

User Demand Aware Soft-Association Control in Ultra-Dense Small Cell Networks

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Abstract—To address the challenge of unprecedented growth in mobile data traffic, ultra-dense network deployment is a cost efficient solution to offload the traffic over some small cells. The overlapped coverage areas of small cells create more than one candidate access points for one mobile station. Signal strength based user association in IEEE 802.11 results in a significantly unbalanced load distribution among access points. However, the bandwidth demand of each user actually differs vastly due to their different preferences on mobile applications. In this paper, we formulate a non-linear integer programming model for joint user association and user bandwidth demand guarantee problem. In this model, we try to maximize the system capacity and guarantee the effective bandwidth demand for each user by soft-association control. Finally, we evaluate the proposed algorithm performance for the edge users with dynamic and heterogeneous bandwidth demands. Simulation results show that the proposed soft-association control performs better than the distributed ones and improves the individual quality of user experience with a little price on system throughput.

Keywords— Association control; Ultra dense network; Software defined network;

I. INTRODUCTION

The 5G technology is the way forward to deal with the significantly higher data rates, traffic volumes and massive connectivity expected in the horizon of 2020 and beyond. This technology will support the ultra-dense small cells. The ultra-dense network has also been introduced in the IEEE 802.11ax project, approved as the standard of High Efficiency Wireless LAN. Current radio access network is cell-centric instead of user centric. Mobile stations are assumed to be tied to at least one serving cell as a consequence of being in the coverage area of a given AP. As the mobile station moves away from the serving AP, the link performance may degrade until the mobile station eventually handovers to a neighboring cell. The degraded link performance near to the cell edge continues to be a limiting factor in dense network.

Software Defined Network (SDN) and Network Function Virtualization (NFV) reshapes the next generation Internet as well as the 5G mobile network to manage ubiquitous radio resources in terms of bandwidth and transmit points with a controller towards a user-centric feature [1]. Cloud-MAC is the first centralized association control approach proposed in the software defined wireless network [2]. However, signal strength based association control may result in significant unbalanced load among access points. In contrast, radio

access virtualization and advanced cloud computational platform are proposed in the future user-centric 5G network to exploit densification at both network and mobile user sides [3]. This paves the way towards overcoming the limitation of cell boundary and breaking away from the cell concept, thereby achieving cell-less radio access and getting rid of the cell-edge curse. Ultra-dense small cells provide each user to be dynamically served by a cluster of small cells [4]. A cluster of small cells form a virtual cell by multiple APs to serve one mobile station. In addition, the dual-connectivity has been supported for macro-small cell heterogeneous networks in the 3GPP Release 12. An enhanced solution [5] is known as the soft-association control, in which each mobile user with multiple interfaces is partially associated with a virtual cell. This virtual cell is mapped to a set of APs dynamically. The optimized serving AP set may be transparent to mobile user. However, the existing user association and resource allocation strategies are proposed based on the assumption that each user has a huge bandwidth demand [6] [7]. It means the demand of users could not be satisfied, no matter how bandwidths are allocated equally or proportionally to the transmission rate of users. Users can use up their allocated bandwidths. However, bandwidth demand of each user differs vastly due to the diverse preferences from mobile applications. Therefore, existing user association strategies never consider a diversity of bandwidth demands on mobile applications. Although the bandwidth demand is mentioned in [8], it is assumed that the bandwidth demand depends on transmission rates and does not analyze user experience and traffic.

In this paper, an application aware soft-association approach is proposed. The different bandwidth demands of application may come from the different requirements on transmission rates, or performance on latency. The weak signal strength or low signal to interference and noise ratio could result that the edge user has a smaller transmission rate than it requires. The latency aware quality experience guarantee results in effective bandwidth vastly different, especially in a high-load scenario. Therefore, the proposed approach has 3 characteristics. Firstly, it is an application centric method, because it can guarantee the quality of user experience with an additional constraint to formulate the problem. Secondly, it is a soft association, because it can support the dual-connectivity for each user on forwarding plane. Thirdly, it works in a centric manner, which balances the trade-off on system throughput and the quality of

individual user experience with the consideration on diverse demands and load balance among small cells.

The rest of this paper is organized as follows. In section II, we present application scenario in a software defined small cell network and formulate the soft-association problem as a non-linear integer programming model. Evaluation results are provided and analyzed in a variety of scenarios in section III. Finally, we make conclusion in the section VI.

II. PROBLEM FORMULATION AND ALGORITHM

A. Application scenario

We consider a typical SDN architecture with an association controller and multiple APs, as shown in the Figure 1. The controller collects the signal strength measurement and the demand of effective bandwidth of each user and load distribution among multiple APs in ultra-dense small cell network. We assume the controller can assign one Virtual Transmission Point (VTP) to each user and this VTP includes at least one AP as the serving cell set for this mobile station. The users connected to this VTP are unaware of the dynamic mapping between the VTP and TPs. The changes of load and user demand are provided via the network status scanning. If the controller detects events it triggers actions on data plane. Similarly, the soft-association manager will issue the specific command to network devices on the data plane to redirect user flows. Open-flow protocol is used to manage the flows across network device. Ultra-dense heterogeneous network is organized with one macro-cell and some small cells. The control plane connects mobile station and controller through the macro-cell AP via the SSL. With the support of dual-connectivity, user mobility among small cells is not going to trigger handover in a common macro-cell. Virtual cell is identified with the VTP-ID, which is an optimized set of AP dynamically.

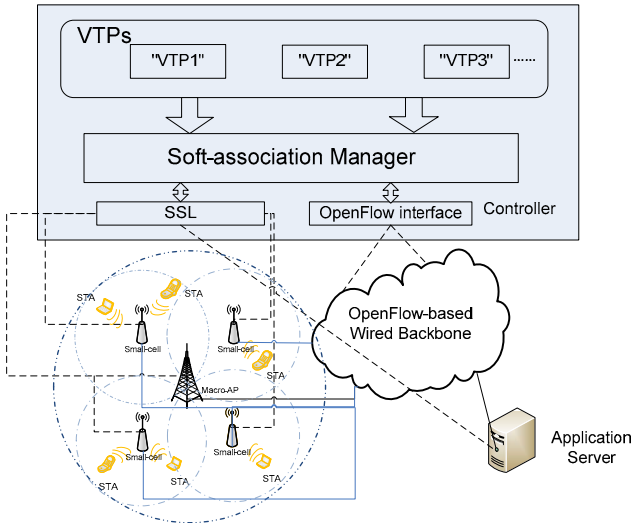


Fig. 1 The virtual-cell based soft-association control

B. Network model

The coefficient β_{ij} indicates specific association relationship between user i and AP j . The coefficient is defined as follows:

$$\beta_{ij} = \begin{cases} 1, & \text{if user } i \text{ associated to AP } j, \\ 0, & \text{otherwise} \end{cases}$$

Where $i=1, 2, \dots, I$, $j=1, 2, \dots, J$. I is the number of users, and J is the number of APs.

Definition 1: Link Capacity

Based on Shannon theory, the link capacity φ_{ij} from user i and AP j can be calculated as

$$\varphi_{ij} = \frac{w_j \log_2(1 + \text{SINR}_{ij})}{\partial_j} \quad (1)$$

Where, w_j is the system bandwidth of each AP j . ∂_j is the load of the AP j , in terms of the number of mobile stations. Therefore, we can get the system capacity τ_s as the sum of expectation throughput of each user in this system:

$$\tau_s = \sum_{i=1}^I \sum_{j=1}^J \frac{w_j \log_2(1 + \text{SINR}_{ij}) * \beta_{ij}}{\partial_j} \quad (2)$$

We assume each user has T interfaces. We define a variable l to indicate the index of interfaces, which ranges from 1 to $I*T$ in the system. In this way, we can get the expected throughput for user i with T interfaces as follows.

$$\psi_i = \sum_{l=(i-1)*T+1}^{I*T} \sum_{j=1}^J \frac{w_j \log_2(1 + \text{SINR}_{ij})}{\partial_j} * x_{lj} \quad (3)$$

where, x_{lj} is a specific association relationship between the AP j and the interface l , different with the β_{ij} . In order to guarantee the experience of user, the expected throughput must be larger than the demand of the user i with T interfaces. As an option, the bandwidth demand can be calculated with the Effective Bandwidth in the theory of network calculus. The theory of Network calculus provides a queue theory with traffic characteristics analysis. We assume each flow will be characterized with a set of parameters (p, e, q, v) in the Traffic Specification (T-SPEC), which is realized with a leaky bucket traffic shaper with p, e, q, v respectively as the peak rate, the maximum packet size, the sustainable rate, and the maximum burst size [9].

Definition 2: Effective Bandwidth.

Consider a system S and a flow through S with an arrival function α , for a fixed but arbitrary delay d , the effective bandwidth $\lambda_d(\alpha)$ of the flow α is defined as the required bit rate at s to serve a flow in a work conserving manner to guarantee the maximum delay d ; that is

$$\lambda_d(\alpha) = \sup_{s \geq 0} \{\alpha(s) / (s + d)\} \quad (4)$$

Finally the effective bandwidth demand is calculated as:

$$\lambda_d = \max \left\{ \frac{e}{d}, q, p \left(1 - \frac{d - \frac{e}{p}}{\frac{v - k}{p} - q + d} \right) \right\} \quad (5)$$

However, the SINR measurement is not available in Wi-Fi network. In [6], it is assumed that data transmissions in each cell are independent of other cells by the orthogonal channels. The background noise is constant, i.e. typically white noise follows Gaussian distribution with a constant mean. Therefore, the SINR-based expectation throughput is roughly replaced by the equivalent goodput with RSSI values in Wi-Fi network, as shown in Equation (6).

Definition 3: Equivalent Goodput

The equivalent goodput is a proportion of the theoretical upper-bound capacity, which is expressed by the Shannon like equation [10]:

$$\text{Goodput} = c * w_j * \log_2(a + b * r_{ij}) \quad (6)$$

Where, a, b, c are coefficients to be determined. We use the nonlinear least squares curve fitting in MATLAB to fit this equation with the observed data to decide them. This model suits the tendency of the observed instantaneous goodput and approaches the mean of the goodput well.

C. Problem formulation

With the goal to maximize the system capacity for users with multiple interfaces via a soft-association method, we formulate an objective function in equation (7) and a set of constraint conditions from (8) to (12) as a mathematical model of non-linear integer programming:

$$\max \tau_s = \sum_{l=1}^{l=I*T} \sum_{j=1}^{j=J} \frac{w_j * \log_2(a + b * r_{lj}) * x_{lj}}{\partial_j} \quad (7)$$

$$\partial_j = \sum_{l=1}^{l=I*T} x_{lj} \quad (8)$$

$$\sum_{j=1}^{j=J} x_{lj} \leq 1 \quad \forall l \in [1, I * T] \quad (9)$$

$$\sum_{l=i*T-T+1}^{l=i*T} x_{lj} \leq 1 \quad \forall (i, j) \in ([1, I], [1, J]) \quad (10)$$

$$\sum_{l=i*T-T+1}^{l=i*T} \sum_{j=1}^{j=J} \frac{w_j * \log_2(a + b * r_{lj})}{\partial_j} * x_{lj} \geq \lambda_i \quad \forall i \in [1, I] \quad (11)$$

$$\forall x_{lj} \in \{0, 1\} \quad (12)$$

Where, the equation (8) means the number of users on the TP j is the sum of elements on a column of association matrix. The equation (9) limits one interface only can attach on a single TP. The equation (10) assumes that multiple interfaces on a common mobile station couldn't attach a common TP at the same time. The equation (11) shows the link capacity for one mobile station should be greater than user demand in term of effective bandwidth. The equation (12) indicates variables in the association relationship matrix can be 0 or 1. Therefore, this integer programming is a 0-1 programming problem.

III. PERFORMANCE EVALUATION

A. Scenario Configuration

In our simulation, we consider user cases of indoor scenario. Firstly, we get the real measurements of RSSI and throughput in our office for Wi-Fi networks. We calculate the coefficients

a, b and c in the formula (6) based on the curve fitting. Finally, we generate the RSSI values based on a path-loss model.

$$\text{RSSI} = P_t - \text{PathLoss} - M \quad (13)$$

Where, the transmit power P_t is -10dBm, and M is a random value for the shadowing effect because of the obstacles, which ranges from 0 to 40 in dB. The PathLoss model is defined as:

$$\text{PathLoss} = 20\lg(F) + 20\lg(D) + 32.4 \quad (14)$$

Where, F is equal to 2.4GHz, D is the distance between the mobile station and TPs. We evaluate our association approach in three use cases: edge/central users, homogeneous change of user demand, and heterogeneous user demands. The system throughput and the individual throughput are defined as two metrics for evaluation. In our simulation, a common set of configuration parameters are summarized in Tab. 1.

TAB. 1: PARAMETERS CONFIGURATION

Parameter and units	Setting Values
Number of APs	3
Number of users	9
Number of interfaces	2
Radius of coverage(m)	150
Distance of neighbor APs(m)	34
Frequency band(GHz)	2.4
Transmit power(dBm)	-10
Shadowing effects(dB)	(0,40)
Bandwidth (MHz)	20
The coefficient a	1.733
The coefficient b	0.005429
The coefficient c	5
RSSI threshold for Edge user (dBm)	-120
RSSI threshold for Central user(dBm)	-90

B. Coefficient Fitting

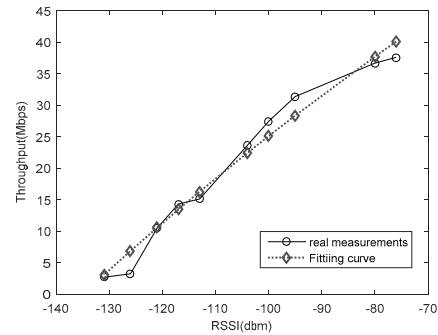


Fig. 2 Model fitting with real measurements

The real measurements are used to fit the goodput in equation (6). The coefficients of a, b and c are given by MATLAB. The result is $a=1.733$, $b=0.005429$, $c=5.0$. The comparison of model fitting and real measurement is shown in the figure 2.

C. Case study: Edge/Central users

The edge user is defined as the user with a bad RSSI value less than -120dBm. The central user is defined as the user with a good RSSI value more than -90dBm. In this case, we assume all of the mobile stations have one flow, and each flow has a common effective bandwidth, 0.5Mbps, which can be reached easily. Three association approaches are employed in the performance comparison. The soft-association approach improves the system capacity about 19.6% and 28.5% for the

edge users, and about 5.6% and 9.8% than the distributed one-path and two-path association, as illustrated in Figure 3(a) and (b). Therefore, one-path RSSI based association results in the unbalanced load distribution for the individual capacity. Two-path RSSI based association can achieve better performance compared with the one-path association on load balance and fairness. However, it results congestion on TPs and decreases the system throughput, as shown in the Fig. 3 (a) and (b). The soft-association approach achieves a trade-off between system capacity and load-balance.

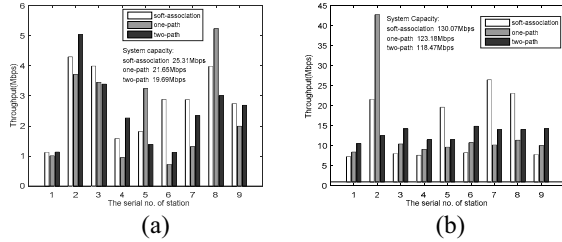


Fig. 3 Edge user vs. Central user

D. Case study: Homogeneous User demands

Here, we assume all user demands change from 1.3Mbps to 1.6Mbps. Initially, we set a common effective bandwidth for all edge users. The soft-association approach can find an optimized transmission point set for each user to meet the improved bandwidth demand. However, it really improves the individual user experience at an expense of system throughput. When effective bandwidth changes from 1.3Mbps to 1.6Mbps, System capacity decreases from 28.73Mbps to 21.54Mbps, almost equal to the capacity achieved by the distributed one-path and two-path association methods. For the individual capacity, the ratio of unsatisfying user is 55.56% for one-path RSSI based association and 22.23% for two-path.

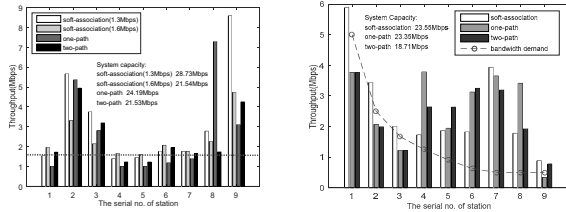


Fig. 5 Homogeneous vs. Heterogeneous user demand

E. Case study: Heterogeneous User demands

In this case, we investigate a scenario with heterogeneous bandwidth demands, which is a result from different latency requirements of different services. Based on the definition of effective bandwidth, it depends on parameters such as e , d and q . We take the elephant flows as an example, e.g. interactive video services. We assume the packet size is set as $e = 1 \times 10^4$ bits. The delay requirements for each flow d_i are set as [2, 4, 6, 8, 12, 16, 20, 50, 100] in million-second, q is set as 0.5Mbps to create a scenario where e depends on q and D_i both. The effective bandwidth λ_i can be given as [5, 2.5, 1.67, 1.25, 0.91, 0.625, 0.5, 0.5, 0.5] in Mbps. The results are illustrated in Figure 5. The one-path RSSI based association can't meet the delay requirements from flow 1, 2, 3 and 9.

The two-path association approach could not meet the delay requirements of flow 1, 2 and 3. The soft-association can satisfy all of users with a little price on system throughput.

IV. CONCLUSION

In this paper, a user demand centric soft-association control schema is proposed in software defined ultra-dense networks. It can provide an adaptive multipath transmission capability for the mobile stations with multiple interfaces. The non-linear integer programming is employed to model the problem. The performance on system throughput and individual user experience for the edge and central users is examined with simulations. Furthermore, homogeneous and heterogeneous user demands are considered. Results show that the proposed soft-association can achieve better performance with a trade-off on system capacity and user experience, even fairness with load balance.

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