A Novel Power-Saving Scheduling Scheme in Large Scale Smart-Grid Networks

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Abstract. The IEEE 802.11ah Task Group is going to specify a global WLAN standard. However, .ah drafts still employs the carrier sense multiple access with collision avoidance (CSMA/CA) medium access protocol, which is an energy-consuming protocol and not suitable for networks where STAs are generally battery supplied. Besides, since .ah could support up to 6000 stations at most to be scheduled within one BSS, the introduced overhead and corresponding processing delay are non-trivial. In this paper, a power saving scheduling scheme is proposed which could greatly reduce the introduced overhead while successfully scheduling the uplink/downlink traffic of meters. Our model could also save the station's battery with best efforts thus making our protocol specifically suitable for Smart-Grid networks where battery changing for stations is difficult. Numerical results show that our scheme outperforms the PSM (Power Saving Mechanism) and PSMP (Power Save Multi-Poll) protocols in terms of overheads, throughput and energy consumptions.

Keywords: Next generation WLAN · Smart grid · Power saving · Scheduling scheme

1 Introduction

Along with the popularity of the easy deployment, simple use, and high penetration of WI-FI interfaces in mobile communication devices, a fast growth is occurring for the outdoor deployment for ubiquitous wireless access. Smart Grid, which is proposed as a typical outdoor use-case [1] in IEEE 802.11ah (abbreviated as .ah later) draft, also require a fast and simple deployment of long-range wireless communication networks for meters and sensor devices in rural areas.

In .ah draft, a wireless coverage range up to 1 km is assumed. Sensors, such as power, gas, or water meter will require at least 100 kbps bit rate. The suggested infrastructure of smart grid meters application is plotted in Fig. 1. The typical discussed scenario involves just one BSS (Basic Service Set) with at most 6000 STAs [2]. Because the special characteristics of .ah networks such as low data rate, short payload, high coverage, large scale and long idle period, specialized MAC layer improvement is

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necessary. Notice that the usages of .ah determine that many small devices are expected to be battery powered. With respect to battery requirements, .ah needs long battery life, short data transmissions and power saving strategies.

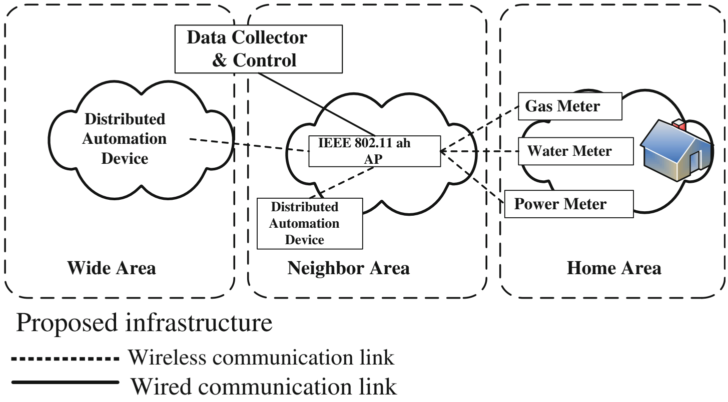


Fig. 1. Our discussed smart grid usecase in IEEE 802.11ah

Particularly, an efficient power saving scheme is mandatory for the following reasons. First, STAs in .ah networks are generally battery supplied and often designed with power sleep functionality. Second, in view of the short payload, a large overhead incurred in power saving polling protocols, such as Power Save Mode (PSM) in IEEE 802.11b [3], Automatic Power Saving Delivery (APSD) in IEEE 802.11e [4] and Power Save Mode Poll (PSMP) in IEEE 802.11n [5], is not permitted. Third, considering the large scale property that there may be at most 6000 STAs contending for the shared medium in the worst case, a well-designed scheduling scheme is needed to further reduce the energy consumption from collisions. Finally, multiple years of battery life might be achieved by lowering the sleep state power consumption with an efficient power saving polling scheme considering energy efficiency and .ah use case with large numbers of STAs. In view of above problems, in this paper, we proposed an efficient power saving scheduling scheme in Smart-Grid Networks based on .ah drafts to reduce the polling overhead and at the same time improve the energy efficiency.

The rest of the paper is organized as follows. Section 2 describes the mechanism of our scheduling scheme in detail. Numerical results and corresponding performance evaluations are shown in Sect. 3. Our paper is concluded in Sect. 4.

2 Proposed Power Saving Polling Scheme

In this section, in view of the three kinds of traffics for a typical .ah network, i.e. down-link data transmitted by AP, up-link data that AP is expected and burst data, we proposed a scheduled multiple access mechanism using our presented Scheduling Indication Message (SIM) field that can unify the scheduling time and reduce the overhead to a great extent. Especially, when AIDs of the STAs which have packets to transmit or be received are successive or partially successive, our proposed scheme could greatly reduce the overhead. The introduced frame structures for scheduling are depicted in Fig. 2. Table 1 shows the corresponding usage of the control field in our proposed frame. Since we attempt to schedule the STAs within one community or one cell, we correspondingly name our proposed frame as Cell Polling Frame (CPF). Next, we will explain the configuration considerations to use our scheme.

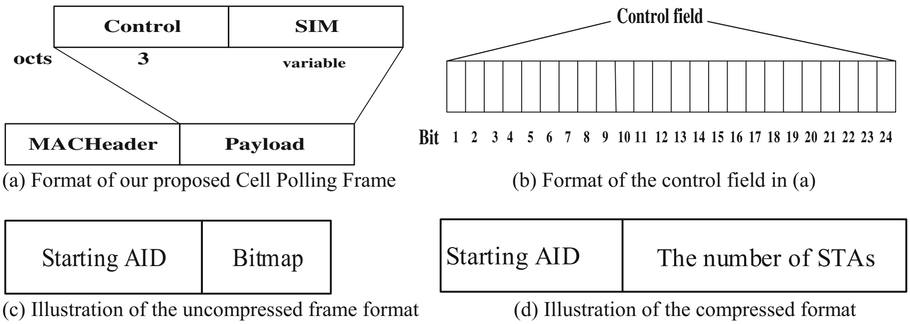


Fig. 2. The proposed frame formats

Table 1. Usage of control field in CPF frame

Bit	Value	Description
1	1	The current PSMP sequence will be followed by another PSMP
	0	There will be no PSMP sequence following the current PSMP sequence
2	1	SIM field is compressed
	0	SIM field is not compressed
3–7	–	The time used by scheduling a single STA
8	1	PSMP-Recovery frame
	0	The normal PSMP frame
9–15	–	Reserved
16–24	–	The length of SIM field

First, we suppose that there are several STAs which have downlink traffics on AP or wait for the opportunities to transmit uplink data to AP. We next divide these data exchanges procedure into multiple steps to demonstrate the usage of our scheme.

Step 1: determine the STAs set for scheduling
First of all, we must determine the set of STAs needed to be scheduled. Let **C_STA** denotes the set of STAs who have buffered downlink data on AP. Since the scale of the number of STAs associated with a single AP could reach or over 6000, an upper limit N_{max} should be configured to confine the number of STAs to be scheduled during one CPF. The determination of N_{max} may consider the configuration of duty cycles for STAs, services requirement, query frequency etc. After N_{max} is given, the

set of STAs to be scheduled during current CPF, i.e. **S_STA**, should be selected from **C_STA**. Two selection criterions are designed as follows:

(a) The STAs with the same service type will be selected as the candidates to be scheduled for a given CPF. In this way, we can calculate a wake up time for each scheduled station in a CPF and make the STAs in **C_STA** doze for a long time before or after they were scheduled. For instance, if all the STAs in a **C_STA** are waiting for the meter reading query and then responding the query with a short ACK, their average service duration could be estimated and may not vary greatly. Therefore, we can easily give their wake up time with our introduced compressed or uncompressed Bitmap mechanism which will be explained later.

(b) The STAs with the continuous AIDs will be selected as the candidates to be scheduled for a given CPF. In this way, our proposed compressed Bitmap mechanism could be used thus greatly reducing the introduced overhead in a CPF.

If the above two criterions both do not work, the STAs will be selected from **C_STA** randomly.

Step 2: set BIT1 of the control field in CPF

As listed in Table 1, BIT1 indicates whether another CPF is needed to transfer the left buffered packets for some or all of the STAs. For an example, if the AP will query a station for some detailed readings according to the returned ACK in the first query, another CPF should be followed to finish this transaction.

Step 3: set the SIM field in CPF

According to whether the AIDs for scheduled STAs are continuous, there maybe exist two different cases for setting the SIM field. Let $AID_{\min}$ denote the minimum AID in **S_AID**. For all the STAs in **S_AID**, if exists

$$AID_i = AID_{\min} + i, i = 1, 2, \ldots, M - 1, \tag{1}$$

where AID_i is a member of **S_AID** and $M \leq N_{\max}$ is the number of STAs schedule in this CPF, then it can be known that the AIDs in **S_AID** are continuous. If so, the compressed Bitmap mechanism could be used as step (a) describes. Otherwise, the uncompressed Bitmap mechanism will be enabled as step (b) indicates.

Fig. 3. SIM field for compressed Bitmap

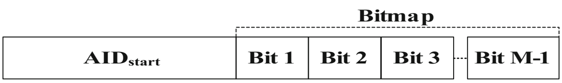


Fig. 4. SIM field for uncompressed Bitmap

(a) If AIDs in current CPF are continuous, the SIM field will only include two subfield as shown in Fig. 3, i.e. AID_{start} and the number of scheduled STAs M, where AID_{start} denotes the AID of the first scheduled station in current CPF. In this way, for the i^{th} scheduled station i, its AID could be derived as $AID_i = AID_{start} + i$. It is worth noting that the introduced overhead using this compressed Bitmap may be greatly reduced compared to the traditional method based on TIM frame.

(b) If AIDs involved in current CPF are not continuous, then the SIM field will has the following structure as shown in Fig. 4. Here, if Bit j in Bitmap is 1, it means that the corresponding station j has buffered data on AP. *j's* AID could also be derived as $AID_j = AID_{start} + j$. Correspondingly, if Bit j in Bitmap is 0, it means that station j will not be scheduled during this CPF.

Step 4: compute the unit service duration
We define the Unit service Duration (USD) as

$$T = \max\{\langle L_i/MCS_i\rangle\} + T_0, i = 1, 2, \ldots, M, \quad (2)$$

where L_i denotes the average packet length for station i and MCS_i indicates the sending rate for i using specific Modulation and Coding Scheme. Symbol $\langle x\rangle$ means adding the MAC and PHY header to payload x. T_0 equals to the needed duration for the transmission of a typical ACK frame whose payload length could be only few Bytes. This ACK frame may act as the querying response or a buffered report packet. The exact length for an ACK frame can be configured for specific applications and here we fix it to 32 Bytes. The introducing of USD into our work has two fold usages:

(a) Giving USD for all STAs to be scheduled, they can easily obtain their wake up time by step (8). In this way, all STAs can doze as long as possible to save energy.
(b) By introducing MCS for each scheduled station, the duration for downlink transmissions of all STAs could be intentionally kept almost the same. In this way, our definition of USD could be made full use thus accurately estimating the wake up time for STAs and saving energy.

Step 5: set the other BITS of the control field in CPF
To indicate whether compressed Bitmap mechanism is enabled, BIT2 needs to be set as listed in Table 1. Besides, according to the configuration of BIT2, BIT16–BIT24 will be set to denote the length of SIM field in Bytes. In other words, our scheme could support $(2^9 - 1) \times 8 = 4088$ STAs. However, since 2 Bytes have been used for AID_{start}, the maximum number of STAs is $(2^9 - 1 - 2) \times 8 = 4072$. We can expand the length of the field by introducing one more Byte, say, using BIT16–BIT32 to express the SIM field to support $(2^{17} - 1 - 2) \times 8 = 1048552$ STAs.
But generally speaking, this case will never occur within one BSS.

Step 6: AP broadcasts the filled CPF
After configurations of the CPF frame, AP then broadcasts it to STAs. Next, STAs in **S_STA** will do corresponding actions according to the values of received fields.

Step 7: STAs receive CPF and do corresponding actions
Receiving the CPF, a station will first extract the value of BIT2 and decide whether this CPF has used the compressed Bitmap. If true, the range of AID to be scheduled can be determined as $[AID_{start}, AID_{start} + M - 1]$. One station i could know whether it will be scheduled during current CPF by judging $AID_i \in [AID_{start}, AID_{start} + M - 1]$ or not. If yes, the station needs to be awake for an USD from $T_{start}(i)$ which will be given in step 8. Otherwise, this station could keep sleeping during this CPF. If BIT2 is set to 0 which means uncompressed Bitmap has been used, a station should first check whether its AID equals to AID_{start}. If true, this station will be scheduled in current

CPF; If not, this station needs to check the corresponding BIT in received Bitmap. If the BIT is 1, this station will be schedule. Otherwise it could keep sleeping.

Step 8: compute the wake up time for a specific station

For a scheduled station, its wake up time $T_{start}(i)$ during a polling can be gotten:

$$T_{start}(i) = N_{before}(i) \times T, \tag{3}$$

where $N_{before}(i)$ is the number of STAs scheduled before i during current polling stage. T is the calculated USD during current CPF. Here, $N_{before}(i)$ could be determined as follows depending on the used Bitmap mechanism.

(a) If uncompressed Bitmap has been used, then

$$N_{before}(i) = \sum_{p=0}^{AID_i - AID_{start} - 1} I_p\{\omega_p : \omega_p \in \mathbf{S\_AID}\}, \tag{4}$$

where I is a indicative function defined as follows:

$$I_p\{\omega_p : \omega_p \in \mathbf{S\_AID}\} = \begin{cases} 0, \omega_p \notin \mathbf{S\_AID} \\ 1, \omega_p \in \mathbf{S\_AID} \end{cases}. \tag{5}$$

(b) If compressed Bitmap has been used, then it is easy to obtain $N_{before}(i)$ as

$$N_{before} = AID_i - AID_{start}. \tag{6}$$

Step 9: payload transmission

After each station scheduled has known its own schedule, data exchange could be initiated between AP and STAs. For a scheduled station i, it will keep sleeping till $T_{start}(i)$. During $[T_{start}(i), T_{start}(i) + T]$, i will first receive the downlink traffic from AP. If there is still time left and i also has traffics to be uploaded to AP, it will keep awake and send the uplink payload. The setting of USD by Eq. (2) has reserved uplink duration for each scheduled station. Indeed, it is possible that some STAs have only uplink traffics. For instance, STAs or meters may trigger an alarm report whenever the predefined peak load threshold is surpassed. For this case, compared to the passive uplink traffics after a downlink query, the active uplink traffics could be uploaded at any time when STAs are awake according to their DTIM settings.

Step 10: AP sends Block ACK

After all the STAs in **S_STA** have been scheduled, they will be awaken again to receive the block ACK sent by AP. This block ACK aims to confirm the uploaded traffics sent by specific STAs.

Next, we explain the CPF scheme in detail with a typical case as shown in Fig. 5. First AP sets the CPF according to the buffered traffics, AIDs of STAs and some related parameters. Then AP broadcasts the configured CPF to STAs in **S_STA**. We assume that STA1, STA2, STA3, STA4 and STA5 form the set **S_STA**. Receiving the CPF, each station orderly extracts the control fields in CPF. Here, STA1 to STA5 all have

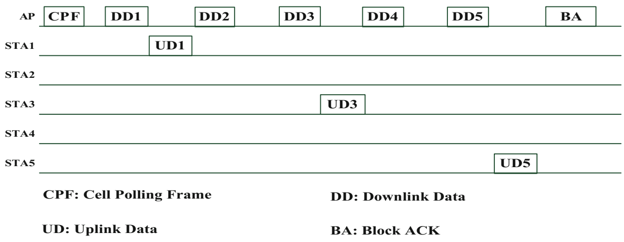


Fig. 5. The interaction mechanism when AP using the proposed scheme

buffered traffics on AP and require 5 USDs. Every station knows its wake up time and keeps sleeping before or after it. Specially, STA1, STA3 and STA5 have also uplink traffics, uploading their uplink packets following downlinks respectively. When the data service is finished, AP responses to the STAs by Block ACK(BA) [6].

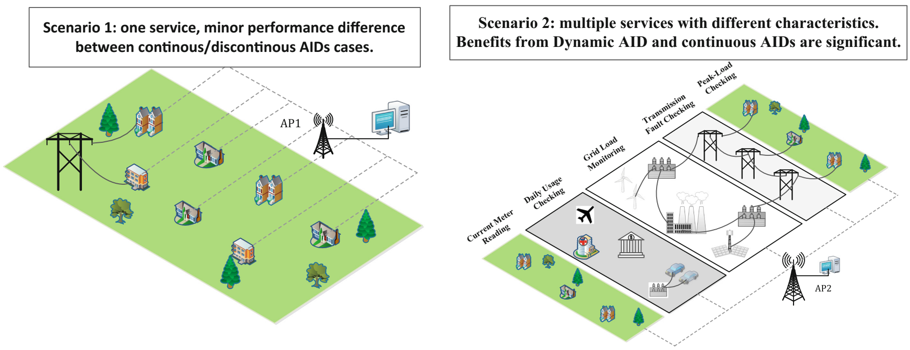
3 Numerical Results

To evaluate the performance of our proposed scheme, we implement it in MATLAB with the typical parameters listed in Table 2. Our simulations are divided into two groups. In group 1, the overheads and throughput are compared among our scheme, PSM and PSMP with the number of scheduled stations changing. In group 2, the throughput and energy consumption are inspected with the data or burst size of each station varying. Since BlockACK has been adopted as an option in IEEE 802.11n draft, its impact on our model is also assessed.

Table 2. The important parameters in simulation

Description	Value	Description	Value
BER threshold	10^(−6)	Awaking power	1 W
Channel capacity	400 kbps	Sleeping power	0 W
Time slot length	20 µs	CW_{min}	32
Transmitting power	2 W	CW_{max}	1024
Receiving power	1.5 W	Size of data frame	100 bytes

The simulation topology is illustrated in Fig. 6, where Fig. 6(a) and (b) correspond to the test scenario for group 1 and group 2, respectively. For group 1, only one service is considered. In this way, since the traffic characteristics of stations for the same service are similar, the scheduling table for those stations will be arranged together. That is, most of the stations under AP1 in Fig. 6(a) will be scheduled in a CPF together whatever their AIDs are continuous or discontinuous. Unlike group 1, there are multiple services existent in group 2 such as current meter reading, daily usage checking, transmission fault checking and peak-load checking etc. Since different services employ different report frequency, a large number of stations may not be scheduled together during a specific duration. For instance, the daily usage checking might be invoked only once during a day while the current meter reading report may be requested several times during a day. Another example is the peak-load checking, which is a special service usually scheduled in summer but few arranged in other seasons regarding their lower possibilities to overpass the peak-load threshold. Therefore, for our simulation scenario 2, there are also a huge number of stations under the cover of AP2 but only few of them will be scheduled together during a specific duration. Note that in group2, because only few stations will be scheduled during a CPF, there will be many “zeroes” in our proposed bitmap. Thereupon, the performance between continuous or discontinuous AIDs cases for group 2 will be of great differences.



(a) Simulation scenario for test group 1 (b) Simulation scenario for test group 2

Fig. 6. Simulation topology

The performance evaluation indexes are defined as follows:

- Overhead: the difference between data rate and throughput;
- Average awaken time: the arithmetic average of the total awaken time for all stations;
- Average Energy consumption: the arithmetic average of the total consumed energy for all stations;
- Normalized throughput: the fraction of time the channel is used to successfully transmit payload bits.

The performance comparisons of overheads suppression among ours, PSM and PSMP have been plotted in Fig. 7 with the number of stations varying. Note that in Fig. 7, the AIDs of stations are not continuous. This case corresponds to the situation such as readings report for stations whose load is over the average load or reaching the peak load. The case with successive AIDs is also inspected with results shown in Fig. 9. The continuous AIDs are usually configured for the meters in a community or company where devices are sequentially installed. It can be concluded that our scheme has the best performance on overheads reduction. If Block ACK is enabled during a

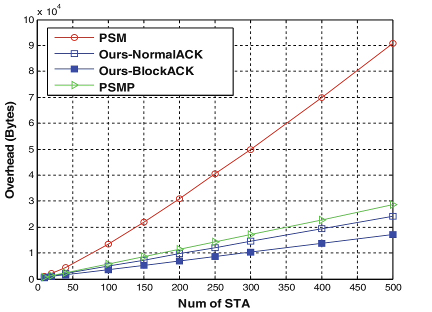


Fig. 7. The overheads comparisons with of the number of stations varying

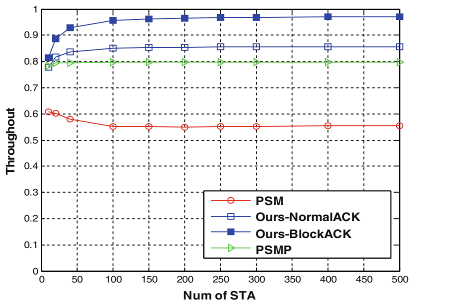


Fig. 8. The normalized throughput comparisons with the number of stations varying

CPF, the overheads will be further decreased. It is worth noting that the superiority of our protocol over the other two is increasing with the number of stations grows. Actually, due to contentions among upload stations and the overheads from notifications sent by the control unit to notify stations to report their readings, PSM needs the most overheads to work. As for PSMP, although centralized scheduling is used to coordinate stations from competing, its larger scheduling overhead, i.e., 8 Bytes for each station, make it unsuitable for mass uplink traffics. In addition, due to the length limitation, only 31 stations can be scheduled at most during a PSMP scheduling frame [7]. In this way, PSMP needs several frames to finish the batch reports from a large number of stations. On the other hand, since our scheme introduces the bitmap mechanism and adopts centralized scheduling, the contention between stations is eliminated and the number of stations schedulable in a CPF is greatly increased thus making the final overheads very few.

Figure 8 shows the normalized throughput of three schemes with the number of stations changing. The normalized throughput is defined as the Bytes successfully received every unit time to the channel capacity. Since PSM uses competition-based multiple access for uplink traffics, part of the channel bandwidth is wasted for backoff and retransmissions. As a result, PSM shows the worst performance. When the number of stations is over 31, PSMP needs multiple scheduling frames to receive the uploaded traffics, thus outputting a worse throughput compared to ours. Another reason is the larger scheduling frame size than ours, which makes PSMP waste many time for overheads transmission thus decreasing the normalized throughput. Our scheduler could arrange up to 4072 stations once and uses a smaller scheduling frame thus resulting in a higher throughput. When BlockACK is enabled, the throughput could be further increased by eliminating the time cost by multiple handshakes.

The normalized throughput comparisons are shown in Fig. 9 with the data size varying. Note that in this simulation scenario, the case for continuous (abbreviated as “Con”) and discontinuous (abbreviated as “Discon”) AID have been investigated for our scheduler. Due to PSM and PSMP do not care the sequence of station’s AID, this “Con” or “Discon” setting will not influence their results. Since PSM is a contention based protocol, its performance is the worst due to channel competing and data

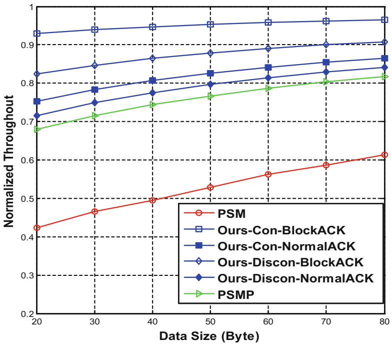


Fig. 9. The throughput comparisons with the data size varying

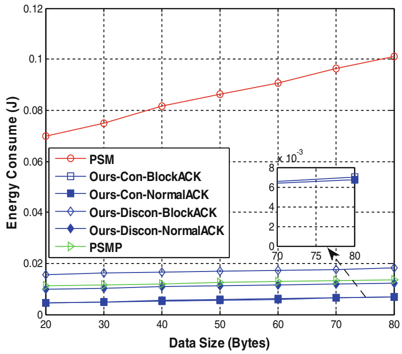


Fig. 10. The energy consumption comparisons with the data size varying

retransmission. Our scheme with four different configurations show a better performance than PSMP and PSM. As stated before, due to smaller scheduling frame and only one CPF needed, ours output superior normalized throughput over others. Especially when the AIDs are continuous, the normalized throughput is further increased considering the reduction of CPF size and generated overheads. It is worth noting that with the growing of data size, the normalized throughput increases for all protocols due to more sent Bytes during a unit time. In addition, the difference of different cases reduces when the data size increase. But as we have known, the data size in Smart-Grid networks is usually small, such as 76 Bytes for MPDU (MAC Protocol Data Unit) of PMU (Power Management Unit) [8], 480 Bytes for interval data read of meter [9], etc. Therefore, we can reasonable consider that our proposed scheme has a significant superiority on stations scheduling in Smart-Grid networks.

The performance for energy consumption is also compared among three protocols with the data size varying as shown in Fig. 10. Since the meters are battery powered, the energy efficiency is a very important factors in practice in Smart-Grid networks. It is worth noting that PSM still shows the worst performance consistent with the results in Figs. 7 and 8. As for PSMP, its energy efficiency is better than our scheme with discontinuous AIDs and BlockACK but worse than ours with normal ACK mechanism. This is because that a group of discontinuous AIDs will need a very long time to finish all active stations' uploading considering many "0" in the bitmap. When BlockACK is enabled, an extra awaking time is needed for all active stations to fetch their ACK from the BlockACK frame. As for the energy consumption for continuous AIDs case, since the bitmap has been greatly compressed, the time used for scheduling all the active nodes is much smaller than the discontinuous AIDs case thus saving the battery life to a great extent.

4 Conclusion

In this paper, a power saving scheduling scheme is proposed which could greatly reduce the introduced overhead while successfully scheduling the uplink/downlink traffic of meters. Our proposed model could also save the station's battery with best efforts thus making the scheme specifically suitable for Smart-Grid networks. Numerical results show that our scheme outperforms PSM and PSMP in terms of overheads, throughput and energy consumptions. Our future work will investigate the possibility to merge the IEEE 802.11ah based network with the public cellular network and extend the scalability of our model to make it suitable for the upcoming 5G mobile communication networks.

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References

1. Sun, W., Choi, M., Choi, S.: IEEE 802.11ah: a long range 802.11 WLAN at sub 1 GHz. J. ICT Stand. **1**, 83–108 (2013)
2. Khorov, E., Lyakhov, A., Krotov, A., Guschin, A.: A survey on IEEE 802.11ah: an enabling networking technology for smart cities. Comput. Commun. **58**, 53–69 (2015)
3. Tauber, M., Bhatti, S.N.: The effect of the 802.11 power save mechanism (PSM) on energy efficiency and performance during system activity. In: 2012 IEEE International Conference on Green Computing and Communications (GreenCom), pp. 573–580 (2012)
4. Gonzalez, F.V., Lundqvist, H., Leppanen, K.: Seamless handover in 802.11 with automatic power save delivery. In: 2014 IEEE 19th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), pp. 380–384 (2014)
5. Ma, C., He, S., Li, Y., Xu, Q., Yang, L.: Enhanced power-save multi-poll mechanism for multi-user downlink transmission in WLAN. In: 2015 IEEE China Summit and International Conference on Signal and Information Processing (ChinaSIP), pp. 881–885 (2015)
6. Chen, H.: Throughput analysis of block-ACK in IEEE 802.11n. In: The 2nd International Conference on Computer Application and System Modeling, ICCASM, pp. 956–959 (2012)
7. Xiao, Y.: IEEE 802.11n: enhancements for higher throughput in wireless LANs. IEEE Wirel. Commun. **12**, 82–91 (2005)
8. Khan, R.H., Khan, J.Y.: A comprehensive review of the application characteristics and traffic requirements of a smart grid communications network. Comput. Netw. **57**, 825–845 (2013)
9. Luan, W., Sharp, D., Lancashire, S.: Smart grid communication network capacity planning for power utilities. In: Transmission and Distribution Conference and Exposition, 2010 IEEE PES, pp. 1–4 (2010)