An Energy Consumption Evaluation of Non-TIM Strategy in IEEE 802.11ah

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Abstract. IEEE 80211ah is a low speed and long distance communication protocol which has two modes of operation: one is that stations in RAW need to listen Beacon for data transfer, and the other is that stations in Non-TIM TWT mode need not to synchronous with AP by listening Beacon. 802.11ah with Non-TIM TWT strategy is very suitable for many IoT applications with low speed and low energy consumption. However, there is no further discussion of energy consumption for stations under Non-TIM TWT mode in 802.11ah networks. Therefore, this paper proposes an 802.11ah Non-TIM Implicit TWT simulation which is built with the 802.11 Legacy simulator added to the transmit traffic distribution, Target Wake Time mechanism and Channel Model. This simulation analysis will evaluate energy consumption performance under different IoT applications (agricultural monitoring, smart metering, and industrial automation).

1. Introduction

Recently, IoT technology has been widely used in many applications which require remote monitoring, such as: agricultural monitoring, smart metering, and industrial automation. These applications remotely collect data through embedded sensors and exchange data by wireless communication transceivers. People get information about things through the wireless network, and then manage and monitor them.

Because the sensing nodes are widely deployed, that is, they are usually far away from the data collector of the wireless network. Sensing data transmitted by the node is usually very short, for example, the temperature data usually needs only one byte or less. The period during which a node transmits data is usually not very frequent, for example, sending temperature data once in 15 minutes. Therefore, how to choose the appropriate wireless network technology in the application to make the sensing node run for the longest time with the least power is an important issue in the current Internet of Things.

At present, long-distance wireless network technologies such as 802.11ah and LoRa both have the ability to make the sensing node consume the least amount of power and exchange data stably in a long-term operation. Both technologies can adapt to different IoT applications in different modes. When comparing LoRa and 802.11ah in low speed applications, 802.11ah under Non-TIM TWT mode saves listening to Beacon time and uses more efficient CSMA/CA compared to LoRa in Class B mode [1, 2, 3, 4].
There are two modes of operation in 802.11ah: Non-TIM TWT and TIM RAW. Since TIM RAW requires more power for each node to listen Beacon for synchronization of data transfer, it is not suitable for applications which need to save power when transferring a tiny data. In the 802.11ah Non-TIM TWT mode, AP and stations come up with an agreement on the TWT Service Period in the association procedure. According to the TWT SP, stations know when to transmit data, and then enter the sleep mode after the data transmission is completed, thus avoiding a large number of stations competing for channels at the same time and saving more power.

Stations send an Association Request with TWT IE and Power Capability IE to AP in the association procedure. AP determines whether to connect with a station according to the Power Capability IE. AP then informs stations with the Association Response to operate TWT using Implicit or Explicit. There are two types in IEEE 802.11ah TWT, namely Implicit TWT and Explicit TWT. Implicit TWT is a periodic use of TWT SP. Explicit TWT is a non-periodic use of TWT SP. The control message such as ACK packet, TWT Information packet or normal packet with TWT information is transmitted through AP to inform stations of the next TWT time. This paper will explore how 802.11ah Non-TIM mode uses the Implicit TWT strategy with grouping functions.

The second section introduces energy analysis of the station in 802.11ah. The third section describes the establishment of 802.11ah TWT simulation environment. The fourth section provides the simulation analysis of energy consumption of the system under different IoT applications. Finally, the fifth section gives some conclusions.

2. Energy consumption analysis of 802.11ah stations

Since the station’s energy consumption for transmission is an important factor in IoT applications. In this section, the theoretical equations for energy consumption of 802.11ah station are explained. It contains how the traffic is generated, the calculation of the transmission power for channel and the energy consumption of the stations in the transmitting, receiving, idle and sleeping states.

2.1. Periodic uniform traffic model

A large number of stations are often deployed in IoT applications. Each station usually transmits data once in a long period of time. In order to avoid stations unable to transmit data due to competitive collisions in timeslot, the probability of collision is greatly reduced by using the allocated transmission traffic. Therefore, the average power consumption of the station is reduced to achieve power saving. An IoT station uses uniform traffic model as the traffic flow, which increases the average time to generate packets [5, 6]. The station does not need to enter the idle state to continue to stay in sleeping state when no transmission traffic is generated. Therefore, the station can sleep longer and save more power than the traditional 802.11.

![Periodic uniform traffic model](image)

Figure 1. Periodic uniform traffic model.

The periodic uniform traffic model used in this paper is shown in Figure 1. Traffic is periodically generated and packets are distributed using uniform traffic model in each cycle.

2.2. Transmission Power for Channel

Rayleigh Block Fading Channel is a channel model used in IEEE 802.11ah [7]. According to different SNRs, the packet error rate is as shown in the equation (1):

\[
\text{PER} = 1 - e^{-\frac{r}{r_{th}}}
\]

where \( r \) is the average SNR value at the receiver and \( r_{th} \) is the SNR threshold.
In general, the greater the given transmit power, the smaller the packet error rate will be. However, how to meet the system's PER with the minimum of transmit power is a tradeoff for IoT applications. In order to let the station transmit longer distances in 802.11ah, this paper uses BPSK modulation and 0.65Mbps Data Rate to establish channel model. Table 1 uses the PER of 0.1 as the parameter condition of the channel model to calculate how much of the transmit power is needed at different distances.

### Table 1. Simulation parameters of transmit power.

| Transmit Distance(m) | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Transmit Power(mw)   | 0.12| 0.4 | 3.2 | 5   | 10  | 20  | 40  | 63  | 100 | 158  |

2.3. Energy consumption in the receiving state

In this paper, the station only receives the ACK packet. The energy consumption of the station in the receiving state is as shown in the equation (2):

\[
Rx_{ACK} = Rx_{power} \times \left( \frac{ACK_{length}}{r} \right)
\]

Where \( Rx_{ACK} \) is the energy consumed to receive an ACK packet, \( Rx_{power} \) is the energy consumed by the receiver per second, \( ACK_{length} \) is the length of the ACK packet, and \( r \) is the system data rate.

2.4. Energy consumption in the transmitting state

Based on different distance from AP, the transmitter of the station uses different transmit power. The energy consumption of the station in the transmitting state is as shown in equation (3):

\[
Tx_{packet} = Tx_{power, distance} \times \left( \frac{Packet_{length}}{r} \right)
\]

Where \( Tx_{packet} \) is the energy consumed to transmit a packet, \( Tx_{power, distance} \) is the energy consumed by the transmitter according to different distance from AP per second, and \( Packet_{length} \) is the length of the packet, and \( r \) is the system data rate.

2.5. Energy consumption in the sleeping and idle state

The energy consumption of the station in the sleeping and idle state is as shown in equation (4):

\[
P = T_{sleep} \times P_{sleep} + T_{idle} \times P_{idle}
\]

Where \( P \) is the total energy consumption, \( T_{sleep} \) and \( T_{idle} \) is the time of station's sleeping state and idle state, and \( P_{sleep} \) and \( P_{idle} \) is the energy consumed of the station in sleeping and idle state.

3. Simulation design of 802.11ah TWT

3.1. System description

The simulation architecture of 802.11ah TWT is shown in Figure 2. The simulation system was built based on the 802.11 legacy simulator with additional modules, include such as Channel Model, Traffic Model and TWT strategy [8, 9, 10].

![Figure 2. Architecture of 802.11ah TWT simulation.](image)
First, the 802.11 legacy simulator adds the Retry Limits module to allow the system to perform Packet Error Rate operations. Traffic Model module allows the system to generate a periodic uniform traffic. Target Wake Time strategy implements the allocation of TWT SP and TWT grouping functions in 802.11ah. Channel Model module performs simulation of the transmit power based on the transmission distance of stations in 802.11ah networks. The parameters of the 802.11ah simulation are shown in Table 2 [11].

3.2. Application scenarios
TWT SP periods will affect the amount of power consumption. A long TWT SP period may enable more stations to have opportunities for transmission, but also make more stations remain in idle state. Such stations are very wasteful of power. Conversely, if the TWT SP period is too short, the station will have no time to transmit data at all. Therefore, this paper uses Packet Drop Rate as an index to find a corresponding TWT SP periods to make the system work well and save power. Finally, the simulator implements the TWT SP grouping function and adjusts the TWT SP periods to observe changes in Power Consumption, Packet Drop Rate, and Packet Delay Time.

The following three common applications are used to evaluate the energy consumption performance of 802.11ah Non-TIM TWT simulation.

(1) Agricultural monitoring: This application has to know whether it needs irrigation for a period of time in order to control the humidity of the environment. This application deploys 3,500 stations in a radius of 1000 meters. Each station generates a packet with 100 bytes every 120 seconds.

(2) Smart metering: This application can monitor the power consumption, gas volume and water consumption of all users in large communities. This application uses 1500 sensor stations in a radius of 500 meters, sending a packet with 100 bytes every 50 seconds.

(3) Industrial automation: For example, it is used in the refrigerating room to get the temperature to ensure that things such as fruits and vegetables in the refrigerating compartment can be kept fresh. This application uses 500 stations in a radius of 250 meters, producing a packet of 100 bytes in every 180 seconds.

Table 2. Simulation parameters of system.

| Parameter       | Value     |
|-----------------|-----------|
| Data Rate       | 0.65Mbps  |
| Packet Length   | 100Bytes  |
| Retry Limits    | 6         |
| DIFS            | 264us     |
| SIFS            | 160us     |
| Slot            | 52us      |
| ACK             | 24 Bytes  |
| MAC Header      | 12 Bytes  |
| PHY Header      | 6 Bytes   |
| Packet Error Rate | 0.1      |
| Idle Power      | 1.5mw     |
| Sleep Power     | 10uw      |
| Receive Power   | 135mw     |

3.3. Simulation Results
This section will discuss the simulation results of three different applications with the TWT Grouping function. Based on the different transmission distances and TWT lengths, the power consumption, Packet Drop Rate and Packet Delay Time of the three applications are evaluated.
Agricultural monitoring is one of the Internet of Things applications, and the number of stations that can be provided is also the largest of the three applications in this simulation. Figure 3 shows the changes in power consumption when the TWT SP length and the location of the station are adjusted in the case of TWT Grouping function using the Periodic Uniform Traffic Model under agricultural monitoring scenario. Figure 4 displays the changes in Packet Drop Rate and Packet Delay Time when the TWT SP length is adjusted. The simulation of agricultural monitoring shows that the shorter the TWT time, the more power consumption decreases. The Packet Delay Time decreases, and Packet Drop Rate increases. However, the changes are quite small.

Smart metering simulation provides a scenario for more dense stations. Figure 5 and Figure 6 show the simulation results of smart metering.

Industrial automation scenario deploys 500 stations in a radius of 250 meters. Since the data period transmitted by each station is 180 seconds, the length of the TWT SP also becomes longer. Figure 7 and Figure 8 display the simulation results of industrial automation.

3.4. Agricultural monitoring

![Figure 3. Power consumption in agricultural monitoring.](image)

3.5. Smart metering

![Figure 5. Power consumption in smart metering.](image)

![Figure 6. PDR vs. PDT in smart metering.](image)

![Figure 4. PDR vs. PDT in agricultural monitoring.](image)
3.6. Industrial automation

![Power Consumption in Industrial automation](image1)

**Figure 7.** Power consumption in industrial automation.

![PDR vs. PDT in industrial automation](image2)

**Figure 8.** PDR vs. PDT in industrial automation.

4. Discussion of results

1. Since different applications use different TWT SP periods, it can be observed that smart metering consumes more power than other applications. The TWT SP period directly affects the system power consumption.

2. In short distances, the power consumption of the station will vary according to distance, but the difference is not obvious. In long distances, the power consumption of station is greatly increased under the application of agricultural monitoring. Therefore, in the case of using TWT grouping, the power consumption of the station in the idle state is the main cause of power consumption in short distances.

3. The smaller the TWT SP is, the more power is saved. Packet Delay Time will continue to drop, and the Packet Drop Rate will slowly increase but not much affect the system. When the TWT SP reaches the minimum value, each TWT SP will only have one station to transmit, so there is no collision problem and Packet Drop Rate will suddenly drop to zero.

4. When the system adopts TWT grouping and each station uses a TWT SP, this usage is similar to RAW, but TWT grouping differs from RAW in that it does not need to listen to Beacon. TWT grouping has better power saving effect than RAW.

5. Conclusions

This paper simulates three applications in 802.11ah with Non-TIM Implicit TWT, and analyzes the relationship between the energy consumed by the three applications, Packet Drop Rate and Packet Delay Time. It also discusses the impact of using different TWT periods on energy consumption in three applications, and provides a reference for deploying 802.11ah IoT systems.

6. References

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