Study of the Degree of Fairness for a Parallel Relay 2-hop OFDMA Virtual Cellular Network

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***Abstract*— With the trend of the evolution of Information and Communication Technology (ICT), high data rate transmission is expected and needed in the next generation mobile network. In order to maintain the same quality of service, the transmission power would need to be increased if the current mobile cellular network architecture is to be considered. To solve this problem, a multi-hop virtual cellular network (VCN) has been proposed. The simulation results of a resource allocation algorithm with interference for a parallel relay 2-hop OFDMA virtual cellular network have shown that the VCN can achieve a better channel capacity than the single hop network for low transmission power. In this paper, using this algorithm, we evaluate the channel capacity of the VCN as the number of users increases, and study the degree of fairness of the VCN compared with that of the conventional single hop network. For low transmission power, the simulation results show: a) the channel capacity of the VCN remains better than that of the single hop network as the number of users increases, and b) the VCN can achieve a better degree of fairness than the single hop network.**

Keywords-component; VCN, Resource allocation, Fairness, SINR, Multi-hop network, Multi-user resource allocation, OFDMA, Channel capacity, Virtual cellular network.

I. INTRODUCTION

The development of mobile computing and the trend of enhanced multimedia communication create an increasing demand of high data rate in mobile network systems [1]. Providing the same quality of service while increasing the data rate will require an augmentation of the transmission power if the current mobile network architecture is to be considered. In the literature, multi-hop networks have been proved to be a key solution to this problem [2-7]. In this context, a multi-hop virtual cellular network (VCN) has been proposed [6-7]. In the VCN, a virtual cell (VC) is composed of a central port (CP) and many distributed wireless ports (WPs). The CP aims at acting as a gateway to the network control center. A mobile terminal (MT) located in a VC can communicate with any surrounding WP and also directly with the CP.

Though multi-hop networks can help in reducing the transmission power, they require tremendous work when it comes to finding an optimal resource allocation scheme. Furthermore, as the number of hops and WPs increases, the task of finding an optimal resource allocation algorithm becomes more difficult. For the VCN, a parallel relaying scheme for a 2-hop OFDMA (Orthogonal Frequency Division Multiple Access) VCN has been proposed [8]. Since the resource allocation algorithm in [8] could not be applied in a multi-user environment, because it did not consider interference between users, we have proposed a resource allocation scheme with interference for a parallel relay 2-hop OFDMA VCN [9] which could be applied in a multi-user environment. In [9], it has been observed that the VCN can provide a better channel capacity than the single hop network in case of low transmission power.

In [9], the study was done with 2 MTs. Fairness was not considered. In any network, as the number of user increases, fairness between users should be evaluated. In this paper, using the proposed algorithm in [9], we aim at evaluating the channel capacity of the VCN as the number of MTs increases, and also studying the degree of fairness of the VCN. We will compare the results with those of the single hop network. Since the objective of the VCN is to reduce the transmission power, and that the single hop network provides a better channel capacity than the VCN for high transmission power [8-9], in this study, we will focus on low transmission power.

The rest of this paper is presented as follows: in section II we partially present the proposed algorithm in [9]. In section III we detail the study of fairness and the evaluation of the channel capacity of the VCN for multi users. We draw some conclusions and present the perspective works in section IV.

II. MULTI-USER RESOURCE ALLOCATION SCHEME

a) Mutiple access method

In the proposed scheme [9], OFDMA is considered. Because of its resilience to frequency selective channels and its multi-user diversity, OFDMA which is an access method derived from Orthogonal Frequency Division Multiplexing (OFDM) has been given a lot of attention recently by researchers involved in resource allocation scheme [10-13].

b) Paralell relaying transmission

In [9], a 2-hop VCN has been considered. Parallel transmission method has been applied. In parallel transmission method, the data are sent simultaneously using multiple logical routes. This method does not only provide frequency diversity but also route diversity. A logical route has been defined to be a set of a physical route and subcarriers assigned along each link of the physical route, as illustrated in figure 1. A physical route can be a 2-hop link route which goes through a WP or a direct link route between the CP and an MT.

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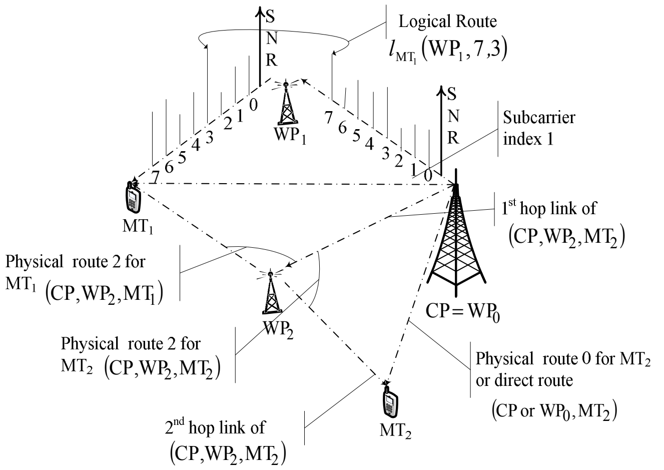

Figure 1. Logical and Physical routes

c) *Proposed Algorithm* [9]

In order to increase the spectrum efficiency, frequency reuse even in the same VC has been applied in the proposed algorithm [9]. Depending on the level of interference, and for a proper allocation and route construction, it is considered:

- ✓ An allocated subcarrier in a first hop link or in a direct link can only be reused by another MT in a second hop link.
- ✓ A subcarrier which is in use by a WP or an MT cannot be reused simultaneously by the same WP or the same MT.
- ✓ A subcarrier in use in a second hop link can be reused simultaneously in a second hop link to transmit data to another MT if the previous rule is respected.
- ✓ The total number of allocated LRs in a VC cannot outnumber the subcarriers in that VC.

The following have been assumed: frequency division duplex (FDD) in the downlink transmission; the channel characteristics do not vary during the communication time; the channel state information (CSI) between each node is available at the CP. A node is defined to be the CP, a WP, or an MT.

In [9], a VC with M WPs including the CP and p active MTs have been considered. For convenience, the following have been defined:

- ✓ $l_{\mathrm{MT}_q,e}(\mathrm{WP}_m, k_i, k_j)$ is the e-th logical route via the m-th WP that is allocated to the q-th MT where i and j represent the indexes of the subcarriers selected in the first and second hop link, respectively; if i=j, the logical route goes via the CP (WP_0); a candidate is denoted by l^*.
- ✓ $L_{\mathrm{MT}_q}(\mathrm{WP}_m) = \{ l_{\mathrm{MT}_q,1}(\ldots), l_{\mathrm{MT}_q,2}(\ldots), \ldots, l_{\mathrm{MT}_q,W_q}(\ldots) \}$ is the set of W_q logical routes via WP_m allocated to the q-th MT, with $1 \le W_q \le D_q \le N_{sc}$. D_q represents the number of logical routes to be allocated to the q-th MT, and N_{sc} the number of subcarriers in the VC. L^* represents the set of S_q candidates with $\begin{cases} 1 \le S_q \le N_{sc}, & \text{if } \mathrm{WP}_0, \\ 1 \le S_q \le N_{sc}(N_{sc}-1), & \text{else.} \end{cases}$
- ✓ C_q is the channel capacity of the q-th MT.

The steps of the proposed algorithm are described below.

1. Resource allocation for MT_1.

   $\forall m,\ 0 \le m \le M-1$ initialize $L^*_{\mathrm{MT}_1}(\mathrm{WP}_m)$ according to the constraints relative to logical routes' construction and subcarriers' allocation.

   Allocate D_1 logical routes to MT_1 using successive construction method in [8].

2. Suppose that resource allocation has been done for h MTs with h<p.

3. Successive logical route allocation for MT_{h+1}.

   $\forall m,\ 0 \le m \le M-1$, initialize $L^*_{\mathrm{MT}_{h+1}}(\mathrm{WP}_m)$ according to the constraints relative to logical routes' construction and subcarriers' allocation.

   $\forall m,\ 0 \le m \le M-1,$
   $\forall l^*_{\mathrm{MT}_{h+1},e}(\mathrm{WP}_m, k_i, k_j) \in L^*_{\mathrm{MT}_{h+1}}(\mathrm{WP}_m),$
   with $1 \le e \le S_{h+1},\ 0 \le i, j \le N_{sc}-1,$
   $\forall q,\ 1 \le q \le h,\ \forall m',\ 0 \le m' \le M-1,$
   If there is $l_{\mathrm{MT}_q,e'}(\mathrm{WP}_{m'}, k_{i'}, k_{j'}) \in L_{\mathrm{MT}_q}(\mathrm{WP}_{m'})$
   with $1 \le e' \le D_q,\ 0 \le i', j' \le N_{sc}$ - 1 so that
   $i = j'$, or $j = i'$, or $j = j'$,
   evaluate using equation (3),
   $$\begin{cases} SINR_{\mathrm{WP}_0\text{-}\mathrm{MT}_{h+1}}(k_i), & \text{if } i = j, \\ SINR_{\mathrm{WP}_0\text{-}\mathrm{WP}_m}(k_i), \text{ or } SINR_{\mathrm{WP}_m\text{-}\mathrm{MT}_{h+1}}(k_j), & \text{else} \end{cases}$$
   and $$\begin{cases} SINR_{\mathrm{WP}_0\text{-}\mathrm{MT}_q}(k_{i'}), & \text{if } i' = j', \\ SINR_{\mathrm{WP}_0\text{-}\mathrm{WP}_{m'}}(k_{i'}), \text{ or } SINR_{\mathrm{WP}_{m'}\text{-}\mathrm{MT}_q}(k_{j'}), & \text{else} \end{cases}$$
   evaluate using equation (2),
   $SINR\left(l^*_{\mathrm{MT}_{h+1},e}(\mathrm{WP}_m, k_i, k_j)\right)$ and $SINR\left(l_{\mathrm{MT}_q,e'}(\mathrm{WP}_{m'}, k_{i'}, k_{j'})\right),$
   Recalculate C_q using equation (1).
   end if
   Evaluate C_{h+1} using equation (1).
   choose $l^*_{\mathrm{MT}_{h+1},e}(\mathrm{WP}_m, k_i, k_j)$ so that
   $\sum_{z=1}^{h+1} C_z$ is maximal.

   For all subcarriers that are already in use by other MTs, the level of interference that they will impose on MT_{h+1} is evaluated, should they ever be reused. For each logical route that can be allocated to MT_{h+1}, the level of interference that the assigned subcarriers will impose on other MTs is calculated. The logical route which maximizes the channel capacity, with respect to interference, is chosen as the present logical route.

4. Reiterate step 3 until D_{h+1} logical routes are chosen.

The last two steps are repeated each time resources need to be allocated to a new MT.

d) *Numerical expressions*

The channel capacity of the q-th MT is evaluated using the following equation [9]:

$$C_q = \frac{1}{N_{sc}} \sum_{i=1}^{D_q} \log_2 \left\{1 + SINR\left(l_{\mathrm{MT}_q,i}\right)\right\}. \tag{1}$$

Where $SINR\left(l_{\mathrm{MT}_{q,i}}\right)$ the signal-to-interference plus noise power ratio (SINR) of the i-th logical route allocated to q-th MT. The total channel capacity of a VC is the summation of the channel capacity of all MTs in that VC. The SINR of the i-th logical route allocated to q-th MT via the m-th WP $SINR\left(l_{\mathrm{MT}_{q,i}}\left(\mathrm{WP}_m, k_e, k_{e'}\right)\right)$ can be found using the following formula [9]:

$$SINR\left(l_{\mathrm{MT}_q,i}\left(\mathrm{WP}_m, k_e, k_{e'}\right)\right) = \begin{cases} SINR_{\mathrm{CP-MT}_q}\left(k_e\right), \text{ if direct route } \left(e = e'\right), \\ \min\left\{SINR_{\mathrm{CP-WP}_m}\left(k_e\right), SINR_{\mathrm{WP}_m - \mathrm{MT}_q}\left(k_{e'}\right)\right\}, else. \end{cases} \tag{2}$$

Where k_e and $k_{e'}$ represent the subcarriers assigned to an MT in the first and second hop link respectively, and $SINR_{x-y}\left(k\right)$ is the SINR of the k-th subcarrier at node y when the desired received signal is from node x. It is expressed as follows [9]:

$$SINR_{x-y}\left(k\right) = \frac{\frac{P_x\left(k\right)}{N} \cdot d_{x-y}^{-\alpha} \cdot 10^{-\delta_{x-y}/10} \cdot \left|G_{x-y}\left(k\right)\right|^2}{1 + \sum\limits_{\substack{j \in \{0,1,\ldots,M-1\} \\ j \neq x}} \frac{P_j\left(k\right)}{N} \cdot d_{j-y}^{-\alpha} \cdot 10^{-\delta_{j-y}/10} \cdot \left|G_{j-y}\left(k\right)\right|^2} \tag{3}$$

$P_x\left(k\right)$ is the transmission power of node x at the k-th subcarrier; d_{x-y}, δ_{x-y}, and $G_{x-y}\left(k\right)$ represent the distance, the shadowing loss, and the instantaneous channel gain at the k-th subcarrier between node x and node y respectively. N represents the noise power per subcarrier and α the path loss exponent. For more information regarding the numerical expression please refer to [9].

III. FAIRNESS AND MULTI-USER EVALUATION

a) Multi-user evaluation

As in [9], we use the Monte Carlo simulation method to evaluate the channel capacity of the VCN as the number of MTs increases and to study the degree of fairness of the VCN compared with that of the single hop network. The same cell layout has been considered (figure 2). A VC is assumed to be of a regular hexagonal shape where the CP is placed at the center of the cell and 6 WPs, each located at each edge of a regular hexagon concentric with the VC. A distance ratio d/d_0 is defined to be the ratio of the distance d between the CP and a WP to the radius d_0 of the VC. In [14], it has been shown that an optimal distance ratio for low transmission power can be found in the interval 0.2~0.3. Therefore, in this paper we consider a distance ratio of d/d_0=0.3.

We evaluate the ergodic channel capacity of the VCN for N_{sc}=32 subcarriers, where the number of allocated logical routes is D_s=2 per MT. The path loss exponent is taken to be α=4 and the standard deviation for the shadowing loss γ=8 dB. We also consider L=8 propagation paths frequency selective Rayleigh fading with independently and uniformly distributed power profile.

In figure 3, we plot the ergodic channel capacity of the VCN compared with that of the single hop network for different values of the normalized transmission power P_t/P_0 [9]. P_t/P_0 is the ratio of the total transmission power P_t in a VC to the average power P_0 of the CP for which the SINR at d_0 is 0dB. We observe that, for low transmission power, as the number of MTs increases, the channel capacity of the VCN remains better than that of the single hop network. This is because, for low transmission power the level of interference between MTs is low. Hence, the channel capacity of the VCN remains better than that of the single hop network. We also remark that when the normalized transmission power is 0 dB, increasing the number of MTs from 14 to 16 causes the channel capacity of the VCN to decrease. This can be explained by the augmentation of the level of interference as the number of MTs increases.

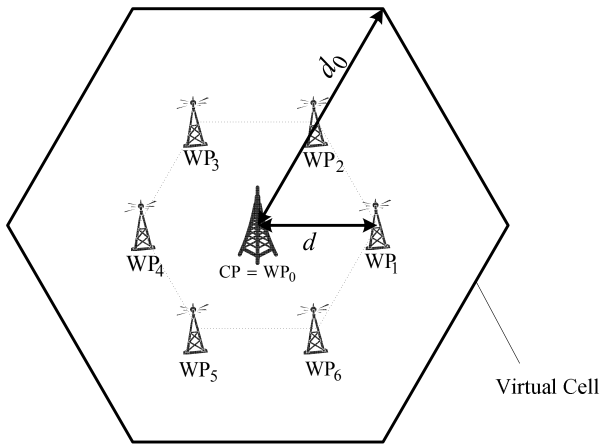

Figure 2. Virtual cell layout.

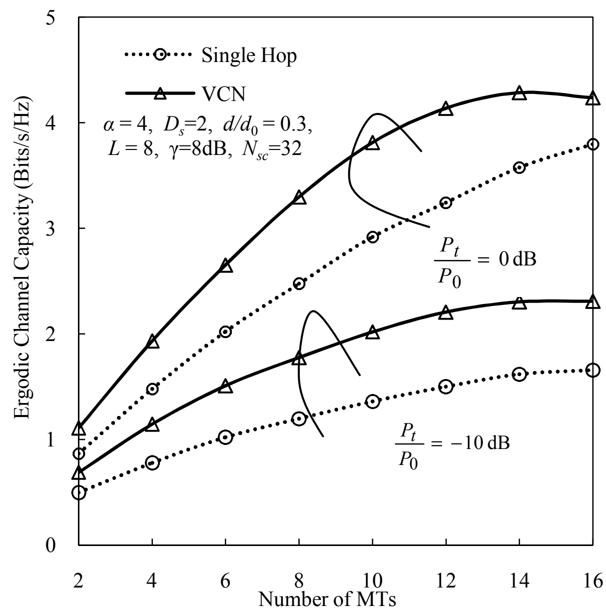

Figure 3. Multi-user ergodic channel capacity.

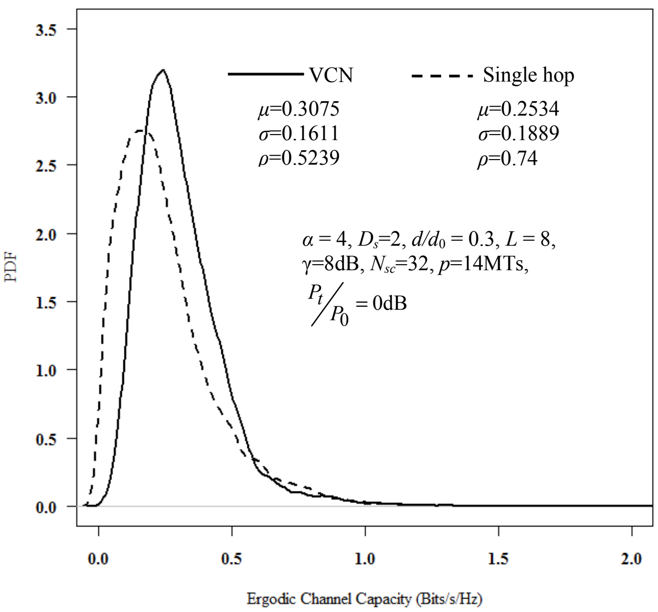

Figure 4. PDF of the channel capacity per MT at transmit power 0 dB.

b) Fairness

In figure 4, we plot the probability density function (pdf) of the channel capacity per MT of the VCN compared with that of the single hop network when the total normalized transmission power is 0 dB. Since the mean values of the pdf functions for the VCN and the single hop network are different, the standard deviation cannot be used to compare the degree of fairness of both architectures. Therefore, we use the coefficient of variation $\rho = \sigma/\mu$ which is the ratio of the standard deviation σ to the mean value μ to evaluate the degree of fairness. In figure 5, we plot the coefficient of variation of the VCN compared to that of the single hop network, based on the total normalized transmission power.

Considering figures 4 and 5, we observe that, for low transmission power, the coefficient of variation ρ of the VCN is less than that of the single hop network, meaning that the VCN presents a better degree of fairness than the single hop network. This is a consequence of multi-hop networks. By introducing a WP between the CP and an MT located at the edge of the VC the channel capacity of the MT at the edge increases; hence the standard deviation decreases and also the average channel capacity per MT increases.

IV. CONCLUSION

Using the proposed algorithm in [9], we have shown that the VCN still provides a better channel capacity than the single hop network for low transmission power as the number of MTs increases. We also acknowledged that the VCN presents a better degree of fairness than the single hop network if the transmission power is kept low. Since the aim of the VCN is to reduce the transmission power, the proposed algorithm remains a promising one. In future works, we will consider QoS and also study the case of multi cells.

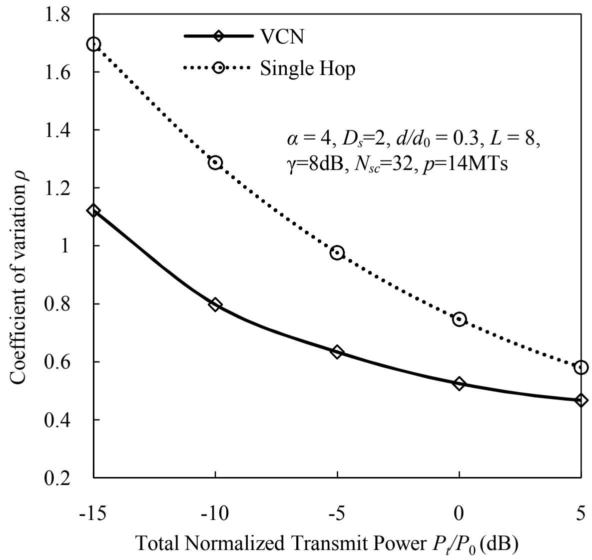

Figure 5. Coefficient of variation based on the transmmision power.

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