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An Energy Efficient Upload Transmission Method in Storage-Embedded Wireless Mesh Networks

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***Abstract*—The recent increase of wireless devices (i.e., STAtions (STAs)) brings forward an increase of energy consumption. We address the energy consumption issues for STAs in Wireless Mesh Networks (WMNs). One of the available techniques for power-saving is the sleep technique. However, since the common transmission mode from the STA to the server is performed based on end-to-end transmission, this results in increase of energy consumption of the STAs since they cannot enter sleep mode until end-to-end communications are completed. To cope with the issue, we focus on an Access Point equipped with External Storage (APES), which provide end-to-end communication instead of STAs. Using this, STAs can shorten the transmission time and decrease the energy consumption since they communicate with neighboring APES. In this paper, we propose a novel method to select the adequate APES as a proxy server based on the number of STAs and the amount of traffic from STAs. The proposed method effectively transmits data and reduces the energy consumption of the STAs. Moreover, we validate the efficiency of the proposed APES selection method through numerical analysis.**

I. Introduction

The energy consumption in wireless communications has increased explosively due to the growth of the number of Internet users and the development of the wireless devices (i.e., STAtions (STAs)), such as smart phones, tablets, and sensor terminals. Since the capacity of battery is limited and the wireless communications have high energy consumption (e.g., Nexus One consumes approximately 700mWh [1].), energy efficiency is one of the most important research directions [2]. To address this serious problem, it is essential to minimize the amount of energy consumed as much as possible. While there are several schemes to reduce energy consumption, STA in Sleep Mode (SM) is considered as a method for conserving battery and enabling long-lasting communications.

Wireless Mesh Networks (WMNs), which is a promising access network architecture [3], increases the energy consumption of STAs. In WMNs, STAs require longer time required to transmit data because transmission data is relayed by multi-hop Access Points (APs). Corresponding to this, STAs operating in SM might miss an opportunity to enter the sleep state, which results in an increase of energy consumption of STAs. Because STAs in SM might decrease the performance of power-saving scheme in WMNs, this paper tackles the issue "developing an energy-efficient networking technique to reduce the energy consumption of STAs in WMN".

AP equipped with External Storage (APES) is one of the networking techniques (or devices) that can reduce the energy consumption of STAs. APES has similar functionalities to a conventional AP with an addition of storage function that stores large amounts of data on external memory such as flash memories or Secure Digital (SD) cards. By using the storage function, APES can provide a traffic shaping, in which each APES controls the amount of traffic to avoid the interference and acquires enough capacity. Additionally, STAs can shorten the transmission time and reduce the energy consumption by using the APES as proxy-server to communicate with the server on behalf of itself.

However, WMN with APESs has the potential to consume much higher energy when all STAs choose the closest neighbor APES as a proxy server. Traffic convergence can lengthens the transmission time and energy consumption of STAs. The reason behind this is because the transmission speed between the AP and the external storage (e.g., flash memories or SD cards) becomes a bottleneck. To cope with this problem, this paper proposes a novel method to select adequate APES as a proxy server. In this scheme, the proxy APES is determined based on the number of STAs transmitting data. By distributing the data traffic, each STA can shorten transmission time and dramatically decrease the energy consumption.

The remainder of this paper is organized as follows. The relevant research works addressing the energy consumption issue are surveyed in Section II. In Section III, we explain the considered network model which includes network topology, transmission mode, traffic model, and so forth. Section IV proposes an APES selection method to reduce energy consumption. We evaluate the energy consumption of the proposed method compared with the conventional data transmission in Section V. Finally, concluding remarks are provided in Section VI.

II. Related Work

In this section, we introduce some of the sleep modes that exist in literatures. In addition, we introduce the APES and its proxy function for efficient transmission. Moreover, the shortcoming of these methods and systems are delineated.

A. Existing Sleep Methods

SM is a technique to reduce energy consumption by introducing two power consumption states, active state and sleep state. In the active state, a STA can send and receive data frames while consuming energy. In the sleep state, a STA cannot send or receive data frames. As a result, the energy

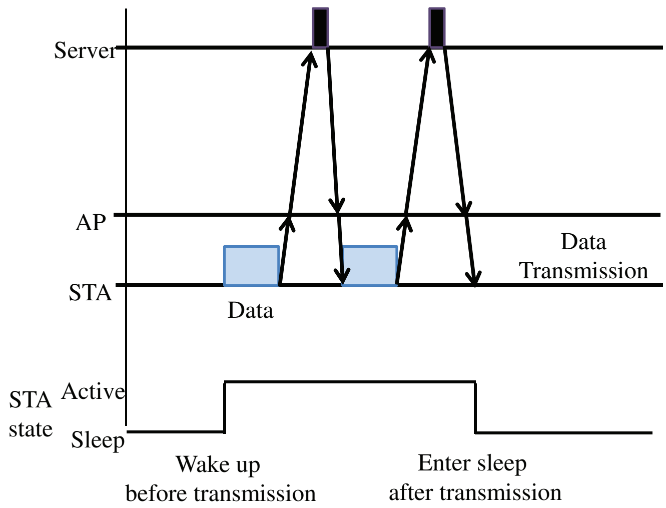

Fig. 1. Supposed queue level sleep model.

consumption in the sleep state is much lower than the energy consumption in the active state. SM can be classified based on the method used to enter the sleep mode, namely a data frame level sleep mode and a queue level sleep mode.

Power Saving Mode (PSM) is one of the data frame level sleep mode for wireless STAs which is mentioned in IEEE 802.11 standard [4]. The STA in PSM switches from the sleep state to active state at every beacon interval to check for any information found in the beacon frame. If the information indicates that the AP is buffering data frames addressed to the STA, the STA requests those data frames from the AP by sending a request frame until it receives all buffered data and goes back into sleep state until the next beacon interval, otherwise the STA enters into the sleep state immediately. The PSM achieves high power efficiency regardless of the amount of transmitted data since the STA switch the state at every beacon interval. However, it lengthens the response time for sending or receiving the data frame, which results in the decrease of transmission throughput between the STA and AP.

Queue level sleep mode, which increases transmission throughput from the STA to the AP, has been proposed in [5]. In this mode, the STA transmits data to the AP and enter the sleep mode after all data in the queue is transmitted. When new data arrives in the queue, the STA wakes up and switches from sleep mode to active mode. Fig. 1 shows the mechanism of the queue level sleep mode. The advantages of this mode are the high reliability and the high throughput of uplink communication. However, on the end-to-end communication between the STA and the server, where the STA transmits data and the server responds to the STA, the performance is profoundly affected by end-to-end transmission time [6]. Especially, the energy consumption increases when the end-to-end transmission time increases. Therefore, in this paper, we propose a method to decrease the communication time of the STAs by using APESs.

B. AP equipped with External Storage (APES)

Many researchers try to realize an efficient communication by using APES [7]. The work conducted in [8] proposed a cache system using APES for content distribution in vehicular networks. In the proposed scheme, the authors use APES as a cache server through vehicular destination prediction. In [9], Dandapat *et al*. proposed a method for video streaming through optimal placement of APES. The authors proposed efficient storage method to realize just-in-time video streaming.

On the other hand, the APES is expected to function as a proxy server in order to provide efficient transmission. In [10], Koutsogiannis *et al*. showed that the APES which provides proxy function instead of the mobile STAs can reduce the latency for the whole wireless network. In [11], Hoque *et al*. proposed proxy-based traffic shaping by considering the current amount of traffic. In this method, proxy server (or APES) stores the received data from client (or STA) so that the client shortens the transmission time. Then, the server forwards the data according to the current traffic situation. In the case of PSM, a proxy is used to reduce energy consumption. In [12], Ding *et al* proposed that the STAs can be put into sleep state when the proxy server performs end-to-end communication with the server.

The problem of existing studies is not considered the capacity of storages. The proxy-based transmission scheme can reduce the transmission time of STAs and the STAs with proxy-based transmission can enter the sleep mode faster. If APES performs the proxy function, writing speed for storing the received data may become a bottleneck. Since writing speed of USB 2.0 flash drives and SD cards [13] is less than the communication speed of IEEE 802.11n, the transmission time from STA to proxy APES becomes longer. Since, we consider both of capacity between AP and storage, and propagation delay in WMNs with APES. Hence, the issue (clearly state what issue are we talking about) is addressed by selecting the adequate proxy APES in order to shorten the transmission time and reduce the energy consumption of STAs in WMNs.

III. System Model

In this section, we explain our network model, which includes network topology and communication scheme. Additionally, the data transmission model of STA and data reception model of APES are presented.

We focus on a shortest path between STAs and server in WMN as shown in Fig. 2. The shortest path consists of following nodes: STAs that are source nodes, a server that is destination node, APESs that forward data to other APES via wireless link and act as a proxy-server, and a gateway APES that connects to the server with wired link. While the communications between the APs and between the AP and the STAs are conducted by IEEE 802.11 wireless link with a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), where an orthogonal channel is assigned for each cell and each link has same capacity, the communication between the gateway and the server is conducted by IEEE 802.3 wired link. We assumed that the capacity of wired link

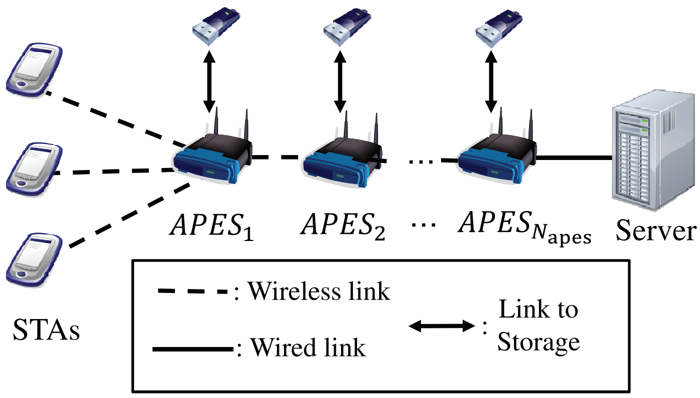

Fig. 2. Our considered network model.

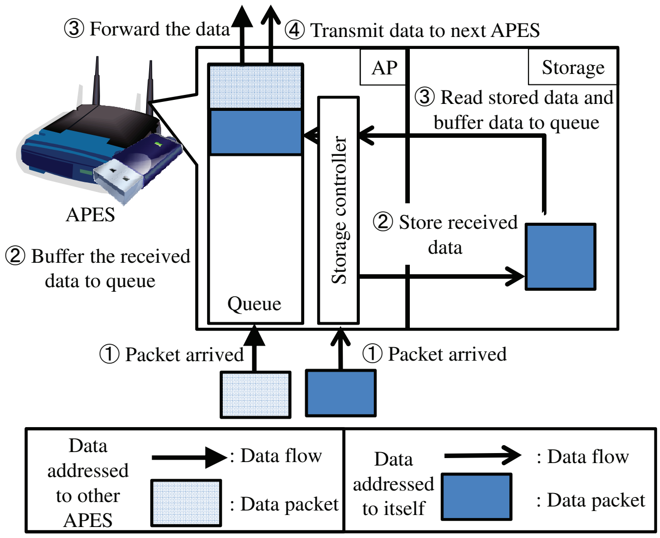

Fig. 3. Data receiving model of APES.

is larger than the capacity of wireless link. Each link has a propagation delay, which is the latency given from distance between point-to-point. We assumed that the propagation delay of wireless link is smaller than that of wired link. Additionally, as mentioned in the previous section, the writing/reading speed to/from external storage (where each APES provides same writing/reading speed) is lower than the wireless communication speed between the APESs (or between the APES and the STAs). Therefore, the writing/reading speed might become a bottleneck in the considered network.

In our considered transmission model, STAs not only transmit data to the server directly but also use APESs as proxy-server. In other words, STAs can choose destination (proxy-APESs or server) to shorten the transmission time, while conventional transmission model chooses only the server and requires longer transmission time due to long propagation delay. Thus, the considered transmission model can reduce the energy consumption.

Fig. 3 shows a procedure of APES to receive the data. When a APES receives the data addressed to itself, its storage controller stores the received data to the external storage. After the APES stores the data, it sends a response to the source node, and thus, the source node can quickly enter sleep mode. When the APES performs communication to the server on behalf of source node, its storage controller reads stored data from external storage and buffers data to queue. Then, the APES transmits data to next APES. In contrast, when a APES receives the data addressed to other APES, it buffers the received data to the queue, and then just forward the data. Since the APES does not reply, source node can not enter sleep mode.

IV. Proposed Destination Selection Method

In this section, we discuss a method to reduce the energy consumption of STAs. First, we define an optimization problem to minimize the energy consumption of STAs. Then, we propose a destination selection algorithm to solve the optimization problem.

A. Definition of optimization problem

This paper aims at minimizing the energy consumption of STAs, E, which is formulated as follows.

$$E = P \times T \times N_{\text{packet}}, \tag{1}$$

where, P, T, and N_{packet} are the energy consumption per a unit of time, the transmission time, which is required to send a packet to the destination, and the number of packets to be transmitted, respectively. The value of P depends on the wireless transmission module of STA and N_{packet} depends on the size of transmitted data. Since P and N_{packet} are constant values, we can minimize the energy consumption of STAs, E, by minimizing the transmission time from STA to destination, T.

To calculate T, we use the Poisson process as a traffic model. Each STA generates the same size of data, S, in a specific period, similar to observation data traffic and background traffic of smartphones. The data is divided into N_{packet} packets, where a packet size is S_{packet}. The source (i.e., STA) transmits the packet to a destination (i.e., the proxy APES or the server). After the destination receives a packet, it sends a response packet to the source, where the size of the response packet is S_{ack}. Since the source can enter into sleep mode after the STA transmits all packets, STA needs to shorten the transmission time in order to enter sleep mode expeditiously. The transmission time from STA to destination, T, is given by the following equation.

$$T = \frac{S_{\text{packet}}}{(C/N)_{\text{bottleneck}}} + \sum D_i, \tag{2}$$

where the first term is the transmission delay that is calculated by the size of packet, S_{packet}, divided by the performance throughput of bottleneck link, which is given by the link capacity of the bottleneck link, C, divided by the number of STAs which access the bottleneck link, N. Second term shows the total propagation delay of each links, D_i, which

TABLE I

A LIST OF NOTATIONS DEFINED AND USED IN ANALYSIS.

E	The energy consumption of STAs.
P	Energy consumption per a unit of time.
T	Transmission time.
N_{packet}	Number of packets to send.
C_{wireless}	Link capacity of wireless link.
C_{wired}	Link capacity of wired link.
S_{packet}	Size of data packet.
S_{ack}	Size of acknowledgment packet.
N_{sta}	Number of STAs.
N_{apes}	Number of APESs.
D_{wireless}	Propagation delay of wireless link.
D_{sto}	Propagation delay of link to external storage.
D_{wired}	Propagation delay of wired link.
WS	Writing speed to storage.
T_{srv}	Transmission time from STA to server.
T_{k}	Round-trip transmission time from STA to k-hop away APES.
N_{srv}	Number of STAs that utilize sever as proxy server.
N_{k}	Number of STAs that utilize k-hop away APES as proxy server.
E_{ave}	The average energy consumption of STAs.

includes wireless links, wired links and links to external storage. From the above equation, we can understand that there is a trade-off relationship between the transmission delay and the total propagation delay. In order to minimize the total propagation delay, it is adequate that all STAs choose the neighbor APES as a destination. However, in this case, the performance throughput drastically decreases due to the traffic convergence on the destination, which results in an increase of transmission delay. Therefore, in order to transmission delay, STAs should distribute their traffic to all APESs and servers.

We derive the explanations that show transmission time from STAs to server and k-hop away APES when STAs distribute their traffic to APESs and server. First, we consider the transmission time from STAs to server. In this case, wireless link between STAs and 1-hop neighboring APES becomes bottleneck link, where its link capacity is C_{wireless}. Because all STAs (let N_{sta} be the number of STAs) use this link, the performance throughput of the bottleneck link is given by $C_{\mathrm{wireless}}/N_{\mathrm{sta}}$. Additionally, the propagation delay from STA to the server is given by $(N_{\mathrm{apes}}D_{\mathrm{wireless}}+D_{\mathrm{wired}})$, where N_{apes}, D_{wireless}, and D_{wired} are the number of APES, the propagation delay of wireless link, and the propagation delay of wired link. Considering the transmission time regarding both data and ACK packets, the total transmission time between STA and server, T_{srv}, is given by the following equation.

$$T_{\mathrm{srv}} = \frac{S_{\mathrm{packet}} + S_{\mathrm{ack}}}{C_{\mathrm{wireless}}/N_{\mathrm{sta}}} + 2(N_{\mathrm{apes}}D_{\mathrm{wireless}} + D_{\mathrm{wired}}). \quad (3)$$

Then we consider the transmission time from STAs to k-hop away APES. In this case, link to external storage on k-hop away APES or wireless link between STAs and 1-hop neighboring APES become bottleneck, where the writing speed to external storage is WS. The performance throughput of link to external storage is given by WS/N_k, where N_k indicates the number of STAs that utilize k-hop away APES as a proxy-server. Thus, the performance throughput of bottleneck link is given by $\min(C_{\mathrm{wireless}}/N_{\mathrm{sta}}, WS/N_k)$. Moreover, the propagation delay from STA to k-hop away APES is given by $kD_{\mathrm{wireless}}+D_{\mathrm{sto}}$, where D_{sto} is the propagation delay of link to external storage. The total transmission time between STA and k-hop APES, T_{k}, is given by the following equation.

$$T_k = \frac{S_{\mathrm{packet}} + S_{\mathrm{ack}}}{\min(C_{\mathrm{apes}}/N_{\mathrm{sta}}, WS/N_k)} + 2(kD_{\mathrm{wireless}} + D_{\mathrm{sto}}). \quad (4)$$

By using Eqs. (3) and (4), the average transmission time of STAs, T_{rmave}, is formulated as follows.

$$T_{\mathrm{ave}} = \frac{1}{N_{\mathrm{sta}}}\left(\sum_{k=1}^{N_{\mathrm{apes}}} T_k N_k + T_{\mathrm{srv}}N_{\mathrm{srv}}\right). \quad (5)$$

Additionally, optimization problem for minimizing the average energy consumption of STAs, E_{ave}, can be formulated as follows.

$$\text{minimize} \quad E_{\mathrm{ave}} = P \times T_{\mathrm{ave}} \times N_{\mathrm{packet}}, \quad (6)$$

$$\text{subject to} \quad N_{\mathrm{sta}} = \sum_{k=1}^{N_{\mathrm{apes}}} N_k + N_{\mathrm{srv}}. \quad (7)$$

All the notations used in our analysis are summarized in Table I.

Algorithm 1 Destination Selection Algorithm

```
Collect network information.
Initialize the minimum energy consumption E_min and the set N, in which each element is the number of STAs choosing each APES.
for each combination of variables in N that satisfies the condition in Eq. (7). do
    Calculate T_k and T_srv by using Eqs. (3) and (4) with the values from collected information.
    Calculate T_ave by using Eq. (5).
    Calculate E_ave by using Eq. (6).
    if E_min is the initialized value or E_ave < E_min then
        E_min = E_ave
        N* = N
    end if
end for
Decide the destination of each STA based on N*.
```

B. Optimal destination selection algorithm

We can derive the optimal set of number of STAs that access each APES or server, $\mathbf{N}^*$, by solving the above mentioned optimization problem. We propose a destination selection method based on the derived optimal set, $\mathbf{N}^*$, which gives the minimum average energy consumption of the STAs. This optimization problem requires network information to solve the problem. In our proposed method, the 1-hop neighboring APES performs the calculation to solve this problem since the APES can efficiently get such information.

Algorithm 1 shows the proposed destination selection method. First, the 1-hop neighboring APES collects information such as the number of STAs, writing/reading speed, link capacity, and propagation delay. In this algorithm, we attempt to change the destination combination of STAs to find the optimal destination selection. We define and initialize the current minimum energy consumption $E_{\rm min}$ and the set $\mathbf{N}$, in which each element is the number of STAs choosing an APES, $(N_1, N_2, ..., N_{N_{\rm apes}}, N_{\rm srv})$. The elements are considered as variables and will be changed following the condition in Eq. (7), which is necessary to solve the optimization problem. For every combination of variables, $T_{\rm ave}$, T_k and $T_{\rm srv}$ are calculated by using the collected information. Then, $E_{\rm ave}$ is calculated by using Eq. (6). After $E_{\rm ave}$ is calculated, it is compared with $E_{\rm min}$. If this calculation is done in the first time or $E_{\rm ave}$ is smaller than $E_{\rm min}$, $E_{\rm min}$ is set to $E_{\rm ave}$ and save the set $\mathbf{N}$ to $\mathbf{N}^*$. This loop is repeated until all combinations of variables in $\mathbf{N}$ are tried. After finding the optimal destination selection method, the destination of each STA is determined based on $\mathbf{N}^*$ with considering the fairness. Finally, each STA selects the destination of transmission based on the designation.

V. Numerical Analysis

In this section, we aim at verifying the performance of the proposed method compared with conventional methods, i.e., constant destination (nearest APES or server), and random destination selection. We show that the proposed method minimizes the average energy consumption of the STAs.

A. Parameter settings

The parameters, which define the considered network in this work, is summarized in Table II. We presume the topology of WMN is as shown in Fig. 2. The capacity of the wireless link between APES and STA or APESs is set to 75MB/s, since we assume the IEEE802.11n is used. Additionally, wired link capacity between gateway and server is set to 125MB/s, which is determined from 1000BASE-T. Assuming SD card with 133x speed is used for external storage, the writing speed is 20MB/s. Each STA transmits 32 data packets, where the size of the data packet is set to 64KB and the size of ACK packet is set to 20B. Additionally, CM9 [14] is used for wireless transmission module to calculate the energy consumption, where the energy consumption of CM9 is 1.4Wh. We evaluate energy consumption of proposed method compared with conventional methods, i.e., the destination of all STAs is nearest APES (shortly Nearest), the destination of all STAs is server (shortly Server), and the destination of STAs is selected in a random manner (shortly Random).

TABLE II
PARAMETER SETTINGS.

Parameter	Value
Capacity of wireless link $C_{\rm wireless}$	75MB/s
Writing speed to external storage WS	20MB/s
Capacity of wired link $C_{\rm wired}$	125MB/s
Propagation delay of wireless link $D_{\rm wireless}$	1μsec
Propagation delay of link to external storage $D_{\rm sto}$	1μsec
Propagation delay of wired link $D_{\rm wired}$	30msec
Data packet size $S_{\rm packet}$	64KB
Acknowledgment packet size $S_{\rm ack}$	20B
Number of packets $N_{\rm packet}$	32
Energy consumption per hour of STA P	1.4Wh

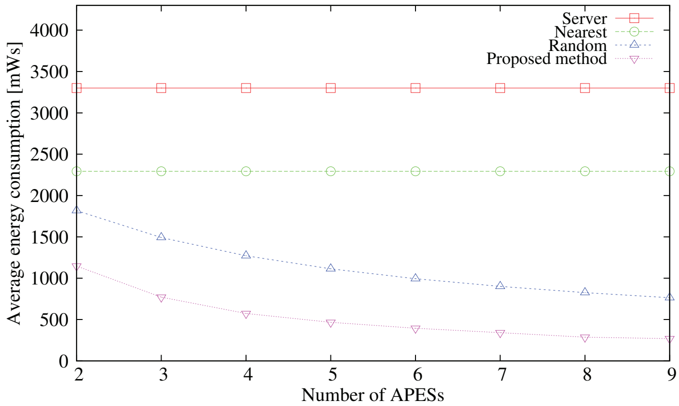

Fig. 4. Comparison of average energy consumption of STAs when the number of APESs is varied.

B. Numerical results

First, we investigate the impact of the number of APESs on the energy consumption of each method. Fig. 4 shows the energy consumption of the proposed method when the number of APESs is varied from 2 to 9 and the number of STAs is set to 16. The X-axis and Y-axis show the number of APESs and the average energy consumption of STAs, respectively. The average energy consumption is given by Eq. (6). The proposed method achieves the lowest energy consumption even when the number of APESs increases. In addition, the proposed method decreases the energy consumption with increases of APESs since it adequately distributes data traffic to APESs and decreases traffic load of each APES. In contrast to this, the wastes much more energy because it evenly distributes data traffic to APESs without consideration of link capacity and writing speed. In case of the Server and Nearest schemes, STAs consume higher and constant energy because they transmit data to only one destination. Compared with the Nearest, the Server consumes much higher energy due to long propagation delay.

Then, we investigate the impact of the number of STAs on the energy consumption of each method. Fig. 5 shows the average energy consumption of the proposed method when the number of STAs that transmit data is varied from 1 to 36 and the number of APESs is set to 2. The X-axis and Y-axis show the number of STAs and the average energy consumption

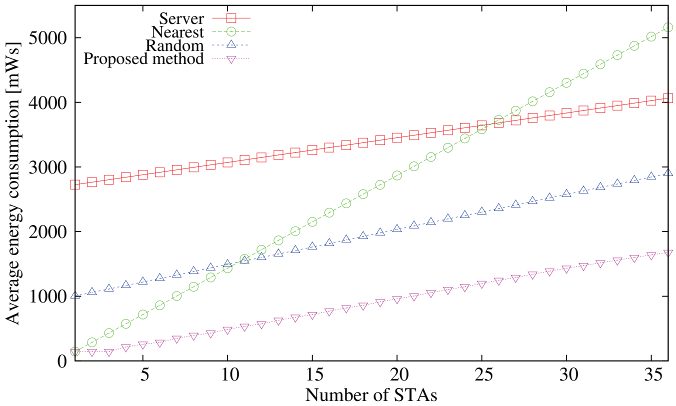

Fig. 5. Comparison of the average energy consumption when the number of STAs is varied.

of a STA, respectively. This result implies that the proposed method achieves the lowest energy consumption regardless of the number of STAs when compared with conventional methods. When the number of STAs is small, the Nearest scheme/method pick one and proposed method achieves the nearly equal performance. However, the energy consumption of the Nearest linearly increases with increase of the number of STAs because the available capacity of each STA decreases by concentrating the traffic to the nearest APES. On the other hand, the energy consumption of the Server scheme/method pick one is the worst in the beginning, but when the number of STAs increases, the energy consumption of server becomes smaller than Nearest method/scheme because of capacity between APES and server is larger than APES and storage. Additionally, the slope of Random scheme/method is similar to that of proposed method, however when destinations of STA concentrate specific APES or server, the energy consumption is higher. Therefore, our proposed method more effective at reducing energy consumption than the Random scheme/method. From these results, it can be concluded that the proposed method reduces the energy consumption of STAs under various network scenarios.

VI. Conclusion and Future Work

Despite the evolution of battery and improvement of wireless transmission modules, energy consumption of wireless device STAs has became a main problem recently. To reduce the energy consumption, the sleep technique has been utilized. However, since the transmission mode from the STA to the server is performed based on end-to-end principle, lengthening the transmission causes an increase of energy consumption. To reduce the transmission time, APES has been used to provide end-to-end communication instead of STAs. STAs utilize APES to reduce the transmission time and the energy consumption. However, when the number of STAs increases, the concentration of traffic causes an increase in the transmission time since the writing speed to external storage becomes a bottleneck. In this paper, we propose a novel method for optimal destination selection for the STAs in WMN. In order to decide the optimal destination for the STAs, we propose the destination selection method to solve the optimization problem which minimizes the average energy consumption of the STAs. Moreover, we validate the efficiency of the proposed method through numerical analysis. In the future, we will focus on considering radio frequency interference [15] and multi-paths [16] by multi-services. Radio frequency interference is not considered in this paper, in addition we need to consider about coordination of communication between different type of services. Therefore, there should be an optimal result to solve the problem that what is the best choice of destinations.

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