A Novel Energy Harvesting Aware IEEE 802.11 Power Saving Mechanism

Yigitcan Celik(✉) and Cong Pu

Weisberg Division of Computer Science, Marshall University,
Huntington, WV 25755, USA
{celik1,puc}@marshall.edu

Abstract. The spread of wirelessly connected computing sensors and devices and hybrid networks are leading to the emergence of an Internet of Things (IoT), where a myriad of multi-scale sensors and devices are seamlessly blended for ubiquitous computing and communication. However, the communication operations of wireless devices are often limited by the size and lifetime of the batteries because of the portability and mobility. To reduce energy consumption during wireless communication, the IEEE 802.11 standard specifies a power management scheme, called Power Saving Mechanism (PSM), for IEEE 802.11 devices. However, the PSM of IEEE 802.11 was originally designed for battery-supported devices in single-hop Wireless Local Area Networks (WLANs), and it does not consider devices that equip with rechargeable batteries and energy harvesting capability. In this paper, we extend the original PSM by incorporating with intermittent energy harvesting in the IEEE 802.11 Medium Access Control (MAC) layer specification, and propose a novel energy harvesting aware power saving mechanism, called *EH-PSM*. The basic idea of EH-PSM is that a longer contention window is assigned to a device in energy harvesting mode than that of a device in normal mode to make the latter access the wireless medium earlier and quicker. In addition, the device in energy harvesting mode stays active as far as it harvests energy and updates the access point of its harvesting mode to enable itself to be ready for receiving and sending packets, or overhearing any on-going communication. We evaluate the proposed scheme through extensive simulation experiments using OMNeT++ and compare its performance with the original PSM. The simulation results indicate that the proposed scheme can not only improve the packet delivery ratio and throughput but also reduce the packet delivery latency.

Keywords: Energy harvesting · Power saving mechanism
Medium access control · IEEE 802.11

1 Introduction

With recent technological advances in portability, mobility, low-power microprocessors, and high speed wireless Internet, embedded computing devices capable of

© Springer International Publishing AG, part of Springer Nature 2018
S. Chellappan et al. (Eds.): WASA 2018, LNCS 10874, pp. 14–26, 2018.
https://doi.org/10.1007/978-3-319-94268-1_2

wireless communication are rapidly proliferating. The growing presence of WiFi and 4G Long-Term Evolution (LTE) enable users to pursue seemingly insatiable access to Internet services and information wirelessly. It is predicted that 30 billion wirelessly connected devices will be available by 2020, nearly triple the number that exists today [1]. The spread of these devices and hybrid networks is leading to the emergence of an Internet of Things (IoT) [2], where a myriad of multi-scale sensors and devices are seamlessly blended for ubiquitous computing and communication. The prevalence of cloud, social media, and wearable computing and the reduced cost of processing power, storage, and bandwidth are fueling explosive development of IoT applications in major domains (i.e., personal and home, enterprise, utilities, and mobile) [3], which have the potential to create an economic impact of \$2.7 trillion to \$6.2 trillion annually by 2025 [4]. We envision that wirelessly connected smart devices under the IoT will not only enhance flexible information accessibility and availability but also improve our lives further.

To realize this vision, however, a limited lifetime of the battery to power wireless devices must be overcome. For example, the TMote$^{\text{TM}}$ Sky node consumes 64.68 mW in receive mode [5]. Using two standard 3,000 mAh AA batteries, the network lifetime is only 5.8 days if nodes are heavily utilized [6]. In addition, rapidly proliferating wearable devices implanted to anywhere of user (e.g., glasses [7], clothes, shoes, accessories, or even under skin [8]) are directly affected by the lifetime of batteries. In order to extend the lifetime of the batteries, energy harvesting from surrounding environmental resources (e.g., vibrations, thermal gradients, lights, wind, etc.) has been given considerable attention as a way to either eliminate replacing the batteries or at least reduce the frequency of recharging the batteries. For example, ambient vibration-based energy harvesting has been widely deployed because of the available energy that can be scavenged from an immediate environment, such as the pulse of a blood vessel, or the kinetic motion of walking or running. Piezoelectric-based energy harvesting is favored when vibration is the dominant source of environmental energy and solar light is not always available. Though energy harvesting from photo-voltaic cells is popular and well-studied, it is inefficient because of the unpredictable availability of solar irradiation, such as installed location (e.g., a shaded area), initial position (e.g., seasonal variations between the sun's angle and solar panel), weather conditions (e.g., a rainy season), and harvesting period (e.g., daytime only).

Thus, we anticipate that energy harvesting will play a pivotal role in making possible self-sustainable wireless devices ranging from nano-scale sensors to hand-held mobile devices, and serve as a major building block for emerging IoT applications. Although environmental energy harvesting has been well studied in civil and mechanical engineering, research on energy harvesting sensitive communication algorithms and protocols embedded into link layer (i.e., IEEE 802.11 Medium Access Control (MAC)) is still in its infancy. Thus, key research motivations of this paper are summarized: (i) Prudent energy-efficient mechanisms have been proposed to extend the network lifetime. Despite the prior best effort-based approaches, manually replacing the batteries or recharging the batteries is ultimately unavoidable. Disposable batteries can address this issue but they may pose a potential environmental hazard; (ii) Energy harvesting from immediate environmental sources may radically shift the paradigm on energy management from reducing energy consumption to maximizing the utilization of opportunistic energy; (iii) With the increasing prevalence of wearable computing, the adoption of energy harvesting techniques to multi-scale wireless sensors and mobile devices is essential to the design of IoT applications.

In this paper, we design and propose a novel Power Saving Mechanism (PSM) of IEEE 802.11 for self-sustainable devices supported by intermittent energy harvesting. The proposed research will shift the paradigm of energy management from conserving limited battery energy to maximizing the utilization of harvested energy, and provide design considerations to the broader IoT community seeking new applications. Our major contribution is briefly summarized in two-fold:

- We design and propose a novel energy harvesting aware power saving mechanism of IEEE 802.11, called *EH-PSM*, incorporating with intermittent energy harvesting from environmental resources. The basic idea of EH-PSM is that a longer contention window is assigned to a device in energy harvesting mode than that of a device in normal mode to make the latter access the wireless medium and earlier and quicker. In addition, the device in energy harvesting mode stays awake as far as it harvests energy and updates the access point of its harvesting mode to enable itself to be ready for receiving and sending packets, or overhearing any on-going communication.
- We develop a customized discrete event-driven simulation framework by using OMNeT++ [9] and evaluate the proposed scheme through extensive simulation experiments in terms of packet delivery ratio, throughput, packet delivery latency, and total active time. We also revisit and implement the original PSM in energy harvesting environment for performance comparison.

The simulation results indicate that the proposed scheme can not only improve the packet delivery ratio and throughput but also reduce the packet delivery latency.

The rest of paper is organized as follows. The prior approaches are analyzed and presented in Sect. 2. A system model and the proposed energy harvesting aware power saving mechanism are presented in Sect. 3. Section 4 presents extensive simulation results and their analyses. Finally, we conclude the paper in Sect. 5.

2 Related Work

In [10], an energy saving algorithm is proposed to reduce power consumption of tethering smartphone, which plays a role of mobile access point temporarily. The basic idea is that smartphone turns off its WiFi interface when there is no traffic in order to conserve battery power without increasing the packet delay substantially. The [11] proposes a system, called *Percy*, to maximize the energy saving of static and dynamic PSM respectively while minimizing the delay of flow completion time. The Percy deploys a web proxy at the access point and suitably configures the PSM parameters, and is designed to work with unchanged clients running dynamic PSM, unchanged access points, and Internet servers. In [12], a detailed anatomy of the power consumption by various components of WiFi-based phones has been provided. Through a measurement-based study of WiFi-based phones, the power consumption for various workloads at various components have been analyzed.

WiFi continues to be a prime source of energy consumption in mobile devices, and energy optimization has conventionally been designed with a single access point. However, network contention among different access points can dramatically increase client's energy consumption. Thus, the [13] designs and proposes an approach to achieve energy efficiency by evading network contention. The basic idea is that the access points regular the sleeping window of their clients in a way that different access points are active/inactive during non-overlapping time windows. In [14], a micro power management is proposed to enable an IEEE 802.11 interface to enter unreachable power saving mode even between medium access control (MAC) frames, without noticeable impact on the traffic flow. To control data lost, the proposed scheme leverages the retransmission mechanism in IEEE 802.11 and controls frame delay to adapt to demanded network throughput with minimal cooperation from the access point. The [15] presents an experimental study of the IEEE 802.11 power saving mechanism on PDA in a Wireless Local Area Network (WLAN), where the power consumption of the PDA in both continuous active mode and power saving mode are measured under various traffic scenarios, beacon period, and background multicast traffic. In [16], the performance of different MAC schemes based on CSMA and polling techniques for wireless sensor networks which are solely powered by solar energy are studied. In [17], the feasibility of powering wireless metering devices (e.g., heat cost allocators) by thermal energy harvested from radiators is investigated.

In summary, there is a significant amount of research effort on the IEEE 802.11 power saving mechanism and its variants. However, to the best of authors' knowledge, the proposed research focusing on designing energy harvesting aware power saving mechanism and integrating it with the original PSM of IEEE 802.11 is new.

3 The Proposed Approach

In this section, we first review the IEEE 802.11 Power Saving Mechanism (PSM). Then we present the system model, and propose a novel energy harvesting aware PSM of IEEE 802.11 for self-sustainable devices supported by intermittent energy harvesting.

3.1 Overview of the IEEE 802.11 Power Saving Mechanism

As proposed in the IEEE 802.11 standard [18], an IEEE 802.11 based wireless network interface can choose to stay in either awake state or sleep state at any time. In the awake state, the device turns on its wireless interface and performs normal data communications, for example receiving or sending packets, or just stay in idle. In order to save the residual energy, the device can switch to the sleep state, where the radio of a device is turned off and the wireless interface cannot detect or sense any wireless communication. Wireless interface in awake state usually consumes an order of magnitude more power than that in sleep state [15].

To reduce the energy consumption of IEEE 802.11 devices during wireless communications, the [18] specifies a power management scheme, called Power Saving Mechanism (PSM). The basic idea of PSM is that the devices sleep most of the time and stay at a low power state (i.e., turn off wireless interface) but periodically wake up and switch to a high power state (i.e., turn on wireless interface) to receive the packets buffered at the access point (AP). In PSM, the AP buffers incoming packets destined for devices in low power state and periodically announces its buffering status through the traffic indication map (TIM) contained in the beacon frames. The device wakes up at beginning of beacon interval periodically to listen to the beacon frames. If the corresponding bit of the association ID (AID) of device is set in the TIM, the device will stay awake, and wait for the AP to initialize a PS-Poll packet to retrieve data packet from it and/or send the buffered packet to it. The AP can issue multiple PS-Poll packets until all outstanding packets from the devices have been retrieved. As opposed to the continuously awake mode, a device applying power saving mechanism can often have opportunities to turn off its wireless interface to save energy when it has no packets buffered at the AP, or no packets need to be sent to the AP. Here, a snapshot of the power saving mechanism of IEEE 802.11 is shown in Fig. 1. For example, the device S_A and S_B wake up at the beginning of beacon interval and listen to the TIM broadcasted by the AP. Suppose that the AP initializes a PS-Poll packet to S_A first and sends the buffered packet $DATA_a$ to it. After receiving the packet $DATA_a$, S_A replies an ACK packet to the AP after a short time period $SIFS$, and then switches to power saving mode and turns off its wireless interfaces to save energy.

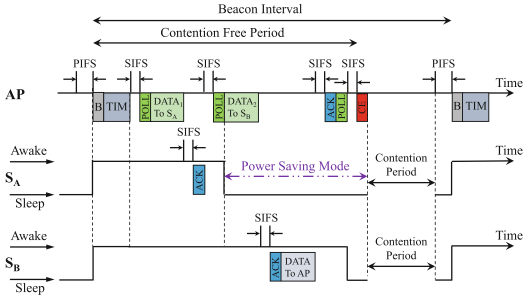


Fig. 1. A snapshot of the power saving mechanism of IEEE 802.11.

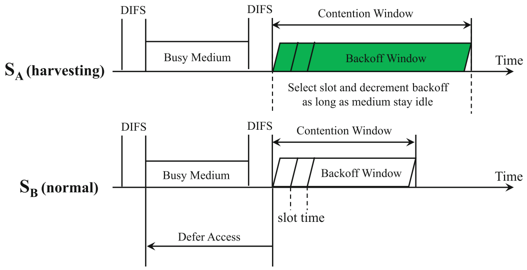


Fig. 2. An example of longer contention window for device in energy harvesting mode.

3.2 System Model

In this paper, we assume that each IEEE 802.11 device equips with an energy harvesting component to replenish its rechargeable battery. For example, a piezoelectric fiber composite bi-morph (PFCB) W14 based energy harvesting from an immediate environment (e.g., disturbance or typical body movements) can generate sufficient power (i.e., 1.3 mW–47.7 mW) for wireless sensors [19–21]. It is envisaged that multi-scale piezo devices and integrated self-charging power cells (SCPCs) [22] will enhance the efficiency of energy harvesting. An energy harvesting is modeled by a two-state Markov process with energy harvesting (S_h) and normal (S_n) modes [6]. A device stays in S_n mode for a random amount of time, which is exponentially distributed with a mean λ_n, and changes its mode into S_h mode. After harvesting energy for some amount of time in S_h mode, which is also assumed to be exponentially distributed with a mean λ_h, the device changes its mode back to S_n mode. Both S_n an S_h modes are repeated.

3.3 Energy Harvesting Aware Power Saving Mechanism

The PSM of IEEE 802.11 was originally designed for battery-supported devices in single-hop Wireless Local Area Networks (WLANs), and does not consider devices that equip with rechargeable batteries and energy harvesting component. In this paper, we will extend the original PSM by incorporating with intermittent energy harvesting in the IEEE 802.11 Medium Access Control (MAC) layer specification, and propose a novel energy harvesting aware power saving mechanism, called *EH-PSM*. The basic idea of EH-PSM is that a longer contention window is assigned to a device in energy harvesting mode than that of a device in normal mode to make the latter access the wireless medium earlier and quicker. In addition, the device in energy harvesting mode stays awake as far as it harvests energy and updates the AP of its energy harvesting mode to enable itself to be ready for receiving and sending packets, or overhearing any on-going communication. The rationale behind of the EH-PSM is to shift the paradigm of energy management from conserving limited battery energy to maximizing the utilization of harvested energy. Thus, we focus on (i) how to assign contention

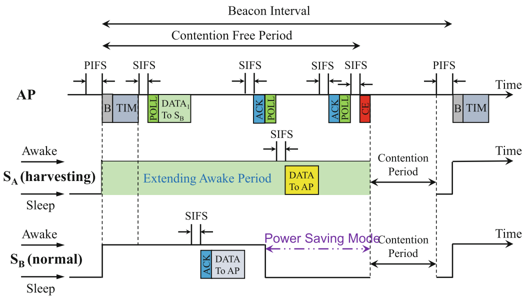


Fig. 3. An example of node in energy harvesting mode extends awake period.

window to a device in energy harvesting mode, and (ii) how to extend the awake time period of device in energy harvesting mode.

First, in the original PSM, each device uniformly chooses the contention window for backoff period before accessing the medium to avoid any potential collision. In the presence of energy harvesting, however, each device may need to adjust its contention window differently. The basic idea is to intentionally assign a longer contention window to a device in energy harvesting mode than that of a device in normal mode. Then a device containing the less amount of residual energy or staying in normal mode has more chances to choose a shorter backoff period to access the medium earlier and quicker, and then turn off its wireless interface, which finally results in lower energy consumption. Since a device in energy harvesting mode may experience a longer delay before initiating the communication, it will have a shorter contention window later to access the medium for fairness when it is in the normal mode. For example, as shown in Fig. 2, suppose that device S_A and S_B is in energy harvesting mode and normal mode, respectively. Since S_A is in energy harvesting mode, it intentionally sets a longer contention window and randomly chooses a backoff period. However, S_B is in normal mode, and it follows the original PSM and select the backoff period from a normal contention window that is shorter than that of S_A. Thus, S_B has more chances to select a shorter backoff period from normal contention window, accesses the medium earlier, and finally consumes less amount of residual energy.

Second, in the original PSM as shown in Fig. 1, a device immediately sleeps back after receiving the buffered packets from the AP or sending generated packets to the AP in order to reduce energy consumption. In the EH-PSM, however, the basic idea is that a device in energy harvesting mode stays awake as far as it harvests energy and updates the AP of its energy harvesting mode. This approach enables the device to be ready for receiving and sending packets, or overhearing any on-going communication. In addition, in order to reduce the energy consumption of device in normal mode, the AP can specify non-harvesting device as early polled device in the Traffic Indication Map (TIM) and send the PS-Poll packet and buffered packets immediately after broadcasting the TIM. After receiving buffered packets from AP or sending the outstanding packet to

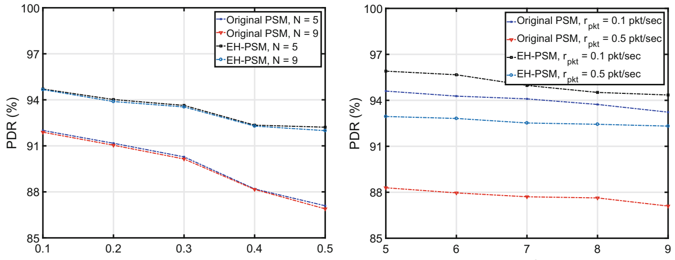
```
Notations:
• $B_{int}$, $T_{CFP}$, $T_{CP}$, $CW_i$, $t_i^{boff}$, and $\delta$: Beacon interval, contention-free period, contention period,
contention window of device $n_i$, backoff period of device $n_i$, and extension of contention window.
• $pkt[src, des, type]$: A packet with source id, $src$, destination id, $des$, and packet type, $type$. Here,
$type$ is $Data$, $PS\text{-}Poll$ or $ACK$.
• $TIM$, $S_h$, $S_n$: Defined before.
◇ At the beginning of $B_{int}$, device $n_i$ wakes up to listen to $TIM$:
  /* Contention free period $T_{CFP}$ begins */
  if $i \in TIM$
    if $n_i$ is in $S_n$
      /* $n_i$ is in normal mode */
      Wait for $pkt[AP, i, PS\text{-}Poll]$ from AP;
      Reply $pkt[i, AP, ACK]$ to AP with potential $pkt[i, AP, Data]$;
      Turn off wireless interface;
    else
      Wait for $pkt[AP, i, PS\text{-}Poll]$ from AP;
      Reply $pkt[i, AP, ACK]$ to AP with potential $pkt[i, AP, Data]$;
      Keep wireless interface on; Overhear on-going communication;
  else
    if $n_i$ is in $S_n$
      Turn off wireless interface;
    else
      Keep wireless interface on; Overhear on-going communication;
◇ When $T_{CFP}$ ends, and $T_{CP}$ begins:
  /* Contention period $T_{CP}$ begins */
  if $n_i$ is in $S_n$
    $t_i^{boff}$ = rand($CW_i$);
  else
    $t_i^{boff}$ = rand($CW_i + \delta$);
```

Fig. 4. The pseudocode of EH-PSM.

AP, the device in normal mode can switch to power saving mode and turn off its wireless interface to save energy. For example, as shown in Fig. 3, S_A is in energy harvesting mode while S_B is in normal mode. In order to reduce the energy consumption of S_B, the AP first polls S_B's packet and sends the buffered packet to it after broadcasting the TIM. After receiving the buffered packet from AP and replying the ACK with the outstanding packet to AP respectively, S_B switches to power saving mode and turns off its wireless interface to reduce energy consumption. However, S_A stays awake as far as it harvests energy in energy harvesting mode, and extends awake time period to overhear any on-going communication, e.g., PS-Poll packet. Since S_A extends awake time period, whenever it has a newly generated packet for AP, it can directly send the packet after overhearing the PS-Poll packet. Here, major operations of the EH-PSM are summarized in Fig. 4.

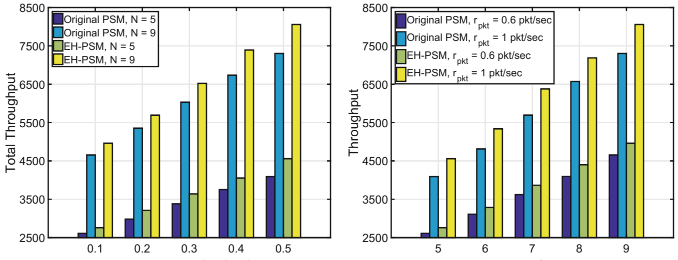
4 Performance Evaluation

We develop a customized discrete-event driven simulator using OMNeT++ [9] to conduct our experiments. A 600×400 m^2 network area is considered, where 5 to 9 devices which belong to one access point (AP) are distributed in the network. The communication range of each device is 500 (m). The radio model simulates CC2420 with a normal data rate of 2 Mbps. The access point generates



(a) (b)

Fig. 5. The performance of packet deliver ratio (PDR) against packet rate and number of nodes.

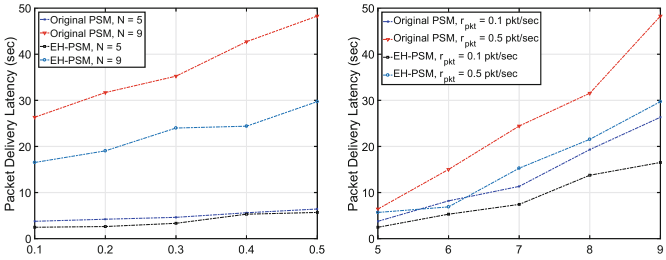


(a) (b)

Fig. 6. The performance of throughput against packet rate and number of nodes.

data traffic with packet injection rate 0.1 to 1.0 pkt/s and the packet size is 60 Bytes. The periods of energy harvesting and normal states are assumed to be exponentially distributed with mean λ_h (50 s) and λ_n (25 s), respectively. The total simulation time is 5000 s. In this paper, we measure the performance in terms of packet delivery ratio (PDR), throughput, packet delivery latency, and total awake time by changing key simulation parameters, including number of nodes (N) and packet rate (r_{pkt}). For performance comparison, we compare the proposed scheme EH-PSM with the original PSM of IEEE 802.11.

First, we measure the packet deliver ratio (PDR) by varying packet rate and number of nodes in Fig. 5. In Subfig. 5(a), as the packet rate increases from 0.1 to 0.5 pkt/s, the PDR of EH-PSM and original PSM decreases from 95% and 92% to 93% and 87%, respectively. Since each node generates more packets with larger packet rate, packets could have more chances to collide with each other, and the PDR decreases. The EH-PSM shows the higher PDR than that of original PSM because each node stays awake as far as it is in energy harvesting mode and overhears on-going communication, it can forward the packets to AP directly with a shorter contention window based on the overhearing network traffic. However, the PDR is not sensitive to the number of nodes in the network, and thus, a slightly lower PDR is observed with larger number of nodes. In



(a) (b)

Fig. 7. The performance of packet transmission latency against packet rate and number of nodes.

Subfig. 5(b), the overall PDR of EH-PSM and original PSM decreases as the number of nodes increases. This is because more number of nodes will content for the medium for sending packets to the AP during the contention period, packets have more chances to collide with each other, the number of packets received by the AP is reduced. As the packet rate increases, a lower PDR is observed. This is because more number of packets are generated and forwarded to the AP, more packets collide with each other at the AP, which results in a lower PDR.

Second, Fig. 6 shows the throughput of EH-PSM and original PSM with varying packet rate and number of nodes. As shown in Subfig. 6(a), the overall throughput increases as the packet rate increases. This is because each node can generate more number of packets and send them to the AP. However, the EH-PSM shows a higher throughput than that of original PSM with different number of nodes, this is because each node in energy harvesting mode can extend their awake time period to be ready for receiving and sending more packets. When the number of nodes increases, a higher throughput is observed by EH-PSM and original PSM, respectively. This is because more number of nodes could send more packets to the AP, the throughput is increased. However, the EH-PSM still performs better than original PSM. This is because more nodes could stay awake for a longer time period in energy harvesting mode and overhear on-going communication, and more packets can be delivered to the AP when the medium is free. In Subfig. 6(b), as the number of nodes increases, the throughput of EH-PSM and original PSM increases, respectively. Since more number of nodes are associated with the AP and could generate and send more packets, finally a higher throughput is achieved. However, our scheme still achieves a better performance than original PSM. This is because more number of nodes can switch to energy harvesting mode and then stay awake as far as they harvest energy, more packets can be generated and sent to the AP, which result in a higher throughput.

Third, we measure the packet delivery latency by varying packet rate and number of nodes in Fig. 7. Overall, the packet deliver latency increases as the packet rate increases in Subfig. 7(a). With a larger packet rate, the AP can

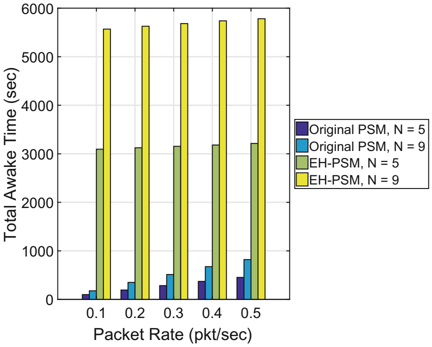


Fig. 8. The performance of total active time period against packet rate and number of nodes.

generate more packets for each node in the network. However, packet receiver could be in normal mode and switch to power saving mode (i.e., turn off wireless interface) after receiving all buffered packets from the AP. The newly generated packets at the AP have to be buffered until the next beacon period, thus, a higher packet delivery latency is observed. But, our scheme shows a lower packet delivery latency than original PSM, because each node could be in energy harvesting mode, extend awake time period, and then receive more newly generated packets from the AP quickly. As shown in Subfig. 7(b), the overall packet delivery latency of EH-PSM and original PSM increases as the number of nodes increases. This is because more number of nodes could be in normal node and switch to power saving mode after receiving all buffered packets from the AP, the newly generated packets have to be buffered at the AP and experience a longer packet delivery latency. However, the EH-PSM still provides the better performance than that of original PSM because the node in energy harvesting mode extends its awake time period and enables itself to be ready for receiving packets. Thus, the AP can directly send the newly generated packets quickly, which results in a lower packet delivery latency.

Fourth, we measure the total active time against packet rate and number of nodes in Fig. 8. Overall, the proposed EH-PSM achieves a much higher total active time than the original PSM. This is because the EH-PSM enables each node in energy harvesting mode to extend its awake time period, a larger total active time period can be observed compared to that of original PSM. As the number of nodes increases, the total active time is increased because more number of nodes could stay in energy harvesting mode and extend their active time period.

5 Conclusion

In this paper, we investigated the power saving mechanism incorporating with intermittent energy harvesting in the IEEE 802.11 Medium Access Control

(MAC) layer specification, and proposed a novel energy harvesting aware power saving mechanism, called *EH-PSM*. In the EH-PSM, a longer contention window is assigned to a device in energy harvesting mode than that of a device in normal mode to make the latter access the wireless medium earlier and quicker. In addition, the device in energy harvesting mode stays awake as far as it harvests energy and updates the access point of its energy harvesting mode to enable itself to be ready for receiving and sending packets, or overhearing any on-going communication. We evaluated the performance of the proposed scheme through extensive simulation experiments, compared it with the original PSM of IEEE 802.11. Extensive simulation results indicate that the proposed scheme achieves better performance in terms of packet delivery ratio, throughput, and packet delivery latency.

References

1. More than 30 billion devices will wirelessly connect to the internet of everything in 2020
2. Palattella, M., Dohler, M., Grieco, A., Rizzo, G., Torsner, J., Engel, T., Ladid, L.: Internet of things in the 5G era: enablers, architecture, and business models. IEEE J. Sel. Areas Commun. **34**(3), 510–527 (2016)
3. Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M.: Internet of things (IoT): a vision, architectural elements, and future directions. Future Gener. Comput. Syst. **29**, 1645–1660 (2013)
4. Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., Ayyash, M.: Internet of things: a survey on enabling technologies, protocols, and applications. IEEE Commun. Surv. Tutor. **17**(4), 2347–2376 (2015)
5. Raymond, D., Marchany, R., Brownfield, M., Midkiff, S.: Effects of denial of sleep attacks on wireless sensor network MAC protocols. In: Proceedings Workshop on Information Assurance, pp. 297–304 (2006)
6. Pu, C., Gade, T., Lim, S., Min, M., Wang, W.: Light-weight forwarding protocols in energy harvesting wireless sensor networks. In: Proceedings IEEE MILCOM, pp. 1053–1059 (2014)
7. Google Glass. http://www.google.com/glass/start/
8. Wearable computing is here already: how hi-tech got under our skin. http://www.independent.co.uk
9. Varga, A.: OMNeT++ (2014). http://www.omnetpp.org/
10. Jung, K., Qi, Y., Yu, C., Suh, Y.: Energy efficient Wifi tethering on a smartphone. In: Proceedings IEEE INFOCOM, pp. 1357–1365 (2014)
11. Ding, N., Pathak, A., Koutsonikolas, D., Shepard, C., Hu, Y.C., Zhong, L.: Realizing the full potential of PSM using proxying. In: Proceedings IEEE INFOCOM, pp. 2821–2825 (2012)
12. Gupta, A., Mohapatra, P.: Energy consumption and conservation in WiFi based phones: a measurement-based study. In: Proceedings IEEE SECON, pp. 122–131 (2007)
13. Manweiler, J., Choudhury, R.R.: Avoiding the rush hours: WiFi energy management via traffic isolation. In: Proceedings ACM MobiSys, pp. 253–266 (2011)
14. Liu, J., Zhong, L.: Micro power management of active 802.11 interfaces. In: Proceedings ACM MobiSys, pp. 146–159 (2008)

15. He, Y., Yuan, R., Ma, X., Li, J.: The IEEE 802.11 power saving mechanism: an experimental study. In: Proceedings IEEE WCNC, pp. 1362–1367 (2008)
16. Eu, Z., Tan, H., Seah, W.: Design and performance analysis of MAC schemes for wireless sensor networks powered by ambient energy harvesting. Ad Hoc Netw. **9**(3), 300–323 (2011)
17. Vithanage, M.D., Fafoutis, X., Andersen, C.B., Dragoni, N.: Medium access control for thermal energy harvesting in advanced metering infrastructures. In: Proceedings EuroCon, pp. 291–298 (2013)
18. Eu, Z., Tan, H., Seah, W.: IEEE Std 802.11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications. In: IEEE Computer Society LAN MAN Standards Committee, no. 3, August 1999
19. Starner, T.: Human-powered wearable computing. IBM Syst. J. **35**(3 & 4), 618–629 (1996)
20. Starner, T., Paradiso, J.A.: Human generated power for mobile electronics, pp. 1–35. CRC Press (2004)
21. Wang, Z.L.: Nanogenerators for self-powered devices and systems. Georgia Institute of Technology, Atlanta, USA (2011)
22. Xue, X., Wang, S., Guo, W., Zhang, Y., Wang, Z.L.: Hybridizing energy conversion and storage in a mechanical-to-electrochemical process for self-charging power cell. Nano Lett. **12**(9), 5048–5054 (2012)