Research on secure Internet of things gateway technology based on multi-communication methods

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Abstract

The Internet of Things, as an important part of important data aggregation, forwarding and control, often leads to objectivity errors due to the huge and complex received data. Based on this, this paper introduces GRU, LSTM, SRU deep learning to optimize the data received by the Internet of Things, and selects the most suitable communication mode optimization algorithm. The experimental results show that the accuracy errors of GRU, LSTM, and SRU algorithms show a downward trend, from 0.024 to 0.010%; the training time is reduced by 254 minutes, and the training speed is increased to 86%, indicating the excellent performance of SRU deep learning in IoT gateways.

Keywords: Multiple communication methods, IoT gateway, GRU, LSTM, SRU
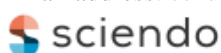**AMS 2020 codes**: 68M10

1   Introduction

The rapid development of computers and the Internet has promoted the transformation of the Internet of Things from concept to reality [1]. The Internet of Things mainly connects massive sensing devices with the Internet through the integration of ubiquitous perception, intelligent identification, ubiquitous network and cloud computing technologies to realize intelligent identification and perception of actual objects [2, 3]. Different from the Internet, the Internet of Things has its unique characteristics. First of all, it uses sensors to sample various actual items and transmits their information to the network; secondly, the Internet of Things is actually a ubiquitous network based on the Internet; The Internet of Things also has the ability to process data and transmit information [4]. The composition and functions of the Internet of Things are shown in Table 1. The Internet of Things mainly includes the perception layer, with many sensors inside, mainly to identify items and collect related information; the network layer is to process and transmit the information collected by the perception layer; the application layer is mainly to combine with user needs to fully realize modernization and intelligence of [5-7].

Table 1. The composition and function of the Internet of Things

Hierarchy	Features
perception layer	Complete functions such as object recognition and information collection
Network layer	The information obtained by the perception layer is transmitted and processed in an orderly manner
application layer	Combine the Internet of Things with industry needs to fully realize the intelligence of the industry

With the rapid development of the Internet of Things, research in this area has also attracted extensive research by experts and scholars at home and abroad. Using CNKI, we searched 1367 articles published since 2009 by article title, IoT, gateway. The trend of annual publication volume is shown in Figure 1(a). Since 2009, the Internet of Things and gateway research work has been in full swing. In 2009, the annual publication volume was only 2. After 2012, the annual publication volume climbed to There are about 100 articles, and then the number of publications is maintained at more than 100 articles per year; in addition, by analyzing the distribution of the main topics of the articles, as shown in Figure 1(b), we can see that the topics containing the Internet of Things keywords are published. There are 706 articles, accounting for 51.6%. Articles with the theme of IoT gateways accounted for the second, with 207 articles accounting for 15.1%; followed by smart home, IoT technology, and Zigbee, all accounting for about 5%. Based on the above-mentioned annual publication volume and topic distribution, we can see that the research on the Internet of Things and its gateway technology is getting more and more attention. ChaoLiu et al. [8] conducted research on cloud-oriented service gateways for cloud manufacturing, and proposed a service-oriented PnP IIoT gateway for efficient data acquisition, communication, query, analysis and visualization of manufacturing equipment, and proposed IIoT A general system architecture for supported cloud manufacturing, as a strategic guide for integrating IIoT technologies in a cloud manufacturing environment, the proposed IIoT-enabled cloud manufacturing system is able to efficiently collect large and various types of field-level manufacturing data and transmit it to A cloud-based manufacturing platform, thereby establishing a link between field-level manufacturing processes and cloud-based decision-making activities. In the research work of Roberto Morabito et al. [9], they proposed a gateway design suitable for IoT and edge computing scenarios, And the prototype has been designed, implemented, and tested on a real sensor network, and the results show that their proposed lightweight edge gateway enables optimized resource management and adoption considering requirements such as energy efficiency, multi-tenancy, and interoperability. In the research work of KikiAdhinugraha et al. [10], they conducted an in-depth study on the expansion of IoT gateway coverage, and they compared the ordinary network Voronoi diagram (NVD) with the

Hops Voronoi diagram (HVD) to allocate according to the number of network hops gateway workload; and extending these methods to identify overlapping routers for gateway failover. Dan Xu [11] et al. conducted research on achieving critical and stable transmission in IoT gateways. In their research, multiple gateways were deployed in IoT applications. They found that when running under variable ratio, the gateway, it will reduce the stability of the last step of data transmission. Amir M. Rahmani et al. [12] developed a gateway between hospitals and individuals, demonstrating all data flow processes from sensor node data acquisition to the cloud and end users. The results show that the intelligence, mobility, interoperability and reliability of the whole system meet the requirements. In ZhoujingYe [13] et al. conducted research on distributed road monitoring based on IoT, they extracted feature data from raw data through built-in preprocessing algorithm. Finally, the alternate information is deduced through the processing of the node. However, during data processing, the accuracy of IoT data processing is often reduced due to the problem of built-in processing algorithms, which affects its stability. KunyeFeng [14] et al. studied and applied the LSTM algorithm, and found that the proposed IB-LSTM network was able to trade off model accuracy and computational resources. The application of the LSTM algorithm in IoT hierarchical clustering was studied by Raj Mani Shukla et al. [15], and they proposed a scalable outlier detector that uses hierarchical clustering and long short-term memory (LSTM) neural networks. Hierarchical clustering provides scalability for outlier detectors by finding correlated sensors. LSTM neural network with robust statistics, M-estimator, accurate detection of outliers in time series data. Simulation results on different datasets show that the accuracy of this method for different attack strengths is above 90%. The above literature proves the effectiveness of computer deep network learning in data processing.
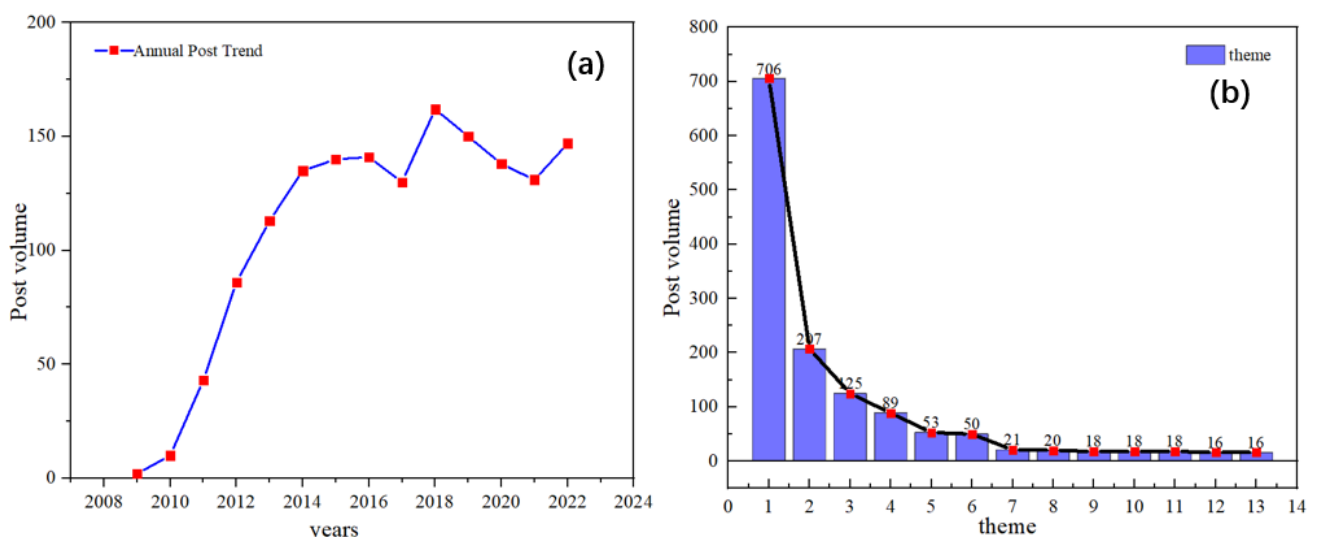
Figure 1. 2009-2022 domestic article volume trend and topic distribution map on the Internet of Things

The rapid economic and social development and the rapid development of computer networks have great research value as the Internet of Things and gateways that realize the connection between objects and the Internet. As the data processing, exchange, and transmission center of the entire IoT network, the IoT gateway must have strong and stable data processing capabilities to handle a large number of data streams and information transmission. Therefore, in this paper, the SRU network is used to optimize and analyze the wireless communication module, and the GRU and LSTM networks are compared and analyzed. Break through the IoT gateway technology, provide acceleration for data processing, exchange, transmission, etc., and promote the development and progress of the domestic Internet of Things.

2   Overview of common communication technologies

In order to realize the collection, identification of object information, and subsequent information transmission, processing, etc., various communication methods need to be used. Common communication methods mainly include wired communication and wireless communication [16-19]. In simple terms, wired communication refers to wired telecommunications, that is, the use of metal wires, optical fibers and other tangible media to transmit information. Light or electrical signals can represent sounds, words, images, etc. According to the transmission direction, it is mainly divided into three types: simplex, half-duplex and duplex; according to the synchronization method of communication data, it is divided into two categories: synchronous communication and asynchronous communication. The biggest advantage of wired communication is stability, strong anti-interference, less loss and low energy consumption. However, as the communication distance continues to lengthen, the drawbacks brought by the extension of the medium are gradually revealed: the cost of increasing the relay and switching equipment has soared, and the convenience Poor sex, restricting movement [20]. In contrast, wireless communication is efficient and convenient, mainly using electromagnetic waves without requiring a medium, and the price is more favorable in terms of long-distance communication. Therefore, wireless communication is more suitable for the requirements of multi-location, multi-scale, real-time IoT communication requirements [21, 22]. At present, the most widely used short-range wireless communication mainly includes WIFI, Bluetooth, and infrared three main methods. The discussion cluster is composed of many subsets. It has undergone more than 20 years of evolution and development, and is still undergoing continuous revision and improvement to meet the requirements of network speed improvement, security certification requirements, and other requirements. Different countries have different WIFI frequency and power standards. Table 2 shows the standards of some countries.

Table 2. Part of the national standard table

country	Frequency Range	bandwidth	Maximum power
Japan	2.471-2.479	26.0	10
France	2.4465-2.4835	37	10
American	2.4-2.4835	83.5	1000
China	2.4-2.4835	83.5	100

At the physical level, the WIFI standard mainly refers to the signal characteristics and modulation methods during data transmission, and supports two radio frequency modes and one infrared transmission mode [23, 24]. The RF method mainly uses mathematical functions to disperse the signal to be transmitted to the frequency within the required range, and then performs the corresponding inverse operation at the receiving end. Bluetooth is also a wireless communication technology with relatively low power consumption and short effective communication distance at the same time [25]. Bluetooth can easily replace cables between computers, mobile communication terminals, fax machines, printers and other devices, establish connections between these devices in a wireless way, and simplify the connection between devices; Strong, suitable for many occasions, such as emergency devices in mountains, communication of monitoring equipment in water, etc. The application address assigned to all Bluetooth devices is unique, which ensures high security between devices; compared with other wireless communication devices, it has the advantages of easier implementation and wider application in all aspects [26, 27]. Bluetooth technology has the following characteristics, as shown in Table 3;

Table 3. Features of Bluetooth technology

Features	Details
Small size and low energy consumption	Can be integrated into the device
interconnectedness	Bluetooth between different devices can communicate with each other
Network features	Support point-to-point and point-to-multipoint communication
Works on 2.4GHz channel	Time division duplex working
Data and Voice Transmission	Simultaneous transmission of data and voice

Bluetooth transmission mainly has the advantages of small size, low energy consumption, interconnectivity and real-time transmission of voice data. With the development of wireless communication technology, NFC, which evolved from non-contact radio frequency identification, has gradually developed, which can establish a wireless network more quickly and automatically, and can establish a connection between surrounding WIFI and Bluetooth to realize the connection between electronic devices. Communication within [28]. NFC greatly reduces the overall security authentication and security identification process, making the connection between electronic devices faster. In addition, NFC helps to solve the cumbersome need to memorize multiple passwords, and also ensures the security of data. It is also possible to "accelerate" other types of wireless communications (such as Wi-Fi and Bluetooth), enabling faster and longer data transfer [29]. The Internet of Things is widely used in all walks of life, involving many fields such as smart home and public safety in life. Simply put, the Internet of Things is the Internet that connects objects in life and society, giving them a sensor, and then connecting the objects. As the connection point - gateway of related object data information in the related Internet of Things process, it has the functions of Internet of Things data collection, forwarding, transmission and management. The IoT gateway, as the connection point between the communication network and the sensed object information, needs to meet the needs of large-scale interconnection, local interconnection, and interconnection transformation in various networks [30, 31]. In China, the standards for gateways mainly include the following main contents: firstly, the gateway needs to support the aggregation, storage and processing of data within the network; secondly, it needs to support long-distance communication such as the Internet and near-end communication; Monitoring; incumbents can support mutual authentication, authorization, deployment, etc. of relevant gateways; finally, resource allocation and scheduling should be satisfied, and relevant sensors can be accessed. We chose the SRU algorithm, a variant of the recursive neural network (RNN) network, to receive signals of different frequencies, and compile them uniformly to obtain important information. At the same time, since each computing layer of the network itself has the same weights to share, the time cost and computing time are greatly reduced.

2.1　Overall framework of multi-communication converged gateway hardware

In this paper, a multi-chimera technology is applied to the Internet of Things gateway (as shown in Figure 2), and its performance is optimized. Among them, the main modules of the IoT gateway are: core board, common interface, power supply module, WIFI/Bluetooth receiving module, etc.
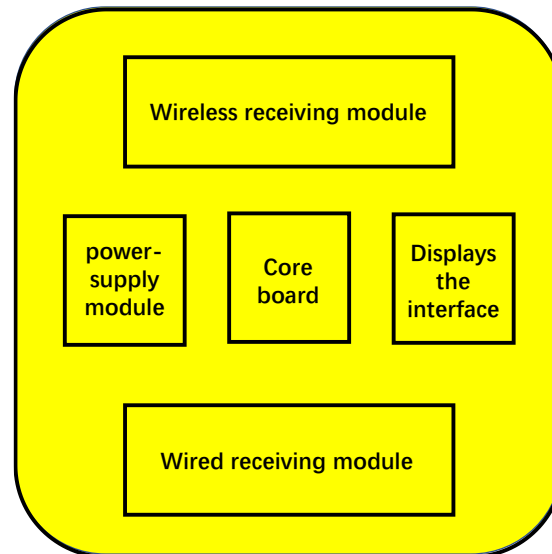
Figure 2. System Tidying Framework

S5PV210 is a kind of microprocessor commonly used in mobile communication equipment, which has the characteristics of high cost performance, low power consumption and superior performance. And it is also equipped with ARM Cortex-A8 core and ARM V7 instruction set, which can meet various needs. In this paper, AMS1117 is used for voltage conversion supply to supply power for display system, WIFI/Bluetooth receiving system and USB and other modules. The LCD adapter board is used, and it comes with an HDMI interface that can output signals after electrical conversion. Because the signal frequency range of wireless reception is wide, and it is also the focus of this IoT gateway optimization design. Therefore, this design has added three communication systems: wireless local area network, Bluetooth system, and NFC. Considering the needs of future design and expansion, three wired interfaces of USB, serial port current and Ethernet have been added.

2.2 Overview of neural network algorithms

The neural network model is composed of a group of interconnected neurons, which consists of three important parts: dendrites, cell bodies, and axons. The dendrites receive signals from other neurons, and the cell body processes the signals and outputs them to other dendrites. It is equivalently described in the neural network in terms of weights, biases, and activation functions. The input data is processed and transmitted through layers of neurons to obtain the final output.

Based on the above-mentioned introduction to the neural network, this paper uses a variant of the RNN network, the SRU algorithm, to optimize the signal receiving module. Compared with the commonly used LSTM and GRU algorithms, the SRU network has a simpler structure, lower computational complexity and faster data training speed. A schematic diagram of the general structure of the SRU network is shown in Figure 3.
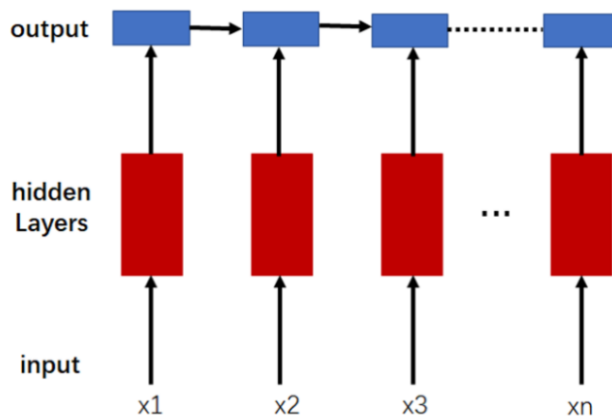
Figure 3. SRU data input diagram

SRU is similar in function to LSTM and GRU. Its main purpose is to prevent problems such as gradient explosion or gradient disappearance caused by excessive time series data. It is mainly composed of output gate, input gate and forget gate. Its flow chart is shown in Figure 4.
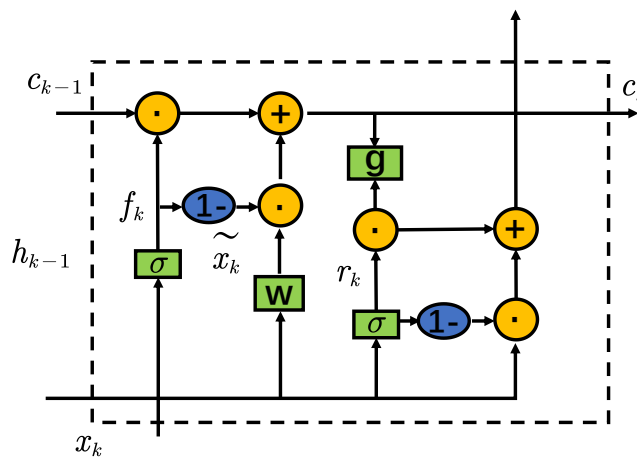

Figure 4. SRU network structure diagram

2.2.1 Learning algorithm of SRU network

The specific calculation process of the SRU algorithm is as follows

1) First, the input data needs to be weighted and linearized:

$$\tilde{x} = wx \tag{1}$$

Among them, k is the input data at time k, w is the weight matrix of the input gate, and is the weighted data.

2) The data weighted linearization is conducted to the forget gate, and it is nonlinearly processed by the activation function:

$$f_k = \sigma\left(w_f \tilde{x} + b_f\right) \tag{2}$$

Where is the activation function, is the bias of the forget gate, is the weight matrix of the forget gate, and is the output of the forget gate at time k.

3) Use the forget gate to modulate the state parameters inside the SRU to serve the state output obtained by parallel computing:

$$c_k = f_k \odot c_{k-1} + (1 - f_k) \odot \widetilde{x_k}$$

(3)

Where is the state quantity at time k.

4) The calculation method of the output gate is similar to that of the forget gate, and it is further processed nonlinearly:

$$r_k = \sigma\left(w_r \, \widetilde{x_t} + b_r\right)$$

(4)

Where is the output gate at time k, and are the weight matrix and output gate bias of the output gate, respectively.

5) Combine the operation results of (1)-(4) to update the output state quantity at time k, and pass it to the SRU layer at time k+1 for operation:

$$h_k = r_k \odot \mathrm{Re}LU(c_k) + (1 + r_k) \odot x_k$$

(5)

Among them, ReLU is one of the activation functions, and is the state output at time k.

2.3 Data preprocessing and model hyperparameter determination

In this paper, the training length of this model algorithm is about N=100000 data points. In addition, because different communication methods correspond to different frequencies, in order to avoid the data influence error caused by different orders of magnitude, the data is normalized in this paper. The purpose of processing is to normalize all data to the same interval and speed up the solution of gradient descent. Therefore, we choose to select max-min normalization for processing, and the calculation method is as follows:

$$\hat{x} = \frac{x - x_{\min}}{x_{\max} - x_{\min}}$$

(6)

Where $x_{\max}$ is the maximum value in the data set and $x_{\min}$ is the minimum value in the data set. After normalization, the network training error will be reduced.

In addition, in order to balance the training cost and training accuracy, the SRU network in this paper adopts a 2-layer hidden layer structure, and the number of nodes in each layer is 24; the activation function is ReLU; and the number of training iterations epoch is set to 300. The learning rate is 0.0015; and the root mean square MSE function is used as the evaluation index; Adam is the network training optimizer.

2.4   Network parallelism and network initialization

In order to give full play to the performance of the SRU network, this paper will optimize it in parallel. Perform matrix multiplication calculation on the input data and turn it into a batch matrix, which makes the data vectorized and greatly simplifies the calculation process. The specific calculation process is as follows:

$$U^T = \begin{bmatrix} w \\ w_f \\ w_r \end{bmatrix} \begin{bmatrix} x_1 & ... & x_N \end{bmatrix}$$

(7)

When the input data becomes a batch matrix, the dimension of U will become (N, k, 3d).

A suitable initial value can reduce the grid training time and the difficulty of gradient descent. This paper firstly draws the parameter matrix of forward propagation with 0 as the matrix 1/d method.

The high-speed computation and light looping of the SRU algorithm reduces the hidden representation variance by 1/4 to 1/2:

$$\frac{1}{4} \ll \frac{Var[h_k]}{Var[x_k]} \ll \frac{1}{2}$$

(8)

This shows that when the number of SRU layers is large, the convergence will be 1/2, and the gradient disappears easily. Therefore, this paper introduces a correction coefficient to solve this potential problem:

$$h_k = r_k \odot c_k + (1 - r_k) \odot x_k \cdot \alpha$$

(9)

Where is the correction correction constant, which is initialized by a non-zero offset b. The specific calculation process is as follows:

$$\alpha = \sqrt{1 + \exp(b) \times 2}$$

(10)

We introduce the hardware of the multi-communication IoT gateway and the specific optimization process of the SRU network. Among them, the frequency reception optimization is mainly for the wireless communication module WIFI/Bluetooth/NFC, etc.; and the optimization algorithm is also extended to the wired communication module.

3   Experimental verification and comparative analysis

3.1   Comparison and Analysis of algorithm accuracy

In order to verify that the SRU network has better performance, this paper compares and analyzes GRU and LSTM. To further analyze the performance of these three networks, we choose the following three evaluation metrics:

Root Mean Square Error (RMSE): A measure of the error between the observed value and the actual value. Calculated as follows:

$$RMSE(X,h) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(h(x_i) - y_i\right)^2}$$

(11)

Mean Absolute Error (MAE): The average value of the absolute error, which can better reflect the actual situation of the predicted value error. Calculated as follows:

$$MAE(X,h) = \frac{1}{N}\sum_{i=1}^{N}|h(x_i) - y_i|$$

(12)

Relative Error (RE): The ratio of the difference between the observed value and the actual value to the actual value. Calculated as follows:

$$RE(X,h) = \frac{h(x_i) - y_i}{y_i}$$

(13)

Among them, Figure 5 is the prediction evaluation index of the translation results of the three networks
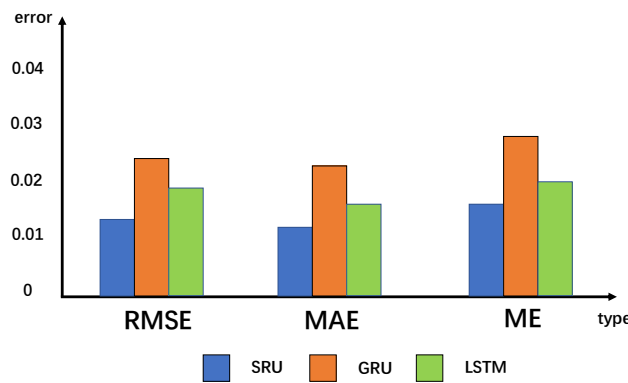
Figure 5. Accuracy Quantitative Test Metrics

Specifically, compared with the actual data received and compiled data at the frequency, the RMSE of the SRU algorithm is smaller than that of the GRU algorithm and the LSTM algorithm, which are 0.012, 0.024, and 0.018, respectively; the SRU algorithm is improved by 50% and 33%, respectively; MAE They were 0.010, 0.021, and 0.015, respectively; the SRU algorithm increased by 52% and 33%, respectively; the RE was 0.015, 0.027, and 0.022, respectively; the SRU algorithm increased by 44% and 36%, respectively.

3.2 Comparative analysis of algorithm training speed

Algorithm training speed is also one of the criteria for neural network evaluation. Because in practical applications, the network should not only pay attention to the training ability of input and output, but also consider the cost of implementing the operation. Therefore, this paper continues to compare the three algorithms of SRU, GRU, and LSTM to test their speed performance. And set the same hyperparameters as the number of iterations, mini-batch, and so on.

Table 4 shows the hidden layers, number of nodes, and parameters of the SRU algorithm, GRU algorithm, and LSTM algorithm. Among them, the number of hidden layers and nodes of the three are the same; and the SRU algorithm has the lowest number of parameters due to its simplicity, which is 3798; compared with the GRU algorithm and the LSTM algorithm, it is reduced by 78% and 86% respectively. As shown in Figure 6.

Table 4. Model parameter comparison table

	Hide layers	Nodes	Parameters
SRU	2	64+32	4051
LSTM	2	64+32	20954
GRU	2	64+32	15486
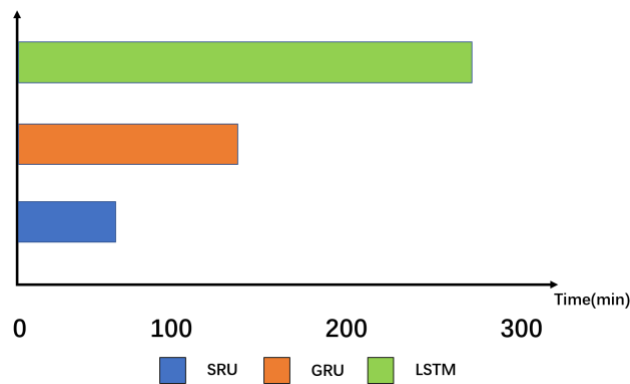
Figure 6. Comparison of network model training time

The training time of SRU, GRU and LSTM under the condition of the same amount of data, it can be seen that the SRU algorithm has huge advantages compared with the other two algorithms, and the training time cost is reduced by 59% and 72% respectively compared with the GRU network and the LSTM network. This has great potential value for future wireless reception signal compilation applications.

4   Conclusion

In this paper, we give a basic description of the concept of multi-communication framework and neural network algorithm, and introduce the structure and calculation process of SRU algorithm for wireless communication receiving module. And we compared the three algorithms of SRU, GRU and LSTM, and the hidden layer, number of nodes, number of iterations, learning rate and activation function in the network structure are all the same. the result shows:

1) The accuracy of GRU, LSTM, and SRU algorithms shows a downward trend under the three error evaluation standards of RMSE, MAE, and ME, from 0.024 to 0.012%, 0.021% to 0.015%, and 0.027 to 0.015, respectively.

2) The training time of GRU, LSTM, and SRU algorithms is reduced by a maximum of 254 minutes, and the training speed is increased by a maximum of 86%, indicating the excellent performance of SRU deep learning in IoT gateways.

3) The SRU algorithm has huge potential application value in the field of multi-communication secure IoT gateways, and combines algorithms, hardware, coordination work and other technologies to make significant contributions to secure IoT gateways.

Funding

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