

# Research on Energy Efficiency of Wi-Fi IoT Systems on Renesas DA16200 Platform

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**Abstract:** This research focuses on a comprehensive analysis of the energy efficiency of the Renesas DA16200 microcontroller. The investigation adopts a comparative approach, directly contrasting the power consumption of the DA16200 with the widely used ESP8266 controller under identical operating conditions. The primary metric employed to assess energy efficiency is average battery life. Additionally, a detailed examination of current consumption is conducted across various operational modes, encompassing active states like data exchange, reception, and transmission, as well as low-power sleep mode. This analysis extends beyond simply measuring peak current draw. Transient current profiles are captured, providing time-resolved insights into how current consumption fluctuates throughout different operational phases. This granular data enables a deeper understanding of the microcontrollers' energy utilization patterns. Furthermore, the research explores and evaluates techniques for minimizing energy consumption specifically in the ESP8266. These findings are then juxtaposed against the inherent energy-saving features of the DA16200 microcontroller. To facilitate a precise and verifiable comparison, a custom test bench accommodating both the DA16200 and ESP8266 is designed and implemented. This controlled environment ensures consistency in operating conditions and minimizes external variables that could influence the results. The culmination of this research is the presentation of a comprehensive analysis, detailing the comparative energy consumption profiles of the studied microcontrollers. This data forms the foundation for objectively evaluating their suitability for various low-power the Internet of Things applications.

## 1 INTRODUCTION

The Internet of Things (IoT) is a network of physical objects, embedded with sensors and connected to the internet. These objects can collect and exchange data, enabling them to interact with each other and with people. The IoT enables these objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy, and economic benefits [1]. Controllers play a vital role in IoT systems, as they are used for data collection, processing, and device control.

Power consumption is a critical issue for IoT systems. IoT devices typically have limited power sources, and their power consumption must be as low as possible to ensure their autonomy.

There are some ways to reduce the power consumption of IoT systems. One way is to use more energy-efficient components, such as low-power

controllers. Another way is to optimize the software of IoT systems to improve energy efficiency.

Reducing the power consumption of IoT systems has several benefits. It can improve the autonomy of IoT devices, reduce operating costs, and extend their lifespan. Additionally, reducing the power consumption of IoT systems can help protect the environment.

In the ubiquitous era of the IoT, millions of interconnected devices are revolutionizing everything from healthcare to environmental monitoring. However, a hidden challenge lies beneath the surface of this transformative technology - power consumption. As these devices often operate on limited battery life or remote power sources, their energy efficiency is paramount. Consider a wearable health tracker constantly monitoring vital signs – even small reductions in power consumption can translate to significantly longer battery life, empowering more seamless and uninterrupted monitoring.

This article delves into the critical issue of energy efficiency in IoT devices, focusing specifically on low-power microcontroller solutions. We compare three popular controllers - the Renesas SoC DA16200, the Espressif ESP32, and the widely used ESP8266. Our primary objective is to evaluate their performance and power consumption under various operating conditions, ultimately seeking to identify optimal solutions for specific IoT applications. Through this analysis, we explore key factors like active and sleep mode power draw, processing capabilities, and software optimization techniques, aiming to provide valuable insights for developers and researchers in the field of energy-efficient IoT design.

## 2 PROBLEM STATEMENT

The Wi-Fi protocol is a high-speed standard designed for efficient transmission of large volumes of media information and internet data through radio frequency exchanges at 2.4 GHz and 5 GHz frequencies. Due to the high data transmission speeds and the volumes of transmitted information, the radio block of a Wi-Fi controller cannot ensure low power consumption at the wattage level [2]. In transmission mode, the average current of a Wi-Fi controller varies from 120 mA to 270 mA [3], depending on the radiation level (+13...+20 dB), making the use of AA/AAA/tiny batteries impractical for several years, which is crucial for IoT devices.

The high power consumption of Wi-Fi controllers is also evident in the receiving mode, where the average power consumption of the receiver fluctuates between 50 mA and 90 mA, which does not meet the power requirements for IoT batteries and does not allow powering IoT devices with batteries for a year or longer. As a result, the Wi-Fi protocol is applied in cases of IoT with stationary power. In contrast, low-power consumption protocols such as Bluetooth Low Energy (BLE), LoRa, 6LoWPAN, and others are used for battery-powered IoT applications, resulting in lower transmission speeds.

However, connecting IoT devices using other protocols like BLE, LoRa, and 6LoWPAN requires specialized gateways/routers, presenting certain challenges due to the diversity of devices, standards, and configuration complexities. Nevertheless, almost every household has a standard Wi-Fi router, providing easy internet access without the need for additional purchases.

In consideration of the aforementioned, concerted efforts are being directed towards a substantial

reduction in the power consumption of Wi-Fi IoT controllers by orders of magnitude, to satisfy battery power requisites spanning multiple years. Initially successful in environments characterized by low IoT operational demands, these initiatives encompassed sporadic information transmissions over Wi-Fi, ranging from daily to monthly intervals. However, the evolution of IoT into the realm of actuators has necessitated a more frequent exchange of data, precipitating a thousandfold reduction in controller response time, bringing it down to 1 second or less.

As an illustrative example, a door lock control system is expected to achieve a response time of no more than a few seconds. This necessitates IoT transmission not on a scale of 1-2 times per day, but rather at intervals of 1 time every 1-3 seconds. Power consumption can only be curtailed by reducing the operational time of the Wi-Fi radio transmitter/receiver to a few milliseconds, coupled with the subsequent transition of the IoT into a deep sleep state during the interludes between transmissions.

Furthermore, in light of the stringent cost constraints associated with IoT microcontrollers, this article restricts its consideration to Espressif SoC microcontrollers, such as ESP8266 and ESP32, for comparative analysis, as other Wi-Fi microcontrollers no longer fall within the confines of this pricing category.

- 1) *Transmitter activation optimization.* The transmitter is activated infrequently to acknowledge requests from the router. An optimally chosen extended pause before responding helps avoid losing communication with the controller, considering variable times dependent on router settings (e.g., Wireless Inactivity Timeout, Connection Timeout, Client Timeout).
- 2) *Periodic receiver activation window.* The receiver is activated not for every router polling message (DTIM) but periodically, for example, every second message or less frequently.
- 3) *Infrequent activation of IoT receiver.* Receiver activation occurs less frequently to align with Wi-Fi exchange standards. For instance, the maximum interval between router polling messages (DTIM) is set to 1000 milliseconds.
- 4) *Minimization of transmitted data size.* The length of transmitted data from the controller is reduced to the minimum value, thereby reducing transmitter operation time.
- 5) *Minimization of router polling message (DTIM) transaction time.* The minimum transaction time

is reduced due to high computational power, ensuring minimal power consumption.

- 6) *Low-level microcontroller programming.* Providing access to the lowest level of microcontroller programming for maximum acceleration of the above requirements.
- 7) *Setting minimum transmission level and optimizing controller placement.* Configuring the transmitter to the minimum transmission level and placing the controller as close as possible to the unobstructed router for radio wave communication.
- 8) *Optimizing receiver/transmitter on/off times.* Technologically reducing the time it takes to turn on/off the receiver and transmitter to minimal values.
- 9) *Minimizing receiver current consumption.* Technologically ensuring minimal receiver current consumption to reduce overall energy consumption.
- 10) *Use of supercapacitors for powering.* Applying supercapacitors for powering the controller with slow charging (from 5 mA to 50 mA) from weak batteries for pulse-powering the transmitter at a level of 300 mA.

Wi-Fi controllers for IoT devices exhibit high power consumption, limiting their applicability in battery-powered devices [4]. In transmit mode, the average current of Wi-Fi controllers ranges from 120 mA to 270 mA [5], rendering the use of batteries impractical for extended periods. For standard IoT controllers like ESP8266 [6] and ESP32 [7], the hardware implementation of real-time methods is absent. Attempts to optimize performance through low-level register code are constrained due to limited access to the internal architecture of these controllers, provided in a closed form [8]. This imposes restrictions on significant improvements in response time and operation of these devices in IoT mode.

In this context, the DA16200 controller stands out as it is proclaimed to be a device originally designed to support sub-second response time in the IoT domain. It is capable of maintaining a constant connection with the router and achieving a power consumption level that enables it to be powered by batteries for a minimum of one year and even longer.

The objective of this article is to compare the energy efficiency of three Wi-Fi controllers (ESP8266, ESP32, and DA16200) for IoT devices.

### 3 POWER CONSUMPTION CHARACTERIZATION OF DA16200 CONTROLLER

#### 3.1 Analysis of the DA16200 Controller's Pulse Current Consumption

For the current consumption investigation, an experiment was conducted to measure the current when breaking the P2 contacts. To achieve this, a shunt with a resistance of 0.5 ohms was connected to the P2 contacts, and a 1:1 probe of the Hantek DSO5102P oscilloscope with a bandwidth of 100 MHz was connected to the shunt contacts, as shown in Figures 1 and 2. The measured voltage drop across the shunt at a current of 250 mA was 0.125 V, which had no significant impact on the controller's operation. To reduce interference during measurement, the DA16200 Module Evaluation Kit (EVK) was powered from a power bank via USB.

#### 3.2 Calculation of Average Current Consumption

Another crucial indicator of energy efficiency is the calculation of the controller's average current consumption. Average current consumption ( $I_{avg}$ ) is the amount of energy consumed by a system in a unit of time. It is calculated as the ratio of the total amount of energy consumed by the system over a given time period to that time period [9].

There are several methods for calculating the average current consumption, such as the geometric and current integration methods. In this study, the geometric method was chosen and calculated using (1). This method is based on the average current ( $I_{avg}$ ) being equal to the area under the consumption pulse (A) divided by the pulse period (T):

$$I_{avg} = \frac{A}{T}. \quad (1)$$

To calculate the area under the consumption pulse, data from the oscilloscope measurement results, as shown in Figures 1 and 2, were used. The area of the consumption pulses is equal to the sum of the areas of all pulse shapes, as indicated in (2):

$$A = A_r + A_{r.t.} + A_{i.t.} \quad (2)$$

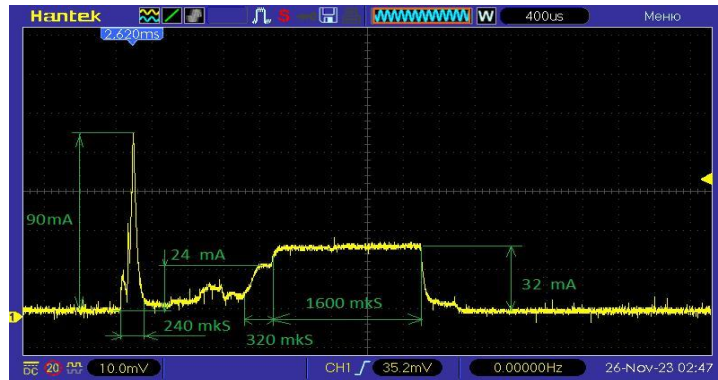


Figure 1: Pulse current consumption of the DA16200 in reception mode.

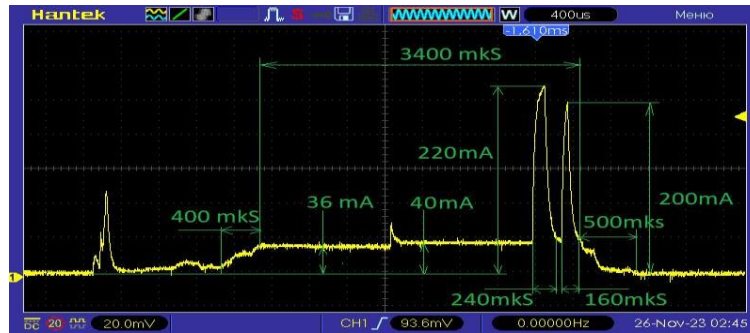


Figure 2: Pulse current consumption of the DA16200 in transmission mode.

The area of rectangular consumption pulses ( $A_r$ ) was calculated using the method of multiplying the sides, that is, multiplying time ( $t$ ) by the current amplitude ( $I_m$ ):

$$A_r = t * I_m.$$

The area of rectangular triangles ( $A_{r,t}$ ), representing the fall and rise of the pulse, is calculated as half the product of the area  $A_{r,t} = \frac{t * I_m}{2}$ , and the area of isosceles triangles ( $A_{i,t}$ ), is calculated as one-third of the product  $A_{i,t} = \frac{t * I_m}{3}$ . The measurement time ( $t$ ) was chosen to be 30 seconds.

As a result of oscilloscope measurements, we obtained the following picture: 30 reception pulses (pulse shapes) and 1 transmission pulse during the measurement time. During this period, when there is neither transmission nor reception, the controller is in Sleep 1 mode, consuming a current of 0.2  $\mu$ A.

The area of one session of consumption pulses during reception is equal to:

$$A_t = 1600 * 32 + \frac{320 * 24}{2} + \frac{240 * 90}{3} = 62.240 (mA \cdot \mu s).$$

The area for 30 sessions is equal to:

$$A_t = 62.240 * 30 = 1\,867\,200 (mA \cdot \mu s).$$

The average receive current is:

$$I_{avg,t} = \frac{1\,867\,200}{30\,000\,000} = 62 (\mu A).$$

The area of consumption pulses during transmission is equal to:

$$A_r = (1400 * 36) + (110 * 40) + \frac{400 * 36}{2} + \frac{240 * 220}{2} + \frac{160 * 200}{2} + \frac{500 * 40}{3} = 150\,667 (mA \cdot \mu s).$$

The average current during transmission is:

$$I_{avg,r} = \frac{150\,667}{30\,000\,000} = 5 (\mu A).$$

To obtain the overall average current, it is necessary to add the Sleep 1 current to the average reception current and the average transmission current.

$$I_{avg} = 62 + 5 + 0.2 = 67 (\mu A).$$

It turned out unexpectedly that the receiver contributes the main share (92%) to the current consumption - 62  $\mu$ A out of 67  $\mu$ A, indicating the potential for further current reduction while maintaining IoT Wi-Fi responsiveness once per second.

The investigation of the DA16200 controller's current consumption revealed that the receiver contributes the majority, consuming 62  $\mu\text{A}$  out of the total 67  $\mu\text{A}$ . This accounts for 92%. Therefore, there is significant potential to reduce power consumption by optimizing the receiver's operation.

### 3.3 Battery Operating Time of DA16200

The measurement of the average current consumption of the DA16200 controller showed that it is 67  $\mu\text{A}$ . This figure is exceptionally low for devices of this class. However, to ensure prolonged operation of an IoT device, it is essential to consider that the operating time also depends on the supply voltage and battery capacity. The supply voltage of the DA16200 controller ranges from 2.1 to 3.6 V [10]. This voltage range allows the use of various types of batteries to power the controller, including two AA or AAA batteries, one Li-ion battery, or a single lithium battery.

Table 1: The capacities of different batteries.

Battery Type	CR2032	AAA	AA	18650
Capacity, mAh	240	1000	2000	2500
Pulse discharge current	15 mA	0.7 A	1.5 A	5 A
Operating time, days at 67 $\mu\text{A}$	149	622	1243	1554

In Table 1, average values of battery capacity and their pulse currents sufficient to operate the DA16200 transmitter with a peak consumption current of ~ 250 mA. The operating time is specified for maintaining a connection to the router with a response time of 1 second. When transmitting data, the operational time decreases proportionally to the increase in the current consumption during transmission.

However, even when addressing the issue of impulse current consumption at a level of 250 mA from a CR2032 battery using a supercapacitor, it is not possible to power the DA16200 for one year. To ensure the operation of the DA16200 transmitter for one year, it is necessary to use batteries with a capacity of at least 600-800 mAh, equivalent to two AAA batteries or more. However, with such initial capacities, the transmitter's runtime for a year will be limited. Increasing the battery capacity will extend the transmission time.

The conducted measurements indicate that DA16200 manufacturers have managed to introduce a high-speed and power-efficient Wi-Fi protocol into the battery-powered IoT domain.

Analysis of the oscillograms depicting the current consumption of the DA16200 has facilitated the elucidation of the underlying success of the new technology. The current consumption in the receiving mode is contingent upon:

- The current consumption of the radio circuits within the Wi-Fi receiver;
- The current consumption of the Wi-Fi protocol processing controller during data reception.;
- The duration of Wi-Fi protocol processing when receiving data.

The current consumption associated with the radio circuits of the Wi-Fi receiver is a nominal few milliamps, contributing insignificantly to the overall consumption of the DA16200. However, the pivotal elements of the technical solution by Renesas reside in the current consumption of the processing controller and the duration of its Wi-Fi protocol processing. Renesas engineers achieved a reduction in the duration of current consumption during reception to 2 milliseconds by employing a proficient and energy-efficient ARM Cortex M4F controller, complemented by the authorship of optimized code for Wi-Fi protocol processing. This reduction is of paramount importance, as the duration of current consumption during reception, particularly for IoT applications requiring response times on the order of several seconds, constitutes the primary (90%) contributor to the total power consumption. After this, the aforementioned metric will be juxtaposed with analogous parameters in competing solutions.

## 4 COMPARATIVE ANALYSIS OF POWER CONSUMPTION OF DA16200 AND ESP8266/ESP32 CONTROLLERS

In this section, a comparative analysis of the energy consumption of the DA16200 and ESP8266/ESP32 controllers will be conducted. The analysis will utilize data obtained during experimental research, as presented in Tables 2 and 3.

As seen from the provided data, the impulse current consumption during transmission for the DA16200 controller is almost identical to the impulse current of ESP8266/ESP32 controllers. The impulse current consumption during reception is

1.6-2.5 times less than that of ESP8266/ESP32 controllers. This is because the activity time during data exchange with the router for the DA16200 controller is less than 2 ms, while the activity time for ESP8266/ESP32 with the most efficient ESP-NOW algorithm is 130 ms.

Table 2: Comparison of current consumption for DA16200, ESP8266 and ESP32 controllers.

Controller	Pulse current consumption during transmission, mA	Pulse current consumption during reception, mA
DA16200	220	32
ESP8266	200	55
ESP32	240	80

Table 3: Comparison of average current consumption and operating time for DA16200, ESP8266 and ESP32 controllers.

Controller	Average current consumption	Operating time from batteries (2000 mah), days
DA16200	67 $\mu$ A	1243
ESP8266	4.7 mA	11
ESP32	10.7 mA	7.7

Based on this data, it can be concluded that the DA16200 is the most energy-efficient controller among the mentioned ones. It exhibits lower average current consumption and longer battery runtime. However, it is essential to note that these data are based on nominal values of controller current consumption. Conducting independent measurements is necessary for obtaining more accurate values.

## 5 CONCLUSIONS

The DA16200 controller, designed for operation within a home environment and connectivity to the internet through standard Wi-Fi routers, represents a significant advancement in the development of the IoT. It addresses a key limitation of existing IoT technologies, such as Bluetooth Low Energy, which require the use of dedicated gateways for internet connectivity. This simplifies and reduces the cost of implementing IoT technologies in household devices, opening up new possibilities for their application.

Based on the research findings, it can be concluded that the DA16200 controller is the most energy-efficient Wi-Fi controller for IoT devices. It is capable of maintaining a constant connection to the

router and providing a level of energy consumption that allows it to be powered by batteries for a minimum of one year and even longer.

In the IoTMark®-Wi-Fi test, the DA16200 received a score of 815, equivalent to 815 days of autonomous operation for an IoT sensor powered by two AA batteries. It is anticipated that the smart door lock will last for over three years without recharging, which is 50% longer than what the closest competitor can offer. For the first time in Wi-Fi history, it can provide autonomous operation time comparable to Zigbee and Z-wave.

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