# Virtual Access Point Allocation Method for High Density WLANs

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## ABSTRACT

Recently, channel interference between access points (APs) due to high density wireless local area networks often results in throughput degradation of mobile nodes (MNs). To solve this problem, research of Virtual Access Point (VAP) has been done. VAP is AP constructed by virtualization technique, and we can run multiple VAPs in one AP. We can stop unnecessary APs by aggregating VAPs into one AP, which results in degrading channel interference. However, aggregating VAP randomly sometimes degrades throughput of MNs. In this paper, we propose a VAP aggregation method considering received signal strength indicator and current bandwidth usage of APs. We can avoid throughput degradation of MNs due to VAP aggregation by this method. We implemented prototype systems of our method and evaluated them in terms of throughput of MNs, and showed that we can reduce the number of running APs while keeping the throughput of MNs by using our method.

*Keywords*: WLAN; access point; virtualization; allocation;

## 1 INTRODUCTION

With the recent growing popularity of wireless local area network (WLAN), access points (APs) are often located in high density. This leads to channel interference between APs especially in a place where many different domains exist in a narrow space such as schools or offices. This happens, because domain managers decide location and configuration of APs independently, which leads to overlapping propagation range of APs. Channel interference makes WLAN performance low, and results in throughput degradation and delay [1].

There are researches about optimization of AP location and AP configuration to degrade channel interference between different APs [2]–[8]. However, these researches do not consider differences between domains. In a case where multiple domain networks are close to each other, it is necessary to conduct optimization including APs of other domains which cause channel interference.

To achieve this, we utilize the virtualization technique. The virtualization technique is often used for networking [9]. Scalable, safe and low-cost networks can be created by virtualizing network connections or equipments. We apply Virtual Access Point (VAP) [10], which is AP created by virtualization technique. VAP provides a "function" as an AP, i.e. connects mobile nodes (MNs) to a LAN. In contrast, we define an "equipment" of AP as physical AP (PhyAP), which refers to a computing resource and a wireless interface. VAPs can be migrated to other PhyAP by using a function called VAP migration, then run on the PhyAP. VAP migration is based on Virtual Routers On the Move (VROOM) [11], which is a migration of a virtual router. In VROOM, they separate a router into "function" and "equipment" by virtualization of a router, and let the virtual router move among the physical routers, which simplify the network management. VAP also can keep its function even when it is migrated to other domain's PhyAP, which makes the management of APs simple.

Furthermore, we can keep the connection after a VAP has been migrated to other PhyAP since packets are delivered over virtualized networks generated for each VAP. We can stop the PhyAPs where VAPs existed after executing migration, and thus the number of PhyAPs in use decreases, which contributes to the degradation of channel interference. We call the process of aggregating VAPs into an AP like this VAP aggregation.

Though VAP aggregation can degrade channel interference, throughput of MNs might be degraded after VAP aggregation. This is because VAPs might be aggregated into a PhyAP with low received signal strength indicator (RSSI) or overload. VAP aggregation can aggregate VAPs into a PhyAP, but there is no method discussed of selecting appropriate PhyAP to be aggregated VAPs into so far. Therefore we need a method to select PhyAPs for VAP aggregation with consideration of RSSI and current bandwidth usage of PhyAPs.

In this paper, we propose VAP allocation method, which is consisted of a VAP allocation algorithm and an information gathering system. The algorithm decides where VAPs are being aggregated with consideration of RSSI and current load of PhyAPs by repeating the two following phases. One is PhyAP decision phase, which selects a PhyAP. The other is VAP decision phase, which selects which VAPs to be aggregated into the PhyAP which is selected in the previous phase. Information needed for the algorithm is RSSI of PhyAPs and current bandwidth usage of MNs. We also create the system for gathering the information, executing the algorithm, and aggregating VAPs.

The proposed algorithm is applied to VASS (VAP allocation Supporting System for users) [12]. There, we propose a model where users migrate their own VAPs to the other domains' PhyAPs to improve communication quality and convenience of MNs. The main purpose of [12] is realizing the model by VASS. On the other hand, this paper intends to prove the effectiveness of the algorithm based on evaluation in many environments.

The rest of this paper is organized as follows. In section 2, we discuss related works on AP optimization, overview of VAP and the problem of VAP aggregation. In section 3, we propose the VAP allocation method. In section 4, we implement a prototype system, and then evaluate it. Finally we conclude this paper in section 5.

# 2 RELATED WORK

In this section, we state related works on AP optimization and the weakness of them, and explain about the solution by VAP. Also, we describe the problem occurred by VAP aggregation.

## 2.1 AP Optimization

The researches on AP optimization is classified roughly into two groups: optimal placement of AP and optimal selection of AP. The former researches aims to optimize the geographic placement of APs. R.C. Rodrigues et al. [2] use the linear programming so that minimal APs cover the range of wireless network. M.Kobayashi et al. [3] applies simulated annealing algorithm to AP placement in simultaneous broadcast system using OFDM. Jane-Hwa Huang et al. [4] cut down the number of APs and improve the communication efficiency in wireless meshed networks in outdoor by the mixed-integer nonlinear programming (MINLP). Meanwhile the latter researches aims to select optimal APs and to allocate optimal channels on the basis of MNs' communication conditions. Andreas Eisenblatter et al. [5] and Iordanis Koutsopoulos et al. [6] pay attention to the fact that the AP placement and channel assignment is executed asynchronously in general, and propose executing the AP placement and channel assignment synchronously, then demonstrate its effectiveness. Youngseok Lee et al. [7] select APs and assign channels to them so as to use only the completely independent channels by CPLEX. Y.Matsunaga et al. [8] propose the Radio Resource Broker(RRB) which optimizes and redistributes the radio resources among the domains by dynamic channel compensation, power control or network-initiated load balancing.

These researches have one thing in common: they assume that they can place and configure APs freely. The assumption is true when AP optimization is conducted in only one network. However, in the case where a number of different domain's networks are geographically close to each other like schools and offices, we can not apply these approaches. In that case we have to make it possible to conduct the AP optimization in a whole network including other domains. One of the solutions for this problem is to aggregate as many domains' networks as possible into a minimum number of APs, and VAP enables this.

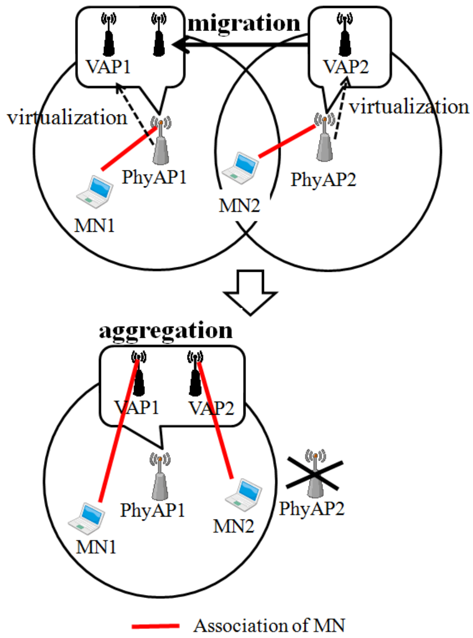



Figure 1: Overview of VAP aggregation.

## 2.2 VAP Overview

VAP [10] is AP constructed by virtualization technique. In contrast, we define equipment of AP as PhyAP. By aggregating VAPs into an AP, the number of PhyAPs in use decrease, which contributes to the degradation of channel interference.

T.Nagai et al. [10] propose the concept of VAP aggregation, and to realize it, they describe the method to construct VAP itself and VAP migration. Figure 1 shows an example of VAP aggregation process, which is proved to be effective to degrade channel interference in [10]. There are two PhyAPs and two MNs, and MN1 and MN2 are associated with PhyAP1 and PhyAP2 respectively. MN2 can receive the radio from PhyAP1 too, so it can associate with both PhyAP1 and PhyAP2. In this situation channel interference occurs, since the frequency bands of channels that both PhyAPs use overlaps. In consequence, communication efficiency of MN2 gets worse. To avoid this, we virtualize both PhyAPs, and create VAP1 and VAP2 on each PhyAP. After creating VAPs, we execute live migration of VAP2 to PhyAP1 which both MNs can be associated with. Here, live migration is migration of a virtual machine to another physical machine without down time. By executing VAP migration to other PhyAP, we can aggregate VAPs. We can stop PhyAP2, because MN2 will be associated with VAP2 on PhyAP1, which solve the channel interference problem.

Furthermore, using VAPs can make an AP offer policies and services of multiple domains, since VAPs are created by virtualization techniques. Policy means regulation for operating networks which decides rules and priorities of security, authentic method and how to allocate addresses etc. Services are offered by a server including mail and web page etc. In VAP technique, policy planes apply policies of each domain, and virtual host offer services of each domain. MNs can keep the connection after VAP has been migrated to other PhyAP since packets are delivered over virtualized networks generated for each VAP. Also, when multiple VAPs are aggregated into a PhyAP, traffics of each VAP can be separated. Thus aggregating of multiple VAPs into a PhyAP can aggregate MNs' communication into fewer PhyAPs, while supporting policies and services as APs and keeping connection of MNs' communication. H.Shindo et al. [12] focus on VAP's such features, and create VASS (VAP allocation system for users). VASS is used by users who have their own VAPs migrate their VAPs to other domains' PhyAP to improve communication quality and convenience of MNs.

### 2.3 Problem of VAP Aggregation

VAP has been researched in terms of VAP realizing mechanism and route construction. These researches realize VAP aggregation to degrade channel interference by decrease running PhyAPs while supporting policies and services and keeping connection of MNs' communication. However, they do not discuss selecting appropriate PhyAP to be aggregated VAPs into so far. Therefore, executing VAP aggregation into random PhyAPs carries a risk of throughput degradation,

When a VAP is aggregated into a PhyAP with low RSSI, throughput of MNs associated with the VAP is degraded. This happens because Auto Rate Fallback (ARF) implemented in a chip set of a wireless interface works to degrade the transmission rate for MNs which receive low RSSI to fixed speed in order to avoid increasing the error rate [13]. Therefore, we should aggregate VAPs into a PhyAP with higher RSSI.

Also, when a VAP is aggregated into a PhyAP with overload, throughput of MNs associated with the VAP is degraded. Besides not all MNs need the same bandwidth. For example, a MN browsing the Internet and a MN playing an online game need different bandwidth. When MNs using large bandwidth are associated with a PhyAP, the PhyAP is overloaded, and then throughput of the each MN is degraded [14]. Therefore, we should aggregate VAPs into a PhyAP with low load.

Thus, we need a method of VAP aggregation with consideration of RSSI and current bandwidth usage of PhyAPs.

## 3 VAP ALLOCATION METHOD

In this section, we propose a VAP allocation algorithm that determines which VAP to be aggregated into which PhyAP by using information about RSSI and current used bandwidth of PhyAPs. Also, we propose a information gathering system using the management server to collect the information needed to execute the algorithm.

### 3.1 System Overview

We start from describing the information gathering system. Figure 2 shows the overview of the system. The system is constructed of a management server, PhyAPs, VAPs and MNs. We assume that VAPs used by each MN have already

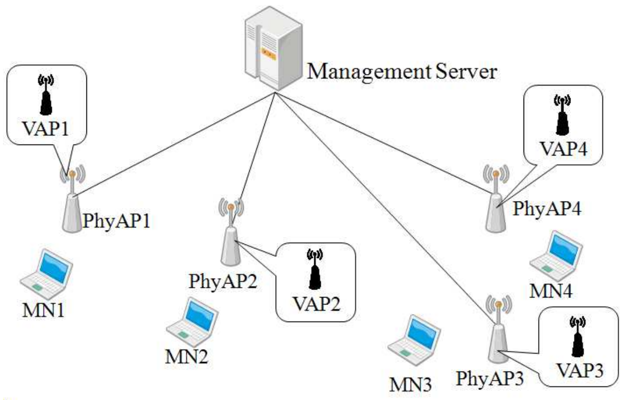



Figure 2: System overview.

exist in any of the existing PhyAPs so that MNs can communicate with the management server through the each VAP.

The management server has wired connections to all PhyAPs, and manages the various information. It determines which VAP to be aggregated into which PhyAP by executing the algorithm explained in section 3.2, and executes VAP aggregation. There are four databases: MN database, VAP database, measurement-by-MN database and association database. Table 1 shows the entities of these databases. MN database has the MN-related information like ID, MAC address, throughput and using VAP of each MN. VAP database has the VAP-related information like ID, ESSID, MAC address and IP address of a wireless interface, IP address of a wired interface and IP address of PhyAP where each VAP exists. Measurement-by-MN database has the information of association between MNs and VAPs like ID of MN and ID and RSSI of VAP MN is associated with. Association database is made from the three databases above. The database is used for executing the algorithm, and has ID of PhyAP, ID of MN, RSSI of the PhyAP measured at the point of the MN, throughput of the MN and ID of the VAP MN is associated with.

The management server make PhyAPs and MNs monitor the information for the databases. PhyAPs get the own IP addresses, information of VAPs aggregated into themselves(ESSID, MAC address and IP address of the wireless interface and IP address of the wired interface) and MAC address of MNs being associated with the VAPs, and calculate the throughput of the MNs. In this case, throughput of MN is the average throughput of MN from when VAP aggregation is executed to when it is executed next. The obtained information is sent to the management server through the wired interface. MNs get the own MAC address, ESSID of the using VAPs, information of the PhyAPs that MNs can associated with such as ESSID and RSSI. This obtained information is sent to the management server through the VAP associated with.

After receiving the various information from PhyAPs and MNs, the management server makes MN database, VAP database and measurement-by-MN database, and then association database from three databases. Next, it executes the algorithm ex-

Table 1: Entities of databases.

| Name of database | Entities |
|---|---|
| MN | ID, MAC address, throughput, ID of VAP |
| VAP | ID, ESSID, MAC address, IP address of wireless I/F, IP address of wired I/F, IP address of PhyAP where VAP exists |
| Measurement-by-MN | ID of MN, ID of VAP, RSSI of VAP |
| Association | ID of PhyAP, ID of MN, RSSI of PhyAP, throughput of MN, ID of VAP |

plained in section 3.2 using the association database, and then determine which VAP to be aggregated into which PhyAP. Finally, it executes VAP aggregation by output of the algorithm. In VAP migration to another PhyAP, it uses IP address of VAP's wired interface and PhyAP's wired interface.

## 3.2 VAP Allocation Algorithm

VAP allocation algorithm determines which VAP to be aggregated into which PhyAP among multiple VAPs and PhyAPs. The purpose for the algorithm is to avoid degrading throughput of MNs by considering RSSI and current used bandwidth of PhyAPs. It is executed with the association database described section 3.1. It consists of two phases: PhyAP decision phase and VAP decision phase. PhyAPs are chosen to be aggregated into among all PhyAPs in PhyAP decision phase, and then VAPs are chosen to be aggregated into the PhyAPs selected before VAP decision phase. After a PhyAP is picked up, VAPs aggregated into the PhyAP are selected. By repeating the two phases until all VAPs are aggregated, we can determine which VAP to be associated into which PhyAP. We describe these two phases in detail in the following sections.

### 3.2.1 PhyAP decision phase

In PhyAP decision phase, PhyAPs are selected to be aggregated into among all PhyAPs. They are PhyAPs with high RSSI measured at the point where MNs exist. In this phase, information about the number of MNs which can associated with the each PhyAP and corresponding RSSI is needed.

Figure 3 shows the flow chart of the algorithm in the phase. First, the management server counts $M_p$, the number of MNs which can associated with PhyAP $p$ according to the information measured by MNs and gathered by the management server. Here, $P$ is a set of all PhyAPs. A MN can be associated with a PhyAP when it can measure RSSI of the PhyAP. This is why connections of MNs are never cut off even when VAPs used by the MNs are migrated to the other PhyAPs whose RSSI can be measured.

Next, the management server selects $p_{can}$, PhyAP candidate to be VAPs aggregated into.It is the PhyAP(s) with the biggest $M$ among the other PhyAPs. This means that by selecting the PhyAP with the biggest $M$, the number of aggregated VAPs is expected to increase, and then the number of PhyAPs to run decrease.

Finally, the management server calculate $R$, the sum of the values of RSSI of each $p_{can}$, and then the PhyAP with the biggest $R$ is determined as $P_{agg}$, the PhyAP(s) aggregated VAPs into. This process can avoid throughput degradation of MN due to ARF because it selects the PhyAP with the biggest $R$ to avoid aggregating VAPs into a PhyAP with low RSSI.

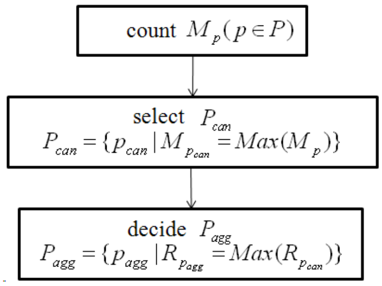



Figure 3: Flow chart of PhyAP decision phase.

### 3.2.2 VAP decision phase

In VAP decision phase, VAPs are selected to be aggregated into the PhyAP determined in previous VAP decision phase among the other VAPs used by MNs which can be associated with the PhyAP. This phase aims to avoid degrading throughput of MNs due to degrading the transmission rate by ARF and overloaded PhyAP by using information of expected bandwidth of MNs calculated from RSSI of PhyAPs and throughput of MNs.

Figure 4 shows the flow chart of the algorithm. First, the management server calculates $B_v$, the expected throughout of each MN from RSSI of PhyAP measured by MNs according to the ARF standards. Here, $V$ is a set of all VAPs. In the case that multiple MNs are in a VAP and the expected throughput of MNs are different among MNs, the minimum one is $B_v$. Thus, $B_v$ is calculated for every VAP uniquely.

Next, the VAP with the biggest $B_v$ and the largest $T_v$ is chosen as a $v_{can}$. $T_v$ is the amount of the traffic in each VAP. $v_{can}$ is VAP candidate which is aggregated into $p_{agg}$ preferentially. This is how the algorithm avoids throughput degradation due to ARF.

Next, the management server calculates $T_{all}$, the amount of traffic on $p_{agg}$. $T_{all}$ is the sum of the throughput of MNs associated with $v_{can}$ and $v_{set}$. $v_{set}$ is a VAP already selected to be aggregated.

If $B_{v_{can}}$ is above $T_{all}$, $v_{can}$ is determined as $V_{agg}$, a VAP to be aggregated. This keeps more traffic than the expected bandwidth of each MN from being congested in the PhyAP. This process contributes to avoidance of throughput degradation due to overload to the PhyAP.

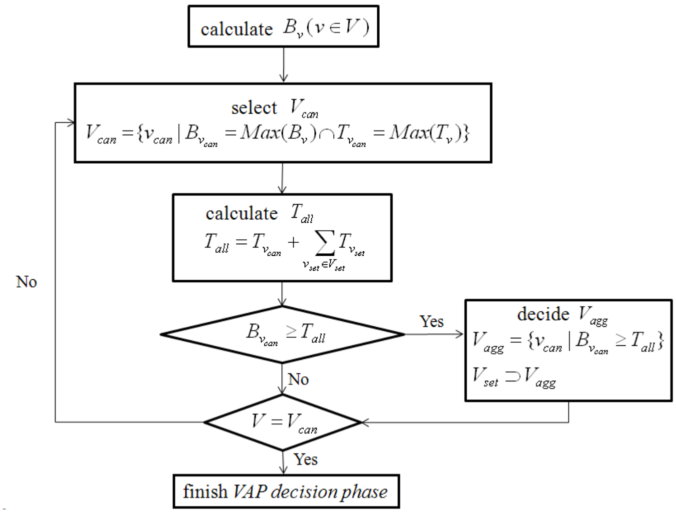



Figure 4: Flow chart of VAP decision phase.

If $T_{all}$ is above $B_{v_{can}}$, the management server selects a new $v_{can}$. It repeats the above processes by all VAPs have been selected as $v_{can}$.

When there are VAPs aggregated into undetermined PhyAP after we finish this phase, we return the PhyAP decision phase.

# 4 IMPLEMENTATION AND EVALUATION OF A PROTOTYPE SYSTEM

We implemented and evaluated the prototype system of the VAP allocation method proposed in section 3.

## 4.1 Implementation Setup

We implemented the prototype system in three environment summarized in Table 3. To create a more realistic environment, we implemented the system on a floor in Keio university. The size of the room where PhyAPs exist is about 7.5m × 7.5m, and the corridor is about 20m long. There are ferroconcrete walls between the rooms and the corridor. 20 or 30 real domains' WLANs are operated in neighbor rooms.

We use the following equipment for our implementation:

- Management Server
  It has a wired network interface, and is connected with PhyAPs. It has OS images of virtual hosts, and allow the PhyAPs to access the OS images over a network. It also stores databases for informations about MNs ,VAP and PhyAP, and runs the management application to execute the VAP allocation algorithm and VAP aggregation.

- PhyAP
  It has multiple wireless network interfaces and a wired network interface. The multiple wireless network interfaces are used to create the virtual wireless network interfaces in PhyAP architecture. We use a wireless network interface card, CG-WLPCI54AG2 which has a chip made by Atheros Communications. Atheros chips are controlled by driver software called MadWifi [15], and their MAC address can be changed. It runs information gathering application for collecting the informations described section 3.1. Throughput of MN is calculated by summing up the size of packets discerning by MAC address of MN per second in the packet capturing program with Jpcap [16].

- Mobile Node (MN)
  It has a wireless network interface card, GW-US54GXS and runs information gathering application to collect the information described section 3.1. We use *iwlist* command to get the information about ESSID and RSSI of the PhyAP which MN can be associated with. By using *iwlist* command and active scanning, we can gather informations of neighbor AP's ESSID, BSSID, RSSI and so on.

Table 2 summarizes the specification of each equipment and running applications.

Here, we use IEEE802.11g for the WLAN standard, so the maximum transmission rate is 54Mbps theoretically. However, the saturated throughput in those environments is about 13Mbps, so we decide the maximum bandwidth PhyAPs can support to 13Mbps. As for Auto Rate Fallback (ARF), we follow the product specification offered by Cisco Systems, Inc [17]. Traffic is generated by Iperf [18] in the server mode at VAPs and in the client mode at MNs. Iperf is a tool for traffic generation and monitoring network performance such as throughput, jitter and packet loss.We run Iperf for 100 seconds 20 times, and calculate the average throughput of MN for all the time.

## 4.2 Evaluation

We evaluated the prototype system in the three environments to confirm that the proposed VAP allocation method can keep the throughput of MNs after executing VAP aggregation. The evaluation point is throughput of each MN. We compare the proposed VAP aggregation to random VAP aggregation, which is the way for executing VAP aggregation into randomly selected PhyAP. Table 3 lists the three environments. First, we set up the system in one room, and all four MNs generate 5Mbps or 10Mbps traffic. We call theses environments A-1 and A-2 respectively. They represent the situation where people in the same group use APs to run similar applications, which means for example they are in a meeting or play an online game together. Next, we set up the system in multiple rooms and a corridor, and some MNs generate 5Mbps bandwidth, others generate 10Mbps. We call the environment B. It represents the situation where people are in different groups, and run different applications.

Figure 5(a) shows the results of the VAP placement in A-1, and Figure 5(b) shows throughput of each MN in the three cases: before VAP aggregation, after random VAP aggregation and after proposed VAP aggregation. Before VAP aggregation in any environments, each VAP exists in the corresponding PhyAP: VAP1 is in PhyAP1, VAP2 is in PhyAP2

Table 2: Specifications and applications.

| | Management Server | PhyAP | MN |
|---|---|---|---|
| CPU | Pentium4 3.2Ghz | Pentium4 3.2Ghz | Pentium4 3.2Ghz |
| Memory | 4GB | 4GB | 2GB |
| OS | CentOS 5.3 | CentOS 5.3 | Windows XP |
| Application | Management application | Information gathering application | Information gathering application |
| Others | NFS, IEEE802.1q, OpenVPN server | Xen, IEEE802.1q, Bridge-Utils | |

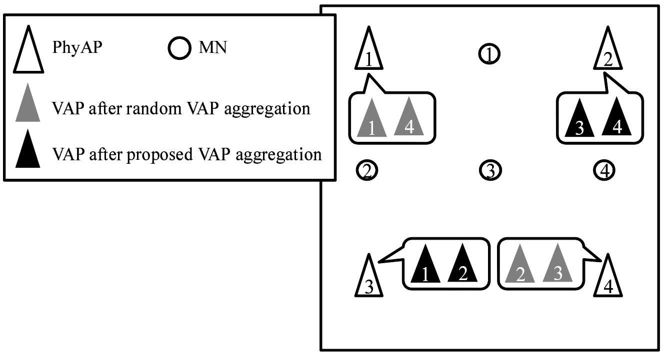
Table 3: Three implementation and evaluation environments.

| | Where the system is | Generated traffic by each MN |
|---|---|---|
| A-1 | in 1 room (Figure 5(a)) | 5Mbps |
| A-2 | in 1 room (Figure 6(a)) | 10Mbps |
| B | in 2 rooms and a corridor (Figure 7(a)) | 5Mbps or 10Mbps |

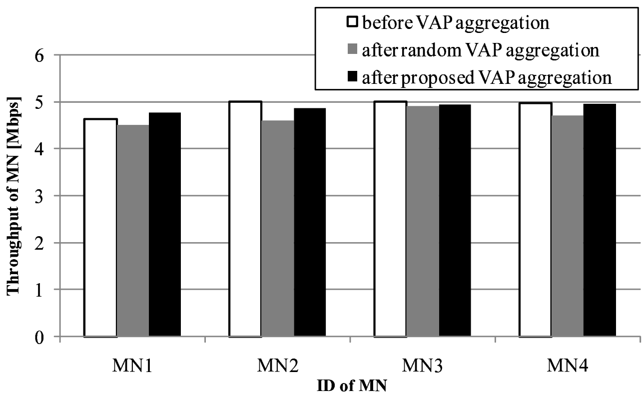
and so on. From Figure 5(b), we can observe the throughput of each MN is degraded more after random VAP aggregation than after proposed VAP aggregation. Table 4 summarize the minimum RSSI of PhyAPs at the point of MN for each cases in A-1, A-2 and B. From the line of A-1, the proposal can be found to avoid migrating a VAP to a PhyAP with lower RSSI, so it can be confirmed to contribute to keep the throughput of MNs. Meanwhile, MN2's throughput degraded the most because VAP2 was migrated to PhyAP4 with low RSSI of $-74$dBm after random VAP aggregation. We can also find the proposal reduced two PhyAPs, which is the same as the random way. Therefore, the proposal is effective in reducing the number of PhyAPs while keeping the throughput of MNs.

Figure 6(a) shows the results of the VAP placement in A-2, and Figure 6(b) shows throughput of each MN. After random VAP aggregation, throughput of each MN, especially throughput of MN1 and MN2 degraded. On the other hand, the proposed method can keep the throughput almost equivalently even after executing VAP aggregation. One reason for this is that as will be noted from the Table 4, the proposal migrated a VAP to PhyAP with RSSI of $-65$dBm even in worst case, while $-80$dBm after random VAP aggregation. Another reason is that only 10Mbps traffic was loaded in one PhyAP in worst case as shown in Table 5 which summarize the maximum amount of traffic in PhyAP. As for the number of PhyAPs after VAP aggregation, there were 4 PhyAPs after the proposal while 3 after the random way. The proposal failed to reducing the number of PhyAP, however, it accomplished the main purpose that we keep the throughput of MNs even after VAP aggregation.

As can be seen in the comparison Fig 5(b) with Fig 6(b), the effect of the proposal is easier to get in A-2 than in A-1. This is because PhyAPs are more likely overloaded in A-2 than in A-1. In other words, though the total bandwidth capacities are the same, the amount of generated traffic is heavier in A-2 than A-1. As a result, PhyAP1 has become overloaded since only two VAPs were aggregated into PhyAP1.

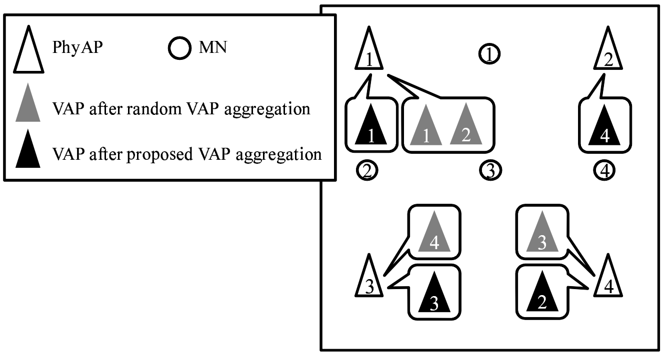



(a) VAP placement in A-1.

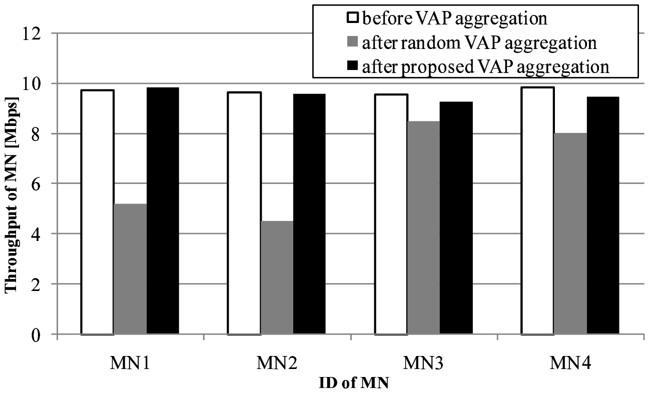



(b) Throughput of MNs in A-1.

Figure 5: Evaluation result in A-1.

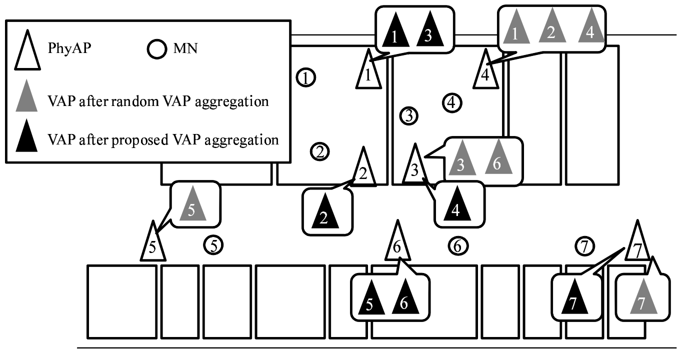



(a) VAP placement in A-2.

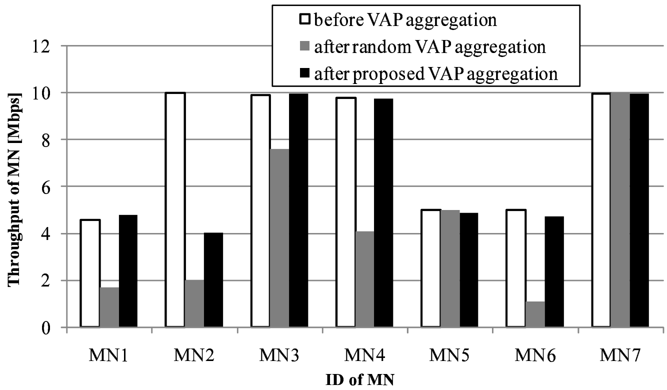



(b) Throughput of MNs in A-2.

Figure 6: Evaluation result in A-2.




(a) VAP placement in B.




(b) Throughput of MNs in B.

Figure 7: Evaluation result in B.

Figure 7(a) shows the results of the VAP placement in B, and Figure 7(b) shows throughput of each MN. When we executed random VAP aggregation, throughput of MN1, MN2, MN4 and MN6 degraded greatly. This is because PhyAP4 is used by the three MNs: MN1, MN2 and MN4. PhyAP4 is overloaded as can be seen from Table 5, and causes throughput degradation of the three MNs. RSSI of PhyAP3 measured by MN6 is low, since MN6 is associated with PhyAP3 over the wall. As the RSSI is low, throughput of MN6 is degraded by ARF function. Meanwhile, the proposed method can keep the equivalent throughput of any MNs even after VAP aggregation. There are two MNs associated with a PhyAP in maximum, and there are no PhyAPs overloaded with more than 15Mbps traffic as you see in Table 5. Thus, we can see the proposed method can avoid the fatal overload at any PhyAPs. The reason for this is current bandwidth usage of PhyAPs are considered in VAP decision phases in our method. In addition, from Table 4, the minimum RSSI of PhyAP is higher after proposed VAP aggregation than the random way. This is because we selects PhyAPs with high RSSI in PhyAP decision phase, and we use expected bandwidth of MNs calculated from RSSI in VAP decision phase. We can avoid the reduction of the bandwidth of MN due to ARF. Also, the proposal reduced two PhyAPs as can be seen from Figure 7(a). In conclusion, we can reduce the number of running PhyAPs while keeping the throughput of MNs even after VAP aggregation by the proposed VAP allocation method because our method can avoid VAPs being aggregated into PhyAPs with low RSSI or overload.

# 5 CONCLUSION

In this paper, we proposed VAP allocation method for high density WLANs. It is the method which determines which VAP to be aggregated into which PhyAP with consideration of RSSI and current used bandwidth of PhyAPs. The purpose of it is avoiding throughput degradation of MNs caused by VAPs' being aggregated into PhyAPs with low RSSI or overload.

To achieve this, we propose VAP allocation method and implemented prototype systems in three environments. The proposal consists of the information gathering system and VAP allocation algorithm. The algorithm has PhyAP decision phase and VAP decision phase. By the prototype systems, we compared the proposed method and random VAP aggregation in terms of throughput of MNs. From the results, we have demonstrated that the proposed method can avoid aggregation of VAPs into PhyAPs with low RSSI or overloaded, which can

Table 4: Minimum RSSI of PhyAP.

| Environment | Random VAP aggregation | Proposed VAP aggregation |
|---|---|---|
| A-1 | −74dBm (MN2 – PhyAP4) | −62dBm (MN1 – PhyAP3) |
| A-2 | −80dBm (MN4 – PhyAP3) | −65dBm (MN1 – PhyAP3) |
| B | −87dBm (MN1 – PhyAP4) | −82dBm (MN5 – PhyAP6) |

Table 5: Maximum amount of traffic in PhyAP.

| Environment | Random VAP aggregation | Proposed VAP aggregation |
|---|---|---|
| A-1 | 10Mbps (all PhyAPs) | 10Mbps (all PhyAPs) |
| A-2 | 20Mbps (PhyAP1) | 10Mbps (all PhyAPs) |
| B | 20Mbps (PhyAP4) | 15Mbps (PhyAP1) |

keep throughput of MNs after VAP aggregation.

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