Journal of Computers Vol. 33 No. 5, October 2022, pp. 95-107
doi: 10.53106/199115992022103305009

A Low-Power Remote Information Monitoring System of Cold Chain Logistic Based on NB-IoT

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Received 13 December 2021; Revised 3 February 2022; Accepted 3 March 2022

Abstract. With the development of information technology, cold chain logistics monitoring systems are widely used in transportation of fresh food to detect the quality parameters in real time. Poor network transmission performance, high packet loss rate and high maintenance cost are the main problems in the current cold chain logistics monitoring. To solve these problems, the paper presents a low-power monitoring system based on Narrow Band Internet of Things (NB-IoT). Considering the characteristics of the moving carriage, the polling mode of Bluetooth is proposed for the communication of one sink node to three sensor nodes. An improved working sequence is designed to reduce the power consumption of Bluetooth modules. Subsequently, analyzing the standard NB-IoT terminal state transition diagram, combining with the practical applications of cold chain logistics, an improved terminal state transition diagram is proposed and its terminal power consumption is analyzed. In the experimental test, the packet loss rate is less than 1% within 8 km. And the battery life of improved Bluetooth module is 143 times of that of traditional one. The power consumption of main service of NB-IoT is discussed, the formula is given which includes the transmission quality, random access times, number of concurrent users, sleep interval and other parameters. Through simulation and calculate, the battery life of terminal is up to 17 years. These improvements will greatly reduce the cost of cold chain logistics monitoring system. In addition, the packet loss rate test experiment proves the high reliability of the communication system.

Keywords: information monitoring system, NB-IoT, low-power consumption

1 Introduction

Monitoring system is widely used in life with the development of information technology. Cold chain logistics monitoring system is one of the typical applications, which is used to detect the temperature, humidity, oxygen concentration, carbon dioxide concentration and other parameters in the mobile carriage in real time to ensure the fresh food quality in the moving carriage. With the improvement of living standards, people have higher and higher requirements for food quality, especially fresh food. However, there are many problems in the current cold chain logistics monitoring, such as poor network transmission performance, high packet loss rate and high maintenance cost. Therefore, it is essential to develop a monitoring system with high reliability and low cost.

Considering the communication performance of the cold chain logistics monitoring system, there are two modes: the short-distance communication between the sink node and the sensor node in the car, and the long-distance communication between the sink node to the monitoring center. Currently, the main short-distance communication technologies include Wi-Fi, ZigBee and Bluetooth [1]. 4G and low-power wide area network (LPWAN) are main long distance communication. Xing proposed a greenhouse intelligent information monitoring system using ZigBee wireless sensor. The system used ZigBee wireless sensor to collect field environmental parameters and realized centralized monitoring, data display, data storage, and data mining [2]. Shen enabled traffic information detection using Bluetooth communication, to transmission of vehicle position, speed information via Bluetooth [3]. Cao studied the embedded tracking and monitoring system of cold chain transportation process, and uses wireless sensors to collect data [4]. G. Derekenaris studied the integration of GPS / GIS / GSM technologies [5]. Jose Santa designed a perfect information communication platform, which can identify the identity of vehicle drivers and plan driving routes [6-7]. Yu put forward a remote monitoring system of meat cold chain logistics integrating GIS/GPS technology [8]. Liu proposed a cold chain monitoring and tracking system of agricultural products based on WSID and WebGIS [9]. Xiaoling Wang proposed a real-time monitoring design of cold chain logistics based on RFID and GPRS technology [10]. Heling Shao proposed a remote monitoring system based on ZigBee wireless sensor network and GPS positioning technology [11]. LoRa and NB-IoT are representative technologies of LPWAN [12]. NB-IoT is a new 3rd Generation Partnership Project (3GPP) wireless access

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technology designed to achieve excellent performance through traditional GSM and LTE technologies [13-15]. It requires a minimum system bandwidth of 180 kHz for downlink and uplink communication. In the downlink, it adopts a sub-carrier interval of 15 kHz, which is the same as the existing LTE, as well as a downlink multi-access mode using Orthogonal Frequency-Division Multiple Access (OFDMA) technology [16-18]. The physical channels and signals of NB-IoT are time-division multiplexed. In common cases, NB-IoT supports a data rate of 160-200 kHz for uplink and a data rate of 160-250 kHz for downlink. The coverage is 18 km in cities and 25km in suburbs. Apart from those, NB-IoT also boasts low manufacturing cost, long service life, and wide coverage. For this reason, it has been applied in various fields [12-13, 19]. NB-IoT is regarded to be a very important technology and a large step for 5G IoT evolution [20-21]. Industries, including Ericsson, Nokia, and Huawei, have shown great interest in NB-IoT as part of 5G systems, and spent lots of effort in the standardization of NB-IoT [22-23] which has been widely considered as a main technique for next-generation wireless communications. Some scholars have devoted themselves to the research of NB-IoT technology [17-18, 24]. L. Huikang and his team studied the relationship between the layout of sink node and network lifetime [17]. Pilar Andres Maldonado team researched the effect of channel design on the user's battery life [18]. The technology begin to be more and more widely used in people's lives, such as remote meter/equipment reading, asset tracking, intelligent parking, intelligent agriculture, etc. References [24-25] studied the application of NB-IoT in massive data transmission. The application of location function was studied in literature [13]. Other application based on NB-IoT such as smart hospital, shipping, information monitoring, traffic lights are developed [25-26]. To sum up, the data communication between sensor nodes and sink nodes in the cold chain logistics carriage belongs to short-distance communication. Wi-Fi technology needs self networking, so the cost is high, and it is rarely used in cold chain logistics monitoring system. The transmission distance of ZigBee depends on the transmission power, ranging from hundreds to thousands of meters. The theoretical value of transmission rate is 250kps, and the actual value is generally 20-30kps. The transmission distance of Bluetooth is only about 10 meters, and the transmission speed is 1.8M/s ~ 2.1M/s.

Therefore, ZigBee is widely used in smart home, while Bluetooth is used for special short-distance information transmission. So Bluetooth technology is the most suitable short-distance communication mode in data acquisition for cold chain logistics carriage.4G has high power consumption and high traffic cost, which is not suitable for non real time communication. Nb-IoT and LoRa are typical representatives of LPWAN in license frequency band and unlicensed frequency bands respectively. Compared to LoRa, NB-IoT can utilize the current 3G/4G network to save the network cost and shortens the developing time with the license frequency band, so we use the NB-IoT technology in long distance communication between the moving carriage and the monitoring centre.

Three main contributions of this paper can be summarized as follows: (1) An improved polling mode is proposed in Bluetooth module. In this mode, the sink node received the data of each sensor node in turn. A sleep time slot is added to the idle slot in the working sequence of the Bluetooth module of the sensor node to effectively reduce the power consumption. Under the new working sequence, the battery life is 143 times that of the traditional mode. (2) A new state transition diagram of NB-IoT terminal is proposed. The connected mode is divided into RACH (random access channel) state and Tx/Rx (transmission/reception) state in the new transition diagram. Through simulation and calculation, the new scheme can effectively reduce the circuit power consumption and prolong the battery life to several years. (3) A new terminal power consumption of NB-IoT calculation scheme is derived, which includes the transmission quality, random access times, number of concurrent users, sleep interval and other parameters. There are three service of NB-IoT, namely periodic automatic reporting service, abnormal automatic reporting service and software upgrade/reconfiguration service. This paper discussed the power consumption of the most important periodic automatic reporting service and give the calculation formulas.

The remaining paper is organized as follows. Section 2 describes the proposed method, including the communications of each module and improved low-power consumption design. Section 3 presents the experimental results and analysis. Finally, Section 4 presents conclusions.

2 Proposed Scheme

According to the NB-IoT technology, the proposed scheme consisted of four layers: data acquisition layer, communication layer, application layer and use layer, as shown in Fig. 1. The data acquisition layer includes sensor nodes and sink nodes. The sensor node is a detection terminal, which converts the surrounding environmental parameters into electrical signals through various sensors. The sink node is used to receive and summarize the information of sensor nodes, and then send it to the monitoring center. The sink node is generally put on the mobile carriage. There are 6 sensor nodes and 2 sink nodes in our experiment as shown in Fig. 2. The communication layer refers to the communication of the sink data and NB-IoT base station and BDS/GPS. The IoT cloud platform is the application layer. The monitoring centre is the user layer.

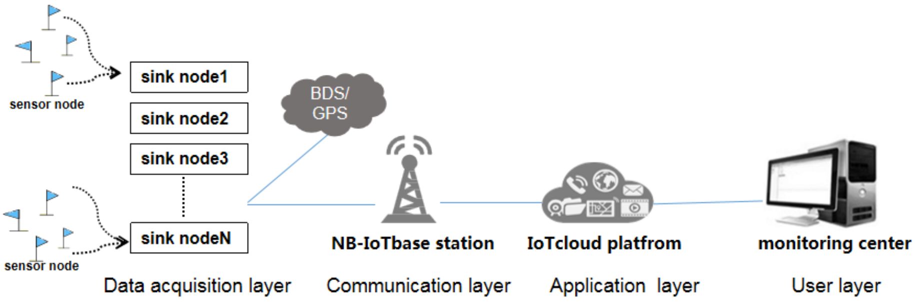


Fig. 1. Network frame of the remote monitoring system

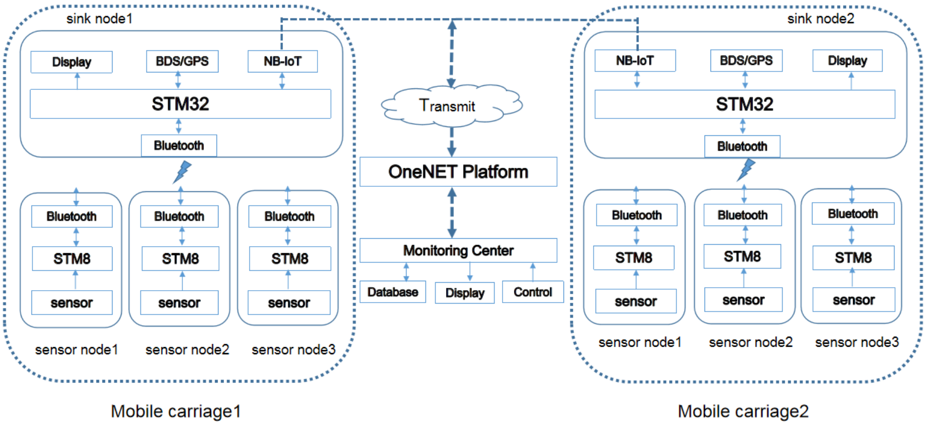


Fig. 2. Block diagram of the remote monitoring system

2.1 Communications

The communication of modules includes three parts: the first is the communication between sensor nodes and sink nodes, the second is the communication between sink nodes and the cloud platform, and the third is the communication between monitoring centre and the cloud platform. Obviously the sink node is the core of all communication. The main program flow chart of the sink node is shown in Fig. 3. The software design of the sink node mainly focuses on three subprograms: NB-IoT subprogram, Bluetooth subprogram and BDS/GPS subprogram. After the initialization of each module, the main program will be looped in each module subprogram to address each module in real time. The watchdog is added to the main program to reset the program to prevent the program from getting stuck or running away.

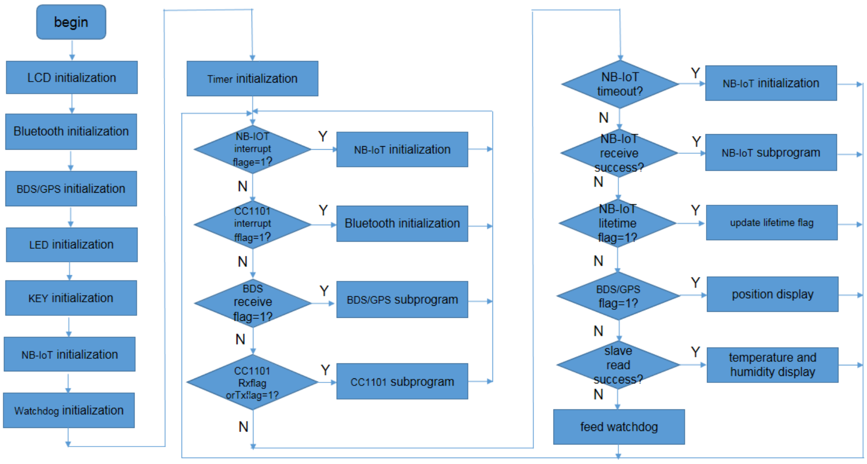


Fig. 3. Main program flow chart of the sink node

The NB-IoT subprogram is shown in Fig. 4. First, if the life period is 3600 second, the timer will determine whether it exceeds 3600. If yes, the NB-IoT module will be initialized. If no, the program continues to determine whether the receive flag bit is 1. If it is 1, the reception is completed, the data must be sent, and the receive flag should be cleared and over. Otherwise, the life cycle flag will be determined, if it is 1, it indicates that the time is over, and the new request of update the life cycle should be sent. The two flags are activated in the timer interrupt and UART interrupt. The sink node cannot simultaneously receive the data of multiple sensor nodes because the original data will be covered after the new data is received. A polling method is designed to solve the problem of data loss. The flow of the communication of the sink node and sensor nodes is shown in Fig. 5. Bluetooth module CC1101 in the sink node accesses data of one sensor node every second. There may be data transmission errors because the sensor node is not in the transmission range and does not respond when the sink node sends a request, so sink node CC1101 should set up the response timeout mechanism of the sensor node. After successfully shaking hands with the sink node, each sensor node sends data in turn.

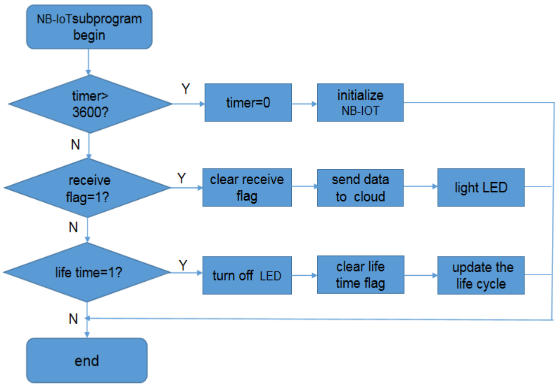


Fig. 4. Flowchart of the NB-IoT subprogram

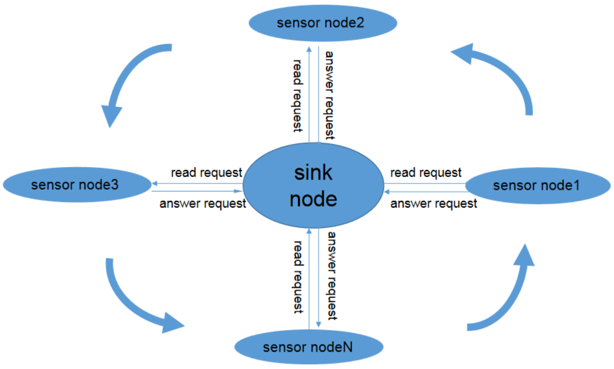


Fig. 5. Polling method of the sink node and sensor nodes

OneNET platform is a NB-IoT cloud platform developed by China Mobile Communication Company (CMCC). It can communicate with multiple sink nodes and simultaneously read data from multiple sink nodes by multithreading as shown in Fig. 6. We should login in the platform 'https://open.iot.10086.cn/' to register the device name for each sink node. Then, we add the objects for each device, number of points and properties of each object. In our experiment, there are three objects in each device: temperature, humidity and generic sensor, which describes the location information. Finally, the data type of each object should be described. According to the Internet Protocol for Smart Objects (IPSO) Alliance Technical Guideline, the Longitude, the object IDs of the latitude, humidity and temperature are 3300, 3303 and 3304, respectively. The instruction format is described in detail in the manual datasheet. After the NB-IoT module is connected to the OneNET platform, the platform will record the life cycle of the sink device (the life cycle is configured for 3600 s in the initialization). When the life cycle expires, the OneNET platform will issue a life cycle update request, and the sink node can update the life cycle. Otherwise, the sink node can actively update the life cycle before the life cycle expires. In this paper, the life cycle is automatically updated, and the life cycle update flag is activated by setting a certain time through the timer. During the life time, the NB-IoT and cloud platform can communicate.

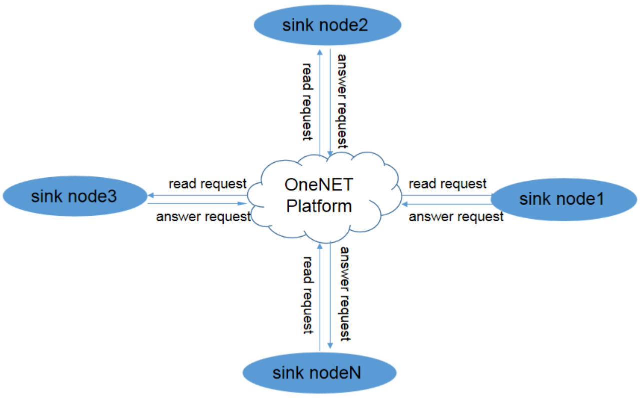
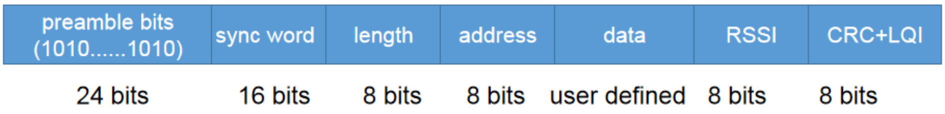


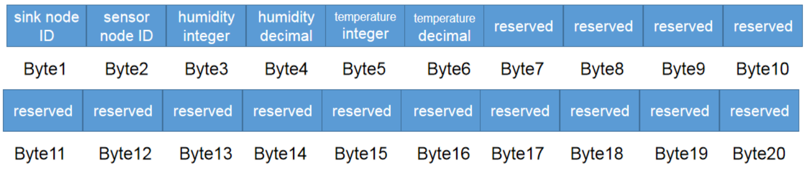
Fig. 6. Communication diagram of the cloud platform and sink nodes

The sensor node has a simpler software than the sink node. The software includes two parts: to read the humidity data and temperature data of DHT11 and to drive the Bluetooth module to send these data to the sink node. In Bluetooth communication, the data sent by the sink node is not only received by one sensor node but received by all sensor nodes within the communication range. Therefore, the sensor node cannot determine whether to respond to the request of the sink node. Thus, the data must carry the identifier of the sink node and one of its sensor nodes. Each frame includes the preamble bits (24 bits), sync word (32 bits), data field and end field (16 bits) as shown in Fig. 7. The data field is designed and shown in Fig. 8. Fourteen bytes are reserved for adding other sensor data in the future. The “answer” instruct may not include data field, and the length of frame is 72 bits. The length of other instructions is 232 bits.



preamble bits (1010......1010)	sync word	length	address	data	RSSI	CRC+LQI
24 bits	16 bits	8 bits	8 bits	user defined	8 bits	8 bits

Fig. 7. Communication frame of CC1101



sink node ID	sensor node ID	humidity integer	humidity decimal	temperature integer	temperature decimal	reserved	reserved	reserved	reserved
Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7	Byte8	Byte9	Byte10
reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
Byte11	Byte12	Byte13	Byte14	Byte15	Byte16	Byte17	Byte18	Byte19	Byte20

Fig. 8. CC1101 Data field of the communication frame

The monitoring centre is developed with C++ language and realizes four main functions: 1) according to the longitude and latitude coordinates obtained from the cloud platform, it can display the location of the mobile carriage (sink node) in real time; 2) it can display the real-time temperature and humidity in the carriage; 3) it can dynamically draw the temperature and humidity change line chart; 4) Using the database to manage the collected data, it can save the historical data for data analysis.

2.2 Improved low-power Consumption Design

Professor Deborah Estrin, who worked in the Embedded Network Sensing Center of UCLA, gave a famous special lecture on the development and research of wireless sensors (Wireless Sensor Networks Part IV: Sensor Network Protocols) at the top conference in the field of wireless and mobile communication (Mobicom) held by the American computer society (ACM SIGMobile). In the fourth part of the report, the energy consumption of each module of the node is described as Fig. 9. shown and analyzed in detail [24]. After a lot of experimental verification, the energy consumption of each part of the node is shown in Fig. 9. module, not the power consumption of the processor and sensor.

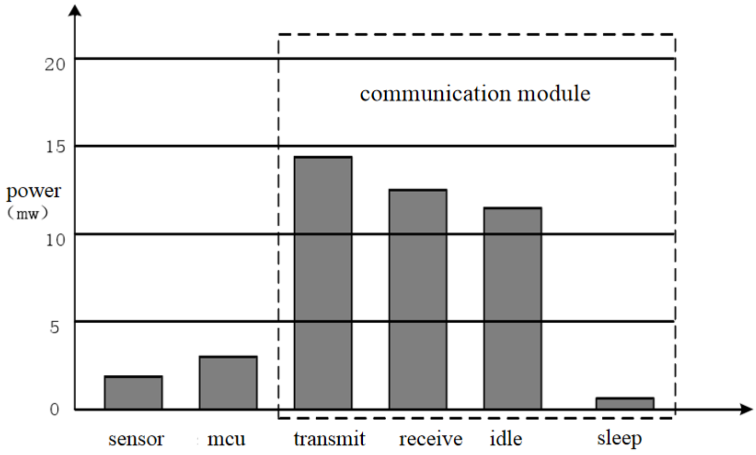
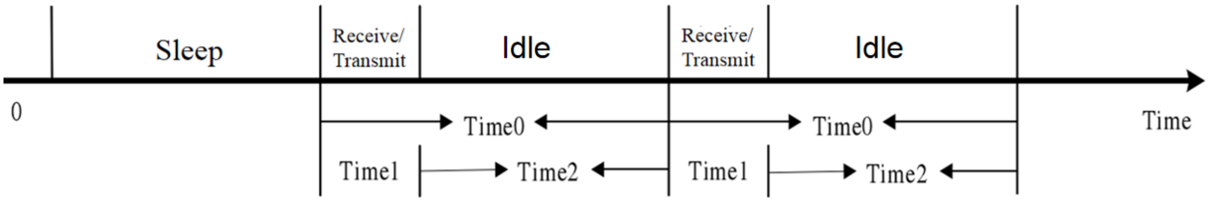
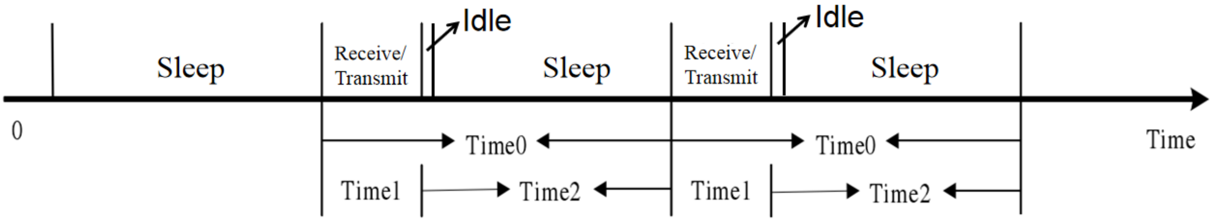


Fig. 9. Energy consumption distribution

Thus, the main power consumption of the sensor node and sink node circuit system is concentrated on the communication module, so the energy consumption of the sensor node is mainly considered by the communication module, not the power consumption of the processor and sensor. We design the program to make CC1101 sleep most of the time in a communication cycle and only wake up in a short period time to receive or send data. Thus, the power consumption of the system can be minimized to ensure the accurate and reliable transmission of data. Fig. 10(a) is the standard working sequence. Fig. 10(b) is the improved working sequence of our design.



(a) Standard working sequence



(b) Improved working sequence

Fig. 10. Working sequence of CC1101 Bluetooth

Besides, we use an improved low-power consumption scheme in NB-IoT. According to 3GPP Release 13, the service of NB-IoT includes three kinds: periodic automatic reporting service, exception reporting service and software upgrade/reconfiguration service. The latter two services rarely occur, so this paper mainly discusses the first service. PSM (power saving mode) and eDRX (extended Discontinuous Reception) are two main technologies in NB-IoT to achieve low-power consumption. The former is to add a new state PSM (sub state of idle) in the idle state. In this state, the transceiver and access functions are turned off, which is equivalent to the partial shutdown state (but the core network retains the user context, and the user does not need to attach /PDN when entering the idle/ connected state) to reduce the power consumption of the antenna, radio frequency and signal processing. The advantage of PSM is that it can sleep for a long time, but its disadvantage is that it cannot respond to MT (called) service in time. It is mainly used in the business with low real-time downlink requirements such as instruments. Latter is an enhancement of the original DRX technology. Its main principle is to support longer-period paging monitoring to achieve the purpose of power saving. The advantage of eDRX is that it has better real-time performance than PSM, but its power saving effect is worse than that of PSM, i.e., compared with PSM, eDRX greatly improves the accessibility of the downlink communication link. Fig. 12 is shown the improved state transition diagram of NB-IoT sink node terminal while the Fig. 11 is the traditional state transition diagram. Starting from each trigger cycle, the transition relationship between states can be summarized as follows. 1) When the sink node terminal is in PSM state (S1), the terminal goes into sleep and starts the sleep timer T_P. If the timer expires, the terminal will send a random access application to the network. 2) When the terminal is in RACH (random access channel) state (S2), the terminal will apply for random access. If the number of random access failures reaches the threshold R_{max} specified by the system, the terminal will return to PSM state (S1) and wait for the next trigger cycle, because it means that the current channel quality is extremely poor. If the random access is successful, the terminal will enter TX / RX state (S3) for data transmission and reception. 3) When the terminal is in T_X state (S3), if the data transmission is successful, it will directly return to PSM state (S1) for sleep; if the number of data transmission failures reaches the threshold N_{max} specified by the system, the terminal will enter idle state (S4) after the N_{max} transmission failure. 4) When the terminal is in idle state (S4), the terminal starts the timer T_i and monitors the channel, waiting for the base station to feedback the data response packet (ACK). If it receives the response packet, it will directly return to PSM state (S1); if it does not receive the ACK at the end of Ti timer timing, the terminal will try to perform random access again (S2).

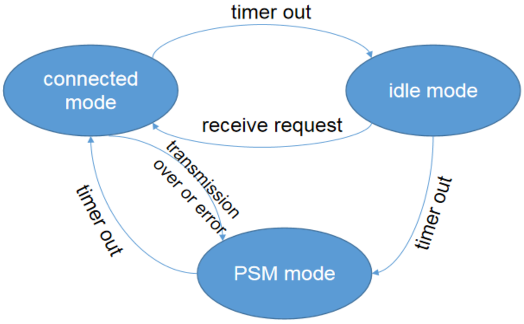


Fig. 11. State transition diagram of NB-IoT terminal

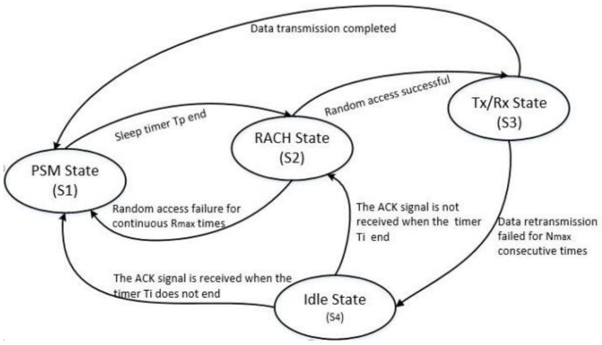


Fig. 12. Improved state transition diagram of NB-IoT terminal

Suppose that the probability of each random access failure is p_r and the average back off time is T_r, and the time of receiving feedback information after each successful random access follows the exponential distribution of parameter λ_r . The failure probability of each data transmission is p_t and the average retransmission time is T_{arq}, and the time of receiving ACK response packet after each successful data transmission follows the exponential distribution of parameter λ_t. Let P_{kl} denote the transition probability of the terminal from state S_k to state S_l,

$k, l \in \{1, 2, 3, 4\}$. As shown in Fig. 12, the probability transition matrix of Markov model can be expressed as fomula (1).

$$P = \begin{bmatrix} 0 & P_{12} & 0 & 0 \\ P_{21} & 0 & 1 - P_{21} & 0 \\ 1 - P_{34} & 0 & 0 & P_{34} \\ 1 - P_{42} & P_{42} & 0 & 0 \end{bmatrix}, \tag{1}$$

where, P_{12}=1, $P_{21} = p_r^{R_{max}}$, $p_r = 1 - e^{-m/n}$, n is the number of random access preamble resources, m is the number of concurrent users, m/n indicates the current degree of network congestion, and the larger the m/n is, the more serious the current degree of network congestion is. In this paper, the state of $m/n > 1.0$ is regarded as the state of network congestion. $P_{34} = p_t^{N_{max}}$. p_t is related to the transmission environment and reflects the quality of the current transmission environment. The higher the p_t value is, the worse the quality of the current transmission environment is. Let q_k denote the steady state probability of state Sk, $k \in \{1, 2, 3, 4\}$, then q_k>0 and

$$\sum_{k=1}^{4} q_k = 1 \ , \tag{2}$$

the steady state probability of each state can be expressed as formula (3).

$$\begin{cases} q_1 = \frac{1+P_{21}P_{34}P_{42}-P_{34}P_{42}}{3+P_{34}+P_{21}P_{34}P_{42}-P_{21}-P_{21}P_{34}-P_{34}P_{42}} \\ q_2 = \frac{1}{3+P_{34}+P_{21}P_{34}P_{42}-P_{21}-P_{21}P_{34}-P_{34}P_{42}} \\ q_3 = \frac{1-P_{21}}{3+P_{34}+P_{21}P_{34}P_{42}-P_{21}-P_{21}P_{34}-P_{34}P_{42}} \\ q_4 = \frac{P_{34}-P_{21}P_{34}}{3+P_{34}+P_{21}P_{34}P_{42}-P_{21}-P_{21}P_{34}-P_{34}P_{42}} \end{cases} . \tag{3}$$

Let $E_p(k)$, $D_p(k)$ denote the terminal average consumption and average delay respectively in state Sk, W_k, T_k denote the power and the average duration respectively.

Here, $k \in \{1, 2, 3, 4\}$. Then the terminal average power E_p and average delay D_p are expressed as formula (4).

$$\begin{aligned} E_p &= \sum_{k=1}^{4} q_k E_p(k) \ . \\ D_p &= \sum_{k=1}^{4} q_k D_p(k) \ . \end{aligned} \tag{4}$$

Here, $E_p(1)=W_1T_1=0$. This is because this paper studies the power consumption and delay of data transmission starting from each trigger cycle, that is, the cycle service is triggered when the sleep period TP expires, so the average duration is 0. Formula (5) is the average access failure times.

$$\begin{aligned} E_p(2) &= E_{RACH}\bar{R} \ . \\ \bar{R} &= \sum_{j=0}^{R_{max}} j(p_r)^j \ . \end{aligned} \tag{5}$$

E_{RACH} is the consumption required for the terminal to send a random access application. Formula (6) is the average times of transmission.

$$E_p(3) = E_{TR}\bar{N} \ . \qquad \bar{N} = \sum_{j=0}^{N_{max}} j(p_t)^j \ . \tag{6}$$

E_{TR} is the consumption required for the terminal to send and receive data once. $E_p(4)=W_4T_i$.

Suppose that the terminal triggers the service when the sleep timer T_P expires (that is, after the end of sleep), then the average delay time of state $S1$ is $D_p(1)= 0$. The average delay time of state $S2$ is shown as formula (7).

$$D_p(2) = \left(1 - p_r^{R_{max}}\right)\left(T_r\bar{R} + \int_0^{T_r} t\lambda_r e^{-\lambda_r t}\,dt\right) + P_r^{R_{max}} R_{max} T_r \ . \tag{7}$$

The average delay time of state $S3$ can be expressed as formula (8).

$$D_p(3) = (1 - P_t^{N_{max}})(T_{ARQ}\bar{N} + \int_0^{T_{ARQ}} t\lambda_t e^{-\lambda_t}dt + P_t^{N_{max}} N_{max} T_{ARQ} \ . \tag{8}$$

The average delay time of state $S4$ can be expressed as formula (9).

$$D_p(4) = \int_0^{T_i} t\lambda_t e^{-\lambda_t}dt + \int_{T_i}^{\infty} T_i\lambda_t e^{-\lambda_t}dt = \frac{1-e^{-\lambda_t T_i}}{\lambda_t} \ . \tag{9}$$

The terminal power consumption E is shown as formula (10).

$$E = \frac{T_L}{T_p}E_p + T_L W_1 \ . \tag{10}$$

The battery life L is shown as formula (11).

$$L = \frac{E}{\frac{E_p}{T_p} + W_1} \ . \tag{11}$$

3 Experimental Results and Analysis

At first, we put a sink node and its three sensor node in a mobile car. Then we drove the car around the downtown, countryside and remote area. Meanwhile the monitor centre receives the information from the sink node. In downtown, the communication distance is about 12 km, the buildings have little effect on the test, because the NB-IoT use sub-GHz band. In remote area, the communication distance is less than 10 km because of the weak signal. Unlike the 2.4 GHz band, the sub-GHz band consists of lower frequencies which therefore experiences lower attenuation and multipath fading caused by obstacles and dense surfaces such as concrete walls as modeled by the Friis formula given by

$$L = 20 \times \log_{10}^{4\pi df/c} \ . \tag{12}$$

where L represents the approximation attenuation, d represents the distance between the transmitting and receiving antennas, f and c represent the frequency and the speed of light respectively. The transmission power of the RF circuit is 13 DBM, the antenna gain is 3 dB, and the transmission rate is 3.9Kbps. Each test point continuously sends and receives 1000 data packets. After the comparative analysis of the data packets at each point, the transmission distance and packet loss rate of the system are obtained in Fig. 13.

As can be seen from Fig. 13, the packet loss rate of the whole network is less than 1% within 8 km, and the packet loss rate is 0% within 400 m. In lecture [27], the packet loss rate is about 10% within 1 km in WiFi, Zigbee or LoRa communication network. So compared with the traditional ZigBee and WiFi networking mode, the system can realize high reliable long-distance networking communication. The latency and mobility performance are affected by the NB-IoT life cycle. The shorter the life cycle, the shorter the delay, the better the mobility, but the power consumption of the system will increase. When the life cycle is 1 second, the communication delay is about 2-3 second.

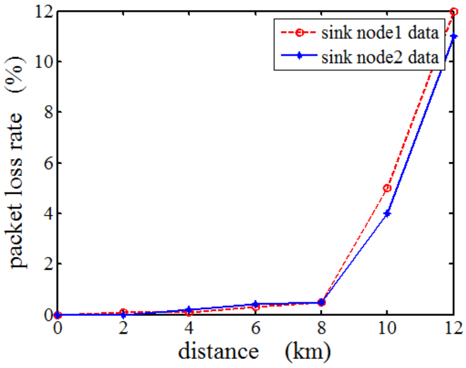


Fig. 13. The relationship of the distance and packet loss rate

We test the actual circuit. The parameters of CC1101 are a carrier frequency of 433 MHz, a baud rate of 100 kbps, and a modulation mode of 2-FSK. The working current of CC1101 under different working modes is shown in Table 1.

Table 1. CC1101 working current

Mode	Theoretical current	Actual current
Data transmission	29 mA	40.5 mA
Data reception	17 mA	15.28 mA
Idle	17 mA	15 mA
Sleep	0.5 uA	1 uA

In Fig. 10, Time0 is the total time of a communication cycle, Time1 is the time when CC1101 works in the receiving mode or transmitting mode, and time2 is the time when CC1101 works in the sleep mode in the cycle. The data transmission power of wireless communication is 0 dbm. The communication period is 1 second.

For CC1101 of the sensor node, it should answer the request and send data to CC1101 of the sink node in each communication period. Thus, we can calculate as follows: the baud rate is 100 kbps, the length of send data is 72 bit+20 Byte, and the length of receive data is 72 bit.

Receiving time of one frame:

$$T_r = 72/100k = 0.72\,ms \quad . \tag{13}$$

Transmitting time of one frame:

$$T_t = (72 + 20 \times 8)/100k = 2.32\,ms \quad . \tag{14}$$

Under the standard working mode: For the convenience of calculation, we assume that both receiving and idle currents are 15 mA,

$$I_{av} = 40.5 \times 2.32/1000 + 15 \times [1 - 2.32/1000] = 15.059\,mA \quad . \tag{15}$$

One 5000-mAh battery is used to supply power to the node. The working time of CC1101 is 332.03 hours, which is approximately 14 days.

Under improved working mode: the same parameters are used

$$I'_{av} = 40.5 \times 2.32/1000 + 15 \times 0.72/1000 + 1 \times 10^{-3} \times [1 - 3.04/1000] = 0.1058\, mA \ . \quad \textbf{(16)}$$

The same 5000-mAh battery is used to supply power to the node. The working time of CC1101 is 47258.98 hours, which is approximately 5.39 years. Performance improvement times is 47258.98/332.03=142.3.

The fundamental reason why such a good improvement effect can be achieved is that the working current of sleep mode is far less than that of idle mode, resulting in that the average working current of Bluetooth module in improved mode is far less than that in standard mode. This means that if the Bluetooth module works in improved mode, a 5000-mAh battery can be used for 5 years, while it can only be used for 14 days in standard mode, which can greatly reduce the maintenance cost of the sensor node circuit. Therefore, our design achieves the low-power consumption of the Bluetooth module in the sensor node.

Next, we analyze the power consumption of NB-IoT. According to the formula (1)-(11), we should set the parameters as Table 2. Like the lecture [28], we set the parameters as Table 3. Let R_{max} = 8 which is the number of random access failures, N_{max} = 8 which is the number of transmission failures, and m/n = {0.5, 1.0, 2.0} denotes {less, critical saturation, and excess} number of concurrent users, respectively. Let p_t = {0.1, 0.5, 0.8} denotes {good, middle, worse} quality of the data transmission channel. Considering the application of the monitoring system, let T_p = 0.5 *h*, simulation and analysis are given as Table 3. If let T_p = 5 *h*, simulation and analysis are given as Table 4.

Table 2. Parameters set

Parameter	Value
E	5 Wh
W_1	0.02 mW
W_4	100 mW
E_{RACH}, E_{TR}	0.05 J
$1/\lambda_r$, $1/\lambda_t$	5 ms
T_r, T_{ARQ}	8 *ms*
T_i	64 *ms*

Table 3. NB-IoT terminal power consumption

R_{max}	N_{max}	m/n	p_t	T_p/hour	L /year
8	8	0.5	0.1	0.5	17.51
8	8	0.5	0.5	0.5	11.92
8	8	0.5	0.8	0.5	4.50
8	8	1.0	0.1	0.5	8.91
8	8	1.0	0.5	0.5	7.23
8	8	1.0	0.8	0.5	4.37
8	8	2.0	0.1	0.5	3.97
8	8	2.0	0.5	0.5	3.61
8	8	2.0	0.8	0.5	2.19

Table 4. NB-IoT terminal power consumption

R_{max}	N_{max}	m/n	p_t	T_p /hour	L /year
8	8	0.5	0.1	5	28.32
8	8	0.5	0.5	5	24.95
8	8	0.5	0.8	5	17.89
8	8	1.0	0.1	5	23.27
8	8	1.0	0.5	5	21.34
8	8	1.0	0.8	5	16.89
8	8	2.0	0.1	5	14.73
8	8	2.0	0.5	5	13.95
8	8	2.0	0.8	5	12.11

From both tables, it means that the fewer concurrent users and the better data transmission quality, the smaller terminal power consumption and the longer battery life. The number of random access failures and that of transmission failure are 8. Obviously, if the number is less, the power consumption will less, the battery life will be longer. When $T_p = 0.5\ h$, according to theoretical calculation, the battery can be used for up to 17 years. In our monitoring system, it is easy to ensure less concurrent users and good data transmission quality, so the theoretical battery life is at least 10 years. From table 5, when $T_p = 5\ h$, the battery can be used for up to 28 years. Of course, this is unlikely in cold chain logistics, but it is possible in other monitoring systems, such as urban well cover status monitoring.

Summarizing the above experiments, the system realizes stable transmission in the range of 10km. The low-power strategy is used in Bluetooth module and NB-IoT module. Through testing, simulation and calculation, the monitoring system can achieve the purpose of low-power consumption.

4 Conclusions

This paper proposed a LPWAN information monitoring approach based on NB-IoT. In the system, we actualize the sensor node based on Bluetooth communication and the sink node based on NB-IoT communication. The proposed scheme of remote monitoring system was based on the improved Bluetooth working sequence and improved NB-IoT terminal state transition, which can effectively reduce the power consumption of the monitoring system and improve the packet loss rate performance. Through experiments and tests in real scenario, the packet loss rate of the whole network is less than 1% within 8 km, and the packet loss rate is 0% within 400 m. Working under the improved mode, the battery life of the Bluetooth module of the sensor node is 143 times that of the traditional mode. A new state transition diagram of NB-IoT terminal is proposed and a new terminal power consumption is derived, which includes the transmission quality, random access times, number of concurrent users, sleep interval and other parameters. Through simulation and calculation, the new scheme can effectively reduce the circuit power consumption and prolong the battery life to several years.

The scheme of this paper had encouraged experiments and was efficient and practicable in remote monitoring and low-power consumption. However, many aspects, such as the sink node data compression, transmission delay, more sensor node and sensor deployment must be further studied. In future research, optimizing the network structure to reduce its consumption and accomplish end-to-end network will be the main direction of our work.

Acknowledgement

This work was supported in part by the Commonweal Projects of Zhejiang Province (Grant No. LGN20F010001), General Project of Zhejiang Education Department (Grant No. Y201940951), General Project of Zhejiang Education Department (Grant No. Y201942626) and Planning project of Zhejiang Provincial Department of Education (Grant No. 2021SCG350).

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