Optimization Approach to Link and Power Allocation in Cellular Networks

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Abstract— **This paper examine algorithms for assigning mobile users to base stations and allocating power in cellular networks. These algorithms are based on results from the problem of assigning users to base stations, and allocate power jointly. The objective in the power allocation examined in this work is either to maximize the minimum user throughput, a fair allocation, or to maximize the total system throughput. The algorithms are implemented and tested in orthogonal frequency-division multiplexing RUNE simulator. The four different algorithms for assigning base stations to mobiles and two power allocating algorithms are described in this paper.**

Keywords— **Cellular Networks, Base Station Allocation, Power Allocation, RUNE.**

I. INTRODUCTION

Cellular phones, also called mobiles, have been developed much over the last years; they are now not only used for making phone calls (voice traffic), but also to connect to the internet (data traffic). In the types of system considered here mobiles can connect to the base stations on different frequencies or channels. In this work the system considered has orthogonal channels, this is true for a variety of modern cellular systems. Orthogonal channels minimize interference within the cell, intracell interference. Since the intracell interference is minimized when the channels are orthogonal only interference between the cells needs to be considered. The quality of the link or connection between a base station and a mobile is described by the path gain, shadow fading and fast fading. For assigning mobile users to base stations (links) the path gain, which is dependent on a distance component, and the shadow fading component are considered.

Our key observation is that link selection and OPC are both multicell schemes and should complement each other task when exercised appropriately, as in [4]. Therefore, in this paper we examine joint cell (link) and power assignment for the purpose of gaining insight into the gains when these tasks are dealt with jointly.

These algorithms are to be implemented in orthogonal frequency division multiple access (OFDMA) context by means of a dynamic system level simulator called Rudimentary Network Simulator (RUNE), as in [5]. RUNE is a suitable tool, since it supports resource allocation algorithms both at the slow and fast time scales and therefore it lends itself to study the gains of joint algorithms.

II. SYSTEM MODEL

In this paper cellular networks consisting of a set B of base stations (BS), such that each BS maintains the coverage area of its associated cell. In the coverage area of the multicell network, there is the set of mobile stations (MS), denoted by M. To allow for a convenient handling of both the downlink and uplink, we denote the set of information sources by S and the set of destinations by D. We say that there is a communication link between a MS and its serving BS.

TABLE I
Definition of the sets of the system model

S	Set of Sources
D	Set of Destinations
C	Set of Channel Per Base Station
M	Set of Mobile Users
B	Set of Base Station

TABLE II
Definition of some variables and constants

x_{ijk}	1, if i ∈ S communicates with j ∈ D on channel k ∈ C
y_{ij}	1, if $x_{ijk} = 1$ on any channel k ∈ C
p_{ik}	the power that source i uses on channel k
η_{ijk}	the throughput between i and j on channel k
g_{ijk}	path gain on channel k of link i to j
g_{ij}	path gain of link i to j, when C = 1
σ_j^2	thermal noise at receiver j
p_i^{max}	the maximum transmit power of sender i
W	transmission frequency bandwidth

The signal-to-interference-and-noise-ratio (SINR) on channel k between source i and destination j is given by, as in [3].

$$\gamma_{ijk} = \frac{g_{ijk} \times p_{ik}}{\sigma_j^2 + \sum_{m \epsilon i} g_{mjk} \times p_{ik}} \quad , i \epsilon S , j \epsilon D , k \in C \qquad (1)$$

while the throughput on channel k between i and j is given by

$$\eta_{ijk} = W\log_2(1 + \gamma_{ijk}) \quad , i \epsilon S , j \epsilon D , k \in C \qquad (2)$$

III. PROBLEM FORMULATION

We first focus on the max-min problem for the downlink and later discuss how this problem can be generalized to uplink and to include the maximum throughput problem (in both directions). The max-min problem for downlink is stated as follows, as in [3]:

maximize , (3a)
subject to $y_{ij}\eta < \sum_{k \in C} x_{ijk} \eta_{ijk}$ (3b)
$\sum_{i \in B} y_{ij} = 1$ (3c)
$\sum_{j \in M} x_{ijk} \leq 1$ (3d)
$\sum_{k \in C} p_{ik} < p_i^{max}$ (3e)
$x_{ijk} \leq y_{ij}$ (3f)
$0 \leq y_{ij} \leq 1$ (3h)
$x_{ijk} \in \{0,1\}$ (3i)
$p_{ik} > 0$ (3g)

In this formulation, η is an auxiliary variable that is defined by constraint (3b). Constraint (3b) ensures that for all active links η is less than or equal to the sum of the throughput on the active channels on that link. Maximizing η in the objective function (3a) ensures that η is equal to the minimum sum throughput on the active links, and that this minimum is maximized. Constraint (3c) ensures that each MS is connected to exactly one BS, while constraint (3d) enforces that each BS at most has one MS per channel. Constraint (3e) is the maximum transmit power constraint.

In [4], the complexity of the joint cell, channel and power allocation problem (3) has been studied and shown to be NP-hard and not approximable unless P is equal to NP. Therefore, we will consider heuristic methods in the following section.

IV. SOLUTION APPROACH

Because of the complexity of problems (3) , this paper resort to heuristic algorithms that are based on the decomposition of the problems to the separate tasks of link, channel and power allocation. Furthermore, to avoid modelling the details of scheduling algorithms, we assume that the overall number of MSs does not exceed the (number of BSs) × (number of channels per BS).

A. Link Assignment

Four different link assignment algorithms are considered, they are derived in [3]. Two of those are heuristic algorithms, direct greedy and reversed greedy link assignment. The other two are optimization based link assignments, maximize the sum path gain over all users and maximize the minimum path gain. Link assignment uses path gain based on the distance component and shadow fading, not fast fading. In the following link assignments all users in the system are assigned to a base station.

1) DIRECT Greedy Link Assignment: The direct greedy approach assigns links according to the largest available path gain. Path gain is the channel condition between mobile and base station. We can find path gain by two different method. As path gain depends on the distance, we can directly find it from below equation:

$$G_p = g \times e^{(-d/k)} \qquad (4)$$

Where, G_p = path gain
g = gain (-28 dB)
d = distance between mobile and cell
k = path gain coefficient (3.5).

Algorithm 1. Direct Greedy Approach

```
$G_p = g \times e^{(-d/k)}$
  Set $\breve{g} \leftarrow g$ and $y_{ij} \leftarrow 0$, $i \epsilon B, j \epsilon M$
 For $\Delta = 1$ to M do
   Let $b_j \leftarrow \arg\max_{i \epsilon B} \breve{g}_{ij}, j \epsilon M$
Consider mobile $m \leftarrow \arg\max_{j \epsilon M} \breve{g}_{ij}$
   Update $y_{bm} \leftarrow 1$ and let $\breve{g}_{im} \leftarrow -1$, $i \epsilon B$, {remove mobile m}
   If $\sum_{j \epsilon M} y_{b_m j} = C$ then
   $\breve{g}_{b_m j} \leftarrow -1, j \epsilon M$, {which removes base station $b_m$}
   end if
end for
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2) Reversed Greedy Link Assignment:

Algorithm 2. Reversed Greedy Approach

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$G_p = g \times e^{(-d/k)}$
  Set $\breve{g} \leftarrow g$ and $y_{ij} \leftarrow 0$, $i \epsilon B, j \epsilon M$
 For $\Delta = 1$ to M do
   Let $b_j \leftarrow \arg\max_{i \epsilon B} \breve{g}_{ij}, j \epsilon M$
Consider mobile $m \leftarrow \arg\min_{j \epsilon M} \breve{g}_{ij}$
   Update $y_{bm} \leftarrow 1$ and let $\breve{g}_{im} \leftarrow -1$, $i \epsilon B$, {remove mobile m}
   If $\sum_{j \epsilon M} y_{b_m j} = C$ then
   $\breve{g}_{b_m j} \leftarrow -1, j \epsilon M$, {which removes base station $b_m$}
   end if
end for
```

The formulation for the reversed greedy approach is similar to the direct greedy assignment but instead of $m \leftarrow \arg\max_{j \in M} \breve{g}_{ij}$ there is $m \leftarrow \arg\min_{j \in M} \breve{g}_{ij}$.

3) Maximize the Total Path Gain Link Assignment: In the MTGA approach, the sum of g_{ij} over the transmission links is maximized, which leads to minimizing the path gain over unused links.

$$\begin{aligned} \text{maximize} \quad & \textstyle\sum_{i \in B, j \in M} g_{ij} y_{ij} && \text{(5a)} \\ \text{subject to,} \quad & \textstyle\sum_{i \in B} y_{ij} = 1,\ j \in M, && \text{(5b)} \\ & \textstyle\sum_{j \in M} y_{ij} \le C,\ i \in B, && \text{(5c)} \\ & y_{ij} \in \{0,1\},\ i \in B,\ j \in M, && \text{(5d)} \end{aligned}$$

Constraint (5b) ensures that each mobile connects to exactly one base station. Constraint (5c) ensures that BSs do not use more channels than what is available. By relaxing constraint (5d) to $y_{ij} \in \{0, 1\}$, the optimization problem becomes a transportation problem, which is a linear programming problem known to give integer solutions.

4) Maximize the Minimum Path Gain Assignment: Next, we consider maximizing the minimum path gain (MMG) link assignment that maximizes the smallest g_{ij} over the transmission links.

$$\begin{aligned} \text{maximize} \quad & \eta && \text{(6a)} \\ \text{subject to,} \quad & y_{ij}\, \eta \le g_{ij}\, y_{ij},\ i \in B,\ j \in M, && \text{(6b)} \\ & \textstyle\sum_{i \in B} y_{ij} = 1,\ j \in M, && \text{(6c)} \\ & \textstyle\sum_{j \in M} y_{ij} \le C,\ i \in B, && \text{(6d)} \\ & y_{ij} \in \{0,1\},\ i \in B,\ j \in M, && \text{(6e)} \end{aligned}$$

Maximizing η ensures that η is equal to the minimum path gain on the assigned links, and that this minimum is maximized.

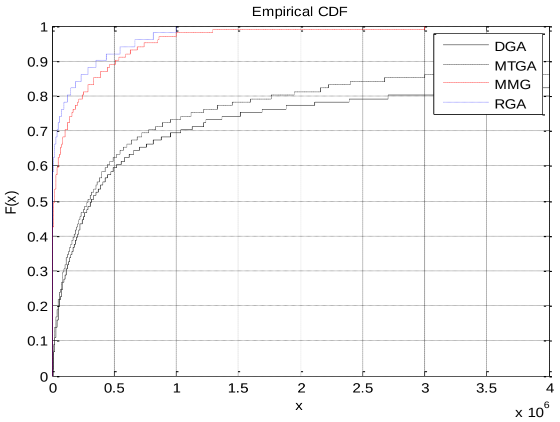

Fig. 1 Comparison of link assignment algorithms.

B. Power Allocation

Two power allocation algorithms are consider here.

1) Distance Based Power Allocation: The distance-based power allocation algorithm (DBPA) uses the distance between base station and each mobile station to allocate transmitted power to each of its served mobile. No correction or feedback is provided, and this is therefore an open loop power control mechanism.

If power control is not employed (i.e., the transmitted power is same for all users), the most constrained value of the signal-to-interference ratio (SIR) will be for a user at the boundary of the cell. Thus, more transmitted power should be allocated to mobiles which are far from their corresponding base station.

The DBPA algorithm computes the transmitted power of mobile m according to the following equation:

$$p_m = k x_{a_m}^n \qquad (7)$$

If $d_{a_m} > d_{min}$ then $x_{a_m} = \frac{d_{a_m}}{R}$, otherwise $x_{a_m} = \frac{d_{min}}{R}$,

Where, k= positive constant
n= real positive value
R= maximum base to mobile distance
d_{a_m}= distance between mobile m and its assigned base station

In order to avoid having very small transmitted powers for mobiles close to the base, mobiles whose distance d_{a_m} is less than a certain threshold value d_{min}, the same transmitted power is allowed.

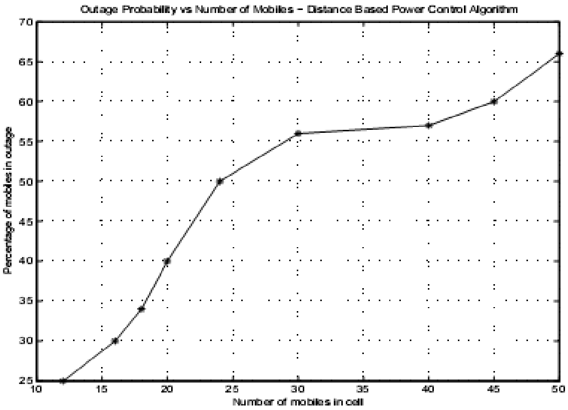

Fig. 2 Outage Probability vs. Number of Mobiles

Outage is defined as the condition when the observed value of the SIR is below the threshold value (SIR_threshold = 14dB).

2) Distributed Balancing Algorithm: The distributed balancing (DB) algorithm is an adaptive approach that uses the received SIR at the mobiles to adjust the transmitted of the base station in order to achieve better global transmission quality , i.e., for the entire network.

Optimal transmitted power is given as,

$$p_{ik} = \frac{\mathrm{SIR}}{1+\mathrm{SIR}} \frac{\sum_J \sum_{m=1}^{N_I} P_{jm}\, Z_{ikj}}{Z_{iki}} \qquad (8)$$

where, N_I = number of communicating mobiles in cell i
B_j = base j
M_{ik} = mobile k in cell i
Z_{ikj} = path gain between B_j and M_{ik}
p_{ik} = power transmitted from B_j to M_{ik}
SIR= signal to interference ratio

Eq.(8) implies that the optimal transmitted power assignment for is proportional to the ratio of the total received power of this mobile to the link{gain between its home base and itself.

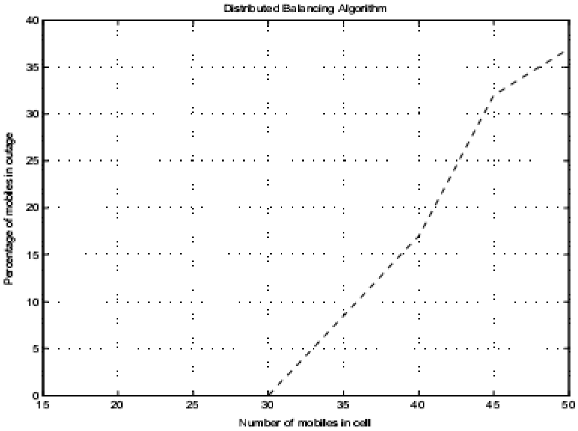

Fig. 3 Outage Probability vs. Number of Mobiles

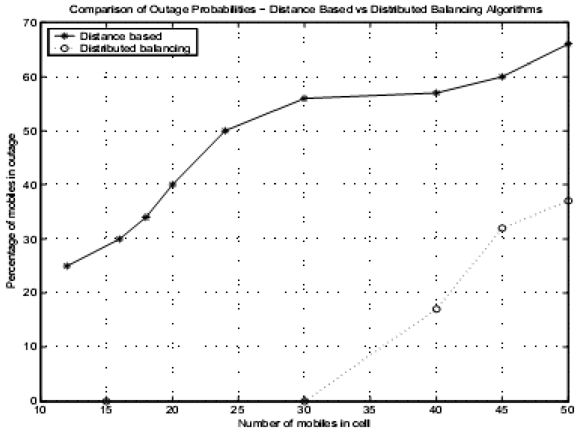

Fig. 4 Comparison of Outage Probabilities

V. SIMULATION TOOL

To simulate realistic cellular systems we used the MAT-LAB based Rudimentary Network Emulator (RUNE). RUNE is available in [4], that also includes a detailed description of the simulator. It can set up a system of base stations, with both Omni and directional antennas and distribute users according to some predefined distribution over the coverage area of the system. RUNE can set up realistic path gain matrices including distance dependent path gain, shadow and fast fading, where fast fading is simulated by Rayleigh fading. A typical RUNE simulation session consists of an outer and an inner loop. The outer loop is concerned with generating and terminating users. The inner loop is responsible for mobility and calculating channel coefficients.

TABLE III
Path Gain Specific Parameters

Parameters	Value
Gain at 1 meter Distance	-28 dBm
Noise	-110 dBm
Distance Dependent Path Gain Coefficient	3.5
Standard Deviation for the log-normal fading	6 dB
Log- normal Correlation Downlink	0.5
Correlation Distance	110 m
Fast fading	Rayleigh

TABLE IV
The main parameters in the system

Parameters	Value
Cell Radius	500 m
Number of Sectors per Site	1
Number of Clusters per System	1
Maximum power of Mobile	27 dB
Maximum Power of Base Station	45 Db

VI. CONCLUSION

In this paper we considered the problem of joint serving cell selection (link selection) and power allocation. We have studied different link assignment algorithms implemented on matlab and rune simulator. We have also implemented and analyzed power allocation algorithms based on outage versus number of iterations. The Distributed Balancing (DB) power control algorithm was shown to give better results compared to Distance Based Power Allocation (DBPA) algorithm (fig 3).

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