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COGNITIVE ENERGY EFFICIENT FOR CLOSED-PROXIMITY DEVICES: AN EMPIRICAL STUDY AND STANDARDIZATION ISSUES

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ABSTRACT

We describe empirical study findings on the impact of throughput performance when transmission power is adjusted among access points in closed-proximity network devices. The experiment was conducted in an office environment to emulate such wireless LAN network. We introduce a potential energy efficient mechanism based on cognitively learning one of the attributes which then triggers the power selection. We show that similar throughput performance at the client can be obtained at reduced transmission power thus prevent an access point from maximizing power unnecessarily. We have also evaluated the impact of increasing and reducing power to other neighbouring access points. It was found that the improvement of throughput is increased to 44% maximum. Throughput performance alert is introduced in the mechanism to be aware of sudden throughput changes in the system.

Key words: transmit power control, interference, dense network, cognitive radio system.

INTRODUCTION

A promising solution to resolve the exponentially increasing demand for wireless data services is to have the concept of small-cell networks. It is founded by the idea of a very dense deployment of self-organizing, low-cost and energy efficient devices. It is well known that cell size reduction is the simplest and most effective ways to increase system capacity (Hoydis, 2011). The 5th generation (5G) of mobile radio access technologies is expected to become available for commercial launch around 2020. It is envisioned that 5G system design for optimized small-cell deployment will start to play a very dominant role to meet multifold capacity and user data rate demands (Mogensen, Pajukoski et al, 2013).

Small cell networks require a paradigm shift from the usual operations, administration, and maintenance (OAM) to self-organizing networks (SONs) with self-learning and intelligent decision making at the close-poximity devices. It is widely acknowledged that a massive network densification poses interference management issue which need to be tackled efficiently while maintaining the expected capacity. It is desirable to have each devices that able to cooperatively manage any inter- or intra-cell interference by learning the network performance and decide based on the learning evaluation.

The interference between small cells and the interference within small cells grow and need to be managed. Interference will adversely impact the aggregate wireless network throughput and thus the quality of applications such as multimedia streaming (Viswanathan, 2009). Intelligent power control is one of the promosing solutions to minimized interference (Claussen, 2010). By means of intelligent power control to prevent or combat interference issue, some elements of cognitive radio networks (CRN) and SON are needed in the mechanism. Among examples of these elements are the ability of the device to scan the network condition, learn on the monitored value and decide to change based on the evaluation from the self-learning.

There exist several devices that incorporate cognitive capabilities element such as WiFiRanger (WifiRanger, 2011), MiFi2352 (Davies, 2011) and NCIT Mobile Wireless Router (Harada, 2007). However, through the review that had been carried out, none of these products' cognitive capability able to change power based on the network behavior let alone be power adjustment based on network condition. In order to provide the communication device with a proactive decision making while maintaining minimal complexity of the system, the algorithm has to be made efficient without compromising the broadband spectrum.

Technique such as transmit power control (TPC) by knowing reliable channel state condition (Gesbert, 2010) is a very complex method and the benefits for practical network usage are still unclear. The objective of Transmit Power control (TPC) on a small cell wireless device such as an access points (AP) is to use minimum transmit power while meeting the requirements for throughput and packet loss rate. TPC helps reduce interference with other devices, improve channel reuse, and eventually increase the overall capacity in wireless networks. In addition, TPC also helps conserve energy and improve battery life of mobile devices (Viswanathan, 2009). However intelligent algorithms are required to adapt transmit power in a practical and distributed way in order to achieve improvement in performance while maintaining good energy efficiency.

Most researchers on TPC concentrate on the theoretical and simulation works because it is challenging to setup an experimental study due to issues on hardware incompatibility as well as proprietary matter that limits the capability to modify the resource management system of the device. In practice, system networking company such as Cisco incorporate its TPC module in specific access point's resource management to reduce power with the assistance of three more nearby access points (Cisco, 2010). Power increment is not programmed in this TPC but it is covered in coverage hole algorithm. In each decrement or increment of power there is a limit that has been set in the device as an example minimum power reduction is at 14dB. Higher power level settings may be constrained by local regulatory requirements and AP capabilities.

Although the TPC mechanism build by Cisco does take into consideration of other nearby APs, it does not evaluate the impact of reducing power to the throughput performance of associated clients. Hence, in this paper, we propose our own transmit power adjustment which minimize cooperation from other neighbouring APs and measure the throughput performance. Our developed algorithm, which we coin the term cognitive energy efficient (CEE) is evolved from our previous work on cognitive selection mechanism (CSM) (Hashim, 2013). In this study, CEE is incorporated on PC engine hardware for empirical study research instead of the more common evaluation in simulation machine.

COGNITIVE ENERGY EFFICIENT

Introduction of cognitive energy efficient

We have extended related work in CSM (Hashim, 2013) to power adjustment application and modification on the selection intelligence. An aspect of cognitive sciences is deployed to intuitively choose and decide for best element of power adjustment hence, energy efficiency. This is achieved by implementing such components in an ingenious algorithm that capable of controlling the element selection at the physical layer of a communication device. The massively discussed Internet-of Things (IoT) (McEwen, 2014), demands for future generation network (5G, 6G) to become smarter, able to learn, to sense the environment and energy efficient. Such requirements obviously need cognitive intelligence in each communication device. Figure-1 depicts the proposed concept of CEE.

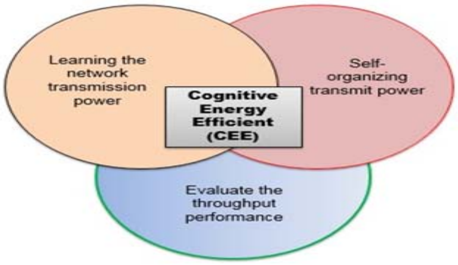


Figure-1. Cognitive energy efficient (CEE) concept.

Cognitive energy efficient process

The proposed CEE algorithm, able to scan, invigilate, analyze and evaluate the given parameters for finding the most suitable AP power that should be adjusted. It is through scanning and invigilating process that this concept manipulates the learning of the network environment in its CEE decision. Figure-2 highlights the flow diagram of CEE which is targeted at AP power management unit. It begins with measuring the current received signal strength (RSS) and device transmission power. Once captured, the current throughput between local AP and randomly select client is measured. That information is stored within a temporary database. Transmission power is adjusted based on some predefined rules. This is considered as temporary power. In our proposal we have set the rules as such;

1) Low: instantaneous RSSI < -75dB, increase transmission power to 27dB.
2) High: instantaneous RSSI > -50dB, reduce transmission power to 15dB
3) Medium: -75< instantaneous RSSI <-50dB, adjust transmission power to 20dB.

Our selection on this value and range is based on the preliminary experiment in the laboratory and also the limitation power given by hardware manufacturer. Once selected, the next period another evaluation of the new throughput is measured and compared with the previous reading. The second measurement is taken to ensure that the decision on the power is stable. An enhancement to our current system as compared to the previous mechanism in our studies is the alert message when the periodic throughput is below certain threshold to trigger for next power adjustment. As our empirical study is still at the preliminary stage, the throughput measurement is taken for random clients associated to access points. For more advanced work, an average throughput performance of each associated clients is still under investigation.

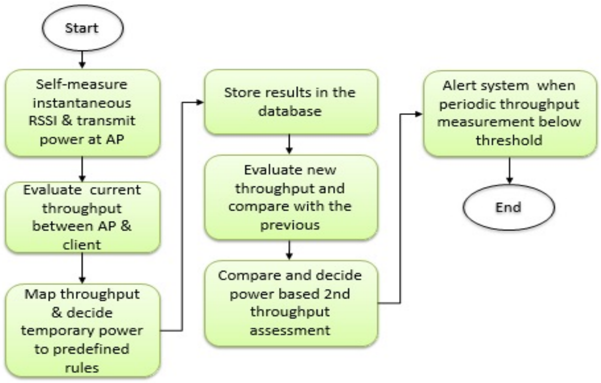


Figure-2. Cognitive energy efficient (CEE) process flow in the power management unit of an access point (AP).

System Architecture

Due to hardware and devices constraint, this study only manage to implement the proposed CEE mechanism for three access points and two clients. Nonetheless for the purpose of illustration, we show our close-proximity network with three access points and several clients for the purpose of understanding. Figure-3 depicts the scenario whereby no CEE is incorporated in the conventional AP.

It is always being perceived in dense deployment network such that, if the AP has maximum transmission power, this may cause unnecessary interference to the nearby AP. Although high transmit power usually known able to improve RSSI and coverage hence throughput, the impact to other AP performances in the whole network can be destructive. Refer to Figure-3, the clients associated to AP 1 can experience cell interference from excessive transmit power of AP 3 (green circle). Whenever the clients of AP 1 try to connect to the associated AP 1, it might get confuse with the signal strength power from AP 3.

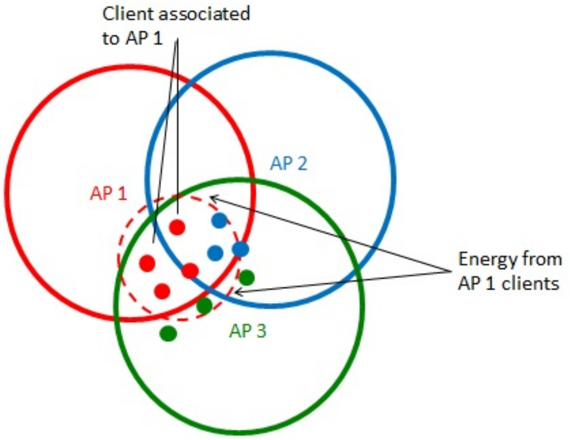


Figure-3. Scenario in close proximity devices in small cell network without the incorporation of cognitive energy efficient.

By having cognitive energy efficient on each access points, unnecessary transmission power can be prevented. Though, this perhaps may be seen to reduce coverage of the AP, situations whereby most clients are near to the AP, can tolerate some transmission power reduction while still maintaining good RSSI, supports such functionality. For the clients at the edge of coverage, if knowing connecting to the AP gives a bad RSSI, the client should be connected to other alternative APs. If this is exercised, a harmony, unselfish and stable wireless LAN network can be achieved. Hence, the incorporation of our proposed CEE can be illustrated as in Figure-4. In this figure, transmission power of AP 3 is reduced and only provide sufficient coverage to its nearby associated clients.

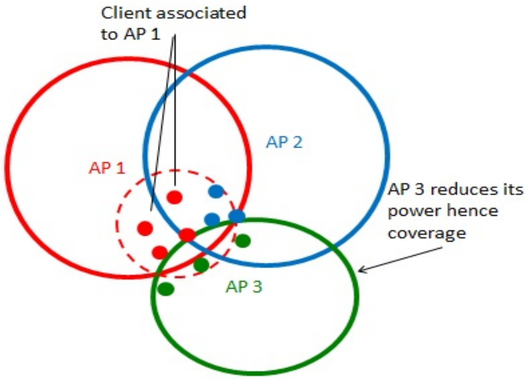


Figure-4. Scenario in close proximity devices in small cell network with the incorporation of cognitive energy efficient.

With CEE, the AP now able to adjust its power based on the RSSI assessment that can either be from the associated clients or the AP itself. By reducing the power, the device not only reduces potential interference to the whole network but also to serve better throughput to the nearby clients. On the other hand, it can also operate in more energy efficient. Figure-5 describes the simplify version of the system components.

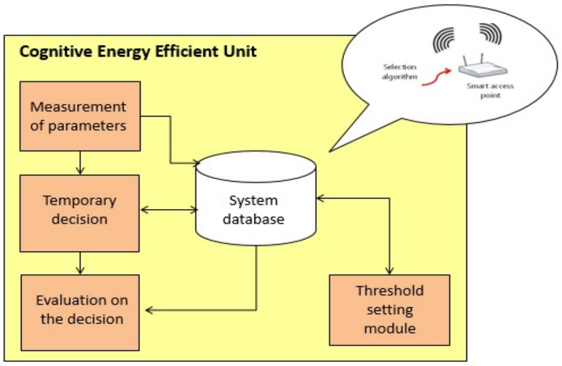


Figure-5. Cognitive energy efficient components module in an access point.

System Architecture

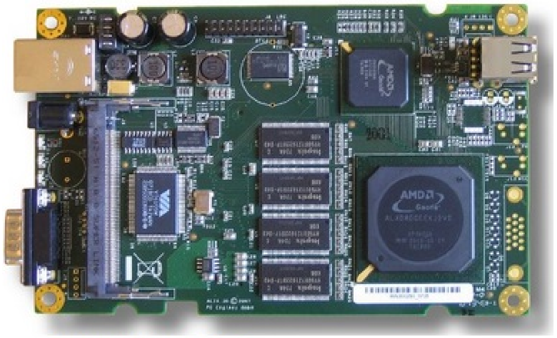
The system analysis in this empirical study is based on the real time measurement. Throughput assessment was measured throughout office hours and an average of the throughputs values is calculated for the final measurement. Average throughput is calculated following equation (1). Whereby, T' is the total of average throughput, and N_i is the instantaneous throughput at a given time of measurement.

$$T' = \frac{1}{k}\sum_{i=1}^{k} N_i \quad (1)$$

EXPERIMENTAL SETUP

System setup

CEE was developed in our laboratory based on an open source programming language such as Voyage Linux system. Once completed, the algorithm was embedded into a development board from PC Engine namely Alix 3D2 model as shown in Figure-6. This is the main processor for the AP.



Source: www.i4-wifi.com

Figure-6. Alix PC engine board of 3D2 model is used to embed with the proposed CEE mechanism.

System parameter

Our system parameters for laboratory experiment are listed in Table-I. We have used WLAN frequency at 2.4 & 5.8 GHz band following the IEEE 802.11 protocols. The main reason for experimenting at high frequency is to avoid any channel congestion.

Table-1. System parameters.

Parameter	Description
Spectrum band	WiFi – 2.4 and 5.8 GHz
Operating system	Ubuntu 12.04 LTS & Voyage
Channel tested	Uncongested available channels
Development board	PC Engine Alix 3D2 model
Throughput assessment	IPERF
Data monitoring time	8am – 5pm
Subscribed network	HSPA, WiMAX
Free network	WiFi
No of days monitoring	1 month
Download file size	2 Mbit

For our empirical study, the completed proof-of-concept (PoC) together with the development board as shown in Figure-7, was tested in two environments. One was in the laboratory shield room (Figure-8) and one is in the office environment. For shield room, the PoC was tested and verify to ensure the algorithm performed at its best.

Figure-7. Alix PC engine board of 3D2 model that is embedded with the proposed CEE mechanism for proof-of-concept.

Figure-8. Shield room that is used to measure the performance of CEE in less congested environment.

EXPERIMENTAL RESULTS

Our experimental results are depicted in Figure-9 and Figure-10 respectively. Figure-9 compiles two impact of throughput performance on AP 1 and AP 2 when transmission power of AP 3 is increased to 20 dBm. This is then compared with the other performance of similar devices when the transmission power of AP 3 is reduced to 15 dBm as shown in Figure-10.

From both figures, the impact of increasing transmission power to other APs throughput performance is significant. As an example, when power of AP 3 is increased to 20 dBm, the average throughput performance for AP 1 is 3.6 Mbps and 4.3 Mbps for AP 2. When the transmission power of AP 3 is reduced to 15 dBm, the corresponding average throughput performance for AP 1 and AP 2 is increased to 5.2 Mbps and 5.4 Mbps respectively.

The power decrement improves the throughput performance for AP 1 up to 44% and 26% for AP 2 when AP 3 only reduces it necessary transmission power to just 5 dBm difference. The reason for little improvement in AP 2 maybe due to the distance between AP3 and AP2 whereby the further position of AP 2 from AP 3 does not give much impact on the throughput improvement. Another reason could be due to non-overlapping of coverage between AP 2 and AP 3.

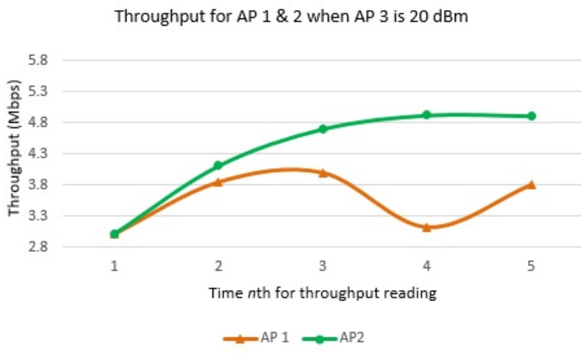


Figure-9. The impact of throughput when one of the APs (AP 3) is increased its power to 20 dBm.

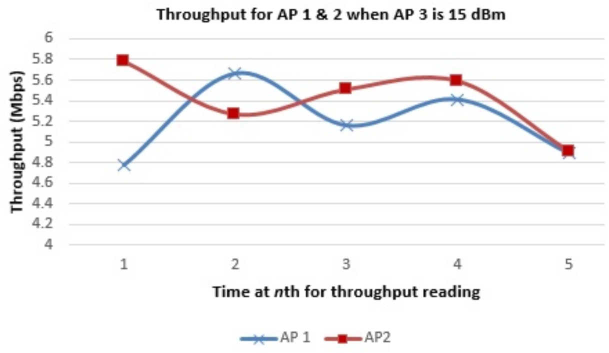


Figure-10. The impact of throughput when one of the APs (AP 3) is reduced its power to 15 dBm.

STANDARDIZATION CHALLENGES

Having discussed the proposed cognitive energy efficient mechanism for potential 5G future small cell network, the issues of standard in future devices with cross multi-functionality over diversify of networks are vital to the success of technology adoption. Since the device is expected to operate in heterogeneous way, developing a standard that covers multidisciplinary technical details will be a big challenge. When a device is expected to operate in such way, a range of frequency bands is obviously required to support such system. This is again going to be a big hurdle to set a one single platform standard since globally, the spectrum arrangement is different from one region to another region.

Other than technical specification detail, 5G future network is expected to meet the following objectives (Lee, 2014):

- **Economic incentives:** Future Networks (FN) are recommended to be designed to provide a sustainable competition environment for solving tussles among the range of participants in the ICT/telecommunication ecosystem such as users, various providers, governments, and intellectual property rights holders by providing proper economic incentive.
- **Network management:** FNs are recommended to be able to efficiently operate, maintain, and provision the increasing number of services and entities. In particular, FNs are recommended to be able to process massive amounts of management data and information efficiently and effectively transform these data to relevant information and knowledge for the operator.
- **Mobility:** FNs are recommended to provide mobility that facilitates high-speed and large-scale network in an environment where a huge number of nodes can dynamically move across heterogeneous networks. FNs are recommended to support mobile services irrespective of node’s mobility capability.

On the other hand, in certain countries, network infrastructures are built per provider basis instead of sharing the base station site and tower. Perhaps sharing leads to technical difficulties in network operations, but think about benefits in terms of economy and environmental awareness, the initiative could be a potential solution to reduce overhead cost.

CONCLUSIONS

The findings from our proposed cognitive energy efficient confirm that there is some degradation in throughput when all APs in dense deployment network boost its power to the maximum unnecessarily. A harmony and stable network can be useful for other APs to give their best performance to the clients. Transmission power adjustment using cognitive energy efficient mechanism is one of the ways to ensure all APs are not contributing interference to other devices. However an intelligent power adjustment will further ensure cooperative communication among all devices and mitigating interference in more systematic solution. A communication device with several network alternatives is certainly improving service reliability to the user. From our experiment, we have found an improvement of throughput performance 26% to maximum 44% depending on the distance between APs in small cell arrangement. Our preliminary research will be extended into calculating how much energy can be saved when such cognitive energy efficient is incorporated in each APs. Perhaps 10

APs will not give significant value of energy saving but imagine if there are thousands of devices, the figure surely gives an impact to the environment.

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