# Resource Management in Dense Heterogeneous Networks

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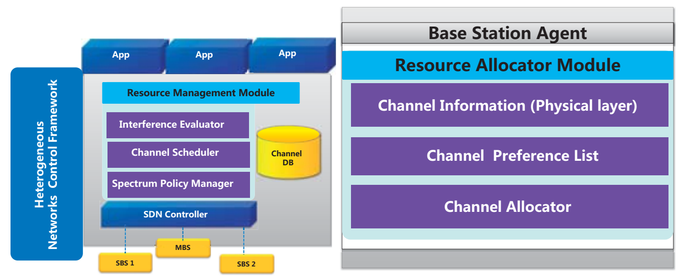
***Abstract*—The installation of low power small cells under macro cells using the same spectrum is a promising approach to enhance the spectral efficiency and data-rate for the end users. These installations are becoming very dense in order to support the users' requirements (especially 5G networks) which make resource allocation using the same spectrum a very challenging problem. In this study, we address the downlink resource allocation problem for underlay small cell tier. We formulate the optimization problem for resource (channel) allocation in small cells while keeping the total interference to macro tier under an acceptable level. The objective of resource allocation is to maximize the throughput of small cells under the cross tier interference constraint. We employ matching theory to find a stable match for the resource allocation problem. We simulate our proposition to validate the stability of the network and the convergence of the resource allocation algorithm in terms of rate in a dense heterogeneous network. The matching results in an optimal solution which outperforms the existing sub-optimal resource allocation solutions.**

***Keywords*—*Femtocell network, Resource allocation, Game theory, Optimization Theory.***




(a) SDN Controller (b) Base Station Agent

Fig. 1: SDN Controller and Base station agent

## I. Introduction

The demand of the mobile applications and number of devices is increasing drastically since recent years forcing mobile operators to enhance their capacity and grade of service. One of the emerging technique to enhance the capacity (sharing traffic load from macro cells) and coverage is to use low power small cell network (SCNs) under the coverage of macro cells, this paradigm is called heterogeneous networks (HetNets). It is envisioned to have a very dense network of small cells in order to fulfill the future network requirements [1]. However, these installation of SC lead to a new set of challenges for the network operators.

Interference management (IM) and resource allocation becomes critical challenge especially in underlay SCN as they use the same band of frequencies as the macro tier. There are two types of interference with underlay SCN which can degrade the system performance drastically: the first type is interference with the macro tier, called the cross-tier interference, and the second type is co-tier interference which comes from the other installed SCNs. In order to utilize the scarce resources (channels) efficiently, intelligent and efficient resource allocation is required which minimizes the interference. A number of static and dynamic interference management approaches have been studied [2] in order to handle interference and perform efficient resource allocation. In static interference management the frequency reuse pattern is determined a priori by the network operators (i.e., fractional frequency reuse, and etc) and with user controlled SCs can not perform efficiently, on the other hand dynamic interference management schemes have shown significant performance improvements but suffer from high complexity and message passing for coordination among neighboring cells [2]. A low message passing scheme for dynamic interference management and user scheduling has been proposed which achieves a near optimal solution [2]. Therefore, it is evident that efficient cooperation and coordination schemes among multiple tiers are required for dynamic interference management and efficient resource allocation especially with dense SCNs and stringent future cellular requirements.

Coordination will play a vital role in operations of IM especially with the dense SC deployment such as in [3], [4], [5]. The biggest challenge in coordination is the message passing which consumes a significant amount of bandwidth in back-haul if a completely centralized solution is used. In this paper, we focus on downlink resource allocation problem in two-tier HetNet. We use a programmable SDN controller for coordination between tiers by developing the resource management module. Our objective is to maximize the throughput of the SCNs while protecting the macro tier from interference (cross-tier interference avoidance) as both macro and SCNs use the same frequency bands. Our contribution to resource allocation in dense heterogeneous networks can be summarized as follows:

First, we present the SDN controller architecture and its function which helps in resource allocation (Section II). Second, we design and discuss the resource allocation problem for the underlay SCs in the network (Section III). Third, we present our solution using the matching theory followed by the resource allocation algorithm (Section IV). Finally, we validate our proposal through simulation (Section V) and present the conclusion.

## II. SDN Controller Architecture

This section describes the SDN controller architecture and the resource management module along with its functions. Furthermore, we discuss about the base stations(BSs) agents and the resource allocator module along with its functions which perform the coordination task, this communication helps the controller to have a global view of the network.

The main motivation of using an SDN controller is the programmability and flexibility features which can support a number of applications (modules) as an independent software

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functions, these functions work together and perform the required task. The SDN controller has an resource management module and a channel database as shown in Fig 1(a). The main function of resource management module is to allocate channels to the underlay SCNs such that its utility is maximized without interfering with the macro tier devices. Three main functions (functions are software instances and can be specified by the vendors) along with a limited data base are presented in this work which help efficient resource allocation. The channel database is used for keeping records of the channels being used both for macro and the underlay tiers with their respective power levels. This information is later used by the resource management module for macro tier protection. A preference list is maintained by the controller for each SBS according to its utility, it uses the interference evaluator and channel scheduler functions to allocate the best channel to each SBS (Section IV details the process). The spectrum policy manager function is used to define network policy by the operators (e.g., some channels used by VIP grade of customers cannot be shared by the underlay SBSs). There are other benefits and functions (i.e., power management, location awareness, and etc) of a controller but are out of the scope of this work which can be found in [5], [4].

All BSs (MBS and SBSs) have a BS agent installed in it to communicate with the controller. Fig. 1(b) shows the BS agent and the resource allocator module which consists of three function. The first function is the channel information which keeps track of the currently used channel in an SBS, the second function is the channel preference list which contains a list of preferred channels to use, this information is used in proposing (matching theory) to the controller for a channel to use (details of this function are explained in Section IV). Finally, the channel allocator gives the list of channels allocated to the BSs.

## III. System Model and Problem Definition

### A. Network Model

We consider a heterogeneous cellular network consisting of an MBS and a set of small cell base stations (SBS), denoted by $J = \{1, 2, ..., J\}$ located under the coverage of MBS and operating in an underlay fashion as shown in Figure 2. The set of macro and small cell users (SC-user) are denoted by $U^M = \{1, 2, ..., M\}$ and $U^J = \{U^1, U^2, ..., U^J\}$ respectively. The macro tier and the underlay tier use the same set of orthogonal channels ($R = \{1, 2, ..., R\}$). As the SC also uses the same channels as the macro for each channel $r \in R$, a predefined interference threshold $I^r_{\max}$ is defined for macro tier protection over each channel $r$. An SDN controller for global view of channels has been installed at the MBS which have $I^r_{\max}$ values for each channel $r$.

In this network model, it is assumed that all the users have already been associated to their designated BSs (i.e macro or SC) prior to resource allocation using maximum signal to interference noise ratio (SINR) scheme. We assume that the same channel can be reused by multiple SC-users $k \in U^j$ in SC $j$ to enhance the spectrum utilization and data rate. This reuse of channel, however, causes severe cross tier interference to macro users (dotted line in Fig. 2) as well as co-tier interference to other underlay users.

### B. Resource Allocation and Link Model

We focus on the downlink transmission in our system where we have limited number of channels (here we refer resource blocks as channels). We assume that MBS and all SBS use a slowly changing transmit power (fixed power) over the resource allocation for carrying out their respective transmissions and thus the interference power is also constant. The practical transmission power for an MBS is around 43dBm which is about 20-30 dBm higher when compared to the SBS [2]. The SBSs at each time slot

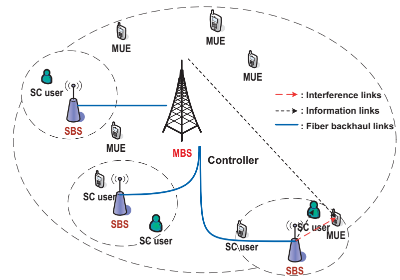



Fig. 2: Network Model. Solid line showing the downlink information links while dotted line showing the cross tier interference caused both by the MBS and SBS transmission.

need to determine which channel is feasible for a specific user in order to maximize the utility of the system while protecting macro users. For this purpose, we use a binary resource allocation indicator defined as follows:

$$x^r_{j,k} = \begin{cases} 1, & \text{if the user k is scheduled by SBS } j, \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

The instantaneous received SINR on a link due to a SC user $k$ at an associated SBS $j$ using channel $r$ with transmit power $P_j$ is given by

$$\gamma^r_{j,k} = \frac{P^r_j g^r_{j,k}}{P^r_M g^r_{M,k} + \sum\limits_{j' \in J\setminus\{j\}} P^r_{j'} g^r_{j',k} + \sigma^2}, \tag{2}$$

where $g^r_{j,k}$ is the gain between SBS $j$ and SC user $k$ whereas $g^r_{M,k}$ and $g^r_{j',k}$ is the interference gain between MBS and other underlay SBS on user at the channel $r$, respectively. The channel gains are time-varying and takes into account the path loss, log-normal shadowing, fast fading, etc. $\sigma^2$ is the noise power on channel $r$. Now using the Shannon's formula the data rate of any user $U$ (i.e. $k \in U^M \cup U^J$) on the channel $r$ can be calculated by $R^r_k = W^r \log(1 + \gamma^r_k)$, where $W^r$ is the channel bandwidth.

### C. Problem Statement

The objective is to maximize the throughput for the SCN using the same channels as being used by the macro tier. It should be noted that a SBS can only use a channel if the interference level is less than the predefined threshold. The data rate of an SBS $j$ can be given by $R_j = \sum\limits_{r \in R} \sum\limits_{k \in U^j} x^r_{j,k} W^r_k \log(1 + \gamma^r_{j,k})$. and the interference on each channel can be given by $I^r = \sum\limits_{j \in J} x^r_{j,k} P^r_j g^r_{j,m}$, where $g^r_{j,m}$ is the channel gain from SBS $j \in J$ to macro user $m \in U^m$ which has been assigned channel $r$. The resource allocation problem for a network can be mathematically presented using the following optimization problem:

($P1$)

$$\max_{x^r_{j,k}} \sum_{r \in R} \sum_{j \in J} \sum_{k \in U^j} x^r_{j,k} W^r_k \log(1 + \gamma^r_k) \tag{3}$$

subject to

$$\sum_{k \in U^j} x^r_{j,k} = 1, \ \forall r \in R, \forall j \in J, \tag{4}$$

$$I^r \le I^r_{\max}, \ \forall r \in R, \tag{5}$$

$$x^r_{j,k} \in \{0, 1\}, \ \forall k \in U^j, \ \forall j \in J, \forall r \in R. \tag{6}$$

The first constraint (4) ensures that each channel must be allocated to at most one user in each SC. This is to avoid strong inter-cell interference. The second constraint (5) ensures the interference to the macro tier below a predefined threshold ensuring macro tier protection. This allows that a channel $r$ can be used by any number of SCs to increase the resource allocation efficiency if the interference constraint can be maintained (5). The binary resource allocation indicator variable is represented by the last constraint (6). The above problem $P1$ is a non-convex and mix integer problem and finding the solution becomes NP-hard for a large set of users and channels. We, therefore, use the concept of matching game to solve this problem in a distributed and practically implementable manner.

## IV. Matching for resource allocation

Matching theory is a promising technique that can be applied for resource allocation problem and can overcome the limitations of optimization especially for combinatorial problems [6]. The benefits of matching theory comes from the distributive nature of control in the system. The technique of matching theory divides the matching players into distinct sets. The matching problem is defined as to find a match between the users and resources, given their individual preferences derived from different objectives. The preference of one set over the other set is derived from the local information available to each player and each player keeping in view of its objective ranks the other set members. The basic solution of a matching problem is called as a "stable matching" if there are no blocking pairs [6].

### A. Resource Allocation as a Matching Problem

In the proposed resource allocation problem, the resources controlled by the controller are the limited channels and the users are the SBSs. In our proposal the decision making agents are the SDN controller (resources) and SBSs(users). Both the decision making entities make a preference profile against each other using their local information. A matching is given as an assignment of channels to underlay SBSs. According to our system model, a channel can be utilized by multiple SBS while each SBS is given a single channel, this scheme corresponds to many-to-one matching [7].

**Definition 1:** A matching $\mu$ is defined as a function, i.e., $\mu : R \times J \rightarrow R \times J$ such that:

$$a\colon\ \mu(j) \in R \ \ and \ \ |\mu(r)| \in \{0, 1\} \ \ and$$

$$b\colon\ \mu(r) \in \{J\} \cup \{\phi\} \ \ and \ \ |\mu(r)| \in \{1, 2, ......J\},$$

where $\mu(j) = \{r\} \Leftrightarrow \mu(r) = \{j\}$ for $\forall r \in R, \forall j \in J$ and $|\mu(.)|$ denotes the cardinality of matching outcome $\mu(.)$. This implies that $\mu$ becomes a one-to-one matching or one-to-many matching if the input to the function is SBS or channel respectively. There are also cases when a SBS is not allowed to use a channel which is represented by the following matching i.e., $\mu(r) = \phi$.

### B. Preference Profile and Utility Function

This data rate is the utility of the SBSs over a specific channels given by (7). The utility is used to rank the channels $r \in R$ for an SBS $j$ and build the preference profile.

$$U_j^r = W_k^r \log(1 + \gamma_{j,k}^r). \tag{7}$$

Similarly, each channel ranks all SBSs according to its utility. This preference list for each channel is formed by the SDN controller, as it has a global view of the network which means it has the information of each MUE and SCN user scheduled, their power levels for each channel in the database and the predefined maximum interference threshold $I_{\max}^r$ at each channel. In order to calculate its utility, it only needs to calculate the interference induced $I^r$ by all the SBS $j$ if a channel $r$ is scheduled for use. Once these information are acquired, $I^r$ is calculated, and the controller updates its utility to rank the SBSs for each channel in its preference profile. The utility function is given by (8).

$$U_r^j = (W \log(1 + \gamma_k^r)) - \alpha(I^r - I_{\max}^r), \tag{8}$$

where the first term represents the achievable data rate at channel $r$, the second term accounts for a penalty caused due to aggregated interference to the macro tier on that channel and $\alpha$ represents the weight. It is to be noted that aggregated interference on a channel in a current timeslot is available at the MBS (macro user sends this information to MBS) and will be forwarded to the controller.

The preference profile of the underlay SBS transmitters $(j \in J)$ over the set of all available channels $R$ and similarly the preference profile for the channels over SBS are defined. We denote that $\{r_1\} \succ_j \{r_2\}$ which means SBS $j$ prefers channel $r_1$ over $r_2$ and consequently data rate achieved by using the more preferred channel is higher. Similarly, for the channels we have the preference according to its utility. The preference profile for the SBS transmitters and channels calculated by their own utility are given by (9) and (10), respectively.

$$P_j(R) = [U_j^r]_{r \in R}, \tag{9}$$

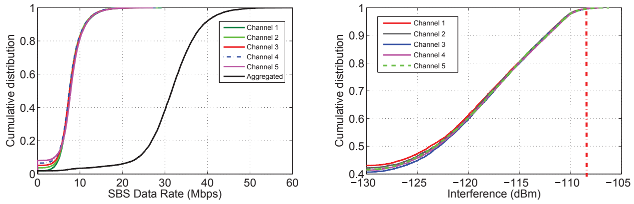
$$P_r(J) = [U_r^j]_{j \in J}. \tag{10}$$

### C. Resource Allocation Algorithm

The output of the algorithm is the allocation vector which maximizes the objective of the optimization problem $P2$. The presented algorithm is guaranteed to converge as it is a variant of "deffered-acceptance algorithm" [8].

**Algorithm 1:** Resource Allocation Algorithm

***Step 1: Initialization***
Channel State Information (CSI) parameter estimation from previous slot.
Each SBS $j \in J$ builds the preference profile $P_j(R)$ using Equation (7).
For every channel $r \in R$, the controller builds the preference profile $P_r(J)$ using Equation (8). ***Step 2: Matching***
Initialize iteration t = 1.
**while** $X(t) \neq X(t-1)$ *and* $t$ *is less than* $T_{max}$ **do**
  **while** *any SBS transmitter* $j$ *is unassigned and* $P_j(R)$ *is not empty* **do**
    SBS $j$ proposes for the most preferred channel $r$ i.e., set $x_j^r = 1$.
    Estimate interference on channel $r$ by adding new SBS $j$.
    **if** $I^r \geq I_{max}^r$, **then**
      repeat
      Remove least preferred SBS $j$ from channel $r$, i.e., set $x_j^r = 0$.
      Update interference level by removing least preferred SBS $j$.
      Update preference profile by removing all successors of SBS $j$ on profile $P_r(J)$.
      Update preference profile by removing channel $r$ on profile $P_j(R)$.
      until $I^r \leq I_{max}^r$.
  Outputs all the resource indicators $X = [x_1^1, ..., x_2^1, ..., x_J^R]$.
  Each SBS transmitter and channel update the profile according to the allocation vector at $X(t)$.
  Update t:=t+1.
  ***Step 3: Allocation***
  Allocation of channel to the SBS based on the matching obtained.




(a) SBS Data Rate (b) Interference at each channel.

Fig. 3: Performance of SBS data rate and interference.

The algorithm is a three step process. The first step is the initialization step where local information is attained by both the agents and is used to build their respective preference profiles. The second step is the matching where a match is found between both the agents and after finite iterations a stable match is found, However, each iteration here finds a local stable match between the players. The final step is the resource allocation in which each SBS is given the channel according to the matching found by the previous step. We next provide its pseudo-code in Algorithm 1. ***Remarks:*** It is to be noted that the matching process is carried out iteratively until a stable match is found between both the agents. The process will terminate when all the SBS are assigned to channels. This process is an iterative process which updates the preference profile dynamically. The algorithm will converge when the matching and data rate of two consecutive iteration remains unchanged (i.e., $X(t) = X(t-1) \;\; and \;\; R(t) = R(t-1)$). The data rate here denotes the achievable sum rate of underlay tier at an iteration $t$.

## V. Simulation Results

We provide simulation results to demonstrates the performance of the resource allocation algorithm. The network topology for our simulations contains SBSs, SUEs and MUEs which are randomly located inside circles of radius of $r_1 = 1000$ m and the radius of each SC is $r_2 = 100$ m. First, we consider a network with $M = 5$ SCs, with $r = 5$ channels, and five MUEs using these channels. The $I^r_{\max}$ is set to $-108dBm$ for macro tier protection in the simulation. The channel gain is given by $g_{m,n} = 10^{(-PL(d_{m,n}))/10}$ (no fading), where function $PL(d_{m,n})$ represents path loss (in decibels) and $d_{m,n}$ (in meters) is the distance between SBS $m$ and MUE of MBS $n$. For modeling the propagation environment we use $PL(d_{m,n}) = 16.62 + 37.6 \log_{10}(d_{m,n})$ for interference path loss and $PL(d_{m,n}) = 37 + 32 \log_{10}(d_{m,n})$ for indoor path loss. It is to be noted that all results stated are averaged over a large number of independent runs of random locations of SCs, SUEs, MUEs and channel gains. Fig 3a presents the cumulative distribution with respect to average SBS data rates on all the channels as well as the average aggregated SBSs data rate for the network. The SBSs on the low percentile (less than 0.2) are either having MUE very close to each other or overlapping SCs which limit their channel allocation due to the interference constraint (macro protection). However, the average aggregated SBS data rate at 50 percentile is higher than 30 Mbps. Moreover, Figure 3b presents the interference on each channel, it can be inferred that more than 98 percent of times the interference on each channel is less than the predetermined maximum threshold for macro tier protection. This ensures that SBS is not assigned a channel if it is interfering with the macro tier above the maximum predefined threshold. The red vertical dotted line in the graph represents the $I^r_{\max}$ for the macro tiers. This is one of the most fundamental requirement for an underlay networks.

In, Figure 4, the convergence is shown in terms of rate with respect to three different interference threshold i.e., $I^r_{\max} = -120, -100, -90dBm$. The convergence is basically achieved when both the set of players (i.e., channels & SBSs) achieve a stable match. It can also be inferred from the graph for all the cases, that the proposed resource allocation algorithm after limited number of iterations converge to the optimal allocation. This optimal allocation showed by dotted line is found by exhaustively searching the complete solution space.

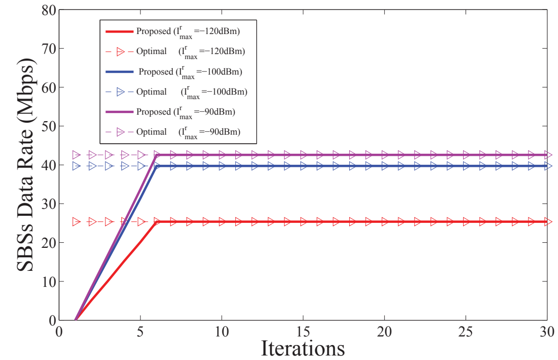



Fig. 4: Convergence of proposed resource allocation algorithm in Rate.

## VI. Conclusion

In this paper, we have proposed a novel approach for resource allocation in underlay SCs while protecting the macro tier. We formulated the resource allocation problem as a many-to-one matching game where a programmable SDN controller builds a preference profile on behalf of all channels and each SBSs build their own preference profile for each channel using local conventional rate maximization parameter which helps each set of players to evaluate each other based on their defined utilities. In order to solve the problem we have also proposed a resource allocation algorithm which guarantees macro tier protection and stable match for the underlay SCs. Simulation results presented for the proposal showed the interference protection for macro tier, convergence of algorithm in terms of rate and stable matching for underlay SC network. In future, we intend to evaluate this problem for dynamic user association in the network.

## References

[1] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, R. Sukhavasi, C. Patel, and S. Geirhofer, "Network densification: the dominant theme for wireless evolution into 5g," *Communications Magazine, IEEE*, vol. 52, no. 2, pp. 82–89, February 2014.

[2] K. Son, S. Lee, Y. Yi, and S. Chong, "Refim: A practical interference management in heterogeneous wireless access networks," *Selected Areas in Communications, IEEE Journal on*, vol. 29, no. 6, pp. 1260–1272, 2011.

[3] M. R. Sama, L. M. Contreras, J. Kaippallimalil, I. Akiyoshi, H. Qian, and H. Ni, "Software-defined control of the virtualized mobile packet core," *Communications Magazine, IEEE*, vol. 53, no. 2, pp. 107–115, 2015.

[4] P. K. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, "Design considerations for a 5g network architecture," *Communications Magazine, IEEE*, vol. 52, no. 11, pp. 65–75, 2014.

[5] U. Kozat, M. Sunay *et al.*, "A new control plane for 5g network architecture with a case study on unified handoff, mobility, and routing management," *Communications Magazine, IEEE*, vol. 52, no. 11, pp. 76–85, 2014.

[6] Y. Gu, W. Saad, M. Bennis, M. Debbah, and Z. Han, "Matching theory for future wireless networks: Fundamentals and applications," *arXiv preprint arXiv:1410.6513*, 2014.

[7] J. Sethuraman, C.-P. Teo, and L. Qian, "Many-to-one stable matching: Geometry and fairness," *Mathematics of Operations Research*, vol. 31, no. 3, pp. 581–596, 2006.

[8] A. E. Roth, "Deferred acceptance algorithms: History, theory, practice, and open questions," *International Journal of Game Theory*, vol. 36, no. 3-4, pp. 537–569, 2008.