Adaptive C-RAN Architecture for Smart City using Crowdsourced Radio Units

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***Abstract*—The spatio-temporal fluctuation in mobile traffic demand drastically deteriorates the efficiency and financial viability of conventional mobile networks. To address this problem, this paper proposes a concept of adaptive centralized radio access network (C-RAN) architecture for a smart city using crowdsourced radio units (CRUs). The proposed architecture contributes to the efficient deployment of mobile networks and the better use of energy in a smart city. The edge server computes the optimum CRU states and activate/deactivate them based on the traffic information measured by road side units. In this paper we present the basic idea and the evaluation results via numerical analysis.**

I. Introduction

Centralized radio access network (C-RAN) architecture has prevailed in mobile networks to efficiently forward the ever increasing traffic [1]. The capacity of networks is enhanced by dense deployment of many small cells along with macro cells, because the spectrum efficiency is improved by cell size reduction. In the today's C-RAN architecture, a mobile base station (BS) is split into three components; a central unit (CU), a distributed unit (DU), and a radio unit (RU) as shown in Fig. 1. A CU pool is installed in a central office, and the link between a CU and a DU is called midhaul. Many RUs are densely deployed to compose small cells, and the link between a DU and an RU is called fronthaul. Since the latency requirement of fronthaul is very strict, e.g. $\leq$ 100 μs [2], DUs are installed near RUs. The optimization of fronthaul links using wireless relay and optical networks has been considered to efficiently deploy a large number of RUs [3].

In metropolitan areas, there is a significant fluctuation in the mobile traffic demand [4], [5], e.g. there are more mobile phone users in city areas during daytime than at night. Such fluctuations will be intensified in the future in accordance with the increase in the data rate. As a consequence, the efficiency and financial viability of conventional mobile networks are drastically deteriorated. This is because BSs has been deployed to deal with the peak rate and their capacities are underutilized for most of time. To address this issue, the autonomous base stations with optical reflex backhaul (ABSORB) architecture was proposed to adapt to fluctuations in mobile traffic [6]. In the ABSORB architecture, moving BSs forward the mobile traffic by following the changes in the demand distribution. The concept of optically backhauled moving network for local trains was proposed in [7], [8] as a deployment scenario of the ABSORB architecture.

To utilize the power of citizens in the deployment of mobile networks, the concept of vehicle-mounted small cells was proposed in [9]. The on-board small cells relay uplink/downlink traffic between DUs and user equipment (UE). The driver turns on/off the cells considering the current incentive value and power consumption. The network carrier determines the incentive value based on the situation in each area such as traffic demand and the number of cells. The vehicle-to-pedestrian (V2P) connectivity on higher frequency band was analyzed in [10].

In this paper, we further investigate the concept of crowdsourced RUs (CRUs) to efficiently deploy mobile networks. This paper proposes a novel concept of adaptive C-RAN architecture for a smart city using CRUs employing the notion of multi-access edge computing (MEC). The contribution of this work is that edge servers optimally control the states of vehicle mounted CRUs based on the distribution of CRUs and road traffic measured by road side units (RSUs), whereas the vehicle-mounted small cells proposed in [9] was managed by drivers. The rest of the paper is organized as follows.

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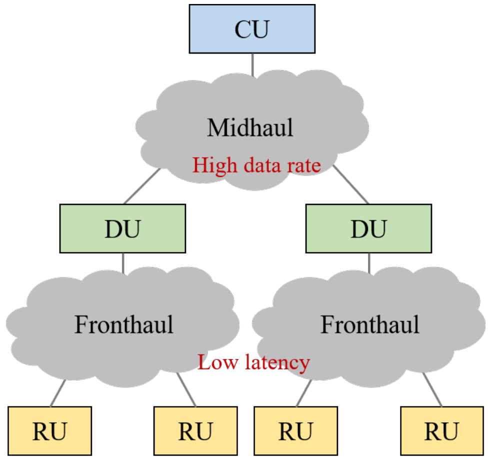

Fig. 1: C-RAN architecture.

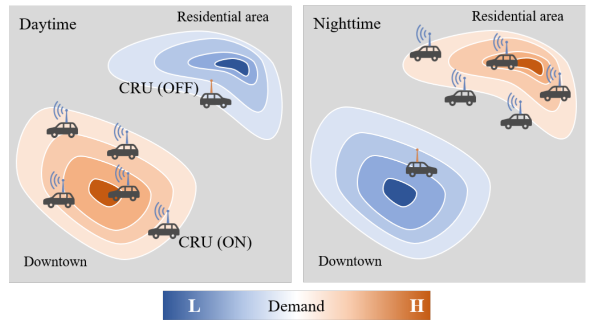

Fig. 2: Demand and CRU distribution.

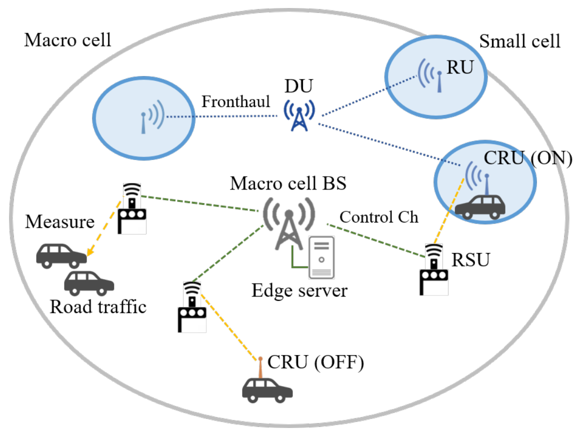

Fig. 3: Conceptual system architecture.

Section II introduces the proposed network architecture. Section III describes the results of performance evaluation via numerical analysis. The conclusion is provided in section IV.

II. Proposed Network Architecture

A. Concept

The basic concept of the proposed network architecture is shown in Fig. 2. A CRU is installed on vehicles, e.g. private cars and taxis. It is activated by an edge server when the vehicle moves to a high-demand area, and deactivated when the vehicle moves to a low-demand area. If a CRU is activated, it composes a small cell. The CRU establishes a fronthaul link to a neighboring DU and relay uplink/downlink traffic between DUs and UE. The advantages of this architecture are high flexibility and low cost, which results from the trend that the distribution of vehicles reflects the human mobility patterns, i.e. there are generally more vehicles in crowded areas.

The system architecture is depicted in Fig. 3. The on-board CRUs are connected to DUs via wireless fronthaul links. They provide moving small cells overlaid on static small cells composed by ground RUs. The power of CRU is supplied by the car battery that generates surplus power while moving; the proposed scheme contributes to the better use of energy. It is assumed that RSUs are widely deployed in the city; an RSU is a widespread concept for enabling various vehicle-to-vehicle communication or intelligent transportation systems for a smart city. RSUs measure the distribution of CRUs and road traffic in their neighborhood area. An edge server is installed with a macro cell BS and establishes logical control channel with RSUs via macro cell connections. The edge server computes the optimum CRU states and activate/deactivate the CRUs via RSUs.

B. Activation sequence

The activation sequence of CRUs is shown in Fig. 4. An RSU cyclically measures the road traffic around it to grasp the demand distribution in the area. When a CRU moves to the cover area of the RSU, it communicates with the RSU via a wireless technology such as Bluetooth low energy (BLE). It checks-in the RSU; it notifies the RSU of available information such as its current location, current battery level, direction of movement, and the destination of the vehicle. If the vehicle is a self-driving car, the destination can be provided to the CRU. The RSU sends the measured and received information to the edge server via a macro cell link. The edge server updates the mobile demand distribution with the received road traffic data. In this process, the current mobile load or user information is utilized if it is provided from the mobile network. Then, the edge server computes the CRU states and the calculated results to RSUs. The RSU activates or deactivates checked-in CRUs in accordance with the received information. An activated CRU establishes a fronthaul link to a neighboring DU and starts to forward mobile traffic.

C. Activation algorithm

This section explains the algorithm for determining CRU states executed by the edge server. The proposed

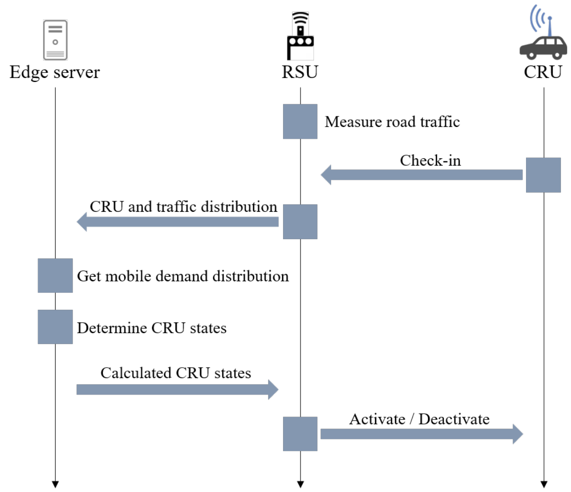

Fig. 4: Activation sequence.

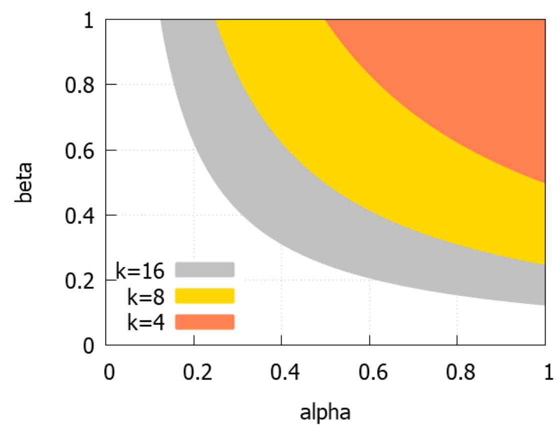

Fig. 5: Requirement for α and β.

algorithm is executed for each cover area of RSUs, and thus it is scalable. Let r denote the identifier for RSUs and their cover areas. d_r denotes the mobile traffic demand in rth area. Let $\mathcal{C}_r$ denote the set of CRUs in rth area, and c denote the identifier for them. It is assumed that cth CRU can accommodate s_c of demand, which is determined by the performance of it including the current battery level. x_c is a binary variable that represents the state of cth CRU; if it is activated $x_c = 1$ is satisfied, and otherwise $x_c = 0$. The objective of the proposed algorithm is to satisfy the demand in rth area with minimum number of activated CRUs. The optimum solution is computed by solving the following binary integer programming problem.

$$\text{Min} \sum_c x_c \tag{1}$$

s.t.

$$\sum_c s_c x_c \geq d_r \tag{2}$$

$$x_c = 0, 1$$

III. Numerical Analysis

This section describes the numerical analysis results of the effectiveness of the proposed network architecture and proposed algorithm.

A. Area demand satisfaction

Let T_r denote the amount of road traffic in rth area. It is assumed that T_r is formulated as

$$T_r = \alpha k d_r, \tag{3}$$

where k denotes the weight and $\alpha (0 < \alpha \leq 1)$ denotes the correlation parameter for the road traffic and mobile demand. When $\beta (0 < \beta \leq 1)$ denotes the attach ratio of CRU on vehicles, the size of $\mathcal{C}_r$ is represented as

$$\begin{aligned} |\mathcal{C}_r| &= \beta T_r \\ &= \alpha \beta k d_r. \end{aligned} \tag{4}$$

The value of s_c is assumed to be determined by the current battery level v with a sigmoid function:

$$s_c(v) = \frac{1}{1 + e^{-av}}, \tag{5}$$

where a is a parameter. Note that the value of d_r is described as the ratio to the value of $s_c(\infty)$. In this paper, it is assumed that a is sufficiently large; that is, the state of a CRU is simply activated or deactivated. Here we assume that v follows a normal distribution, and thus $s_c(v)$ is 0 or 1 in 50%, respectively; the number of available CRUs is the half of $\mathcal{C}_r$. Let $\mathcal{C}'_r$ denote the set of available CRUs in rth area, which satisfies $2|\mathcal{C}'_r| = |\mathcal{C}_r|$. Considering only $c' \in \mathcal{C}'_r$, (2) is redefined as

$$\sum_{c'} x_{c'} \geq d_r. \tag{6}$$

Therefore, the minimum number of activated CRUs in rth area is equal to d_r. To satisfy this, $|\mathcal{C}'_r| \geq d_r$ is required. From (4) and $2|\mathcal{C}'_r| = |\mathcal{C}_r|$, α and β must satisfy

$$\alpha \beta \geq \frac{2}{k}, \tag{7}$$

which is depicted as the filled area in Fig. 5. Fig. 5 shows that the strictness of requirement is determined by the weight k, and the attach ratio of CRU β can be low if the correlation α is high. The minimum value is $\beta_{min} = \frac{2}{\alpha k}$. The reason why (6) does not depend on the demand d_r is that the correlation between road traffic and mobile demand is assumed.

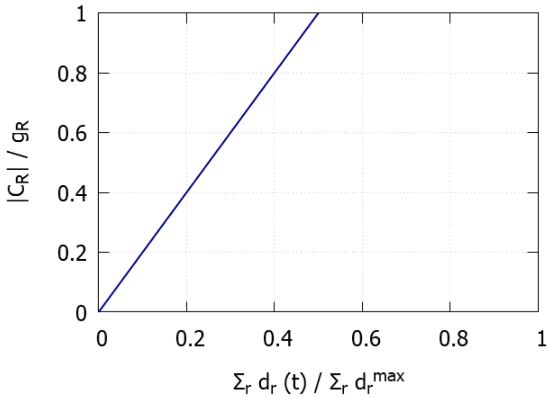

Fig. 6: Cost ratio.

B. Multi-area demand satisfaction

Let $\mathcal{R}$ denote the set of areas in a target region that includes both commercial and residential areas. It is assumed that there is daily commuter movement between these areas; the distribution of vehicles and mobile demand changes with time, while the total number of vehicles in the region is fixed. The mobile demand in rth area at t is described as $d_r(t)$.

When $\beta_{min} = \frac{2}{\alpha k}$ is employed, the number of deployed CRU in rth area is described as $|\mathcal{C}_r| = 2d_r(t)$ from (4). The total number of CRU in the target region is

$$|\mathcal{C}_\mathcal{R}| = 2\sum_{r\in\mathcal{R}} d_r(t). \tag{8}$$

If the conventional ground RU deployment is employed, the required number of ground RUs in rth area g_r is equal to d_r^{max}, which is the maximum value of $d_r(t)$. Thus, the total number of ground RUs in the target region is

$$g_\mathcal{R} = \sum_{r\in\mathcal{R}} d_r^{max}. \tag{9}$$

Therefore, the cost ratio of the proposed CRUs and ground RUs is

$$\frac{|\mathcal{C}_\mathcal{R}|}{g_\mathcal{R}} = 2\frac{\sum_{r\in\mathcal{R}} d_r(t)}{\sum_{r\in\mathcal{R}} d_r^{max}}, \tag{10}$$

which is depicted in Fig. 6. This result implies that the proposed architecture is effective as the spatio-temporal fluctuation of mobile traffic demand increases.

C. Discussion and future work

In this paper, we presented the basic idea for the activation algorithm of CRUs, which is a rather simple one. Thus, we need to further investigate the activation algorithm; e.g. considering the moving directions and destination of the vehicles and improving the estimation of mobile traffic demand in each cover area using road traffic information. Moreover, it is required to simulate and analyze the wireless transmission rate and stability of V2P connections and fronthaul links between CRUs and DUs to ensure the validity of the proposed architecture.

IV. Conclusion

This paper proposed a concept of adaptive C-RAN architecture for a smart city using CRUs to deal with fluctuations of mobile traffic demand caused by the pattern of human mobility. The proposed network architecture contributes to the efficient deployment of mobile networks and the better use of energy in a smart city. The edge server computes the optimum CRU states and activate/deactivate the CRUs based on the traffic information measured by RSUs. In this paper we presented the basic idea of the proposed architecture and the evaluation results via numerical analysis. It constitutes future work to further investigate the details of the proposed architecture and more comprehensive analysis on wireless transmission performance.

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