C-RAN Enabled Seamless Mobility Mechanism in Autonomous Driving

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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 cause safety hazards.

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.

Lack of collaboration between 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 cannot 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.

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.

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

Considering a downlink of a C-RAN system as shown in fig. 3, where a set \( L \) of RRHs denoted as \( L = \{1, 2, \ldots, l\} \) are serving a set \( V \) of vehicle user equipments denoted as \( V = \{1, 2, \ldots, v\} \), 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 \( \mu \) vehicle user equipments and for each V-UE, there is a corresponding RRH cooperative cluster for its signal jointly transmission. Let \( L_i \subseteq L_V = \{L_1, L_2, \ldots, L_v\} \) denote the RRH collaboration cluster corresponding to V-UE \( i \) and \( V_q \) denote the set of V-UEs served by RRH \( q \). \( H^q_i \in \mathbb{C}^{N \times M} \) denote the channel matrix from \( q \) th RRH to \( i \) th V-UE. Define \( W^q_i \in \mathbb{C}^{M \times N} \) as the beamformer from RRH \( q \) to V-UE \( i \) and let \( W_i = [(W^1_i), (W^2_i), \ldots, (W^L_i)] \in \mathbb{C}^{ML_i \times 1} \) denote the beamformer collection intended for V-UE \( i \). The received signal at \( i \) th V-UE can be expressed as

\[
y_k = \sum_{q \in L_k} H^q_k \cdot W^q_k \cdot s_k + \sum_{q \in L_k} \sum_{j \neq k} H^q_k \cdot W^q_j \cdot s_j + \sum_{p \in L_k} \sum_{l \in V_q} H^p_l \cdot W^p_l \cdot s_l + Z_k
\]
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 \( i \),

\[
\text{if} \left\{ \begin{array}{l}
\text{size}(L_i) < \alpha \text{ and } cg(L_i, L_i \cup \{b\}) > 0 \\
b = \arg \max \{cg(L_i, L_i \cup \{x\})\}
\end{array} \right.
\]

**Departure rule:** RRH \( b' \) leaves the cooperative cluster of vehicle user \( i \),

\[
\text{if} \left\{ \begin{array}{l}
\text{size}(L_i) = \alpha \text{ and } SinR_i < \gamma \\
\text{and } cg(L_i, L_i \cup \{b'\}) > 0 \text{ and } b' = \arg \max \{\|H_i^{x}\|\}
\end{array} \right.
\]

where \( \gamma \) is the predefined threshold of SinR for the vehicle user \( i \) in cooperative state. Cooperative gain parameter \( cg \) is defined as

\[
\text{cg}(L_i, L_i \cup b) = \log \left( \frac{SLNR_{L_i \cup b}}{SLNR_{L_i}} \right) \tag{3}
\]

\[
\begin{align*}
\text{SinR}_i &= \frac{\sum_{p \in L_i} |H_i^{p}W_i^{p}|^2}{\sum_{p \in L_i} \sum_{j \neq i} |H_i^{p}W_j^{p}|^2 + \sum_{q \in L_i} \sum_{t \in V_q} |H_i^{q}W_q^{q}|^2 + \sigma_i^2} \\
\text{SLNR}_{L_i} &= \frac{\sum_{p \in L_i} |H_i^{p}W_i^{p}|^2}{\sum_{p \in L_i} \sum_{k \neq i} |H_i^{p}W_k^{p}|^2 + \sigma_i^2} \tag{4}
\end{align*}
\]

\( SLNR_{L_i} \) denote the signal-to-leakage-plus-noise-ratio of vehicle user \( i \), which can be calculated by
Algorithm 1 User-centric RRH cooperative cluster dynamic update algorithm

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

1) Initialization:
   Find a RRH $l_j \in L'$ 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 $\alpha$ by Eq. 5;
   Compute the beamforming vectors $w_i$;

2) 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 $L' = L' \setminus l_k$
      5) Update the beamforming vectors $w_i$;
   else if SINR $< \gamma$ 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) $L_k = L_k \cup l_m$; $R_{idle} = R_{idle} + 1$;
      4) Update the beamforming vectors $w_i$;
   end if
   return $L_i; W_i$

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**TABLE I: Parameters for Simulation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_d$</td>
<td>926Hz</td>
<td>$\mu$</td>
<td>4</td>
</tr>
<tr>
<td>$T_d$</td>
<td>$10^{-3}$s</td>
<td>$\nu$</td>
<td>72km/h</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>2</td>
<td>$\gamma$</td>
<td>$3 \times 10^8$ bps</td>
</tr>
<tr>
<td>pathloss</td>
<td>15.3+37.6 log$_{10}$ (dist)</td>
<td>system bandwidth</td>
<td>3MHz</td>
</tr>
<tr>
<td>$N_0$</td>
<td>-174dbm/Hz</td>
<td>RRH transmit power</td>
<td>43 dbm</td>
</tr>
</tbody>
</table>
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.

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.


