

# Design of electronic fence system for shared transportation vehicles

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## ABSTRACT

Nowadays, numerous shared transportation vehicles not only meet users' demand for convenient travel and address the "last mile" problem, but also pose new challenges to operating companies and urban public management. The management method of shared transportation vehicles with recommended parking spots and fixed parking piles has gradually faded out of the market due to unsatisfactory implementation results. Against this backdrop, electronic fence technology has emerged and become the primary technical means for managing the parking of shared bicycles and other transportation vehicles. This paper proposes a new type of electronic fence technology for shared transportation vehicles.<sup>[2,3]</sup> The system is based on a distributed ZigBee network and utilizes the CC2530 chip to build a fence system, achieving parking management and forecasting functions for shared transportation vehicles with low cost and low power consumption. This improves the management efficiency of shared transportation vehicles, greatly reduces the phenomenon of disorderly parking, ensures urban traffic order, enhances user experience, and provides strong support for the construction of urban smart transportation.

**Keywords:** shared transportation ,electronic fence,parking management, ZigBee technology

## I. INTRODUCTION

The launch of shared bicycles and shared electric vehicles has provided a very good solution to the "last mile" problem of transportation for citizens, and has received widespread praise from society. Although these solutions have solved the problem of short distance transportation for citizens from subway or bus stations to their destinations, they have also brought new problems to society. Among them, the technology for managing the return of shared transportation vehicles is obviously flawed, with problems of disorderly parking and placement everywhere. In light terms, it can damage the city's appearance, hinder the

effective use of shared transportation vehicles, occupy public resources, and in severe cases, cause casualties and accidents<sup>[1]</sup>.

At present, there are various management methods for bicycle parking in China, such as recommending parking locations, setting up fixed parking piles for shared bicycles, and electronic fences<sup>[10]</sup>. The recommended parking spot scheme almost relies on the personal qualities of users. Managers only need to set up parking signs in the planned areas to guide users to park, without dedicated fixed hardware constraints. The parking effect of this method is not ideal and the operability is poor. The problem of disorderly parking is still prominent.

With the rapid development of the Internet, the use of electronic fences is rapidly replacing the sharing bicycles with piles in the public view. Based on the Internet and combined with various communication and positioning methods, the electronic fence system sharing bicycles is launched. Virtual electronic fence technology usually refers to an information system that generates virtual signal boundaries through signal and signal feedback and intervenes within the boundaries. The shared bicycle electronic fence system is actually a virtual fence, whose main function is to guide users to park their shared bicycles in the planned area. While regulating user parking, it also improves the utilization rate of shared bicycles. At the same time, combined with the use of intelligent terminals, it does not require more hardware facilities, has strong operability and low cost, and is more easily accepted by the general public. Its application prospects are relatively more extensive compared to the recommended management methods of parking spots and fixed parking piles.

## II. Overview of ZigBee Wireless Communication Sensor Networks

### 2.1 ZigBee Technology

The name ZigBee technology comes from the honey gathering process of bees, which forms a unique shape. The bee colony relies on this unique shape to communicate with each other, conveying information such as the direction and location of food to other bees. The physical and link layers of ZigBee technology mainly adopt the IEEE802.15.4 standard, while the network layer, security protocols, application documentation, and market promotion are mainly handled by the ZigBee Alliance [8]. The long-term goal of the ZigBee Alliance is to establish a scalable, low-cost embedded infrastructure based on interoperable platforms and configuration files.

## 2.2 ZigBee protocol stack

ZigBee protocol stack The structure of ZigBee protocol stack is a layered structure, and each layer plays a different role in the network to achieve different functions. In ZigBee technology, the protocol stack is equivalent to the rules that need to be followed when using ZigBee technology, which is manifested in practical applications as calling function libraries and code to implement design functions.[4] Protocol definition is a series of communication rules and standards, and the ZigBee protocol stack is the specific implementation form of the protocol.

### (1) Physical Layer (PHY)

The complexity of the physical layer design directly affects the complexity of building circuits and the energy consumption used.[7] At the same time, there are various transmission media in the network, and in practical operation, the most commonly used is based on radio frequency circuits. The near surface channel is the most common and typical communication channel, and the closer the antenna is to the ground, the greater the relative loss factor.

### (2) Media Access Layer (MAC)

The medium access layer of the ZigBee protocol stack continues to use traditional CSMA/CA listening access technology, which not only simplifies the application of topology structures but also improves system compatibility.[6] The media access layer provides two types of services, namely data management and layer management services. The main tasks completed are:

- ① The coordinator generates concurrent message frames.
- ② Simplify functional devices to synchronize with the coordinator based on its frame structure.

③ Support for PAN association building cancellation.

④ Shared physical channel.

⑤ Provide a stable data link for two equal MACs.

### (3) Network Layer (NWK)

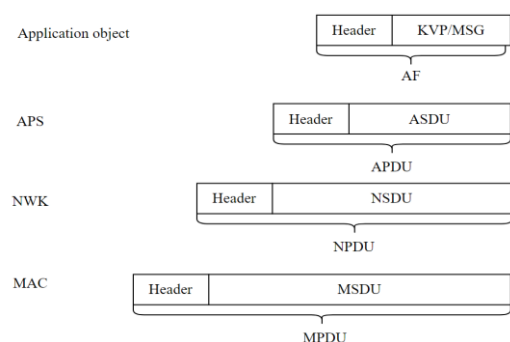
The establishment and maintenance of network topology connections are the main tasks of the network layer, and the routing discovery and handover of devices in the network are also completed at the network layer. At the same time, the network layer also provides some functions to ensure that the layer can work properly and provide interfaces for the application layer.

### (4) Application Layer (APL)

For wireless networks with certain practical applications, the application layer is the core part of the entire network, and the network layer requires designers to develop and apply it. In the ZigBee protocol stack, the application layer is composed of the application support sublayer, device configuration layer, and relevant programs set by users according to their actual needs.

### (5) Application Layer Support Sublayer (APS)

The application support sublayer mainly provides interfaces for the network layer and application layer, generates application data units, and can open or close ports for data reading work. Figure 1 shows the relationship between the frame structures of the protocol layer.



**Fig.1 Composition of each layer frame structure**

## 2.3 ZigBee positioning mechanism

Wireless positioning algorithms based on ZigBee technology can be divided into two types: Range Based (RB) and Range Free (RF) [11]. The distance based positioning mechanism measures the actual distance or orientation between adjacent known nodes and determines the position of unknown nodes through calculation. The RSSI (received signal strength indication) positioning

algorithm is currently widely studied and applied by scholars and institutions at home and abroad.

Due to the high requirement for positioning accuracy in the research content of this article, an RSSI based positioning algorithm is adopted to achieve fence positioning and monitoring. The RSSI positioning process is generally divided into three steps:

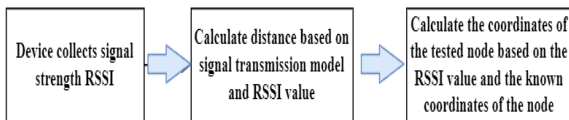


Fig.2.RSSI positioning steps

The relationship expression between the value of signal strength RSSI and distance (1)<sup>[13]</sup>:

$$RSSI = -(10n \log_{10} d + A) \quad (1)$$

In the formula: Parameter A represents the absolute value of the signal strength received at a distance of 1 meter from the location where the signal was emitted; n represents the path loss index; d the distance between the signal transmission point and the receiving node.

This article mainly uses the trilateration method to determine the position. Its principle is that when the distance between an unknown node and at least three beacon nodes is known, a circle is drawn with the beacon node as the center and the distance as the radius. The point obtained by intersecting the circles is the coordinate point of the unknown node<sup>[12]</sup>.

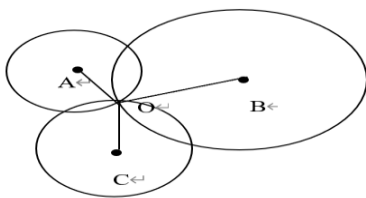


Fig.3.Three sided measurement method

The premise of using the trilateration method is to determine the position information of known points, such as the coordinates of points A, B, and C being (XA, YA), (XB, YB), and (XC, YC). Based on the ZigBee hardware device, the RSSI value can be directly measured, and combined with the loss formula, the distances between the three reference nodes and the unknown test node can be calculated as dA, dB, and dC, respectively. Assuming that the coordinates of the unknown test node are (X, Y), the coordinates of the unknown test node can be calculated according to formula (2).<sup>[5]</sup>

$$\begin{cases} (X_A - X)^2 - (Y_A - Y)^2 = d_A^2 \\ (X_B - X)^2 - (Y_B - Y)^2 = d_B^2 \\ (X_C - X)^2 - (Y_C - Y)^2 = d_C^2 \end{cases} \quad (2)$$

After conversion, formula (2.3) can be obtained to determine the coordinates (X, Y) of the unknown node O.

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} 2(X_A - X_C) & 2(Y_A - Y_C) \\ 2(X_B - X_C) & 2(Y_B - Y_C) \end{bmatrix}^{-1} \begin{bmatrix} X_A^2 - X_C^2 + Y_A^2 - Y_C^2 + d_C^2 - d_A^2 \\ X_A^2 - X_C^2 + Y_B^2 - Y_C^2 + d_C^2 - d_B^2 \end{bmatrix}$$

In an ideal situation with minimal external interference, three circles should intersect at one point. However, in practical applications, due to differences in the environments where the three nodes may exist, the degree of signal attenuation may vary, resulting in significant errors in the final RSSI value. In order to solve the above problems in practical application, it is generally considered to increase the number of known reference nodes to reduce errors and improve positioning accuracy.

### III. Design of ZigBee based electronic fence system

#### 3.1 Overall Design of Fence

The ZigBee based regional wireless positioning and monitoring system has a wide range of applications and has received widespread attention from the market and major companies in recent years. This article designs an electronic fence system that standardizes the parking and effective utilization of personal shared transportation vehicles, effectively solving the problem of disorderly parking and placement of shared transportation vehicles and providing guidance to users during the borrowing process to a certain extent.<sup>[4]</sup> While effectively managing, it can also reduce the investment costs of manpower and materials, increase the utilization rate of shared transportation vehicles, and achieve efficient dynamic management. Figure 4 shows the workflow of the electronic fence system.

The electronic fence system uses ZigBee technology as the communication carrier and combines intelligent terminals to dynamically manage the parking of shared transportation vehicles. After completing self-organization from the ZigBee network, users can search for the location of the fence on their smart terminal devices and check if there are still parking spaces available. This way, users can choose different fence areas for parking or borrow transportation according to the situation. If there are remaining spaces, users can park their shared transportation vehicles inside the fence and arrange them according to regulations.<sup>[9]</sup> At this time, users can

complete the settlement work by entering the fence. If the user fails to successfully list the shared transportation vehicle, the system will issue a return reminder. If the user ignores the correct return reminder and continues to lock the car, the system

will take additional dispatch fees and reduce the user's reputation points as punishment measures.



Fig.4. Workflow of electronic fence system

### 3.2 Fence Hardware Design

#### (1) Design of Dedicated Right-Turn Lanes for Motor Vehicles

Nowadays, a large number of enterprises have joined and participated in the development of relevant standards in the ZigBee Alliance, such as Amazon, Google, Apple, Huawei, Panasonic, Philips and other international first-line enterprises that we are familiar with. And with the development of the ZigBee Alliance, these enterprises are constantly launching ZigBee solutions that suit their own characteristics. Currently, there are three main ZigBee implementation solutions [12]. The above three ZigBee solutions each have their own characteristics, as shown in Table 1.

Table. 1 Characteristics of ZigBee Solution

ZigBee Solution Name	advantage
MCU and RF dual chip	High flexibility
Integrated MCU and RF single-chip	Easy to develop and takes up less space
Dual chip of coprocessor and MCU	High flexibility and shortened product launch time

Although each of these three solutions has its own advantages, based on the main characteristics of ZigBee systems and user needs, integrated single-chip solutions are the main recommended solutions for major enterprises and an important development trend. From the current market environment, mainstream integrated single chips include TI's 2530, Jennic's JN5139, Freescale's MC1322X provided in Platform In Package form, and Ember's EM357. This article will compare several chips from the aspects of microcontroller, current loss in receiving and transmitting modes, built-in flash RAM, and signal reception sensitivity.

From Table 2, it can be seen that the CC2530 chip has low current loss in both receiving and transmitting modes, and its built-in flash memory speed is fast, resulting in a fast network operation speed. However, its MCU bit count is low, leading to a lower data processing capability.

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Chip type	MCU	ARM	Flash	Sensitivity	RX/TX
CC2530	8-bit8051	8kB	256kB	-92dBm	24mA/29mA
JN5139	32-bit RISC	96kB	192kB	-96dBm	37mA/37mA
EM357	32-bit ARM Cortex-M3	12kB	192kB	-100dBm	28mA/33mA
MC13224	32-bit ARM7	96kB	128kB	-100dBm	25mA/36mA

comparison of the above chips, the reason for choosing CC2530 chip is<sup>[11]</sup>: ① CC2530 chip can be used with any MCU, and existing MCUs can be

directly used for design during use. ② The microprocessor used in the CC2530 chip is quite common and easy to operate and get started with [11]. It has strong anti-interference ability and good receiver sensitivity. At the same time, TI also provides a free protocol

### 3.3 Design of Fence Communication Node Base Plate

The hardware of each node in a ZigBee network mainly consists of two parts: the core board and the expansion board. The core board is the smallest application system in the CC2530 chip, which includes chips, RF circuits, and crystal oscillator circuits, while the expansion board may have differences due to different node functions.

#### (1) Design of Gateway Node Expansion Board

The gateway node is the core of the entire network, and serial communication needs to be carried out at the gateway node, so the expansion board should be designed with serial port functionality. In order to display the network status and control effect more clearly, simulator interfaces, power circuits, LED indicator lights, and reset circuits should be designed on the expansion board. The main structure is shown in the figure, which is a physical diagram of the gateway node.

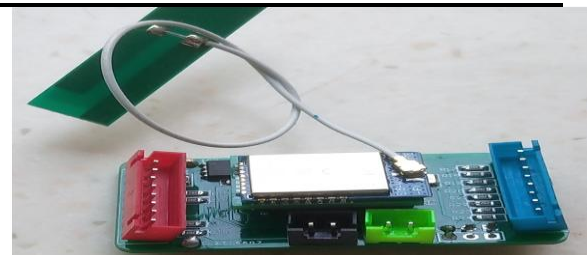
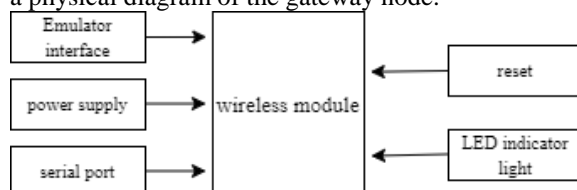


Fig.5.Hardware diagram of gateway node

#### (2) Design of Mobile Terminal Node Expansion Board

The mobile test node is a movable node device that does not require serial port, reset, or simulation functions. In order to facilitate use and embedding, it is designed to be powered by batteries,

and the node should have data transmission and reception functions. The hardware diagram can refer to the gateway node, and Figure 6 is a physical diagram of the mobile terminal node.

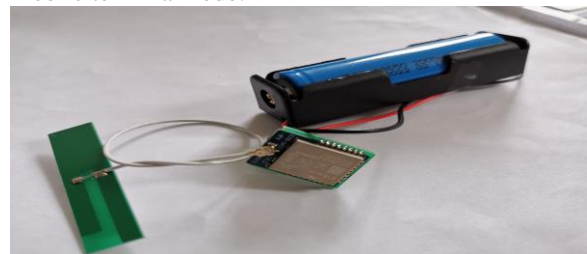


Fig.6.Schematic diagram of intersection safety island setup

## IV. Software Design for Electronic Fence System

### 4.1 Software Development Platform

The electronic fence system design in this article uses IAR Embedded Workbench software developed by IAR Systems in Sweden. This software is an integrated development environment that includes a full software simulation program, allowing users to simulate the software's operating environment without any external hardware support.

The terminal nodes, routing and coordinator nodes in this system use CC2530 chips as microprocessors, and the development platform uniformly uses IAR7.51 to design and run software. The main function of router nodes is to relay and transmit data packets<sup>[12]</sup>, and the code is basically unchanged, which can use existing code in the protocol stack. The implementation code for both the terminal node and coordinator is completed in the application layer of the Z-Stack protocol stack.

#### 4.2 Terminal Node Software Design

Terminal nodes are an important component of the fence system, and their network access status is used to determine whether shared transportation vehicles have entered the fence and take the next steps. The terminal node establishes task events and triggers event handling functions, calling underlying programs such as the network layer, circuit layer, and power layer to complete tasks such as data transmission and sleep.

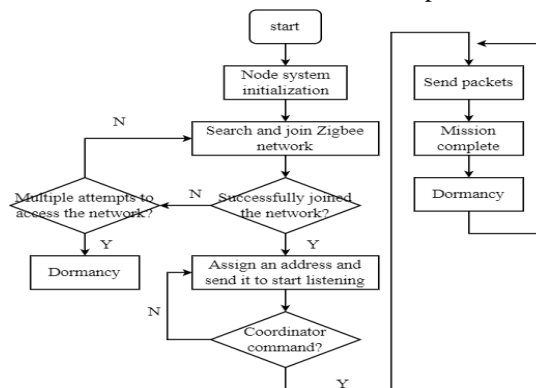


Fig.7.Workflow of Terminal Node Software

As shown in Figure 7, the main task of the terminal nodes in the electronic fence system is to participate in network access communication, send information data wirelessly to the coordinator, and also receive operation commands sent by the coordinator. After power on reset, the terminal nodes will perform initialization and a series of network access operations.

#### 4.3 Router Node Program Design

The ZigBee routing function is implemented on the Z-Stack protocol stack network layer. The router can search for the

optimal transmission path for each data frame and transmit the data information to the target node. The routing algorithm provided in Z-Stack has high applicability and is the core of routers. Routers improve the flexibility of the network<sup>[13]</sup>. When a node in the network fails, the router will avoid this path and find a new network connection.

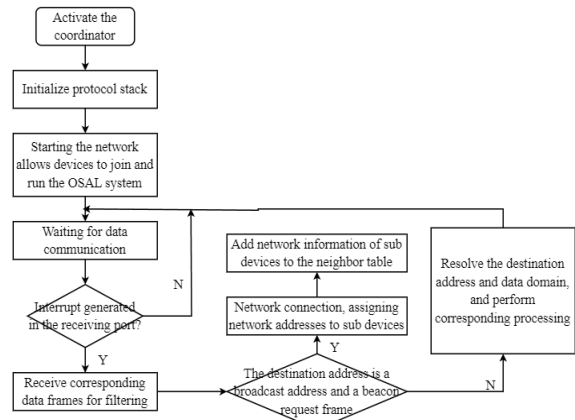


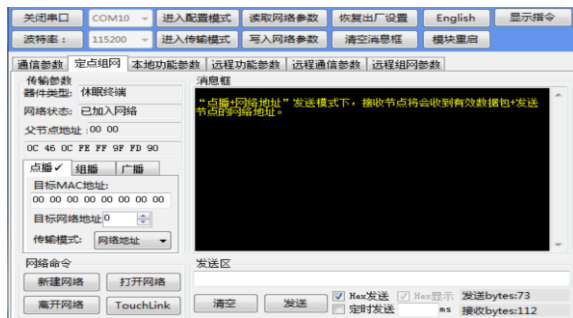
Fig.8.Coordinator Node Networking Flow Chart

As shown in Figure 8, during the networking process, the coordinator first determines whether it has coordination function, detects the existence of other networks nearby, and establishes a new network communication channel; Next, configure the network parameters to determine the PAN ID of the network; Finally, start the coordinator and run the new network, allowing terminal devices and routing devices to join the network and participate in communication.

## V. System Validation and Conclusion

### 5.1 Network construction communication testing

First, select the port number, set the serial port baud rate (default 115200), and open the serial port. Secondly, determine the node type, build a network based on the coordinator, modify the network channel, PAN ID<sup>[2]</sup>, and transmission power. Finally, modify the parameters of the terminal node. Its PAN ID and transmission channel parameters must be the same as the network to be joined. When the network status shows that the terminal node has successfully joined the network, it represents the successful design of the system. The testing process is shown in Figure 9.



**Fig.9. Terminal Node Joining Network Diagram**

From the process of network construction mentioned above and the successful integration of terminal nodes into the ZigBee network, it can be seen that terminal nodes in the fence design system can join the ZigBee wireless network composed of coordinators to participate in communication and monitor the entry status of shared transportation vehicles.

## 5.2 Conclusion

The ZigBee module designed in this article is mainly divided into three parts: coordinator, router node, and mobile node. The nodes are deployed in corresponding positions according to their functions, and the communication function between each node is implemented according to the program written at the application layer.

This article analyzes various electronic fence technologies for existing shared bicycles from the beginning to propose an electronic fence system based on wireless communication network ZigBee technology. Through specific design of the functions of the upper computer, network, and intelligent terminal, it provides a detailed introduction to the application of this technology in the electronic fence system of shared transportation tools. At the same time, it is hoped that ZigBee technology can be more widely applied in related fields while technology is developing.

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