Joint Cloud Collaboration Mechanism between Vehicle Clouds Based on Blockchain

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***Abstract*—With the development of the Internet of Vehicles, more and more applications require collaboration between vehicles. Vehicles from different car manufacturers have their own private clouds, and the collaboration between them is poor, resulting in inefficient collaboration between heterogeneous vehicles. A single cloud lacks collaboration between vehicles and it's an inevitable trend for developing collaboration between clouds. JointCloud is a new computing model in which collaboration services provided between clouds are used to server users in a software-defined manner based on blockchain. This paper proposes the collaboration framework of multiple vehicle clouds, introduces the blockchain to establish the coordination mechanism, and describes standardization method and service combination method of the vehicular cloud service in detail. At the end of this paper, we designed a distributed cloud service evaluation method based on blockchain to provide users with an effective cloud service evaluation solution.**

Keywords—Jointcloud, internet of vehicle, Blockchain

I. Introduction

The Internet of vehicles is an open and integrated network system composed of multiple vehicles, users and networks and the purpose is to improve overall traffic quality and provide safe travel of the users[1], [2]. Vehicles can communicate with Roadside Units(RSU) and other vehicles through IoV and also exchange data with the vehicular cloud where traffic information is uploaded, processed, stored and disseminated using cloud architecture[3]. In the recent years, car manufacturers cooperate with their cloud service providers to build intelligent IoV management system, for example, Audi connect[4], One Digital Platform built by Volkswagen and Misrosoft[5], SAIC Simulation Computing Cloud built by SAIC Motor Passenger Vehicle Corporation and Alibaba Cloud[6], IOV OS built by Baidu[7], Cloud Native built by Vodafone and Huawei[8], FordPass built by Ford in Alexa[9]. Various applications have been implemented through the cloud platform such as remote control, route planning, intelligent parking[10], online vehicle management, and entertainment services.

However, all mentioned above are private cloud platform that can only be accessed and supervised by authorized users[11]. Since it is difficult for a single cloud to meet the high-quality service requirements of the diverse applications as well as the flexible and personalized customization requirements[12], federation of different clouds is a promising scheme for the sharing of vehicular information which may contribute a lot to realize intelligent driving, intelligent transportation and auto-driving. Moreover, there is no interworking mechanism between cloud computing. At the same time, with the development of edge computing, 5G and other technologies, the cloud computing model is also facing a trend from centralized to distributed. Therefore, designing the collaboration mechanism between clouds is one of the main problems to be solved in the development of cloud computing.

JointCloud network interconnection can solve many problems faced by traditional cloud computing by connecting multiple clouds. JointCloud Computing can provide reliable and secure cloud services together while controlling costs through realizing the collaboration of multiple physical clouds. Since JointCloud supports the negotiation of computing, storage and data between different physical clouds, vehicles belong to different clouds can share information. Through the deep integration and cooperation of multi-level cloud resources and services, it is convenient for drivers to customize cloud services.

To realize JointCloud, the collaborative service of the JointCloud network interconnection is the foundation of the JointCloud Computing. It is necessary to establish a model and mechanism for the network interworking, service coordination and trusted settlement of the heterogeneous and diversified cloud from the physic cloud layer, the network layer and the service layer respectively.

However, in the implementation level, cloud collaboration faces new challenges different from traditional cloud computing: 1) the cloud network environment will change dynamically at any time, making it difficult to build a reliable and quality-assured cloud service network environment; 2) the resources and services of different physical clouds have different characteristics, and there are difficult to build cloud services standardization, which need to be effectively discovered and coordinated in order to measure and settle the quality of service and the number of services; 3) The relationship between various elements of the cloud system is complex and changeable. The JointCloud aggregation and collaboration of a single element

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usually affect other factors, and it is difficult to solve multiple factors and achieve multi-objective optimization.

In order to solve the above challenges, a lot of research has been carried out in the last few years. A variety of JointCloud collaboration products have emerged, such as JointCloud[13], SuperCloud[14], Multi-Cloud[15], FederatedCloud[16], Cloud Service Broker[17]. Due to the lack of large-scale network collaboration mechanisms, standardized service description languages, service aggregation methods, decentralized intelligent collaboration and value exchange methods, these products mentioned above have not been commercialized on a large scale.

In this paper, we introduces blockchain technology into the JointCloud network collaborative service model and designs a set of information and value exchange platform that supports independent peer-to-peer collaboration among different clouds.

The rest of this paper is organized as follows: Section II gives a general description of the JointCloud inter-network collaborative service framework; Section III describes the JointCloud services measurement method. Then the paper is concluded in Section IV.

II. AN OVERVIEW OF JOINTCLOUD COLLABORATIVE SERVICE MECHANISM AIMING AT VEHICLE CLOUDS

In order to solve problems in the collaboration between vehicular clouds, this paper studies the key technologies of JointCloud network interconnection and collaborative services, proposes a cloud inter-network interconnection model, and designs a cloud-internet interconnection method to support JointCloud peering. Thereby the collaborative services between the cloud peer entities is supported. The specific research contents include 3 parts. The first part is establishing a software defined abstract model of JointCloud interconnection, researching automatic network optimization construction based on abstract service description and realizing service quality assurance and security privacy protection based on dynamic optimization; The second part is forming service standard abstraction and description for cloud collaboration, realizing cloud service measurement based on standardized description and establishing decentralized consensus trusted automatic settlement; The third part is constructing a structure-independent measurement method for the underlying heterogeneous cloud facility, normalizing evaluation models and computable evaluation indicators and establishing discovery, indexing and evaluation mechanisms for JointCloud resources and services.

The framework of the inter-network interconnection and collaborative between IoV and JointCloud, as shown in Fig.1, can be divided into three parts:

Firstly, we researched the on-demand aggregation of JointCloud resources and services, proposed the software defined abstract model of JointCloud network interconnection and researched the underlying JointCloud network layered architecture supporting software definition. In order to achieve efficient and autonomous on-demand coordination of corresponding resources and services according to users need, we designed hierarchical negotiation, automatic construction and dynamic services of JointCloud networking quality assurance method. Meanwhile we established a heterogeneous peer entity cloud network layer interconnection networking mechanism.

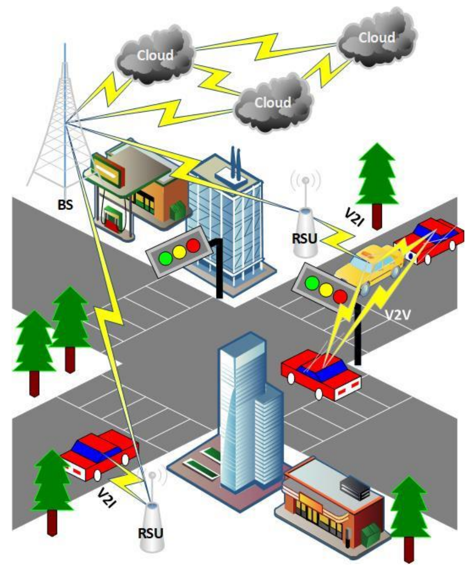

Fig. 1. The framework of Collabration between IoV and JointCloud

Secondly, we researched the perception and standardization of JointCloud services, established a cross-entity cloud unified cloud service identification and calling mechanism. We also built a big data-driven cloud network information plane, which support capability evaluation of physical cloud service and dynamic measurement of cloud network. The perception of JointCloud services provides data parameter support for on-demand aggregation of JointCloud resources and services. Besides, the standardization of JointCloud services provides clearing basis for auditing and tracing in the cloud interconnection.

Thirdly, we researched the event auditing and tracing in the JointCloud interconnection. On the basis of network interoperability and service collaboration, we designed a cloud-based decentralized service measurement, value exchange and collaborative trust mechanism based on blockchain. Then we further realized the automatic and credible settlement of smart contracts.

A. On-demand aggregation of JointCloud resources and services

The cloud network needs flexible network software defined capabilities and the underlying architecture. It can perceive the networking requirements, network configuration requirements, security requirements, and service quality requirements of the upper-layer cloud applications and automate the negotiation networking on demand as well. In addition, the heterogeneous architectures of different clouds, the independence of operations, and the dynamics of the JointCloud network bring more challenges for the service quality assurance of the cloud network interconnection. Different from the existing hybrid cloud and private cloud access tunneling methods, the cloud network interconnection has no centralized control point or management platform. We need to design a multi-entity, multi-layered collaborative service mechanism to achieve heterogeneous cloud architecture and diverse interconnection collaboration of peer-to-peer cloud service providers. It is necessary to design a new collaborative service mechanism based on multi-layered facing multi-entity.

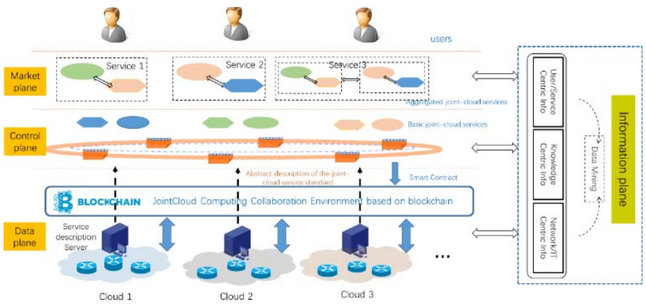

Fig. 2. Software-defined cloud network interconnection

We envision four essential planes of future Internet that lead to cost-effective, reliable, and agile network architecture. As illustrated in Fig. 2, the four planes are data, control, information, and market planes. The data plane forwards packets and schedules flows based on rules, and the network operating systems and abstractions of network devices serve as the interface to the control plane. The control plane runs centralized network control services to apply forwarding, scheduling, and security policies onto the data plane. The information plane collects network measurement data and provides them to the control plane, which utilizes real-time network snapshots for responding to significant events or statistical data for periodical network tuning. The market plane hosts a marketplace where users, services, and infrastructures interact, allowing users to compare cost and quality, negotiate transactions, and pursue the most suitable matches to maximize the tangible metrics. The market plane requires information completeness, symmetry, and transparency from the information plane. The knowledge learned from the information plane drives economical functions in the market plane to shape Internet architecture advancement.

Therefore, a plurality of inter-network interconnection planes as shown in Fig.2 are constructed: the data plane, the control plane, the market plane, and the information plane. And based on this, we need to design and implement the technical architecture of the JointCloud network interconnection. In the data plane, a peer-to-peer negotiation mechanism for each physical cloud network controller is designed. At the same time the negotiation and coordination of trust authentication, network configuration, format encapsulation, security policy and service quality management in the process of cloud networking is also realized. Thereby interconnection between the inter-cloud entity and the JointCloud service is achieved. In the control plane, the configuration and delivery of the JointCloud networking strategy are researched, and the hierarchical networking protocol between the entities is designed to provide effective means for the collaborative networking between peer entities. The market plane and information plane build a complete JointCloud service management capability through the perception, standardization, auditing and traceability of JointCloud services.

The on-demand aggregation of inter-cloud resources and services needs to break through the following two key technologies: 1)dynamic network resource self-adaptation; 2) automation deployment policy of JointCloud security, specifically described as follow.

B. Dynamic network resource self-adaptation

The physical realization of the interconnection of JointCloud network depends on the Internet. However, the Internet has the characteristics of dynamic fluctuations in link resources may caused by geographic location, time zone changes, major events, live video traffic etc. The mobile traffic grow rapidly , which has become the main body of traffic on the Internet. Under these circumstances, the dynamic and complex nature of Internet links will become more prominent. This also brings a greater challenge to provide a reliable and stable JointCloud network interconnection. Technically, the requirements of the JointCloud networking can be extracted from the upper description, and the dynamic optimizaiton of JointCloud network can be automatically achieved by software-defined network technology. The control plane is used to obtain the information of the JointCloud network and is controlled through the data dynamic routing algorithm. Furthermore, traffic engineering and task scheduling are used to improve the utilization and service quality of the network link. Based on the global network resource information plane, we integrate user requirements and current resource and provide reasonable resource sharing and global optimization of networking strategies. Through the traffic scheduling mechanism, the service consistency and dynamic network service quality in the cloud network optimization are guaranteed.

C. Automation deployment policy of JointCloud security

JointCloud network interconnection involves the interconnection of multi-entity cloud physical resources. Different cloud service providers have different competition, cooperation, and corresponding connection strategies. At the same time, cloud service providers also have a layered network architecture. Different logical areas have different system functions, different security levels and different interconnection strategies with the outside world. In addition, different security measures should be applied for different data transmissions. Therefore, security is one of the core challenges of the Internet interconnection. An important component of the technical framework is the generation, deployment, and automated verification of JointCloud security rules. According to the upper layer of the inter-network interconnection description, it detected whether the service, access control and other strategies among the cloud service providers are satisfied. According to the high-level security policy, the rules for automatically generating the data plane are automatically delivered to the logical boundary of the inter-network interconnection when the networking is performed, and the automatic update of the topology change with the cloud interconnection is supported. At the same time, it supports automatic verification of network rules, real-time alarm and repair of configurations that violate security policies. In addition, security-aware devices are deployed for security policies, leveraging the infrastructure of each cloud service provider to provide resilient JointCloud security capabilities.

III. JOINTCLOUD SERVICES MEASUREMENT METHOD

Cloud measurement, auditing and comparison need to be performed through multiple layers of physical cloud. Performance parameter is monitored on the network data plane to assess system service capabilities and service quality. Service settlement is audited on the network control plane and the settlement result is verified by combining service measurement data to ensure the fairness of the system. Experience feedback is establish on the network service plane and integrated with other measurement data. The network information plane integrates the measurement data aboved and establishes a comparable and computable service evaluation model through a unified data evaluation method.

This part mainly describes constructing structure-independent measurement methods for the underlying heterogeneous entity cloud, performance measurement methods and service quality models of abstract cloud service interfaces, and the normalized model of multi-source measurement data and establish computable evaluation indicators.

Collaborative scheduling and service performance-based settlement between cloud services are based on explicit parameter measurement and perception of the cloud service environment and the service itself.

So a big data-driven information plane is established in the JointCloud network interconnection, and objectively builds an information view of the entire JointCloud network interconnection system, provides parameters related to service performance and quality in the CSDL description and data for scheduling optimization of software-defined JointCloud service, Also it provides conditions for automatic settlement of services between cloud networks.

A. *Service measurement*

From the perspective of application, cloud service is a black box that the states of the network and inside the service are hidden. The resources in the cloud are difficult to control and coordinate. From the perspective of cloud service, the high-level application is also a black box that the content, context and even performance of the application indicators are not transparent.

The problems mentioned above are mainly caused by the lack of a unified description specification of cloud services. In the current technical architecture, it is often that a specific service corresponding to a specific cloud service, the interface standards are inconsistent, so cloud services and applications from different entities are difficult to integrate across the clouds. Similar to the Web Service Description Language (WSDL) [17], we design the Cloud Service Description Language (CSDL) to describe the cloud service in a unified way. It needs two levels in the clouds and the JointCloud. The main contents are shown in Table I and Table II.

TABLE I. DESCRIPTION OF STANDARDIZED SERVICES IN THE CLOUD

Description	Details
Type	Service type: storage, calculation, etc.
Operation dictionary	Interpretation of the interface
Service call interface	Standardized interface description with input and output parameters
Underlying service binding	Service abstraction layer and service entity binding relationship
Performance	Service processing power, including calculation speed, storage, etc.
Pricing model	Service charging standard
……	

TABLE II. DESCRIPTION OF THE STANDARDIZATION OF JOINTCLOUD SERVICES

Description	Details
Virtual network	Software Defined Foundation Virtualization Network Service
Workflow	Combined workflow for multiple services
Smart contract	Multiple physical cloud business contracts for this service
Performance evaluation	Overall performance indicators of the cloud service
……	

B. *Service Evaluation Based on Analytic Hierarchy Process*

Automakers work with cloud service providers to build vehicle clouds that distribute computing resources to vehicles through cloud paradigms. However, the cooperation between vehicles and clouds is very scarce, and there is no interaction between multiple cloud service providers. Through the cooperation between global cloud service providers, the ability to build a cloud service environment is growing, and services can be provided anytime, anywhere. However, the lack of quantitative evaluation indicators between various clouds hinders collaboration between vehicle clouds.

In this paper, the proposed availability evaluation indicators of cloud service are hierarchically represented, and each cloud is evaluated according to different levels of indicators, which solves the problem that qualitative indicators cannot be quantified and therefore cannot be compared. The AHP can evaluate the availability of various cloud services according to user needs, and provide users with advices of cloud service availability.

In order to compare the availability of various cloud services, it is necessary to obtain the weight assigned by the user to each evaluation index. The weight can be assigned to the indicators according to the subjective will of the user, or the degree of association between the indicators can be customized.

For example, for a certain indicator, the schemes under it are compared in pairs, and the grades are rated according to their importance. It is assumed that a_{ij} indicates the degree of importance of indicator x_i in the scheme i than the index x_j in the scheme j. Then a mathematical model can be built. The specific evaluation model is expressed as follows, where v_{xi} represents the weight of the x indicator in the scheme i, and v_{xj} represents the weight of the x indicator in the scheme j.

$$a_{ij} = {}^{v_{xi}}/_{v_{xj}}$$

It is obvious to know that vice versa.

$$a_{ji} = {}^{v_{xj}}/_{v_{xi}} = {}^{1}/_{a_{ij}}$$

According to the results, the method of judging the degree of importance is shown in the following table III.

TABLE III. METHOD OF JUDGING THE DEGREE OF IMPORTANCE

Description of importance	**Value**
Equally important	1
Slightly important	2
Stronger	3
Strongly important	4

The comparison of parameters between cloud services requires the design of uniform standards for quantitative comparison. First the indicators of the cloud service should be determined, such as CPU, memory, storage performance and price. Then, the same indicators of different schemes are compared in pairs, and the N-order matrix of the cloud service evaluation sub-indicators is established, and the feature vector of the matrix is extracted as the evaluation result of the current index. The analytic hierarchy process is used to hierarchically process the sub-indicators of cloud service indicators, and the weight values of users attribute assignments are comprehensively considered. The performance evaluation results of multiple cloud services are obtained through matrix transformation.

C. Equations

This paper simulates the current three mainstream cloud service providers, and illustrate how to use AHP to compare different cloud services. The performance data of Amazon EC2, Microsoft Azure and Alibaba Cloud was collected separately, and the user's attribute weights of the three cloud services were randomly assigned. The specific attribute indicators, test data, and random weights are shown in Table IV below.

TABLE IV. METHOD OF JUDGING THE DEGREE OF IMPORTANCE

Indicator (weight)	**Sub-indicator (weight)**	**Service 1**	**Service 2**	**Service 3**
Functional suitability (0.4)	Completeness(0.4)	1	0.9	0.8
	Correctness(0.2)	0.8	0.8	0.7
	Suitability(0.1)	1	0.7	0.6
	Effectiveness(0.2)	0.99	0.9	0.99
Specialization (0.1)	Professional technology(0.2)	5	4	4
	Device independence(0.2)	1	1	1
	Platform independence(0.3)	1	1	1
	Cloud-specific features(0.3)	1	1	1
Humanizaiton (0.1)	Easy understanding(0.3)	0.6	0.7	0.8
	Easy operation(0.3)_	0.7	0.8	0.9
	User error defensive(0.2)	0.7	0.6	0.8
	User interface(0.2)	0.6	0.6	0.7
Credibility (0.2)	Data quality(0.4)	0.7	0.8	0.7
	Identity management(0.2)	0.8	0.8	0.8
	Rights protection(0.4)	1	1	1
Value (0.2)	Cost(0.3)	5	3	3
	Satisfaction(0.4)	8	7	6
	Utility(0.3)	0.9	0.7	0.8

The hierarchical structure model constructed according to the above indicators is shown in Fig.3.

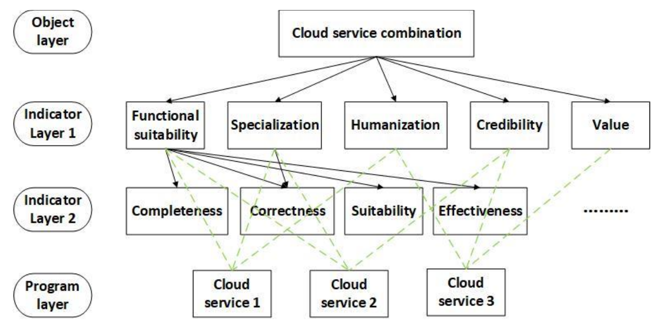

Fig. 3. Hierarchical model

Firstly, the sub-indicators are compared. Taking the cost indicators in the value indicators as an example, the third-order matrix of the relationship between the cost sub-attributes of the three cloud service provider value attributes is obtained.

$$E_{cost} = \begin{bmatrix} 1 & 5/3 & 5/3 \\ 3/5 & 1 & 3/3 \\ 3/5 & 3/3 & 1 \end{bmatrix}$$

Then, the eigenvector of the matrix is obtained, and it is $\alpha_{cost} = [1.43,\ 1,\ 1]$. By analogy, the eigenvectors of all sub-indicators are obtained. And the eigenvectors of rest sub-indicator of Value indicator are $\alpha_{satisfaction} = [1.14,\ 1,\ 0.85]$ and $\alpha_{utility} = [1.2,\ 1,\ 0.94]$. According to the weight of each sub-indicator, the weight vector of the Value indicator can be obtained, i.e. $\alpha_{weight\ of\ value} = [0.3,\ 0.4,\ 0.3]$.

Next, the eigenvectors of the three sub-indicators of the Value indicator are matrixed and multiplied by the weight vector to obtain the eigenvector of the value indicator.

$$\alpha_{value} = \begin{bmatrix} 1.43 & 1.14 & 1.20 \\ 1 & 1 & 1 \\ 1 & 0.85 & 0.94 \end{bmatrix} \begin{pmatrix} 0.3 \\ 0.4 \\ 0.3 \end{pmatrix} = \begin{pmatrix} 1.245 \\ 1 \\ 0.922 \end{pmatrix}$$

By analogy, the eigenvectors of the other four main indicators are $\alpha_{funtionalSuitability} = [0.987,\ 0.9,\ 0.816]$, $\alpha_{specializaion} = [1,\ 1.12,\ 1.28]$, $\alpha_{humanization} = [0.953,\ 1,\ 1.178]$ and $\alpha_{credibility} = [0.948,\ 1,\ 0.948]$.

$$\alpha_{result} = \begin{bmatrix} 0.987 & 1 & 0.953 & 0.948 & 1.245 \\ 0.9 & 1.12 & 1 & 1 & 1 \\ 0.816 & 1.28 & 1.178 & 0.948 & 0.922 \end{bmatrix} \begin{pmatrix} 0.4 \\ 0.1 \\ 0.1 \\ 0.2 \\ 0.2 \end{pmatrix} = \begin{pmatrix} 1.0287 \\ 0.972 \\ 0.9462 \end{pmatrix}$$

Finally, the eigenvectors of the five main indicators are matrixed and multiplied by the corresponding weight vector, i.e. $\alpha_{weight} = [0.4,\ 0.1,\ 0.1,\ 0.2,\ 0.2]$. According to the results, the recommended cloud service provider is service 1> service 2>service3. That is, for the current specific needs of the user, recommendation order of the cloud service provider is Amazon EC2, Microsoft Azure, and Alibaba Cloud.

The AHP can help users or controllers choose a better cloud service portfolio with extracting the availability metrics of different cloud services and comparing them with analytic hierarchy. It also can provide users with quantitative evaluation indicators of various cloud services according to the diverse needs of users, so it is more able to meet individual needs. Through data testing and experimental verification of the current mainstream cloud services, the experimental results show that the proposed method can provide a more effective cloud service evaluation scheme within a lower time complexity and establishes a comparable and computable service evaluation model through a unified data evaluation method.

IV. CONCLUSION

This paper presented the framework of JointCloud, a new computing model designed to enable collaboration between multiple vehicular clouds. From bottom-up analysis, we researched the abstract software-defined model of JointCloud and described the abstract description and standardization of cloud services. In order to ensure the quality and security of services, we considered self-adaptation of network resource and automatic placement of security policies. Finally, we designed a distributed cloud service evaluation method based on blockchain to provide users with an effective cloud service evaluation solution.

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