PAPER

Public WLAN Virtualization for Multiple Services

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SUMMARY The recent widespread use of high-performance terminals has resulted in a rapid increase in mobile data traffic. Therefore, public wireless local area networks (WLANs) are being used often to supplement the cellular networks. Capacity improvement through the dense deployment of access points (APs) is being considered. However, the effective throughput degrades significantly when many users connect to a single AP. In this paper, users are classified into guaranteed bit rate (GBR) users and best effort (BE) users, and we propose a network model to provide those services. In the proposed model, physical APs and the bandwidths are assigned to each service class dynamically using a virtual AP configuration and a virtualized backhaul network, for reducing the call-blocking probability of GBR users and improving the satisfaction degree of BE users. Finally, we evaluate the performance of the proposed model through simulation experiments and discuss its feasibility.

key words: *Wi-Fi, bandwidth guarantee, network virtualization, virtual AP, multiple services*

1. Introduction

In recent years, with the widespread use of high-performance terminal equipment, the amount of data traffic in wireless networks has increased rapidly. As a result, the wireless networks are constantly congested. To overcome this situation by improving the capacity, public wireless local area networks (WLANs) are being used often to supplement cellular networks, and small cells such as WiFi are being deployed densely [1].

However, the effective throughput degrades significantly when many users connect to a single access point (AP) due to the access control of WLANs based on carrier sense multiple access with collision avoidance (CSMA/CA) [2], [3]. Therefore, constant bit rates cannot be guaranteed even if many APs are placed.

In this paper, we propose a network model which provides the guaranteed bit rate (GBR) service, such as audio/video streaming and VPN, to obtain a constant bit rate. This model can provide not only GBR service but also traditional Best Effort (BE) service by using network bandwidth effectively. BE services include conventional WWW browsing, email, and file transfer. Specifically, users are classified into GBR users and BE users. A GBR user requires a constant bandwidth. If a GBR user cannot obtain a constant bandwidth when he/she has arrived, his/her requirement is rejected by the call admission control (CAC). BE users conventionally share the available bandwidth among themselves. Note here that the satisfaction of BE service must be remarkably degraded if GBR service is excessively prioritized. From the viewpoint of service management, the call-blocking probability of GBR users must be small enough and BE users should not be ignored. To achieve a good balance between GBR service and BE service, the goal of this paper is to satisfy the target call-blocking probability for GBR users and to improve the satisfaction degree of BE users as high as possible.

The proposed network model consists of a backhaul network and AP-deployed areas. The backhaul network is configured with OpenFlow [4] switches and is controlled by a software-defined networking (SDN) [5] controller. In AP-deployed areas, APs are deployed densely. These days, a variety of WLANs operating at different frequency bands, such as IEEE802.11ad, af, and ah [6]–[8] are being promoted, so that APs with different coverage areas can coexist efficiently in the future. Therefore, we assume that not only small-cell APs but also macro cell APs are deployed.

When APs and bandwidths of the backhaul are assigned to each service, they are assigned to the GBR service as it has priority. Therefore, the BE users' throughputs diminish remarkably when excess bandwidth is assigned to the GBR service. However, a lot of the bandwidth assigned to the GBR service may remain unused. In order to enhance both GBR and BE services, APs and the bandwidth of the backhaul should be assigned to each service flexibly, according to the ratio of GBR and BE users.

Virtualization is a possible technique to achieve this by enabling the efficient use of multiple APs and bandwidths of the backhaul network. Therefore, in the proposed model, the bandwidth assigned to each service class is changed dynamically using virtualization in APs and the backhaul network. In the areas where physical APs are deployed, we propose a virtual AP configuration method [9]. In this method, the BE and GBR virtual APs are configured using multiple physical APs, and the configurations of both types virtual APs are

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reconfigured dynamically at constant intervals. In addition, the backhaul network is virtualized and is sliced into each service network. Bandwidths are reassigned to each slice after a different constant interval [10].

This paper is extended version of [9] and [10], mainly on estimation and reduction of ensured bandwidth. The rest of this paper is organized as follows. In Sect. 2, we introduce some related works. Section 3 explains the proposed network model including the virtual AP configuration method and the backhaul bandwidth assignment method. In Sect. 4, we evaluated the proposed model and discuss its scalability. Section 5 describes the summary and future work.

2. Related Work

2.1 Guaranteeing Bandwidths in Wireless Networks

The IEEE802.11e standard can be used in WLANs to control the quality of service (QoS) [11]. IEEE802.11e contains two methods, enhanced distributed channel access (EDCA) and hybrid-coordination-function controlled channel access (HCCA) [12]. However, both of them just prioritize a specific class and strict bandwidth guarantee is not achieved.

On the contrary, the long term evolution (LTE) technology used in cellular networks can guarantee bandwidth using a QoS class identifier (QCI) [13]. The QCI has GBR classes and non-GBR classes, and QoS controls are achieved by establishing logical paths called bearers.

As described above, LTE achieves QoS control easilier than WLAN. In recent years, however, LTE networks are heavily loaded and traffic offloading from LTE to WLAN is often used. Therefore, in this paper, we realize the GBR service which achieves the end-to-end bandwidth guarantee in public WLANs.

2.2 Wireless Network Virtualization

Network virtualization is a technique used to configure one or more virtual networks logically. Virtualization enables the efficient construction of logical networks through the sharing of physical resources. Consequently, it can reduce the operational expenses (OpEX) and the capital expenses (CapEX) [14].

Moreover, virtualization enables the configuration of networks matching the QoS requirements. Therefore, bandwidth can be guaranteed. In addition, the changes in the network configuration can be hidden from the users, and users can continue using the service without knowing about the changes. Since network virtualization enables flexible control for multiple services, GBR and BE services are effectively controlled on the same physical network.

These days, SDN has become a popular technique for network virtualization and OpenFlow is one of the most popular standards used to realize SDN. SDN can decouple the C-plane and D-plane, and achieve centralized control. The assigned flows can be used like leased lines, and thus, bandwidth can be guaranteed. Therefore, GBR service can be achieved by using SDN.

Recently, virtualization is also being considered in wireless networks [14]–[16], and the researches of WiFi virutalization are offen studied[17]–[25].

Among WiFi virtualization studies, AP virtualization has been frequently addressed, and many studies have been proposed to configure multiple virtual APs on a physical AP [17]–[22]. [17] proposes airtime-based sharing of a physical AP with internet service providers (ISPs) and focuses on the fairness between them. [18], by assuming that physical APs are densely distributed, guarantees fairness and maximizes the throughput in the cases of sharing among virtual APs. [19] addresses the virtual AP aggregation onto a physical AP, in order to avoid channel interference in highly dense environments.

In [20]–[22], SDN is considered for AP virtualization and OpenFlow is introduced. [20] proposes LVAP (Light Virtual Access Point) abstraction. LVAP can virtualize user association and separate them with physical APs. LVAP can realize load balancing and seamless mobility etc. [21], [22] use LVAP. [21] proposes the handoff with centralized controller for real-time services by using Virtual AP technique. [22] proposes user-oriented load balancing and improves the resource utilization by using the virtual resource chain that enables to view all the resources at different layers.

[23]–[25] are being conducted on QoS control through virtualization of the WiFi network. [23] proposes bandwidth allocation and pricing/reimbursement strategy in home network by ISP (Internet Service Provider) using SDN. Each household is equipped with an AP and neighbors use other household APs with proper reimbursement. In [23], the service which require minimum bandwidth and reserve resources is called virtualized service. [24] proposes the virtualized architecture which satisfies QoS/QoE from the perspective of three parties, ISP, CP (Contents Provider), end users. Specifically, ISP virtualizes the access network and introduce open APIs which assign bandwidth per flow. APIs are opened to CPs. Users' QoS is guaranteed by CP using APIs according to contents. Users are given one parameter, and they control service priority by controling the parameter. Services are used via WiFi AP that is equipped in user's house. Authors propose space virtualization argorithm that decide which access points in neighbor houses users are connected. In [25], unlike [17]–[22], another AP virtualization approach has been studied. This paper proposes WiFi network virtualization, which configures service-specific virtual APs using multiple physical APs. It controls the QoS by changing the number of physical APs assigned to each virtual AP. It also improves the delay violation ratio (DVR) of voice over IP (VoIP), compared to the traditional IEEE802.11 DCF and IEEE802.11e EDCA.

In the researches of AP virtualization, virtual APs are configured by using small-cell APs such as IEEE 802.11a/b/g/n only. In this paper, we consider not only small-cell APs but also macro cell APs such as IEEE802.11af/ah and focus on the AP virtualization approach of [25]. Moreover, in the researches of the QoS control, they focus on only

QoS controlled services. Our research considers not only them but also traditional BE service.

3. Proposed Model

3.1 Overview

In this section, we propose a public WLAN model and methods to use resources effectively for multiple services. First, we show the total design of the proposed network model. Next, we describe the virtual AP configuration method and the backhaul network slicing method including the following elements.

1. The users' wireless connections of newly arriving users.
2. The virtual AP reconfiguration method which assigns physical APs to each service AP dynamically.
3. Changing BE users' wireless connections after the virtual AP reconfiguration.
4. The assigning bandwidth for backhaul to each service dynamically.

3.2 Network Model

In Fig. 1, we show the proposed network model. Physical APs are controlled by an AP controller, and configure virtual APs. We call the area where physical APs provide communication as the virtual AP area. In this area, we assume the environment where small cells are deployed densely on the area where macro cells are largely overlapped. No cell experiences channel interference from the other cells by careful channel assignment based on a simple graph coloring. We assume that macro cells follow the IEEE802.11af standard and small cells follow the IEEE802.11n standard. The physical APs in a virtual AP area are connected to an AP gateway (A-GW). All A-GWs are connected to the Internet through AP network (AP NW) and a backbone gateway (B-GW). The A-GW can aggregate flows from AP NW, and the B-GW can limit traffic from servers to rate required by GBR users. The A-GW, B-GW, and routers in AP NW are OpenFlow switches, and they are controlled by a SDN controller.

An AP controller is connected to each A-GW, and it decides which physical AP a newly arriving user should connect to. The CAC for GBR users is also performed by the AP controller.

In order to provide GBR service, we propose a mechanism of bandwidth guarantee as shown in Fig. 2. GBR users install a dedicated application in their equipment beforehand. The roles of this application are user authentication and traffic shaping in order to transmit packets without exceeding the guaranteed bandwidth. The number of GBR users connected to an AP is strictly limited as explained in 3.3. In addition, the flows are set for all UE (User Equipment) to guarantee bandwidth in the backhaul network. As a result, each GBR user can obtain the sufficient bandwidth statistically.

Next, we explain the concept of virtual AP configuration and backhaul network slicing.

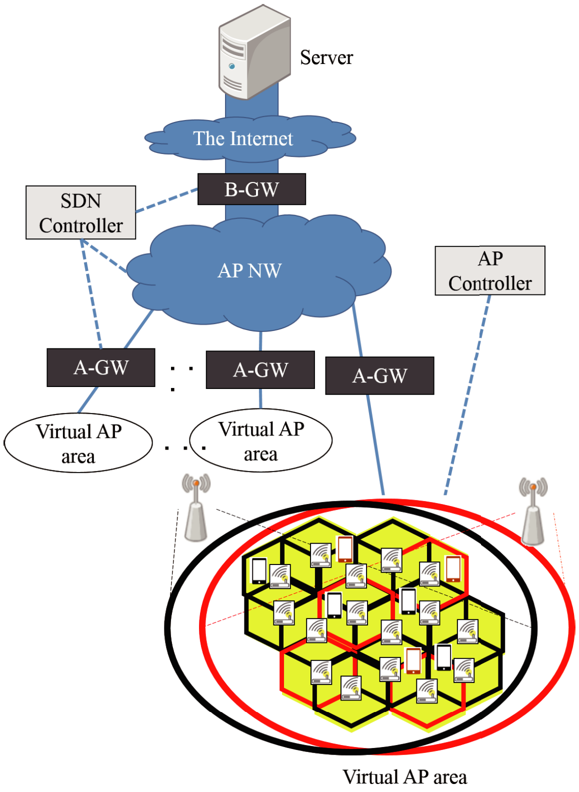

Fig. 1 Proposed model.

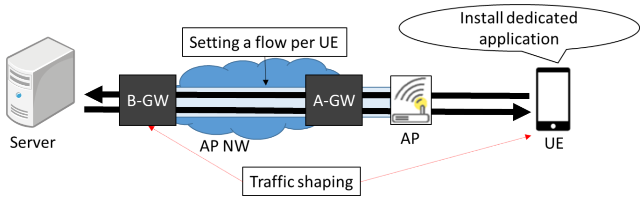

Fig. 2 Mechanism of GBR service.

(1) Virtual AP Configuration

In each virtual AP area, GBR and BE virtual APs are configured. The yellow colored area of Fig. 1 is the target area for virtualization. In the existing AP virtualization research, it is normal to divide a single AP into multiple virtual APs. In our research, to the contrary, multiple physical APs are integrated into one virtual AP. This approach can enhance the utilization of physical APs, without the users knowing about the change in the connection. In our model, a virtual AP is configured with multiple physical APs indicated by the same color. Specifically, each physical AP's extended service set identification (ESSID) is set as GBR or BE, and users are aware of only these ESSIDs. The AP controller decides the physical APs the users are connected to. It also decides which physical AP is assigned to each BE or GBR virtual AP. Both virtual APs cover the entire area, and thus, any user can use either service anywhere. It is to be noted that when both BE users and GBR users connect to a single physical AP, and the BE traffic becomes heavier, the constant bandwidth

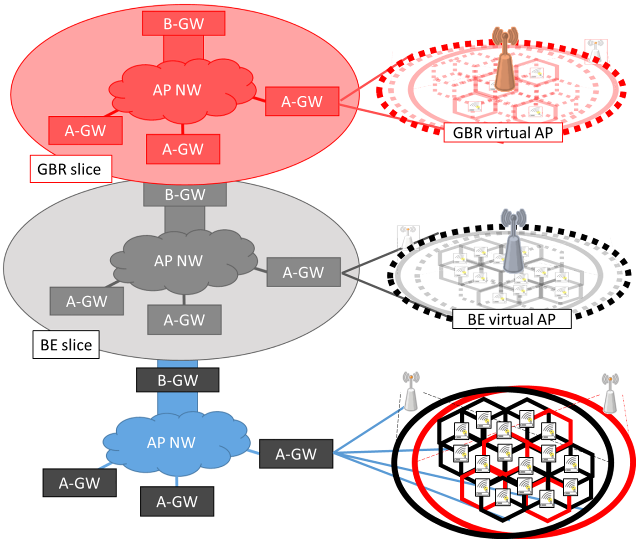

Fig. 3 Slicing backhaul.

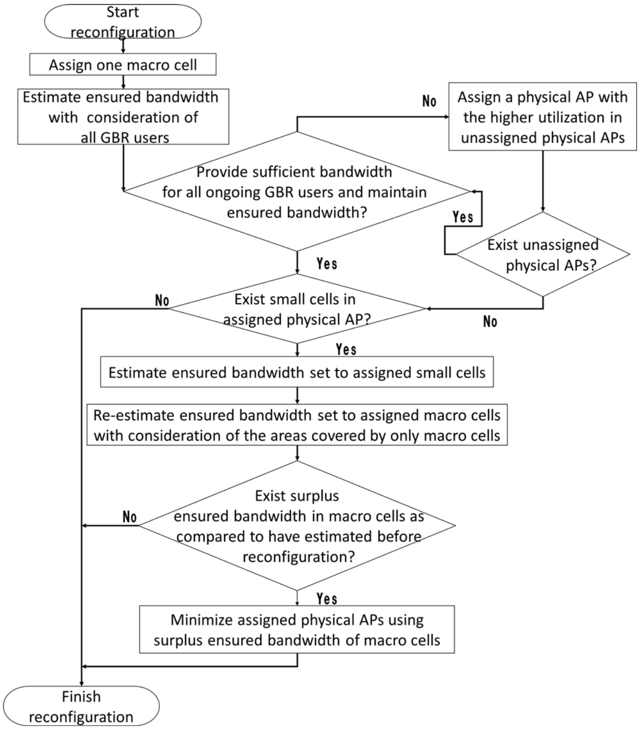

Fig. 4 Flowchart of virtual AP reconfiguration.

of GBR traffic cannot be guaranteed. Therefore, a physical AP cannot be assigned to both virtual APs simultaneously.

The physical APs assigned to each virtual AP are changed dynamically, so that the physical APs each service user can use are distributed according to the arrival ratio. Specifically, the AP controller changes the ESSID of each physical AP. We call this method *virtual AP reconfiguration*.

(2) Backhaul Network Slicing

The proposed model provides not only GBR service but also BE service. Therefore, as shown in Fig. 3, the backhaul network is sliced into two service networks, and the GBR traffic and BE traffic are isolated to achieve guaranteed bandwidth for GBR users. The adequate amount of bandwidth should be assigned to each service. Therefore, we propose a dynamic bandwidth assignment method based on the same concept as the virtual AP configuration. It will be explained in Sect. 3.6 specifically.

3.3 Users' Wireless Connections

Virtual APs are visible to users and physical APs are hidden. A user's connection to physical AP is controlled by the AP controller. When a user starts a service, the AP controller selects an adequate physical AP, which should be connected physically. The specific procedure is as follows.

When a GBR user arrives at an area covered by multiple cells, he/she is connected to one of the small cells covering the area. Since macro cells cover the whole area, it makes easier to accept the next GBR users. When no small cells have sufficient available bandwidth, the user is connected to the macro cells. On the contrary, in the case where two or more small cells can afford to provide the requested bandwidth, the GBR user is connected to the small cell whose number of connected users is the smallest, since it will find it easier to accept the next GBR users.

When a BE user arrives in the area covered by multiple physical APs, he/she is connected to one of the physical APs covering the area, so that he/she can obtain a higher throughput. The throughput is decided by dividing the capacity of a physical AP by the number of connected BE users.

3.4 Virtual AP Reconfiguration

We propose a virtual AP reconfiguration method that changes the physical APs assigned to each virtual AP after a constant interval τ. In addition, users are reconnected to more adequate physical APs. Note that it is difficult to assign physical APs to GBR virtual APs immediately, when GBR users arrive. In other words, some amount of bandwidth should be reserved to accept the next GBR users. We call this unused bandwidth *ensured bandwidth*.

Figure 4 shows the flowchart of the proposed reconfiguration method. We assume that all GBR users require the same bandwidth. Therefore, the maximum number of GBR users that can be connected to a physical AP is decided. Hereafter, we define *utilization* as the ratio of the number of connected GBR users to the maximum number of GBR users.

In the beginning, no physical APs are assigned to any virtual AP. To cover the entire area, at least one macro cell must be assigned to each virtual AP. Then, the physical APs assigned to GBR virtual APs are selected. Note that the physical APs with higher utilizations should be assigned to GBR virtual APs, as GBR users require constant bandwidths.

Next, we explain the estimation of ensured bandwidth, physical AP assignment to GBR virtual APs and reduction of ensured bandwidth in detail.

(1) Estimation of Ensured Bandwidth

First, we introduce the method for calculating the ensured bandwidths for the GBR users who arrive between the next τ seconds.

We assume that the GBR users follow the Poisson arrival process with mean λ, and that their service times follow an exponential distribution with mean $\frac{1}{\mu}$. When n is the number of ongoing GBR users, the probability $P(K = k)$ that k users finish their service in τ seconds, is derived as follows.

$$\begin{aligned} P(K = k) &= P(X_1 \leq \tau) \cdot P(X_2 \leq \tau) \cdot \\ &\quad \cdots \cdot P(X_k \leq \tau) \cdot P(X_{k+1} > \tau) \\ &= \prod_{j=1}^{k} (1 - e^{-(n-(j-1))\mu\tau})(e^{-(n-k)\mu\tau}) \qquad (1) \end{aligned}$$

X_i is the time when the i-th user finishes his/her service.

In this paper, the call-blocking probability is approximately derived as the probability that k users finish the service and $c + k + 1$ new users arrive in τ seconds, where c means the number of acceptable GBR users. Let Y denote the number of blocked calls; the probability that one or more calls are blocked is approximated as follows [27].

$$\begin{aligned} P(Y \geq 1) &= \sum_{k=0}^{n} P(K = k) P(Z \geq c + k + 1) \\ &= \sum_{k=0}^{n} P(K = k)(1 - \sum_{i=0}^{c+k} P(Z = i)) \\ &= \sum_{k=0}^{n} \Big\{ \Big\{ \prod_{j=1}^{k} (1 - e^{-(n-(j-1))\mu\tau})(e^{-(n-k)\mu\tau}) \Big\} \cdot \\ &\quad \Big\{ 1 - e^{-\lambda\tau} (\sum_{i=0}^{c+k} \frac{(\lambda\tau)^i}{i!}) \Big\} \Big\} \qquad (2) \end{aligned}$$

$P(Z \geq c + k + 1)$ is the probability that more than $c + k$ users arrive. Let d denote the bandwidth a GBR user requires. The smallest c is chosen to achieve a $P(Y \geq 1)$ less than the target call-blocking probability; then, $c * d$ is defined as the ensured bandwidth.

(2) Physical AP Assignment to GBR Virtual APs

We show the method to select the physical APs whose utilizations increase when GBR users are connected. The selected physical APs are assigned to GBR virtual APs, and the ensured bandwidths are assigned to them. The procedure is as follows.

1. Assign one macro cell.
2. Estimate ensured bandwidth in case all n users are GBR users.
3. If the assigned macro cell can afford to maintain the ensured bandwidth in addition to providing sufficient bandwidth for all ongoing GBR users, this configuration procedure is ended.
4. Among the unassigned physical APs, select one whose utilization becomes the highest when as many GBR users as possible are connected to it. If there are no unassigned physical APs, this procedure is ended.
5. If the assigned macro cell in step 1 can afford to maintain the ensured bandwidth in addition to providing sufficient bandwidth for the remaining ongoing GBR users, the configuration procedure is ended. Otherwise, return to step 4.

Figures 5–7 demonstrate how the proposed method works. Figure 5 shows the state after step 2; a macro cell has been assigned to a GBR virtual AP to cover the entire area. In this case, macro cell 1 cannot support all GBR users and maintain the ensured bandwidth. In Fig. 6, small cell

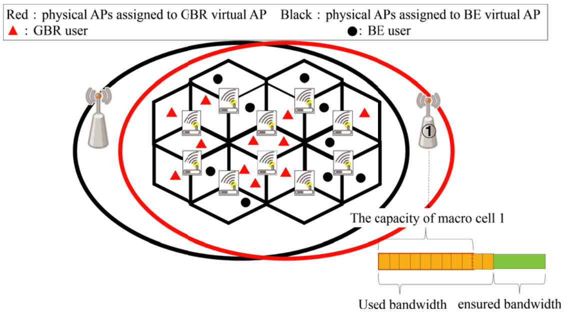

Fig. 5 Step 2: assign a macro cell.

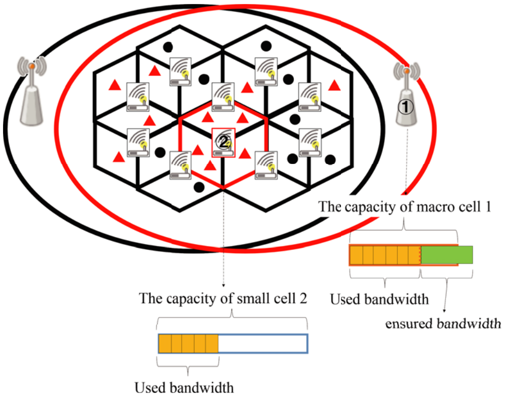

Fig. 6 Step 4: assign a physical AP whose utilization ratio is high.

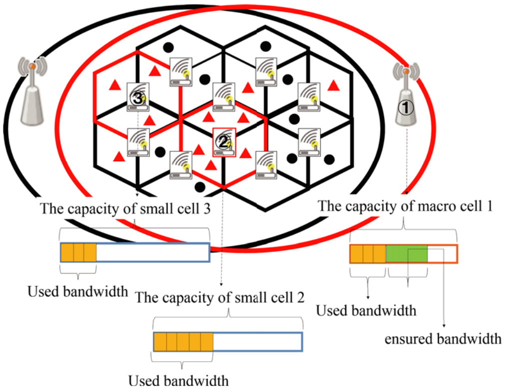

Fig. 7 Step 5: return to step 4 and assign a physical AP.

2 is assigned to the GBR virtual AP, as it can support five (highest among all physical APs) GBR users. In this case, as well as in Fig. 5, macro cell 1 cannot set the ensured bandwidth. Figure 7 shows the state whose assignment cannot be finished from the state of Fig. 6 in step 5 and return to the step 4. It shows that physical AP 3, which can support three GBR users, is selected in the same manner, and is assigned to a GBR virtual AP. After that, macro cell 1 can set the ensured bandwidth, and this procedure is completed successfully.

Finally, all unassigned physical APs are assigned to BE virtual APs. This process maximizes the amount of resources the BE users can use.

(3) Reduction of Ensured Bandwidth

The ensured bandwidth should be minimized as long as it achieves the target call blocking probability, since it means to maximize the bandwidth for BE users, This paragraph tries to reduce the ensured bandwidth.

In previous processes, only the macro cell assigned at the beginning had the responsibility to maintain the ensured bandwidth. We define c_f as this ensured bandwidth. When a small cell is assigned to a GBR virtual AP, the GBR users who arrive at the area covered by the small cell can connect to it. Thereby, the expected number of GBR users connected to a macro cell decreases according to the number of assigned small cells, and the required ensured bandwidth of the macro cell may be smaller than c_f. Specifically, the λ in Eq. (2) changes. Therefore, the ensured bandwidths of the macro cells should be re-estimated by considering the user arrivals at the area covered by only macro cells. We define c_m as this ensured bandwidth.

Let c_{s_i} denote the ensured bandwidth maintained by the small cell i; it is estimated by considering the GBR user arrivals in the area covered by the small cell. We define b_s and b_{u_i} as the capacity of the small cell and the bandwidth utilized by the users connected to the small cell i, respectively. If b_s is larger than $c_{s_i} + b_{u_i}$, the small cell can maintain the ensured bandwidth. Otherwise, the small cell maintains the ensured bandwidth as much as possible and the rest of the ensured bandwidth is maintained by the macro cells. Namely, c_l means the re-estimated ensured bandwidth maintained by the macro cells. Let $\mathbf{Z}$ denote the set of small cells, which fulfill $b_s \leq c_{s_i} + b_{u_i}$. c_l is $c_m + \sum_{i \in \mathbf{Z}} \{(c_{s_i} + b_{u_i}) - b_s\}$. c_f is less than or equal to c_l, so that the required ensured bandwidth may be reduced depending on the area considered for the arrival of users. We propose to use $c_l - c_f$ as the ensured bandwidth.

- Reassign small cell to BE virtual AP
  The small cell with the highest utilization is selected. If the ensured bandwidth of $c_l - c_f$ is more than the bandwidth used by the GBR users connected to a small cell assigned to a GBR virtual AP, and the utilization of the small cell is zero, the GBR users are connected to the macro cell by using the remaining bandwidth of $c_l - c_f$. In some cases, the utilization of multiple small cells can be zero. In such cases, the selection of small cells reassigned to the BE virtual AP is as follows. Among the combinations of small cells whose utilizations are zero, a combination is selected in the ascending order of the sum of the number of BE users covered by those small cells. For example, in Fig. 8, a macro cell has an unused bandwidth of $c_l - c_f$, which can support three GBR users, and there are three, one, and two GBR users connected to small cells 1, 2, and 3, respectively. The candidate combinations are $\{1\}$, $\{2\}$, $\{3\}$, and $\{2, 3\}$. Among these candidates, $\{1\}$ is selected. Therefore, small cell 1 is assigned to the BE virtual AP, and the three GBR users are reconnected from small cell 1, and connected to the macro cell by using the bandwidth of $c_l - c_f$.
- Reassign macro cell to BE virtual AP
  If the bandwidth of $c_l - c_f$ is less than the bandwidth used by the GBR users connected to a small cell assigned to the GBR virtual AP, the utilization of the small cell cannot be zero. In this case, if $c_l - c_f$ is larger than or equal to the capacity of the macro cell, the macro cell assigned to the GBR virtual AP is reassigned to the BE virtual AP. For example, in Fig. 9, a macro cell just maintains the ensured bandwidth and does not support any ongoing GBR user, and this macro cell capacity is less than $c_l - c_f$. In this case, it is assigned to a BE virtual AP.

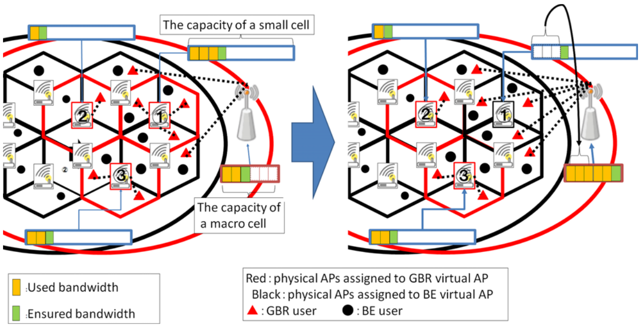

Fig. 8 Assign small cell to BE virtual AP.

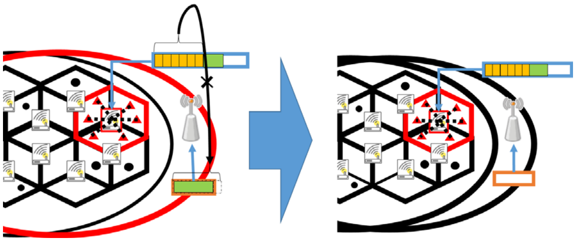

Fig. 9 Assign macro cell to BE virtual AP.

3.5 Changing BE Users' Wireless Connections

The BE users' satisfaction U follows a logarithmic function. It is defined by

$$U = \log X, \quad (X > 1) \tag{3}$$

where X indicates the obtained throughput [13]. After reconfiguring the virtual APs, the BE users should be reconnected in order to maximize the sum of U. When all BE users' throughputs are identical, the sum of U becomes the maximum. When M macro cells and S small cells are assigned to a BE virtual AP, the average throughput X_{avg} is calculated as follows.

$$X_{avg} = \frac{M \cdot b_m + S \cdot b_s}{u_a}, \tag{4}$$

where b_m and b_s are the capacities of a macro cell and a small cell, respectively. u_a is the number of BE users in the entire area.

In order to ensure that all BE users obtain identical throughput, each macro cell and small cell should support u_m and u_s users, respectively.

$$u_m = \left\lfloor \frac{b_m}{X_{avg}} \right\rfloor, u_s = \left\lfloor \frac{b_s}{X_{avg}} \right\rfloor \tag{5}$$

In the case where the number of BE users in a small cell is less than u_s, they are connected to its AP. Then, if u_r denotes the number of unconnected BE users and S' denotes the number of small cells the BE users are connected to, the target average throughput X_{avg} is updated to $\frac{M \cdot b_m + (S - S') \cdot b_s}{u_r}$. u_m and u_s are also updated.

The remaining users are reconnected as follows.

1. Select an area with the smallest number of overlapped cells. If there are multiple areas with the smallest number, one of them is selected randomly.
2. In the selected area, first, u_s BE users are connected to the small cell. Next, u_m users are connected to the macro cell.
3. For all areas, repeat steps 1 and 2.

In some areas, there are more users than u_m or u_s; therefore, some users may not have chosen their APs. Therefore, u_m and u_s are updated considering only those areas where unconnected BE users exist. This process is as follows.

1. Select a physical AP that covers any area where unconnected BE users exist.
2. The average throughput X_{avg} is updated to $\frac{M \cdot b_m + S'' \cdot b_s}{u'_r}$, and u_m and u_s are also updated. S'' is the number of small cells that cover areas where unconnected BE users exist. u'_r is the number of unconnected BE users.
3. Repeat steps 1 and 2 until unconnected BE users do not exist.

Note that even though the updated X_{avg} cannot be obtained, it can be used as a metric to select the BE users' connections.

In fact, the number of users in a small cell may be lesser or larger than u_s, since users are not always distributed uniformly, and so too with macro cells. Therefore, in the proposed method, the BE users are reconnected, so that each AP can support u_m or u_s users.

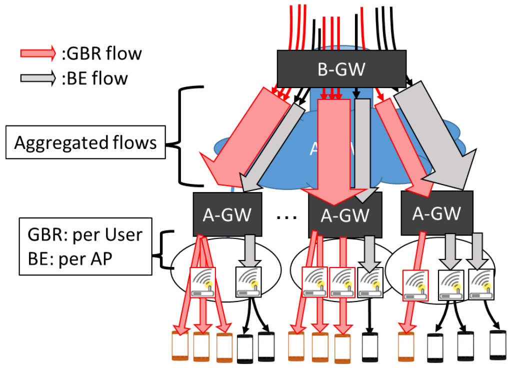

Fig. 10 Setting flows and bandwidths for GBR and BE.

3.6 Assigning Bandwidth for Backhaul

In this subsection, we propose the bandwidth assignments to GBR and BE users in the backhaul network in Fig. 10. Between the B-GW and each A-GW, it is difficult to set the flows from B-GW to the UE due to the scalability problem. Therefore, we propose these flows be aggregated into big flows. These big flows have enough bandwidth and are set to each A-GW. This method does not need to set/release flows per user between B-GW and each A-GW. Between the A-GW and UE, the GBR flows are set/released per user, and BE flows are set/released per AP because the GBR users have the required application installed and the BE users do not have one.

Bandwidth is assigned to GBR as a priority, and the bandwidth for BE is obtained by subtracting the bandwidth for GBR from the total bandwidth the B-GW can provide. Therefore, the bandwidth for BE diminishes remarkably when excess bandwidth is assigned to GBR. Hence, the bandwidth is reassigned to the BE and GBR users between the B-GW and A-GWs at constant intervals, and they should be assigned to each service correctly.

In the virtual AP area, bandwidth is reassigned per physical AP, following the virtual AP reconfiguration, and the assignment is realized in a very short interval τ, compared to the users' arrival intervals. Ideally, the bandwidth assignment and virtual AP reconfiguration should be done simultaneously. However, it is difficult to change the bandwidth assignment during a virtual AP reconfiguration interval because the B-GW aggregates numerous flows between the A-GWs and itself. Therefore, the assignments are changed between the B-GW and A-GWs at constant intervals (T) longer than τ.

Specifically, as shown in Fig. 11, a used bandwidth and a *variation-predicted bandwidth* are assigned between the B-GW and an A-GW. We call this assigned bandwidth *advance prepared bandwidth*. The used bandwidth includes not only the bandwidth used by GBR users but also the ensured bandwidth.

The bandwidth is assigned in the following steps. $AP_i (i = 1, 2, \cdots, n)$ indicates the i-th virtual AP area. n

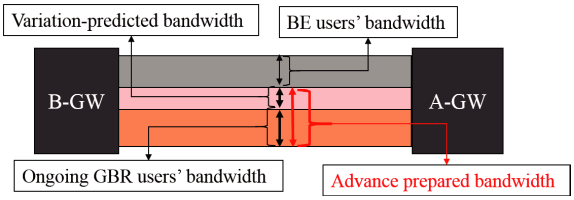

Fig. 11 Assigning bandwidth.

is the number of virtual AP areas.

1. Variation-predicted bandwidths between B-GW and A-GW$_1$, A-GW$_2$, $\cdots$, A-GW$_\mathrm{n}$ are defined as $c_1, c_2, \cdots, c_n$.
2. Used GBR bandwidths between A-GW$_1$ and AP_1, A-GW$_2$ and AP_2, $\cdots$, A-GW$_\mathrm{n}$ and AP_n are defined as $c_{g_1}, c_{g_2} \cdots, c_{g_n}$, and advance prepared bandwidths between B-GW and A-GW$_1$, A-GW$_2$, $\cdots$, A-GW$_\mathrm{n}$ are defined as $c'_{g_1}, c'_{g_2} \cdots, c'_{g_n}$. Then, the advance prepared bandwidth is calculated as follows.
$$c'_{g_n} = c_{g_n} + c_n \tag{6}$$
$c_{g_1}, c_{g_2} \cdots, c_{g_n}$ correspond to the used bandwidths between B-GW and A-GW$_1$, A-GW$_2$, $\cdots$, A-GW$_\mathrm{n}$.
3. BE bandwidth c_{be} is calculated as follows.
$$c_{be} = c_{bgw} - (c'_{g_1} + c'_{g_2} + \cdots + c'_{g_n}) \tag{7}$$
Note that c_{bgw} should be the bandwidth the B-GW can provide.

Next, we show the variation-predicted bandwidth estimation. From the maximum bandwidth variations in the past T [s] intervals, the bandwidth variations in the next T [s] intervals can be estimated.

When B_i is defined as the bandwidth at t_i and B_{max_i} is defined as the maximum bandwidth in $[t_i, t_i + T]$, the maximum bandwidth variation is $B_{max_i} - B_i$ in $[t_i, t_i + T]$. Note that t_{i+1} means $t_i + T$. When t_k is the current assignment time, the variation-predicted bandwidth B_{pre} is calculated using the average of $B_{max_i} - B_i$ over N intervals of $[t_{k-N-1}, t_{k-N-1} + T], [t_{k-N}, t_{k-N} + T], \cdots, [t_{k-1}, t_{k-1} + T]$. Then, the weight parameter α_i is introduced. B_{pre} and α_i are calculated as follows.

$$B_{pre} = \frac{\sum_{i=k-1}^{k-N-1} \alpha_i (B_{max_i} - B_i)}{\sum_{i=k-1}^{k-N-1} \alpha_i} \tag{8}$$

$$\alpha_i = \frac{u_k}{u_k + |u_k - u_i|} = \begin{cases} \frac{u_k}{2u_k - u_i} (u_i \leq u_k) \\ \\ \frac{u_k}{u_i} (u_i > u_k) \end{cases} \tag{9}$$

u_i means the number of users at t_i. α_i is estimated based on the prediction that the same variation is likely to occur when u_i is close to u_k.

In addition, when B_{max_i} is smaller than B_i in T[s] interval, $B_{max_i} - B_i$ is calculated as if the variation is negative, as shown in Fig. 12. B_{max_i} is decided when the bandwidth variation has changed to increase.

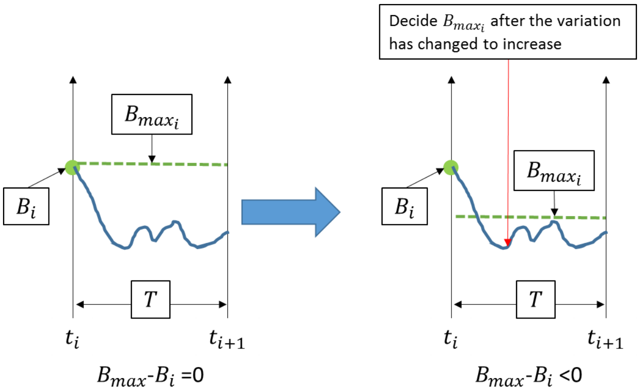

Fig. 12 Negative variation.

4. Performance Evaluation

We evaluated the performance of the proposed model by simulation experiments. The simulation model includes a pair of one virtual AP area and its backhaul as shown in Fig. 13. In the virtual AP area, we assumed 16 small cells with hexagonal transmission area are deployed on the area where 4 macro cells are overlapped. The capacity of a small cell and a macro cell were 65.0[Mbps] and 35.6 [Mbps], respectively [28], [29]. In the initial assignment, red cells were assigned to GBR virtual AP and black cells were assigned to BE virtual AP.

A user arrived at one of the diamond-shaped (e.g. yellow-colored) areas following Poisson arrival process with parameter λ, and never moved until finishing the service. A GBR user required a constant bandwidth of 2.0 [Mbps] and its communication time was following the exponential distribution with mean 3.5 [min]. It assumes a video streaming service. A BE user downloaded a file of 52.5 [MB] in the best effort manner. It assumes browsing WWW pages with some pictures. In other words, the traffic volume of each user was equal.

We set the target call-blocking probability of GBR users to 0.01. This is just an example, but a typical value for streaming services [30]. As for the parameter of the proposed methods, the interval time τ of virtual AP reconfiguration and interval time T of backhaul flow setting were 5 [s] and 70 [s], respectively. We discuss their propriety later.

We evaluated the call-blocking probability of GBR users and the satisfaction degree of BE users averaged over 100000 samples.

4.1 The Performance of Virtual AP Reconfiguration

At first, we evaluated the performance of virtual AP reconfiguration. We set the call arrival rate λ was 0.04 and the arrival ratio of BE and GBR users was $r : (1-r)$. In this evaluation, B-GW assumed to have sufficient bandwidth, in other words, c_{bgw} was larger than $16 \times 65 + 4 \times 35.6$. In order to confirm

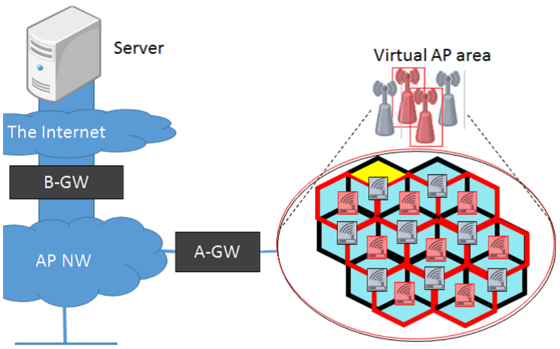

Fig. 13 Evaluation model.

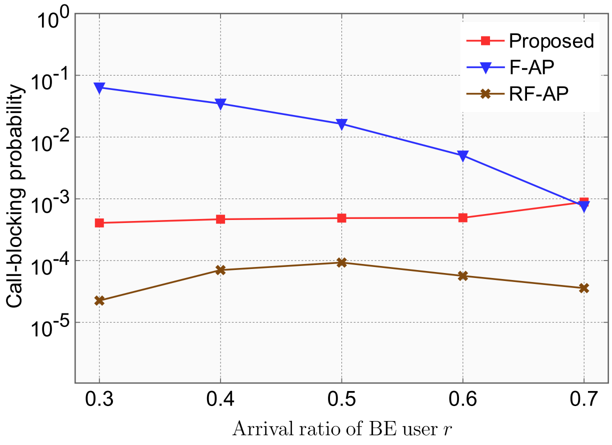

Fig. 14 Call-blocking probability of GBR users (arrival ratio evaluation).

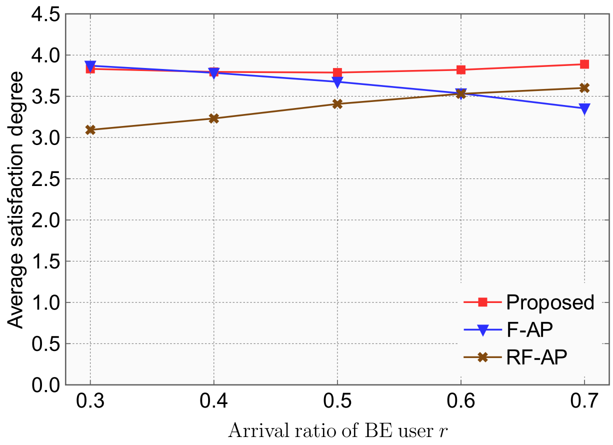

Fig. 15 Average satisfaction degree of BE users (arrival ratio evaluation).

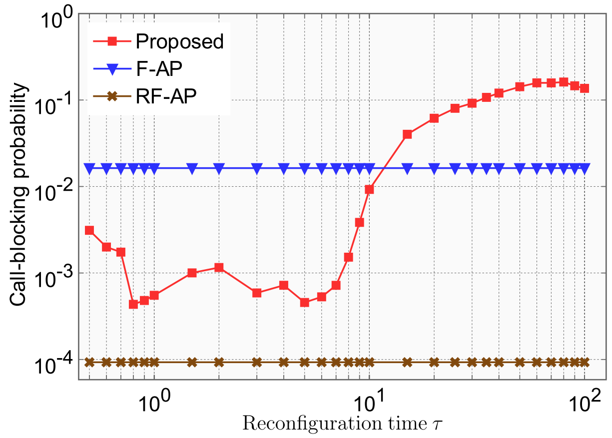

Fig. 16 Call-blocking probability of GBR users (interval of τ evaluation).

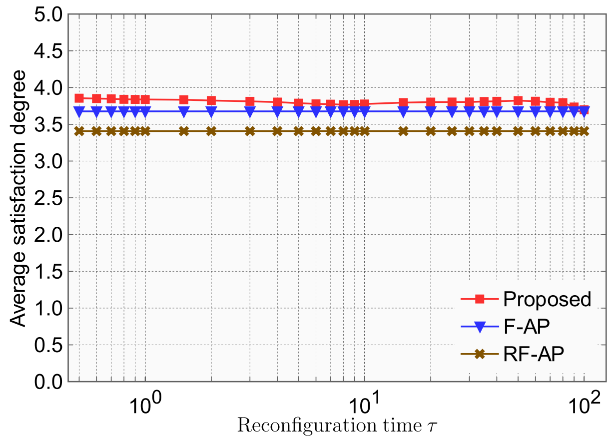

Fig. 17 Average satisfaction degree of BE users (interval of τ evaluation).

the performance of virtual AP reconfiguration, GBR users' requirements were not blocked in backhaul.

We compared the proposed method with fixed AP assignment (F-AP) and ratio-fixed AP assignment (RF-AP). F-AP assigns 8 small cells and 2 macro cells to each virtual AP statically and never changed. RF-AP also assigns physical APs to each virtual AP statically and never changed, but the number of assgined physical APs is decided according to the arrival ratio which is assumed to be given. The assigned physical APs are selected randomly.

Figure 14 shows the call-blocking probability of GBR users as a function of r. Regardless of r, the proposed method and RF-AP achieve the target call-blocking probability. Figure 15 shows the satisfaction degree of BE users. The satisfaction degree was calculated by Eq. (3). The proposed method obtains much higher satisfaction degree, since it can assign adequate number of physical APs to BE virtual AP according to the arrival ratio of BE users. RF-AP achieved the target call-blocking probability, but the satisfaction degree of BE users was lower than that of the proposed method. It means that the adequate number of physical APs cannot be assigned to each virtual APs even if the arrival ratio is given since user location is ignored. The proposed method can assign the essential and sufficient number of physical APs to GBR virtual AP since it considers the number of users connecting to each physical AP. These results indicate that the proposed method works flexibly.

Moreover, we changed the interval time τ of virtual APs reconfiguration. The arrival ratio of BE and GBR was $1:1$. Figures 16, 17 show the proposed method works effectively when the interval of reconfiguration is less than 10 [s]. Due to probabilistic fluctuation, Fig. 16 shows a complex

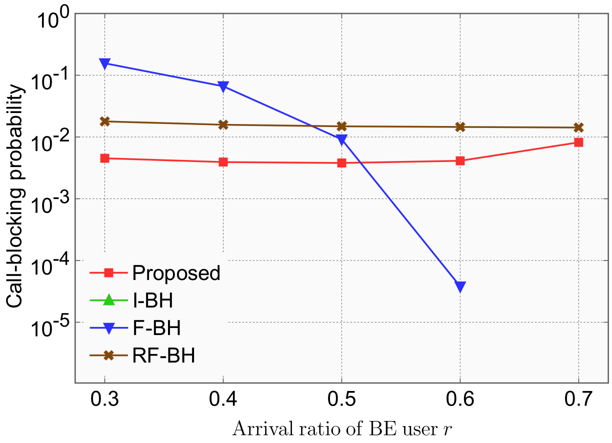

Fig. 18 Call-blocking probability of GBR users (backhaul).

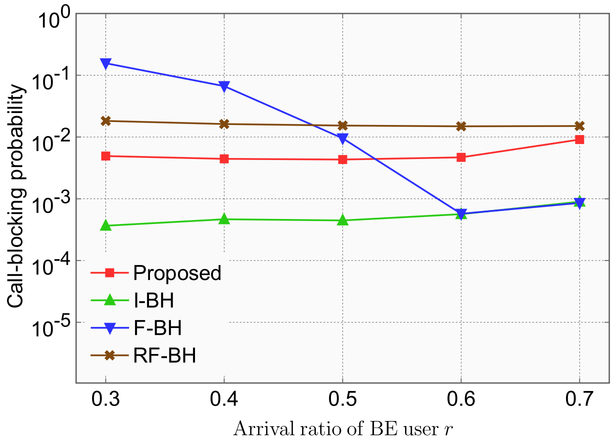

Fig. 19 Call-blocking probability of GBR users (all).

curve. However, the conclusion remains essentially intact. This result confirms that the proposed method is sufficiently practical.

4.2 The Performance of Backhaul Bandwidth Assignment

Next, we evaluated the bandwidth assignment between B-GW and an A-GW. In this evaluation, the total bandwidth of B-GW was 600.0 [Mbps]. The compared methods are ideal backhaul bandwidth assignment (I-BH), fixed backhaul bandwidth assignment (F-BH) and ratio-fixed backhaul bandwidth assignment (RF-BH). All methods used the proposed virtual AP reconfiguration method. I-BH assigns the required bandwidth whenever a GBR user arrives, and releases the bandwidth for BE service immediately when his/her service finishes. Note that it is an ideal method and cannot be realized. It is used as a measure of the maximum performance. F-BH divides the bandwidth of the B-GW equally to each service. RF-BH assigns the bandwidth of the B-GW to GBR and BE services according to the arrival ratio which is assumed to be given.

Figure 18 shows the call-blocking probability in the backhaul, i.e. in the case where AP was available but its backhaul had been exhausted. I-BH never causes to block, since this method can assign the required bandwidth as soon as a GBR user arrives. The proposed method achieves the target call-blocking probability. In other words, it provides necessary and sufficient amount of bandwidth. Figure 19 shows the overall call-blocking probability of GBR users. It confirms that the combination of the proposed backhaul bandwidth assignment and the virtual AP reconfiguration method works effectively.

Figure 20 shows the average satisfaction degree of BE users. Compared with F-BH, the proposed method achieved the flexible assignment since it can assign adequate bandwidth to the BE service according to r. On the other hand, although RF-BH achieves almost the same satisfaction degree as the proposed method, it does not satisfies the target call-blocking probability.

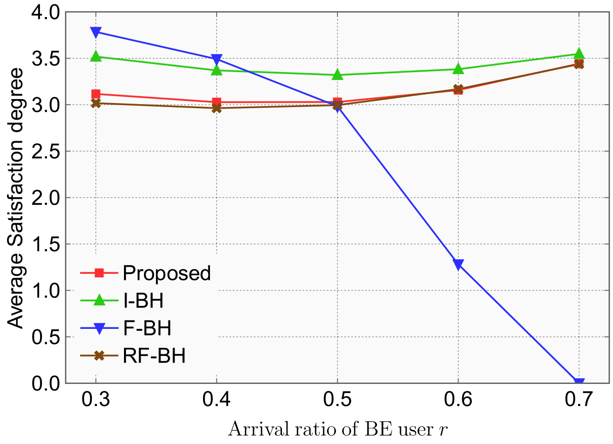

Fig. 20 Average satisfaction degree (between the B-GW and APs).

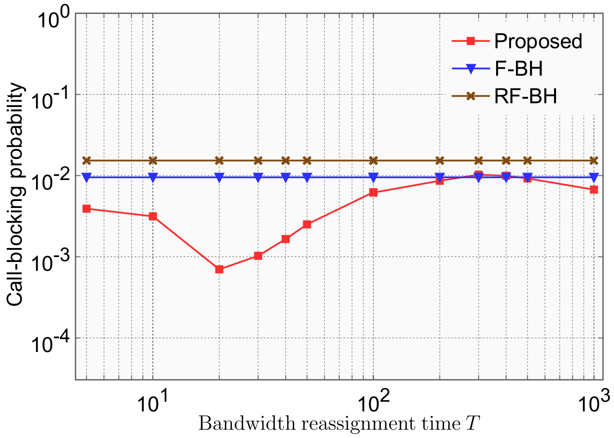

Fig. 21 Call-blocking probability of GBR users (interval of T evaluation).

Next, we evaluated the interval time T in order to confirm the scalability of the proposed method. Figure 21 shows the call-blocking probability of GBR users. The proposed method always achieved the target regardless of T. Figure 22 shows the satisfaction degree of BE users. When T was smaller than 100, the proposed method outperforms

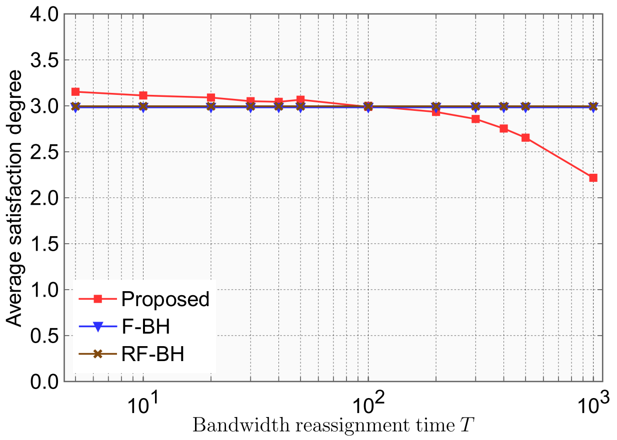

Fig. 22 Average satisfaction degree (interval of T evaluation).

F-BH and RF-BH.

Here, we discuss the number of A-GWs that can be supported. Setting a flow takes 10[ms] at a typical OpenFlow switch [31]. GBR flows between a B-GW and all A-GWs should be set in the interval time T. Therefore, the range of T can be decided as follows.

$$T \geq \frac{10}{1000} \times m \tag{10}$$

m is the number of A-GWs. From Eq. (10) the maximum value of m is 10000 when $T = 100$. It comes to the conclusion that the proposed method can be used in large scale networks.

5. Conclusions

In this paper, we proposed a network model in which GBR and BE services are provided by Public WLANs. It has dense AP-deployed areas and a backhaul network. In order to enhance both GBR and BE services, APs and the bandwidths of backhaul in the proposed model are distributed to each service with network virtualization. In AP-deployed areas, we proposed the virtual AP reconfiguration method, which dynamically assigns physical APs to GBR and/or BE virtual APs. Furthermore, in the backhaul network, we proposed the bandwidth assignment method, which the bandwidth between B-GW and A-GWs is assigned to each service dynamically.

Performance evaluations showed that the proposed method achieved the target call-blocking probability of GBR users and improved the satisfaction degree of BE users regardless of users' arrival ratio. Finally, we discussed the scalability of the proposed model and showed the model can be used in large scale networks.

As a future work, we will enhance the method to consider the mobility of users and ARF (Auto Rate Fallback) in APs.

Acknowledgments

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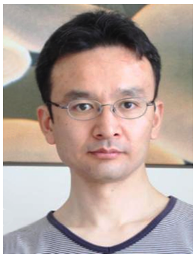

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