Study of Resource Allocation Schemes for a 2-Hop Network in a Multi-Cell Environment

Gerard Jimmy PARAISON

In the next generation mobile network, the demand for high data transmission rates will require an increase in the transmission power if the current mobile cellular network is considered. Multi-hop networks are considered to be a key solution to this problem. Many resource allocation schemes have been proposed for two-hop networks. However, to the best of our knowledge, the resource allocation problem which considers the joint allocation of routes and different sub-carriers in the two hops, with sub-carrier reuse, has not yet been solved in the literature. Jointly allocating route and sub-carriers can provide route and frequency diversity. Furthermore, the intra-cell reuse of sub-carriers can enhance the capacity of the network. This joint route and sub-carrier allocation problem in a multi-user and multi-cell environment is extremely complex. The optimal solution would require an exhaustive search which may not be applied in a practical system. In this work, we study three allocation schemes which can be used to solve that allocation problem. Firstly, we propose a successive allocation scheme (SAS) which considerably reduces the computational complexity while providing better ergodic capacity than the single hop network (SHN), in the noise dominant transmission power region. Secondly, to improve the performance of the two-hop network in the interference dominant transmission power region, we propose a sequential iterative allocation scheme (SIS). Lastly, we propose an evolutionary allocation scheme (EAS) which can approximate the optimal solution with low level of complexity.

I. INTRODUCTION

While high transmission power is required in the conventional single hop network (SHN) to provide high data transmission rates, support for data rate augmentation is available in multi-hop networks with no additional energetic cost [1]–[5]. Therefore, with the increasing demand for high data transmission rates in mobile wireless networks, multi-hop networks can be regarded as a suitable candidate to replace the current mobile network architecture.

Some proposed multi-hop networks consider the relay stations to be in motion [1]–[3]. However, the multi-hop virtual cellular network (VCN) in [4], [5] defines the relay stations as fixed nodes called wireless ports (WPs). In the VCN, a group of WPs and a central port (CP) constitute a virtual cell (VC). The term "virtual cell" is used because the installation or removal of WPs in a cell can be made whenever it is necessary. The WPs relay the transmitted signal from the CP to the mobile terminals (MTs). The proposed networks in [4], [5] consider the CP to be a WP with the capability to act as a gateway to the core network. An MT can communicate not only with the WPs but also directly with the CP. As a migration step will be needed to replace the SHN by multi-hop networks, in this work, we focuse on a 2-hop VCN.

Multiple resource allocation schemes have been proposed for two-hop OFDMA networks [6]–[12]. However, to the best of our knowledge, the joint allocation problem of routes and sub-carriers, where the subcarrier allocated in the first-hop link is different from that allocated in the second-hop link and a subcarrier can be reused simultaneously in multiple links reuse, has not yet been solved in the literature. By jointly allocating routes and sub-carriers, route and frequency diversity can be achieved in the network. Furthermore, the spectral efficiency can be increased by allowing a sub-carrier to be reused concurrently in multiple links. The joint route and subcarrier allocation problem is very complex when considering a multi-user and a multi-cell environment. The optimal solution which requires an exhaustive search cannot be applied in a practical system.

To solve this problem, in Section 2, using the parallel relaying transmission method, we model the joint route and subcarrier allocation problem as a logical route (LR) allocation problem. In Section 3, to reduce the computational complexity, we propose a successive allocation scheme (SAS). We show that using the SAS, the VCN can provide better channel capacity than the SHN, in the noise dominant transmission power region. Since the performance of the SAS degrades with interference, in Section 4, we propose a sequential iterative allocation scheme (SIS) to alleviate the effect of intra-cell and inter-cell interference in the VCN. We show that SIS can improve the performance of the VCN in the interference dominant transmission power region. To approximate the optimal solution, in Section 5, we propose an evolutionary allocation scheme (EAS). We show by computer simulations that EAS can approximate the optimal solution with low levels of computational complexity. In Section 6, we compare the performance of the proposed schemes, SAS, SIS, and EAS, with that of the optimal exhaustive scheme. We conclude in Section 7.

II. RESOURCE ALLOCATION PROBLEM

A. System model

We consider the downlink transmission in a system with a set $\mathcal{V}$ of V virtual cells. In the v-th VC (VC$_v$), a set $\mathcal{R}_v$ of R_v WPs including a CP ensure the data transmission between the core network and a set $\mathcal{M}_v$ of M_v MTs. The available bandwidth of the v-th VC is divided into a set $\mathcal{S}_v$ of S_v sub-carriers. The WPs and CP are assumed to be able to transmit concurrently in the same timeframe using different sub-carriers in the first-hop and second-hop links.

B. Parallel relaying transmission

The parallel relaying transmission method is used to transmit data to an MT. In the parallel relaying transmission

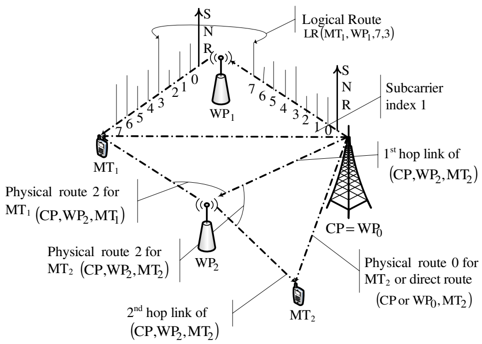

Fig. 1: Physical and logical route

method, the transmitting data of an MT is divided into data streams. Those data streams are transmitted simultaneously from the CP to the MT using multiple parallel logical routes (LRs) [13]. An LR is a set of a physical route and sub-carriers allocated along each link of the physical route as illustrated in Fig. 1. A physical route is a direct route or a 2-hop route going through a WP. In Fig. 1, the dashed dotted lines represent the physical routes. Three physical routes enable communication between the CP and MT_1, one direct route and two 2-hop routes. Along the physical route going through WP_1, between the CP and MT_1, an LR, LR(MT_1, WP_1, 7, 3), is constructed using subcarrier index 7 in the first-hop link and subcarrier index 3 in the second-hop link. In the parallel relaying transmission method, the allocations of routes and sub-carriers are carried out simultaneously using the concept of logical routes. As a result, parallel relaying transmission yields route and frequency diversity [13].

C. Numerical expression of channel capacity

We assume that the channel state information (CSI) between CP and WPs, WPs and WPs, CP and MTs, and WPs and MTs, is available at the CP of a VC. Consider two nodes[1], *node x* and *node y*. The channel between these nodes is modeled as the product of the log-normally distributed shadowing loss δ_{x-y}, the instantaneous channel fading gain H_{x-y}, and the path-loss $d_{x-y}^{-\alpha}$ between these nodes, α represents the path-loss exponent. The signal-to-interference-plus-noise power ratio (SINR) at *node y* located in the *v*-th VC, at the *k*-th subcarrier, when the desired transmitted signal is from *node x* (also located in the *v*-th VC) is given by:

$$\beta_{x\text{-}y}(k) = \frac{\frac{P_{x,v}(k)}{N} d_{x\text{-}y}^{-\alpha} 10^{-\delta_{x\text{-}y}/10} |H_{x\text{-}y}(k)|^2}{1 + \sum_{u\in\mathcal{V}} \sum_{\substack{z\in\mathcal{R}_u \\ (z,u)\neq(x,v)}} \left(\frac{P_{z,u}(k)}{N} d_{z\text{-}y}^{-\alpha} 10^{-\delta_{z\text{-}y}/10} |H_{z\text{-}y}(k)|^2 \right)} \tag{1}$$

N, and z represent respectively the noise power per subcarrier, and the WP's index in the *u*-th VC ($\text{WP}_{z,u}$). For simplicity it is assumed that the noise power per subcarrier is identical for all equipment in all VCs. $P_{x,v}(k)$ is the transmission power of $\text{WP}_{x,v}$ at the *k*-th subcarrier; $\text{WP}_{z,u}$ is the interfering WP. In Eq. (1), the right term in the dominator represents the added inter-cell and intra-cell interference to this particular link.

We define $\text{MT}_{m,v}$ as *m*-th MT located in the *v*-th VC; $l_e(v,m,r,k_i,k_j)$ represents the *e*-th LR in the *v*-th VC allocated to $\text{MT}_{m,v}$ via $\text{WP}_{r,v}$, with k_i and k_j being the respective sub-carriers assigned in the first-hop and second-hop links. The CP is represented by $r = 0$ in which case $k_i = k_j$. The SINR $\Gamma\big(l_e(v,m,r,k_i,k_j)\big)$ of the *e*-th LR allocated to $\text{MT}_{m,v}$ via $\text{WP}_{r,v}$ is given by:

$$\Gamma\Big(l_e(v,m,r,k_i,k_j)\Big) = \begin{cases} \beta_{\text{WP}_{0,v}\text{-MT}_{m,v}}(k_i), \text{if } r = 0 \text{ or } k_i = k_j; \\ \min\Big(\beta_{\text{WP}_{0,v}\text{-WP}_{r,v}}(k_i), \beta_{\text{WP}_{r,v}\text{-MT}_{m,v}}(k_j)\Big), \text{else.} \end{cases} \tag{2}$$

Let $\mathcal{D}_{m,v}$ be the set of $D_{m,v}$ LRs allocated to $\text{MT}_{m,v}$, the channel capacity $C_{m,v}$ of $\text{MT}_{m,v}$ is expressed as:

$$C_{m,v}(\mathcal{D}_{m,v}) = \frac{1}{S_v} \sum_{e=1}^{D_{m,v}} \log_2 \Big\{ 1 + \Gamma\Big(l_e(v,m,r,k_i,k_j)\Big) \Big\}. \tag{3}$$

Denoting the set of ψ_v LRs allocated to all MTs in VC_v as Ψ_v, the total channel capacity $C(\Psi_v)$ of that VC is the summation of the capacity of all MTs in that VC and it is given by:

$$C(\Psi_v) = \frac{1}{S_v} \sum_{m=1}^{M_v} \sum_{e=1}^{D_{m,v}} \log_2 \Big\{ 1 + \Gamma\Big(l_e(v,m,r,k_i,k_j)\Big) \Big\}. \tag{4}$$

D. Problem formulation

Given a set $\mathcal{R}_v$ of WPs including the CP, a set $\mathcal{M}_v$ of MTs, and a set $\mathcal{S}_v$ of sub-carriers in VC_v, the objective is to find the optimal solution candidate Ψ_v^* which maximizes the total channel capacity of VC_v with the subcarrier reuse constraints defined below. The resource allocation problem is formulated as:

$$\arg\max_{\Psi_v} \frac{1}{S_v} \sum_{m=1}^{M_v} \sum_{e=1}^{D_{m,v}} \log_2 \Big\{ 1 + \Gamma\Big(l_e(v,m,r,k_i,k_j)\Big) \Big\} \tag{5}$$

Subject to :

1) A wireless port cannot transmit and receive in the same subcarrier simultaneously in a timeframe,

$$\forall\ l_e(v,m,r,k_i,k_j) \text{ and } l_{e'}(v,m',r',k_{i'},k_{j'}) \in \Psi_v,$$
$$\begin{cases} k_i = k_j \Leftrightarrow r = 0; \\ k_i \neq k_j \Leftrightarrow r \neq 0, \end{cases} \text{ and } \begin{cases} k_i = k_{j'} \Rightarrow r \neq r'; \\ k_{i'} = k_j \Rightarrow r \neq r'. \end{cases} \tag{6}$$

2) Multiple WPs cannot transmit concurrently on the same subcarrier to an MT; neither can the CP reuse the same

[1] A node is defined as a CP, or a WP, or an MT

subcarrier to transmit to multiple WPs or MTs in the same timeframe,

$$\forall\ l_e(v,m,r,k_i,k_j) \text{ and } l_{e'}(v,m',r',k_{i'},k_{j'}) \in \Psi_v,$$
$$\begin{cases} k_i = k_{i'} \Rightarrow l_e = l_{e'}; \\ k_j = k_{j'} \Rightarrow m \neq m' \text{ and } r \neq r'. \end{cases} \tag{7}$$

3) A subcarrier allocated in a first-hop link in an LR can be reassigned simultaneously in a second-hop link in an other LR, and vice versa. Denoting Ω_v the problem space containing the set of solution candidates in the v-th VC, $\Omega_v = \Big\{\Psi_v : \Psi_v \textit{ is a solution candidate}\Big\}$,

$$\begin{aligned} &\exists\ \Psi'_v \in \Omega_v \quad \text{so that} \ : \\ &l_e(v,m,r,k_i,k_j) \text{ and } l_{e'}(v,m',r',k_{i'},k_{j'}) \in \Psi'_v \\ &\text{with } k_i = k_{j'} \text{ or } k_{i'} = k_j, \text{ and } r \neq r'. \end{aligned} \tag{8}$$

4) A subcarrier assigned to an MT in a second-hop link can be reused concurrently to transmit data to another MT in a second-hop link,

$$\begin{aligned} &\exists\ \Psi'_v \in \Omega_v \quad \text{so that} \ : \\ &l_e(v,m,r,k_i,k_j) \text{ and } l_{e'}(v,m',r',k_{i'},k_{j'}) \in \Psi'_v \\ &\text{with } k_j = k_{j'},\ m \neq m',\ \text{and } r \neq r'. \end{aligned} \tag{9}$$

5) The number of allocated LRs in a VC cannot exceed the number of sub-carriers available in that VC,

$$\forall\ v \in \mathcal{V}, \quad \psi_v \leq S_v. \tag{10}$$

The optimal solution of the resource allocation problem in Eq. (5) would require an exhaustive search which considers the simultaneous allocation of the LRs. If we consider a single VC with D LRs to be allocated to a single MT, the number of combinations $\mathcal{O}$ to be evaluated, without sub-carrier reuse, is given by:

$$\mathcal{O}(D,R,S) = \sum_{i=0}^{D} \frac{R^{D-i} \cdot S!}{(S-2D+i)!\,(D-i)!i!}. \tag{11}$$

S represents the number of sub-carriers in the network, and R the number of WPs. The complexity in a multi-user scenario with frequency reuse is therefore exponential.

III. Successive allocation scheme (SAS)

To reduce the computational complexity we propose a successive allocation scheme. In the SAS, the LRs are allocated successively to the MTs. In the v-th VC, we denote the set of all LR candidates of $MT_{m,v}$ by $\mathcal{L}^*_{v,m}$ and the the temporary set of allocated LRs by $\mathcal{L}_{v,m}$. Suppose that logical route allocation has been completed for $m-1$ MTs in the v-th VC. The allocation of $D_{m,v}$ LRs to the m-th MT in the v-th VC is executed as follows in **Algorithm** 1.

Algorithm 1: Successive Allocation Scheme

Input: $\mathcal{V}$, $\mathcal{M}_v$, $\mathcal{R}_v$, $\mathcal{S}_v$.
Output: Allocate $D_{m,v}$ LRs to $MT_{m,v}$
begin
step 1 Initialize $\mathcal{L}^*_{v,m}$, $\forall\ w \in \mathcal{R}_v$, based on constraints in Eq. (6)– (10);
step 2 /* Successive allocation */
repeat
  foreach $l^*_e(v,m,r,k_i,k_j) \in \mathcal{L}^*_{v,m}$ **do**
    foreach $p \in \mathcal{M}_u$, $\forall\ u \in \mathcal{V}$ **do**
      foreach $l_h(u,p,r',k_{i'},k_{j'}) \in \mathcal{D}_{p,u}$ **do**
        Evaluate interference using Eq. (1);
      end
      Evaluate $\Gamma\big(l^*_e(v,m,r,k_i,k_j)\big)$ and $\Gamma\big(l_h(u,p,r',k_{i'},k_{j'})\big)$ using Eq. (2);
      Evaluate $C_{p,u}(\mathcal{D}_{p,u})$ using Eq. (3);
    end
    Update $\mathcal{L}_{v,m} \leftarrow l^*_e(v,m,r,k_i,k_j)$;
    Evaluate $C_{m,v}(\mathcal{L}_{v,m})$ using Eq. (3);
  end
  /* Choose best candidate */
  Choose $l^*_e(v,m,r,k_i,k_j)$ according to Eq. (5);
  Add $l^*_e(v,m,r,k_i,k_j)$ to $\mathcal{D}_{m,v}$;
  /* Update candidates */
  Update $\mathcal{L}^*_{v,m}$ based on Eq (6)– (10);
until $D_{m,v}$ *LRs are allocated to* $MT_{m,v}$;
end

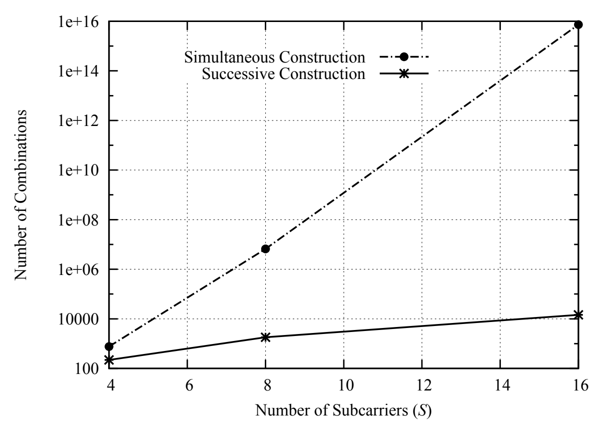

Fig. 2: Number of combinations

A. Complexity

In Fig. 2, we plot the total number of combinations to evaluate in order to allocate LRs to an MT for both the SAS and optimal scheme. In the case of the optimal scheme, subcarrier reuse is not considered. Based on Fig. 2, we observe that SAS can reduce considerably the number of combinations to evaluate in order to allocate LRs to an MT.

B. Simulation Performance

We consider a system with $V = 19$ VCs. In a each VC, $R = 7$ WPs including the CP ensure the data transmission between the core network and $M = 14$ MTs. Two LRs are

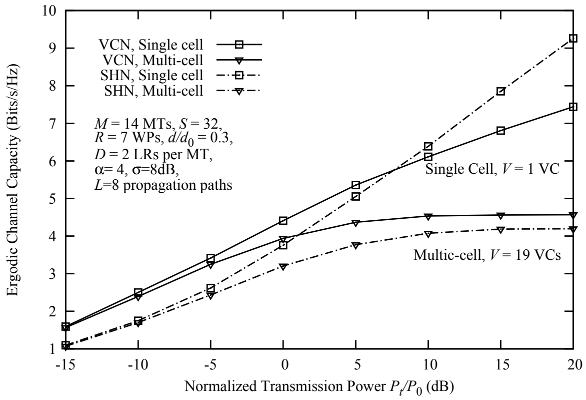

Fig. 3: Single cell and multi-cell Ergodic channel capacity

allocated per MT. The WPs are located at a distance ratio $d/d_0 = 0.3$ from the CP, d being the distance between a WP and a CP and d_0 the radius of a VC. The VC are considered to be of a hexagonal shape.

In Fig. 3, we plot the ergodic channel capacity of the VCN compared with that of the SHN when SAS is applied in a single cell and a multi-cell environment based on the normalized transmission power $P_n = P_t/P_0$. According to Fig. 3, in the case of a single cell, the channel capacity of the VCN is greater than that of the SHN only for low transmission power. However, if inter-cell interference is accounted for, the capacity of the VCN remains greater than that of the SHN even for high transmission power. This can be explained by the fact that in a single cell environment, SHN does not suffer from interference, however VCN does. In the case of a multi-cell environment, the performance of both networks degrades because of interference. In the VCN, the presence of the WPs helps to mitigate the effect of intra-cell and intercell interference on the edge-MTs and the VCN can achieve route diversity by using the WPs. This is different for the SHN which has no WP to assist the edge-MTs and to achieve route diversity.

C. *Drawbacks of SAS*

SAS considers the MTs of a VC to be arranged in a certain order for resource allocation. Though selecting the MTs in a successive order for LR allocation lessens the complexity of the problem, the channel capacity of the former MTs degrades when interference from the latter MTs is added. This capacity loss can be explained by the fact that while allocating resources to $\mathrm{MT}_{m,v}$, interference from $\mathrm{MT}_{h,v}$ is not taken into account, $h > m$. Therefore, if any subcarrier allocated to $\mathrm{MT}_{m,v}$ is reused in any LR assigned to $\mathrm{MT}_{h,v}$, the channel capacity of $\mathrm{MT}_{m,v}$ will deteriorate because of interference from $\mathrm{MT}_{h,v}$. This explains the reason why the capacity of the VCN degrades with intra-cell and inter-cell interference.

IV. Sequential iterative scheme (SIS)

To alleviate the effect of interference from the latter added MTs in the VCN, we propose a sequential iterative scheme (SIS). In the SIS, we consider the reallocation of the LRs to the MTs. The reallocation of the LRs to the MTs is performed

Algorithm 2: SIS

Input: $\mathcal{V}$, $\mathcal{M}_v$, $\mathcal{R}_v$, $\mathcal{S}_v$, I Number of Iterations
Output: Reallocation of logical routes
begin
  Allocate LRs to all MTs using SAS (Algorithm 1);
  `/* Iterative reallocation */`
  for $i = 1 \to I$ **do**
    Deallocate LRs to $\mathrm{MT}_{i,v}$ from Ψ_v;
    Reinitialize LR candidates $\mathcal{L}^*_{i,v}$ for $\mathrm{MT}_{i,v}$ based on constraints of Eq. (6)– (9);
    Reallocate LRs to $\mathrm{MT}_{i,v}$ using steps 2 of Algorithm 1;
  end
  Choose the best solution candidate among those provided by the iterations based on Eq. (5)
end

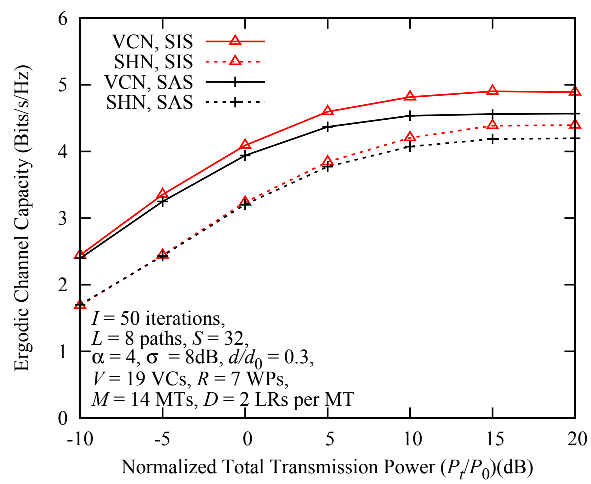

Fig. 4: SIS and SAS multi-cell ergodic channel capacity

sequentially. The MTs are selected in the same order they were chosen in the SAS. This infers that the first step of SIS is to allocate LRs to all MTs using SAS and later on apply reallocation of the LRs. At each iteration, one MT is designated for LRs reallocation while the other MTs withhold their allocated LRs. During reallocation of LRs to an MT, step 2 described in SAS is implemented. The channel capacity of the solution candidates generated by all iterations are compared and the solution candidate with the highest channel capacity is retained as the best candidate (see Algorithm 2).

A. *Simulation performance*

Using the same simulation parameters as in the SAS, we plot in Fig. 4 the ergodic channel capacity based on the normalized transmission power for the VCN and the SHN when SAS and SIS are applied in a multi-cell environment. For the SIS we consider $I = 50$ iterations. Based on the results in Fig. 4, compared to SAS, SIS can improve the ergodic channel capacity of both networks, VCN and SHN, in a multi-cell environment. In the SHN, this improvement of the channel capacity is mainly observed in the interference dominant transmission power region. This enhancement of the ergodic channel capacity of these networks is due to the reallocation of LRs implemented by SIS. By iteratively reallocating LRs to MTs, SIS is able to find the sets of LR candidates which create the least intra-cell and inter-cell interference in the VCN and the least inter-cell interference in the SHN.

B. Drawbacks of SIS

Though SIS can alleviate the effect of intra-cell and interference in the VCN, it cannot approximate the optimal solution since it is a successive scheme. SIS cannot avoid sub-optimal solutions. To approximate the optimal solution, we will need a scheme which considers the simultaneous allocation of the LRs to the MTs.

V. EVOLUTIONARY ALLOCATION SCHEME

Evolutionary algorithm is a programming method based on the evolution theory. It has been applied in many research fields such as scheduling, combinatorial optimization, etc. Its main advantage compared to other optimization methods is its black box where few assumptions regarding the objective functions are necessary.

We define a solution candidate in the v-th VC as $\Psi_v^{(t)} = \{\mathcal{D}_{1,v}^{(t)}, \mathcal{D}_{2,v}^{(t)}, \ldots, \mathcal{D}_{m,v}^{(t)}, \ldots, \mathcal{D}_{M_v,v}^{(t)}\}$ where $\mathcal{D}_{m,v}^{(t)}$ denotes the set of LRs allocated to $\text{MT}_{m,v}$. In our evolutionary scheme, a population of candidates is refined iteratively using the following methods *Creation*, *Evaluation*, *Fitness Assignment*, *Archiving*, *Selection*, *Mutation*, *Crossover*, *Validation*, and *Reproduction*, to produce the best set of solution candidates.

At the *Creation*, an initial population of P solution candidates is created. The *Evaluation* method evaluates the channel capacity of each candidate using the objective function in Eq. (4) and takes into account interference between the allocated LRs. The *Fitness Assignment* method assigns a fitness value to each candidate based on their channel capacity, The candidates with the highest channel capacities receive the highest fitness values. The *Archiving* methods archive a set of φ best candidates which will be reused in the next generation. The *Selection* method selects a set of U candidates called mates for reproduction. New offspring are created by the *Reproduction* method using *Mutation* or *Crossover*. Each offspring is validated based on the sub-carrier reuse constraints in Eq. (6)– (10) using the *Validation* method before joining the population of candidates.

These methods are connected to produce the set of the best candidates after G generations (see Algorithm 3). At the end of the algorithm, the best candidates in the archive represent the optimal solutions.

A. Simulation performance

We consider a system with the same layout as in the case of SAS. However, the number of sub-carriers is taken to be $S = 16$ sub-carriers per VC. $M = 7$ MTs are distributed in a each VC and two LRs are allocated per MT.

For the EAS we consider the following parameters, $G = 19000$ generations so that each VC can be selected for an

Algorithm 3: Evolutionary Allocation Scheme (EAS)

Input: $\mathcal{M}_v$, $\mathcal{R}_v$, $\mathcal{S}_v$, P, G, φ, U
Output: $Arch$ containing the best solution candidates
begin
  $g \leftarrow 0$;
  Create population using *Creation* method;
  while $g < G$ **do**
    Evaluate population using *Evaluation* method;
    Assign fitness value using *FitnessAssignment* method and archive best candidates;
    Select candidates using *Selection* method;
    Reproduce using *Reproduction* method;
  end
end

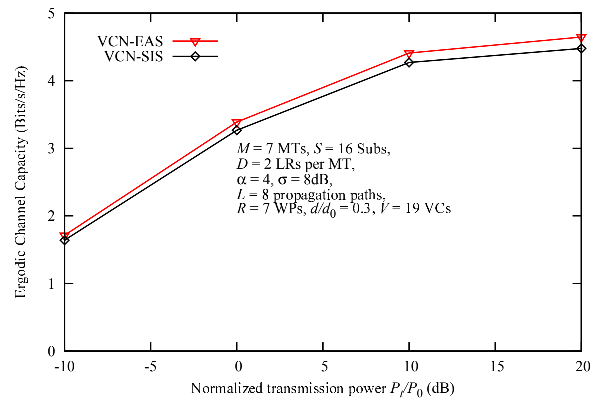

Fig. 5: Ergodic channel capacity of EAS, and SIS

average of $G_{aver} = 1000$ generations, an initial population of $P = 800$ candidates, an archive containing $\varphi = 300$ candidates, and set of mates of $U = 1000$ candidates for reproduction. In the SIS, $I = 50$ iterations are simulated.

In Fig. 5, we plot the ergodic channel capacity of the VCN for the EAS and SIS based on the normalized transmission power in a multi-cell environment. Based on Fig. 5, we notice that EAS can provide better ergodic channel capacity than SIS in a multi-cell environment. This is because EAS simultaneously allocates resources to MTs while the SIS implements a successive allocation of resources to MTs. Hence, a better degree of route and frequency diversity can be achieved by the EAS. Furthermore, since simultaneous allocation is implemented in EAS, EAS can avoid sub-optimal solutions while SIS cannot.

VI. OPTIMAL ALLOCATION SCHEME

In order to evaluate the performance of each scheme compared to the optimal exhaustive allocation scheme, we consider a single cell with $R = 3$ WPs including the CP. The system bandwidth is divided into $S = 8$ sub-carriers. $M = 2$ MTs are randomly distributed in the VC and four LRs are allocated per MT.

In Fig. 6, we plot the ergodic channel capacity of EAS compared with that of SIS, SAS, and the optimal exhaustive allocation scheme. For the EAS these parameter values have

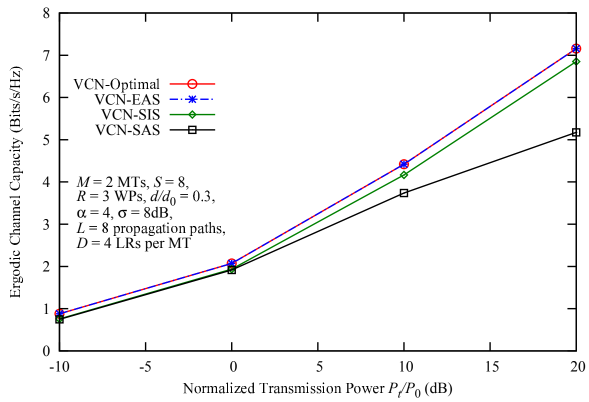

Fig. 6: Ergodic channel capacity of EAS, SIS, SAS, and exhaustive scheme

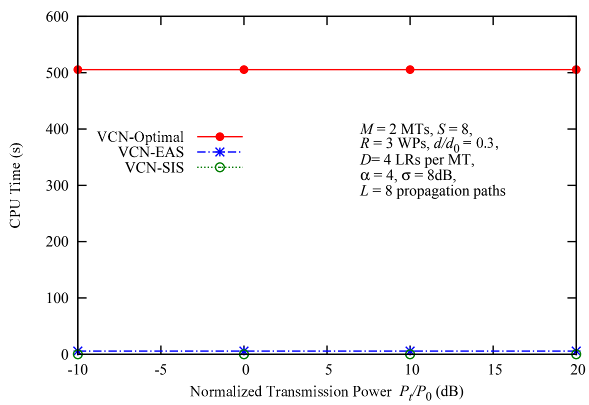

Fig. 7: Computational complexity of EAS, SIS and exhaustive scheme

been used, initial population $P = 800$ candidates, $G = 1500$ generations, $U = 1000$ mates, and $\varphi = 300$ candidates. For SIS, $I = 500$ iterations have been simulated. According to Fig. 6, EAS can provide the same ergodic channel capacity as the optimal exhaustive allocation scheme. As for SIS and SAS, their performance is less than that of the optimal scheme. This is because EAS by considering the simultaneous allocated of LRs to MTs is able to avoid local optimal solution and find global optimal solutions. SAS and SIS cannot provide optimal solutions because they are successive schemes. These results prove that EAS can be considered as an optimal allocation scheme to solve our resource allocation problem in Eq. (5).

In Fig. 7, we compare the computational complexity of the three algorithms, EAS, SIS and the optimal exhaustive scheme. We plot the CPU Time in second (s) of each algorithm based on the normalized transmission power. The CPU Time is defined as the running time of an algorithm to solve our resource allocation problem in Eq. (5). We observe that EAS requires far less computational time than the optimal exhaustive allocation scheme. Hence, we conclude that EAS can be considered as an optimal candidate to solve the joint route and subcarrier allocation problems in a two-hop network in a multi-user and multi-cell interference.

VII. Conclusion

The joint allocation of routes and sub-carriers in a two-hop network can provide route and frequency diversity which consequently will improve the capacity of the network. In this work, we have proposed three allocation schemes (SAS, SIS, and EAS) which can be used to solve the problem of joint route and subcarrier allocation in a multi-user and multi-cell environment. We show by computer simulations that the VCN using SAS can provide better performance than the SHN. SAS can reduce considerably the computational complexity of the problem. Compared to SAS, reallocating the logical routes using SIS can improve the capacity of the network in the interference dominant transmission power region. We show also that by simultaneously allocating LRs to the MTs, EAS can approximate the optimal solution and provide better performance than SIS. In this work we have considered that the CSI of all links in the network is available at the CP. Transmitting the CSI to the CP will create signalling overhead in the network. Hence, efficient overhead signalling transmission methods will need to be developed to reduce signalling overhead in the network. This can be considered as an interesting research subject for the future.

References

[1] J. N. Laneman and G. Wornell, "Energy-efficient antenna sharing and relaying for wireless networks," in *Proc. IEEE Wirel. Commun. Net. Conf.*, pp. 7–12, Aug. 2002.

[2] A. Sendoris, E. Erkip, and B. Aazhang, "User cooperation diversitypart i: System description," *IEEE Trans. Commun.*, vol. 51, no. 11, pp. 1927–1938, Nov. 2003.

[3] ——, "user cooperation diversitypart ii: Implementation aspects and performance analysis," *IEEE Trans. Commun.*, vol. 51, no. 11, pp. 1939–1948, Nov. 2003.

[4] E. Kudoh and F. Adachi, "Distributed dynamic channel assignment for multi-hop DS-CDMA virtual cellular network," *IEICE Trans. Commun.*, vol. 88-B, no. 6, pp. 2525–2531, Jun. 2005.

[5] ——, "Power and frequency efficiency wireless multi-hop virtual cellular concept," *IEICE Trans. Commun.*, vol. 88-B, no. 6, pp. 1613–1621, Apr. 2005.

[6] C. Bae and D.-H. Cho, "Fairness-aware adaptive resource allocation scheme in multihop OFDMA systems," *IEEE Commun. Lett.*, vol. 11, no. 2, pp. 134–136, Feb. 2007.

[7] J. Shi, G. Yu, Z. Zhang, and P. Qui, "Resource allocation in OFDM based multihop wireless network," in *Proc. IEEE Veh. Technol. Conf. (VTC-Spring 2006)*, Melbourne, Australia, May 2006.

[8] I. C. Wong and B. L. Evans, "Optimal downlink OFDMA resource allocation with linear complexity to maximize ergodic rates," vol. 7, no. 3, pp. 962–971, Mar. 2008.

[9] R. Kwak and J. M. Cioffi, "Resource-allocation for OFDMA multi-hop relaying downlink system," in *Proc. IEEE Global Telecom. Conf.*, pp. 3225–3229, Nov. 2007.

[10] C. Jeong and H. Kim, "Radio resource allocation in OFDMA multihop cellular cooperative networks," in *Proc. IEEE Pers. Indoor and Mob. Radio Commun. Conf. (PIMRC 2008)*, Cannes, France, Sep. 2008.

[11] N. Esseling, B. H. Walke, and R. Pabst, "Performance evaluation of a fixed relay concept for next generation wireless system," in *Proc. IEEE Pers. Indoor and Mob. Radio Commun. Conf. (PIMRC 2004)*, pp. 744–751, Sep. 2004.

[12] Y. Hua, Q. Zhang, and Z. Niu, "Resource allocation in multi-cell OFDMA-based relay networks," in *Proc. IEEE Infocom'10*, San Diego, USA, Mar. 2010.

[13] H. Ishida, E. Kudoh, and F. Adachi, "Channel capacity of parallel relaying 2-hop OFDMA virtual cellular network," in *Proc. IEEE Veh. Technol. Conf. (VTC-Fall 2009)*, Anchorage, Canada, Sep. 2009.