Throughput Improvement of a Range-aware WiFi network by Minimizing Signal Interference

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***Abstract*—In the smart-phone era, many WiFi devices around us need higher throughput and larger signal coverage which also generate unwanted signal interference among the devices. Signal interference is inevitable problem because of the broadcast nature of wireless transmissions. However, the interference could be minimized by reducing signal coverage of nearby wireless devices. But, smaller signal coverage means low transmission power and low data throughput. In the paper, we analyze the relationship among signal strength, coverage and interference of WiFi networks, and as a tradeoff between transmission power and data throughput, we propose a range-aware WiFi network scheme which controls transmission power according to locations and RSSI of WiFi devices. We analyze the efficiency of the proposed scheme by simulation.**

Keywords- signal interference; range-aware; data throughput; WiFi network,;signal coverage

I. INTRODUCTION

Many WiFi networks have been introduced these days, and they usually need high power for larger transmit range and data throughput. However, with rapid increasing number of wireless devices such as smart phones, large signal coverage of WiFi causes high signal interference especially in densely populated area.

Signal interference is inevitable problem in wireless network, which may decrease throughput and cause security problems. The signal interference could be reduced by controlling network configuration. [1] and [2] suggested topology control method with changes transmission power in order to reduce signal interference in wireless ad-hoc network.

In WiFi networks, the interference can be managed by controlling the sender's transmission power. However, small signal power results in low throughput. There is a trade-off between signal interference and network throughput [5] [6]. In the paper, we analyze the relationship among signal transmission power, interference and network throughput. We propose a range-aware WiFi Network, which can adjust transmission power depending on the locations and Received Signal Strength Indication (RSSI) of the devices. We also showed the efficiency of the proposed scheme by simulations.

Section II is about interference problems in wireless network and related researches. In section III, we extract the relationship between signal strength, signal coverage and data throughput with experiments. Section IV proposes the Range-aware WiFi network and analyzes the efficiency with simulations. Conclusion followed.

II. RELATED WORK

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is IEEE 802.11 wireless protocol designed to avoid signal collision in local area network. CSMA/CA operates in the process:

1) Before sending data, listen the channel to be IDLE

2) When channel is IDLE, send a Request To Send (RTS) to the receiver, and wait for a Clear To Send (CTS). After receiving CTS, the sender starts transmission, and broadcast a NAV(Network Allocation Vector) message to its neighbors to announce the transmission activity.

3) After successful data receiving, the receiver sends an ACK (acknowledgement) to the sender.

Giuseppe Bianchi [3] analyzed the network performance of CSMA/CA, including network throughput with RTS/CTS handshake. Long distance communication with CSMA/CA suffers tough signal interference due to many interfering devices in between the sender and receiver.

Signal interference deteriorates network throughput and also wastes power. Reducing signal interference is widely researched in wireless ad-hoc network in order to minimize power consumption. Martin Burkhart et al. compared several topology control methods which claim to resolve interference, and proposed an interference-minimal method in wireless ad-hoc network with connectivity-preserving and spanner construction [1]. N. M. Karagiorgas introduced a multicost routing that constructs route with variable transmission power to reduce interference in ad-hoc network [2]. Sutep Tongngam [4] proposed a reducible transmission range approach for wireless network, which optimizes broadcasting latency. Ilenia Tinnirello and Giuseppe Bianchi analyzed the interference effects in WiFi networks [5].

Anand Kashyap et al. presented a passive monitoring of wireless traffic to estimate interference in WiFi networks [6].

Above researches show that in any of wireless network like ad-hoc network or broadcasting network, performance in data throughput takes high influence from signal interference. Wireless interference cannot be removed because of broadcasting properties but can be optimized by routing algorithms or topology control algorithms.

III. WiFi Signal Strength and Transmission Rate

A. *Signal strength and data transmission rate*

The IEEE 802.11 WiFi network is composed of Basic Station Set (BSS), which contains an Access Point (AP) as a relay station to the Internet for the wireless local area network (see Figure 1).

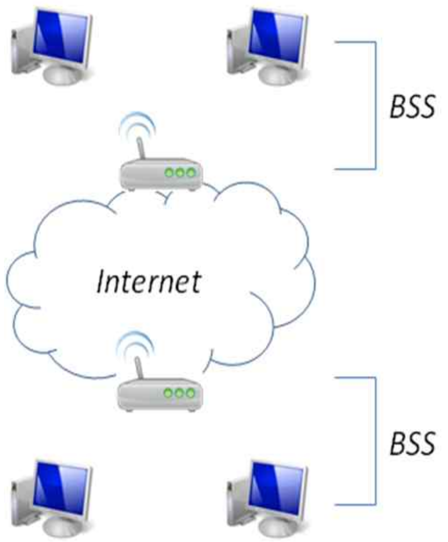

Figure 1. A WiFi network is composed of BSS (Basic Station Set), which contains AP(Access Point) and wireless devices

The most widely used scheme for a WiFi station to choose the appropriate AP is measuring the received signal strength from AP, known as RSSI. However, many researches showed that AP selection scheme based on the RSSI does not show good efficiency in optimizing throughput [7-9]. This is because the wireless communication quality depends on signal interference, fading and many other effect besides the signal strength itself. In the paper, we first simulate an interference-free environment and measure data throughput with different signal strength to find out the relationship between RSSI level and network throughput. Then, we extend the experiment with various signal interferences.

B. *Throughput under interference-free conditions*

Table 1 shows the specifications of the wireless device we used in the experiment to measure the RSSI and throughput under interference-free conditions.

TABLE I. Experiment Device Parameters Used to Measure the RSSI and Throughput

Wireless protocol	802.11g
Transmission power(AP)	18dBm
Antenna gain(AP)	4dBi
Receive sensitivity	-74dBm
Maximum signal range	70m
Maximum throughput	54Mbps

We measured the upload and download throughput for every 5dBm of RSSI from -35dBm to -70dBm, and the result is shown in Figure 2.

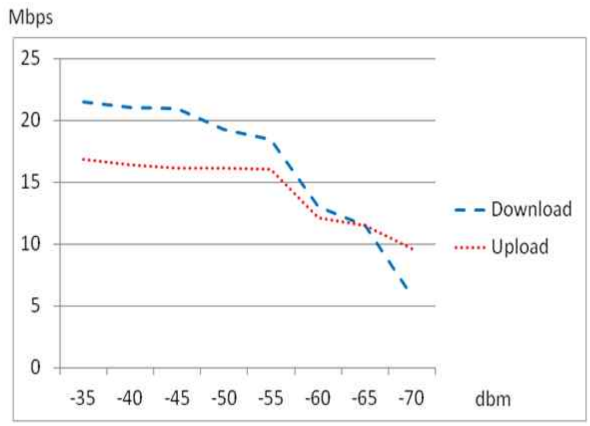

Figure 2. Throughput in a WiFi network without signal interference as a function of RSSI

Maximum bandwidth of the WiFi channel was 54Mbps, as a common throughput of WiFi network in 2.4GHz, however, the actual maximum throughput was 20Mbps because of the protocol overhead, such as control traffic and Ack frames etc.

C. *Signal transmission range and throughput*

In order to analyze interference effects in wireless network, we estimate the number of active WiFi networks in the signal range and evaluate the average throughput. Signal range is expressed by the path loss model as [10].

$$PL = PL_{1Meter} + 10\log(d^n) + s \quad (1)$$

$$RSSI = TxPower + AntennaGain - PL \quad (2)$$

Variables used in the formula are:

- PL: Total path loss experienced between the receiver and sender in dB
- PL_{1Meter}: Reference path loss in dB for the desired frequency when the receiver- to-transmitter distance is 1 meter
- d: Distance between the transmitter and receiver in meters
- n: Path loss exponent for the environment, 2 in free space, 3.5 – 4.5 in indoor environment

- s: Standard deviation associated with the degree of shadow fading in dB (3 ~ 7 dB)

From (1) and (2), signal distance between transmitter and receiver is given by

$$d = 10^{(TxPower + AntennaGain - RSSI - PL1Meter - s)/10n} \quad (3)$$

Signal distance between AP and client devices obtained from the experiment of Section 3.2 and (3) is shown in Table 2. Distance and throughput is measured in each RSSI levels.

TABLE II. NETWORK THROUGHPUT AND SIGNAL TRANSMISSION DISTANCE FOR DIFFERENT RSSI VALUES

RSSI	Distance	Throughput (Downlink)
-35dB	1 m	21.49Mbps
-40dB	1.778279m	21.03Mbp
-45dB	3.162278m	20.94Mbp
-50dB	5.623413m	19.25Mbp
-55dB	10m	18.42Mbp
-60dB	17.78279m	13.04Mbp
-65dB	31.62278m	11.47Mbp
-70dB	56.23413m	5.79Mbp

In (1), PL_{1Meter} is set to be 54dB, path loss exponent n is 2 assuming free space, and shadow fading s is 3dB.

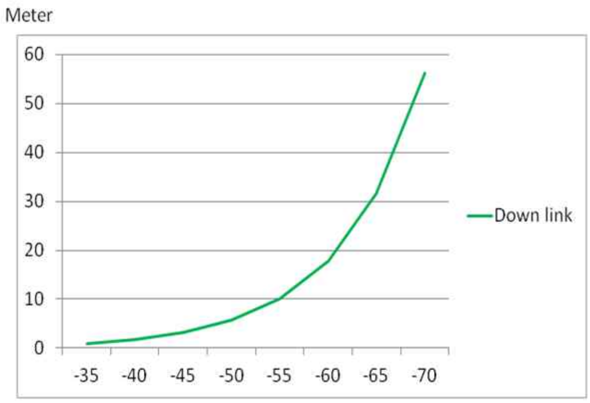

Figure 3. Signal transmission coverage for various RSSI values

Figure 3 shows the signal range variations for various RSSI levels, which may explain the relationship between distance of wireless nodes and related signal degrees.

IV. RANGE-AWARE WIRELESS WIFI NETWORK

High transmission power gives high signal interference. Low transmission power may increase throughput because of low interference, but small signal power would make shadow areas. We proposed a range-aware WiFi network in order to find optimum value of transmission power and signal interference. Figure 4 shows an instance of the proposed network scheme where APs have different signal coverage in order to minimize signal interference.

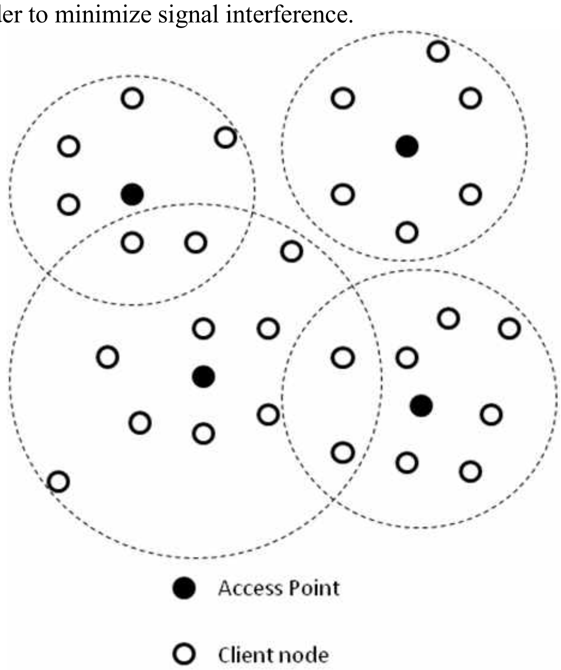

Figure 4. An example of range-aware wireless WiFi networks where APs have different signal coverage in order to minimize signal interference

The range-aware WiFi network can increase network efficiency by minimizing signal interference. The rationale of the range-aware wireless WiFi networks is controlling AP’s transmission power considering the locations of the wireless devices. There are three steps in configuring a range-aware WiFi Network.

1) Measuring clients’ RSSI periodically, calculate distances to the devices

2) Set AP's transmission power to reach the farthest client device

3) Announce the transmission power set at 2) to client devices

Clients’ transmission power control is set based on AP's transmission power. When client moves, the transmission power of AP and client are adjusted (see Figure 5).

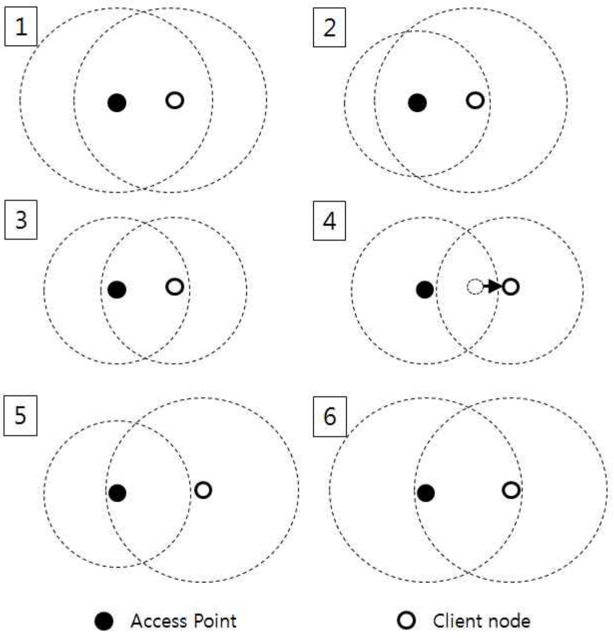

Figure 5. Transmission coverage changes as a client wireless device moves

The steps in Figure 5 are described as follows.

1) *Initial state of AP and client device*

2) *AP sets signal coverage considering clients' location, transmission power and announce it*

3) *Client device sets transmission power based on the announced AP's transmission power*

4) *The client device moves away from its AP*

5) *Client device uses default transmission power*

6) *AP recalculates distance between client and adjusts signal coverage*

We performed simulations to investigate the proposed method. Simulation topology is illustrated in Figure 6. A 120m x 120m area is divided into 9 cells, each cell contains one AP at the center and 6 randomly located devices. Network throughput for downlink (from AP to clients) is measured for different transmission powers of 18dBm, 13dBm and 8dBm. In the simulation, we assumed all clients use same channel and channel access time is equally shared by all client devices no matter how the actual throughput is. The simulation program is written by Java language, UDP unicast is used with maximum throughput of 54Mbps.

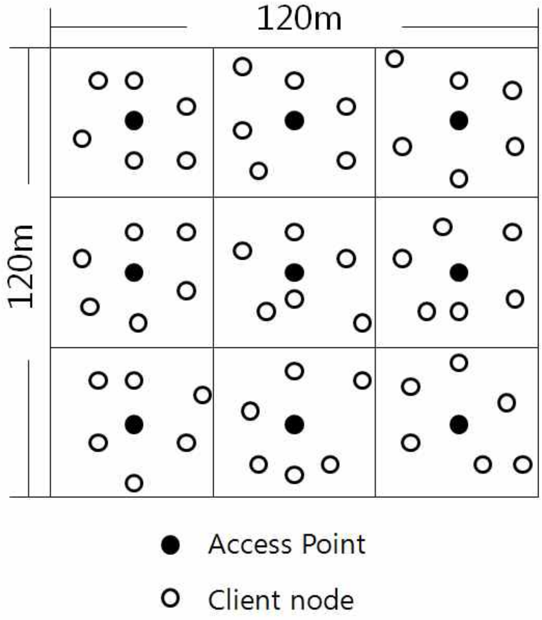

Figure 6. Simulation topology with 9 cells and 54 devices

First, we considered a conventional WiFi network without range-aware WiFi scheme. Figure 7 shows the simulation result with 18dBm (high) transmission power. All client devices show similar network throughput, however the throughput is quite low because of the high signal interference. Figure 8 shows the case with transmission power of 8dBm, where the network throughput is much higher than the case of Figure 7 (i.e., 18dBm) because of low signal interference. However, in this case, the AP's signal coverage is not long enough to cover all clients in the network that may cause shadow zone.

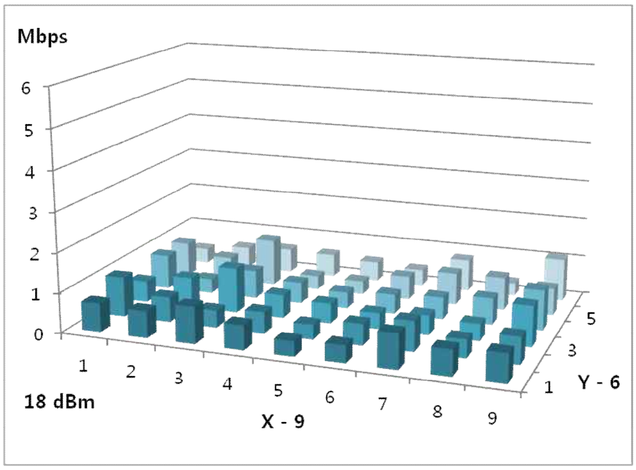

Figure 7. Throughputs at randomly located 54 clients with 18dBm transmission power

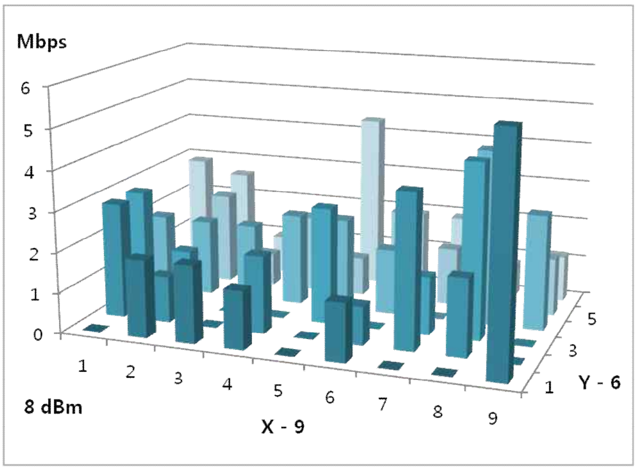

Figure 8. Throughputs at randomly located 54 clients with 8dBm transmission power

Figure 9 shows the simulation result of the proposed range-aware WiFi network. AP's transmission power is adjusted depending on the clients' location to be 18dBm, 13dBm and 8dBm, respectively. As shown in Figure 9, shadow zone does not exist and network throughput is much better than that of Figures 7 and 8. By choosing optimum transmission power associated with client's distance, we can minimize signal interference and maximize network throughput.

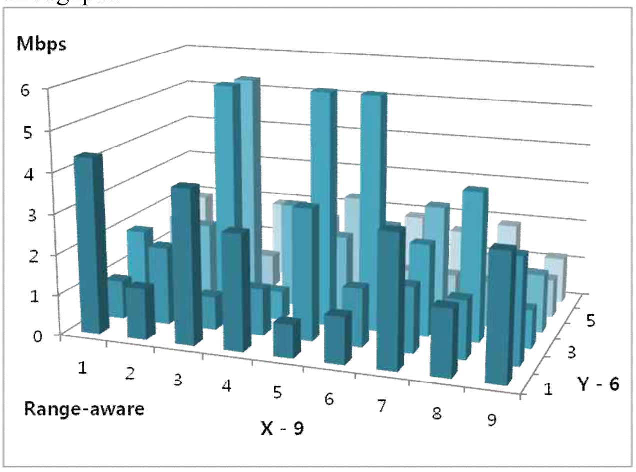

Figure 9. Throughputs at randomly located 54 clients with range-aware WiFi network scheme

Table III compares average network throughput of conventional WiFi network and range-aware WiFi network with transmission power 8dBm, 13dBm and 18dBm. It also compares the cases with 6 client devices in every cell (6x9 clients) and 9 client devices in every cell (9x9 clients).

TABLE III. AVERAGE THROUGHPUT(MBPS) COMPARISON OF A RANGE-WARE AND CONVENTIONAL WIFI NETWORK

	Range-Aware	8dBm	13dBm	18dBm
6 x 6	2.09	1.58	1.09	0.64
9 x 9	1.30	1.07	0.78	0.42

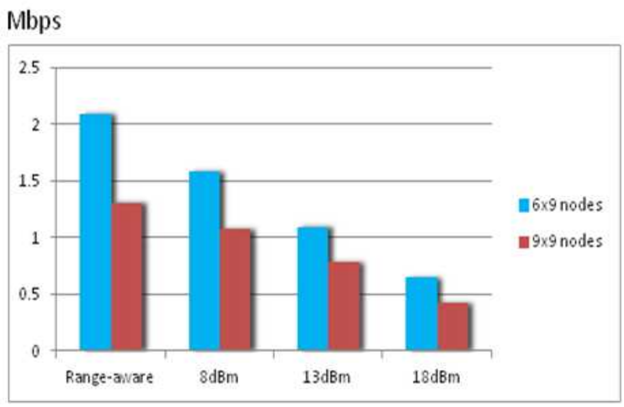

Figure 10. Average throughput comparison of a range-ware and conventional WiFi network (with different transmission powers)

Figure 10 shows that the proposed range-aware WiFi network gives much higher throughput from clients than conventional WiFi network. Throughput with the case of 9 client devices in each cell shows lower throughput than the case of 6 client devices in a cell, because 9 clients in a cell will use small amount of bandwidth than 6 clients in average.

In [7], Yutaka Fukuda et al. presented an AP selection scheme based on measurement of signal interference and showed a throughput improvement of 100% around. Controlling client to reach interference-minimum AP might improve certain node's throughput however should show few efficiency in improving whole network performance; the scheme should show similar result of Figure 9 with our simulation model. Today's WiFi environment has a very high density of wireless client due to rapid increase of WiFi devices, typically Smartphones. The most efficient way to optimize WiFi network should be controlling network topology, proposed Range-aware WiFi network presents one example.

V. CONCLUSION

Performance of a WiFi network does not only depend on signal strength but also on the interference from neighbor wireless devices. Higher transmission power from AP gives higher signal interference to other WiFi network. On other hand, if transmission power is too small it can reduce signal interference but may cause shadow zones where client devices could not connect to the network.

In the paper, we analyze the relationship between signal power, signal interference, and network throughput. We proposed a range-aware WiFi network that may increase network efficiency by minimizing signal interference with

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controlled transmission power. Simulation results show that the range-aware WiFi network gives higher network throughput than conventional WiFi network.

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