Nonlinear Perron-Frobenius Theory Based Resource Allocation in Wireless Virtualization Network

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Abstract

The successful virtualization of wireless access networks is strongly affected by the way in which radio resources are managed. The infrastructure provider (InP) is required to deploy efficient and flexible resource allocation techniques to dynamically allocate the resources for the users associated with different service providers (SPs). Service contracts with different SPs and energy efficiency are crucial to the success of the virtualization scheme deployed by the InP. In this paper, an algorithm based on nonlinear Perron-Frobenius theory is proposed for resource allocation in OFDMA virtualized wireless network. The framework considers a market model consisting an InP and multiple SPs. Regarding the virtual resource for a virtualized wireless network as commodities, the SPs want to serve their users at the best performance and want to pay the minimum to InP.

I. Introduction

Virtualization has seen as one of the main evolution trends in the forthcoming fifth generation (5G) cellular networks which is expected to provide higher data rate, lower end-to-end latency, improve spectrum/energy efficiency, and reduced cost [1][2][3]. The main idea of wireless virtualization is to enable resource sharing and to decouple the infrastructure from the service it provides. In this case, the roles of infrastructure providers (InPs) and mobile virtual network operators (MVNOs) can be logically separated and the physical resources (e.g., subchannels, base station) owned by an InP can be transparently shared by multiple MVNOs, while each MVNO virtually owns the entire base station and subchannels. Virtualization involves abstraction and sharing of resources among different parties.

Similar to wired network virtualization, in which physical infrastructure owned by one or more providers can be shared among multiple service providers, wireless network virtualization needs physical wireless infrastructure and radio resources to be abstracted and isolated to a number of virtual resource, which then can be offered to different service providers [1][2].

Wireless network virtualization is a means by which an InP can slice the wireless and physical resources to slices. These slices are assigned to MVNOs (or service providers SPs in some literatures) so that they can serve their subscribers. The main motivation behind wireless network virtualization is cost saving of network roll-out, maximization of revenue for InPs

II. System model

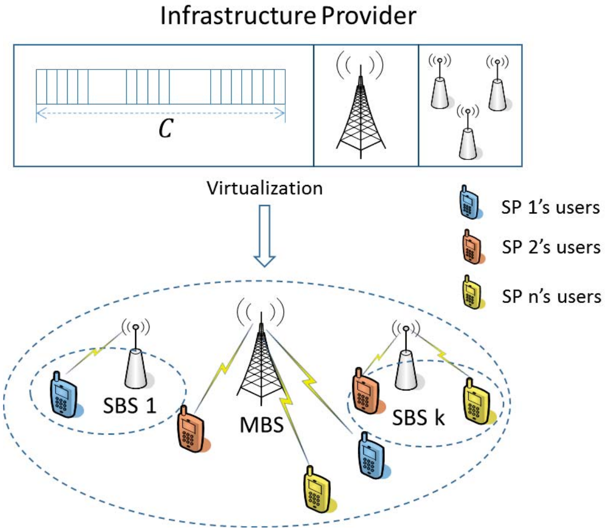

Fig.1 System model

We consider a set of infrastructure providers (InPs) provide (through leasing) the physical substrate infrastructure to a mobile virtual network operator (MVNO) while a set of service providers (SPs) buy virtual network from MVNO to provide specific services to subscribed end users (SUEs). With mobile network virtualization, MVNOs will play a key role in future mobile network exist as a connector in the network. Each SP provide certain services (e.g., video,, voice, game) to its subscriber through the virtualized resources. An InP owns and operates all of the physical substrate of a wireless virtual network, including cell sites, the radio access network (RAN) and the core network (CN). An InP has its own subscriber and lease part of its network to MVNOs.

MVNOs create virtual resource (VR) slices based on the request from SPs, and operate the VR slices and assign them to SPs [1][2]. In additionally, the virtualization and management of slices is executed by MVNO hence it will charge the SPs a management fee beside the price of slices. We simply assume that if a certain amount of spectrum resource and base station power are allocated to a SP, then the corresponding physical substrate resource (e.g., base station (BS)) is also available for it in the form of VR slice.

We consider N SPs who rent VR slices from M InPs via a MVNO. In this paper, we formulate a three sides market scenario in which SPs, InPs and MVNO want to maximize their utility. We propose an algorithm for SPs to dynamically update their demand according to the adjustment of price. The InP *m* holds a total W_m Hz bandwidth which is divided into S_m orthogonal subcarriers. Each subcarrier is with the bandwidth size w_0Hz. The BS correspond to InP *m*'s infrastructure has a total transmission power P_m. The VR slices are created from the available subcarriers and power of the InPs and then to be leased to the SPs. the achievable data rates for the SUE *j* (*j* = 1,..., J_n) of the SP *n* can be formulated using Shannon capacity as

$$R_{n,j}=c_{n,j}w_0\log_2\left(1+\frac{P_{n,j}g_{n,j}}{c_{n,j}w_0n_0}\right), \qquad (1)$$

where $c_{n,j}$ represents the number of subcarriers allocated to the *j*th SUE of *n*th SP. Let $P_{n,j}$ denote the BS transmission power to the *j*th SUEs of *n*th SP, respectively, and $g_{n,j}$ is the channel power gain accordingly. n_0 is the background noise. Each SP guarantees its SUEs satisfy the QoS contract constraint by allocating necessary bandwidth to its SUEs based on its own QoS requirement, i.e., SUEs' transmission rate must be at least as much as a target rate

$$R_{n,j}\geq\bar{R}_n,\forall n,j. \qquad (2)$$

III. Problem Formulation and Algorithm

The utility of SP *n* is given by the following revenue function

$$U_n^{SP}(\mathbf{c}_n,\mathbf{P}_n,p_n^b)=\sum_{j=1}^{J_n}R_{n,j}-(p_n^b+\rho)\left(\sum_{j=1}^{J_n}c_{n,j}+\sum_{j=1}^{J_n}P_{n,j}\right),$$

(3)

where p_n^b is the price per unit of slice (i.e., unit of subcarrier and unit of power) that SP *n* is willing to pay to MVNO for purchasing VR slices. ρ is the VR slices management fee charged by MVNO. Since (3) is decreasing in p_n^b, SPs always wish to buy VR at lower price. Given price $p_n^b$the SP choose $c_{n,j}^*(p_n^b)$ and $P_{n,j}^*(p_n^b)$ so as to maximize the utility (3). The optimization problem for SP *n* can be formulated as

$$\begin{aligned}\mathbf{P_{SP}}:\ &\underset{\mathbf{c}_n,\mathbf{P}_n}{\text{maximize}}\ U_n^{SP}(\mathbf{c}_n,\mathbf{P}_n,p_n^b)\\ &\text{subject to:}\,(2)\end{aligned} \qquad (4)$$

To solve problem P_{SP} we use the nonlinear Perron-Frobenius theory [5] for Algorithm 1:

Algorithm 1: Virtual Resource Algorithm:

Initialization

1. The *n*th SP updates the amount of bandwidth and power to be purchased:

$$c_{n,j}(t+1)=\frac{P_{n,j}(t)g_{n,j}}{\log\left(1+\frac{P_{n,j}(t)g_{n,j}}{c_{n,j}(t)\omega_0n_0}\right)-(p_n^b+\rho)}-P_{n,j}(t)g_{n,j},$$

(5)

$$P_{n,j}(t+1)=c_{n,j}(t)\omega_o\left(\frac{1}{p_n^b+\rho}-\frac{n_0}{g_{n,j}}\right). \qquad (6)$$

2. Normalize:

$$c_{n,j}(t+1)=\frac{c_{n,j}(t+1)}{\beta_n(\mathbf{c}_n(t+1),\mathbf{P}_n(t+1))}, \qquad (7)$$

$$P_{n,j}(t+1)=\frac{P_{n,j}(t+1)}{\beta_n(\mathbf{c}_n(t+1),\mathbf{P}_n(t+1))}. \qquad (8)$$

$\beta_n(\mathbf{c}_n(t+1),\mathbf{P}_n(t+1))$ can be computed by Bisection search algorithm.

Algorithm 2: Computation of β via Bisection Search

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1. Initialization

Set $i\leftarrow 0, L\leftarrow 0, U\leftarrow 2^i$.

If there exists j such that $R_{n,j}(c_{n,j}(t+1)/U, P_{n,j}(t+1)/U) < \bar{R}_n$, then increment $i \leftarrow i+1$, and set $U \leftarrow 2^i$.

Repeat until $R_{n,j}(c_{n,j}(t+1)/U, P_{n,j}(t+1)/U) \geq \bar{R}_n$ for all j.

2. Bisection Search

Set $\beta_n \leftarrow (U+L)/2$ If $R_{n,j}(c_{n,j}(t+1)/U, P_{n,j}(t+1)/U) < \bar{R}_n$ for some j, then set $L \leftarrow \beta_n$. Otherwise, set $U \leftarrow \beta_n$

IV. Numerical Results.

The network scenario in our numerical simulation is shown in Fig. 2, where SPs' subscribed users are randomly deployed inside 3 macro cell of radius 500m which belong to the InP. We consider three SPs with 10 subscribed users for each SP. We assume the InP owns $C=50$ OFDMA subchannels, each of which has a total bandwidth of 180 KHz. We set the $P^{max} = 40W$. The noise power is assumed to be 10^{-13}W for all subchannel. Channel gains are set as $g_{n,j} = \chi\, d_{n,j}^{-\beta}$, where χ s a random value generated according to the Rayleigh distribution, $d_{n,j}$ is the geographical distance between BS n and user j of $\beta = 3$ is the pathloss exponent.

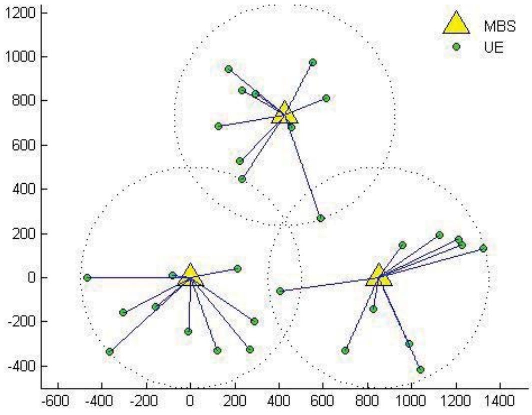

Fig. 2: Network topology

It can be seen that the Alg. 1 converges very fast to the optimal value, i.e., less than 5 iterations. The total throughput of a SP' users can achieve up to 93Mbps.

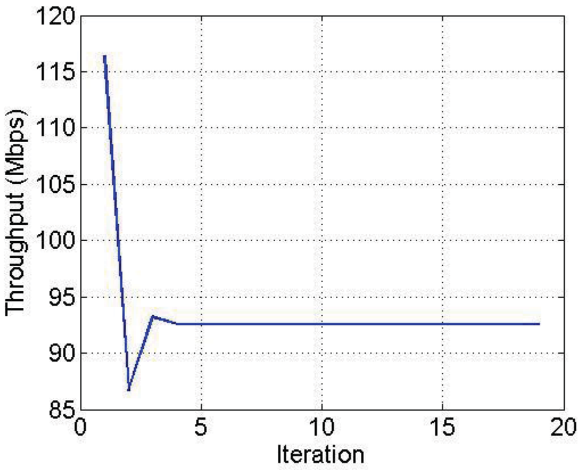

Fig 3: Network Throughput.

V. Conclusions

In this paper, we have developed a fast algorithm based on the nonlinear Perron-Frobenius theory to optimally solve the resource demand for a SP's users for a given resource price offered from the InP. The numerical results have illustrated the fast convergence speed of our proposed algorithm.

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