ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

ZJUI Clickers for Undergraduate Version 2

Team #23

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March 5, 2024

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1 Introduction

1.1 Problem

In the contemporary educational landscape, the incorporation of technology within classrooms has witnessed a widespread adoption, yielding significant impacts on teaching and learning practices. Among the various tools introduced to enhance classroom interactivity and streamline administrative processes, the I-clicker has emerged as a pivotal instrument. This technological solution serves as an indispensable element in meeting the digital demands of the classroom environment. By enabling the efficient collection of attendance data and promoting interactive learning experiences through question-and-answer sessions, the I-clicker empowers students to actively engage with academic material, fostering a deeper understanding of complex concepts and improving overall learning outcomes.

However, despite its evident advantages, the present iteration of the I-clicker system is confronted with inherent limitations that impede its ability to accommodate a substantial user base. Issues such as limited capacity to handle higher user loads, significant signal delays, and signal loss hamper the system's efficacy. The preceding iteration of the Clicker, known as Version 1, remained unfinished and underwent limited testing. It exhibited a restricted capacity to accommodate a large user base, thereby rendering it inadequate for practical use. Furthermore, the absence of support for mobile applications as an alternate means of participation fails to cater to the preferences of students who favor mobile technology. To ensure a seamless and engaging educational experience for all students, it is imperative to address these challenges and enhance the functionality of the I-clicker system.

1.2 Solution

In response to the aforementioned practical challenge, our project endeavors to augment the system's capacity to cater to a larger participant base of approximately 100-150 individuals. Furthermore, our objective encompasses the facilitation of diverse front-end devices, encompassing mobile, PC, and Clicker interfaces. A crucial aspect of this enhancement involves expanding the receiver's radius to encompass the spatial dimensions of a typical classroom setting.

To realize these objectives, our team has formulated a comprehensive plan involving five core components: front-end development, back-end implementation, Clicker design, receiver design, and shell design. Moreover, the system has been architected as a closed-source solution, utilizing an internal Local Area Network (LAN) for signal transmission. This strategic measure serves to safeguard the system's integrity and mitigate the potential risks associated with external interference.

1.3 Visual Aid

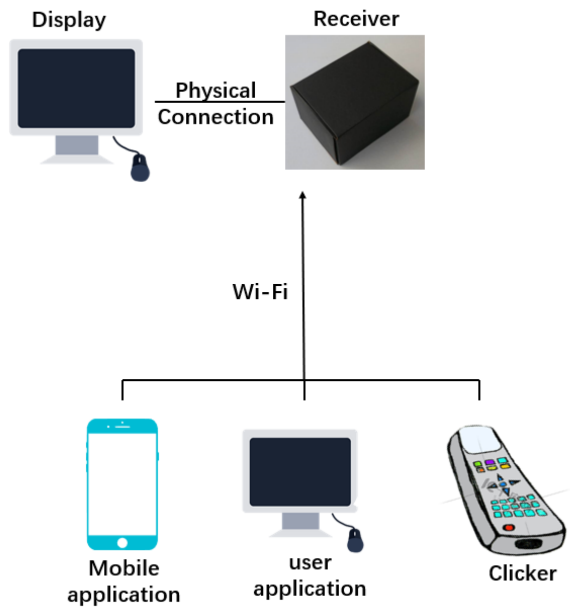

Figure 1: Visual Aid

1.4 High-level Requirement Lists

- The system has been designed to accommodate a substantial number of students, specifically supporting 100-150 individuals in a classroom environment to utilize the answer function efficiently. By considering the system's capacity to handle this volume of users, it aims to ensure smooth and uninterrupted functionality for all participants.
- The system has been optimized to ensure reliable signal transmission within a classroom environment of approximately 100 meters in size. Within this range, users can expect a strong and stable signal that enables them to effectively utilize the system's features, including the ability to answer questions. However, it's important to note that the system should not be designed to support long-distance signal transmission beyond the specified classroom size to avoid cheating.
- The delay from the user pressing a button on a mobile phone, web page or Clicker to the receiver receiving the signal does not exceed 500ms.

2 Design

2.1 Block Diagram

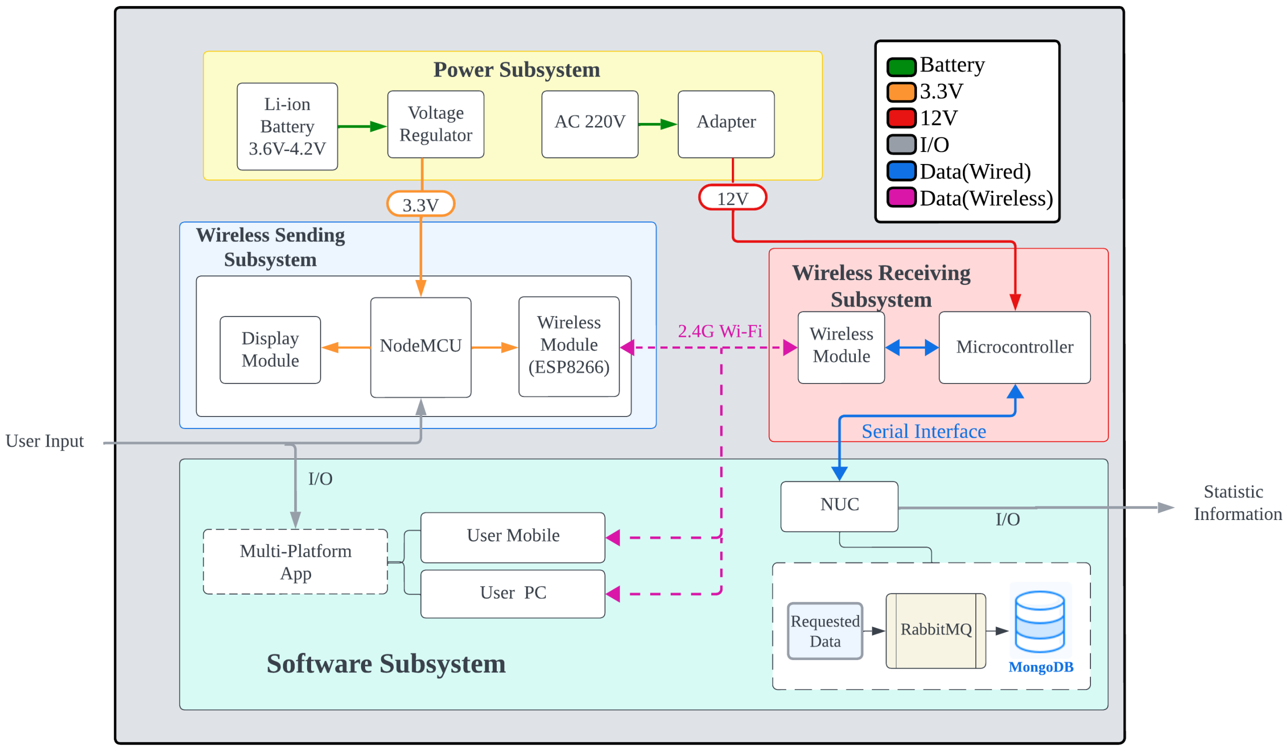

Figure 2: Block Diagram

2.2 Subsystem Overview

The power subsystem under consideration comprises several integral components, including a 220V DC voltage source, adapters, and a series of batteries with a voltage range of 3.6-4.2V. These components play a crucial role in supplying power to the receiving device by employing a DC-to-DC Converter Module. The fundamental objective of this power supply system is to effectively support the clicker subsystem and the wireless receiving subsystem within the hardware segment.

The clicker subsystem encompasses a physical clicker equipped with Wi-Fi modules such as the ESP8266 and a micro-controller (MCU). Additionally, the physical clicker is equipped with auxiliary devices like display modules, display screens, and buttons. It can utilize the Wi-Fi module to transmit command information to the receiving subsystem through the local area network (LAN).

The wireless receiving subsystem consists of a wireless module and a micro-controller. Its primary function revolves around receiving signals from the wireless sending subsystem or the software subsystem and subsequently transferring the received data to the software subsystem (NUC) via a physical connection.

The software subsystem is aimed at developing a **cross-platform** classroom interaction application that supports Windows, Mac, iOS, and Android. It is designed to efficiently handle **high-concurrency** requests and includes a robust **identity verification** mechanism to prevent cheating practices such as proxy attendance.

2.3 Power Subsystem Requirement

This subsystem ensures that students and teachers can use the system for a long time without maintenance. This subsystem can power the clicker subsystem and the wireless receiving subsystem.

We need a DC power supply to power our microcontroller and OLED. Considering the size of the microcontroller, OLED and energy consumption, we should choose a voltage of 3.3V-5V and a current of less than 10mA. Excessive voltage can easily cause irreversible damage to the microcontroller and screen, including but not limited to burning. We chose to employ the use of a LIR1220 (fluctuating from 3.6v to 4.2v) battery as the power source, which will be supplied along with the clicker in. This subsystem also contains a voltage of 220V AC, which necessitates the use of an adapter to convert the high AC voltage to an appropriate DC voltage.

Requirements

- The power supply must provide a voltage range of 3.3V-5V to adequately power the microcontroller and OLED.
- The current provided by the power supply should be less than 10mA to meet the energy consumption requirements of the system.
- The power supply should prevent excessive voltage to avoid irreversible damage to the microcontroller and OLED, including the risk of burning.

2.4 Clicker Subsystem Requirement

This subsystem ensures that 100-150 students can send answers in a stable and efficient manner. This subsystem can send signals to the wireless receiving subsystem.

2.4.1 Transmit Module

On the clicker side, we use the ESP8266 as the functional module for data transmission to connect with the central processing module. the ESP8266 chip supports the standard IEEE 802.11b/g/n Wi-Fi protocol, and is able to connect with the wireless network. it realises wireless communication and data transmission through the built-in Wi-Fi module. the microcontroller inside the clicker can connect to the teacher's receiver through this chip to achieve data exchange. It realises wireless communication and data transmission functions through the built-in Wi-Fi module.The microcontroller inside Clicker can be connected to the teacher's receiving end through the chip to realise data exchange.The ESP8266 chip is also characterised by its low power consumption, which enables it to operate stably under low-voltage and low-power conditions. This also makes it ideal for use in battery-powered scenarios, in line with CLICKER's needs. In addition, advanced power management technology is integrated inside the chip, which enables intelligent sleep and wake-up functions to further reduce energy consumption and ensure the single battery life of the clicker.

2.4.2 Display Module

Clicker needs a screen to provide feedback to users. we use 0.96 inch OLED screen, it can support wide range of power supply, 3.3V-5V.The power consumption is only 0.04W, with a resolution of 128 * 64, the viewing angle is greater than 160 degree, we use the IIC communication with the ESP8266 development board connected.

2.4.3 Hardware Process module

We use the NodeMCU development board (CP2102), which works with the ESP8266, as the signal processing module. It can send the information pressed by the user through the button to the receiver through the ESP8266 module.

2.4.4 Shell Design

For the exterior design of the clicker, we will use 3D printing, relying on the existing 3D printing equipment in the school laboratory, we can make the shell quickly and in bulk. At the same time, 3D printing clicker shell can be based on the shape of the microcontroller, battery, button design, the microcontroller, battery buckle in the shell, to protect the internal circuitry will not be damaged because of changes in the external environment.

Requirements

- The subsystem should provide reliable wireless communication and data transmission capabilities.
- The OLED screen should have a size of 0.96 inches and support a wide power supply range of 3.3V-5V. The screen should have a resolution of 128x64 pixels and a viewing angle greater than 160 degrees.
- The shell design should accommodate the microcontroller, battery, and buttons, providing a protective enclosure for the internal circuitry.

2.5 Wireless Receiving Subsystem Requirement

This subsystem ensures that it can meet the high level requirement for the signal range. The subsystem can receive the signal stably within a certain range and convert the signal into data for transmission to the software system for processing.

Our receiver unit has 8 antennas and uses MTK's MT7986A CPU, quad-core 2.0GHz, 12nm process, with better heat control. The memory is 512MB of DDR4 and 128MB of flash. 2.4G supports up to 8 OFDMA users, while 5G supports up to 16 OFDMA users. 5G's RF chip is MT7976AN, which supports 4x4MIMO, and 5G's maximum rate is 4804Mbps at 160MHz bandwidth and 1024-QAM. 5G's amplifier chip is RTC66568. 2.4G external four FEM chip, model RTC66266, 2.4G maximum rate of 1147Mbps. Our receiver can load 248 units, to meet our requirement (load 150 Mobile). By openwrt system code override.

Requirements

- The receiver unit should have 512MB of DDR4 memory for efficient data processing.
- The receiver unit should support the load of up to 248 units to meet the requirement of accommodating 150 mobile units.
- The receiver unit's firmware should be based on the OpenWRT operating system, allowing for customization and code overrides to meet specific requirements.

2.6 Software Subsystem Requirement

This subsystem ensures that the signal range requirements in the high level requirement can be met, and because of the optimized architecture used in the backend, we expect to make the system more responsive. This subsystem, on the one hand, acts as the client that sends the signal, on the other hand, acts as the management side that processes the database information and finally displays the statistical results. It can receive data from the wireless receiving subsystem.

2.6.1 Frontend Design

The frontend design of our software system skillfully integrates the Electron framework with the React library for cross-platform development. Utilizing React, a JavaScript-based library, our team can efficiently develop user interfaces in a componentized manner, creating both coherent and highly interactive interfaces. This component-based architecture significantly enhances the reusability of code and ensures consistency in appearance and functionality across different platforms, regardless of whether users access the application via desktop or mobile devices.

For desktop platforms, including Windows and Mac, the Electron framework aids in transforming the React-based web application into a native-like desktop application, achieving seamless integration with the desktop environment. This allows the application to offer familiar desktop application features while retaining the flexibility and convenience of web technologies. As for mobile platforms, although Electron does not directly support iOS and Android, the use of tools like Electron Forge for packaging can achieve some degree of compatibility with mobile platforms. Such frontend design not only meets the diverse needs of users but also allows for efficient reuse of code logic across applications on different platforms.

2.6.2 Backend Design

The backend design of our software system is engineered to effectively handle high concurrency demands and ensure robust performance. At its core, the system uses MongoDB, a NoSQL database, for its flexibility in handling large volumes of data and its scalable nature, which is essential for accommodating a growing user base and diverse data requirements. MongoDB's schema-less design allows for the efficient storage and retrieval of various types of data, making it a fitting choice for dynamic educational environments.

To manage communication and asynchronous processing, particularly under high load scenarios, the backend incorporates RabbitMQ, a message queue system. RabbitMQ serves as the backbone for handling communication between different services in the backend, ensuring that data processing remains efficient and reliable, even during peak usage times. This approach aids in maintaining the responsiveness and stability of the application, crucial for providing a seamless user experience. The combination of MongoDB and RabbitMQ in the backend is strategic, catering to the need for high performance, scalability, and reliability in handling concurrent operations and data management.

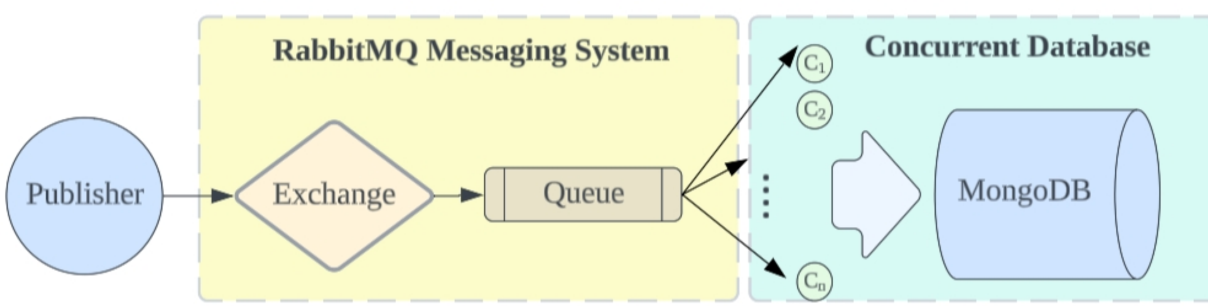

Figure 3: Backend System Diagram

2.6.3 Authentication module

The application includes a robust identity verification mechanism. When a user first logs in on a device, the system automatically recognizes and collects the device's unique identifiers, such as device ID, MAC address, or serial number. Then, during the device registration phase, the user's account information is associated with the unique identifier of the device used and is securely stored on the server. This means each student's account can only be bound to a specific device. When users attempt to log in, the system verifies whether the device identifier being used to access matches the one bound to the account. This mechanism ensures that each account can only be operated on its bound device, effectively preventing the possibility of logging in using someone else's device.

When binding a new device or changing a bound device, the system requires users to go through a secondary verification to confirm the legitimacy of the device binding or change request. Additionally, the system continuously monitors and records the process, including tracking every login attempt and device change activity. Through this continuous monitoring, the system can promptly detect and prevent fraudulent activities like proxy attendance, thereby maintaining the integrity and fairness of the system.

Requirements

- Cross-Platform Development: The software system should utilize the Electron framework and React library to enable cross-platform development, supporting both desktop (Windows and Mac) and mobile platforms.
- The backend design should ensure robust performance and responsiveness, even during peak usage times, to provide a seamless user experience.
- The system should continuously monitor and record login attempts and device change activities to detect and prevent fraudulent activities such as proxy attendance.

2.7 Tolerance Analysis

2.7.1 MongoDB Analysis

MongoDB's robust tolerance capabilities, including features like replication and sharding, are further exemplified by its performance in handling operations efficiently. For instance, in a scenario where 10,000 search operations are conducted, MongoDB's performance is markedly superior, taking only 0.55 milliseconds per operation, compared to 4.47 milliseconds in a traditional SQL database[1]. This efficiency, alongside its flexible write concern levels and schema-less design, highlights MongoDB's suitability for applications requiring rapid data retrieval and high availability. However, it's essential to balance these benefits with effective data governance, especially given the potential for inconsistencies in its schema-less nature[2]. This combination of features and performance makes MongoDB an attractive choice for applications where speed and fault tolerance are critical.

2.7.2 RabbitMQ Analysis

In a teacher-student interactive Q&A application, employing RabbitMQ as the message queue greatly enhances the efficiency and stability of the database system. RabbitMQ's asynchronous message processing accelerates application responsiveness and decouples various system components, such as the teacher and student interfaces, reducing their interdependencies. Additionally, RabbitMQ excels in load balancing, effectively preventing system overloads during peak periods, and offers remarkable fault tolerance by safely storing messages in case of processing failures[3].

However, the introduction of RabbitMQ is not without drawbacks. Firstly, it increases system complexity, necessitating additional maintenance and management, especially for applications aimed at being user-friendly. Secondly, RabbitMQ can become a performance bottleneck in scenarios of high load or heavy message traffic, particularly when message size increases or the number of clients surges. For instance, test data shows that when the number of clients increases from 1 to 20, the average message processing time in RabbitMQ increases from 2 milliseconds to 16 milliseconds. Furthermore, this processing time tends to escalate more rapidly as the number of clients continues to grow[3].

This aspect is particularly crucial in our designed teacher-student interactive Q&A application. Given the potential need to support over 100 student users simultaneously, the increased latency due to a higher number of clients could lead to unexpected delays, failing to meet the minimal response time requirement of 500 milliseconds and adversely affecting user experience. Therefore, ensuring the effective operation of RabbitMQ under high-load conditions through appropriate configuration optimizations and performance testing becomes critically important.

2.7.3 Wi-Fi Analysis

The IEEE802.11 standard operates within a freely available frequency band, such as 2.4GHz, which is shared by numerous wireless technologies, including Bluetooth, 3G, and cordless telephony. This shared frequency environment gives rise to the possibility of signal overlap and RF interference when wireless devices operating within the same band transmit signals.

CSMA/CA (Carrier-sense multiple access with collision avoidance) is a network multiple access method utilized in computer networks. It employs carrier perception to ensure that nodes initiate transmission only when they sense that the channel is free, thereby avoiding collisions. When transmission occurs, nodes transmit their packet data in its entirety, following the successful carrier sensing process.[4]

In our project, the Wi-Fi receiving device, utilizing CSMA/CA collision detection, encountered competition from other routers within the classroom environment. It is worth noting that in areas such as schools, where routers are extensively deployed, only one device on the same channel can receive or send a signal simultaneously. However, in cases where the load capacity of the receiving device is insufficient, the distribution of multiple receiving devices becomes necessary.

In the context of CSMA/CA, the Wi-Fi signal operates on three non-overlapping channels. If the total number of routers exceeds three, it becomes imperative to consider the potential implications of interference and signal-to-noise ratio (SNR). Specifically, the utilization of CSMA/CA may lead to a lower overall throughput.[5]This slower response may pose challenges in meeting the high-level requirement of achieving 100-150 users.

In our project, we employed a research paper's model to estimate the receiver throughput.[6] The model, operating under the assumption of an ideal error-free channel, incorporates various aspects crucial to wireless communication systems. These include arbitrary packet arrival rates, channel access delays due to collisions and other station transmissions, resetting of transmission retry counters, combined media access methods, arbitrary packet length assignment, and the existence of beacon frames. To analyze the system, the interface queue at each site is modeled using an M/G/1 queue, which provides a suitable framework for inspecting our project. This model's comprehensive consideration of relevant parameters and its utilization of the M/G/1 queueing approach contribute to its applicability and effectiveness in estimating receiver throughput accurately.

The probability q, representing the likelihood of an empty message interface queue, can be approximated using the following expression:

$$q = 1 - \rho \tag{1}$$

Under the assumption that the model of the arriving signal follows a Poisson distribution with a rate of λ, we express the probability as follows:

$$p_i = e^{-\lambda T} \tag{2}$$

where the probability p_i is the probability that queue is empty after successful transmission and followed back-off. T is the average time spent by the system at the upper row of the Markov chain.

Additionally, the collision probability (p) in a CSMA/CA network can be approximated using the formula:

$$prob = 1 - (1 - p)^N \tag{3}$$

where p represents the probability of collision, and N denotes the number of contending nodes. These mathematical models enable the evaluation of CSMA/CA-based networks, considering factors such as collision avoidance and channel contention.

A refined formula, derived by combining the three aforementioned formulas and incorporating additional relevant equations, was obtained, omitting the need for explicitly including the transmission probability λ:

$$S = C \frac{(1 - p^l) p_s E[P]}{E[\Psi] + p_s T_s + (1 - p_s) T_c + p^l l (E[B] + T_c)} \tag{4}$$

Where $E[P]$ is the average IP packet length; C is the beacon coefficient; T_s is the average time that the channel is busy due to successful transmission, and T_c is the average time that the channel is busy due to collision; p^l is the probability that the packet will be dropped because the maximum number of retry attempts has been reached; $E[B]$ is the average number of slots required for the back counter to reach zero. $E[\psi]$ is the expectation of a random value; p_s is the probability that the system will successfully transmit.[6]

In the figure below, exponential time periods with a rate of lambda=25 were configured, accompanied by a fixed payload size of 1000 bytes for access. The channel's bit rates were set at 1148 Mbps, and the resulting throughput was examined for verification purposes. Through the calculations performed, it was determined that exceeding 100 clients would lead to sub-optimal optimization of the receiver's throughput. However, despite this limitation, the application requirements could still be met due to the relatively short length of the transmitted signal.

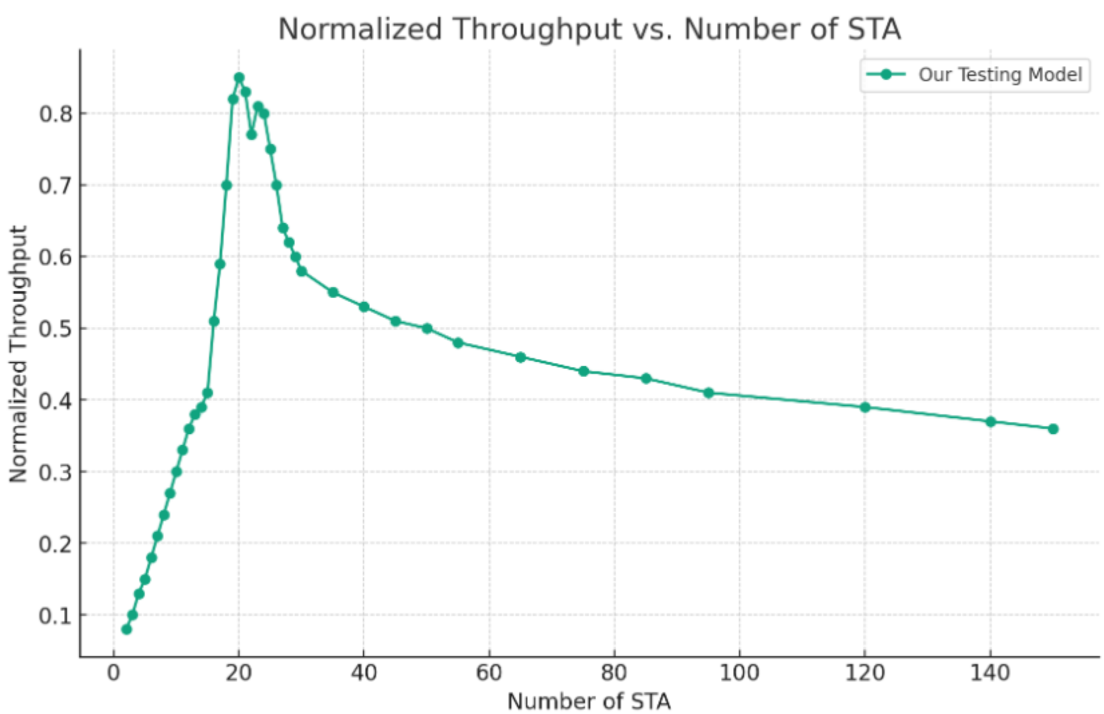

Figure 4: Throughput Vs Number of STA

3 Ethics & Safety

3.1 Ethics

Everything we do is in compliance with the IEEE Code of Ethics.

During the design and development of our products, we always adhere to the highest ethical standards and avoid any violations of the law.We ensure that the privacy of the users of our products is protected, regardless of the transmitting terminal. We guarantee to collect only the personal data we need, including but not limited to account information, device information, location information, locally stored bio metric information, etc. We will use 2.4GHz, 5GHz Wi-Fi as the data transmission medium, and we will strictly control the emission power of the RF module to prevent the radiation from harming the user. This is our adherence to Article 1 of the IEEE Code of Ethics[7].

Based on respect for human rights, our devices are open for use by everyone, regardless of race, religion, gender, disability, age, nationality, sexual orientation, gender identity or gender expression. This is our adherence to Article II of the IEEE Code of Ethics[7].

3.2 Safety

In terms of product safety, our central processing modules use 12V-19V DC. Although the voltage of all equipment is lower than the safe voltage for human beings, we always pay attention to the risk of short-circuits and leakage that may exist inside the electrical equipment, and comply with the safety rules in order to prevent the user from suffering from unintentional electrical injuries.

In order to prevent all accidents that may occur during the operation of the central processing module, as well as to prevent injuries to people, we will design the enclosure to isolate the module from the external environment, and in order to prevent the enclosure from harming people, we will avoid the appearance of sharp bends in order to maximise the protection of the user.

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