# A LoRa Communication Network Based On Wake-Up

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## Abstract

**In the past, civilian wireless communication technologies were mainly divided into two categories, one is short-range communication technology represented by Wi-Fi, Bluetooth and ZigBee, the other is cellular communication technology. Both these communication technology can not meet the requirements of most IoT applications. Therefore, LPWANs which designed for IoT applications with low-power, long-distance, and large-scale connectivity have emerged. LoRa, working on the ISM channel, is one of the most famous communication technology of LPWANs currently. LoRaWAN specification matained by LoRa Alliance defines the communication protocol and system architecture for the LoRa communication system. In the architecture of LoRaWAN, the gateway uses the digital baseband chip SX1301 with 49 virtual LoRa channels to accommodate tens of thousands of nodes. However, LoRaWAN does not meet the needs of all application scenarios. This paper proposes a wake-up based LoRa communication network, which utilizes the CAD mode of the LoRa transceiver. The gateway can wake up the node in a short time without consuming too much energy, which effectively improves the real-time performance of the downlink.**

## Keywords

**LoRa, SX1278, CAD, TDMA.**

## 1. Introduction

### 1.1 LoRa

LoRa, proposed by Semtech, is a derivative of chirp spread spectrum (CSS) modulation technology and integrates forward error correction (FEC). While maintaining the same low-power characteristics as FSK, it significantly improves the sensitivity, thus the communication distance. Over the past few decades, CSS modulation technology has been widely used in military and space communications due to its long-range characteristics and robustness to interference, and LoRa is its first low-cost commercial usage. [1] reported the results of LoRa outdoor coverage test, and the results show that the maximum communication distance in the line-of-sight is over 15km. [2] reported the results of the LoRa indoor coverage test, the test was conducted at the main campus of the University of Oulu which has an indoor area spanning for over 570 meters North to South and over 320 meters East to West. The results showed that the whole campus area can be covered by a single LoRa gateway.

### 1.2 LoRaWAN and Its Limitation

LoRaWAN is both a system architecture and a communication protocol. It is released and maintained by the non-profit LoRa Alliance. In theory, any system architecture and communication protocol can be built on the basis of the LoRa physical layer. [3] proposed a LoRa mesh networking system, which achieved better coverage than the star-network topology, but increased the complexity of the communication protocol and the uncertainty of communication delay. When long-range connectivity can be achieved, star-network topology used in LoRaWAN can be applied to more IoT applications. LoRaWAN uses the ALOHA-based MAC protocol and is ideal for IoT applications with low-traffic and sporadic communication requirement. In the LoRaWAN architecture, the gateway is only responsible for transparent transmission of data, and the complexity of the entire network is placed on the network server. The advantage of this approach that it is easy to standardize and reduce the development difficulty of embedded gateways.

However, LoRaWAN still has its drawbacks and cannot be applied to all application scenarios. In some densely communication scenarios, the probability of collision of communication increases due to the randomness of the ALHOA protocol [4]. In some downlink-based applications, such as streetlight control, LoRaWAN does not work well. [5] pointed out that the introduction of downlink traffic will have a significant impact on uplink throughput. And for those who want to build a small, low-cost private network, using LoRaWAN is too wasteful and costly.

### 1.3 Approach

[6] present an approach based on asynchronous TDMA communication protocol which combine the capabilities of short-range wake-up radios together with the long-range connectivity of LoRa, effectively improve the energy efficiency and latency of the LoRa network. But this approach requires an increase in hardware cost, and the wake-up radio can only reach a line of sight of 20 meters indoors, which limits the application scenario. We propose an approach based on the LoRa transceiver's CAD mode instead of wake-up radio, which can achieve farther wake-up distance and save hardware costs. The introduction to CAD's wake-up function is in section 2.3. Next, we introduce the physical layer of LoRa in Chapter 2, in preparation for introducing the LoRa communication network in Chapter 3.

## 2. LoRa Physical Layer

LoRa encodes information using wideband frequency modulated pulses (chirp) whose frequency can varies linearly betwen $f_c - \frac{BW}{2}$ and $f_c + \frac{BW}{2}$ over a certain amount of time, see Fig. 1.

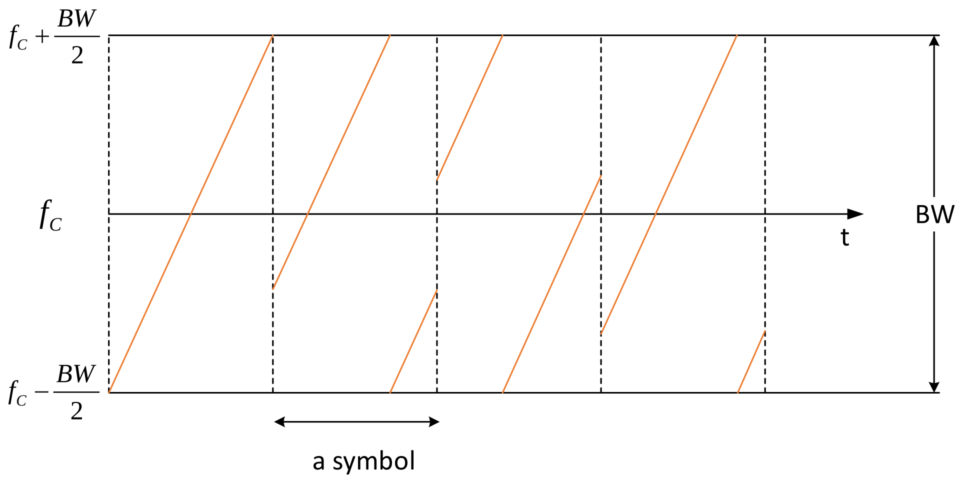


Fig. 1 LoRa Modulation

The advantages of this approach are three-fold :

The sensitivity is significantly increased due to the processing gain of the spread spectrum technique.

Due to the linear nature of the chirp, the frequency offset caused by the low-cost crystal is equal to the time offset and can be easily eliminated, which means that the hardware cost can be reduced.

The LoRa transceiver can demodulate signals up to 19.5 dB below the noise floor for a very long communication distance and more resilient to interference.

### 2.1 LoRa Radio Parameters

There are three main parameters of LoRa modulation, namely bandwidth (BW), spreading factor (SF) and coding rate (CR) [7]. In a LoRa symbol that encodes information of *SF* bits, the frequency varies linearly by $2^{SF}$ times, and the vary rate named $R_c$ is equal to *BW*. From equation 1 we can derive the time of a LoRa symbol named $T_s$ , and then derive the rate of LoRa symbol named $R_s$, see equations 2 and 3.

$$R_c = BW \tag{1}$$

$$T_s = \frac{2^{SF}}{R_c} = \frac{2^{SF}}{BW} \tag{2}$$

$$R_s = \frac{1}{T_s} = \frac{BW}{2^{SF}} \tag{3}$$

LoRa integrates forward error correction (FEC) coding, which means adding some redundant information to reduce the error rate caused by short pulse interference. CR is the FEC coding rate and can be set to either 4/5, 4/6, 4/7 or 4/8. From Equation 3 we can deduce the effective bit rate named $R_b$, see equations 4.

$$R_b = SF \cdot R_s \cdot CR = \frac{SF \cdot BW}{2^{SF}} \cdot CR \tag{4}$$

It can be found from Equation 4 that a higher BW provides a higher bit rate but a lower reception sensitivity (due to the integration of additional noise). Similarly, a lower SF provide higher bit rates but decrease SNR, thus sensitivity and communication range. And, a lower CR provide better robustness but decrease bit rate. Therefore, the transmission data rate and link performance cannot be optimal at the same time, developers can use different combinations of these parameters to make trade-offs based on a specific application scenarios.

## 2.2 LoRa Packet Structure

The LoRa packet contains three elements, a preamble, an optional header and the data payload, see Fig. 2.

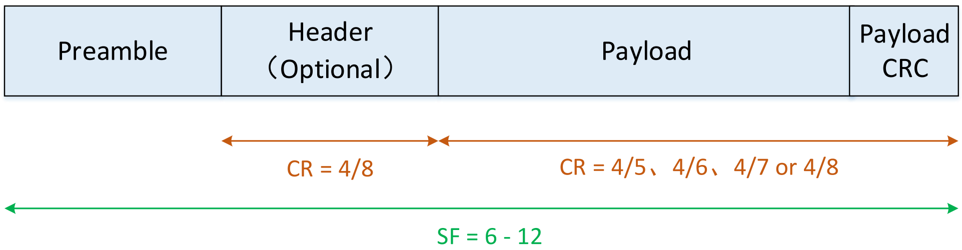


Fig. 2 LoRa Packet Structure

The preamble is used to synchronize the receiver with the signal transmitted by the transmitter, and the length in units of symbols can be programmed. The header contains payload length in units of bytes, CR used by payload and the presence of an optional 16-bits CRC for the payload. In some scenarios, these are agreed in advance, then the header can be omitted to reduce the on-the-air time of the packet. In this article, the header is always explicit.

For a given combination of SF and BW, the symbol time can be calculated by equations 2. And the total on-the-air time of a LoRa Packet can be calculated as below.

$$T_{preamble} = (N_{preamble} + 4.25) \cdot T_s \tag{5}$$

$$T_{payload} = N_{payload} \cdot T_s \tag{6}$$

$$T_{packet} = T_{preamble} + T_{payload} \tag{7}$$

The size of $N_{payload}$ is related to payload length, CR, SF, etc. In this article we use the following settings:

SF = 11,

BW = 125kHz,

CR = 4/5,

preamble length = 6,

maximum payload length = 25.

Through LoRa Calculator (a tool which use equations 5-7 to calculate the on-the-air time of a LoRa packet), we get the maximum time required to send a packet is 790.53ms.

### 2.3 SX1278

The SX1278 is a single-channel LoRa modem chip for the Chinese frequency band launched by Semtech [8]. It is a half-duplex transceiver with five different modes, see Table 1.

Table 1 The Modes of SX1278

| Mode | Power Consumption | Description |
|---|---|---|
| Sleep | 0.2μA | The most energy efficient mode. |
| StandBy | 1.6mA | Ready to TX、RX or CAD. |
| TX | 100mA | Transmit a LoRa packet. |
| RX | 12mA | Receive LoRa packets. |
| CAD | 9mA | Detect LoRa signal in a channel. |

Obviously, the transceiver can only receive data in RX mode or transmit data in TX mode, and once it selects other modes, the receiving or sending will stop. And communication can only be performed when the carrier frequency, SF and BW at both ends of the transceiver are the same. The CAD mode is used to detect whether the current channel contains the LoRa signals with the same SF and BW, which is the key to realize the function of wake-up and Listen Befor Talk (LBT).

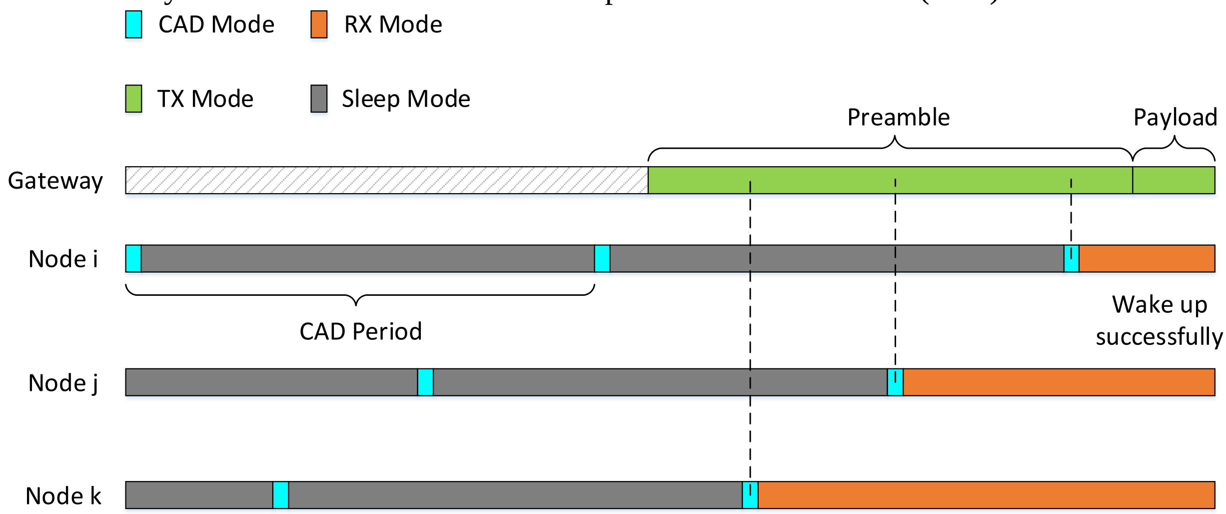


Fig. 3 CAD's Wake-Up Function

Figure 3 is a schematic diagram of the CAD's wake-up function. Node starts CAD mode according to a certain period, and it takes 2 symbols' time to perform detection. If it is not detected that the LoRa signal of same setting, the node starts sleep mode. On the contrary, it starts RX mode. If the gateway wants to wake up nodes, it needs to send a very long packet. The duration of the preamble of this packet should be longer than the CAD period.

## 3. Wake-Up Based LoRa Communication Network

### 3.1 Network Architecture

Before the formal design begins, the type of network topology need be specified first. Due to the limited coverage of short-range communication technologies, mesh-network topology that can increase communication range shine in wireless sensor networks (WSNs). However, the mesh network topology will increase the complexity of the communication protocol and the uncertainty of the communication delay, and the LoRa communication network based on the star-network topology can meet the communication distance requirements of most applications. Therefore, in order to simplify the network architecture and communication protocol, we chose the same star-network topology as LoRaWAN. In the network architecture, there are two kinds of roles, one is the node and the other is the gateway. Transmission between nodes is prohibited, see Fig. 4.

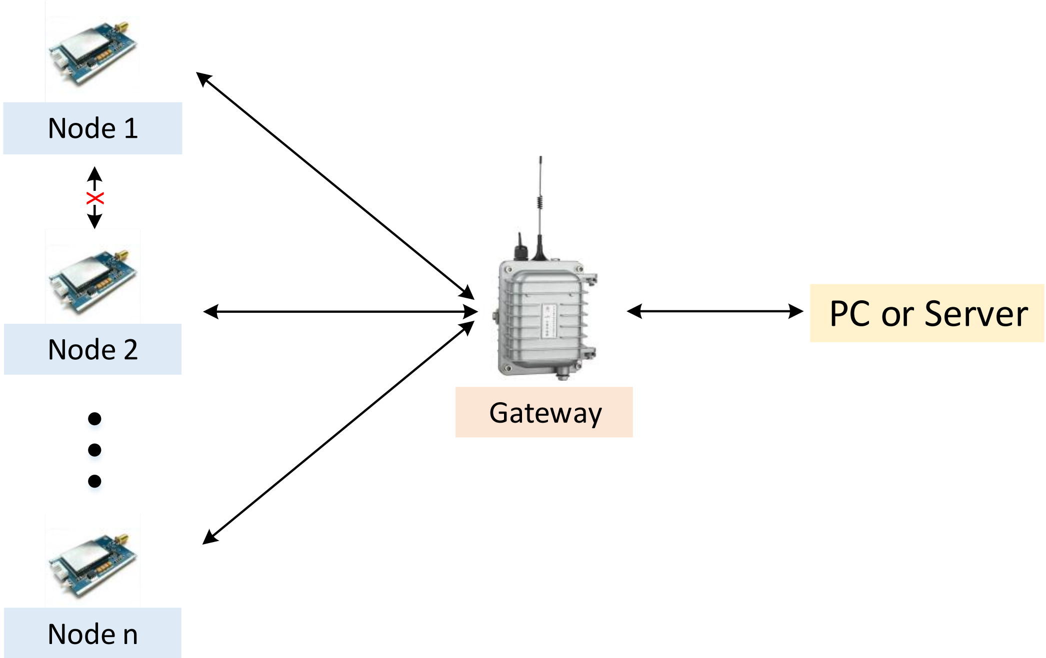


Fig. 4 LoRa Network Architecture

This network uses three different center frequencies to achieve different functions. The first frequency is used to join the network; the second frequency is used to wake up; the third frequency is used to send commands and replies. In this article, they are 432MHz, 433MHz and 434MHz respectively.

The nodes are battery powered and will spend most of the time in sleep mode. The tasks of nodes include :

Send a join-request at 432MHz according to the CSMA protocol when powering up.

Periodically starts CAD mode at 433MHz, waiting for the gateway to wake up.If the node is woken up by the gateway and the ID matches, start RX mode at 434MHz and wait for the command; if the ID does not match, repeat 2).

Execute the command and reply to the gateway at 434MHz, then repeat 2).

The gateway is powered by the power supply and has no energy constraints, therefore, in addition to sending, the other time is always in RX mode. The tasks of gateway include :

Start RX mode at 432MHz, and if the gateway receives a join-request for a node, assign an unique ID to the node and reply to it.

Wake up nodes at 433MHz according to the instructions of the PC or server.

Send command to nodes at 434MHz.

Receive replys from nodes at 434MHz, then repeat 1).

### 3.2 Join the Network

After the node is powered on, it needs to perform the process of joining the network, and this process follows the CSMA protocol. The CSMA contains two aspects :

Listen Befor Talk(LBT) ;

Random delay backoff.

In this article, we use CAD mode to implement LBT, and equation 8 shows the algorithm of random delay backoff.

$$T_B = 2^{n-1} \cdot T_S, (1 \le n \le 5) \tag{8}$$

$T_B$ is the time to backoff, and $n$ is the number of times the competition fails. $T_S$ is the time to send a packet, in section 2.2 we calculated the maximum time required to send a packet is 790.53 millisecond, and the $T_S$ should use 20% of the time as a reservation, so in this paper, we assume the $T_S$ to 1 second.

The join-request contains the address of the node, and the reply contains the ID assigned by the gateway and the address of the node. Fig. 5 illustrates the specific process of joining the network.

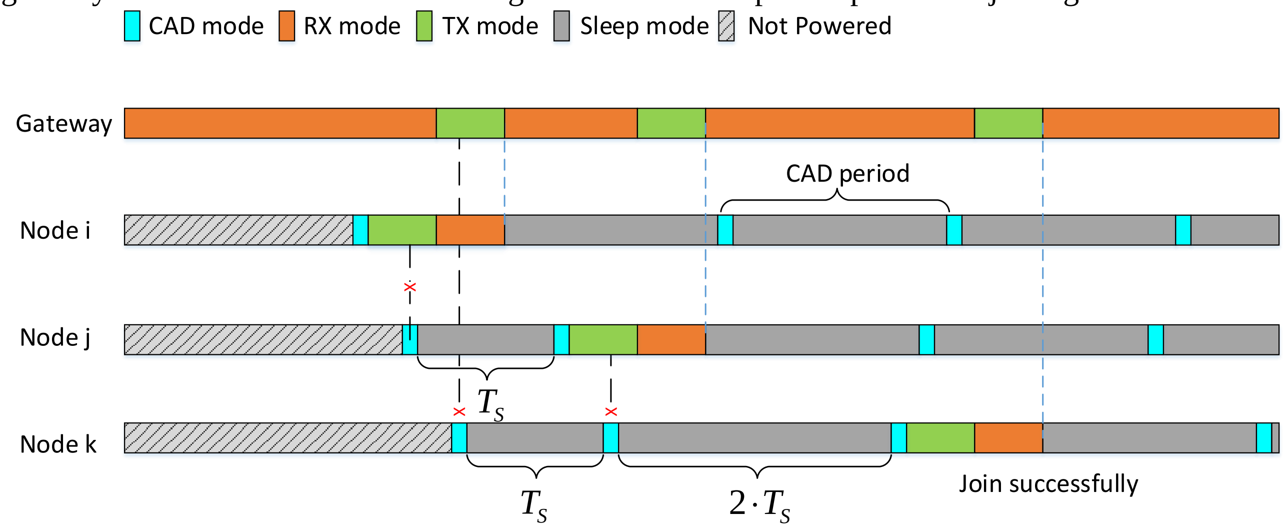


Fig. 5 The Process of Joining Network

## 3.3 Communication Processes

The communication of this network consists of three processes :

Wake-up

Send command

Reply

### 3.3.1 Wake-up

The payload of wake-up signal cotains the ID of the node to be woken up, and all nodes receive this signal during a wake-up process. If the ID match by a node, it change the center frequency to 434MHz and start RX mode. Otherwise, it continue to monitor the wake-up signal at 433MHz. There are two wake-up methods, unicast and broadcast. We specify an ID number as the broadcast ID, and all nodes will wait for the command when they receive a signal containing this ID.

### 3.3.2 Send Command and Reply

The gateway will send a command after sending the wake-up signal. After receiving the command, the node needs to execute the command and reply, see Fig. 6.

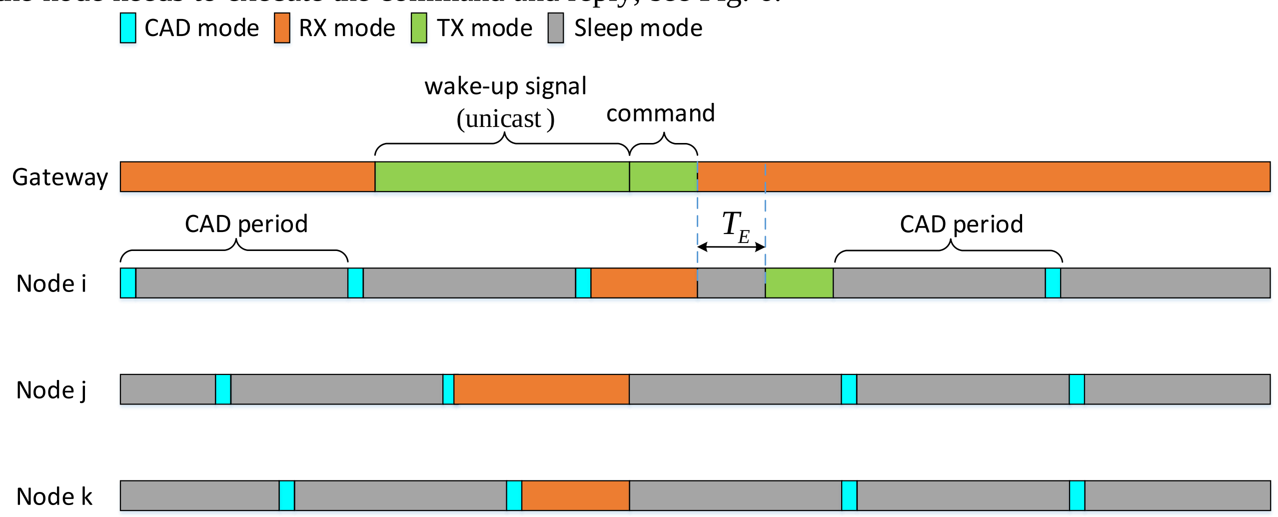


Fig. 6 Communication Process (unicast)

$T_E$ is the time to execute the command, and its value is determined by the specific command.

If the wake-up method is broadcast, there is a problem that multiple devices compete for one channel at the same time. The MAC protocol solves the problem of signal collision and saves energy as much as possible to ensure the robustness and stability of the communication [9]. It can be roughly divided into three categories :

channel-based

pakcet-based

duplexing methods

More specifically, channel-based can be divided into TDMA, FDMA, CDMA, etc; packet-based can be divided into ALOHA, S-ALOHA, CSMA/CD, CSMA/CA etc; duplexing methods includes TDD, FDD, etc. Due to the single-channel and half-duplex nature of the SX1278, in order to maximize the utilization of channel resources and achieve collision-free communication, we propose a TDMA-based MAC protocol in this LoRa network, see Fig. 7.

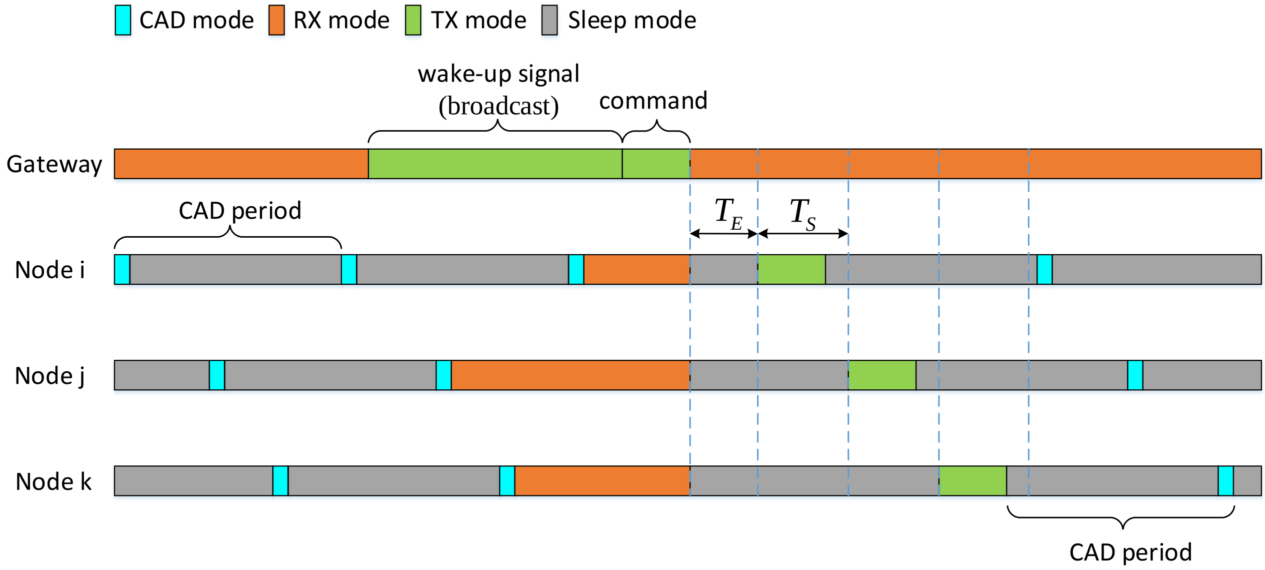


Fig. 7 Communication Process (broadcast)

Suppose the node ID is numbered from 1, we can get the time when each node start to reply, see equations 9.

$$T_W = T_E + (ID - 1) \cdot T_S \tag{9}$$

After all nodes reply, the network can start the next communication process.

## 4. Conclusion

This paper presents a LoRa communication network based on the LoRa transceiver's CAD mode, which can achieve farther wake-up distance and save hardware costs compared with [6] . In the design of the MAC layer protocol, we have designed two according to different needs. The first uses CSMA, which is used for nodes to join the network; the second is TDMA, which is used for multiple nodes to reply at the same time after broadcast wake-up.

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