C-RAN Enabled Seamless Mobility Mechanism in Autonomous Driving

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Background

Limitations Of Single vehicle autonomous driving

1 Insufficient computing power

The current vehicle-mounted computing platform has insufficient computing power due to its limited size and power consumption. However, due to the complex traffic conditions in reality, the amount of perception calculations to be processed in the automatic driving process is large.

2 Limited perception

The sensor of a single vehicle has limitations in its scope of application. Among them, cameras and lidars are easily interfered by light, bad weather, etc., which may c-ause safety hazards.

3 Missing multi-vehicle collaboration

Lack of collaboration between the vehicle and the vehicle and roadside facilities, the vehicle cannot perceive the danger of beyond the visual range and the overall road conditions

» Single-vehicle autonomous driving has several limitations that can not be avoided

» Connected autonomous driving has become a new direction of exploration

Issues Analysis

Network requirements

- Network-linked autonomous driving technology needs to upload vehicle driving data in real time and obtain driving decisions from the Internet;
- The computing power of the vehicle is weak, and the analysis and processing of sensor data needs to be performed on the edge server of the mobile network;
- The vehicle is moving fast, and the autonomous driving decision unit needs to be able to make driving decisions quickly and send it to the autonomous vehicle

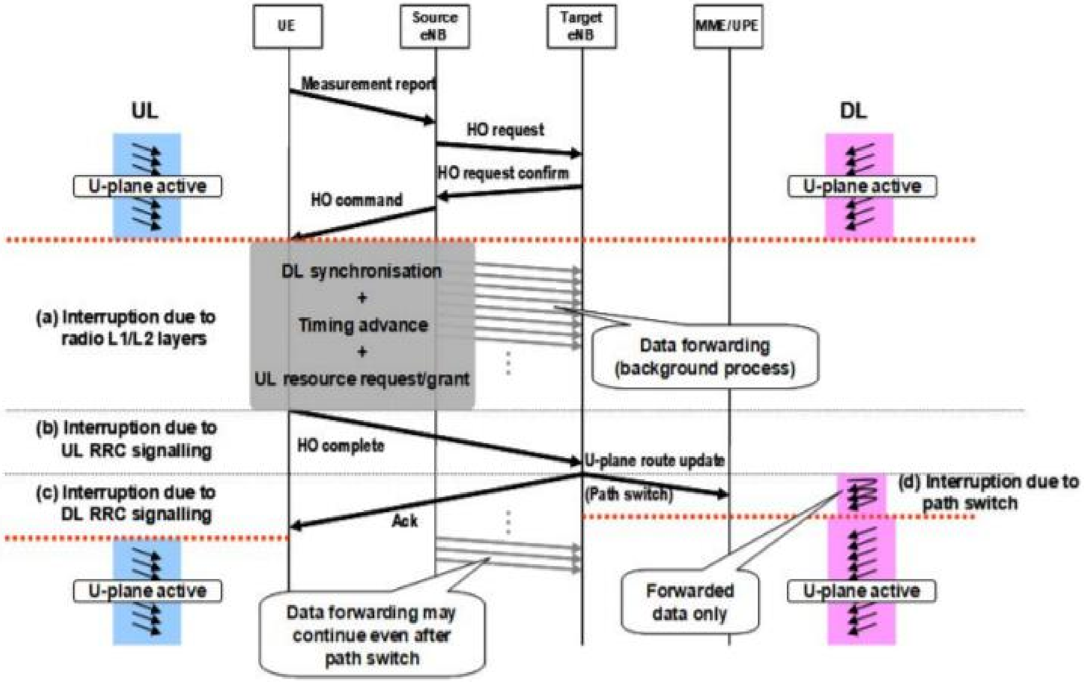

Fig. 1: U-Plane interruption involved in the intra-MME/UPE HO procedure in E-UTRAN

Current problems in mainstream networks

- The current switching mode is the hard handover of LTE, which has a obvious user plane interruption delay
- The high mobility of the vehicles makes the channel conditions more complex and variable, and will inevitably lead to frequent handover.
- People have higher and higher demands for service quality, and businesses are more sensitive to delay.

A low-latency, highly reliable network and a reasonable mobility mechanism is required to increase system throughput and reduce user throughput loss caused by frequent handovers.

Network Architecture

Cloud Radio Access Network C-RAN: Development Trend of Future 5G Network Architecture

Centralized deployment

Through the centralized BBU baseband pool, the computing resources of the base station are centralized.

Collaboration

Realize collaboration capabilities such as seamless mobility management and efficient coordination of spectrum resources.

Wireless cloudification

Dynamic real-time adjustment of processing resources and air interface resources according to actual business load, user distribution, business needs and other actual conditions, to improve the rapid deployment of new services.

Energy saving

Reduce the cost of supporting equipment and computer room construction and overall comprehensive energy consumption. Realize on-demand wireless coverage adjustment and processing resource adjustment。

Connected autonomous driving

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Cloud Radio Access Network

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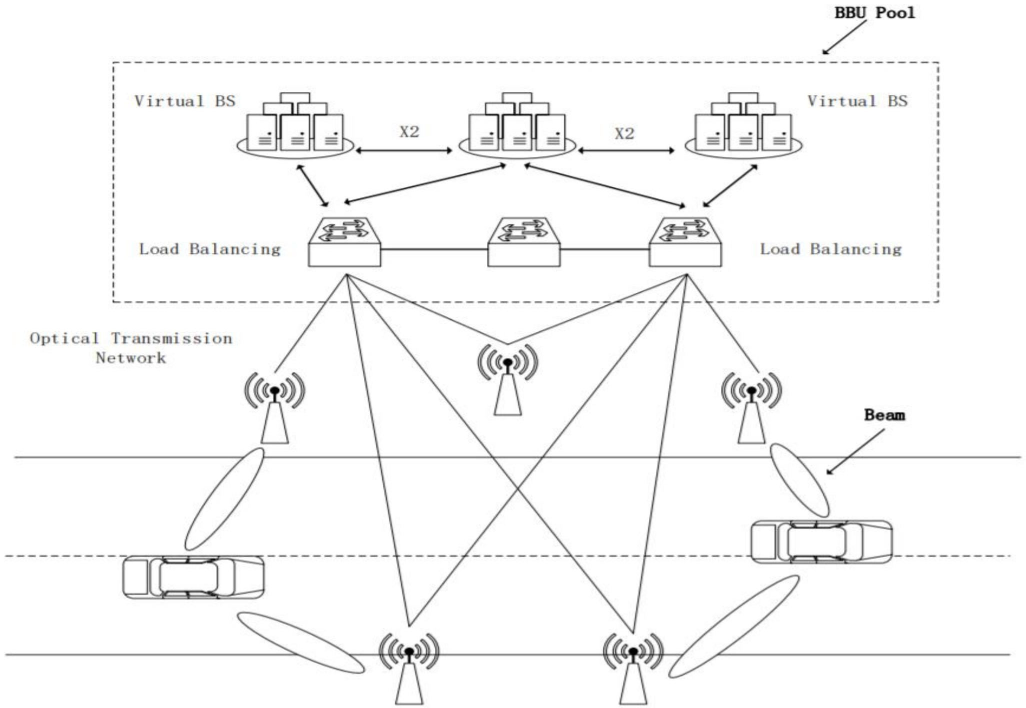
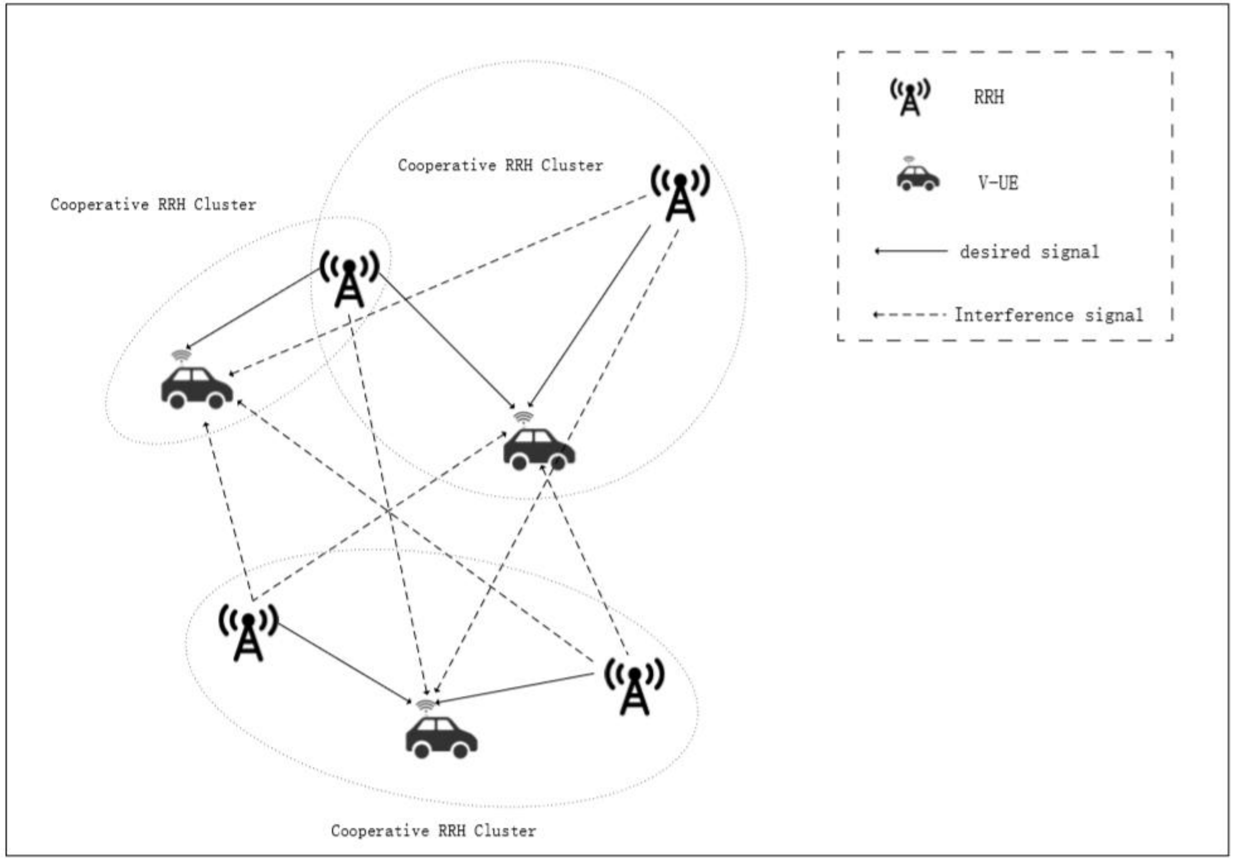


Signal Model

Considering a downlink of a C-RAN system as shown in fig. 3, where a set L of RRHs denoted as $\mathcal{L} = \{1, 2, ..., l\}$ are serving a set V of vehicle user equipments denoted as $\mathcal{V} = \{1, 2, ..., v\}$, 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



Received signal power of user k

$$y_k = \sum_{q\in L_k} H_k^q * W_k^q * s_k + \sum_{q\in L_k} \sum_{j\neq k}^{\mu} H_k^q * W_j^q * s_j + \sum_{p\notin L_k} \sum_{l\in V_q} H_k^p * W_l^p * s_l + Z_k$$

User-centric RRH Cooperative Cluster Dynamic Update Scheme

Cooperative gain(cg):Benefits obtained by adding a RRH to the collaborative cluster

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

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

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

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

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

Simulation

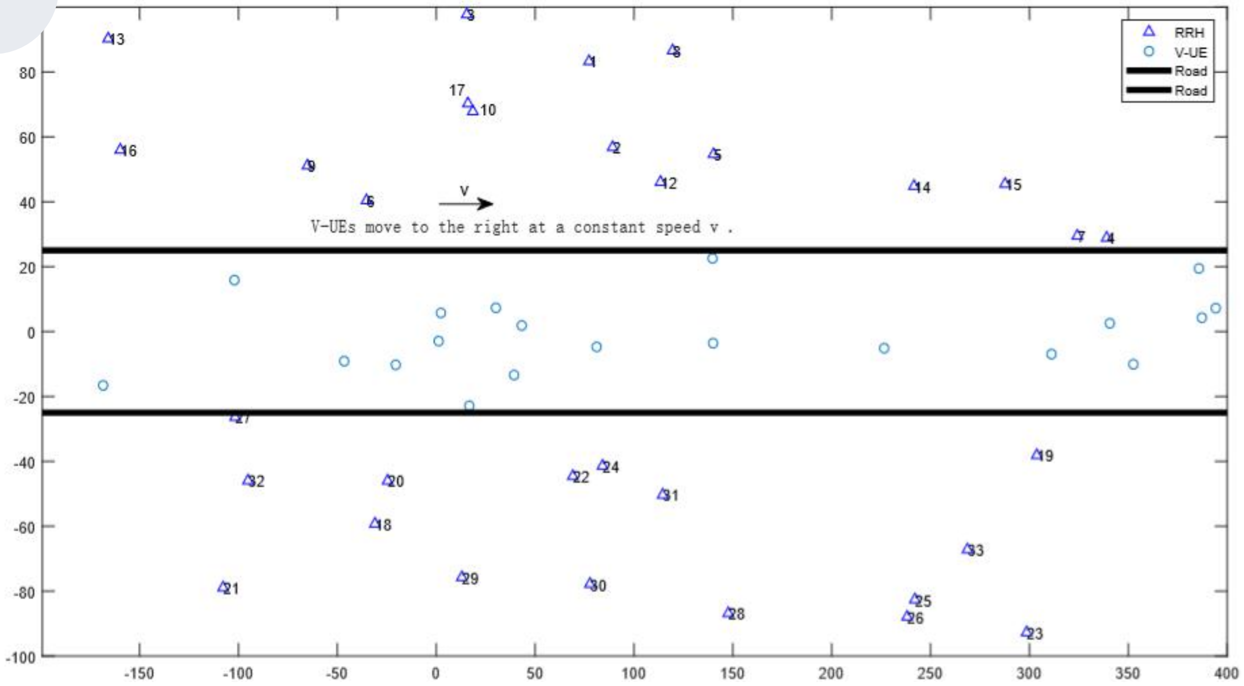
Algorithm 1 User-centric RRH cooperative cluster dynamic update algorithm

Input: the channel matrix **H**; RRH set which is not fully allocated L' l dimension RRH resource vector Res;
Output: L_i;W_i

A) **Initialization:**
Find a RRH $l_j \in \overline{X}$ with the best channel conditions $||h_{il_j}||$ for V-UE i from L';
$R_{idle} = R_{idle} - 1$; $L_i = L_i \cup \{l_j\}$; $Res(l_j) = Res(l_j) - 1$;
Compute the α by Eq.5;
Compute the beamforming vectors w_i;

B) **Update:**
if SIZE(L_i)$< \alpha$ **then**
1) Compute the cooperative gain for each RRH in L' by Eq. 6;
2) Find the RRH $l_k \in L'$ that enables V-UE to get the maximum positive cg;
3) $R_{idle} = R_{idle} - 1$; $L_i = L_i \cup \{l_k\}$; $Res(l_k) = Res(l_k) - 1$;
4) if Res(l_k)==0 then $L' = L' l_k$
5) Update the beamforming vectors w_i;
else
if $SINR_i < \gamma$ **then**
1)Find the RRH $l_m \in L_i$ with the worst channel condition $||h_{il_m}||$ in the cooperative cluster
2) if Res(l_m)==0 then $L' = L' \cup l_m$;
3)$L_k = L_k l_m$; $R_{idle} = R_{idle} + 1$;
4) Update the beamforming vectors w_i;
end if
end if
return L_i;W_i

Simulation Scene



Simulation Parameters

TABLE I: 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

Simulation

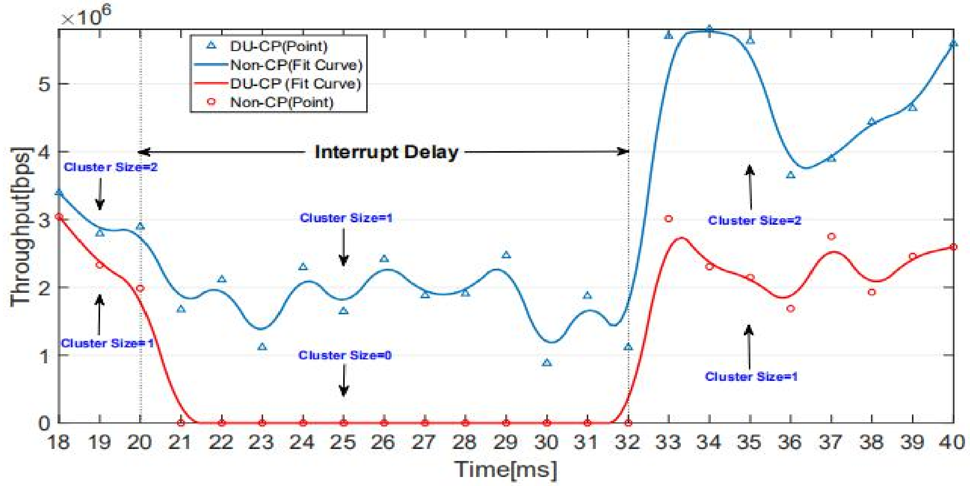


Fig. 6: Performance comparison of a handover, the algorithm cycle is 20 milliseconds, and the U-Plane interruption is 12 milliseconds.

Obviously, the throughput gain before and after the handover of our proposed scheme is far superior to the non-switching scheme, and it is non-disruptive during the handover process.

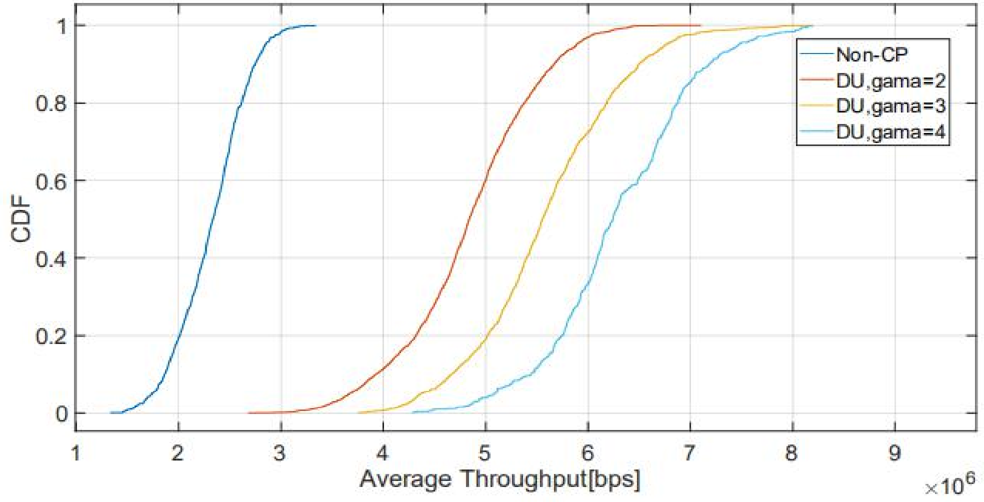


Fig. 7: Average rate of the system at 3MHz bandwidth

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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