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Delay-aware Power Saving Mechanism for 802.11 Wireless LANs via NDN

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***Abstract*—Idle listening (IL) is the major source of power consumption in Wi-Fi interface for mobile station. The reason is that station (STA) does not know when there would be data for it and it has to stay in IL to wait for the data. With the advantages of named data networking, this problem can be solved well, However, stations may have different requirements on delay, the existing power saving mechanism lacks consideration of delay. In order to improve the quality of service (QoS), we apply an innovative network architecture of NDN and mark the real-time requirements of stations in the Interest packets using a flag bit. And we use a priority sending queue to further reduce the latency of the delay-sensitive packets. The requirements of delay and energy efficiency can be satisfied with different settings of the flag bit. The simulation results show that the proposal can reduce the average delay up to 20% compared with the power saving mode in NDN and gain the commendable energy efficiency.**

Keywords—delay-aware, energy efficiency, NDN, idle listening, QoS

I. Introduction

With the fast development of mobile Internet applications and hardware technologies, intelligent mobile terminals are developing rapidly. And the way users access the internet has changed with the wide coverage of wireless networking. More users choose wireless internet to adapt to the mobile terminal. The demands for mobile terminals are getting higher which include multiple functions, response speed, network conditions, but also include energy consumption. However, the capacity of the battery is gradually difficult to meet the energy consumption of mobile stations. The problem of energy consumption needs to be solved urgently.

Energy limitation is a crucial issue in mobile terminals. And wireless network adapter has become one of the most important reasons for mobile terminals' high energy consumption. Wi-Fi energy consumption accounts for more than 10% of current laptops [1], the Wi-Fi interfaces vastly exceed the energy consumption even the device is idle [2]. There are some solutions to save energy consumption of wireless networking. Power saving mode (PSM) is the most widely used strategy to save energy in IEEE 802.11 protocol which contains four energy states: transmit (Tx), receive (Rx), idle listening (IL) and sleep [3]. In the basic PSM, access point (AP) buffers the returning data and station (STA) sleeps simultaneously. The default state in PSM is IL in which stations listen to the channel to decide whether to receive or transmit data. The highest energy consumption among these states is IL. The fundamental cause is that stations do not know when there would be packets for them, they must stay awake to wait for the packets. Stations will also be woken up frequently and stay in IL state by broadcast frames or the beacons with delivery traffic indication message (DTIM). Traditional PSM is unable to reach an ideal power saving goal according to these reasons. It is pivotal to reduce the idle listening time to save energy consumption. What's more, STAs are often set to stay in active mode to meet the real-time requirement and enhance user experience. This oversimplified dispose is unreasonable and wastes more energy consumption because of the different delay and energy efficiency requirements. It is necessary to adapt the delay and energy consumption according to the needs of the stations.

Named Data Networking (NDN) [4] is an innovative receiver-driven network structure whose basic nodes are consumer and producer. NDN aims to solve the problems in traditional TCP/IP infrastructure like lack of IP address, safety, dynamics and extensibility. It is a content-centric architecture to fit the requirement of information itself and solve the problem of traditional architecture. NDN consumer sends Interest packets and adds an entry to the pending Interest table (PIT) to record the information of request. The returned Data packet will be forwarded by the way Interest came from. In this case, consumer knows there would be data for it soon after in the networking if its PIT is not null. So that consumer can go to sleep or wake up according its PIT information instead of always listening to the channel. The multicast mechanism in NDN is not beneficial to energy efficiency and some applications may be sensitive to delay rather than energy efficiency sometimes. The information of Interests can be used to identify the requirement of consumers.

This paper makes the following contributions.

- We use the advantages of NDN and make a good trade-off between energy consumption and delay-aware.
- We apply the proposed mechanism to different traffic models and the results show that the proposal can achieve effective results in different situations.

II. Related Work

IEEE 802.11 WLANs has been widely deployed in public and private areas in recent years, however, WLAN employs carrier sense multiple access with collision avoidance (CSMA/CA), which is an energy-consuming protocol, WLAN interface consumes a significant portion of the energy

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resources[5]. In WLAN environment, the energy consumption and battery lifetime of wireless terminals is a thorny problem to solve. Some works have been done in this area by researchers. The high energy consumption not only during the active state, but idle state [6],[7], the PSM and its variants[8] cannot reduce the IL time that IL still dominates the stations' energy consumption more than 80 percent of energy consumption for clients in a busy network and 60 percent in a relatively idle network [9]. Reducing energy consumed by IL state is an important aspect of reducing energy consumption, the work in [11-13] is to deal with this problem.

As an innovative architecture, the energy efficiency of NDN is also a focal point of researches. In the area of video stream in NDN, the researchers proposed energy-efficient video streaming over NDN, using Interest aggregation to improve the throughput performance and using playout buffer-size control to reduce the overhead energy[13]. The paper [14] proposed a dual mode Interest forwarding scheme for NDN-based wireless sensor network which includes two combines forwarding modes to save and balance the energy consumption. Every Data packet has its own independent meaning in NDN so that router can re-use the Data and PIT to attain the most efficient Data transmission, base on this characteristic, Reference [15] makes improvements on NDN routing mechanism to achieve energy efficiency. There are also aspects including cache and content distribution that can be optimized to save the energy consumption based on the advantages of NDN[16],[17]. Most of the researches on power saving are implemented on terminal nodes, and in NDN architecture, the energy efficiency of consumer nodes needs to be considered. Consumers send Interest to request Data packets in the receiver-driven NDN architecture[4]. The network minimizes upstream bandwidth demand to maximize the performance [18]. Therefore, we aimed to optimization of energy consumption of consumers in downstream data for them.

There are some researches about improving QoS. Some researchers propose to classify different types of Data and imports the idea of Data lifetime to improve QoS[19], and there is research about forwarding strategy in NDN to improve QoS[20]. Considering energy efficiency with QoS support, some researchers proposed mechanisms based on information centric networking (ICN) or content centric networking (CCN)[21],[22]. As our best knowledge, there is scarcely any universal power saving mode considering real-time support in NDN nowadays.

III. Preliminary Work

A. Power Saving Mode for NDN

We proposed a power saving mode in NDN (NDNPSM)[23]. Based on NDN's receiver-driven mechanism, NDNPSM used consumers' PIT information to decide energy states. In traditional networking architecture, stations do not know when there would be data packets for them, they should stay in the IL state for most of the time to wait. In NDN architecture, consumer must have sent an Interest, which indicates it need the data, otherwise it do not need to care about the packets in networking. Based on the characteristic in NDN consumer can predict whether there are returning data in networking without listening to the channel when it has not requested any Interests. We can significantly reduce the IL time of stations and save energy consumption in wireless networking.

B. Prediction of Data Using PIT

With a receiver-driven architecture, NDN is different from traditional network structure. In NDN, consumer will add a pending Interest table (PIT) entry in the local Data structure after sending an Interest, recording the information of unsatisfied Interests. The entry would not be removed until the Interest can be satisfied or it is timeout. In other words, consumer can know the information about its requests. Based on this mechanism, NDN consumer can estimate whether the network has the required data by checking the states of PIT entry.

When there is an unsatisfied Interest and PIT entry is not empty, we define the PIT state is 1 (PIT=1). And define the PIT state is 0 (PIT=0) if consumer does not have any unsatisfied Interests. Intuitively, PIT = 0 means there is not any data to retrieval from the network, consumer can go to sleep state and do not need to pay any attention to the packets in networking. PIT = 1 signifies there is data in the networking which is consumer in need, consumer should stay awake to wait the returning data. Therefore, consumer can change its energy states via PIT information.

C. Traffic Notification with AID and TIM

There is a mechanism that AP can inform its buffer using less fields in IEEE 802.11 protocol. AP sends the Beacon frame periodically for notification and synchronization in infrastructure networking. The Beacon frame includes association identifier (AID) and traffic indication map (TIM) fields. The length of AID fields is 2 octets that can represent the ID of the STA. AP will distribute the AID when a node sends the association request and associates with it. And the AP will notify the buffer information along with the Beacon frame after the distribution of AID using TIM. The TIM element contains a traffic-indication virtual bitmap. Each bit in the traffic-indication bitmap corresponds to data buffered for a specific STA[3]. Each location in the bitmap represents a STA. The value of the location bit is 1 or 0 which represents whether the AP has the corresponding buffered packets for that STA or not. When the STA wakes up to listen to the Beacon frame, it can check the corresponding TIM fields to determine whether AP would send data to it. Therefore, we use the TIM information to indicate which node has the buffered packets.

IV. Mechanism Design

NDN architecture is receiver-driven pattern unlike the sender-driven in TCP/IP architecture. Stations can get the needed data through Interest packets. With the natural advantages and information of Interests, we propose a delay-aware power saving mechanism (DAPSM) which considers the different requirements of real-time to improve QoS and energy efficiency.

A. Real-time Requirement of NDN consumers

The delay is not a tricky problem in wireless NDN since that the NDN architecture uses multicast mechanism to deliver packets. And with the content store, data may be returned from the near node rather than the producer which further reduces the delay. In the same channel condition, NDN can get more effective low delay effect than TCP/IP network architecture. But the time of idle listening is exceedingly long in wireless NDN. The energy consumption of NDN's multicast mechanism is very high since consumers can be woken up by the multicast packets.

The proposed NDNPSM can effectively reduce the idle listening of wireless NDN, but it is lack of consideration of the real-time support and QoS improvement. If all of the consumers in NDNPSM are in light doze state [23], they have to wait at least one beacon to get the data. Applications in consumers consequentially have different requirements in actual network environment. They may not care about the energy consumption in a short period of time, but need the real-time transmission. The need of real-time is the most tricky side for that it is the opposite side of power saving in the majority of cases. The requirement of real-time is so important to improve users' experience. When designing an power management mechanism, it cannot be ignored. So that we propose a mechanism based on the NDN receiver-driven architecture to make a trade-off between real-time requirement and power saving, where consumers can decide which state to switch to according to their requirement.

B. Support of Real-time

The sensitivity to delay is different for consumers in actual wireless network environment. If we implement the same power saving scheduling strategy for all consumers, users' practical experience would be affected and the requirement of low latency would not be satisfied. So that we propose the DAPSM to support delay-aware and the power saving.

To make a good use of the information of Interest, we add a flag bit into the Interest to indicate the real-time requirement of the consumer. The value of flag bit is 0 and 1, indicating delay-insensitive and delay-sensitive Interest respectively. And we randomly mark the value of flag bit. AP can recognize the flag bit and decide whether to put the returning data into buffer or not. For example, AP can forward directly if the flag bit is 1 which indicates the consumer needs the returning data at once, and consumer can get the data without waiting another beacon. If the flag bit is 0, consumer may not need the data immediately and pay more attention to energy efficiency. It can sleep a while after sending the Interest until AP sends its buffered data.

In addition, we use a priority sending queue to further increase the priority of delay-sensitive data and improve the support for QoS. When the returned delay-sensitive data reach the forwarding layer, it can be forwarded with a higher priority. The proposal takes full advantage of the low latency of NDN.

C. Delay-aware Power Saving Mechanism in NDN

In NDN architecture, consumers send Interest to retrieval the Data, and deal with the downstream Data in the majority of cases. We propose the DAPSM based on these characteristic to effectively reduce the idle listening time and save the energy consumption of the consumer nodes. We defined five energy states including transmit state, receive state, idle state, light doze, and deep doze state. Fig. 1 illustrates the state of stations may be one of the five states. The detailed explanations of these states and their switch condition are as follows.

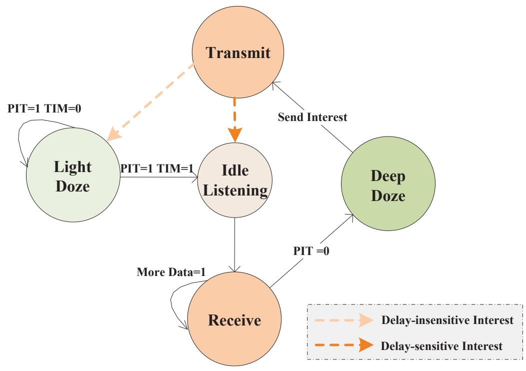

Fig. 1. Switch of consumers' states

- **Transmit state(TX).** The station is transmitting packets include Interest and other requisite packets. The energy consumption is the highest among these five states. The consumer will wake up itself when it needs to send Interest to require the Data packets.
- **Receive state(RX).** The station is receiving the returned Data packets. The energy consumption of this state is close to the transmit state. Stations will wake up to receive the data after a short time for idle listening state.
- **Idle Listening state(IL).** There are two cases in the proposed mechanism, case 1: after the station sent a delay-sensitive (Flag = 1) Interest indicating it needs the data returned immediately, PIT state would be 1, station will stay in Idle Listening state waiting for the returning data. In this case, the requirement of real-time is satisfied. Case 2: station has sent a delay-insensitive (Flag = 0) Interest, it will stay in light doze state and check the TIM bit of beacon frame until the TIM bit is 1 which indicates AP has its buffered data. The station will switch to idle state when it finds the corresponding TIM = 1 waiting for the Data packets. The energy consumption of this state per unit time is less than TX and RX.
- **Light doze state.** The station goes into light doze state after it sent a delay-insensitive Interest, indicating that it can wait awhile and do not need to receive the returning data immediately. In other words, it may have a high demand for energy efficiency. Station will wake up periodically to receive the beacon frame only to check the TIM bit, and would stay in this state until the TIM = 1 or the PIT entry is timeout. The energy consumption of this state is a little higher than that of the deep doze.
- **Deep doze state(sleep).** If there is not a PIT entry (PIT = 0), indicating that station has not required any Interest and no data would come back to it, the station goes into

deep doze state with no need to wait for the data or listen the channel. Stations can stay in deep doze state up to the set listening interval time or need to send an Interest to wake itself up, regardless the AP's behavior. Station can stay longer time in NDN than traditional architecture in which station would be woken up by broadcast or multicast frames. The station can save the most energy in deep doze state.

D. The Implementation of the Priority Sending Queue

We use a sub-queue mechanism to raise the priority of the delay-sensitive Data packets. The Data packets would be forwarded along the path of the corresponding Interest. With the flag bit information of the Interest in the PIT, AP can do different processing of the returned Data packets. The data packets in normal data queue are arranged in time. If there are too many packets from AP's cache in front of the queue, the delay-sensitive packets would be blocked behind and cannot be sent out in time. To further reduce the delay of these packets, we use two sub-queues to separate the two kinds of Data packets according to the value of flag bit. As shown in Fig. 2, the delay-sensitive Data packets are stored in sub-queue1 sending buffer, waiting to be sent. Delay-insensitive packets are in sub-queue2. The priority of sub-queue1 is higher than sub-queue2 means that the packets in the sub-queue1 can be sent earlier. To avoid the starvation effect of the queues, we add a timer on the sub-queue2, if the time Data packets in sub-queue2 have been waiting for is more than the set threshold, the priority of sub-queue2 would be improved.

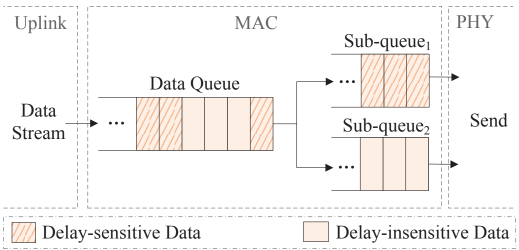

Fig. 2. The priority sending queue

E. An Example

We compared the behaviors of stations with the same demand but in different strategies. As shown in Fig. 3, STA1 is a normal NDN consumer without any power saving strategy, it does not go to sleep state and stay in the default idle listening state when not receive or transmit data. STA2 is a node with NDNPSM, it can stay in sleep state when PIT is null. When PIT=1, it switches to light doze state and check the TIM bit of beacon periodically. When the corresponding TIM bit is 1, it needs to go to IL state, wait for the returning data and receive it. STA3 is in our proposed mechanism, it can sleep when PIT = 0, and the requirement of real-time is satisfied with the flag bit. STA3 can get the data in the first beacon by setting the flag bit to 1 if it needs it immediately rather than get the data after the second beacon like STA2. In this way, STA3 can get the data timely, it can go to light doze state with the flag bit set to 0 if the requested data is not urgent and it needs to save energy.

As shown in Fig. 3, STA3 can go to deep doze state after it has completed the data transmission. STA3 can get longer dormant time than STA2, when the channel situation is very ideal. It only need to stay in IL state for a short time in this case. What's more, the station can decide to send which kind of Interest with NDN's natural receiver-driven advantage, and realize the delay-awareness according to the requirement of itself.

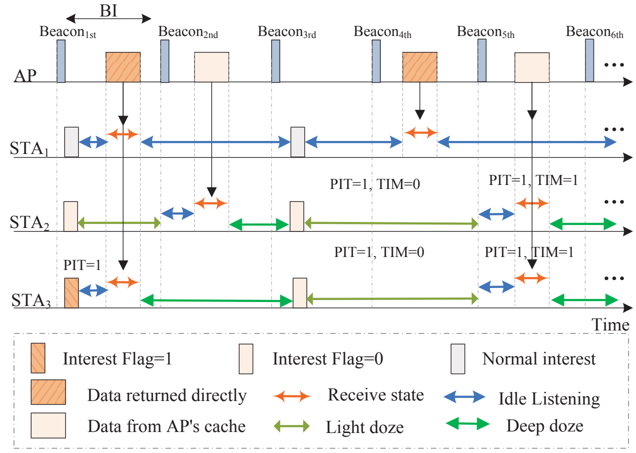

Fig. 3. Stations' operations in wireless NDN

V. Performance Evaluation

A. Topology and Traffic Model

In this paper, we consider the DAPSM of NDN in infrastructure networking since it is the most widely used networking topology, and the behaviors of the stations are representative in this environment. We consider an universal topology including an AP, a producer and multiple consumers (stations), producer and AP are connected through point-to-point link (P2P) . And we use the energy models of ns-3 to investigate and calculate the energy consumption. We compared the key parameters in DAPSM with different factors. Our performance evaluation is based on ndnSIM [24] which is a simulation of NDN and effectively support the different traffic models. We considered the behaviors of the proposal in these representative traffic models. The influence of the traffic models on the delay-aware power saving mechanism is investigated.

B. Comparison of Delay Awareness

In order to achieve the effect of low latency, we sacrifice a fraction of the light doze time to keep the station in idle listening state and wait for the delay sensitive data to return. Compared with the NDNPSM which can reduce the time of IL state according to the request information of PIT, the DAPSM may take a little more time in IL state. But the delay-aware power saving mechanism can effectively reduce the average delay compares to the NDNPSM. The flag bit of Interest packet is set at random in proportion. With the increase of the proportion of delay-sensitive Interest, the delay decreases and the energy consumption increases. Energy consumption is maintained at a lower level compared with the basic NDN. To represent the general situation, we randomly labeled 50% Interest packets in the simulation.

We compare the average delay in different traffic models. Fig. 4 shows the average delay of NDNPSM and DAPSM in ConsumerCbr which is a continuous traffic model. The delay of NDNPSM is the highest in this case apparently because of its light doze state. DAPSM can reduce the most of delay according to its awareness of delay sensitive processing. What's more, the average latency of delay-sensitive (flag=1) packets are much lower than NDNPSM. Compared with the NDNPSM, the proposed mechanism can reduce the average delay by 11%. And the delay can be reduced up to 20% for the Interests with flag bit is 1 whose delay efficiency is in need. That is to say, when the consumer considers more about delay efficiency rather than energy consumption, it is necessary to guarantee low latency and improve the QoS. Furthermore, the average delay of delay-sensitive packets is a bit lower than basic NDN, the reason is that we applied the priority sending queue to further reduce the delay of these packets.

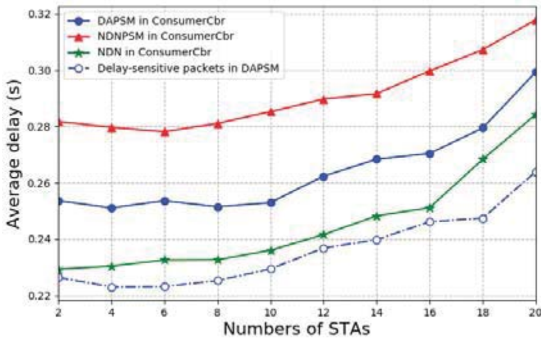

Fig. 4. Average delay of consumers in ConsumerCbr model

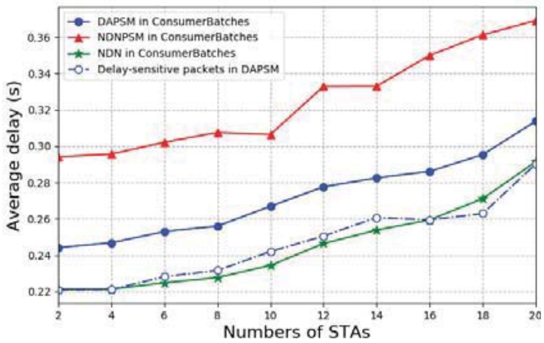

Fig. 5. Average delay of consumers in ConsumerBatches model

In addition to considering the continuous traffic model, we also considered the performance of the proposal in ConsumerBatches which is an on-off-style traffic model. The result is shown in Fig. 5, DAPSM can reduce the delay by 16% and reduce the delay of delay-sensitive packets by 27%. Considering that the traffic of the actual network is more likely to the on-off-style, that is the proposal may achieve better delay adaptability in the actual network environment.

C. Comparison of Energy Consumption

The energy consumption of the proposal is the sum of the five states. Generally, the Idle Listening time is longer in the DAPSM than it in NDNPSM that energy consumption is a little higher. In the simulation experiment, the stations have requested 500 packets and the delay of P2P connection is set to 50ms. The delay of P2P connection can effectively represent the channel condition. As shown in Fig. 6, the average energy consumption of DAPSM is a bit higher than NDNPSM in the two kinds of traffic models. The DAPSM can reduce energy consumption up to 74% compared to the basic NDN without any power saving mechanism. The proposed mechanism can still achieve the commendable energy efficiency.

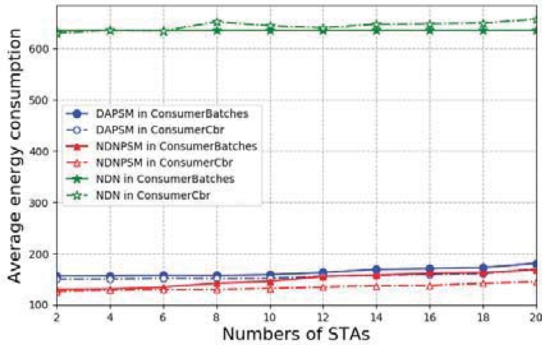

Fig. 6. Average energy consumption of consumers

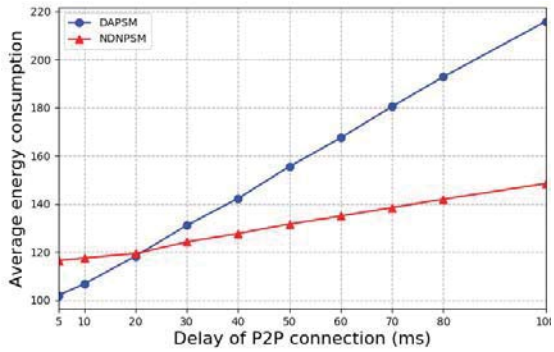

Fig. 7. Average energy consumption with different delay of P2P connection

We also considered the influence of the transmission delay. As stated in the example, stations can receive the returned data timely and the time of deep doze state can be increased if the latency is very low. The time spent in the transmission of Interest and Data packets can reflect the channel condition, we investigate the transmission delay by changing the parameter of P2P connection and use the delay of P2P connection to represent the transmission delay. Fig. 7 indicates that transmission delay has influence on the energy consumption. Intuitively, lower delay during transmission can get better energy efficiency as the consumer can enter the deep doze state in time. When the delay of transmission is very low and ideal, indicating that Data can return immediately, stations do not need listening to the channel for a long time and can go to deep doze more effectively. The energy consumption of DAPSM is a lower than NDNPSM, that is, the proposal can obtain better energy efficiency in low latency case. But in the majority of cases, the energy efficiency of NDNPSM is better than DAPSM.

In summary, the proposal can keep a low energy consumption level compares with the basic NDN. Since that the station may have different requirement in different situation, it is important to adapt to the actual needs of the station. An effective trade-off can meet the requirement of users better and further enhance the QoS.

VI. CONCLUSION

The energy consumption of Wi-Fi radio is a significant factor in reducing the battery lifetime and there are many researches in this field under the traditional networking architecture. The NDN can be used to reduce the idle listening time effectively. However, the delay efficiency is very important to the quality of service and the requirements of station may be diverse in different periods of time. We propose a delay-aware power saving mechanism to make a trade-off between energy consumption and delay. To provide a quantitative assessment of the DAPSM, we carried out a simulation experiment on the ndnSIM. The results show that the proposal can reduce the average delay up to 20% compares with the NDNPSM. We get almost the same or even better delay efficiency as the basic NDN in delay-sensitive packets. At the same time, we reduced the power consumption by about 70% compared to basic without any power saving mechanisms. The proposed mechanism can be parallelized and stacked with other NDN-based energy optimizations. As part of future work, the flag bit should be set by the applications according to their requirements of delay to make the delay-aware more effective and adaptable.

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