CHANNEL REASSIGNMENT, AUGMENTATION AND POWER CONTROL ALGORITHM FOR WIRELESS COMMUNICATIONS NETWORKS CONSIDERING GENERIC SECTORIZATION AND CHANNEL INTERFERENCE

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Abstract - In this paper, we study the problem of channel reassignment, augmentation and cell transmission power control in wireless communications networks under the consideration of irregular cell allocation/sectorization and generic channel interference, including both co-channel and near-channel interference. Channel reassignment may be required in a wireless communications network when channel interference and/or the distribution of traffic demand changes. Like channel reassignment, cell transmission power control is another effective and economical measure to alleviate performance problems. However, when the traffic demand exceeds a critical point and the current network capacity becomes insufficient, even when the above two cost-effective measures are applied, channel augmentation is required. We formulate this problem as a combinatorial optimization problem, where the objective function is to minimize the channel augmentation cost subject to configuration, capacity, QoS constraints and call dropping constraints. The basic approach to the algorithm development is Lagrangean relaxation. In computational experiments, the proposed algorithm is shown to be efficient and effective.

I. INTRODUCTION

Due to the rapid growth of wireless communication systems in the world, the scarcity of spectrum necessitates efficient resource management mechanisms. In order to efficiently utilize the scarce spectrum resource, channel assignment is becoming one of the most important issues for wireless communication researchers and practicians [7, 8]. Whether the channel sharing is based upon given cell configuration environment, there exists a fundamental limit on the number of users sharing the same frequency simultaneously [10, 11]. Since higher resource utilization can achieve higher service revenue gains, how to reorganize original cell configuration by optimize channel utilization and transmission power control to achieve more higher system resource utilization than apply pure channel assignment approach is the objective of this paper.

Although various resource management approaches have been proposed to increase the channel efficiency, the majority of current results still focus on hexagonal or regular sectorization network structures due to simplicity of implementation and ease of operation. However, real wireless communications networks may be far from such regular configurations. In this paper, due to mobility and unbalanced traffic demands distribution, we propose a more generic sectorization approach to model any kind of real wireless networks and operate the resource management of real wireless communication systems more precisely.

Interference model used in this paper is different from the traditional "co-channel reuse distance" approach applied by several literatures to simplify interference model [3, 10]. We estimate the frequency interference precisely by accumulating all interference from all of the other cells to the interested cell. By doing that, we can assure received interference must not violate the carrier-to-interference ratio (CIR) constraint from the signal receiver's point of view. This is referred to as generic quality of service (QoS) assurance interference model [9].

Another interference issue, which is concerned by practicians in real wireless networks, is near-channel interference. Although hardware device may eliminate some effect of near-channel interference, the avoidance of near-frequency reused rate under a small-scale region is still adopted by network operation practicians. Mobile terminals homing on the interested cell will receive the near-channel interference from the same cell and all of the others. In this paper, we together accumulate the co-channel and near-channel interferences in our QoS assurance approach to calculate the total interferences on mobile terminals when resource management policy is applied.

In general, channel reassignment, augmentation, and power control problem on generic sectorization structure is NP-complete [5] and is more complex than traditional channel assignment problem. We formulate the problem as an integer programming problem where the objective function is the minimization of the augmentative channel license fee of whole wireless communication system the objective function is to minimize the channel augmentation cost subject to configuration, capacity, QoS constraints and call dropping constraints, referred to as generic wireless network servicing and sizing problem. The configuration and capacity constraints require that the transmission radius and the assigned capacity for each cell be admissible. Whereas, the QoS constraints require that the call blocking probability constraint for each cell and co-/near-channel interference constraints for each channel assigned to the cell be satisfied. The call dropping constraints ensure that the loss revenue due to channel reassignment or mobile re-homing is less than the modification cost threshold. As such, to take into account computation time constraints, instead of attempting to solve the problem optimally we would propose an efficient and effective heuristic algorithm to solve this problem.

The remainder of this paper is organized as follows. Section II provides the generic sectorization and interference models. Section III develops the problem formulation. The solution approach is described in Section IV. Finally, Section V is our computational results based on the proposed algorithm.

II. THE GENERIC MODELS

In this section, we proposed several generic models about the key issues of generic wireless network servicing and sizing problem. The propagation model adopted in this paper is assumed a distance-dependency function that is traditionally applied on a no-shadowing flat macro-cellular environment. The existing and augmentation frequencies are labeled in continuous number. So we can use channel number to simplify the notation of a channel by i that has the interfering near-channel numbers i-1 and i+1.

A. Generic Sectorization Model

Traditionally, wireless communication systems are considered an omni-direction antenna cell structure and

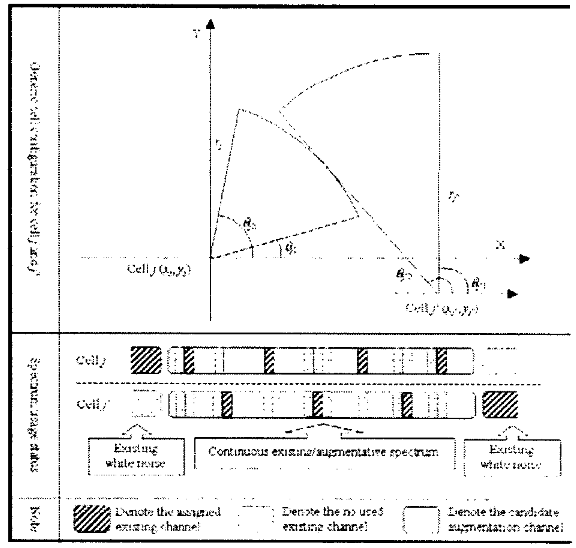

Fig. 1. Generic cell configuration and spectrum usage status

modeled by hexagonal network structures, which is suitable for the assumption of mobile terminal normal distributed over the cell coverage area. Sectorization has been introduced to handle the unbalanced and numerous traffic demands in real system. The advantage of sectorization is that sectorization can reduce the co-channel interference to improve spectrum efficiency [1].

In this paper, generic sectorization model allows the locations of base stations are not regular, the radiuses of cells are not identical and the radian types of sectorization cells are not limited. Therefore, the proposed generic approach can model any kind of real wireless networks, such as omni-direction antenna, regular sectorization and irregular smart antenna structure. We depict the generic cell configuration and spectrum usage status in Fig. 1 [9].

B. Generic QoS Assurance Interference Model

To satisfy the required QoS level of wireless communication for each mobile terminal in the network, interferences must be considered on the mobile terminal's point of view. Most of researches calculate the co-channel interference by simply reference the location of base station to estimate average interference received by mobile terminals. These approaches are suitable under omni-direction cell but no reasonable on a sectorization system. Whereas, the grid-based interference approaches [2] are advantage on its higher precision at each grid region interference measurement. Its disadvantage is that its time complexity depends on the granularity of grid size against network service area.

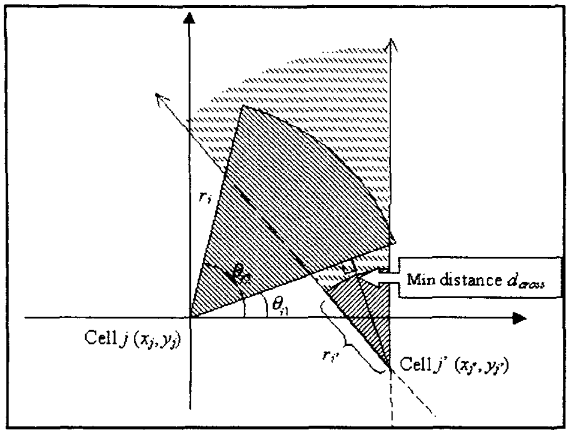

Fig. 2: A case for the radian of interested cell is less than π

In this paper, to take into account computation time constraints and QoS assurance purpose, we propose a generic QoS assurance interference model, which would rather to over-estimate the maximum interference received by mobile terminals than under-estimate it in order to ensure QoS constraint. Under a flat none-shadowing macro propagation environment, signal attenuation factor is only dependent on propagation distance from transmitter to receiver. Due to the characteristic of this network servicing and sizing problem, transmission power of each cell is one decision variable to be determining after optimizing the system. We simplify pre-calculate the minimum interference distance by using the maximum candidate radius of interested cell. By this way, we can assure that any mobile terminal homing to interested cell must not violate QoS constraint because we have over-estimated interference effect before we apply channel assignment policy. We formulate a nonlinear programming problem to estimate interference for interested cell case in the following and depict in Fig. 2.

Objective function for cell radian smaller than π:

$$Z_{NP1} = \min\sqrt{(x-x_j)^2+(y-y_j)^2} \qquad (NP1)$$

subject to:

$$(x-x_j)^2+(y-y_j)^2 \le r_j^2 \qquad \forall j \in C \quad (1)$$

$$x\sin\theta_{j1} - y\cos\theta_{j1} \le x_j \sin\theta_{j1} - y_j\cos\theta_{j1} \qquad \forall j \in C \quad (2)$$

$$x\sin\theta_{j2} - y\cos\theta_{j2} \ge x_j \sin\theta_{j2} - y_j\cos\theta_{j2} \qquad \forall j \in C \quad (3)$$

$$x\sin\theta_{j'1} - y\cos\theta_{j'1} \le x_{j'} \sin\theta_{j'1} - y_{j'}\cos\theta_{j'1} \qquad \forall j' \in C \;\; j' \ne j \quad (4)$$

$$x\sin\theta_{j'2} - y\cos\theta_{j'2} \ge x_{j'} \sin\theta_{j'2} - y_{j'}\cos\theta_{j'2} \qquad \forall j' \in C \;\; j' \ne j. \quad (5)$$

If the radian of one cell is larger than π, the obtuse angle sector must be separated into two acute angle sectors and apply $NP1$ algorithm on each other and then the shorter result distance is the shortest interference distance of this case.

III. GENERIC CHANNEL AUGMENTATION PROBLEM

Channel reassignment, augmentation and power control problem is one kind of wireless network servicing and sizing problems. It considers not only the channel rearrangement but also the network expansion problems. In such a problem, give the configuration of existing wireless network and a set of augmentation channels. The decision will be how to reassign existing channels to deal with the changes of channel interference and/or the distribution of traffic demand. Cell transmission power control is another effective and economical measure to alleviate performance problems for each cell. As the traffic demand growth and exceeds a critical performance point, the current network capacity becomes insufficient even when the above two cost-effective measures are applied. A channel augmentation decision is required to expand system capacity as network sizing purpose.

Table 1: Notations descriptions for given parameters

Given Parameters	
Notation	Descriptions
F	the set of available existing channels
A	the set of augment channels
C	the set of cells
T	the set of mobile terminals
M_j	the loss revenue limitation for Cell j to rearrange channel allocation and power level
N_j	upper bound on number of channels that can be assigned to Cell j
R_j	upper bound of transmission radius of Cell j
α_j	attenuation factor (2< α <6) for Cell j
β_j	threshold of acceptable call blocking probability of Cell j
γ_j	threshold of acceptable CIR (in dB) of Cell j
δ	the NFD (net filter discriminator) is the filter reduction constant for adjacent frequencies
$\theta(g_j, \beta_j)$	minimum number of channels required for traffic demand g_j such that the call blocking probability shall not exceed β_j
$D_{jj'}(r_j)$	minimum distance between interested Cell j and interfering Cell j' under the condition of the transmission radius of Cell j
G_j	an arbitrarily large number
k_t	traffic load of mobile terminal t
f_{ji}	indicator function which is 1 if existing Channel i is used by Cell j and 0 otherwise

d_{jt}	the distance between Cell j and mobile terminal t
h_{jt}	the homing relationship between mobile terminal t and Cell j
p_{jt}	indicator function which is 1 if mobile terminal t locates in the candidate service area of Cell j and 0 otherwise
Δ_i^F	loss of revenue for the decision of reassignment existing channel i
Δ_t^H	loss of revenue for the decision of re-homing mobile terminal t
Δ_i^A	license fee function of augmentation Channel i

Table 2: Notations descriptions for decision variables

Decision Variables	
Notation	Descriptions
y_{ji}	decision variable which is 1 if Channel i is assigned to Cell j and 0 otherwise
z_{jt}	decision variable which is 1 if mobile terminal t is homed to Cell j and 0 otherwise
a_i	decision variable which is 1 if augmentative channel i ($i \in A$) is installed and 0 otherwise
g_j	the aggregate flow on Cell j
r_j	decision variable which is the transmission radius of Cell j

The given parameters and decision variables for this algorithm to formulate generic network servicing and sizing problem are defined in Table 1 and 2 separately. This problem can be formulated as the following integer programming problem.

Objective function:

$$Z_{IP} = \min \sum_{i \in A} \Delta_i^A a_i \qquad (IP)$$

subject to:

$$\sum_{i \in F} \Delta_i^F \left(y_{ji}(1-2f_{ji}) + f_{ji} \right) + \sum_{t \in T} \Delta_t^H \left(z_{jt}(1-2h_{jt}) + h_{jt} \right) \le M_j \qquad \forall j \in C \quad (6)$$

$$\sum_{j' \in C} \delta\left(y_{j',(i-1)} + y_{j',(i+1)} \right) \left(\frac{r_{j'}}{D_{jj'}(r_j)} \right)^{\alpha_{j'}} + \sum_{\substack{j' \in C \\ j' \ne j}} y_{j'i} \left(\frac{r_{j'}}{D_{jj'}(r_j)} \right)^{\alpha_{j'}} \le G_j + \left(\frac{1}{\gamma_j} - G_j\right) y_{ji} \qquad \forall j \in C, i \in F \cup A \quad (7)$$

$$\theta(g_j, \beta_j) \le \sum_{i \in F \cup A} y_{ji} \qquad \forall j \in C \quad (8)$$

$$\sum_{t \in T} k_t z_{jt} \le g_j \qquad \forall j \in C \quad (9)$$

$$d_{jt} z_{jt} \le r_j p_{jt} \qquad \forall j \in C, t \in T \quad (10)$$

$$z_{jt} \le p_{jt} \sum_{i \in F \cup A} y_{ji} \qquad \forall j \in C, t \in T \quad (11)$$

$$y_{ji} \le a_i \qquad \forall j \in C, i \in A \quad (12)$$

$$\sum_{i \in F \cup A} y_{ji} \le N_j \qquad \forall j \in C \quad (13)$$

$$\sum_{j \in C} z_{jt} = 1 \qquad \forall t \in T \quad (14)$$

$$0 \le r_j \le R_j \qquad \forall j \in C \quad (15)$$

$$a_i = 0 \text{ or } 1 \qquad \forall i \in A \quad (16)$$

$$y_{ji} = 0 \text{ or } 1 \qquad \forall j \in C, i \in F \cup A \quad (17)$$

$$z_{jt} = 0 \text{ or } 1 \qquad \forall j \in C, t \in T. \quad (18)$$

The objective function is to minimize the license fee of augmentation channels. Constraint (6) is reformulated from the purpose of to ensure that the loss revenue of call dropping due to channel reassignment $\sum_{i \in F} \Delta_i^F |y_{ji} - f_{ji}|$ and rehoming $\sum_{t \in T} \Delta_t^H |z_{jt} - h_{jt}|$ is lower then the modification cost constraint. Constraint (7) is to ensure that the sum of interferences introduced by other co-channel cells and near-channel cells is less than the CIR threshold for each channel. Constraints (8, 9) are to ensure the number of channels assigned to each cell is larger enough than the required minimum trunks to service aggregate traffic. Constraint (10) is to ensure that one cell can only serve those mobile terminals that are in its coverage area of effective candidate radius of cell. Constraint (11) is to ensure that if a cell is not assigned any channel, it cannot provide any service. Constraint (12) is to count the number of augmentation channels used in this system. Constraint (13) is to ensure that the number of channels assigned to each cell is satisfied its configuration limitation. Constraint (14) is to enforce that one mobile terminal can only home to one cell. Constraint (15) is to ensure the transmission radius of each cell ranges is between 0 and the maximum transmission radius limitation. Constraints (16, 17 and 18) are to enforce the integer property of the indicator variables.

IV. SOLUTION PROCEDURE

The above integer programming formulation problem is NP-complete, and therefore we use Lagrangean relaxation and subgradient method as our solution approaches to solve the problems. In applying the Lagrangean relaxation approach [4], a number of complicating constraints of integer programming problem (*IP*) are relaxed (i.e. Constraints 6-12) [9] and the problem can be decomposed into four independent sub-problems. According to the weak Lagrangean duality theorem, for any $\mu_{ji} \ge 0$, $Z_D(\mu_{ji})$ is a lower bound on Z_{IP}. Then, We use subgradient method to calculate the tightest lower bound [6]. Not only get a theoretical lower bound of primal feasible solution, but also get some hints of the process. We propose an efficient heuristic algorithm for getting primal feasible solutions purpose, denoted by Algorithm *A*.

Algorithm A:

Step 1. For each mobile t, according to homing coefficients $\left(\mu_j^1 \Delta_t^H (1-2h_{jt}) + \mu_j^4 k_t + \mu_{jt}^5 d_{jt} + \mu_{jt}^6\right) z_{jt}$, make homing decision in increasing order.

Step 2. For each cell j, aggregate the total traffic load to calculate the minimum required channels and derive the radius of this cell.

Step 3. Ensure to satisfy the capacity constraint. Otherwise, go to Step 1 to re-home t to next candidate homing cell and reduce cell radius.

Step 4. Applying load balance approach as cell order to re-assign existing channels in the order of coefficients $\left(\mu_j^1 \Delta_i^F (1-2f_{ji}) - \mu_j^3 + \mu_{ji}^2 (G_j - 1/\gamma_j)\right.$

$$\left. - \sum_{t \in T} \mu_{jt}^6 p_{jt} + \sum_{j' \in C} \left(\mu_{j',(i-1)}^2 \delta + \mu_{j'i}^2 + \mu_{j',(i+1)}^2 \delta\right) \left(\frac{r_j}{D_{j'j}(r_{j'})}\right)^{\alpha_j} \right) y_{ji}$$

Step 5. Check the QoS constraint of each cell for the existing channels to assure no violate QoS constraint of assigned channels.

Step 6. If re-assignment and power control cannot satisfy the network, add augmentation channels in the increasing order of $\left(\mu_{ji}^7 - \mu_j^3 - \sum_{t \in T} \mu_{jt}^6 p_{jt}\right.$

$$\left. \sum_{j' \in C} \left(\mu_{j',(i-1)}^2 \delta + \mu_{j'i}^2 + \mu_{j',(i+1)}^2 \delta\right) \left(\frac{r_j}{D_{j'j}(r_{j'})}\right)^{\alpha_j} + \mu_{ji}^2 (G_j - \frac{1}{\gamma_j}) \right) y_{ji}$$

Step 7. Check the QoS constraint of each cell for the augmentation channels to assure no violate QoS constraint of assigned channels.

Step 8. Accumulate the license fee of total augmentation channels in this system.

V. COMPUTATIONAL EXPERIMENTS

In the experiments, the Algorithm A is performed on a sectorization scenario of network components, which is depicted in Fig. 3, and the given parameters is listed in Table 3. This network has five cells and twelve random generation clusters of mobile terminals. Four cells have $\pi/2$ radians of sectorization smart-antennas and one cell construct by omni-direction antenna. For experiment the Algorithm A, we increase and unbalance the traffic load of some mobile clusters to violate the initial status. After performing on several random generated traffic demand case, we can observe the feasible results found by Algorithm A and find that the servicing policies will be applied first when traffic load becomes unbalance or traffic distribution change against initial status on network planning period. After applying channel re-assignment and power control schemes, Algorithm A can find feasible solution. Once the traffic demand growth, wireless networks become infeasible. Network sizing scheme must be applied by augment another available channels in this network.

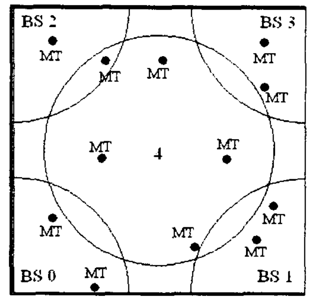

Fig. 3: The scenarios

Given	Value
α_j	4
γ_j	63 (18 dB)
δ	1/8
Δ_i^F	2000
Δ_t^H	10000
Δ_i^A	200000

Table 3: Given parameters

On the average, Algorithm A takes 235 sec for running 1000 iterations to find out a better feasible solution and only uses half number of channels than it used by applied no channel reuse schemes. Because the license fee of augmentation channel dominates the cost structure of this problem and it becomes the objective of proposed formulation, using Algorithm A can reduce network operation cost dramatically. This formulation will be helpful for wireless network operators to servicing/sizing wireless networks become feasible.

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