A Novel Adaptive Clustering Algorithm in 3D CoMP Communication for the Internet of Vehicles

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Abstract—**The Internet of Vehicles (IoV) necessitates high data throughput and minimal latency for effective and practical implementation. In addition, the rapid movement of vehicles can lead to considerable load imbalances in IoV base stations (BSs). This paper proposes an adaptive clustering algorithm for 3D IoV coordinated multipoint (CoMP) transmission and reception communication within the 5th-generation (5G) communication environment to address these challenges. The IoV communication nodes are divided into BSs and vehicle users (hereafter called "users"). Among the users, there are two subcategories: Cell-center users (CCUs) and cell-edge users (CEUs). To select the Cluster Head (CH), the user with the highest count is chosen based on the number of distances to similar users that meet a specific distance criterion. The remaining associated users form a user cluster with the CH. The process continues in this manner until all users have been clustered. The CHs of CCUs and CEUs communicate with the primary service BS situated at the minimum distance to the CH and with coordinated BSs, respectively. The simulation results show that the novel algorithm can improve the average information rate of the IoV by 108.11%, reduce the delay by 43.88%, and decrease the load of IoV BSs by 73.56%.**

Keywords—**Internet of Vehicles (IoV), Adaptive clustering algorithm, Coordinated multipoint**

I. INTRODUCTION

During the last decade, the number of vehicles worldwide has grown substantially [1], and, as a result, many cities have already reached their road network's maximum carrying capacity. Concurrently, challenges like deteriorating traffic safety, reduced travel efficiency, and environmental degradation have increased enormously. Information technology has transformed all facets of life and continues to flourish, significantly improving social interaction and productivity [2]. New opportunities for resolving the above traffic problems are emerging, thanks to the IoV, which uses information and communication as its core technology[3]-[6].

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IoV communication can significantly enhance the safety and effectiveness of future transportation systems while also reducing pollution. In addition, it can facilitate the development of intelligent transportation technologies, such as autonomous driving. However, several technical challenges must be addressed before the IoV can achieve widespread adoption. [7][8].

First, it is understood that vehicles frequently travel at relatively high speeds on public roads. In this high-speed mode, the vehicles must exchange data with pedestrians, other vehicles, and the base station (BS) while continuously monitoring the road environment. In addition, there are strict delay constraints for emergency messages and real-time collaborative control messages. Infotainment applications, on the other hand, can tolerate a moderate degree of delay[9]. It is reasonable to assume that the IoV has stringent latency and data throughput requirements.

Additionally, the IoV experiences frequent network topology changes and shorter lifespans of communication links due to the swift vehicle movement. To ensure uninterrupted communication when the vehicle nodes move, the load of the BSs must be taken into account. In conclusion, the problems with delays, information rates, and load imbalances must be resolved for the IoV to be widely adopted.

Current research focuses primarily on anti-fading and anti-interference technologies to tackle the problem of low information rates. Anti-fading technologies encompass diversity reception [10], channel equalization [11], channel coding [12], and interleaving coding [13], among others. These technologies can be deployed individually or in combination. However, the density of vehicles may change significantly over time and location while the vehicles drive on the road. The communication between vehicles is limited by interference, mainly when the vehicles are close. Three specific anti-interference technologies are typically utilized: inter-cell interference cancellation, inter-cell interference randomization, and inter-cell interference coordination (ICIC) [14]. As an effective ICIC technology, coordinate multipoint (CoMP) transmission and reception can reduce adjacent cell interference, improve CEU (cell-edge user) performance, and increase spectral efficiency [15]-[17]. A novel wireless network design for CoMP in the air was developed by [18]. The latest advancements inspired the group in unmanned aerial vehicle technology to reduce interference caused by the high mobility of unmanned aerial vehicles through CoMP. In order to share spectrum resources and collaboratively serve users, [19] divided the cells with significant interferences into clusters. In addition, spectrum multiplexing between clusters was implemented to reduce interference. Inter-cell cooperation is the primary method that CoMP uses to enhance cell-edge throughput. During CoMP transmission, multiple cooperation points serve a single user simultaneously; hence, the cooperative set must be selected. Cooperative set selection can now be done in three different ways: statically, dynamically, and using a predefined cooperative set selection. The predefined and dynamic cooperative set selections have become the subject of recent research because static cooperative set selection typically cannot adapt to a channel's stochastic fading. In [20], a centralized medium-access-control scheduling approach for joint transmission coordinated multipoint (JT CoMP) was proposed. Furthermore, [21] reported that when the number of cooperative BSs was three, the cost-effectiveness ratio was optimal. [22] proposed an algorithm for load-sensing self-organization and user-centered dynamic CoMP clustering in 5th-generation (5G) networks. CoMP was used in many different fields and regions. For instance, [23] conducted unified research on the wireless communication of smart grids and CoMPs by studying a new method of joint communication and energy cooperation. [24] investigated the energy management in a CoMP system supported by the smart grid. In this system, each BS equipped with local renewable energy generation capabilities could engage in bidirectional energy transactions with the grid. Specifically, the study focused on downlink transmission within a single CoMP cluster. It aimed to jointly optimize the energy units that BSs buy/sell from/to the grid and their cooperative transmit precoding strategies. The goal was to minimize the total energy expenditure while meeting the established quality-of-service constraints for users. [25] introduced load-aware JT CoMP clustering and inter-cell resource scheduling in heterogeneous ultra-dense cellular networks. Wide-band (1GHz) BS diversity and CoMP large-scale measurements at 73 GHz were described by [26] for an urban micro-district square environment at the campus of New York University in Brooklyn, New York. However, the aforementioned anti-interference technologies are mostly used in typical 2D scenarios and are rarely utilized in 3D and IoV scenarios. Furthermore, load imbalance can likely occur when using pure CoMP technology. Therefore, CoMP alone cannot fully meet the IoV's low latency and load balancing requirements.

The problem of communication delay can be addressed by implementing mobile edge computing (MEC) and collaborative task scheduling. MEC enables short-distance deployment and service localization by adding intelligence and computing units at the edge of the network. MEC offloading technology not only alleviates the load on the core network but also minimizes the latency caused by transmission. Recently, the development focus of the IoV has shifted from the core network to the edge network [27]. Distributed deployment of the original centralized cloud-computing platform at the edge of the wireless access network can significantly reduce the transmission computing delay of tasks uploaded to the cloud server, which provides a low-delay, high-quality service experience to users [28].A cooperative task-scheduling scheme was proposed by [29]. In this scheme, a mission vehicle and multiple service vehicles jointly performed on-board missions [30][31]. The task vehicle comprehensively considered the computing power and maximum service time of each service vehicle. This was done to determine what percentage of tasks should be allocated to each service vehicle to minimize task execution time. Here, the maximum service time for each service vehicle depended not only on its dwell time at the assembly point but also on the relative motion between the task vehicle and the service vehicle. It was essential to ensure the mission vehicle and each service vehicle were always within each other’s communication range. Considering the two methods, MEC has rigorous configuration requirements. If the device configuration falls short of these standards, successful implementation becomes challenging. This cooperative scheduling scheme is proposed based on the idle resources scheduled in the resource pool. The resource pool consists of service tools that move together slowly, which has limitations for the IoV, and it is random and very dynamic.

Load balancing technology and clustering algorithms are frequently used to address the load imbalance of BSs. Load balancing relies on the existing network structure. It represents a low-cost, effective, and transparent method to expand the bandwidth of network equipment and servers, increase throughput, strengthen network data processing capabilities, and improve network flexibility and availability. For example, [32] proposed a distributed load-balancing algorithm that could handle any type of grid structure. [33] combined dynamic channel-allocation and channel-borrowing technologies to divide all BSs in the system into six groups. Each group of BSs belonged to the same mobile switching center. First, each mobile switching center allocated a certain number of channels to its lower BSs. Then, the channels were allocated among the BSs as needed. When a channel demand arose from the MSC, the channel was allocated via the BS under the same MSC. When no channel was available, it was borrowed from another mobile center to achieve load balancing. [34] used game theory to balance the load between channels. In [35], the "central load balancer" was a load-balancing algorithm designed to balance the load between the virtual product and the reasoning data center. The final result demonstrated that this formulation can achieve a higher level of insertion in a large-scale inferential computing environment compared to the previously used balancing algorithm. For the center, the most important thing is how to correctly handle and repair the many requests by the end users. Load balancing enhances performance and optimizes resource utilization by ensuring that each computing resource functions as a simple, effective, and reliable component. Furthermore, appropriate load balancing contributes to optimizing the use of valuable resources, implementing failover strategies, enabling scalability, and preventing bottlenecks as well as over-configuration. The clustering algorithm is generally widely used in wireless sensor networks, primarily to address the problem of insufficient sensor energy. For example, in order to balance network energy consumption and alleviate the "energy hot zone" problem, many routing protocols have been proposed in the past. The low-energy adaptive clustering hierarchy protocol [36] uses a clustering algorithm where nodes take turns serving as the cluster head (CH) and communicating with the sink node through the single-hop mode. In an IoV, the vehicular ad hoc network is a branch of vehicular networks that is applied for safety warnings and collaborative driving in intelligent transportation systems. It is a type of centerless, unorganized, and open structured inter-vehicle communication network. The routing in the vehicular ad-hoc networks is divided into plane routing and hierarchical routing [37]-[39]. The clustering algorithm is an important method that is used by the vehicular ad-hoc network to implement hierarchical routing. In terms of vehicle clustering, many researchers improved the clustering algorithm. For example, in [40], the nodes in the network were categorized into different levels, but only energy was considered in the selection of CH, and neither mobility nor distance between CH nodes and members of the cluster were considered. In conclusion, load balancing is primarily applied in cloud computing and other domains but rarely used in the IoV. A single clustering algorithm cannot solve other problems in the IoV.

Currently, most research only focuses on one or two specific problems. However, factors like user information rate, delay, and BS load levels are often either interrelated or at odds with each other, which should be considered thoroughly. Therefore, this paper proposes an adaptive clustering algorithm for 3D IoV CoMP communication within the context of 5G networks. The algorithm is an adaptive dynamic clustering algorithm, which cannot only provide high information rates and low latency but also reduce the complexity of the system and BS load.

The remainder of the paper is structured as follows: Section II introduces a model for the IoV communication system. Section III proposes an adaptive clustering algorithm, which includes three parts: user classification, user clustering, and base station selection. In Section IV, the simulation results are discussed in terms of three aspects: average information rate, BS's load, and communication delay. Finally, conclusions are summarized in Section V.

II. IOV COMMUNICATION SYSTEM MODEL

The IoV communication system consists of three components: the user cluster, the BS, and the vehicles, as illustrated in Fig. 1.

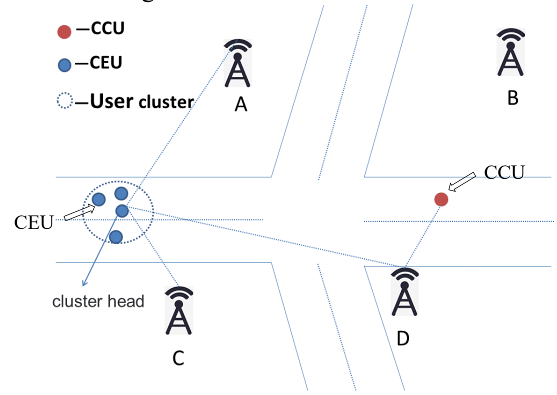

Fig. 1. IoV communication system model.

i. Vehicles: The solid dots represent vehicles, which are referred to as users. The red and blue dots represent CCUs and CEUs, respectively.
ii. BSs: A, B, C, and D denote several adjacent BSs. If the user is a CEU, it communicates with the cooperative BSs. Conversely, the CCUs communicate with the closest BS (the master serving cell).
iii. User cluster: The dotted circle represents a user cluster. The CH communicates with the BSs, while the affiliated users communicate with the CH. Instead, if users cannot cluster, they communicate with the BSs alone.

III. ADAPTIVE ALGORITHM

The three steps that comprise the adaptive algorithm are user classification, user clustering, and BS selection. The steps used by the algorithm are shown in Fig. 2. The parameters for this algorithm are displayed in Tab. 1.

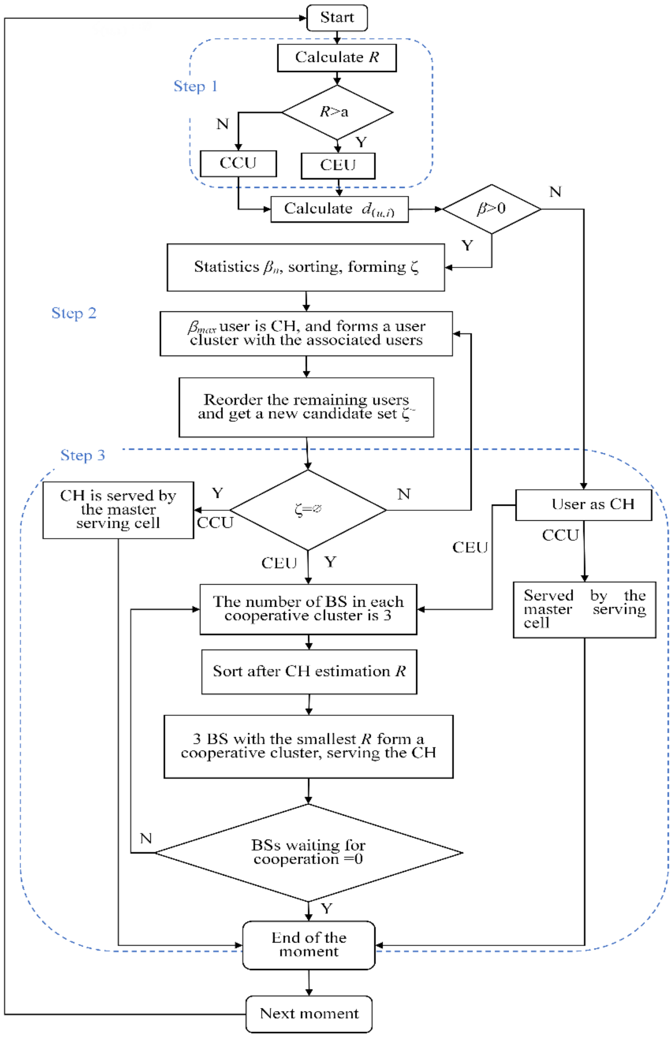

Fig. 2. Adaptive clustering algorithm flow.

TABLE I. ALGORITHM PARAMETERS

Parameters	Description
CCU	Cell-center user
CEU	Cell-edge user
R	Distance between users in the cell and the BS
r	Distance threshold between users of the same class
a	R's threshold
$d(u,i)$ $(\forall u=1,2,3,\dots,u,\ u\le n,\ \forall i=1,2,3,\dots,i,\ i\le n,\ u\ne i)$	Distance between user u and user i of the same class
β_n	Number of distances where a single user n of the same class meets condition $d_{(u,i)}\le r$
β_{max}	Maximum value obtained by sorting β_n
ζ	A candidate set formed by sorting all βs in order from largest to smallest

Step 1: User classification. Calculating R and determining the relationship between R and a. If R>a, these users are considered CEUs, and their service BSs need to cooperate. Conversely, these users are CCUs, and their service BSs do not need to cooperate.

Step 2: User clustering. CEUs and CCUs are separately clustered and described in detail in Section III.A.

Step 3: BS selection. This operation is done by the CH for clustered users or by the users themselves for un-clustered users, as described in detail in Section III.B.

A. User Clustering Algorithm

User clustering is widely used in wireless sensor networks, primarily to address the problem of sensor-energy shortage. It aims to balance network energy consumption and alleviate the problem of an "energy hot zone" User clustering is applied to the IoV to increase the information transmission rate and reduce the BS load as well as to minimize time delay.

Step 1: Determine cluster conditions. Calculating the $d_{(u,i)}$ of similar users and judging the relationship between β_n and 0. If β_n >0, proceed to step 2. If β_n =0, this user does not perform the user clustering operation.

Step 2: Sort β_n. β_n of each user in the same category is counted, and β_n *s* of all users are sorted (from largest to smallest) to form a candidate set ζ.

Step 3: Select the CHs. Users with β_{max} are selected as the CH from ζ. In the candidate set, users who satisfy $d_{(u,i)} \leq$r with CH as the subordinate entity constitute the user cluster.

Step 4: Exclude users from the cluster. All the users in the user clusters are excluded from the candidate set ζ to form a new candidate set ζ~.

Step 5: Repeat Steps 3~4 until the candidate set ζ is empty, i.e., ζ=∅.

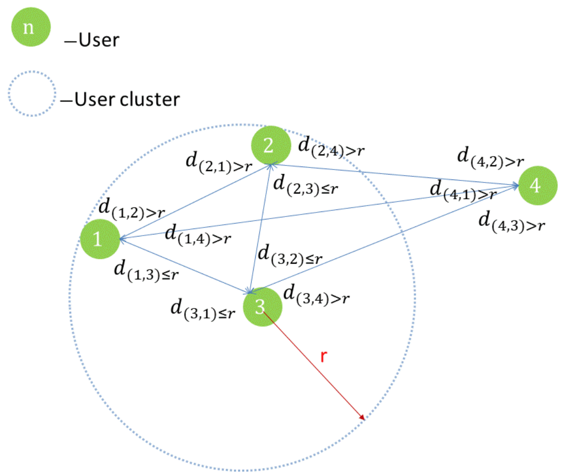

Fig. 3. User cluster.

The user cluster is shown in Fig. 3, and the following results can be obtained based on the conditions that need to be satisfied for the distance between users. As shown in Fig.3, β_1=1, β_2=1, β_3=2, β_4=0. Sorting the β_ns above yields β_3>β_1=β_2>β_4=0. So, user 3 is the CH, user 1 and user 2 are the subsidiary users. These three users form a user cluster, whereas user 4 forms a separate user cluster on its own.

B. Base Station Selection

CoMP can be used as an important means to reduce the interference of a neighboring cell and improve the performance of peripheral users and spectral efficiency. In CoMP, CCUs are served by the closest BS, while CEUs perform the following operations: The number of cooperative BSs contained in each cooperative cluster is defined as 3 [21].

The base station selection is done as follows:

Step 1: Sort R. R is estimated and sorted from smallest to largest.

Step 2: Select cooperative BSs. Three BSs with the smallest distance are selected as the cooperative BSs by the CEU to form the cooperative cluster.

Step 3: Repeat step 1 and step 2 until all BSs, which are waiting for cooperation, finish the cluster operation.

IV. SIMULATION ANALYSIS

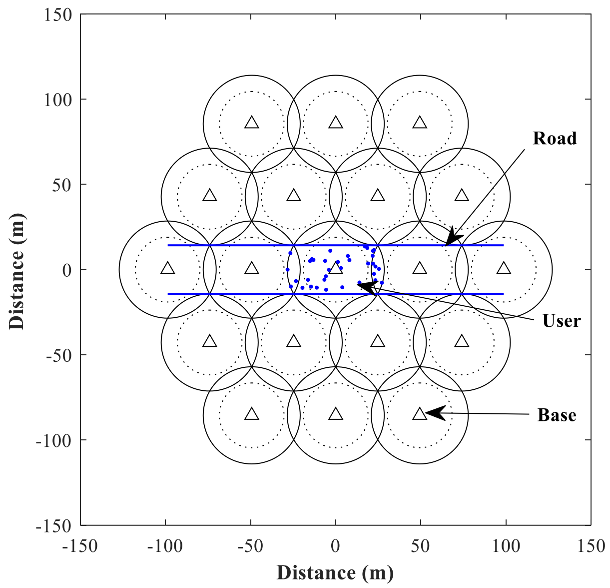

Fig. 4. The simulation scenario.

In this section, the simulation results are discussed in terms of three aspects: average information rate, BS's load, and communication delay. The simulation scenario is shown in Fig. 4, and the parameters involved in this section are shown in Tab. 2. In the simulation figures below, "Edge Non-clustering" and "Cell Non-clustering" respectively refer to CEUs and all cell users who do not utilize the proposed algorithm. Conversely, "Edge Clustering" and "Cell Clustering" refer to CEUs and all cell users, respectively, who utilize the proposed algorithm. Note that "Edge Non", "Cell Non", "Edge", and "Cell" have similar meanings. Furthermore, the simulation curves in the figures below vary substantially because the number of vehicles changes non-linearly during each time cycle (0.1s).

TABLE II. SYSTEM PARAMETERS

Parameters	value
Cell radius (m)	28.5
Transmission power of small BS (W)	20
Bandwidth of BS (MHz)	20
Frequency (MHz)	3500
Clustering radius (m)	10

A. Average Information Rate

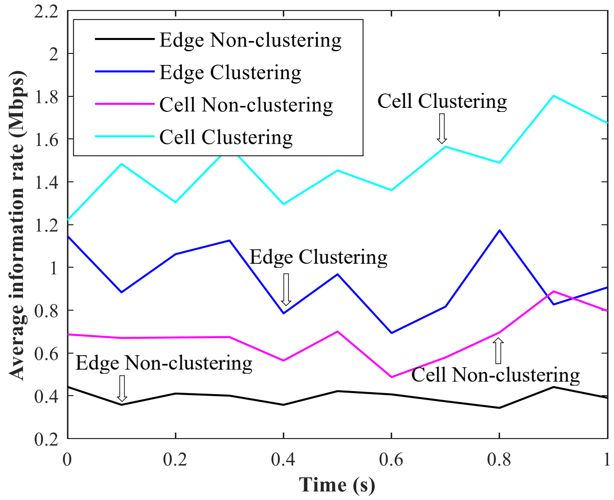

Fig. 5. Average information rate.

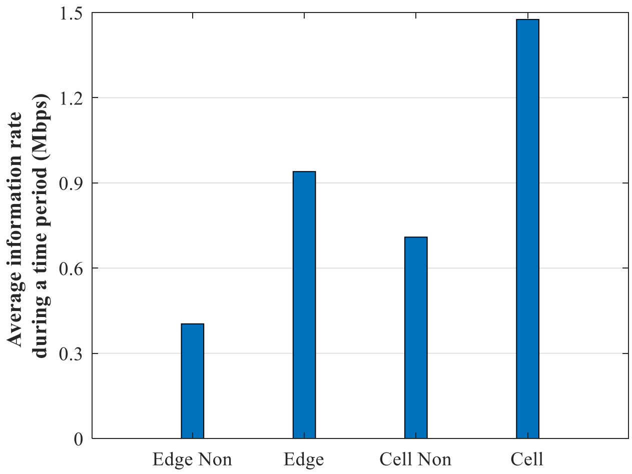

Fig. 6. Average information rate during a given time.

Fig.5 shows the change in the average information rate of users over time. According to Fig. 5, the average information rate of clustered CEUs is significantly improved over that of un-clustered CEUs. In addition, the average information rate of clustered users is clearly higher than that of un-clustered users.

According to Fig.6, during a specific time period, once the cluster is formed, only the CH communicates with the BSs. The average information rate between CH and BSs of clustered CEUs is 132.90% higher than that between CEUs and BSs of un-clustered CEUs. Moreover, the average information rate between the clustered users and the BSs is 108.11% higher than that between the un-clustered users and the BSs.

As shown in Fig.5 and Fig.6, the proposed algorithm can significantly improve the average information rate of users. In the proposed algorithm, the information rate can be very high because only the CH communicates with the BS, and the users within the cluster communicate with each other, i.e., through D2D (Device to Device) communication. In this approach, the high bandwidth requirements of the IoV can be met to provide users with a high-quality experience.

B. User Load of BSs

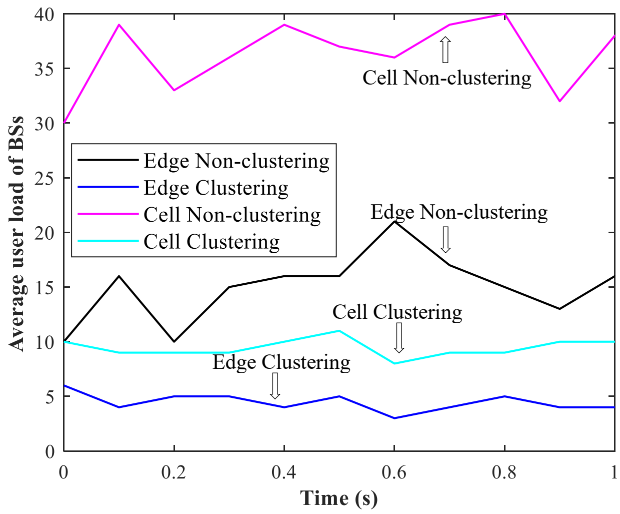

Fig. 7. Average user load of BSs.

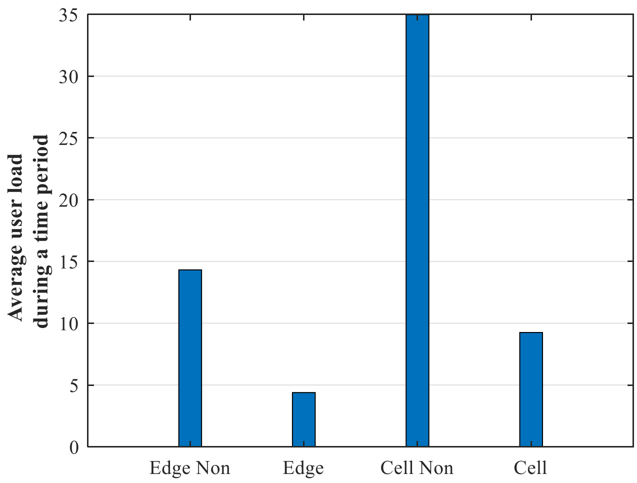

Fig. 8. Average user load during a given time.

Fig.7 shows the average user load of BSs over time. According to Fig. 7, the average clustered CEUs' load of BSs decreased significantly compared to that of BSs with un-clustered CEUs. Moreover, the average user load with clustering is clearly lower than without clustering.

According to Fig.8, during a specific time, the average user load of the BSs in the case of clustered CEUs decreases by 69.36% compared to un-clustered CEUs. Moreover, the average user load of the BSs with clustered users decreased by 73.56% compared to un-clustered users.

As shown in Fig.7 and Fig.8, the proposed algorithm can effectively reduce BS load, improve communication quality, minimize system complexity, and boost customer satisfaction, which aids the development of the IoV.

C. Communication Delay

In this paper, only the round-trip delay of signal propagation is considered. Fig.9 shows the variation of the average round-trip delay for the user signal. According to Fig. 9, the average user signal round-trip delay of clustered CEUs is significantly reduced compared to un-clustered CEUs.

Moreover, clustering can reduce the average signal round-trip delay for all cell users.

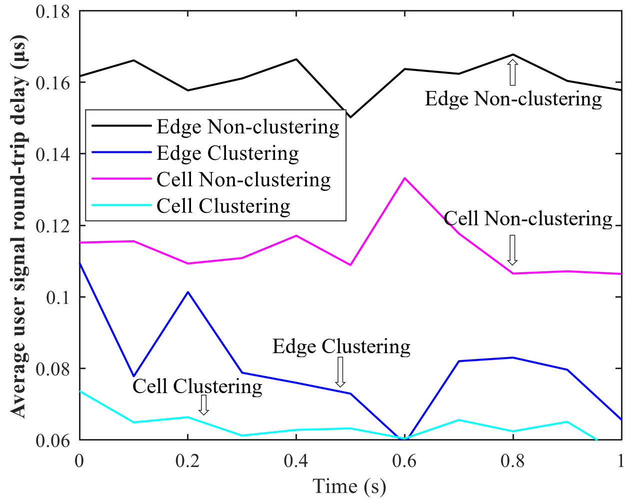

Fig. 9. Average user signal round-trip delay.

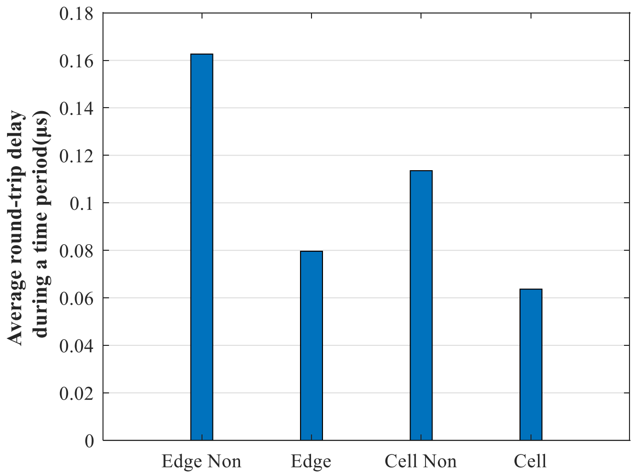

Fig. 10. Average round-trip delay of the user signal during a given time.

According to Fig. 10, during a specific time, the average signal round-trip delay of CEUs with clustering decreased by 51.05% compared to un-clustered CEUs. Moreover, the average round trip delay of all cell users with clustering is 43.88% lower than those without clustering.

As shown in Fig. 9 and Fig. 10, the proposed algorithm can significantly reduce communication delay. The proposed algorithm improves the IoV due to the critical need for low latency and the significant impact of (even minor) reductions in delay.

V. CONCLUSION

An adaptive clustering algorithm was proposed for 3D IoV CoMP communication within the 5G networking scenario. User classification, user clustering, and base station selection were the three components of the algorithm. The simulation results indicate that the average information rate improved by 108.11%, the signal propagation round-trip delay was reduced by 43.88%, and the load of BSs was reduced by 73.56%. Therefore, the proposed algorithm addresses low data throughput, BS load imbalance, and high communication latency. Moreover, the proposed algorithm met the requirements of the IoV while maintaining lower computational complexity. Therefore, the algorithms and findings presented in this paper hold significant implications for advancing the IoV.

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