Research on Delay Optimization of Telemedicine Real-Time Vital Signs Monitoring System Based on 5G MEC

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Abstract: With the development of telemedicine, the application effect of real-time vital signs monitoring system based on 5G MEC is affected by the delay. This paper focuses on this, constructs a theoretical model of delay optimization and puts forward corresponding strategies. Firstly, the technical basis of 5G, MEC and monitoring system is expounded, and the links and factors causing delay are analyzed. Then, the model is constructed from the aspects of network transmission and edge computing processing to quantify the system delay. Based on the model, network resource allocation optimization, such as dynamic bandwidth allocation and link selection optimization, is proposed. MEC calculates resource scheduling, such as task priority scheduling and resource collaborative allocation; And data processing and transmission process optimization, including data preprocessing and asynchronous transmission processing. Through these measures, it is expected to reduce the system delay, improve the performance of the real-time vital signs monitoring system of telemedicine, and provide more reliable support for telemedicine.

1. Introduction

With the rapid development of digital medical care, telemedicine real-time vital signs monitoring system, as a key means to improve the accessibility and efficiency of medical services, has been widely concerned [1]. With the help of modern communication technology, the system realizes the real-time collection, transmission and analysis of patients' vital signs data, which provides a basis for doctors' remote diagnosis, especially for patients in remote areas or with mobility difficulties [2]. The characteristics of high bandwidth, low latency and massive connection of 5G technology bring an opportunity for the optimization of real-time vital signs monitoring system in telemedicine [3]. At the same time, MEC, as a technology that sinks the cloud computing ability to the edge of the network, can effectively reduce the data transmission distance, reduce the processing delay and improve the system response speed [4]. The integrated application of 5G and MEC is regarded as an important way to solve the delay problem of telemedicine real-time vital signs monitoring system.

However, the telemedicine real-time vital signs monitoring system based on 5G MEC still faces many challenges, especially the delay problem [5]. The real-time requirement of vital sign data is extremely high, and even a short delay may affect the doctor's accurate judgment of the patient's condition and delay the treatment opportunity [6]. Although remarkable progress has been made in 5G and MEC technologies, in practical applications, the system delay has not been completely solved due to complex network environment, different equipment performance and imperfect system architecture [7]. In view of this, it is of great practical significance to study the delay optimization of real-time vital signs monitoring system for telemedicine based on 5G MEC. The purpose of this study is to analyze the root causes of system delay, build an effective theoretical model of delay optimization, and put forward targeted optimization strategies. The performance improvement of remote medical real-time vital sign monitoring system helps promote the innovative development of remote medical technology, thereby providing more efficient and accurate medical services for patients.

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2. Technical basis

As the fifth generation mobile communication technology, 5G network has the characteristics of high bandwidth, low delay and massive connection. Its millimeter wave frequency band can provide wider spectrum resources, greatly improve the data transmission rate, and meet the needs of real-time transmission of a large number of vital signs data [8]. At the same time, new network architectures introduced by 5G, such as Software Defined Network (SDN) and Network Function Virtualization (NFV), enhance the flexibility and manageability of the network and lay the foundation for reducing the delay. MEC technology deploys cloud computing and storage capabilities at the edge of the network, close to user equipment. This architecture makes it possible to complete some or all of the processing tasks at the edge nodes without going through a long transmission path to the core network for processing [9]. For telemedicine real-time vital sign monitoring system, MEC can quickly process the collected vital sign data, reduce transmission delay and improve response speed.

Telemedicine real-time vital signs monitoring system usually consists of front-end data acquisition equipment, communication network, edge computing nodes and telemedicine platform. The front-end equipment is responsible for collecting the patient's vital sign data in real time, such as heart rate and oxygen saturation. The communication network undertakes the task of data transmission, and transmits the collected data to edge computing nodes or telemedicine platforms. The edge computing node primarily processes and analyzes the data, and the telemedicine platform completes the final diagnosis and decision. System delay mainly comes from data acquisition, transmission, processing and other links, including network congestion, equipment processing capacity constraints and other factors, which have an impact on the real-time performance of the system.

3. Delay optimization theory model construction

In order to effectively solve the delay problem of telemedicine real-time vital signs monitoring system based on 5G MEC, it is necessary to build an accurate delay optimization theoretical model. This model deeply analyzes the composition and influencing factors of system delay from the aspects of network transmission and edge computing processing. Schematic diagram of MEC architecture is shown in Figure 1:

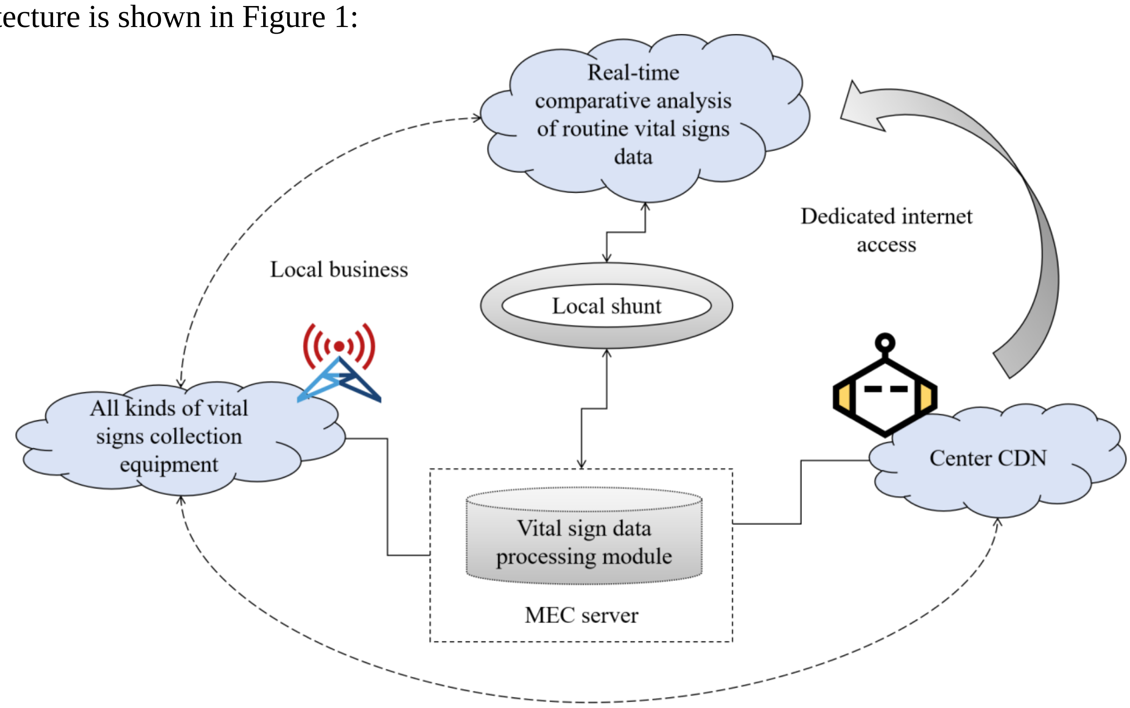

Figure 1 MEC architecture diagram

In the telemedicine real-time vital signs monitoring system, the data is transmitted from the front-end acquisition equipment to the MEC server through the 5G network, and then to the telemedicine platform, and the network transmission delay is the key part. Assuming that there are n links on the data transmission path, the transmission rate of the i link is R_i (unit: bps) and the data volume is D (unit: bit), the time $T_{trans-i}$ required to pass through the i link can be expressed as:

$$T_{trans-i} = \frac{D}{R_i} \quad (1)$$

The transmission delay T_{trans} of the whole network is the sum of the transmission time of each link, that is:

$$T_{trans} = \sum_{i=1}^{n} \frac{D}{R_i} \quad (2)$$

Network transmission delay is affected by many factors, such as signal attenuation, interference and network congestion. See Table 1 for the relationship between transmission rate and delay in different network environments. As can be seen from Table 1, the lower the transmission rate, the higher the delay required to transmit the same amount of data. In practical application, it is necessary to dynamically adjust the transmission strategy considering the network environment to reduce the network transmission delay.

Table 1: Relationship between Transmission Rate and Latency in Different Network Environments

Network Environment	Transmission Rate R (Mbps)	Data Volume D (MB)	Transmission Latency (s)
Ideal 5G Environment	1000	10	0.08
General 5G Environment (Mild Congestion)	500	10	0.16
Complex 5G Environment (Moderate Congestion)	200	10	0.4

MEC server will also introduce delay in processing the collected vital sign data. Assuming that the average time for MEC server to process a single data task is $T_{proc-avg}$, and the number of data tasks received by MEC server is N in a certain period of time, the edge calculation processing delay T_{proc} can be expressed as:

$$T_{proc} = N \times T_{proc-avg} \quad (3)$$

The processing delay of MEC server is related to server hardware performance and task scheduling algorithm. If the CPU performance of the server is insufficient, when dealing with complex vital sign data analysis tasks, the processing time T_{proc} of a single task will increase, which will lead to an increase in the overall processing delay.

Considering the network transmission delay and edge computing processing delay, the total system delay T_{total} is the sum of them, namely:

$$T_{total} = T_{trans} + T_{proc} \quad (4)$$

This model fully reflects the delay of telemedicine real-time vital signs monitoring system based on 5G MEC. Through the quantitative analysis of network transmission delay and edge computing processing delay, it provides a clear theoretical framework for the subsequent targeted delay optimization strategy, which is helpful to deeply understand the mechanism of system delay and lay the foundation for improving the real-time performance of the system.

4. Delay optimization strategy

Based on the theoretical model of delay optimization constructed above, in order to effectively reduce the delay of telemedicine real-time vital signs monitoring system based on 5G MEC, it is necessary to formulate corresponding optimization strategies and methods from the aspects of network transmission and edge computing processing.

(1) Network resource allocation optimization strategy

The high bandwidth of 5G network provides a guarantee for data transmission, but in practical application, network congestion may lead to uneven bandwidth allocation and increase transmission delay. Therefore, it is very important to adopt dynamic bandwidth allocation strategy. According to the priority of real-time vital sign data and the demand of data volume, the bandwidth resources of each transmission link are dynamically adjusted. The network resource allocation strategy should prioritize providing sufficient bandwidth support for key medical data such as electrocardiograms and large-scale data transmission.

The 5G network has built a complicated communication environment. In this environment, there are many optional data transmission links in the process of data transmission from the collection end to the processing end. These links present different real-time states at different times and different spatial locations, and these states will have a decisive impact on the quality and efficiency of data transmission. In order to realize efficient data transmission and reduce transmission delay, it is very important to select the best link for data transmission by evaluating the real-time status of each link. The evaluation process involves several key indicators, and signal strength is one of them. The signal strength is directly related to the stability and reliability of data transmission. The stronger the signal, the lower the probability of data loss or error during transmission. The degree of interference can not be ignored. External interference will seriously affect the accuracy and speed of data transmission. The higher the degree of interference, the higher the bit error rate during transmission, and the data needs to be retransmitted repeatedly, thus greatly increasing the transmission delay. The transmission rate directly reflects the amount of data that the link can transmit in a unit time. The higher the rate, the shorter the data transmission time. In practical application, the system needs to monitor the key parameters such as signal strength, interference degree and transmission rate of each link in real time. In order to visually show the influence of different link selection strategies on delay, Table 2 is made:

Table 2: Relationship between Transmission Rate and Latency in Different Network Environments

Link Selection Strategy	Average Signal Strength (dBm)	Average Interference Level (%)	Average Transmission Rate (Mbps)	Average Transmission Latency (s)	Ability to Ensure Critical Data Transmission
Random Link Selection	-70	30	200	0.4	Weak
Link Selection Based on Signal Strength	-60	20	300	0.27	Moderate
Comprehensive Evaluation-based Link Selection	-55	15	400	0.2	Strong

(2) MEC computing resource scheduling method

The processing tasks of vital sign data received by MEC server are complicated and diverse, covering the analysis of routine data such as heart rate, blood pressure and oxygen saturation, as well as special detection tasks for special diseases. Different types of tasks have different requirements for processing time because of their different functions in medical diagnosis and urgency in judging patients' condition. In order to deal with these tasks accurately and timely, it is the key to establish a perfect task priority mechanism. This mechanism makes a detailed ranking according to the urgency and importance of tasks. Among many tasks, such as the detection of sudden arrhythmia, because this kind of situation is directly related to the life safety of patients, once delayed, it may have serious consequences, so it must be given the highest priority so that it can be given priority in the task queue of MEC server. In this way, patients can be guaranteed to be analyzed and processed quickly in critical situations to the greatest extent, and precious time can be gained for doctors to make timely and accurate diagnosis.

5. Data processing and transmission process optimization approach

The computing resources of MEC server are limited. In order to improve the utilization rate of resources, it is necessary to allocate CPU, memory and other computing resources cooperatively. According to the characteristics of resource requirements of different tasks, resources are allocated reasonably. For data preprocessing tasks, CPU resources are mainly consumed, and more CPU cores can be allocated appropriately; For data storage related tasks, it focuses on the allocation of memory resources. Data preprocessing is carried out in front-end data acquisition equipment or edge nodes close to data sources to reduce the amount of transmitted data. Real-time denoising and feature extraction are carried out on continuously collected vital sign data, and only key feature data are transmitted to MEC server or telemedicine platform. This not only reduces the network transmission burden, but also reduces the processing pressure of MEC server. Using asynchronous mechanism, data transmission and processing can be carried out in parallel in different threads or processes. When data is transmitted in the network, MEC server can prepare processing resources in advance, and immediately process the data once it arrives, so as to avoid processing waiting time and effectively reduce the overall delay of the system.

Through the comprehensive application of the above strategies and methods, such as network resource allocation optimization, MEC computing resource scheduling and data processing and transmission flow optimization, it is expected to significantly reduce the delay of the real-time vital signs monitoring system of telemedicine based on 5G MEC, improve the reliability of the system, and provide strong support for the efficient development of telemedicine.

6. Conclusions

In this paper, the delay of telemedicine real-time vital signs monitoring system based on 5G MEC is deeply studied. Through the analysis of relevant theories and technical foundations, it is clear that the system delay is caused by data acquisition, transmission and processing. The theoretical model of delay optimization, which quantifies the delay from the aspects of network transmission and edge computing, provides a theoretical basis for optimization strategy.

In terms of optimization strategy, dynamic bandwidth allocation and link selection optimization in network resource allocation optimization adjust resources according to the real-time state and data characteristics of the network, which effectively reduces transmission delay. The task priority scheduling and resource collaborative allocation in MEC computing resource scheduling improve the processing efficiency of MEC server. The pretreatment and asynchronous mechanism of data processing and transmission process optimization can reduce the transmission volume and processing waiting time.

Through the comprehensive application of the above strategies and methods, it is expected to significantly improve the system delay and enhance the real-time and reliability of the telemedicine real-time vital signs monitoring system. However, in practical application, the network environment is complex and changeable, and there are differences in equipment performance. Future research can consider more complex factors and further improve the optimization model and strategy.

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