Analysis of Vehicle Network Architecture and Performance Optimization based on Soft Definition of Integration of Cloud and Fog

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Abstract: In order to solve a series of problems such as the high degree of heterogeneity and the lack of scalability in the traditional vehicle networking due to the increase of the scale of vehicles and the variety of vehicle applications, this study proposes to research and develop an innovative vehicle networking; firstly, by introducing the architecture, technology and problems encountered in the traditional car networking, the detailed analysis of the cloud and fog based software defined vehicles networking is carried out, and the problem of performance optimization of the vehicle's network is discussed and studied to establish a fog server to make it play a coordinating role, so that the central fog servers can complete the load and deliver them to each other, and then load and unload based on the cloud computing service. Finally, based on the technologies of controller and virtualization, the quality of service and the consumption of energy are optimized from the aspects of system and equipment. Based on this, a two-way constrained particle swarm optimization algorithm can be adopted to mitigate these difficulties. Finally, the experiment and simulation analysis of the proposed algorithm shows that the proposed algorithm has the performance advantages and can help improve the communication delay and energy consumption. Therefore, research and discussion on this aspect are of great significance to the development of future vehicle networking technologies.

Keywords: Cloud and Fog Based; Software Defined Vehicles Networking; Collaborative Cloud-Fog Computing Mode; Service Preloading

1. Introduction

As a particularly important part of the urban transportation system, the number of cars is continuous growing accompanied by sustainable development of the automobile industry. It is estimated that by 2021, the number of cars in China will be around 350 million, and China has begun to enter the ranks of automobile powers [1]. Urban traffic is facing unprecedented challenges in the growing number of cars and its growing demand for traffic. The congestion and blocking of urban roads lead to particularly low transport efficiency, and the form of traffic safety is worrying. The harmful gases are also a severe threat to our living environment. For these serious problems, the Intelligent Transportation System (ITS) brings people to the dawn of solving the problems. The core part of ITS is vehicles networking. The vehicles networking can collect and process traffic information and share it in time, realizing the connection between the vehicle, the city traffic, and the networking, so that the safety, comfort, and smoothness of the user's driving have been greatly improved. Studies have shown that in energy saving and vehicle safety performance, the meaning of the application of vehicles networking is very significant. When urban traffic has caused trouble, the vehicles networking brought a new way to solve this problem.

Due to the application of big data, Internet of Things and cloud computing technology, there are large number of mobile devices and household appliances and many sensors connected to the network, which will generate a large amount of data. A large amount of data is currently stored in the cloud data center, so a
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large amount of data is also generated in the cloud. However, as the data continues to increase, the core network becomes severely blocked with the influx of large amounts of data. Any error of any link in the network of the terminal to the cloud platform, such as the failure of the data center, will lead to an irreversible security problem. Therefore, the real-time performance and reliability required by big data cannot even be satisfied by cloud computing [2]. As a highly virtualized platform, fog computing is considered as a cloud that can be close to ending users. It can provide computing, storage, and network services between terminal devices and traditional cloud computing data centers, providing a higher quality of service at less cost. Therefore, the discussion of these technologies is of great significance to the development of vehicles networking in the future.

2. Literature review

The concept of the vehicles networking was put forward based on the Internet of Things. Many researchers have studied the establishment of the vehicles networking architecture. Zhu et al. (2016) believed that the traditional vehicle network communication architecture is based on special short-range communication, which is difficult to meet the service quality requirements of vehicle network data transmission. Combined with the idea of mobile cloud service, new network architecture and data transmission method is proposed. [3]. Luo et al. (2017) proposed a lightweight vehicle networking application (VNA) middleware framework, which designed a multi-layer middleware architecture in the middle framework to separate the VNA from the software platform and improve the adaptability of heterogeneous network and various vehicle network communication protocols [4]. Sandonis et al. (2016) analyzed the vehicle networking system architecture composed of various performance indicators in the context of vehicle networking research, identified the cloud platform’s recognition of big data processing efficiency, and proposed a room for improvement, and then proposed a main memory database. It replaces the traditional computing platform I/O disk database to improve the data processing efficiency of the cloud computing platform [5]. Jr et al. (2016) focused on the differential clustering algorithm and proposed a clustering routing algorithm based on differential clustering to reduce the traffic of wireless sensor networks in the vehicle network and reduce redundant flooding and routing overhead [6]. Uysal et al. (2016) studied the multi-channel transmission of MAC layer security information to optimize the delay and reliability of information transmission and has certain reference value for the development of multi-channel transmission technology of vehicle network security information [7]. Cidronali et al. (2016) studied a one-dimensional serial vehicle formation control scheme in which each member tracks the movement of its immediate previous member, but the first vehicle also tracks the position of the last member of the string and discusses the stability of the fully interconnected system. The condition showed that if a fixed car spacing strategy is adopted, the interconnect system becomes unstable when the string size exceeds the critical value [8]. Li et al. (2016) proposed a heterogeneous network interconnection model based on semi-transparent routing gateways and Linux virtual devices, which solved the problem of heterogeneous communication between various devices in the vehicle network and the internet. In this model, the c inner CAN node in the car is considered a common node on the internet and is assigned an IPv6 address and a MAC address [9]. Sridharamurthy et al. (2016) discussed the modeling and verification of multi-network computer systems supporting vehicle embedded applications based on the development of reusable component models with well-defined interfaces. Through the integration of these components, a complete application model is set up [10]. Wei et al. (2018) introduced a structural design of a vehicle Wimac wireless local area network for railway environmental monitoring, and evaluated the performance indicators of vehicle wireless network simulation results based on switchover performance [11]. Johri et al. (2016) proposed an architectural framework to implement a directional link vehicle network using dynamic switching, which helps solve channel contention problems associated with omnidirectional antenna-based network architectures and leads to vehicle-to-vehicle (V2V) simple protocol specification for communication [12].

Research on cloud and fog computing has also attracted a lot of scholars’ attention. Chang et al. (2016) provide a way to combine cloud computing infrastructure with traditional or unconventional network deployments, taking advantage of the best of both fields and enabling centralized logical control of them [13]. You et al. (2016) believed that cloud computing technology has become more and more popular.
recently. It can be applied to vehicle applications to ensure real-time performance and improve driver accuracy and comfort. The study introduced some innovative and real-time vehicle cloud services. It demonstrates the wide application potential of vehicles and discusses the research [14]. Chang and Ramachandran (2016) proposed a new smart battery energy management and control scheduling service charging solution based on a cloud computing network, and proposed smart car-network scheduling service that provides the required computational scalability. When the number of charging devices and electric vehicles is large, it can make the necessary decisions to enable the electric vehicle battery energy management system to operate efficiently [15]. Deng et al. (2017) proposed a normal vehicle-oriented WSN cloud infrastructure that combines the concepts of normal vehicle, wireless sensor network (WSN) and cloud computing to provide drivers with a safe and comfortable driving environment and improve environmental conditions [16]. Hong et al. (2016) considered that commercial vehicle operation (CVO) is a widely used application of intelligent transportation system. The location determination of vehicular unit in automobiles is an important issue of CVO, and an efficient mobile positioning method is proposed to analyze the cellular network signals for CVO data [17]. Yang et al. (2017) considered the technological advancement and economic advantages of integrated architecture and cloud computing, and believe that realizing a real-time cloud (called FOG) will be the next step in the development of automobiles, which provide reliable electronic services for automobiles and provide effective and flexible on-board temporary security [18]. Abdel-Basset et al. (2018) proposed a certificate-free aggregated signature encryption scheme and proved its security in a random Oracle model. The results revealed that the proposed scheme has independent advantages, the advantages of certificateless cryptography and signature cryptography can be achieved simultaneously [19]. Yang et al. (2018) offered a learning-based vehicle network switching optimization, which will facilitate the smooth transition of equipment connections and the unloading task between fog nodes, and it uses machine learning algorithms to learn from vehicle interactions with fog nodes [20]. Cha et al. (2017) proposed an urban traffic overspeed monitoring system based on fog calculation. This system not only can track overspeed vehicles in real time and obtain vehicle speed information, but also can achieve multi-target tracking by single target tracking algorithm [21]. Fog computing is a new computing paradigm that has recently appeared in the convergence of Internet of Things, wireless sensor networks, mobile computing, edge computing, and cloud computing, and is particularly suitable for smart urban environments [22].

3. Proposed method

3.1 New vehicles networking technology

The most recent new form of network architecture in recent years is Software-Defined Networking (SDN), which is different from the vertical integration of traditional networks. Its core idea is to separate the control plane from the data plane. Liu et al. (2018) For example, the functions of devices such as routers and switches are both data forwarding and forwarding control. The SDN architecture separates the control capabilities of the network in the underlying device. Since the controller is logically centralized, it is managed by it. The controller generates the flow table and rules[23]. Liu et al. (2018) The forwarding of the message according to the rules of the flow table is implemented by a series of devices of the underlying switch router. At this time, the soft-defined network introduces the feature of network programming[24]. The controller owns the entire view of the global network, so the humanized customized network becomes a reality. Zhang et al. (2018) The idea of network control strategy formulation and data forwarding separation is a key factor for the flexibility and scalability of SDN, which makes it easier to create new network abstractions on existing networks, and also make it possible to create different network policies for different services, driving the upgrade of the traditional network architecture[25].

![Figure. 1 Soft Definition Network](image)

A complete soft-defined network can
usually be divided into three-layer structure connected by two interfaces, as shown in Figure 1. Soft-defined networks have attracted much attention because of their unique advantages. Jing et al. (2018) Their flexibility, scalability, and programmability are well suited to the needs of the current development of the vehicles networking. It is considered to be one of the core architectures of future vehicles networking[26].

Since traditional IP address-based networks have many limitations in fast-moving environments, the cause of connection interruptions is the change in network topology, which has an impact on the quality of the service. Zhu et al. (2018) Therefore, a better solution to replace the IP network is the Internet-Centric Networking (ICN), and the Named Data Network (NDN) is its main implementation method[27]. Wang et al. (2018) Restricting the content of services that most users need to obtain is not the so-called acquisition of data in a certain orientation[28]. Zhang et al. (2018) The satisfaction of this feature is achievable by NDN. It communicates between the information and is driven by the data content, not the IP address as expected[29]. Chen et al. (2018) The two parties exchange the two types of packets for implementing communication in the NDN[30]. These two packets are interest packets and data packets, and they carry the names of the designation slices. Branceo et al. (2018) The interest packet contains some data requesting the name of the data to be obtained. The entire network is transmitted by the router and other devices[31]. Chen et al. (2018) When the data requested by the interest packet appears on a certain node, the data packet containing the requested content is returned, and the signature of the data source is binding to the packet[32].

3.2 Cloud computing and fog computing

Cloud computing is a hot new technology in recent years. It is widely used in people’s lives and is considered as a reasonable example to meet the growing demand for computing resources and service quality [33]. Cloud computing utilizes the hardware and software of the data center to provide relevant capabilities to users in a service manner, allowing users to obtain demanded services without knowing the service technology and without the relevant equipment operation skills. It is a computing model combined with distributed computing, parallel computing and grid computing, which has the following three service modes:

Infrastructure as a Service (IAAS); Software as a Service (PAAS); Platform as a Service (SAAS).

The basic service model of cloud computing is shown in Figure 2 below:

**Figure. 2 Cloud Computing Architecture**

The rapid development of cloud computing has been applied to various industries and fields, but in some emerging fields, especially in the use of mobile sensor networks, the performance of cloud computing is barely satisfactory, and much inadaptability has emerged. It is for this reason that the concept of fog computing is proposed to compensate for the shortcomings of cloud computing.

Fog computing is as easy to understand as cloud computing. In nature, the fog is closer to the ground than the cloud, so the fog computing is closer to the bottom layer than the cloud computing, which is the intermediate state between the cloud data center and the underlying device.

As a virtualization platform, fog computing exists between end users and network cloud data centers, which can make the services provided better, and has a certain role in reducing time delay, energy consumption, and data traffic. The main feature of fog computing is the ability to support the low latency, position sensing and mobility of the required equipment, which also determines that the fog computing is distributed and very close to the way of the user works. The architecture of the fog calculation mainly includes the cloud computing layer, the fog computing layer, and the end user layer, which can be represented as a three-level hierarchy, as shown in Figure 3. In this architecture, each smart device (mobile phone, office building, car, monitoring device.) is connected to a nearby fog device and connected to the cloud server via a fog device. The fog device is mainly deployed at the edge of the network. In the environment of accessing the network and network endpoints, it can provide three main functions of data cache, localization computing, and wireless access to meet the low latency and high traffic requirements of mobile devices.
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Since the equipment of the fog definition controller, and C represents the cloud service center. Therefore, the device processing delay $t_{\text{com}}$ is:

$$t_{\text{com}} = \frac{u_i}{C_i} = \frac{\delta_i U}{C_i}$$

The transmission delay in the network is mainly affected by the link type and...
transmission distance. In this study, $t_{Fi, Fj}$ indicates the delay between two devices. The delay between the device and the cloud service center is $t_{F_i, C}$, and the transmission delay $t_{tran}$ is:

$$t_{tran} = \tau_{Fi, Fj} \cdot m_{Fi, Fj}$$

(3)

$m_{Fi, Fj}$ indicates whether a connection can be established between two devices. When the value is 1, it indicates that the two devices can communicate indirectly or directly; that is, resources can be shared between the two devices. A value of 0 means that the two devices are completely independent, as indicated below:

$$m_{Fi, Fj} = \begin{cases} 1 & e_{Fi, Fj} \in E \\ 0 & e_{Fi, Fj} \not\in E \end{cases}$$

(4)

In summary, the communication delay of a single device and the delay of the cloud service center can be expressed as:

$$t_i = t_{com} + t_{tran} = \frac{\partial_i U}{C_i} + \tau_{F_i, F_j} \cdot m_{F_i, F_j}$$

(5)

$$t_c = t_{com} + t_{tran} = \frac{\partial_d U}{C_d} + \tau_{F_i, c_j} \cdot m_{F_i, c_j}$$

(6)

The energy utilization optimization inside the fog server utilizes the virtualization technology to control the number of tasks distributed to the device through the control of the adaptive resource manager, to minimize the energy consumption without affecting the overall task, thereby improving energy efficiency. Suppose a core fog service device has $N$ virtual service units, namely $S=\{S_1, S_2, ..., S_N\}$. The workload of each service unit is allocated by the adaptive resource manager. If $M$ represents the workload that the core fog service device needs to process per unit time, the workload allocated of each virtual service unit in per unit time should at least satisfy:

$$\sum_{i=1}^{N} m_i = M$$

(7)

The energy consumption of a device mainly includes buffer area storage consumption and compute consumption. Buffer area storage energy consumption refers to the energy consumed when data is transmitted inside the fog server. The current consumption for this part is usually expressed by the formula (8), where $\gamma$ is a constant term scale factor.

$$E_S = \gamma m^2_i$$

(8)

Each virtual service unit is assigned with different computing resources, so their processing power and energy consumption are different. Currently, most devices have a default CPU speed and working CPU rate. In the default state, the device maintains a static power. When the task flow enters, the device generates dynamic energy consumption. For device $S_i$, the default processing rate is assumed to be $p_i^{min}$, the maximum processing rate is $p_i^{max}$, and the current processing rate is $p_i$. When in the default state, its static energy consumption is $e_i$, and when the device is fully loaded, its energy consumption is $e_i^{max}$. The calculated energy consumption of the device can be expressed as:

$$E_C = e_i^{min} + \left(\frac{p_i}{p_i^{max}}\right)^2 (e_i^{max} - e_i^{min})$$

(9)

Therefore, the total energy consumption of a device during operation can be obtained as follows:

$$E_i = E_S + E_C$$

$$E_i = E_S + \gamma m^2_i + e_i^{min} + \left(\frac{p_i}{p_i^{max}}\right)^2 (e_i^{max} - e_i^{min})$$

(10)

In this mode, the goal of this scheme is to reduce the energy consumption in the case where the number of tasks reached can be processed in a unit time, so the objective function can be expressed as:

$$\min \sum_{i=1}^{M} E_i$$

s.t. $\sum_{i=1}^{N} p_i \geq M$

From the previous formulas (7), (9), the above function can be converted into:

$$\min \gamma m^2 + e_i^{min} + \frac{p_i}{p_i^{max}}^2 (e_i^{max} - e_i^{min})$$

s.t. $\sum_{i=1}^{N} p_i \geq \sum_{i=1}^{N} m_i$

(12)

The solution to this problem can be solved by the bidirectional constrained particle swarm optimization algorithm. This problem can be transformed into a standard optimization problem, like the following functions:

$$f(m_i, p_i) = \gamma m^2 + e_i^{min} + \left(\frac{p_i}{p_i^{max}}\right)^2 (e_i^{max} - e_i^{min})$$

$$p_i = m_i$$

(13)
5. Discussion

In this mode, the coordination fog server collects status feedback from the core service devices and adaptively adjusts the number of tasks each server needs to undertake. In the previous section, the problem has been mathematically modeled, and the algorithm is designed to solve it. In this experiment, the performance of the algorithm and the effectiveness of the system level solution need to be verified.

Table. 1 Experimental parameter of DSC-PSO algorithm

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
<th>Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>50</td>
<td>Initial particle swarm size</td>
</tr>
<tr>
<td>L&lt;sub&gt;max&lt;/sub&gt;</td>
<td>1000</td>
<td>Maximum number of iterations</td>
</tr>
<tr>
<td>γ</td>
<td>10</td>
<td>Penalty factor</td>
</tr>
<tr>
<td>C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>2</td>
<td>Acceleration factor</td>
</tr>
<tr>
<td>C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>2</td>
<td>Acceleration factor</td>
</tr>
<tr>
<td>C(ɭ)</td>
<td>10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>Penalty factor</td>
</tr>
<tr>
<td>ω</td>
<td>[0.4, 0.9]</td>
<td>Inertia factor</td>
</tr>
</tbody>
</table>

During the experiment, 20 computing devices with general processing capacity were simulated as core fog service equipment, and some computers with strong processing capabilities worked together as cloud service centers. The processing capacity of core fog service equipment was randomly set within the range of 100Mb/s to 200Mb/s, while the cloud service center has a processing capacity of 2Gb/s. In reality, the different distances of the server lead to different transmission delays. In the experimental environment, other factors affecting the transmission delay are ignored, and the transmission delay is controlled by using different bandwidths. By widening the transmission bandwidth gap between the core fog service device and the cloud service center, the distance between the two users is simulated.

Figure. 6 Performance comparison of algorithms

It can be seen from Figure 6 that as the number of tasks increases, the delay characteristics of the proposed algorithm are always better than other methods, mainly because the greedy algorithm and the extreme load balancing algorithm do not take the computing power of the device into account, so the solution has large delay. At the same time, the algorithm of this study mitigates the local optimal problem by the inverse mutation factor, so the result is improved based on the traditional Particle Swarm Optimization (PSO) algorithm, and the delay characteristic is the best.

Figure. 7 Energy Consumption Comparison under Different Arrival Rates

It can be seen from Figure 7 that as the task arrival rate increases, the energy consumption of both solutions will increase, but the energy-aware solution in this study has better performance. At the same time, when the task arrival rate is low, the optimization effect of this study is obvious. However, as the task rate increases, the energy consumption gap is shrinking. Through analysis, it can be found that the main reason is that the computing
capacity of the core fog service equipment is limited. When the task volume is continuously increased, the performance of the equipment will be affected to some extent, so the energy consumption will continue to increase. When the device reaches full load, the energy consumption will continue to increase. When the number of tasks to be processed in a unit time is within a certain range, the solution of the present scheme can effectively reduce the energy consumption of the device and improve the energy efficiency.

6. Conclusions
This study introduces the architecture of traditional vehicles networking and some difficulties and problems encountered. It uses some popular technologies to conduct comprehensive evaluation and analysis. Based on this, the idea of cloud and fog based software defined vehicles networking architecture is proposed. In the context of the optimization of the software definition control layer and the collaborative fog service layer, the calculation methods are designed for each of them. Then the experiments and simulations of the two schemes are carried out. The experimental results show that the performance of the proposed algorithm can help improve the performance compared with the traditional ones. On this basis, the scheme of this study can reduce the communication delay, and improve the service quality, optimizing the performance of the vehicle’s network.

Software-defined networks, cloud computing, and fog computing technologies are comprehensively applied based on this study. These technologies have a relatively short development history and have a certain degree of limitations so that they will be further improved in the future. In the future, the network architecture is an information-centric network. The central technology Named Data Networking (NDN) has a high degree of similarity with the Internet of Vehicles. However, many studies are still at a theoretical level and therefore, are not cited in this study. To provide a better quality of service, the NDN network will be boldly applied to the vehicles networking in the future. This study optimizes the system and equipment by cooperating with the cloud-fog computing service mode. However, the energy consumption proposed in this study is based on the completion of task allocation, and in the actual situation, such as emergency, it pays more attention to the quality of service rather than cost. Therefore, the solution should be improved in the future so that the service policy is automatically adjusted according to the scenario.

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References