the interference avoidance approach to cognitive radio, where the secondary user periodically monitors and detect the occupancy in different frequency bands and communicates over the spectrum holes.

Research done by [4] and [11] take into considerations of transmission range and interference range where power control is part of the optimization space. This work will look into the interference among non-adjacent co-channel APs by considering the two ranges (transmission range and interference range) in ESS infrastructure network.

Ahmed in [6] applies a successive refinement approach in order to improve client performance by coordinating the choice of channel and power levels at wireless AP but not on cognitive radio network. Yu et.al solves the same problem by proposing a new framework for radio channel allocation (RCA) strategy for WLAN APs with power control capabilities [14].

## IV. THE PROPOSED MODEL

This section describes the initial algorithm which performs power level adjustment using CR techniques which tries to optimize power adjustment in Wi-Fi. The algorithm takes into consideration the distance between a WS and the associated AP in a multi-AP deployment. However, the algorithm would be generic enough to be adapted in a single-AP deployment.

In the scenario as shown in Fig. 4, the channels are pre-allocated to the APs in a way that it will not interfere with the adjacent AP. But there are possibilities that interference will occur from the non-adjacent co-channel APs.

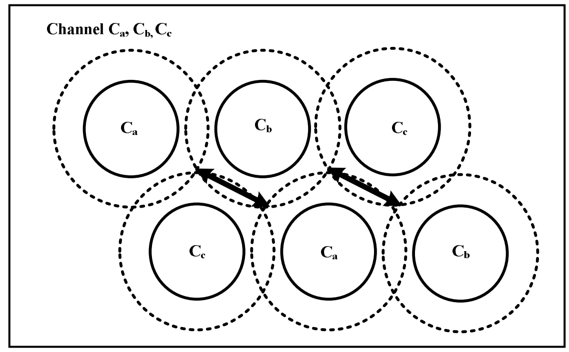


Figure 4. The topology of non-adjacent co-channel APs

A simplified topology is shown in Fig. 5 as the proposed network model that consists of three APs and several WSs, where some of the WSs are associated to their respective APs. As mentioned earlier, in this initial work phase the WSs are static. Each AP will have its own transmission range, $R_T$ with a radius of $r_t$ and interference range, $R_I$ with a radius of $r_i$. The channel of the middle AP ($AP_2$) is different from the other two APs.

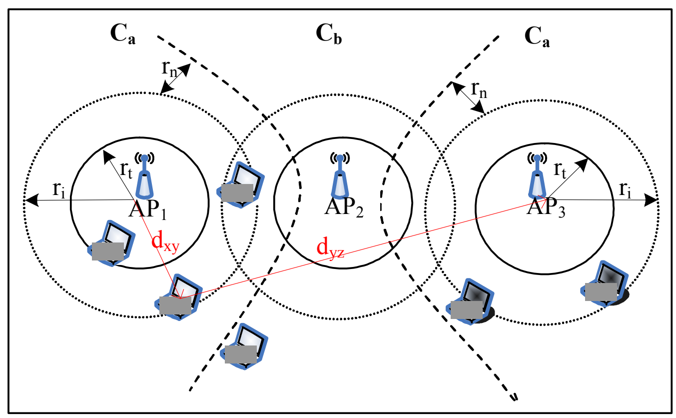


Figure 5. The simulation scenario

There are some assumptions made in the proposed model where all transmissions are to be omni-directional. Transmission range, $R_T$ and interference range, $R_I$ for each transmitter (AP) is centered at the AP position. Therefore, by adjusting the transmission power, both ranges can be controlled. $R_T$ is defined as the maximum range for a transmitter to transmit a signal that receiver can decode. Whereas, $R_I$ is the interference range for the AP that may interfere to other co-channel APs or overlapping channel APs.

We assume all APs belong to the same wireless LAN network and thus are connected to the same Ethernet backbone. A constant bandwidth is provided by a channel at an AP regardless of the number of users and the receive sensitivity are the same for all nodes. This paper only considers AP to AP interference where power adjustment only can be done at the AP and not at the WS where the WSs have a fixed power level.

The WS within the $R_T$ of the $AP_1$ will be guaranteed of any transmission occurrence without the node moving to other location. This also applies to other WSs within the $R_T$ of $AP_2$ and $AP_3$.

The idea behind the algorithm is to have an acceptable power level transmitted to the active WSs. The adjustment of the power levels are based on the estimated distance of the WS until the maximum power is reached, or when the transmission begins to interfere with another non-adjacent co-channel AP.

First, this proposed heuristic algorithm will estimate the distance between the AP and the WSs. This distance will determine the transmission power level according to the transmission range and the interference range of each AP; which one relates. The distance is proportional to the RSSI for the WSs. Thus, the RSSI information will be sent to the AP by the RTS packet. Based on the estimated distance, the algorithm will make some decision on the transmission power level. The algorithm will also consider other WS in the same range by repeating the process.

We defined $d_{xy}$ as the estimation distance between the WS and the associated AP. Whereas; $d_{yz}$ is the estimation distance between the WS and the other non-adjacent co-channel AP. While $d_{xy}$ is within the $R_I$ of $AP_1$, and $d_{yz}$ is greater than $r_i + r_n$ of $AP_3$, the algorithm will check whether the WS is at the overlapping area or not. Transmission power will be incremented in order to obtain a successful transmission. Otherwise, the WS located at the overlapping area will handover to the adjacent $AP_2$, if transmission power, $P_{tx(AP2)}$ is greater than $P_{tx(AP1)}$ or else it remain its association with $AP_1$.

Based on the IEEE 802.11, a WS will associate to the highest RSSI. Uniform traffic load is assumed among all the APs. The algorithm will be repeatedly adjusting the transmission power level until it gets an appropriate power level for all the individual WSs to improve the overall network system performance. The transmission power level will be reduced, increased or remains the same. The process of handover to another AP will also happen if appropriate power is received from the AP. Finally, if the WS is located beyond the $R_I$ of an AP, no transmission will be executed due to out of coverage area.

By controlling the transmission power, the transmission and interference range can be adjusted. The proposed algorithm adapts cognitive radio that can be seen as the intelligence in maximizing the utilization of communication channels using reasonable power level. Each AP will be the secondary AP by assuming other APs as the primary APs. Therefore, those APs should avoid the interference to the primary AP. As for the other co-channel AP, for example; $AP_3$, will also assume the same thing where it considers itself as a secondary AP.

The algorithm is based on the WS position, whether it is situated:

- within the transmission range of an AP;
- in between both transmission and interference range of an AP;
- in the overlapping area OR
- beyond the interference range of an AP.

This work applies the CR techniques on Wi-Fi where only unlicensed band is used. Therefore, only secondary AP is being implemented. Thus, only one pair of secondary transmitters and receivers while all others are the primary transmitters and receivers. Therefore, from each AP's perspective, the AP itself is the secondary user and other APs are the primary users. For instance;

- $AP_1$ will assume $AP_2$ and $AP_3$ as the primary users;
- $AP_2$ will assume $AP_1$ and $AP_3$ as the primary users;
- $AP_3$ will assume $AP_1$ and $AP_2$ as the primary users;

On the contrary, in a physically cognitive radio network, the secondary user (unlicensed users) may have access to the spectrum under the condition of no interference to the primary users (licensed users).

Finally, a centralized decision-making on power adjustment algorithm will be implemented to be added to the architecture of wireless LAN infrastructure network which considers multi-AP deployment where the co-channel inference is the main constraint.

**Algorithm** : Heuristic Power Adjustment Algorithm.

A = { $AP_1, AP_1, \ldots, AP_i$ }

**if** $d_{xy} \leq r_t (AP_1C_a)$ **then**
/*node within $R_T$*/
*remain $AP_1$'s transmission power*

**While** $d_{xy} \leq r_i (AP_1C_a)$ AND $d_{yz} \geq (r_i + r_n) (AP_3C_a)$
/*protocol model*/
*Estimate the distance $d_{xy}$ based on RSSI from RTS packet.*

**if** $P_{tx} (AP_1C_a) \neq P_{max} (AP_1C_a)$ **then**
/*if power not max*/
**if** $r_t (AP_1C_a) \leq d_{xy} \leq r_i (AP_1C_a)$ **then**
/*node between $r_i$ and $r_n$*/
*increase $AP_i$'s power by one step*
*associate to the $AP_i$*
**end if**
**else if** $P_{tx} (AP_2C_b) > P_{tx} (AP_1C_a)$ **then**
*handover to $AP_2$*
/*have to switch to different channel AP2*/
**end if**
**end while**

**if** $d_{xy} \leq r_i (AP_1C_a)$ **then**
/*outside the transmission range of all APs*/
*no transmission*
**end if**

## V. CONCLUSION

Finding an optimal configuration even for a simple problem is hard; this algorithm with a simple heuristic approach is expected to be the solution. An algorithm for optimizing power adjustment in Wi-Fi is presented for optimal performance of the whole network. The algorithm applies cognitive radio capability to achieve balanced distribution of power level among the APs.

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