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C-RAN Enabled Seamless Mobility Mechanism in Autonomous Driving

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Abstract

Connected autonomous driving has already been a new paradigm of driving for safety, efficiency and mobility. Connected autonomous driving can overcome the perceptual limitations of single vehicle, which has a high demand for high speed and seamless network connection. With the superiority of C-RAN, autonomous driving network can effectively support a vast number of vehicles communications and flexible multi-RRH cooperative transmission to improve throughput. However, due to the high mobility of vehicle, the problem of long latency or even link break caused by frequent hard handover still exists. In this context, based on cooperative transmission and the idea of multiple connections, we studied seamless mobility mechanism in C-RAN enabled autonomous driving. In this paper, we propose a user-centric dynamic cooperative cluster updating scheme with the purpose of guaranteeing the seamless of the vehicle during handover process due to mobility. Simulation results demonstrate that the proposed scheme can effectively solve the interruption latency or link interruption problem caused by handover. And compared with the non-cooperative case, the proposed scheme is superior in throughput gain.

1 Introduction

Connected autonomous vehicles can break through the perceived limitations of traditional single-vehicle automatic driving, thereby improving safety, efficiency and comfort of mobility, challenging the traditional human-controlled driving mode [1]. Connected autonomous driving requires real-time uploading of massive data and obtaining driving decisions from the network. Therefore, this technology has extremely high demand for seamless network connection. Simultaneously, owing to limited computing resource on the vehicle side, the analysis and processing of sensor data needs to be handled at the the mobile network edge server, so connected automatic driving requires higher network bandwidth to transmit raw sensor data.

In addition, the high mobility of the vehicles makes the channel conditions more complex and variable, and will inevitably lead to frequent handover. The current switching mode is the hard handover of LTE, which has a obvious user plane interruption delay. In [2], 3GPP assess the U-plane interruption time during handover. The generic handover procedure assumed in E-UTRAN is shown in figure 1, with associated delays encountered in the procedure. In the figure four constituents for the U-plane interruption are identified, i.e., (a) radio layer process, (b) UL RRC signalling, (c) DL RRC signalling, and (d) path switch. According to this model, the total interruption time of the U-plane in the UL is (a) + (b) + (c), whereas the interruption in the DL is (a) + (b) or (d), whichever is larger. Therefore, frequent handovers inevitably lead to a long handover latency or even link break, which does not meet the requirements of network seamlessness and is also a urgent problem.

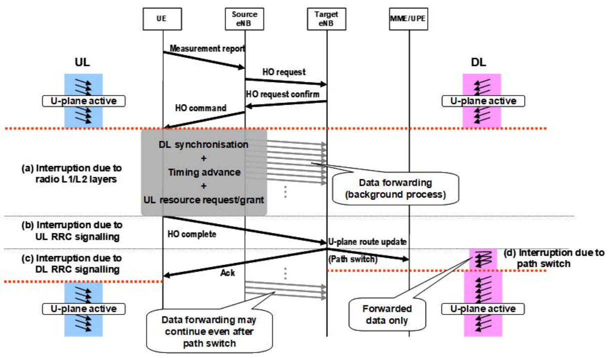

Figure 1. U-Plane interruption involved in the intra-MME/UPE HO procedure in E-UTRAN

2 Related Work

Although there is no direct research on the seamless mobility of vehicles in the C-RAN enabled networked autonomous driving scenario, with the continuous development of 5G technology, some possible solutions have been proposed. In [3], the authors use multiple MAC entities to realize seamless intra/inter-cell handover between physical transmission and reception points and reduce the interference levels across the network in NR. The authors in [4] introduce a logical architecture for network-slicing-based 5G systems, and present a scheme for managing mobility between different access networks, as well as a joint power and subchannel allocation scheme in spectrum-sharing two-tier systems based on network slicing. Moreover, the description of the FRAN (Fog Radio Access Network) architecture and the associated mobility and resource management mechanisms are provided to reduce the signaling cost and increase the net utility for the RAN in [5]. Inspired by the above literature, considering feasibility and practicality, we propose a simple and feasible seamless mobility mechanism based on the C-RAN enabled networked autonomous driving scenario.

In this paper, we study the seamless handover problem of vehicles in C-RAN enabled autonomous driving scenarios, aiming at designing a simple and effective seamless mobility mechanism. Actually, referring to the idea of multi-connection, if the vehicle always has at least one RRH with better channel conditions serving it, the drastic handover latency or even link interruptions will be invisible to vehicle user. In other words, we eliminate the U-plane interruption delay of the handover process on the existing LTE handover scheme.The main contributions of this paper are summarized as: (1)Combined with the characteristics of the scenario, a simple and practical signal model is proposed to simulate vehicle signal transmission in the case of overlapping cooperative clusters. (2) A novel user-centric low-complexity jointly RRH dynamic clustering and handover scheme is proposed to maximize user revenue. Considering the actual deployment, we have adopted a network-user joint selection framework (3) We evaluate and analyze the performance of the proposed approach from the extensive simulations, and the results prove that the proposed approach can guarantee the seamless throughput of the user during the handover process compared with non-cooperation scheme.

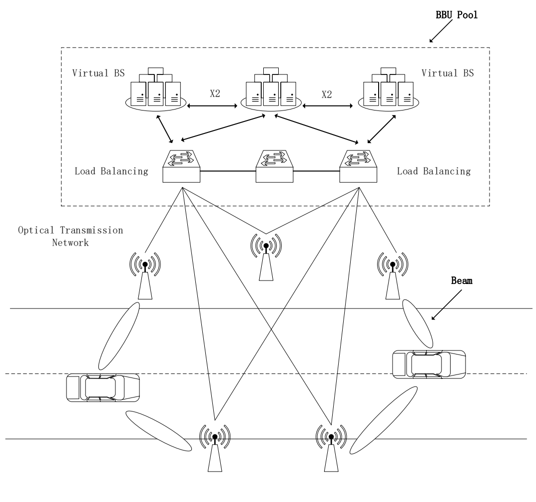

Figure 2. Basic network scenario

Regarding the notation, $(\cdot)^T$, $(\cdot)^H$, $E[\cdot]$ and $\|\cdot\|$ are transpose, Hermitian transpose, expectation and L2 normal form operator.

3 System Modeling

3.1 Scene model

Fig. 2 depicts the data-control separation cloud radio access network architecture. We can see that the base band units (BBU) with powerful signal processing ability are grouped together to form a BBU pool, and the radio remote header (RRH) are geographically separated from each other but connected to the same BBU pool via fiber optic transmission links. Autonomous-driving vehicles periodically perform link measurement and send a measurement report including the vehicle position and channel status information (CSI) to the BBU. Then the network side carried out a corresponding cooperative cluster construction and allocation algorithm, which maintain an optimal service cooperation cluster for each vehicle user.

3.2 Signal model

Considering a downlink of a C-RAN system as shown in fig. 3, where a set L of RRHs denoted as $\mathscr{L}=\{1,2,...,l\}$ are serving a set V of vehicle user equipments denoted as $\mathscr{V}=\{1,2,...,v\}$, which are worked as the distributed MIMO style. Each RRH is equipped with M transmit antennas, and each vehicle user equipment has N receive antennas. Suppose that each RRH can serve up to μ vehicle user equipments and for each V-UE, there is a corresponding RRH cooperative cluster for its signal jointly transmission. Let $L_i \in L_V = \{L_1, L_2, ..., L_v\}$ denote the RRH collaboration cluster corresponding to V-UE i and V_q denote the set of V-UEs served by RRH q. $H_i^q \in C^{N\times M}$ denote the channel martix from q th RRH to ith V-UE. Define $W_i^q \in C^{M\times N}$ as the beamformer from RRH q to V-UE i and let $W_i = [(W_i^1),(W_i^2),...,(W_i^{L_i})] \in C^{ML_i\times 1}$ denote the beamformer collection intended for V-UE i. The received signal at ith V-UE can be expressed as

$$\begin{aligned} \mathrm{y}_i = \sum_{p\in L_i} H_i^p W_i^p s_i + \sum_{p\in L_i}\sum_{j\neq i} H_i^p W_j^p s_j + \\ \sum_{q\in L_K q\notin L_i}\sum_{l\in V_q} H_i^q W_l^q s_l + Z_i \end{aligned} \tag{1}$$

where $s_i \in C$ is the normalized data symbol designated for V=UE i and satisfies $E[|s_i|^2]=1$, Z_i is the additive white Gaussian noise(AWGN) vector subject to $\mathscr{CN}(0,\sigma_i^2 I_N)$. Hence,the signal-to-interference-plus-noise ratio(SINR) for

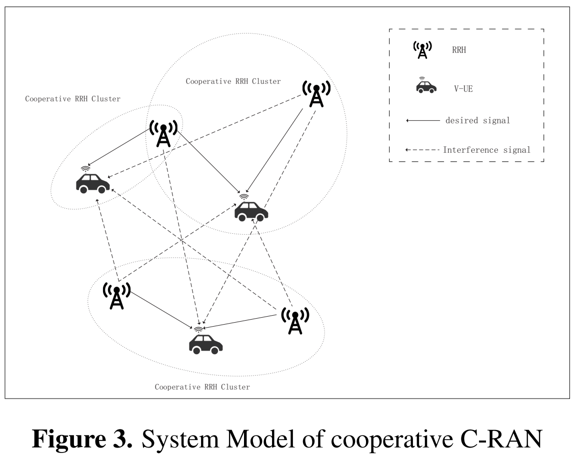

Figure 3. System Model of cooperative C-RAN

V-UE i is

$$SINR_i = \frac{\sum\limits_{p\in L_i} |H_i^p W_i^p|^2}{\sum\limits_{p\in L_i}\sum\limits_{j\neq i} |H_i^p W_j^p|^2 + \sum\limits_{q\notin L_i}\sum\limits_{l\in V_q} |H_i^q W_l^q|^2 + \sigma_i^2} \quad (2)$$

4 Proposed Seamless Mobility Mechanism

In this section,we focus on solving the problem of transmission delay reduction and seamless handover from the perspective of maximizing user revenue. To obtain the optimal dynamic RRH cooperative cluster for each vehicle user, we define the accession and departure rules. The basic idea is to enable RRH to join or leave a cluster based on the predefined preferences so as to maximize the user revenue utility. Specifically, we set the algorithm period to a suitable value such as 20ms. At the beginning of each algorithm cycle, determine whether the user is in a state where a RRH needs to be added. If so, perform the add operation and end the algorithm cycle; if not, determine whether the user needs to delete the RRH, and if necessary, disconnect the RRH and re-add a new RRH, which is equivalent to handover, and finally end the algorithm cycle.

We introduce a cooperative gain parameter cg as a reference to which RRH has the greatest possibility to join the cluster. A parameter α is adopted to limit the size of the cluster. Then the accession and departure rules can be respectively defined as

Accession rule: RRH b joins the cooperative cluster of vehicle user i,

$$if \begin{cases} size(L_i) < \alpha \ and \ cg(L_i, L_i \cup \{b\}) > 0 \\ b = argmax(cg(L_i, L_i \cup \{x\})) \end{cases}$$

Departure rule: RRH b' leaves the cooperative cluster of vehicle user i,

$$if \begin{cases} size(L_i) = \alpha \ and \ SINR_i < \gamma \\ cg(L_i, L_i \cup \{b'\}) > 0 \ and \ b' = argmax(\|H_i^x\|) \end{cases}$$

where γ is the predefined threshold of SINR for the vehicle user i in cooperative state. Cooperative gain parameter cg is defined as

$$cg(L_i, L_i \cup b) = log(\frac{SLNR_{L_i \cup b}}{SLNR_{L_i}}) \quad (3)$$

$SLNR_{L_i}$ denote the signal-to-leadkage-plus-noise-ratio of vehicle user i,which can be calculated by

$$SLNR_{L_i} = \frac{\sum\limits_{p\in L_i} |H_i^p W_i^p|^2}{\underbrace{\sum_{p\in L_i}\sum_{k\neq i} |H_k^p W_i^p|^2}_{\textbf{leakage power of the ith V-UE}} + \sigma_i^2} \quad (4)$$

To simplify the calculation, when computing Eq. **??**, we assume that maximum ratio transmitter (MRT) [6] is used to maximize the useful signal power. Assume that the total power of the RRH is P_t, the power allocated by the base station to each user is equal and fixed as P_{tr}, then the beamforming vector W_i^p can be taken as

$$\begin{aligned} W_i^p &= \sqrt{\rho} \times \frac{(H_i^p)^H}{\|H_i^p\|} \\ \|W_i^p\|^2 &= P_{tr} \end{aligned} \quad (5)$$

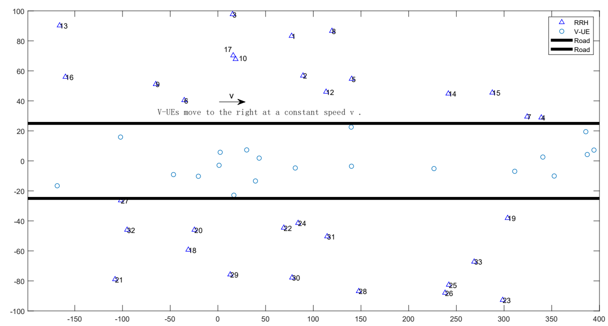

Figure 4. Network model

5 Performance Evaluation

5.1 Simulation setup

Simulations were done using MATLAB 2018b and specific simulation parameters are in table 1. As shown in Fig. 4, the RRH distribution is simulated by the Poisson point process on both sides of the road, and the vehicle users are randomly distributed in the lane area. In addition, the small scale fading coefficient h is modeled as the Jakes [7] where doppler frequency f_d is 926 Hz and sampling period T_d is 1e-5s, which is shown in figure 5.

Table 1. Parameters for Simulation

Parameter	Value	Parameter	Value
f_d	926Hz	μ	4
T_d	$10^{-5}s$	v	72km/h
α	2	γ	3×10^8bps
pathloss	15.3+37.6 $log_{10}(dis)$	system bandwidth	3MHz
N_0	-174dbm/Hz	RRH transimit power	43 dbm

5.2 Handover seamlessness analysis and performance comparison

In this section, we evaluate the seamlessness of user switching and the superiority of the algorithm by observing changes in user throughput. For the credibility of the results, We take the statistical average throughput of a user under different channel conditions simulation. We present the throughput of a V-UE as a function of time and compare it with non-cooperation scheme. It should be noted that the

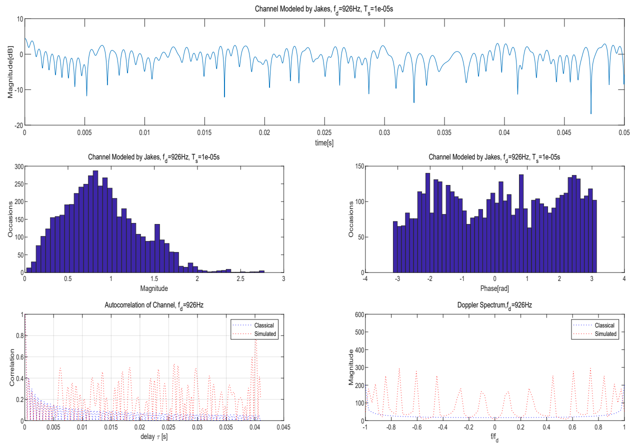

Figure 5. Channel model

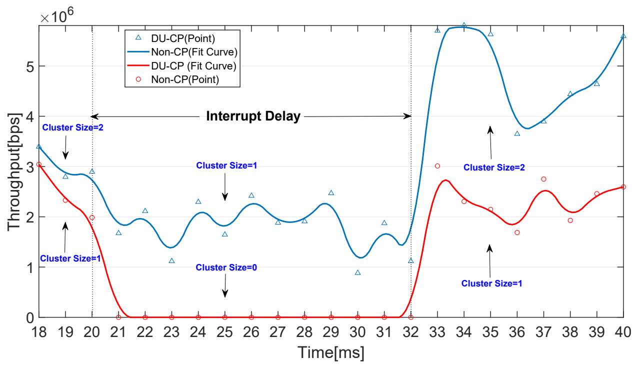

Figure 6. Performance comparison of a handover, the algorithm cycle is 20 milliseconds, and the U-Plane interruption is 12 milliseconds.

result is intercepted from 18th millisecond to 40th millisecond, the throughput is calculated every millisecond and the parameter α is set to 2. As shown in fig. 6, during the handover process, the throughput of DU scheme is greater than that of Non-CP scheme and remains at a stable non-zero level. Obviously, our proposed scheme is far superior to the non-cooperative one,it can keep user services uninterrupted during the handover.

Fig. 7 shows a cumulative distribution function(CDF) plot of the average rate of the system for 3MHz system bandwidth. It can be observed that the system average user throughput gain of the DU-CP scheme is much larger than that of the Non-CP. Moreover, within the range of *gama* values, as the cluster size *gama* increases, as more RRHs provide services to users, the greater the user throughput gain obtained by the algorithm, which is also the typical advantage of multipoint coordinated transmission.

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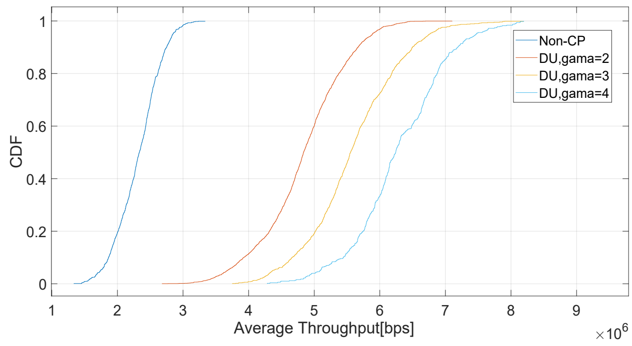

Figure 7. Average rate of the system at 3MHz bandwidth

References

[1] E. Yurtsever, J. Lambert, A. Carballo, and K. Takeda, “A Survey of Autonomous Driving: Common Practices and Emerging Technologies,” *arXiv e-prints*, p. arXiv:1906.05113, Jun 2019.

[2] 3GPP, “Feasibility study for evolved Universal Terrestrial Radio Access (UTRA) and Universal Terrestrial Radio Access Network (UTRAN),” 3rd Generation Partnership Project (3GPP), Technical report (TR) 25.912, 1 2016, version 13.0.0. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=1341

[3] J. Liu, K. Au, A. Maaref, J. Luo, H. Baligh, H. Tong, A. Chassaigne, and J. Lorca, “Initial access, mobility, and user-centric multi-beam operation in 5g new radio,” *IEEE Communications Magazine*, 2018.

[4] H. Zhang, N. Liu, X. Chu, K. Long, A.-H. Aghvami, and V. C. M. Leung, “Network slicing based 5g and future mobile networks: Mobility, resource management, and challenges,” *IEEE Communications Magazine*, vol. 55, no. 8, pp. 138–145.

[5] H. Zhang, Y. Qiu, X. Chu, K. Long, and V. C. Leung, “Fog radio access networks: Mobility management, interference mitigation, and resource optimization,” *IEEE Wireless Communications*, vol. 24, no. 6, pp. 120–127.

[6] T. K. Y. Lo, “Maximum ratio transmission,” *Communications IEEE Transactions on*, vol. 47, no. 10, pp. 1458–1461, 1999.

[7] P. Dent, G. E. Bottomley, and T. Croft, “Jakes fading model revisited,” vol. 29, no. 13, pp. 1162–1163, 1993.