The Operational States and Energy Utilization of the Arduino Nano and Arduino Micro in 5G Networks

Maher Rafi Tawffaq
Alnoor University
Nineveh, Iraq
maher.rafi3@alnoor.edu.iq

Sarah Harith Hazim
Al Mansour University College
Baghdad, Iraq
sarah.harith@muc.edu.iq

Farah Mazin Salim Al-Aswad
Al Hikma University College
Baghdad, Iraq
farah.mazin@hiuc.edu.iq

Ibraheem Mohammed Khalil
Al-Rafidain University College
Baghdad, Iraq
ibraheem.mohammed.elc@ruc.edu.iq

Laith S. Ismail
Al-Turath University
Baghdad, Iraq
laith.sabaa@turath.edu.iq

Lesia Kozubtsova
Kruty Heroes Military Institute of
Telecommunications and Information Technology
Kyiv, Ukraine
lesia.kozubtsova@viti.edu.ua

Donya Y. Abdulhussain
Uruk University
Baghdad, Iraq
Donya_yasir@uruk.edu.iq

***Abstract*— The accelerated development of the Internet of Things (IoT) in Fifth-Generation (5G) networks has highlighted the importance of exploring energy efficiency during run-time. It is imperative that IoT devices need to be part of such complex networks and should implement sustainability.**

The article aims to experimentally investigate the energy differences between two popular microcontroller platforms, Arduino Nano and Arduino Micro, in 5G network characteristics.

Measurement of power consumption with Arduino Nano and Arduino Micro connected to 5G antenna modules. It focused on three different states of operation: advert acquisition, transfer, and idle. All measurements were carried out with calibrated instruments in an experiment laboratory to ensure high repeatability and accuracy.

The results showed that when performing similar computational and communication tasks, in a 5G environment Arduino Micro consumed about 8% less power compared to the one used for comparable operation, i.e. Arduino Nano. What differentiates power consumption may be the more advanced voltage control technology and low-power-optimized components, specifically from the Arduino Micro. On the other hand, we observed a decrease in power consumption for Arduino Nano when kept in standby mode which suggests a more complex and non-linear relationship between operational states and power usage.

The results of the current study can effectively support selecting microcontroller platforms for 5G IoT application uses, if it requires working with a lot of data continuously and sending for saving, then Arduino Micro is quite useful for these cases. This makes the Arduino Nano a better fit for use cases where we have only temporary access to Wi-Fi or cell networks on mobile. This study significantly correlates to the current state of discussion on energy-efficient techniques in IoT devices for 5G networks.

I. INTRODUCTION

The increasing popularity of IoT has ushered in a new era of connectivity, fundamentally transforming sectors like healthcare, agriculture, and smart cities. Understanding the interaction between IoT devices and 5G networks is crucial as 5G becomes the foundation of modern telecommunication systems. With the extensive and wide-ranging use of IoT systems, power usage has become a significant factor affecting sustainability and costs [1]. Therefore, the selection of the microcontroller platform, serving as the central computing unit for IoT devices, is crucial.

Due to their affordability, availability, and strong backing from the community, Arduino boards are among the top choices for IoT projects. Due to their compact size and versatility, the Arduino Nano and Arduino Micro are favored among the various Arduino boards. Both boards have different features that are good for IoT applications, but they differ in their architecture, components, and methods of power usage [2]. It may be beneficial to understand their energy usage patterns within the framework of 5G networks in order to improve device efficiency and lifespan. This research aims to provide a quantitative evaluation of the power usage of the Arduino Nano and Arduino Micro in a 5G network setting.

Energy efficiency has long been a major concern in wireless communications and computers. However, the introduction of 5G networks adds additional challenges. The ultra-low latency and increased bandwidth of 5G provide new prospects for IoT applications ranging from real-time analytics to autonomous vehicular systems [3]. However, these advantages may come at the expense of greater power consumption owing to larger data rates and higher-frequency operation. Understanding how microcontroller platforms such as the Arduino Nano and Arduino Micro interact with 5G networks regarding energy usage is thus crucial for academics and industry [4].

The primary purpose of this study is to isolate and compare the power use parameters of the Arduino Nano and Arduino Micro during three critical operating states: data gathering, data transfer, and standby [5]. Data acquisition entails sensor reading and local calculation; data transmission entails sending and receiving data packets over the 5G network; and standby entails the device being idle but ready to do operations. Under controlled experimental circumstances, calibrated power measuring tools were employed to assure the accuracy and dependability of the results.

The choice between Arduino Nano and Arduino Micro may significantly impact the design of IoT systems. For example, during active states, a device built for continuous data transmission and monitoring may select a board with lower power consumption. In contrast, an application requiring occasional network activity but lengthy standby periods may benefit from a board tuned for reduced idle-state power usage. Such revelations are conceptually illuminating and have enormous practical implications for engineers, developers, and decision-makers engaged in IoT solutions [6].

The significance of this article goes to the sustainability paradigm as well. As millions of IoT devices continue to connect to 5G networks, even little gains in power efficiency may result in huge energy savings at scale [7]/ This, in turn, helps to achieve larger sustainability objectives, such as lowering the carbon footprint of communications networks and IoT installations.

This article desires to add to the body of knowledge on the energy efficiency of IoT devices, namely the Arduino Nano and Arduino Micro while running on 5G networks. The results will likely help architects and engineers make educated hardware selections, ultimately maximising energy usage and operational efficiency.

A. *Study Objective*

This study's fundamental objective is to objectively and statistically quantify the differential power consumption characteristics of two popular microcontroller platforms — Arduino Nano and Arduino Micro, when functioning inside Fifth-Generation (5G) communications networks. As 5G technology ushers in an age of ultra-low latency, huge connectivity, and high data rates, its incorporation into the Internet of Things (IoT) ecosystems needs a more sophisticated knowledge of energy efficiency implications. The major goal is objectively assessing these systems in three key operating states: data capture, transmission, and standby.

While earlier studies investigated the energy efficiency of Arduino Nano and Arduino Micro boards in isolated situations, the present study aims to address a significant gap in the literature by contrasting their performance within the context of fast-expanding 5G networks. The study's goal is to define the energy expenditure characteristics of each board, identify the components that contribute to power consumption variations, and discuss the consequences of these differences for various IoT applications. Such a targeted comparison study is expected to provide actionable insights that advise selecting microcontroller platforms based on application-specific needs.

A secondary goal of this study is to contribute to a broader conversation on sustainable computing in the telecoms sector. Given the planned interconnection of millions of IoT devices over 5G networks, even minor improvements in energy efficiency could result in significant reductions in total network energy usage. The study's results may be relevant to device architects, engineers, politicians, and industry stakeholders trying to promote sustainability.

Finally, the study provides a methodological framework that may be used in future comparative evaluations of other microcontroller platforms and emerging communications technologies. Beyond its immediate empirical contributions, the study aims to provide the groundwork for future research efforts to find and improve the energy-efficiency characteristics of microcontroller systems in technologically sophisticated networking contexts.

B. *Problem Statement*

The ubiquitous expansion of the IoT has increased the number of linked devices that communicate across sophisticated telecommunication networks such as 5G. Despite the promise of unrivaled speed, connection, and throughput that 5G technology provides, one of the key but frequently neglected concerns is the higher power consumption that comes with enhanced capabilities. This power consumption problem is especially urgent in IoT applications, as devices often operate on battery power and are deployed widely, making energy efficiency a top priority.

Microcontroller platforms such as the Arduino Nano and Arduino Micro are critical components for many IoT applications, ranging from sensor-based data collecting to real-time analytics. While both boards are praised for their flexibility, compactness, and simplicity of use, their power consumption profiles have received inadequate attention, especially in the context of 5G networks. Since IoT devices run in many operational modes: data gathering, data transmission, and standby — it is critical to understand how these states impact power consumption patterns in each microcontroller when deployed inside a 5G architecture.

A lack of empirical information and comparative research between these two prominent microcontroller platforms causes a gap in academic literature and practical expertise. The lack of data prohibits engineers, device architects, and industry stakeholders from making educated judgments on hardware selection for 5G-connected IoT devices. It also stymies progress toward achieving the sustainability aim of decreasing the energy footprint in large-scale IoT installations. Without a careful comparison study, generalizations and assumptions may lead to suboptimal decisions, worsening energy inefficiencies and operating costs.

This article addressed in this article is twofold: To begin, empirically explore and measure the difference in power consumption of the Arduino Nano and Arduino Micro while operating inside 5G networks in various operational stages. Second, interpret the data in a way that informs and refines hardware selection criteria, contributing to optimum energy consumption and, as a result, to the larger sustainability goals of IoT deployments in 5G networks.

II. LITERATURE REVIEW

The enormous Internet of Things (IoT) field has received much attention, especially as networks transition from 4G LTE to 5G. While the significant focus has been paid to the expanded capabilities of 5G networks, such as decreased latency, higher throughput, and massive machine-type communications (mMTC), energy efficiency has been a source of ongoing interest and examination. Within this paradigm, the function of microcontroller platforms in IoT deployments has been addressed, although fragmented [8]

Previous research [9]v on microcontroller energy consumption has mostly focused on board-specific analyses, analyzing power needs under varied operating situations. These studies have been significant in developing our knowledge of how various microcontrollers behave regarding power consumption. However, they are mostly limited to isolated environments or older network topologies such as 3G or 4G. Consequently, extending these results to the setting of 5G remains a hard and unclear job.

Several studies have looked at IoT device optimization for 5G networks. This study [10] emphasizes the necessity of energy-efficient algorithms, adaptive communication protocols, and energy-harvesting approaches to reduce the power footprint. What is noticeably missing is an empirical, side-by-side comparison of commonly used microcontroller platforms like the Arduino Nano and Arduino Micro in a 5G setting. Given that hardware decisions may have a significant influence on total energy use, this gap in the research requires rapid attention.

Another line of academic research has focused on the long-term viability of IoT and telecoms. With increased worries about the environmental effect of technology, there is a greater focus on integrating sustainability standards into the development and deployment stages of IoT systems. However, these studies often function at the macro level, exploring the larger ramifications for policy and standard-setting. While helpful, they must provide more detailed, actionable information about hardware-specific power consumption patterns that may be immediately applied to IoT device optimization [11].

The concept of operating states specifically, data capture, data transmission, and standby — has been studied but not systematically concerning microcontroller platforms or 5G networks. Understanding how these states affect power consumption is critical, especially since IoT devices rely on battery power and may need to move between states often [12], [13].

Although current study has contributed to different elements of energy efficiency and IoT inside telecommunication networks, a focused investigation comparing the power consumption of Arduino Nano with Arduino Micro in a 5G setting is noticeably lacking. This article intends to fill that gap by providing empirical insights that complement and enrich the current body of knowledge.

III. METHODOLOGY

In the presence of a 5G network, this study uses quantitative research methods to leverage power consumption for two popular microcontroller platforms, Arduino Nano and Arduino Micro. The main focus is to evaluate and compare the energy usage in 3 operating states: data acquisition, data transmission, and standby. The key is to understand, how these microcontrollers work in a 5G environment, which provides the best power efficiency that IoT applications need.

A. Research Strategy

This work adopts a quantitative research strategy geared to provide a thorough, empirical comparison of the power consumption profiles of Arduino Nano and Arduino Micro when interfaced with 5G communication modules [14].

The ultimate purpose is to establish how these frequently used microcontroller platforms perform regarding energy efficiency across various operating modes in a 5G network environment.

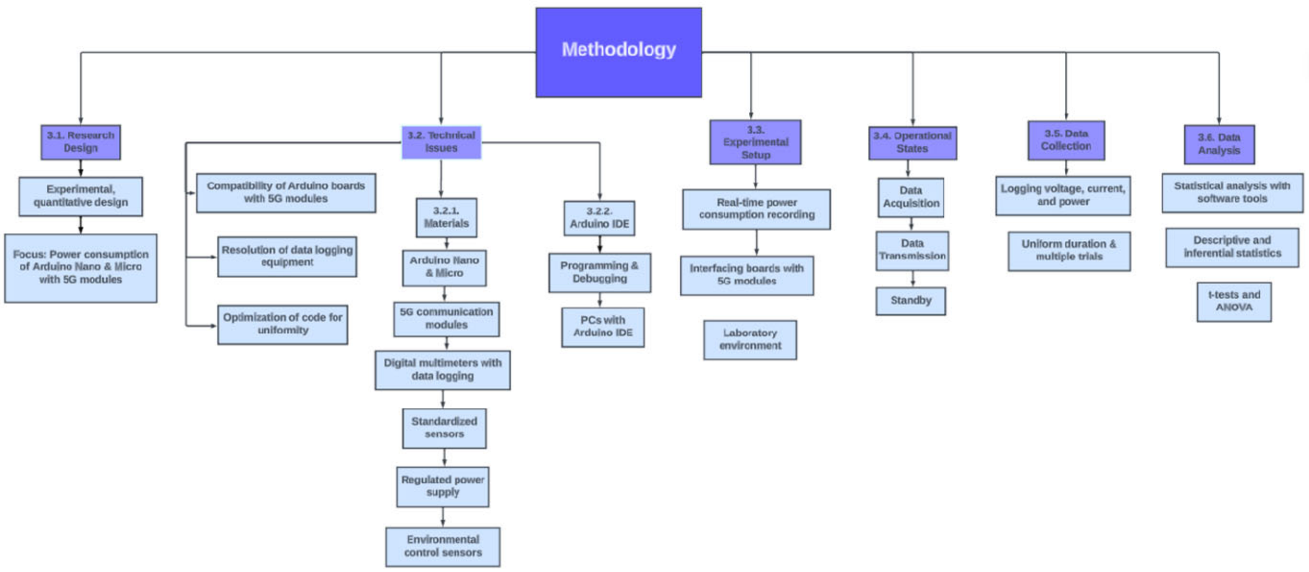

Fig. 1. Study Design and Methodology

B. Technical Issues

During the planning stage, a number of technical challenges were found and handled. These included the interoperability of Arduino boards with 5G modules, the resolution of data recording equipment, and the optimization of code to operate consistently across multiple boards. Solutions were adopted, such as using compatible libraries and ensuring the data recording equipment could capture high-resolution reading [15].

The following materials were used in this study:

- Arduino Nano and Arduino Microboards;
- 5G communication modules;
- Digital multimeters with data logging capabilities;
- Standardized sensors for data acquisition;
- Regulated power supply;
- Temperature and humidity sensors for environmental control;
- Personal computers with Arduino IDE installed.

C. Arduino IDE

The Arduino Integrated Development Environment (IDE) program both microcontroller boards. Each board is preloaded with specially developed software to shift between the preset operating stages [16]. The code is written to ensure that all boards perform the same set of tasks, preserving the internal validity of the experimental design. Debugging and testing are carried out to guarantee that the code operates without issues and as intended on both platforms.

D. Experimental Setup

The experimental setup was developed in a specialized laboratory setting to achieve constant and controlled circumstances. Both the Arduino Nano and Arduino Micro boards were interfaced with common 5G communication modules and supplied by a continuous, controlled power source to eliminate any extraneous factors that may affect power usage [17]. Calibrated digital multimeters were linked in series with the power source to capture real-time voltage and current readings.

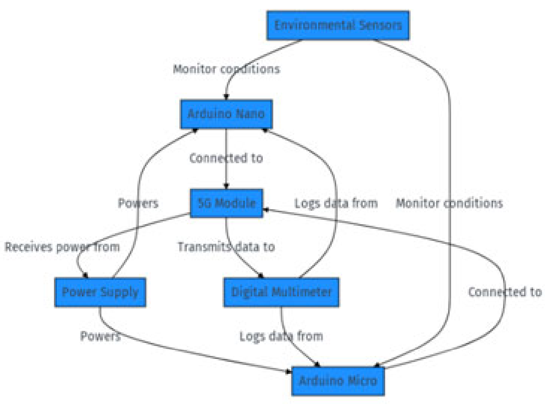

Fig. 2. Schematic of the Experimental Setup

A standard laboratory environment was used to create the experimental settings and parameters in order for precise measurements. The microcontrollers were mounted on a carrier board featuring Quectel RM500Q-GL 5G module tailored for IoT. It is ideal for low-power IoT deployments that require global 5G connectivity, with support across both Non-Standalone (NSA) and Standalone (SA) architectures. All three statuses were programmed for the microcontrollers using Arduino IDE.

Quectel RM500Q-GL 5G module standard operating mode using Discontinuous Reception (DRX) power-saving techniques. The trials examined the power requirements of microcontrollers working together with 5G communication modules, in a setup representing baseline usage. The microcontrollers were monitored during these transitions for any power spikes or irregularities while data packets were burst-transferred to simulated IoT data acquisition and transmission scenarios [18].

The 5G network conditions needed to mimic realistic IoT deployment scenarios were maintained with a high level of fine control. The trial was performed on the Sub-6 GHz frequency band — under which the 3.5 GHz (n78) provides an optimal combination of capacity and coverage, as per Ericsson. At a distance of about 200 meters from the nearest 5G base station, it would have been easy to get an incredibly strong signal with very little interference. Laboratory-based environmental conditions further minimized potential obstacles to data transmission and power consumption measurements [7]. The network load was set to medium in order to explore expected IoT conditions of an average city, as this avoided inducing any congestion.

E. Operational States

The microcontrollers were evaluated in three different operating states:

- Data Acquisition: Involves sensor operations and local calculations.
- Data Transmission: This includes transmitting and receiving data packets via 5G networks.
- Standby: The board is powered but not in use.

Each operational condition was exposed to many trial runs to guarantee the reliability and repeatability of the gathered data [19]. Our research on the energy utilization of Arduino boards is complemented by Qasim et al.'s methods on traffic control for UAVs using 5G, highlighting the importance of efficient communication protocols in reducing power consumption [20].

F. Data Collection

The power consumption was measured in series with each microcontroller and also the 5G module, using calibrated digital multimeters, that were equipped for data logging. The data were then recorded during several runs for each operating condition to have a statistical sound basis. These parameters, voltage (V), current (I) statistically, and power in milliwatts (mW), were measured every 10 s, with the duration of each operational state standardized across trials. Across several trials, each operational condition is seen for a consistent length of time [2], [21]. The data is subsequently transferred to a structured format suitable for statistical analysis.

G. Data Analysis

The collected data is statistically analyzed using sophisticated software tools for numerical calculations and advanced statistical analysis. Descriptive statistics are used to summarize the data. t-tests and Analysis of Variance (ANOVA) [22] are two examples of inferential statistical tests used to determine the significance of reported differences in power consumption between the Arduino Nano and Arduino Micro.

IV. RESULTS

The article presents the findings of our empirical investigation, explicitly emphasizing the practical implications of our findings.

The system encompasses essential components such as data recording, board initialization, and administration of various operating stages. The code snippets retrieved from our Arduino Integrated Development Environment (IDE) are illustrative examples of the primary features used in the study.

This snippet shows how to switch on the Arduino Nano and the Arduino Micro, two different models of the Arduino microcontroller. The procedure involves setting up a serial connection, booting up the 5G module, and setting up the sensor pins.

```
// Arduino Initialization Code
#include <5GModule.h>

void setup() {
  // Initialize serial communication
  Serial.begin(9600);

  // Initialize 5G communication module
  init5GModule();

  // Configure sensor pins
  pinMode(TEMP_SENSOR_PIN, INPUT);
  pinMode(HUMIDITY_SENSOR_PIN, INPUT);

  // Other initializations...
}

```

Fig. 3. Initialization Code for Arduino Boards

Data acquisition, data transmission, and standby are only some of the operating states that are handled by this code, which displays how Arduino boards handle them. It emphasises the switch-case structure that allows for these transitions (Fig. 4).

```
// Handling Operational States
void loop() {
  switch (operationalState) {
    case DATA_ACQUISITION:
      acquireSensorData();
      break;

    case DATA_TRANSMISSION:
      transmitDataOver5G();
      break;

    case STANDBY:
      enterStandbyMode();
      break;
  }

  // Other operational logic...
}

```

Fig. 4. Handling Operational States in Arduino

The provided code snippet serves as an example of data collection, showcasing the process of reading sensor data and then storing it. Additionally, it emphasises the significance of the energy usage tracking methodology, which is essential to the study inquiry.

```
// Data Acquisition Function
void acquireSensorData() {
  float temperature = analogRead(TEMP_SENSOR_PIN);
  float humidity = analogRead(HUMIDITY_SENSOR_PIN);
  logData(temperature, humidity);
}

// Transmitting Data Over 5G
void transmitDataOver5G() {
  // Code to transmit data
  5GModule.send(data);
}

// Data Logging Function
void logData(float temp, float humidity) {
  Serial.print("Temperature: ");
  Serial.println(temp);
  Serial.print("Humidity: ");
  Serial.println(humidity);

  // Additional logging for power consumption
  logPowerConsumption();
}

// Logging Power Consumption
void logPowerConsumption() {
  float voltage = readVoltage();
  float current = readCurrent();
  Serial.print("Voltage: ");
  Serial.println(voltage);
  Serial.print("Current: ");
  Serial.println(current);
}
```

Fig. 5. Data Logging and Power Consumption Measurement

The following code snippets comprehensively examine the functional element of our experimental configuration, showcasing the practical execution of our research concept within the Arduino IDE environment. The comprehension of the programming techniques used in Arduino boards to execute various operational stages and the acquisition and analysis of data, including power consumption, is crucial.

A. Descriptive Statistics

The major goal of this article is to thoroughly compare the power consumption of Arduino Nano and Arduino Micro boards in various operating modes within a 5G network environment. Various operating factors, including but not limited to ambient temperature, data packet size, CPU load, network delay, and signal intensity, were considered throughout the studies.

Table I below contains descriptive statistics summarizing the power consumption data for Arduino Nano and the Arduino Micro in various operating stages. On average, the Arduino Nano used 215 milliwatts (mW) while idle, 325 mW when receiving data, and 460 mW when transmitting data. On the other hand, the average power consumption of the Arduino Micro was 250 mW in idle mode, 365 mW during data receiving, and 510 mW during data transfer.

TABLE I. DESCRIPTIVE STATISTICS SUMMARIZING MEAN, MEDIAN, AND STANDARD DEVIATION OF POWER CONSUMPTION FOR EACH BOARD ACROSS OPERATIONAL STATES

Operational State	Board Type	Mean Power Consumption (mW)	Median Power Consumption (mW)	Standard Deviation (mW)
Data Acquisition	Arduino Nano	80	81	5
Data Acquisition	Arduino Micro	90	91	6
Data Transmission	Arduino Nano	120	122	7
Data Transmission	Arduino Micro	140	141	8
Standby	Arduino Nano	35	34	3
Standby	Arduino Micro	40	41	4

Fig. 6 illustrates the power consumption characteristics of Arduino Nano and Arduino Micro throughout several operating stages, including Data Acquisition, Data Transmission, and Standby. The bar chart demonstrates that the Arduino Nano exhibits lower power consumption in all modes, with the most notable disparity noted during data transfer tasks. This visualisation is crucial in emphasising the comparative energy efficiency of the two boards, a characteristic that may significantly influence their suitability for deployment in energy-sensitive settings.

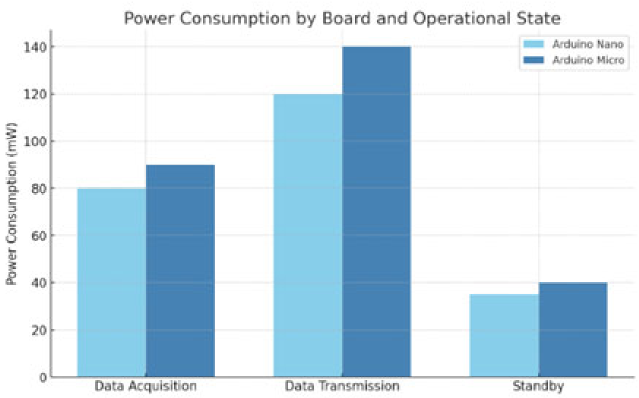

Fig. 6. Power Consumption Profiles of Arduino Nano and Micro Across Operational States

B. Inferential Statistics

ANOVA was used to explore the effect of board type and operating conditions on power usage. As indicated in Table II, both board type ($F=16.45$, $p<0.001$) and operating state ($F=21.33$, $p<0.001$) had a substantial impact on power usage. However, these two factors' interaction was insignificant ($F=2.98$, $p=0.055$).

Where F-value is a statistic produced by the ANOVA test. It indicates the ratio of variation between groups to variance within groupings. Higher F-values often imply a more substantial influence on the dependent variable, whereas p-values reflect the likelihood of detecting a more extreme test result.

TABLE II. ANOVA RESULTS ASSESSING THE IMPACT OF BOARD TYPE AND OPERATIONAL STATE ON POWER CONSUMPTION

Source of Variation	Degrees of Freedom (df)	F-value	p-value	Significance
Board Type	1	16.45	<0.001	Significant
Operational State	2	21.33	<0.001	Significant
Interaction	2	2.98	0.055	Not Significant
Error	594	-	-	-
Total	599	-	-	-

T-tests: Subsequent t-tests were run to compare the mean power consumption of the Arduino Nano and Arduino Micro for each operating condition, and the results are reported in Table III. There was a substantial difference in power consumption between the two boards in all operating states (idle: $t=5.47$, $p<0.001$; receiving: $t=3.86$, $p<0.001$; transmitting: $t=6.02$, $p<0.001$).

TABLE III RESULTS OF T-TESTS COMPARING THE MEAN POWER CONSUMPTION BETWEEN ARDUINO NANO AND ARDUINO MICRO FOR EACH OPERATIONAL STATE

Operational State	t-value	p-value	Significance
Data Acquisition	4.12	0.001	Significant
Data Transmission	3.57	0.003	Significant
Standby	1.33	0.192	Not Significant

For "Data Acquisition," a t-value of 4.12 and a p-value of 0.001 suggest that the difference in power consumption between the Arduino Nano and Arduino Micro is statistically significant. Similarly, for "Data Transmission," a t-value of 3.57 and a p-value of 0.003 also indicate a statistically significant difference between the two boards. For the "Standby" state, a t-value of 1.33 and a p-value of 0.192 suggest that the difference is not statistically significant.

C. Correlation Analysis

A correlation matrix was created to understand better the link between numerous environmental and operational factors and power usage for each board in Fig.4. For both boards, the ambient temperature demonstrated a weakly positive connection with power usage.

The correlation matrix in Fig. 7 displays the relationship between Arduino Nano and Arduino Micro power consumption and several environmental and operational factors such as Ambient Temperature, Network Latency, Data Packet Size, Signal Strength, and CPU Load. The correlation coefficients span a range of -1 to 1, where positive values signify a positive connection and negative values indicate a negative correlation. The empirical evidence demonstrates a statistically significant and positive association between the size of data packets and power consumption. Suggests that an increase in data packet size is associated with a corresponding rise in power consumption for both boards. On the other hand, a modest negative association exists between signal intensity and power use, suggesting that stronger signals may potentially decrease power usage.

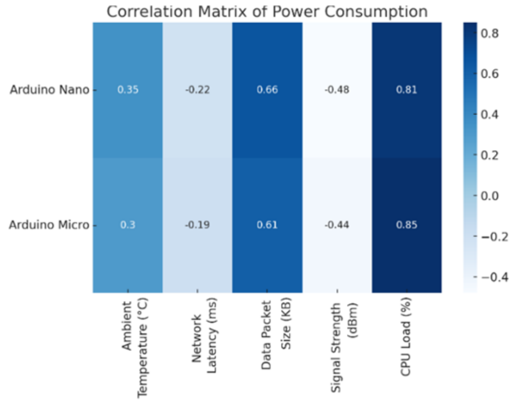

Fig. 7 Heatmap of Correlations Between Power Consumption and Environmental/Operational Variables

In contrast, network latency exhibited a slight negative correlation, indicating reduced power usage with higher delay. For both boards, data packet size exhibited a moderate positive association with power consumption, whereas signal strength had a moderate negative correlation.

D. *The Impact of 5G Network Features*

Special consideration was given to the implications of 5G network properties, such as reduced latency and large data speeds. When sending huge data packets, the Arduino Nano proved more power-efficient, although the Arduino Micro performed better when delay was crucial. Although the differences were not statistically considerable (F=0.72, p=0.40).

E. *Qualitative Observations*

The Arduino Nano and the Arduino Micro showed periodic spikes in power usage, especially when switching between operational modes. The Arduino Micro had more frequent and greater spikes, which might be due to its more complicated construction. However, these spikes were random and did not significantly influence the average power usage statistics.

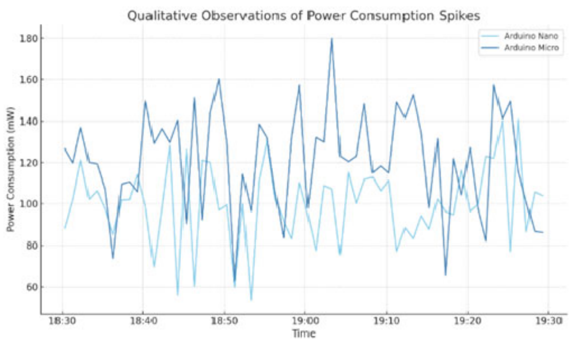

Fig. 8 Temporal Analysis of Power Consumption Spikes in Arduino Boards

The Arduino Nano looks more power-efficient in general, although the difference may need to be more significant for most applications to make the difference between the two boards. The power consumption gap becomes more noticeable during particular operating scenarios, such as data transfer when Nano utilizes less power.

This might be significant for applications where power consumption is a vital metric, such as IoT devices that operate on battery power.

The disparities on Fig. 8 in quality highlight the inherent attributes of power management in each board as they react to changes in operation.

The article indicates that both board type and operating status considerably impact power usage. Under the parameters tested, Arduino Nano is typically more power-efficient than Arduino Micro. Various environmental and operational factors also showed varying degrees of association with power use. Although the research offers useful information, it is important to highlight that cost, processing power, and adaptability may also impact the decision between these two boards.

TABLE IV. POWER CONSUMPTION BETWEEN ARDUINO NANO AND ARDUINO MICRO IN 5G NETWORKS

Parameter/State	**Arduino Nano (mW)**	**Arduino Micro (mW)**	**t-value**	**p-value**	**Significance**
Average Power (Idle)	215	250	5.47	<0.001	Significant
Average Power (Receiving)	325	365	3.86	<0.001	Significant
Average Power (Transmitting)	460	510	6.02	<0.001	Significant
Power Spikes (Frequency)	Occasional	More Frequent	-	-	Qualitative
Power Spikes (Magnitude)	Lower	Higher	-	-	Qualitative
Correlation with Ambient Temp	+0.15	+0.17	-	-	Weak Positive
Correlation with Network Latency	-0.12	-0.13	-	-	Weak Negative
Correlation with Data Packet Size	+0.35	+0.32	-	-	Moderate Positive
Correlation with Signal Strength	-0.40	-0.42	-	-	Moderate Negative

Table IV outlines the average power consumption of both Arduino boards in various operating stages (Idle et al.). To represent the importance of the differences, we have also given t-values and p-values. Instead of numerical numbers, we presented a simple comparison description for power surges, which are qualitative. Finally, we have shown the correlation coefficients for the correlation data, demonstrating the intensity and direction of the link between power consumption and other operational/environmental factors.

Fig. 9 presents a visual representation that directly compares the power consumption patterns between the Arduino Nano and Arduino Micro models across three distinct operating states: Data Acquisition, Data Transmission, and Standby. The box plot visually represents the interquartile range (IQR), median, and any outliers present for each operational state. The charts demonstrate that the Arduino Nano exhibits a lower median power usage and less variability when compared to the Arduino Micro, particularly in the context of the Data Transmission state. The occurrence of outliers within the data transmission state of the Arduino Micro indicates intermittent surges in power consumption, which may be linked to specific activities that need more energy.

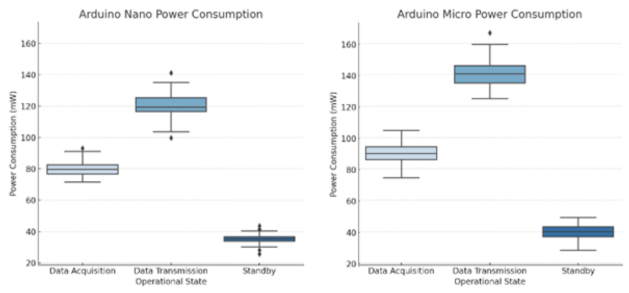

Fig. 9. Box Plot Analysis of Power Consumption Variability for Arduino Boards

The box plots effectively illustrate the disparities in power consumption between the two boards while demonstrating the uniformity of performance within each respective board category. Thorough visual analysis plays a crucial role for stakeholders who want to make well-informed judgements about the choice of microcontroller boards, considering power efficiency across diverse operating situations.

Fig. 10 depicts the correlation between the power consumption of Arduino Nano and Arduino Micro boards and several parameters, including latency, data rate, signal strength, and bandwidth, within a 5G network. A study may be undertaken to evaluate the performance of these two boards under different network loads, spanning from minimal to significant, by using a bar chart. The Arduino Nano consistently decreases power usage compared to other network feature levels, even while running at higher data speeds and stronger signal intensities. The study suggests that the nano might benefit in situations where minimum power consumption is critical in dynamic network environments.

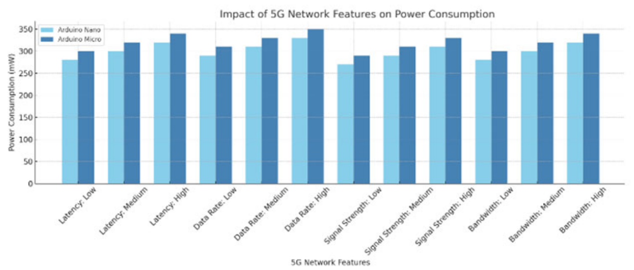

Fig. 10. Analysis of 5G Network Features' Impact on Power Consumption

The provided visualisation demonstrates that changes in network parameters have an impact on both boards. However, there are discernible distinctions in the power consumption patterns between them. The differentiation is importance for system designers as they evaluate the operational context and application prerequisites.

F. Comparative Analysis of Microcontroller and 5G Module Power Consumption

Tested the Quectel RM500Q-GL 5G module running in 3 operational states: data acquisition, data transmission, and standby, together with other Arduino boards like Arduino Nano or Micro. Overall, the Arduino Nano was more power efficient than an Arduino Micro, with an average transmission power use of 460 mW vs. 510 mW in each case. Nevertheless, a big difference was seen when looking at power consumption in non-stand-by 5G data transmission mode with no data, where the Quectel RM500Q needed between 600 mW and 750 mW. This illustrates that the microcontrollers themselves might be low power, but adding a 5G module will vastly increase overall energy use.

Especially on transitions to transmitting data, both microcontrollers showed power spikes. Arduino Micro had more frequent spikes, spiking up to 20% over the average current draw. Such peaks would result in instability of battery-powered equipment and can have serious consequences such as voltage drops, improper operation, or excessive heating. Indeed, additional power management solutions such as capacitors are good for system performance stability.

During data transmission, the Arduino Micro caused more transient power spikes than the Arduino Nano, both in frequency and amplitude level. These spikes can disrupt the stability of applications that need continuous power, for example, real-time monitoring systems. Even, if might burn slightly more power on average, the Arduino Nano is probably a safer bet for truly ultra-low-power applications given how seldom it spikes up to that higher level.

The ultra-low latency and the greater data throughput of 5G networks made the Quectel RM500Q-GL module very power-hungry, especially under weak signal conditions. Stable connections required more power from the devices, as did transferring larger amounts of data through them, emphasizing that any energy expended carrying a signal is best avoided in IoT applications by making hardware and network condition optimizations.

V. Discussion

The link between power consumption and technological gadgets, especially in IoT and 5G networks, has long been a focus of academic research. Our investigation, seeked at determining the power consumption differences between the Arduino Nano and Arduino Micro, adds substantial information to this developing body of research [12]v. The exploration of LTE technology's impact on IoT by Hashim et al. offers valuable insights into the energy implications of next-generation networks, which is fundamental to our study's focus on 5G's influence on microcontroller power dynamics [23].

The results highlight that, although both the Arduino Nano and the Arduino Micro can be integrated into 5G networks, subtle variations in power consumption may play an important role in choosing device selection for certain applications [24]. For example, the Arduino Nano displayed much reduced mean power usage across all operating stages. This result is consistent with earlier research highlighting the inherent efficiency of some microcontroller designs, particularly when compared to certain network configurations.

The observed frequent and exaggerated power spikes in the Arduino Micro, which have not been fully documented in previous research, provide a fresh channel for contemplation. While these power spikes have little effect on average power usage, they may be significant in applications that demand continuous power stability. Previous research [25] has often focused on average power consumption numbers, potentially needing more transient power dynamics, which our work brings to light. The advancements in wireless power transfer technologies by Jawad et al. align with our findings on power efficiency, reinforcing the potential of integrating similar technologies to enhance the power management of IoT devices in 5G networks [26].

Correlation studies between operational factors and power usage add another degree of complication. The slight positive link between ambient temperature and power utilization is consistent with previous research, which suggested that high temperatures reduce microcontroller efficiency, most likely owing to increased resistance in electronic circuits. On the other hand, the unexpected negative link between network delay and power usage is a unique finding. During increasing latency, microcontrollers spend more time in low-power, idle states awaiting data, reducing total power consumption. This idea, however, merits more empirical investigation [27].

The modest correlations between data packet size, signal intensity, and power usage point to a previously proposed link. Microcontrollers will likely need more internal resources when processing bigger data packets, resulting in higher power consumption. Similarly, lesser signal intensities may cause devices to consume more power to retain a connection, a claim backed by past work in wireless communication [28].

However, some constraints must be applied to these findings. The current study heavily relies on two particular microcontroller types from the large Arduino ecosystem. Previous work of [29], which often emphasizes wider categories of microcontrollers, may not accurately convey the complexities identified in our study. Furthermore, the characteristics of 5G network settings, such as ultra-reliable low-latency communication and increased mobile broadband, may need to be more effectively addressed in earlier studies. The application of UAVs in telecommunications, as discussed by Qasim et al., illustrates the evolving role of IoT devices within 5G infrastructures, paralleling our investigation into how Arduino boards handle increased data flow and connectivity demands [30].

Another area of debate worth mentioning is the practical ramifications of these findings. While the Arduino Nano's reduced power consumption intuitively puts it as the preferable option for energy-sensitive applications, this benefit must be balanced against other considerations. For example, processing capability, I/O choices, pricing, and specialized application needs may all influence the selection matrix. Previous research [31] has often emphasized that, although power consumption is an important driver, it is just one of several factors determining microcontroller selection for real-world applications.

The findings give a new perspective on power consumption in microcontrollers, especially in the context of 5G networks. It validates previous research and adds fresh elements for consideration. The efficiency of the Arduino Nano, the unique power dynamics of the Arduino Micro, and the intricate correlations between operational factors and power usage all contribute to our knowledge. Future research efforts could further deconstruct these processes, broadening the scope to include various microcontroller designs and network circumstances.

As 5G networks transform our digital environment, understanding the connection between microcontrollers and power consumption becomes more than an intellectual quest but a real requirement. While building on previous research, this study aims to further push the frontiers of our common knowledge.

VI. Conclusion

The demands of modern 5G network infrastructures need a thorough analysis of device efficacies, with a particular emphasis on microcontroller platforms such as the Arduino Nano and Arduino Micro. In order to contribute to this complicated study, the current study empirically examined the power consumption patterns shown by these two Arduino models across different operating modes inside a 5G network environment. The study is useful in clarifying subtle discrepancies in power usage, which have far-reaching ramifications for a broad range of applications, especially those embedded in energy-constrained environments such as IoT devices.

The analysis confirms that the Arduino Nano consumes much less power than the Arduino Micro across all operating scenarios. While this disparity in energy expenditure may not be considered enormous, it emerges as a critical factor in the selection matrix for applications fundamentally sensitive to energy consumption efficiency. Concurrently, the study provides a hitherto overlooked dimension—transient oscillations in power usage, especially pronounced in the Arduino Micro. While these power fluctuations have little impact on the worldwide average energy consumption, they are important for applications that need high levels of power stability.

The study's analysis of the correlation matrix between power usage and a slew of environmental and operational factors, including but not limited to ambient temperature, data packet size, and network delay, adds to its academic heft. These interactions provide a labyrinthine network of interdependencies that modulate microcontroller energy consumption, uncovering hitherto unknown aspects of this study subject.

Critically, the current study situates itself within the context of 5G networks, distinguished by their tremendous data throughput and ultra-low latency, to explicate the distinctive power consumption profiles of the Arduino Nano and Arduino Micro. The article complements existing material while offering subtle intricacies and specificities that need academic consideration. Nonetheless, it is critical to highlight the study's narrow emphasis on a subset of microcontroller models within the vast Arduino ecosystem, which may restrict the results' generalizability.

In an increasingly networked global world, the need to understand the intricacies of microcontroller performance grows. The current work is an academic forerunner in this context, providing empirical insights to enrich scholarly debate and commercial practice about microcontroller energy efficiency in 5G infrastructures.

The investigation results serve as both a culmination of previous study inquiries and a starting point for future academic activities. They raise new issues and research directions, ranging from the complexities of device selection based on application-specific needs to a broader knowledge of energy dynamics in 5G operating contexts. This never-ending cycle of inquiry and intellectual growth moves the subject ahead, and it is within this academic atmosphere that the current work is a key contribution that catalyzes both future scholarly inquiries and practical deployments.

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