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An improved communication resource allocation strategy for wireless networks based on deep reinforcement learning

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A R T I C L E I N F O

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A B S T R A C T

With the advent of 5G networks, user demand for high-speed, low-latency, and high-reliability services continues to grow. When traditional communication technologies cannot meet the needs, wireless network LoRa technology has emerged. Although LoRa has low power consumption, Long-distance, and other advantages, terminal nodes still face frequent data collection and energy consumption issues how to more efficiently combine the deep reinforcement learning method for LoRa wireless network communication and allocate resources reasonably and effectively. This paper proposes a communication channel resource allocation strategy based on deep reinforcement learning, the CL-LoRa strategy. It uses extended preamble and low-power interception technologies to achieve on-demand synchronization and low-power communication. The basic idea of this strategy is to detect channel quality based on CAD, coordinate node scheduling, and wireless channel allocation. The node will choose different ways to acquire the channel according to the current network load, namely CSMA-CA competition and dynamic duty cycle communication. In this way, the channel utilization rate is improved, and the energy consumption problem of the long-distance communication data volume is perfectly solved. The duty cycle access method is based on the imbalance of energy consumption in the Internet of Things. It uses the remaining energy of the remote central node to dynamically adjust the duty cycle of the node, wake up the working time of the node, and send more beacons to the sleeping node. Reduce the sleep delay of the node. Through theoretical analysis of CL-LoRa protocol performance, compared with DDC-LoRa protocol and ADC-LoRa protocol, CL-LoRa protocol can increase channel utilization by 9%, reduce terminal energy consumption by 1.6%, and increase throughput by 1.5%.

1. Introduction

The internet of Things (IoT) has received extensive attention and has achieved considerable development. Until now, it has been limited by the technologies that provide IoT, unable to meet scenarios with real-time connectivity, and unable to cope with scalability at the same time., All three conditions cannot be satisfied at the same time, as a result, a mathematical theorem described as Low Power-Wide Region Network (LP -WAN) has developed as a viable option for providing low-cost and minimal connection to end-nodes scattered across a number of different locations. It still lacks a dedicated network protocol. As the name suggests, the Internet of Things is the Internet of Things. Although the mobile Internet and the Internet of Things are both wireless network connections, there is an essential difference between the two. Because of the low power consumption and a wide range of industry has proposed a low power wide area network. There are many network technologies suitable for Low power WAN (LPWAN) [1], including LoRa, Sigfox, LTE-M, LoRa technology, etc. LoRa technology is a radio modulation and demodulation technology suitable for long-distance, low-power, and low-data transmission rate applications. Long Range Radio (LoRa) is a technology that is mostly used in M2M and IoT networks. This innovation will make it possible for public or multi-tenant networks to interconnect many apps that are executing on the very same channel. According to the spreading factor and the frequency of the communications platform, the LoRa Gateway can accept and spread the information with different propagation things simultaneously.

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It's designed for very short sensor packets of data which can be utilized for alerts, triggering, and surveillance. Lora modified communication is impervious to interference and maybe receivable across long distances. The LoRaWAN [2] protocol based on LoRa technology uses a single-hop star topology, reducing power consumption. The LoRaWAN protocol is an LPWAN network. The lifetime of the entire system depends on the terminal lifetime, that is, the energy consumption of the LoRa terminal battery. Effectively reducing the terminal battery's energy consumption can achieve low power consumption. The LoRaWAN protocol still has much room for improvement and optimization on the MAC layer and application layer. The LoRaWAN communication protocol sits on top of the physical LoRa layer. Its nodes are synchronous, which means that only interact when information is willing to send. A system based on an open LoRaWAN protocol, implemented in a star topology, is ideal for applications requiring long-range or deeper in-building connectivity as one of a large number of low-power devices that gather moderate volumes of data. Video adaption at the Medium Access Control (MAC) layer uses selective packet discarding and prioritized transmissions to guarantee that even the most critical video data are routed with the greatest chance over the wireless channel. When the MAC layer planning is allowed, it is possible to achieve a near-zero loss condition in terms of packet losses carried by the base layers, resulting in a peak-signal-to-noise ratio that is highly similar to the original. The application layer defines whether the desired communication requires adequate system resources. All communications between apps necessitate collaboration, which is handled at an application level [3].

As a result, understanding how to use it to lower the power usage of cluster centers through interface refinement and processing methods is critical for the popularisation and use of LoRa methodology in the IoT. The introduction of 5G networks has increased consumer demand for high-speed, low-latency, and high-reliability services. When standard communication technologies proved insufficient, wireless network LoRa technology evolved. Despite the low power consumption of LoRa, terminal nodes encounter frequent data collecting and energy consumption concerns. The duty cycle access approach is based on the Internet of Things' energy consumption imbalance.

As uplink messages may still collide with beacons from neighboring gateways. Therefore, in the 5G network, a LoRaWAN protocol based on CAD channel detection, referred to as CL-MAC, is proposed. The main contribution of the paper is discussed as follows:

(1) We analyze the channel contention mechanism nodes utilizing superframe dormancy to improve the performance of communication in 5G networks and propose an adaptive duty cycle protocol-based medium access control method based on maximizing the use of energy consumption.

(2) We formulate an energy efficiency optimization problem in communications by carefully considering the number of beacons in a wake-up slot when network data is transmitted. In our system model, the node scheduling mechanism is determined by the actual flow and remaining energy. channel allocation is determined based on the network traffic load in IoT to improve energy efficiency.

(3) We then apply a wake-on-air algorithm to solve this energy efficiency optimization problem to maximize energy efficiency while ensuring high system throughput and network longevity to meet high QoS requirements. In addition, the performances of other algorithms are compared to show the feasibility of our proposed solution.

(4) Our numerical results demonstrate that our proposed solution has a significant effect in terms of energy efficiency and system throughput of 5G communication compared to other mechanism solutions.

In the theoretical analysis, the CL-MAC protocol improves the channel utilization and reduces the terminal energy consumption with increased throughput. The rest of this work is organized as follows. Section 2 discusses related work. Section 3 provides a system model and problem formulation for communication in 5G networks. Section 4 presents the social-aware energy efficiency optimization problem and a solution using the wake-on-air technique. Numerical results demonstrating the effectiveness of our proposed method are shown in Section 5. Finally, we summarize this work in Section 6.

2. Related Work

Novel Internet of Things (IoT) categories in order to ensure validity, end-node energy usage, and architecture, including smart buildings agricultural, place significant demands on Radio Access Network (RAN) adaptability.

It is an important factor of a mobile telecommunication system that uses a radio link to connect individual devices to certain other portions of the system. Base stations and antennae which cover a specified region, dependent on its capability, are RAN components. RAN function is provided by silicon chips both in network infrastructure and the user equipment. As of now, the technology used to offer connection to IoT environments, such as wireless sensor networks and communication devices, have not been able to meet all three needs at the same time.

As a result, a unique technology defined as Low Power - Wide Region Network (LP-WAN) [4] has developed a viable option for providing low-cost and reduced connection to end-nodes scattered across a large geographic area. However, terminal nodes face high-load work in many real-world application scenarios and cannot fully utilize energy. The research on LoRa technology at home and abroad mainly focuses on protocols and hardware.

Feng et al. [5] have found the ADC-MAC protocol. The LoRaWAN protocol uses ADC to access channels without duty cycle restrictions in a low-power vast area network. ADC is a simple communication system whereby the transmission of each source in a system provides data whenever a frame needs to be sent. The number of nodes in the ADC protocol could be raised with limited bandwidth, and it also has the ability to reduce transmitter and receiver capacities as well as protocols complexity by minimizing carrier detection. In order to maximize the utilization of energy consumption, medium access control of the adaptive duty cycle (ADC-MAC) protocol is proposed. The basic idea of the protocol is that each sensor node maintains three indicators, including remaining energy, node load, and network congestion rate. Since time synchronization is not required, asynchronous solutions are more comfortable implementing. In a situation that may lead to the nodes' unfairness, the energy efficiency of the nodes and the robustness to changing traffic loads are not considered.

Chen et al. [6] have found the dynamic duty-cycle medium access control (DDC-MAC) protocol in the IoT. See the previous studies. It dynamically adjusts the node duty cycle by calculating node utilization and average sleep delay. The duty cycle is changed in the Duty cycle MAC protocol by taking into consideration the pace of energy usage by nodes and the duration of the filled queues. By eliminating idle hearing, it reduces the time and effort consumed. Sensors with a short duty cycle consume less energy but have longer communication delays, while those with a long duty cycle require more calories but have shorter communication delays. Its shortcomings are that the change in the duty cycle does not take into account energy consumption. If you change it without discretion, it will inevitably affect the network's life and fundamentally cannot solve the load balancing phenomenon in the network.

Huyhnh, et al. [7] propose a social-aware energy efficiency optimization solution for D2D communications in 5G networks. In particular, The EEO problem is then solved for optimal channel mode selection and optimal transmission powers allocated to each MU to maximize the energy efficiency, by utilizing an adaptive genetic algorithm. Simulation results reflected that the Optimized channel mode selection could serve as alternatives to superframe sleep, which inspired us. However, the researchers did not consider the channel competition mechanism.

Liu et al. [8] have found that the channel competition mechanism based on super-frame sleep [9]. Mathematical analysis was performed on network parameters such as the transmission state probability, channel detection collision probability, and the average energy consumption of nodes, which reduced network energy consumption and improved the protocol. The only shortcoming is that we need to suggest a corresponding optimization model analyze and evaluate the performance indicators to make it more extensive. Based on the above research, it is found that the channel competition mechanism is based on superframe dormancy, which is the theoretical basis of the CL-MAC scheme proposed in this paper.

In this paper, we study the problem based on the channel contention mechanism using a deep learning algorithm that fully takes into account the effects of transmission state probability [10], channel detection collision probability, and node average energy consumption [12]. On the basis of previous research, CL-MAC brings a new method of communication resource allocation strategy.

3. System Model and Problem Statements

3.1 Network Architecture

LoRaWAN's network architecture is a typical star topology. A star topology is a structure that is meant to resemble a star, with a central core and several units tied directly to it. A star network topology is being used here, which implies that groupings of mobile nodes are linked to gateways via LoRa wireless networks, and the gateways are coupled to a distant server via an Internet protocol. The router acts as a translucent relaying in this design process, linking the front-end interface devices to the centralized back-end database. As illustrated in Fig.1, the terminating devices connect to one or more access points through a single-hop LoRa or FSK link. All nodes are two-way communications, but uplink communications dominate. We can choose various data rates and different channel frequencies for communication between terminal equipment and gateways.

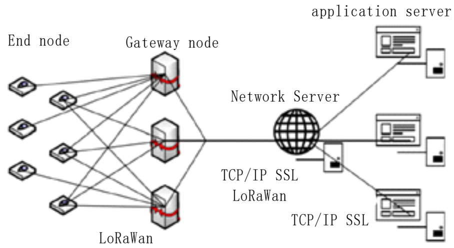

Fig. 1. LoRaWAN network structure diagram

In order to maximize the battery life and the entire network capacity, the LoRa network uses a data rate adaptation (ADR) scheme to control the data transmission rate and the RF output of each terminal device. Adaptive Data Rate (ADR) is a network optimization strategy that optimizes data rates, airtime, and energy usage. An end device's transmission parameters are controlled by the ADR mechanism. ADR can reduce devices' power consumption even while maintaining the delivery of messages to the gateway.

3.2 Energy Consumption Model

Due to the limited energy supply of nodes, the queue of transmitted data is limited. Given the situation, we adopt the typical energy consumption model in studies [11], The energy consumption of the transmitted data is shown in Eq. (1), and the energy consumption of the received data is shown in Eq. (2). In this thesis, the specific Settings of the above parameters are taken from the previous studies.

$$\begin{cases} \beta_{t,1}(l, r) = l\varphi_{elec} + l\delta_{afs} r^2 & \text{if } r < r_0 \\ \beta_{t,2}(l, r) = l\varphi_{elec} + l\delta_{afs} r^4 & \text{if } r > r_0 \end{cases} \tag{1}$$

$$E_{t,r} = l\varphi_{elec} \tag{2}$$

3.3 System Parameters of Duty Cycle

Since the cl-mac technique presented in this dissertation is based on the unequal power usage in the internet of things, how to fully utilize the residual power in the non-hot zone region to raise the operating frequency of the base station, therefore increasing bandwidth utilization.

CL-MAC enables multi-packet, multi-hop, and multi-flow traffic conditions to be managed effectively while responding to a broad range of traffic loads. CL-scheduling mac is based on a different flow preparation packet structure that effectively uses route data to give numerous packets of data via many multi-hop flows [12]. In the IoT, the cl-mac protocol additionally makes use of a number of crucial factors. Suppose that, in order to improve energy, the cluster can frequently switch off the transmitter to snooze based on the set switching frequency.

$$\mathcal{H}^i = \mathcal{T}_{act} / \mathcal{T}_{total} = \mathcal{T}_{act} / \left(\mathcal{T}_{act} + \mathcal{T}_{sle}\right) \tag{3}$$

Based on Eq. (3), $\mathcal{T}_{total}$ - a cycle, $\mathcal{T}_{act}$ - active time of the node, and $\mathcal{T}_{sel}$ - sleep time. A node's energy demand mostly incorporates a wide range. This thesis' framework is comparable to the research. The particular parameters are listed in Table 1. To improve the efficiency of low-power remote communication in the IoT, we have optimized its theoretical analysis. Utilizing a plan to make sure that the networking lifespan stays constant can reduce overall latency while increasing power usage.

Table 1
Parameters of The Duty Cycle.

Symbol	Description	Value
χ_{com}	Cycle	1s
ξ_{tra}	Transmission	0.0511W
ξ_{rec}	Receiving	0.0588W
ξ_{lpl}	LowPower Listening	0.0127W

In summary, maximize $\mathcal{E}_{eff}$, maximize $\mathcal{I}$, minimize $\mathcal{K}^{e2e}$ the optimization target of the thesis can be attained from the subsequent in Eq. (4). The central emphasis is on how to maximize power consumption and decrease latency without reducing the IoT's life points. Initially, a careful examination of 3 basic system outcome measures: latency, power consumption, and networking lifespan. It can be observed that, underneath the assumption of not harming the broadcaster's lifespan, the latency is greatly decreased, the energy demand is decreased to satisfy the reduction, as well as the accessible residual electricity demand, is maximized, resulting in the system reducing the transmitting data latency. It demonstrates the platform's process speed but also versatility.

$$\begin{cases} \max(\mathcal{E}_{eff}) = \max\left[\left(\Sigma_{i=1}^{n}\xi_i\right) / \left(\Sigma_{i=1}^{n} E_i\right)\right] \\ \max(\mathcal{I}) = \max\left[E_i / \max\limits_{1 \le i \le n}\left(\gamma_t^i \varsigma_t^i + \gamma_r^i \varsigma_r^i + \xi_{lpl}^i + \xi_{sen}^i\right)\right] \\ \min\left(\mathcal{K}^{e2e}\right) = \min\left(\sum\limits_{i \in d_k^i} \Gamma_k^i\right) \end{cases} \tag{4}$$

3.4 Problem Statements

Although LoRa has the advantages of low power consumption and long-distance, the terminal node still faces frequent data collection and energy consumption problems. How to more efficiently combine the deep reinforcement learning method for LoRa wireless network communication and allocate resources reasonably and effectively. The problems to be solved by the CL-MAC scheme in this paper are as follows:

(1) Based on the above research, it is found that the channel competition mechanism is based on superframe dormancy [13]. Mathematically analyzes network parameters such as transmission state probability, channel detection collision probability, and node average energy consumption, which reduces network energy consumption and improves the protocol. The only shortcoming is that we need to propose corresponding optimization models to analyze and evaluate performance metrics, making it more extensive.

(2) The whale optimization algorithm (WOA) [14] has recently received a lot of interest from the scientific community as a fast way to address a wide range of optimization issues. We give the essential foundations and binary version of the WOA in this paper, as well as a penalty mechanism for dealing with optimization limitations. In this paper, we show three applications of WOA to resource allocation in 5G networks [17-19]. The Mobile edge computing (MEC) [15] paradigm operates the virtual source with the edge communication between data terminals and the execution in the core network. Swarm intelligence-based and reinforcement learning strategies enable neural caching for memory during task execution. The effectiveness establishes a communication network to improve the quality of service and constructs a cognitive agent model to measure resource allocation [16].

(3) The uplink messages could still collide with beacons from neighboring gateways. Therefore, a LoRaWAN Protocol based on CAD channel detection is proposed, referred to as CL-MAC. The LoRa chip can implement the Channels Activities Detection method, which is known as CAD. We put the LoRa CAD function to the test, using a specialized device to perform the CAD procedure on a regular basis and

then another specialized device to transmit information of varied sizes on a regular basis. Despite this, the LoRa CAD process is capable of successfully detecting all LoRa transmissions, not just the preliminary.

Based on the proposed ADC-MAC and DDC-MAC scheme above, it reduces packet collisions by nearly 20% compared to standard LoRaWAN, but it does not completely eliminate them. With the proposed CL-MAC scheme, packet collisions are nearly reduced by half.

4. Design of The CL-MAC Scheme

CL-MAC protocol is designed to rely on LoRa's low power expenditure of CAD channel activity detection. The node scheduling mechanism is determined by the actual traffic volume and remaining energy. We need to prioritize scheduling nodes with high traffic and low remaining energy. Channel allocation is determined according to a load of network traffic in the Internet of Things. That is to say, for a single node, use the CSMA-CA competition mechanism to access the CAD channel; for multiple nodes, use the Duty Cycle mechanism, which is used to access the CAD channel to achieve synchronization and requires low-power communication. The CPL-MAC protocol is very energy-efficient in low traffic because, at the wake-up time of each work cycle, the node only needs to spend a short time checking the CAD channel.

4.1 Node channel activity detection, access method

The channel is categorized into two as, single-node CAD detection and multi-node CAD detection dependent on LoRa's reduced energy usage. CL-MAC is a hybrid MAC protocol, which refers to the nodes in the network using a combination of contention and scheduling to obtain channels. The core idea is: when a node has data to transmit, the node will choose different ways to get the channel according to the current network load level. The communication is performed at the time of minimum network activity load through CSMA-CA competition mode, i.e., scalable. The hubs interact in a flexible duty-cycle programming manner whenever the channel's communication traffic is heavy, which not only avoids collision and crosstalk between nodes but also improves channel utilization and ensures the stability of the transmission. The advantages of the hybrid protocol are flexible scalability, low energy consumption, and low latency.

CSMA-CA carrier sense multiple access is utilized by the CL-MAC system at the time occurrence of the unique hub. Initially, the network is recognized, then it is determined if the route is active or vacant, then finally, the stream is delivered whenever it's inactive. Once the network is active, delayed back off, and thereafter identify ever since the interval; if the detecting remains preoccupied, back out rather than back off.

Whenever channel competition develops between several nodes, the LoRa-MAC protocol [17] employs a variable duty-cycle load balancing algorithm. Because all hubs are on the same wavelength, the CAD assumes the receptive mode whenever it senses a transmission. If, after successful reception, the received data frame is not sent towards the hub, then it cannot enter the normal working state. If the received data frame is not the local node, continue with CAD detection. In this way, the data frame will not be missed, thereby avoiding collision retransmission as well as improving the communication success rate, as shown in Fig. 2.

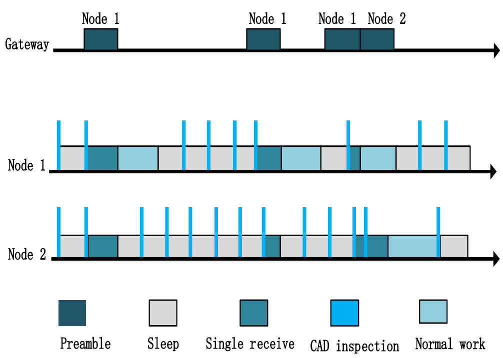

Fig. 2. Single-node and multi-node operating modes

When using CAD communication energy-saving technology, it must be determined according to the actual business volume and remaining energy. That is, nodes with greater business volume and less remaining energy can be scheduled first. According to the network traffic load in the Internet of Things, the channel allocation is determined to realize on-demand synchronization and low-power communication. When wireless transmission occurs, it is necessary to add a preamble code before the user data to make sure the preamble transmission time is greater than the node periodic recognition period.

4.2 Air Wake-Up Technology

In applications of the IoT, nodes are required to sleep as much as possible to minimize power consumption, but nodes need to send and receive wireless data promptly. Based on this situation, we propose air wake-up technology. IoT devices will be able to consume substantially less energy owing to Wake-Up Radio, improving battery life between months or even years. This lowers the number of batteries that end up in landfills every year, which has an influence on the IoT's ecological impact. Even if the node is dormant, when the node needs to work, it can be awakened directly by LoRa wireless technology [18]. This function gives nodes that cannot miss any wireless information, some sleep opportunities, and saves some power. Use the sleep mode to reduce performance to eliminate the extra overhead when the MOS tube is turned on. The method of always supplying power to the radio frequency is adopted. When the radio frequency does not need to work, the MCU drives the radio frequency to enter the sleep state. Therefore, the CL-MAC protocol uses two techniques of the extended preamble besides a low-power interception to attain on-demand synchronization then reduce energy usage.

(1) Preamble Variants

In the air wake-up mechanism, he changed the wake-up probe preamble. Different from the cycle of the ordinary preamble, it is to send the data packet in multiple cycles. CAD detects the preamble part of the data packet to achieve wake-up in the air, combined with the periodic detection time of the node. Wireless nodes will not miss valid data during data transmission.

It desires to set an appropriate preamble transmission period to make sure that the preamble transmission time is higher as compared with the periodic recognition period of the hub, which flawlessly resolves the issue of long-distance, low-power communications with small data volumes in complex environments.

The principle is simply that when wireless transmission occurs [19], a preamble is added before the effective date. The size of the preamble is determined according to the sleep time of the receiving end. The wireless node wakes up periodically, monitors the network, and enters the normal receiving process once the preamble is captured. The sleep time is mainly based on the remaining energy consumption of the node to adjust the duty cycle dynamically. The transmission time of the specific preamble is shown in Fig. 3. The proof process of this transmission is demonstrated in Theory 1.

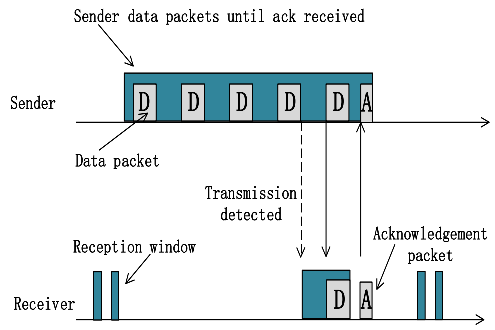

Fig. 3. Schematic diagram of air wake-up with response

Theorem 1: If the time to send each preamble symbol is $\mathcal{S}_{sym}$, $\mathcal{L}_{pre}$ represents the preamble length that has been set, and its value comes from *RegPreambleLsb* and *RegPreambleMsb* bits on the register. Thus, the time to send the preamble can be obtained, shown in Eq. (5).

$$\mathcal{S}_{pre} = (4.25 + \mathcal{L}_{pre})\mathcal{S}_{sym} \tag{5}$$

Proof: The most significant bit of the preamble length is the length of the preamble *PreambleLength*+4.25 symbols. With the iteration processes of Eqs. (6) to(7), it can be easily obtained the symbol period of a single LoRa packet $\mathcal{S}_i$ that is, the time to send a symbol, shown in Eq. (7). $\mathcal{S}_r$ is the rate, *BW* is the bandwidth, *SF* is the spreading factor, $\mathcal{S}_i$ is the time to send a symbol, $\mathcal{S}_{pre}$ is the total time required to send the preamble, $\mathcal{L}_{pre}$ is the set length of the preamble, and $\mathcal{S}_{sym}$ is the length of each preamble symbol time. So we can get Eq. (5).

$$\mathcal{S}_r = BW / 2^{SF} \tag{6}$$

$$\mathcal{S}_{sym} = 1 / \mathcal{S}_r \tag{7}$$

Theorem 2: If the spreading factor *SF* and signal bandwidth *BW* are known, the CAD receiving period can be calculated using the following formula, as shown in Eq. (8). The whole CAD cycle is calculated by Eq. (9).

$$C_{rec}^{one} = \left(32 + 2^{SF}\right) / BW \tag{8}$$

$$C_{rec}^{all} = 1.85 * C_{rec}^{one} \tag{9}$$

Proof: The CAD cycle is divided into two stages: the receiving cycle is the following Eq. (8), and the entire CAD cycle is the above Eq. (9), then the Eq. (9) can be obtained.

Theorem 3: The preamble time $\mathcal{S}_{pre}$ of the sender is greater than the entire cycle C_{rec}^{all} of the CAD, as shown in Eq. (10).

$$2^{SF}(4.25 + \mathcal{L}_{pre}) > 1.85 * (2^{SF} + 32) \tag{10}$$

Proof: There is a prerequisite $\mathcal{S}_{pre} > C_{rec}^{all}$, and by Eq (5) to (9). The Eq. (10) can be proved. Satisfy the above Eq. (8), and this can ensure that the receiver receives data typically.

(2) Low Power Listening

In the CL-MAC protocol, each node is periodically awakened, uses idle channel evaluation, and checks the wireless network to determine whether the current channel is active. If the channel is active, the node remains active to send receive incoming packets. Before data transmission, the sender has a "wake-up signal" called a preamble, which lasts slightly longer than the sleep time of the receiver. This strategy can ensure that the receiver wakes up at least once during the sender's preamble, allowing each node to choose to wake up or sleep according to its remaining energy. The CL-MAC algorithm periodically replaces the large preface including a brief prelude and LPL. This is analogous to switching from the lengthy prologue phase to the LPL phase, which consumes less power. If the recipient awakes throughout the sender's listening session, the information site is down, as well as data must be displayed whenever the transmitter is turned to the prelude phase, consuming less power [20]. Furthermore, CL-MAC entails effective use of the node's transmission power to emit a signal (see in Fig. 4) repeatedly prior to the scheduled up phase, reducing the sleep latency or promoting sustainability. If the residual energy is fully utilized, the networking delay could be lowered even more.

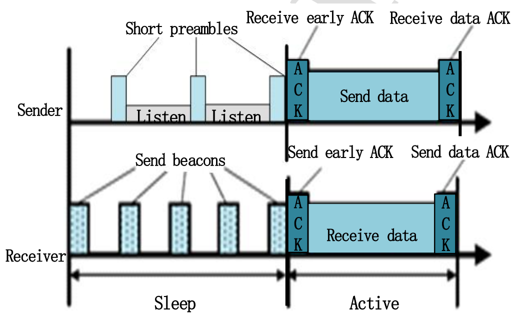

Fig. 4. Timeline of CL-MAC protocol

4.3 *Mechanism of Dynamic Duty Cycle*

Whenever the connection fails, transmission power of the terminals beyond the center zone surpasses 7 0percent of the starting power.

Theorem 4: presume σ_f - the hub with the power usage at the distance central region from *f*, besides they take power is ξ_{fas}^{f}. Let the hub where the distance central region is *i* be σ_i then its energy usage be ξ^i. Relative to a node σ_f, at least the residual energy of node σ_i is ξ_{lef}^{i}, which can be articulated through Eq. (11).

$$\xi_{lef}^{i} = \gamma_t^i\left(\varsigma_t^i - \varsigma_t^{fas}\right) + \gamma_r^i\left(\varsigma_r^i - \varsigma_r^{fas}\right) + \xi^{fas,i}\chi_{com}$$

(11)

Where $\xi^{fas,i} = \delta_t^i + \delta_r^i - \delta_t^{fas} - \delta_r^{fas}$

$$\vartheta_t^i = \frac{\varsigma_t^i}{\chi_{com}}\left\{\delta_r\left(\mathcal{L}_{pre} + \mathcal{L}_p\right) + \delta_s\left[\left(\mathcal{L}_{pre} + \mathcal{L}_p\right) + \mathcal{L}_{ack} + \frac{\chi_{com}\left(1 - \mathcal{H}_{set}^i\right)}{2}\right]\right\}$$

$$\vartheta_r^i = \frac{\varsigma_r^i}{\chi_{com}}\left[\delta_r\left(\mathcal{L}_{pre} + \mathcal{L}_p\right) + \delta_s\left(\mathcal{L}_{ack} + \mathcal{L}_d\right)\right]$$

Proof: Effect on the energy gap issue in IoT environments, inparticular, overall power consumption of cluster is the region nearest to centralized, which is the base station with the quickest energy. Utilization in the system σ_f is ξ_{fas}^{f}. For the node's energy σ_f, the difference is ξ_{lef}^{i} among the node's energy usage σ_i as well as the expenditure of energy of the largest hub σ_f in the system. Since the networks σ_f & σ_i operate on a constant duty frequency, the resource differential behind them is mostly caused by a volume of information collected as well as transferred. With Eq. (12), the energy of 2 sections is computed respectively.

$$\begin{aligned} \xi_{lef}^{i} &= \xi^i - \xi_{fas}^{f} \\ &= \left(\xi_{tra}^{i} + \xi_{trc}^{i} + \xi_{lpl}^{i} + \xi_{sen}^{i}\right) - \left(\xi_{tra}^{fas} + \xi_{trc}^{fas} + \xi_{lpl}^{fas} + \xi_{sen}^{fas}\right) \\ &= \gamma_t^i\left(\varsigma_t^i - \varsigma_t^{fas}\right) + \gamma_r^i\left(\varsigma_r^i - \varsigma_r^{fas}\right) + \chi_{com}\left(\delta_t^i + \delta_r^i - \delta_t^{fas} - \delta_r^{fas}\right) \end{aligned} \tag{12}$$

Whenever the switching frequency is adjusted to 0.25, estimate the residual data at higher terminals from the center region, as illustrated in Fig.5 underneath. Since the network node location from the core region varies, so does its switching frequency. The node *i* at a distance of *i* from the center is represented as σ_i. The secure switching frequency of the hub σ_i is $\mathcal{H}_{set}^i$, afterward, the accustomed duty cycle $\mathcal{H}_{cha}^i$ can be attained by utilizing the subsequent theorem 5. Initially, compute the power expenditure ζ_{all}^i of σ_i when the switching frequency is $\mathcal{H}_{set}^i$; and compute the residual power ζ_{lef}^i of the hub σ_i in accordance with the association among the preliminary power as well as the used power; in conclusion, utilize the residual power $\zeta_{lef}^i/2$ to improve $\mathcal{H}_{set}^i$ of σ_i Getting the changing duty cycle $\mathcal{H}_{cha}^i$. By the accustomed switching frequency, the programmed hubs are awakened to accept information, diminishing the latency system.

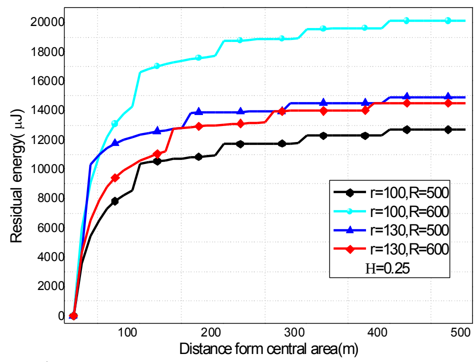

Fig. 5. Residual energy under different communication and radius

Theorem 5: Establish the duty ratio of the hub σ_i with a standard switching frequency $\mathcal{H}^i_{set}$ and a distance of *i* m from central to $\mathcal{H}^i_{set}$ .Underneath the proposed CL-MAC protocol, utilize the residual power $\zeta^i_{lef}/2$ towards enhancing the duty cycle of the hub σ_i then the novel duty cycle $\mathcal{H}^i_{cha}$ of the hub σ_i . Enhance the operating frequency of the appropriate node in accordance with the frequency of the polling strategy, as shown below in Eq. (13).

$$\mathcal{H}^i_{cha} = \delta^i_{lef} + \left[\zeta^i_{lef}/2\chi_{com}\left(\delta^i_{com} - \delta_s\right)\right] \tag{13}$$

Where $\delta^i_{com} = \xi^i_{tra} + \xi^i_{rec} + \xi^i_{lpl} + \xi^i_{sen}$

Proof: Whenever employing a constant operating frequency, it is expected that the cluster closest to the core of the system consumes the most power. In accordance with the research [21], the residual power ζ^i_{lef} of a hub σ_i relative to a node σ_f can be obtained by Eq. (14). As soon as utilizing a standard operating frequency of the hub σ_i is $\mathcal{H}^i_{set}\left(\mathcal{H}^i_{set} = \mathcal{H}^{fas}_{set}\right)$, as well as the transmission usage of hub σ_i can be attained as the subsequent Eq. (14).

$$\xi^i_{lef} = \gamma^i_t\left(\varsigma^i_t - \varsigma^{fas}_t\right) + \gamma^i_s\left(\varsigma^i_s - \varsigma^{fas}_s\right) + \chi_{com}\left(\delta^i_t + \delta^i_s - \delta^{fas}_t - \delta^{fas}_s\right)$$

$$\mathcal{C}^i_{set}\left(\sigma_i\right) = \chi_{com}\left[\delta^i_s\left(1 - \mathcal{H}^i_{set}\right) + \delta^i_{com}\mathcal{H}^i_{set}\right] \tag{14}$$

Presumptuous a novel adjustable duty cycle $\mathcal{H}^i_{cha}$, At that time, the novel communication usage of the hub σ_i can be attained in Eq. (15):

$$\mathcal{C}^i_{cha}\left(\sigma_i\right) = \chi_{com}\left[\delta^i_s\left(1 - \mathcal{H}^i_{cha}\right) + \delta^i_{com}\mathcal{H}^i_{cha}\right] \tag{15}$$

For adjusting the hub σ_i , the utilized power of the adjustable phase shift $\mathcal{H}^i_{cha}$ is the residual power ζ^i_{lef} , which describes that it is higher as compared with the power usage at the time prior to standard operating frequency $\mathcal{H}^i_{set}$ is utilized. The power usage of the augmented portion should be remaining power $\zeta^i_{lef}/2$ so that we can get in Eq. (16), It can be deduced to the Eq. (17).

$$\mathcal{C}^i_{cha}\left(\sigma_i\right) = \xi^i_{lef}/2 + \mathcal{C}^i_{set}\left(\sigma_i\right) \tag{16}$$

$$\chi_{com}\left[\delta^i_s\left(1 - \mathcal{H}^i_{cha}\right) + \delta^i_{com}\mathcal{H}^i_{cha}\right] = \xi^i_{lef}/2 + \chi_{com}\left[\delta^i_s\left(1 - \mathcal{H}^i_{set}\right) + \delta^i_{com}\mathcal{H}^i_{set}\right]$$

$$\mathcal{H}^i_{cha} = \mathcal{H}^i_{set} + \xi^i_{lef}/2\left[\chi_{com}\left(\delta^i_{com} - \delta^i_s\right)\right] \tag{17}$$

The basic objective of the dynamic switching frequency in the CL-MAC procedure, according to this hypothesis equation, is to maintain the cluster sampling frequency of the terminals in the approaching region static. Utilize leftover power to boost the operating frequency of operating frequency of networks in the far-central region. When illustrated in Fig. 6, as the phase shift levels increased, so does the energy utilization in the distant transition zone. The phase shift modification completely utilizes the residual energy consumed in the distant center.

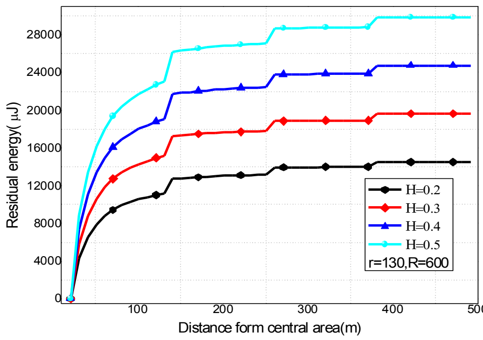

Fig. 6. Residual energy under different duty cycles

4.4 *Number of beacons in a wake-up time slot*

The CL-MAC protocol effectively utilizes the remaining energy of nodes far away from the hub, sending more beacons during sleep time, reducing sleep delay. The remaining one-third of the energy consumption of the node is used to increase the sleep beacon of the inserted node to reduce the sleep delay of the node further. In the most extreme case [22-24], if the remaining energy of the node is sufficient, the sleep time of the node can be used to send a beacon.

Theorem 6: Suppose that the sleep state increases the energy consumption of one unit of the beacon δ^i_b , and the remaining 1/2 of the energy consumption is used to insert the beacon in the sleep state. Thus, the number of inserted beacons at the node σ_i at the distance central area of *i* can be calculated as $\mathcal{N}^i_b(n)$ follows by Eq. (18).

Proof: Since the energy consumption of consuming one unit beacon is δ^i_b , according to the theorem, 1/2 of the remaining energy $\zeta^i_{lef}/2$ is obtained as follows.

$$\xi^i_{lef}/2 = \left[\gamma^i_t\left(\varsigma^i_t - \varsigma^{fas}_t\right) + \gamma^i_s\left(\varsigma^i_s - \varsigma^{fas}_s\right) + \chi_{com}\left(\delta^i_t + \delta^i_s - \delta^{fas}_t - \delta^{fas}_s\right)\right]/2 \tag{18}$$

Where $\mathcal{N}^i_b(n) = \zeta^i_{lef}/2\delta^i_b$, Thus, the number of beacons inserted into the wake-up time slot can be obtained. Through the relevant analysis of the above content, we can distinguish between the IoT communication energy-saving technology [25] and the traditional energy-saving technology and compare it in terms of low energy consumption, stability, transmission distance, etc., as shown in Fig.7 below.

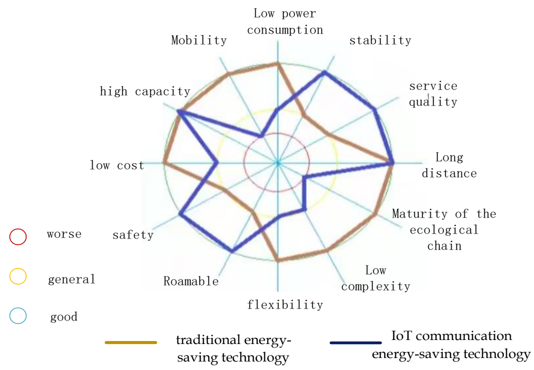

Fig. 7. The difference between IoT communication energy-saving technology and traditional energy-saving technology

In most existing studies, they are always incompatible [26,27] because low latency consumes more energy at the cost of this, which will damage the network's life. First, the CL-MAC protocol uses two techniques of the extended preamble and a low-power interception to achieve on-demand synchronization and low-power communication. Finally, according to channel activity detection, different communication access methods are selected, considering the energy efficiency of the node and the robustness to the changing traffic load.

From the above theoretical analysis, we can get the following conclusions. Under the same data volume communication situation at the same time, the CL-MAC protocol can maximize the use of communication channels [28-30], maximize network throughput, maximize network-life.

5. Experiments and Simulations

This section first presents the experimental setup, and secondly, to evaluate the performance of our proposed scheme, simulation results for the CL-MAC scheme are presented. Factors related to the MAC protocol, such as channel utilization, terminal energy consumption, throughput, etc. These factors are used to compare the experimental performance with other ADC-MAC and DDC-MAC schemes.

5.1 Channel Utilization Rate

The utilization efficiency of the channel is related to the transmission cycle. The channel utilization rate is the highest, and it takes the most time to transmit data. From the comparison in Fig. 8, it can be seen that in the number of frames sent per cycle, the channel utilization rate of the CL-MAC protocol is the highest, followed by the DDC-MAC. After comparison, the CL-MAC protocol works best in terms of channel utilization performance.

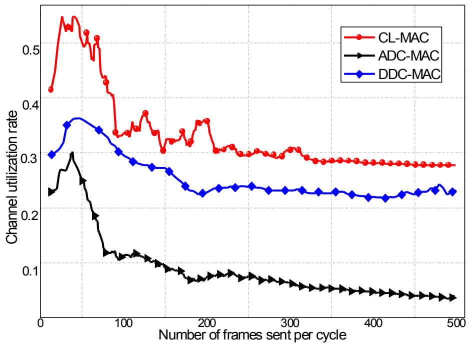

Fig. 8. Comparison of channel utilization rates under the three protocols

5.2 Terminal energy consumption

The abscissa represents time, and the ordinate represents the power consumption of the terminal [31] in Fig. 9. reduce the power consumption of the terminal than the ADC-MAC and the DDC-MAC protocol. We can see it is using the CPL-MAC protocol can effectively. At the beginning of 100ms, the same power consumption is due to use. After 100ms, the CL-MAC protocol shows less power consumption, indicating the effectiveness of the CPL-MAC.

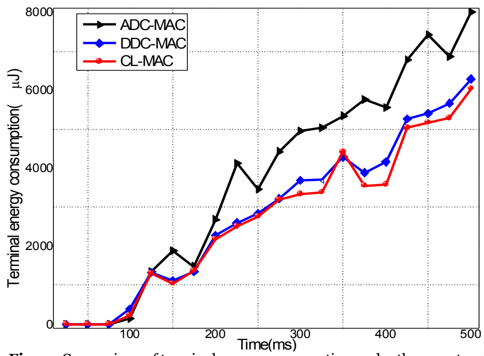

Fig. 9. Comparison of terminal energy consumption under three protocols

5.3 Throughput

Throughput refers to the study [32] to the maximum data rate that a device can receive and forward without frame loss. It refers to the number of bits per second that can be transmitted on the link. It can be seen from Fig. 10 that the throughput of the three protocols gradually keeps unchanged with time. With the continuous arrival of data, the throughput of the Internet system will fluctuate around a saturation value. Through the comparison of the vertical axis, the throughput performance of the CL-MAC has far exceeded the DDC-MAC protocol and the ADC-MAC by about 1.5 times in the beginning.

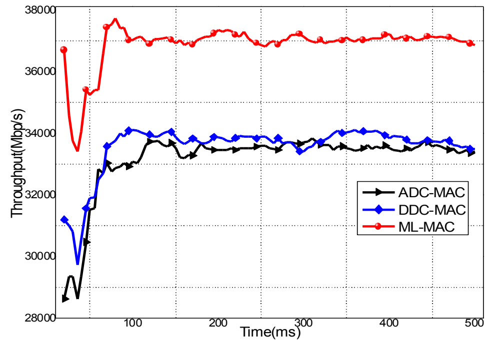

Fig. 10. Comparison of Throughput under three protocols

5.4 Lifetime

In the Internet of Things, the end of network life is when battery power is exhausted. Factors that affect longevity are often related to the energy in the network. From Fig. 11. It can be seen that at the beginning of the CL-MAC protocol, with the adjusted duty cycle value, the life of the network is lower.It can be seen from the figure that under the adjusted duty cycle of the three protocol nodes, the network's life can be increased by 12%.

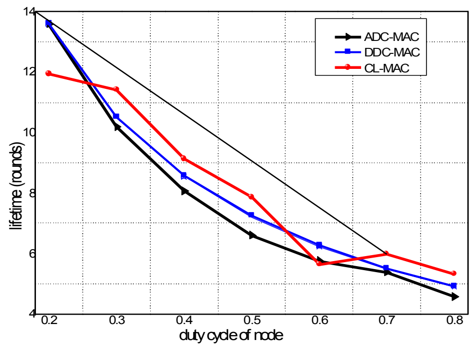

Fig. 11. Comparison of a lifetime under three protocols

6. Conclusions

From the comparison results of the experiment, the CL-MAC protocol has the following obvious advantages: network delay can be reduced by 29%, energy efficiency can be increased by 19%, channel utilization is increased by 9%, terminal energy consumption is reduced by 1.5%, and throughput increased by 1.5%. LoRa network has many advantages, but it also has certain disadvantages. For example, spectrum interference. With the continuous development of LoRa, the deployment of LoRa devices and networks continues to increase, and inevitable spectrum interference will occur between each other.

A new network needs to be built, and during the LoRa deployment process, users need to develop their network. The payload is small, and a load of LoRa transmission data is relatively small, and there is a byte limit. 1) Assuming that the contention window and time slot are changing, the analysis method and experimental data are given are complete. In future work, we can regulate the phase shift by matching as well as additional enhance the protocol.2) When organized, the hubs in this article assume incorrect locations. Nevertheless, in practice, the cluster migration procedure is quite difficult.

This effort is a step to making resource but reactive connectivity utilizing long-range technologies, providing the entrance network service management. CAD-based LoRaWAN protocol technology will blossom and co-exist. Lora will be a powerful supplement to traditional IoT technology in many aspects.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, author-ship, or publication of this article.

Author Statement

All authors contributed to the content of the manuscript, including the concept, methodology, design analysis, valuation, writing, and correction of the manuscript. In addition, each author verifies that this work has never been published anywhere.

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Author Statement

All authors contributed to the content of the manuscript, including the concept, methodology, design analysis, valuation, writing, and correction of the manuscript. In addition, each author verifies that this work has never been published anywhere.

Declaration of Conflicting Interests

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