공학석사 학위논문

A Grouping Algorithm to Alleviate the Hidden Node Problem in 802.11ah Networks

802.11ah 네트워크 환경에서 히든 노드 문제를 완화시키기 위한 그룹화 알고리즘

2014년 2월

서울대학교 대학원
전기·정보 공학부
서정오

A Grouping Algorithm to Alleviate the Hidden Node Problem in 802.11ah Networks

지도교수 박세웅

이 논문을 공학석사학위 논문으로 제출함

2014년 2월

서울대학교 대학원

전기·정보 공학부

서정오

서정오의 석사학위논문을 인준함

2013년 12월

위 원 장 : 이 병 기 (인)

부위원장 : 박 세 웅 (인)

위　　원 : 최 상 현 (인)

Abstract

A Grouping Algorithm to Alleviate the Hidden Node Problem in 802.11ah Networks

Seoul National University Graduate School
Electrical and Computer Engineering
SEO JEONG O

IEEE 802.11ah offers a transmission range of up to 1km and about 8000 nodes are handled by a single access point (AP). As a result, 802.11ah networks have more hidden node pairs than 802.11a/b/g/n/ac networks. Especially, when a node sends a PS-Poll frame to an AP in the power saving mode, the hidden node problem is aggravated, resulting in frequent packet collisions. In this paper, we propose a grouping algorithm to alleviate the hidden node problem, which consists of three steps. At first, it finds hidden pairs in a network and, second generates a hidden node matrix accordingly. Then, the algorithm regroups the hidden nodes using the hidden node matrix. Through extensive simulations, we showed that our proposed algorithm almost eliminates the hidden node pairs. Therefore, our proposed algorithm improves network performances such as throughput and delay in 802.11ah networks.

Keywords : 802.11ah, power saving mode, hidden node problem, group based contention

Student Number : 2012-20787

Contents

List of Tables

List of Figures

Chapter 1

Introduction

One of the most widespread Wireless Local Area Networks (WLANs) is IEEE 802.11. However, Current Wi-Fi systems which use 2.4GHz and 5GHz carrier frequency are prone to be interfered with other devices using same band. In addition to that, exsting IEEE 802.11 systems are highly congested and backward compatibility is big burden for making new WLAN systems. Because of these drawbacks of the exsting IEEE 802.11 systems, these day, a new WLAN operating in interfere free band is needed. So the 802.11ah Task Group (TGah) has standardized a new IEEE 802.11 WLAN, which is called IEEE 802.11ah. Spectra of the IEEE 802.11ah are sub 1GHz Industrial, Scientific and Medical (ISM) bands. Owing to superior propagation feature of lower frequency spectrum to exsting IEEE 802.11, the 802.11ah provide longer transmission range compared with the exsiting 802.11 WLANs using 2.4GHz and 5GHz frequency bands. Due to the good characteristics of low frequency, 802.11ah can be used for a vast range sensor networks such as smart grid. Sensor devices are mostly battery operated devices so the life span of the devices are critical issue. To save the power consumption of the sensor device, the 802.11ah provides power saving mode. In accordance with transmission coverage, the number of supported devices is also increased.

However, the increased number of devices associated to an Access Point (AP) makes hidden node problem, which makes overall network performance severely degraded. Statistically, the probability of any two nodes having hidden node relationship is up to 41% in case of randomly deployed situation. For example, if there are 8000 nodes are deployed in AP's coverage with random distribution, the number of hidden node pairs occurs up to 1,311,836.

To solve the hidden node problem, first of all, we need to know which nodes are in hidden node relationship. Concerning the hidden node detection, in previous work [1], they focus on checking whether the hidden node exists or not through Clear Channel Assessment (CCA). Likewise, in other papers [2], node check the received packet from hidden node, and based on packet header information, they find hidden node. This approach is big overhead for each node and the node can't decode the packet by so many collisions when there are many nodes.

So in our paper, we reference hidden detection method which is time based detection mechanism in paper [3]. In the paper, they detect the hidden node by using around AP's help. This method can figure out which nodes are in hidden node relationship exactly and also don't impose burden for detecting hidden node to node because of AP centric detection.

In order to alleviate the hidden node problem, IEEE 802.11ah is also designed by using group based contention, but the group based contention can't be fundamental solution. It just reduces the number of contending node in some time slot.

In our work, therefore, we propose an algorithm to alleviate the hidden node problem in 802.11ah power saving mode. The proposed algorithm consists of 3 phases. In first phase, AP detects hidden node. Hidden node detection is based on the Power Saving (PS)-Poll transmission time. In second phase, AP generates hidden node matrix with the hidden node information of first phase. In last phase, AP moves the hidden node to other group to eliminate the hidden node pairs. All the acquired information during the algorithm operation are maintained and accumulated whenever the proposed algorithm is executed.

The rest of this paper is organized as follows: Overview of 802.11ah is presented in Section 2. Section 3 presents system model and Section 4 presents the proposed algorithm: Hidden node Matrix based Regrouping (HMR). Section 5 shows the simulation results. The analysis is presented in Section 6. Finally we conclude our paper in Section 7.

Chapter 2

Overview of 802.11ah

The most remarkable difference between IEEE 802.11ah and other IEEE 802.11 is available bandwidth. Beside for exsting IEEE 802.11 using 2.4GHz and 5GHz, IEEE 802.11ah uses Sub 1GHz. Advantage from using low frequency is that transmission range can be larger even though transmission power is same with high frequency due to its path loss characteristic[4][5]. So 802.11ah can covers much larger range than 2.5GHz and 5GHz band. So the 802.11 TGah needs to modify time values because of extended propagation delay. Table 1 shows time parameter related with 802.11ah.

Table 1 : 802.11ah Time Parameter

Parameter	Value
ACK (µs)	240
SIFS (µs)	160
DIFS (µs)	264
A Slot Time (µs)	52

In Table 1, a slot time and Short Interframe Space (SIFS) are longer than the other IEEE 802.11 respectively. It is result from reflecting the changed propagation delay.

Acknowledgement (ACK) size of 802.11ah is shorter than the exsting normal ACK size. The 802.11ah task group reformulates ACK structure. The modified ACK is called short ACK. The TGah reduces Medium Access Control (MAC) frame such as service, frame control, duration, Receiver Address (RA), Frame Check Sequence (FCS). The TGah combines the MAC frame and Signaling (SIG) field of physical layer header. The reason why they can fix the ACK is IEEE 802.11ah doesn't need to consider backward compatibility with the exsting 802.11 for different frequency band. That is the IEEE 802.11 ah is green field system.

802.11ah main requirements are following things.

- Cellular off-loading operation
- Data rate is more than 100kbps
- Transmission coverage is up to 1km
- One AP services about 8000 stations (STA).
- Coexistence with IEEE 802.15.4 and IEEE 802.15.4g devices.
- Power saving mode.

Use case of IEEE 802.11ah is smart grid, indoor healthcare system and so on. Transmission coverage is achieved by 1MHz of PHY layer using 32 Fast Fourier Transform (FFT) and 2x repetition code as lowest data rate and preamble format for long range is robust and simple to detect packet. IEEE 802.11ah standardization project was initiated by TGah in November 2010 and the TGah will aim to finalize the standardization of 802.11ah by 2014. Following things are feature of Physical (PHY) layer and Medium Access Control layer (MAC).

2.1 PHY Layer

Basically, PHY layer of IEEE 802.11ah is down-clocking version of IEEE 802.11ac's PHY later in terms of symbol times and other parameters. We present channelization.

2.1.1 Channelization

IEEE 802.11 supports for 1MHz, 2MHz, 4MHz, 8MHz and 16MHz PHY transmission. The 2MHz PHY transmission is OFDM based waveform which consists of a total 64 tones including pilot tones, guard subcarriers and direct conversion subcarrier (DC). It means space of tones is 31.25 KHz. Merit of 64 tones is a provision of sufficiently long cyclic prefix (CP) for outdoor deployments [6]. Table 2 shows channelization according to nation [6].

Table 2: Worldwide Available Sub 1GHz Band

Country	Frequency[MHz]	Bandwidth[MHz]
South Korea	917.5-923.5	1, 2, 4
Europe	863-868	1, 2
Japan	917-927	1
China	755-787	1, 2, 3, 8
United States	902-928	1, 2, 4, 8, 16

Channelization for South Korea is 917.5-923.5MHz and bandwidth is 1, 2, 4MHz. 0.5MHz offset is needed for reducing the possible mutual interference with legacy systems. [7] Spectra of Europe, Japan and China are 863-868MHz, 917-927MHz and 755-787MHz respectively. Frequency of United States is 902-928MHz and Bandwidth is 1, 2, 4, 8 and 16MHz. United States has the most different bandwidth up to 16MHz which is maximum width defined in 802.1ah specification document.

2.2 MAC Layer

MAC layer of 802.11ah shows enhancement of various part of previous 802.11 in terms of the number of associated station, power saving mode and so on.

The supported number of station is up to $2^{13}-1$(=8,191)[8], which is achieved with 13bits of Assocation Identifier (AID) imposing unique ID to station. The supported number of station in 802.11ah is about 4 times of legacy 802.11ah which supports 2,007 stations. The large number is suitable for large scale network such as smart grid.

2.2.1 Power Saving Mode (PSM)

Key feature of 802.11 is to provide power saving mode, which is useful to save energy of sensor device. Figure shows down link channel access in power saving mode.

In power saving mode, AP transmits Traffic Indication Map (TIM) packet periodically. The TIM packet carries information about buffered packet heading for associated station. In response to the TIM packet, each STA sends a PS-Poll frame to receive own data within a time slot assigned by AP. Then, AP sends an ACK immediately which contains an indication bit. The indication bit notifies that if there are data for STA, the bit is 1. Otherwise, the bit is 0. If STA receives ACK containing the 1 indication bit, STA waits for own data in Restrict Access Window (RAW)2 duration. Otherwise, STA goes to sleep mode. RAW1 is total duration of time slots.

AP sends a synch frame at the slot boundary if the channel is idle to help a STA synch to the medium quickly. So STAs wake up at slot boundary and wait for synch packet. Through the synch packet, the STAs synchs to the channel and ready to access the channel.

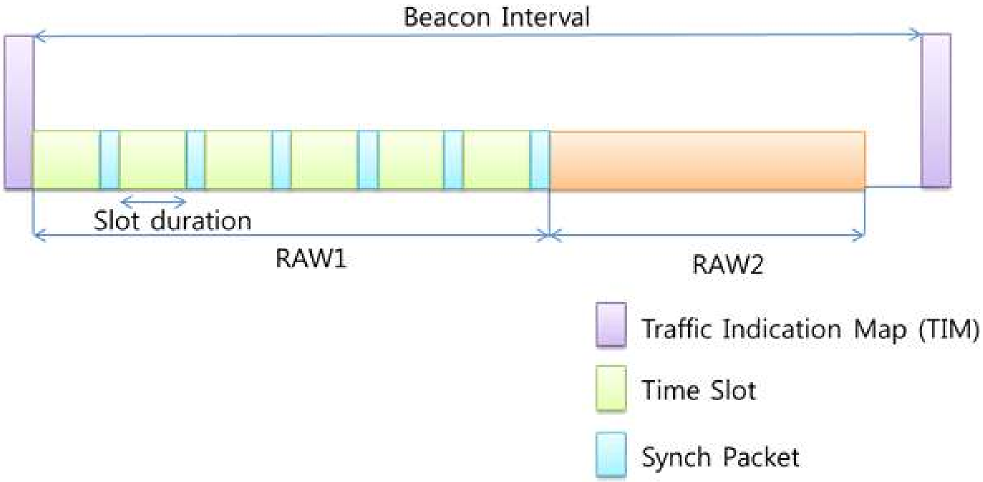

Figure 16. Downlink Channel Access in 802.11ah Power Saving Mode

2.2.2 Grouping Method

STA contends medium only within the assigned time slot. That means 802.11ah power saving mode uses group based contention. One time slot formulates one group. How to make groups is determined by STA-Slot mapping function. AP calculates STA's group number by using modulo operation (mod). Modulo operation finds the remainder of division of one number by another. In our case, we calculate x mod N_{RAW}. x is Association Identifier (AID) and N_{RAW} is the number of time slots in RAW1. After the operation ends, AP assigns the result to STA as a group number. The group number information is delivered through the TIM packet. [6]

STA-Slot mapping function f(x) :

$$f(x) = x \bmod N_{RAW} = i$$

Chapter 3

System Model

We consider a power saving mode in 802.11ah. We shall make the following assumptions for the remainder of this paper:

1) Downklink channel access
2) One AP exists.
3) Each STA has a one PS- Poll to transmit between Target Beacon Transmit Time (TBTT).
4) Each STA retransmits the PS-Poll, if STA fails to transmit the PS-Poll.
5) STAs are deployed as a Random disc allocation in AP's transmission range.
6) AP and STAs don't have mobility, i.e. fixed position.
7) Medium Access Control (MAC) operates with Distributed Coordination Function (DCF)
8) If the PS-Poll frame is correctly received, we assume that data for STA will be delivered successfully.
9) Capture effect isn't considered.
10) Transmission range is equal to sensing range.

Chapter 4

Proposed Scheme: Hidden node Matrix Regrouping (HMR)

The grouping method of 802.11ah doesn't consider hidden node problem. By group based contention, it makes packet collision reduced, but the hidden node problem still exist and degrade the network performance due to the increased number of STAs.

In this section, therefore, we propose a grouping algorithm to alleviate the hidden node problem. The proposed algorithm consists of three phases: hidden node detection, hidden node matrix generation and hidden node regrouping.

4.1 Hidden Node Detection

Basically, detection metric is the PS-Poll transmission time. In Figure 2, PS-Poll (1) and PS-Poll (2) are transmitted by STA 1 and STA 2 respectively. In a situation of PS-Poll (1)'s transmission not finished, STA 2 transmits PS-Poll (2), which means STA 2 doesn't sense the STA 1's transmission. Therefore we can determine two STAs are in hidden node relationship. On the basis of the situation, we design the hidden node detection method.

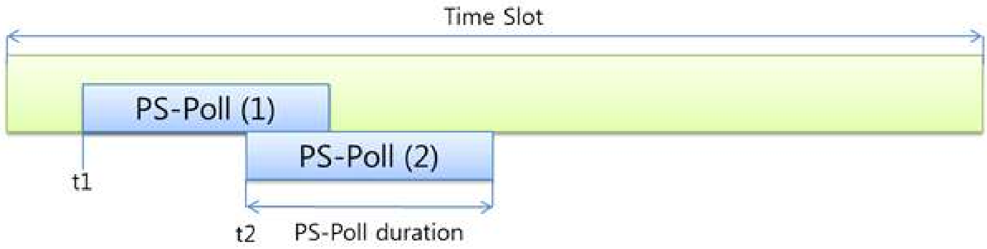

Figure 17. PS-Poll Collision by Hidden Node

The hidden node detection is like equation (2). When a STA firstly fails to transmit the PS-Poll, the STA saves the first transmission time and retransmit the PS-Poll with the time to AP. Assume t1 and t2 are first transmission time of STA1 and STA2 respectively. If the difference between t1 and t2 are longer than slot time and less than PS-Poll duration, then AP determines two STAs are in hidden node relationship. The reason why difference is longer than slot time is to exclude the hidden node detection due to for STA's random counter becoming zero at the transmission.

$$\text{slot time} < | t1 - t2 | < \text{PS-Poll duration}$$

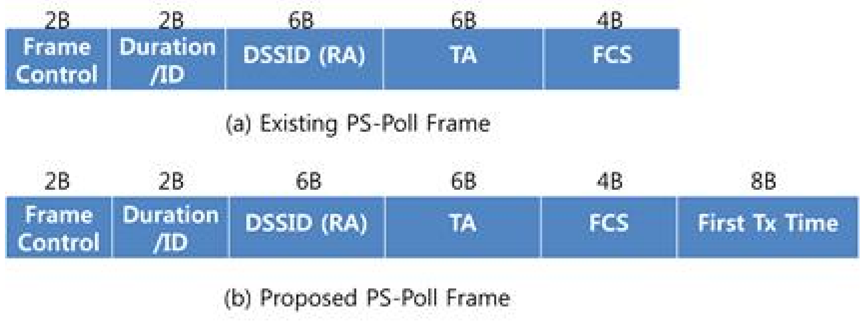

Figure 18. Existing PS-Poll Frame and Proposed PS-Poll Frame

There need some bits to save the first transmission time in PS-Poll frame. However, PS-Poll frame doesn't have reserved bits. So we add 8bytes to the PS-Poll frame to save the first transmission time.

4.2 Hidden Node Matrix Generation

Based on the hidden node detection information, AP generates hidden node matrix. Row and column correspond with node number. Elements indicate relationship between two nodes. If the element is 1, two nodes are in hidden relationship. Otherwise, two nodes are not in hidden relationship or have not been detected yet as hidden node relationship. In Figure 4, element of (3, 1) is 1, which means node 1 and node 3 are in hidden node relationship.

$$\begin{array}{l} \text{node 1} \\ \text{node 2} \\ \text{node 3} \\ \text{node 4} \\ \text{node 5} \\ \text{node 6} \end{array} \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Figure 19. Hidden Node Matrix

We define the number of hidden pairs as the number of hidden node relationship with one node. For example, node 2's number of hidden pairs is 4 that is sum of row 2 elements.

4.3 Hidden Node Regrouping

Hidden node regrouping operates per group. Regrouping starts from group 0 and the next is increasing order. If the last group finishes the regrouping, then the third phase ends.

Figure 5 shows hidden node regrouping algorithm when the group number is n. Variable m is used to express the other group number, mod means modulo operation and N represents the number of groups.

Fundamental principle of the hidden node regrouping algorithm is that hidden nodes in a group which have hidden node are moved into the other group where there doesn't exist any hidden node with the moved node.

Assume group n starts regrouping. Group n is one of groups from group 0 to group N-1. AP sorts the node in descending order of the hidden node pairs from hidden node matrix then selects the first node which has the highest hidden node pairs. The AP input group number n to variable m which is used to save the other group number. The regrouping of group n is finished when there doesn't exist any node to be selected in the group n or the hidden node pair of the selected node is zero. If the conditions to finish the regrouping aren't satisfied, then the AP increases the number of m by one and checks whether any node in the group (m mod N) has hidden node relationship with the selected node. (mod means modulo operation) If it doesn't have the hidden node relationship, then the AP regroups the selected node from the present group to the group (m mod N). After the selected node is regrouped successfully, regrouping procedure goes to the start state and does same things again.

However, if there exists any hidden node in the group (m mod N) with the selected node, the AP increases the number of m and does same procedure until the selected node is regrouped or m-n-1 equal to N. If m-n-1 is N, the AP selects the next node among the sorted nodes. With the second selected node, the AP proceeds the regrouping.

By regrouping procedure, hidden node pairs can be reduced as the proposed algorithm operates.

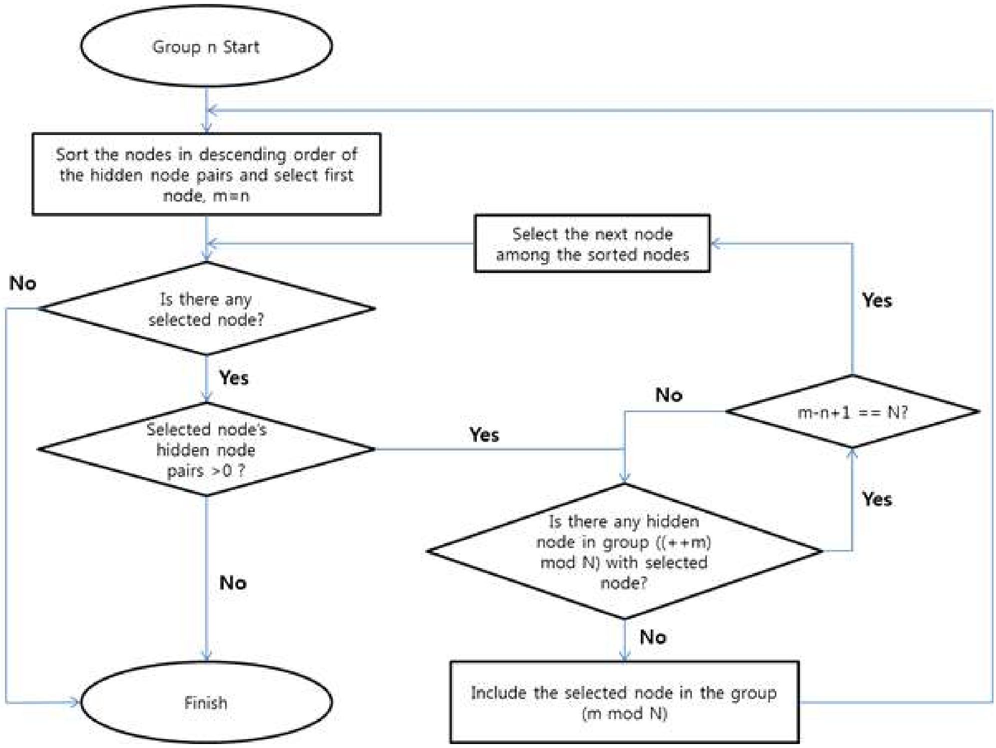

Figure 20. Hidden Node Regrouping Algorithm When the Group Number is n

Chapter 5

Analysis

This section presents an analysis about the number of groups for simulation. That is finding the number of groups which is the minimum number of groups for geographically not having hidden node in a group.

5.1 Finding the Number of Groups

We can think a group shape like a sector intuitively. If condition for nodes in the sector not to have hidden relationship is that distance between any nodes should be within transmission range.

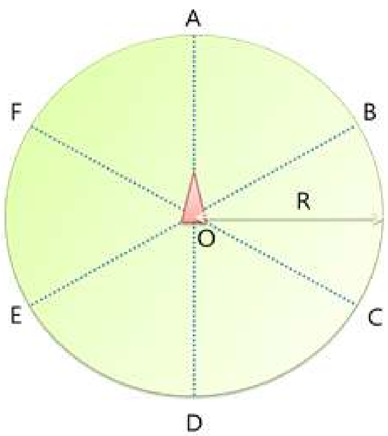

Figure 21. Ideal Group Shape

Figure 6 shows group shapes when the number of groups is 6. In this case, all nodes in each sector don't have hidden relationship. In a sector OAB, assume the nodes are on outmost line. The longest position from nodes on arc AB is point O and the distance of them is R which is the transmission range. Likewise, a segment OA and OB are also proved. Therefore, all nodes in sector OAB don't have hidden relationship each other. If the number of groups is 5, Distance between a point A and a point B is longer than transmission range R. On the other hands, if the number of groups is more than 6, there are synch packet overheads between time slots. As the number of groups increase, the overheads also increase. In summary, the number of groups which don't have hidden node relationship and have the least overhead is 6. So we use this number for simulation.

Chapter 6

Simulation

In this section, we present the simulation results which compare the 802.11ah specification and Our HMR algorithm. Table 3 shows simulation parameter.

Table 3: Simulation Parameter

Simulation parameter	Value
Data rate (Mbps)	0.65
Bandwidth (MHz)	2
PHY header (μs)	240
Existing PS-Poll (bytes)	20
Proposed PS-Poll (bytes)	28
Contention window min	32
Contention window max	1024
Total number of nodes	120
The number of groups	6
The number of node per a group	20
Simulation duration (TBTT)	100
HMR period (TBTT)	1
Simulation number	100

To evaluate our scheme, we simulate our scheme and 802.11ah specification with parameters in Table 3. Data rate is 0.65Mbps. Because PHY of 802.11ah is down-clocking version of 802.11ac, 0.65Mbps data rate comes from when MCS0 is selected. MCS0 means BPSK modulation, 0.5 code rate and 2MHz bandwidth. Size of PHY header is 240µs. Exsting PS-Poll frame size and Proposed PS-Poll frame size are 20bytes and 28 bytes respectively. We simulate with 120 nodes and 6 groups. So the initial nodes per group are 20. Simulation duration is 100 TBTTs and the proposed algorithm is applied whenever each TBTT finish. Average values of 100 simulations are used for simulation results.

We consider the number of hidden node pairs, PS-Poll transmission completed time and retransmission number as performance metrics.

6.1 The Number of Hidden Node Pairs

Through the measurement of hidden node pairs, we evaluate how many hidden node pairs are eliminated using our HMR. This metric show directly our proposed scheme working well.

Figure 7 shows number of hidden node pair versus TBTT. We applied our HMR algorithm at the end of every TBTT. So Figure 7 shows the change of the number of hidden node pair as the proposed algorithm operates. As shown in Figure 7, the number of hidden pair decreases as TBTT increase. After 48 TBTTs, sum of the number of hidden pair is under 5% of the beginning number.

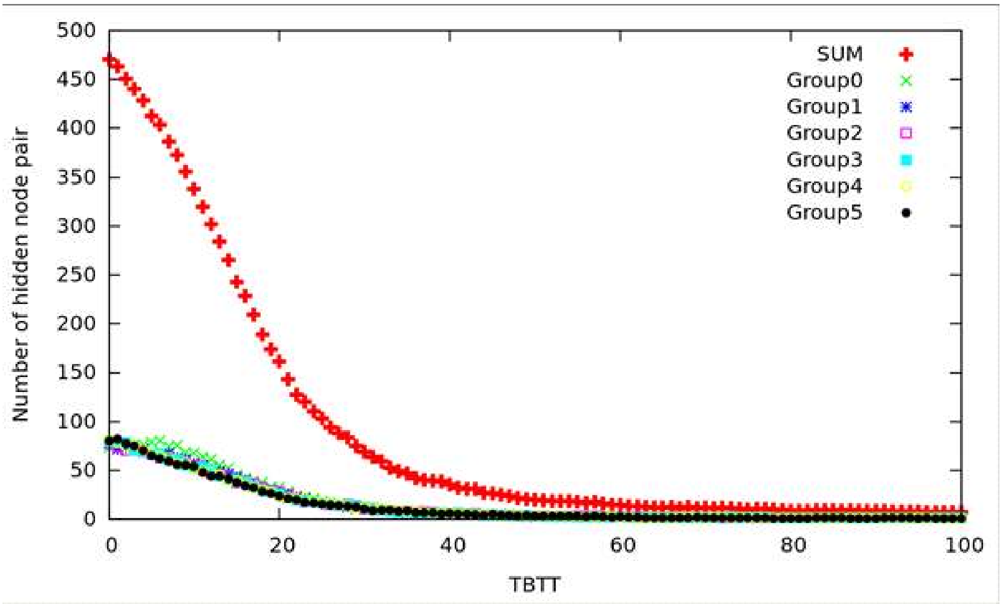

Figure 22. Number of Hidden Node Pair vs. TBTT

Table 4 show the number of hidden node pairs according to the group before and after HMR are applied.

Table 4: Hidden Node Pair

	Before HMR	**After HMR**
Group0	77.4	1.5
Group1	80.0	1.3
Group2	79.6	1.1
Group3	79.7	1.3
Group4	80.3	1.3
Group5	79.2	1.3
Sum	476.5	8.2

The average total sum of Before HMR and After HMR are 476.5 and 8.2 respectively. Through the HMR algorithm, we can eliminate 98.26% hidden node pairs. Figure 8 shows bar graph that represent total sum of hidden node visually.

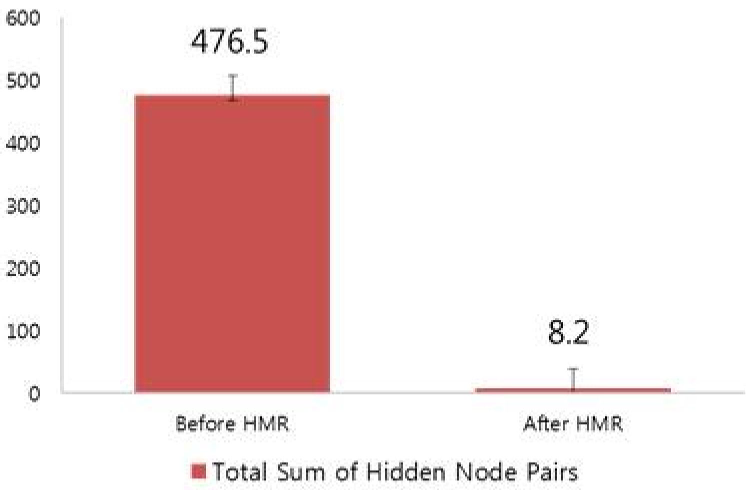

Figure 23. Total Sum of Hidden Node Pairs

6.2 PS-Poll Transmission Completed Time

We measured the PS-Poll transmission completed time to find throughput indirectly. In average sense, we measured time for all nodes to transmit PS-Polls successfully. We can know the throughput by measuring the transmission completed time because what needs the smaller amount of time to transmit the same amount of PS-Polls is that it can more transmit PS-Polls for same duration.

Table 5: Average Transmission Completed Time

	802.11ah (msec)	HMR (msec)
Group0	71.0	41.8
Group1	68.4	34.3
Group2	68.4	25.5
Group3	69.7	29.0
Group4	70.8	23.5
Group5	69.4	24.0
Sum	417.7	178.4

Table 5 shows average time until all nodes in each group transmit PS-Polls successfully. Total sum of the average times are 418.3msec and 178.4msec in case of 802.11ah and HMR respectively. After the proposed algorithm is applied, time to transmit PS-Polls successfully is reduced by 57.3%.

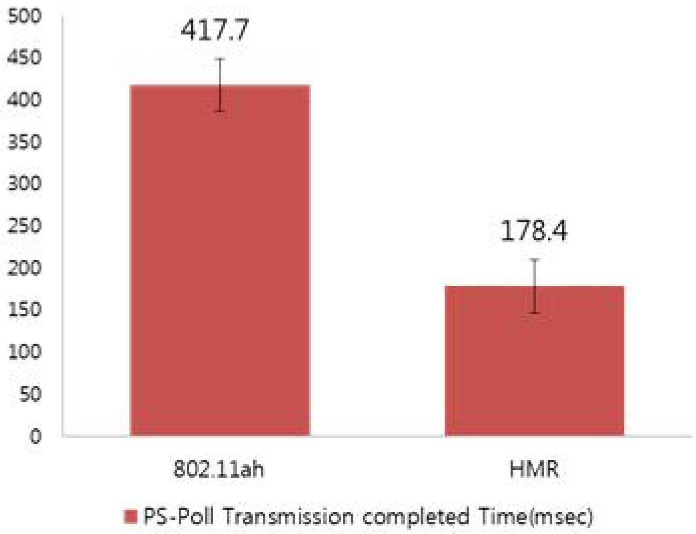

Figure 24. Average Transmission Completed Time

6.3 Retransmission Number

We measured average retransmission number per group. 802.11ah power saving mode is used for sensor networks. In sensor networks, node' energy consumption is critical issue. The most of energy consumption occurs when sensor nodes wake and transmit data. So as many as reduce the retransmission, it can save more energy.

In Table 6, existing 802.11 and HMR of average retransmission number per group are 45.2 and 15.0 respectively. Reduced ratio of the retransmission is 66.8% which means that HMR can save the energy 66.8% approximately and that makes the sensor node' s life span longer.

Table 6: Average Retransmission Number per Group

	802.11ah	**HMR**
Average retransmission number per group	45.2	15.0

6.4 Regrouping Result

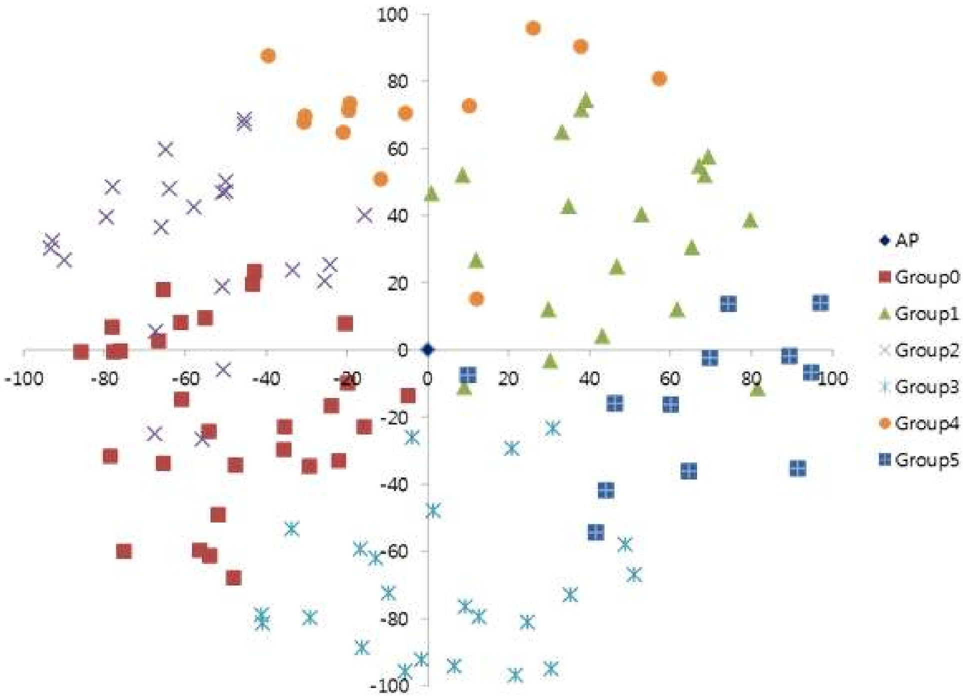

Figure 25. Node Distribution After a Simulation

This Figure 10 shows an example for node distribution after a simulation ends. We present nodes with different color according to the node's group. As shown in Figure 10, we can see the nodes in the same group are properly gathered together like a sector.

Chapter 7

Conclusion

This paper considered the hidden node problem in the IEEE 802.11ah power saving mode. To reduce performance degradation by the hidden node problem, we proposed a HMR algorithm which consists of hidden node detection by the first PS-Poll transmission time, hidden node matrix generation based on the hidden node detection and hidden node regrouping using the hidden node matrix. In the simulations, we compared our scheme and the existing 802.11ah specification. The simulation results demonstrated that the proposed algorithm can eliminate the hidden node pairs up to 98.26% and shorten the PS-Poll transmission completed time as 57.3%. Moreover the proposed algorithm reduced retransmission number by 66.8%. Therefore, we conclude the proposed algorithm not only is simple but also achieves good performance.

Reference

[1] Y. Kim, J. Yu, S. Choi and K. Jang, "A Novel Hidden Station Detection Mechanism in IEEE 802.11 WLAN." *IEEE Commuun. Letters*, VOL. 10, NO. 8, Aug. 2006

[2] A.K, Frank Y. Li and P. Engelstad, "Passive and Active Hidden Terminal Detection in 802.11-based Ad Hoc Networks," In *INFOCOM*, 2006.

[3] Koichi Nishide, Hiroyuki Kubo, Ryoichi Shinkuma and Tatsuro Takahashi "Detecting Hidden and Exposed Terminal Problems in Densely Deployed Wireless Networks" *IEEE Transaction of Wireless Communications*, VOL. 11, NO. 11, pp. 3841-3849, Nov. 2012

[4] S. Aust, T. Ito, "Sub 1 GHz Wireless LAN Propagation Paht Loss Models for Urban Smart Grid Applications," *the International Conference on Computing, Networking and Communication (ICNC) Workshop on Communication Technologies Support to the Smart Grid, Maui, Hawaii*, USA, January 30 - February 2, 2012.

[5] R. Porat, et al., TGah channel model - proposed text. IEEE 802.11-11/0968r3, Jul. 2011, https://mentor.ieee.org/802.11/dcn/11/11-11-0968-03-00ah-channel-model-text.docx.

[6] M. Park. IEEE P802.11ah. Specification framework for TGah. IEEE 11/1137r15 May 2013.

[7] S. Aust, R.V Prasad, and I.G. Niemegeers. IEEE 802.11ah: advantages in standards and further challenges for sub 1 GHz Wi-Fi. In *Proceedings of IEEE International Conference on Communications (ICC)*, Jun. 2012.

[8] W. Sun, M. Choi, and S. Choi, "IEEE 802.11ah: A Long Range 802.11 WLAN at Sub 1 GHz," *Journal of ICT Standardization*, vol. 1, pp.83-107, May 2013.

초록

802.11ah 네트워크 환경에서 히든 노드 문제를 완화시키기 위한 그룹화 알고리즘

서울대학교 대학원
전기·정보 공학부
서정오

802.11ah에서는 전송거리가 1km 이상 되고 최대 8000여개의 노드를 서비스할 수 있다. 따라서 802.11ah 네트워크에서는 기존의 802.11 보다 더 많은 히든 노드 쌍을 가지게 된다. 특히나 저전력 모드에서 단말이 AP에게 PS-Poll을 전송할 때 히든 쌍에 의한 문제는 더욱 심해지고 히든 노드 쌍으로 인한 패킷 충돌이 빈번히 일어나기 때문에 전반적인 네트워크 성능이 저하된다. 따라서 본 논문은 802.11ah 저전력 모드에서 발생할 수 있는 히든 노드 문제를 조명하고 그 문제를 완화시키기 위한 알고리즘을 제안한다. 제안하는 알고리즘에서는 먼저 히든 노드를 찾아내고 그 정보를 바탕으로 히든 노드 행렬을 만든다. 그리고 히든 노드 행렬을 기반으로 그룹을 재편성 시켜주는 순서로 진행이 된다. 모의 실험을 통하여 제안하는 기법이 히든 쌍을 거의 소거하는 것을 확인하였다. 결과적으로 802.11ah 네트워크의 수율과 전송 지연이 크게 개선된 것을 확인하였다.

주요어 : 802.11ah, 저전력 모드, 히든 노드 문제, 그룹 기반 경쟁
학번 : 2012-20787

감사의 글

연구실을 입학한 지가 엊그제 같은데 벌써 연구실을 떠난다고 생각을 하니 시간이란 것이 참으로 빠르고 야속하기만 합니다. 돌이켜 생각해 보면 주마등처럼 지나온 시간들이지만 그 안의 행복했던 추억들이 넘쳐나 떠나는 마음이 외롭기만은 하지 않은 것 같습니다.

연구실을 컨택하기 위해 전전긍긍하던 시절 흔쾌히 연구실 학생으로 받아주신 박세웅 교수님 정말 감사합니다. 짧으면 짧다고도 느껴질 수 있는 2년 동안 실수도 잦고 크고 작은 사고도 많이 있었지만 아버지와 같은 마음으로 용서해 주시고, 때로는 격려와 좋은 말씀을 해주신 교수님은 정말 저에게 있어선 행운이라고 생각합니다. 학생의 눈높이에서 학생의 마음을 이해해 주시고 믿어주신 교수님께 다시 한 번 감사한 마음을 표현하고 싶습니다. 받은 은혜 갚을 길이 없지만 앞으로 사회에 나가서 저 또한 다른 이에게 사랑과 은혜를 베풀 수 있는 사람이 되도록 노력하겠습니다. 그리고 부족한 논문이지만 논문 심사를 해 주신 이병기 교수님과 최성현 교수님께도 감사의 말씀을 올립니다.

교수님과 더불어 연구실 선배님들 후배님들 모두 감사드립니다. 먼저 저의 논문의 틀을 잡아주기고 완성이 되기까지 많은 부분을 도와주신 성국이형에게 감사합니다. 논문이 완성되기까지 많은 우여 곡절이 있었지만 성국이형의 도움이 큰 힘이 되었습니다. 연구 이외에서 큰 형님으로써 격려해 주시고 조언해 주신 점 다시 한 번 감사드립니다. 그리고 논문의 시뮬레이션에 큰 도움을 주신 서우형에게 감사하다는 말을 전하고 싶습니다. 연구실 분위를 유쾌하게 해주시고 저에게 아낌없는 조언과 격려의 말을 해 주셔서 감사합니다. 서우형의 딜레마 문제는 졸업하고 나면 그리울 것 같습니다. 연구실 생활 시작하여 연구실에서 즐거운 시간 보내고 그리고 때로는 진지한 인생의 선배로써 조언도 아끼지 않았던 관석이형에게도 감사의 인사를 드립니다. 그리고 항상 유쾌하고 남자다운 희수형 고맙고 감사합니다. 항상 절 챙겨 주신 점 감사합니다. 같은 방을 하지 못해 많이 아쉬운 마음을 앉고 졸업을 하네요. 허리 문제없이 항상 건강하길 바랍니다. 그리고 졸업에 와서야 같은 방을 하게 된 창원이형! 끝날 때 돼서야 같은 방을 하게 되어 많이

아쉽지만 연구를 할 때 진지한 모습과 놀 때는 또 확실히 노는 그 모습 배워가겠습니다. 그리고 동생들을 생각하는, 형으로써 듬직함을 보여주는 상규형! 같이 밤새며 먹던 불닭발 생각이 많이 날거 같습니다. 먹은 다음날은 단단히 각오를 해야 하지만 새로운 음식의 지평을 열어 주신 점 잊지 못할 것 같습니다. 논문 심사 전날 늦게까지 하나하나 도와주신 점 다시 한 번 감사드립니다. 같이 동거 동락하면 보낸 1년 동안 정말 동네 형같이 느꼈습니다. 연구실 들어와서 가장 기억에 남는 것을 떠올리자면 1학년 여름방학 울산 UNIST에서의 방문연구일 것입니다. 두 달 가까이 되는 시간동안 저를 맡아 주신 주창희 교수님께 감사의 인사를 드립니다. 그리고 아무것도 모르는 저를 데리고 고생하신 대호형과 세용이형에게 감사의 말씀을 드리고 싶습니다. 연구실 생활 및 기본적으로 연구에 대해 아낌없는 조언과 도움을 주시고, 때로는 응원과 칭찬해주신 대호형 정말 감사드립니다. 연구실 생활에 슬럼프를 느끼고 힘들어 할 때 진심으로 저를 걱정해주고 조언을 아끼지 않았던 세용이형! 박사를 진학하지 못해 많이 아쉽고 미안한 마음이 먼저 듭니다. 제가 잘못 할 때면 아낌없이 질책 해 주시고 격려해 주셔서 감사합니다. 그리고 논문 작성과 졸업과정에 대해 질문하면 언제나 흔쾌히 도와주신 종훈이형에게 감사의 말씀을 전하고 싶습니다. 귀찮은 내색 없이 도와주시고 마지막까지 신경 써 주셔서 정말 감사합니다. 미안한 마음을 안고 졸업하네요. 그리고 한 살 차이 이자 한해 위 선배인 진우형. 때로는 친구같이 때로는 든든한 형같이 저를 편하게 대해 주셔서 감사합니다. 같이 있어서 많이 즐거운 시간이었습니다. 함께 동고동락 하며 연구실에서 보낸 시간이 바로 어제 같은데, 그때 추억은 잊지 못 할 것 같습니다. 그리고 우리 사랑하는 태섭이! 동생이지만 어쩔 땐 형같은 든든한 모습을 보여주고, 귀여움과 화끈함 삼박자가 갖추어진 삼위일체 태섭이! 같은 방을 쓰지 못해 못내 아쉬운 마음이 먼저 드네. 날 먼저 챙겨 주고 내가 힘들 땐 또 옆에서 힘이 되어줘서 너무 고마워. 작년엔 내가 정말 깜빡해버리는 바람에 얘기를 못했지만 이번엔 정신 빠싹 차리고 적고 있어. 기쁜 일이 있을 땐 내일처럼 기뻐해주고 언제나 밝은 모습 보여줘서 태섭이게 정말 고맙고 감사하다는 말을 전하고 싶습니다. 그리고 같이 박사 진학을 하지 못해 못내 미안한 현중이에게 먼저 미안하다는 말을 전하고 싶습니다.

동기로써 같은 방을 사용한 것은 아니지만 참으로 많은 의지가 되었고, 언제가 내가 좀 모자란 부분이 있어도 든든한 나무처럼 자리를 지켜준 점 고맙고 감사한 마음이 듭니다. 박사 진학하여 쓰지 못한 내 논문까지 많이 써서 훌륭한 박사로 졸업해줘. 컴퓨터와 관련하여 물어보면 언제나 친절해 대답해주는 영준이에게 감사의 말을 전합니다. 내가 힘들 땐 같이 걱정해 주며 위로 해준 줬던 일들이 내겐 큰 힘이 되었습니다. 작년에 새로와 넷랩 식구가 된 형신이! 푸근하면서도 연구자의 진지한 모습을 보여줘서 보면서 항상 닮고 싶다는 생각을 많이 했습니다. 졸업 논문을 준비하기 시작 할 때 나를 위해 적극적으로 논문에 대해 준비하고 신경 써주어 고맙고 감사합니다. 한국에 와서 고생하는 령이에게 힘내라는 메시지를 보내고 싶습니다. 그리고 연구실 외국인 친구들 후르칸, 피카두에게 못내 친해지지 못해 아쉬움 마음이 듭니다. 연구에 대해 함께 고민했었고 영어 공부와 관련해 많은 조언을 해준 후삼에게 감사의 말을 드리고 싶습니다. 그리고 연구실 생활 1년을 같이한 승범이와 용훈이에게 감사의 말을 전합니다. 승범이에게는 넷랩의 전력을 가다듬어 숙원의 사업인 뉴미연 컵 우승을 일궈내 봤으면 하는 기대를 해봅니다. 내가 말하는 것 하나하나 과도하리 만큼 웃어준, 내가 웃음 알레르기 항원이 아닐까 의심이 되는 용훈이! 시청료를 따로 받아도 되겠다는 생각이 잠깐 들었지만 나를 이렇게 까지 좋아해 줄 사람이 어디 있을까 하는 생각에 고마운 마음이 가득 찹니다. 논문 심사를 받는 날 준비에 많은 도움을 주어 감사합니다. 이와 더불어 논문 심사 받는 날 잘 준비 할 수 있도록 도와주고, 자잘한 일에도 흔쾌히 도움을 많이 준 이세련 비서님에게 감사의 인사를 전합니다. 이번에 새로이 들어온 신입생 박원빈, 이명섭, 조호수 모두 열심히 연구하고 생활도 알차게 하여 많은 것을 배우고 얻어가는 시간이 되었으면 합니다.

대학 생활동안 늘 한결같이 있어 주고 힘이 되어준 919동 룸메이트 분들 현모형, 호용이, 현석이, 막내 귀여운 동호에게 감사의 인사를 전합니다. 더불어 같이 고민해주고 인생에 대해 진지한 이야기를 많이 나눈 윤재에게도 감사의 인사를 전합니다.

힘들 때면 옆에서 항상 큰 힘이 되어준 간달프 상현이 언제나 고맙게 생각합니다. 뒤에서 든든히 있어준 최고의 친구 성찬이에게도 고맙고

덕우, 홍기, 세휘, 정두, 종률이, 병훈이에게도 감사의 인사를 전합니다.

언제나 집에서는 막내아들인 저를 믿어 주고 때로는 걱정해주며 든든하게 버텨 주는 아버지 어머니 정말 감사합니다. 존재만으로도 저에게는 큰 힘이 됩니다. 어머니 아버지를 보면서 말은 하지 않지만 항상 많은 것을 느끼고 배우고 있습니다. 언제나 감사하고 사랑합니다. 자랑스런 아들이 될 수 있도록 항상 노력 하겠습니다. 이제는 몸 걱정 먼저 하시고, 사회에 나아가 열심히 사는 아들의 모습 지켜봐 주세요. 집에 가면 항상 반겨 주시는 할머니에게도 자랑스런 손자가 될 수 있도록 노력하겠습니다. 대학원 생활동안 항상 옆에서 힘이 되어준 큰누나에게 감사의 인사를 전합니다. 옆에 있는 존재 차제만으로도 의지가 되고 외롭지 않았는데 누나로써 동생을 항상 챙겨주어서 고맙고 감사하게 생각합니다. 멀리 있지만 항상 마음만은 옆에 있는 작은누나와 매형에게도 감사의 인사를 전합니다. 저를 생각해주시는 따뜻한 마음 언제나 느끼고 있습니다. 준석이도 아프지 말고 건강하게 잘 자라길 바랄게.

돌이켜 감사한 일들을 떠올려 보면 제가 받은 은혜가 한없다는 것이 느껴집니다. 이렇게 받은 은혜만큼 내가 과연 다른 사람에게 주었을까하는 부끄러운 마음도 같이 듭니다. 앞으로 받은 사랑 이상으로 모두에게 보답할 수 있는 사람이 되겠습니다.

이제는 학생의 신분의 아니라 사회인으로써 앞으로 나아가야할 때가 온 것 같습니다. 언제나 집의 막내이고 어리숙한 저이지만 한층 더 성숙해진 모습으로 첫 발을 딛여 보려고 합니다. 응원해 주신 모든 분들에게 감사하며 힘을 내어 잘 살아 보겠습니다. 감사합니다.

2014년 2월,
서정오 드림.