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Energy Efficient Resource Allocation in Millimeter-Wave-Based Fog Radio Access Networks

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Abstract

Both caching and Millimeter wave (mmWave) are promising techniques for next generation wireless communications. Moreover, the combination of fog radio access network and mmWave communication helps to improve the energy efficiency of both. We consider subchannel assignment and power control in mmWave-based fog radio access networks with attention to network caching scheme, user experience constraints, cross-layer interference suppression, system energy efficiency. Specifically, the power optimization problem is explored based the alternative direction method of multipliers (ADMM). A low compute complexity subchannel assignment algorithm is proposed. The simulation results demonstrate that the method has fewer iterations and the energy efficiency is optimized obviously.

1 Introduction

With the dramatic increase in demand for network services, the mobile data traffic is exponentially increasing. To solve this problem, in [1], fog radio access network (Fog-RAN) is unanimously considered as a promising network architecture for future development of radio networks to improve spectral efficiency, and reduce energy consumption. In [2] and [3] , the authors thinks that caching the content into the terminal node will push the popular content to the user by caching them at the edge nodes in Fog-RANs. According to the characteristics of mobile data transmission, some popular content will be requested by multiple users at the same time, which accounts for a large part of the bandwidth. According to these, early caching of popular content can effectively reduce the burden on the backhaul link.

Another new communication method called millimeter wave (mmWave) communication has attracted great enthusiasm from both academia and service provider [4]. Due to the great physical characteristics of 60 GHz mmWave communication, Many high-speed bandwidth access network problems can be effectively solved, especially in short distance communication, which has broad application prospects and commercial potential. Moreover, due to the 60 GHz huge bandwidth, even with a low spectral efficiency, mmWave systems can provide relatively high data rates[5]. Many scenarios such as small cells can be adapted to 60-GHz mmWave access technology[6]. In order to achieve high-rate transmission, the authors in[7] adopted an iterative gradient subchannel allocation and power allocation scheme to solve the dynamic resource optimization issues. According to the author's knowledge, energy efficient resource allocation Fog-RANs using alternative direction method of multipliers (ADMM) has not appeared in previous studies.

The rest of this paper is organized as follows. In Section 2, the mmWave-based FRAN architecture is described, and a utility function based on energy efficient resource allocation in mmWave-based FRANs is formulated. A low complexity subchannel assignment algorithm and the power control algorithm are proposed in Section 3. In the Section 4, we present the performance of the proposed algorithm and the corresponding analysis, followed by conclusion in Section 5.

2 System Model and Problem Formulation

2.1 System Model

The mmWave-based FRAN architecture is proposed in Figure 1. A lot of fog computing access points (F-APs) with low energy consumption are highly densely and widely deployed in terminal layer, which act as the small base stations in traditional cellular networks. The Macro base stations (BS) connect to baseband unit (BBU) pool through the fronthaul links. The F-APs are equipped with a finite of caching, cooperative radio resource management capabilities. We consider a mmWave-based FRAN in which B F-APs are overlaid by each central Macro BS. Let $\forall \mathrm{M} \in \{1,2,...,M\}$ denotes the F-APs set, $\forall \mathrm{L} \in \{1,2,...,L\}$ denotes the distributed user set, and $\forall \mathrm{N} \in \{1,2,...,N\}$ denotes the subchannel set. We assume that a subchannel can only be assigned to one user, $a_{l,m}^{n}$ is used to represent a association indicator. That is, if the subchannel n is assigned to user l on F-AP m $a_{l,m}^{n} = 1$, otherwise $a_{l,m}^{n} = 0$. Then, the channel's gain from F-AP m to user l is given by [8]

$$H_{l,m}^{n} = \frac{H_{l,m,n}^{Tx} H_{l,m,n}^{Rx} \varsigma^{2}}{16\pi^{2} d_{l,m}}. \qquad (1)$$

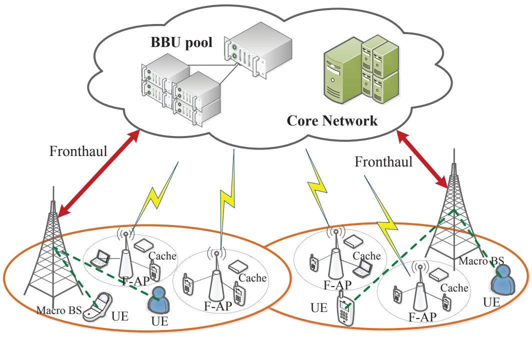

Figure 1. A mmWave-based FRAN Architecture.

where $H^{Tx}_{l,m,n}$ denotes the emission antenna gain from F-AP m to user l on subchannel n, $H^{Rx}_{l,m,n}$ represents the obtain antenna gain from F-AP m to user l on subchannel n, ς denotes the mmWave wavelength, $d_{l,m}$ indicates the actual distance between F-AP m to user l.

The rate for user l from F-AP m on subchannel n is calculated as

$$\mathrm{r}^n_{l,m} = W\log_2\Big(1+\frac{p^n_{l,m}H^n_{l,m}}{\sum\limits_{k\in \mathrm{M},k\neq m} p^n_{k,m}H^n_{l,m}+\sigma^2_{AWGN}}\Big), \forall \mathrm{m}\in \mathrm{M}. \tag{2}$$

where $p^n_{l,m}$ is the emission power, and σ^2_{AWGN} denote additive white Gaussian noise (AWGN) power, and W denotes the mmWave-based FRAN bandwidth.

According to [9] the reward of a caching is defined as

$$\text{Caching} = \sum_{l\in L} q_l o^n_{l,m} z^n_{l,m}. \tag{3}$$

where q_l indicates the rate at which user l request popular content, where $o^n_{l,m}$ is the gain user l achieved by caching popular content from F-AP m on subchannel n, If F-AP m caches the popular content that requested by user l on subchannel n, $z^n_{l,m}=1$; otherwise $z^n_{l,m}=0$.

And then the capacity of user l is

$$R_l(\mathrm{A},\mathrm{P}) = \sum_n\sum_m a^n_{l,m} r^n_{l,m}(1+Caching) \tag{4}$$

The all capacity of the network is

$$C(\mathrm{A},\mathrm{P}) = \sum_l R_l(\mathrm{A},\mathrm{P}). \tag{5}$$

where $\mathrm{A}\triangleq\left[a^n_{l,m}\right]_{\mathrm{L}\times\mathrm{M}}$ and $\mathrm{P}\triangleq\left[p^n_{l,m}\right]_{\mathrm{L}\times\mathrm{M}}$ are the subchannel assignment matrix, the power control matrix respectively.

The all network power usage can be calculated as

$$U(\mathrm{A},\mathrm{P}) = \sum_m p_{c,m} + \sum_n\sum_l\sum_m a^n_{l,m}p^n_{l,m}. \tag{6}$$

where $\sum\limits_m p_{c,m}$ indicates the entire circuit power of all F-APs, $\sum\limits_n\sum\limits_l\sum\limits_m a^n_{l,m}p^n_{l,m}$ is the total emission power of F-APs.

We define the energy efficiency as the ratio of the total system capacity to the total power used. The energy efficiency is given as

$$\eta = \frac{C(\mathrm{A},\mathrm{P})}{U(\mathrm{A},\mathrm{P})}. \tag{7}$$

2.2 Problem Formulation

With attention to the constraints, we can construct the following optimization problems:

$$\max_{\mathrm{A},\mathrm{P}} \eta = \frac{C(\mathrm{A},\mathrm{P})}{U(\mathrm{A},\mathrm{P})}. \tag{8}$$

$$\begin{aligned}&s.t.\\ &C1: \sum_m a^n_{l,m} = 1, \forall l \in \mathrm{L}.\end{aligned} \tag{9}$$

$$\mathrm{C2}: a^n_{l,m} \geq 0, \forall l\in\mathrm{L}, \text{and} \forall m \in \mathrm{M}. \tag{10}$$

$$\mathrm{C3}: \sum_l a^n_{l,m}p^n_{l,m} \leq p_{\max}, \forall m\in\mathrm{M}. \tag{11}$$

$$\mathrm{C4}: R_l(\mathrm{A},\mathrm{P}) \geq R_{\min}, \forall l \in \mathrm{L}. \tag{12}$$

$$\mathrm{C5}: \sum_l \sum_{k\in\mathrm{M},k\neq m} a^n_{l,m}p^n_{k,m}H^n_{k,m} \leq I_m, \forall m\in\mathrm{M}. \tag{13}$$

$$\mathrm{C6}: \sum_{l\in\mathrm{L}} a^n_{l,m} z^n_{l,m} s_l \leq Z_m, \forall m\in\mathrm{M}. \tag{14}$$

The above constraints are defined as follows:

1. Subchannel scheduling constraint: Constraint C1 is the subchannel scheduling constraints. A subchannel can be associated with only one user at a time. C2 specifies the ranges of $a^n_{l,m}$.
2. Total power constraint: Constraint C3 sets the total transmit power of each F-AP m must be less than its maximum transmit power.
3. User experience constraint: Constraint C4 represents the QoS guarantee, where $R_{\min}$ indicates the data rate that meets the user's minimum quality of service requirements.
4. Cross-layer interference suppression: C5 is the constraint that the cell is subject to other cell interference, where I_m is the maximum value of the interference that the cell can tolerate.
5. Caching strategy constraint: Because each F-AP cacheable space is limited, constraint C6 ensure the cache is limited to a limited space.

3 Energy Efficient Optimization Based ADMM

3.1 Subchannel Assignment

In this section, we mainly study the solution process of optimization problem (8)-(14). First, we assume that all the users can use any subchannel n in a mmWave-based Fog-RAN to communicate. We consider the dynamic matching process between the user and the channel as a bidirectional match between the user set L and the channel set N. According to each channel status information, we assume user l prefers channel n_1 over n_2 if and only if $H_{l,n_1} > H_{l,n_2}$, which means that given the power control of each subchannel from each F-AP to each user, the subchannel should be allocated to that particular link, whose power gain is the highest. Then the remaining subchannels are allocated to guarantee the QoS requirements, while maximizing the total system capacity. To reduce the computational complexity, we propose a subchannel assignment algorithm as follows. The subchannel allocation matrices A can be obtained by Algorithm 1. We can reformulate the optimization problem of Equation (8) as

Algorithm 1 Subchannel Assignment Algorithm

```
Initialization
Let matched list $Q_n$ to indicate the number of users assigned to subchannel $n$ $(\forall n \in \{1,2,...,N\})$ ,and $Q_l$ to indicate the number of subchannels assigned to user $l$ $(\forall l \in \{1,2,...,L\})$;
Let $a^n_{l,m} = 0, \mathrm{r}^n_{l,m} = 0, \forall \mathrm{l}, \mathrm{m}, \mathrm{n}$;
The N subchannels equally divided among B F-APs,$\mathrm{K}_m = \frac{\mathrm{K}}{\mathrm{N}}, \forall m \in M$;
for $l = 1$ to $L$ do
    while $R_l < R_{\min}$ do
        Find $m$ and $n$, where $(\hat{m},\hat{n}) = \arg\max_{m,n} H^n_{l,m}$;
        update $R_l$;
    end while
end for
while $N \neq \phi$ do
    Find $\hat{m}$ and $\hat{n}$, where $(\hat{m},\hat{n}) = \arg\max_{m,n} H^n_{l,m}$;
    if $K_{\hat{m}} > 0$ then
        $K_{\hat{m}} := K_{\hat{m}} - 1$;
        Let $N := N/n$
    else
        Let $M := M/\hat{m}$
    end if
end while
```

$$-F(U) = q\mathrm{U}_p(A,P) - C(A,P) \\ s.t. C1, C2, C3, C4, C5, C6. \tag{15}$$

where q represents an auxiliary variable. We can solve the optimization problem (15) by ADMM algorithm.

Algorithm 2 Power Control Based ADMM

```
Initialize;
Each F-AP $j \in B$ collects CSI;
Initialize the $x^n_{i,j}$ using suboptimal Algorithm 1;
F-AP initializes $x^0 = 0, z^0 \in C5$ and $\mu^0 > 0, \rho = 0$, when $\xi > 0$, iteration number $t = 0$, stop;
if $F(U) > \xi$ then
    Each F-AP $j \in B$ expands $x^{t+1}$;
    Each F-AP $j \in B$ expands $z^{t+1}$ through (14);
    Each F-AP $j \in B$ expands $\mu^{t+1}$ through (15);
    $t := t + 1$.
end if
```

3.2 Energy Efficiency and Power Control

To get the solution to the optimization problem in (8) by ADMM, the auxiliary variables x and z are introduced, and x contains the value in the power control matrix, z is a global variables with each of its element for one in x. Also, we define Φ_1, Φ_2 and Φ_3 as the constraints set with respect to C4, C5 and C6 respectively. Let us first introduce a piecewise function according to [10].

$$g(\mathrm{z}) \begin{cases} 0, \mathrm{z} \in \Phi_2 \\ +\infty, \text{otherwise.} \end{cases} \tag{16}$$

And then, based on [10] the problem (15) can be rewritten as

$$\arg\min_{\mathrm{X,Z}} -\mathrm{F(U)} + \mathrm{g(z)}. \tag{17}$$

$$\mathrm{s.t.x - z = 0.} \\ \mathrm{x} \in \Phi_1 \cap \Phi_3 \tag{18}$$

In scaled form, the augmented Lagrangian is given.

$$L_\rho = -F(U) + g(z) - \frac{\rho}{2}\|\mu\|_2^2 + \frac{\rho}{2}\|x - z + \mu\|_2^2. \tag{19}$$

where μ indicates the scaled dual parameter, $\rho > 0$ indicates a predefined variable. According to the scaled-form of ADMM, we can solve this problem by iterating the following steps:

$$\mathrm{x}^{t+1} := \arg\min_{x \in \Phi_1 \cap \Phi_3} \{-F(U) \\ + \frac{\rho}{2} \sum_l^L \sum_m^M \sum_n^N (p^n_{l,m} - [z^n_{l,m}]^t + [\mu^n_{l,m}]^t)^2\}. \tag{20}$$

$$\mathrm{z}^{t+1} := \arg\min_{z \in \Phi_2} \sum_l^L \sum_m^M \sum_n^N (p^n_{l,m} - [z^n_{l,m}]^t + [\mu^n_{l,m}]^t)^2. \tag{21}$$

$$\mu^{t+1} := \mu^t + \mathrm{x}^{t+1} - \mathrm{z}^{t+1}. \tag{22}$$

where t denotes the number of iterations. By updating the formula (20) and (21), we can use the ADMM to obtain the power control matrices. The power control algorithm based ADMM is described in Algorithm 2.

4 Simulation Results and Discussions

In this section, we verify the validity of the proposed resource allocation algorithm by analyzing the simulation results. At the same time, we also simulated the iterative many-to-one matching algorithm and compared it with our proposed algorithm.

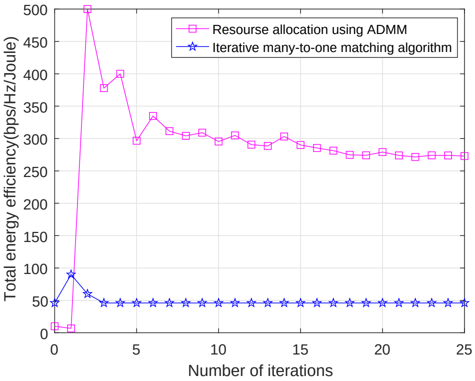

Figure 2. Convergence in terms of the total EE.

Figure 2 shows the convergence of the resource allocation algorithm over the number of iterations. In Figure 2, we compare our algorithm with the iterative many-to-one matching algorithm, which was turned in[8] to optimize network energy efficiency. The iterative many-to-one matching algorithm shows that if multiple users match the same macro cell at the same time, because the macro cell has higher transmit power, it will lead to serious load imbalance. Compared with the iterative many-to-one matching algorithm, our algorithm is no need to compute the optimization problem in every iteration. The main character of Algorithm 2 can greatly reduce the computational for Fog-RANs.

5 Conclusions

In this paper, we investigated an energy efficient resource allocation scheme of Millimeter-Wave-Based Fog Radio Access Networks. We consider subchannel assignment and power control in mmWave-based fog radio access networks with attention to network caching scheme, user experience constraints, cross-layer interference suppression, system energy efficiency. Then, we developed a power control algorithm relying on the ADMM method. Mathematical results show that by controlling power allocation and channel matching can significantly improve energy efficiency and provide a satisfactory user experience.

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References

[1] H. Zhang, Y. Qiu, K. Long, G. K. Karagiannidis, X. Wang, and A. Nallanathan, “Resource allocation in NOMA based fog radio access networks," IEEE Wireless Communications, 2018.

[2] H. Zhang, Y. Qiu, X. Chu, K. Long, and V. C. M. Leung, “Fog radio access networks: Mobility management, interference mitigation and resource optimization," IEEE Wireless Communications, vol. 24, no. 6, pp. 120-127, Dec. 2017.

[3] X. Wang, M. Chen, T. Taleb, A. Ksentini, and V. C. M. Leung, “Cache in the air: Exploiting content caching and delivery techniques for 5G systems," IEEE Commun. Mag., vol. 52, no. 2, pp. 131-139, Feb. 2014.

[4] A. Al-Sayadi, H. Vettikalladi and M. A. S. Alkanhal, "Millimeter wave antenna based on SIW technology for WLAN/WPAN 5G networks at 60GHz," 2017 International Conference on Electrical and Computing Technologies and Applications (ICECTA), Ras Al Khaimah, 2017, pp. 1-4

[5] G. Athanasiou, P. C. Weeraddana, C. Fischione, and L. Tassiulas, “Optimizing client association for load balancing and fairness in millimeterwave wireless networks," IEEE/ACM Trans. Netw., vol. 23, no. 3, pp. 836-850, Jun. 2015.

[6] J. Hoydis, M. Kobayashi, and M. Beddah, “Green small-cell networks," IEEE Veh. Technol. Mag., vol. 6, no. 1, pp. 37ÍC43, Mar. 2011.

[7] Y. Yu, M. Peng, J. Li, A. Cheng, and C. Wang, “Resource allocation optimization for hybrid access mode in heterogeneous networks," IEEE Wireless Communications and Networking Conference (WCNC), pp. 1243-1248, Mar. 2015.

[8] R. Mudumbai, S. Singh, and U. Madhow,“Medium access control for 60 GHz outdoor mesh networks with highly directional links," in Proc. IEEE INFOCOM, Rio de Janeiro, Brazil, Apr. 2009, pp. 2871-2875.

[9] C. Liang, F. R. Yu, H. Yao and Z. Han, “Virtual Resource Allocation in Information-Centric Wireless Networks With Virtualization," in IEEE Transactions on Vehicular Technology, vol. 65, no. 12, pp. 9902-9914, Dec. 2016

[10] S. Boyd, N. Parikh, E. Chu, B. Peleato, and J. Eckstein, “Distributed optimization and statistical learning via the alternating direction method of multipliers," Foundations and Trends in Machine Learning, vol. 3, no. 1, pp. 1-122, 2011.