# A NOVEL DYNAMIC CHANNEL ASSIGNMENT STRATEGY USING NORMAL GRAPHICAL SIGNAL PROCESSING FOR HIERARCHICAL CELLULAR SYSTEMS

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**ABSTRACT**

Evolution of cellular systems in urban environments results in microcell and macrocell overlaying architectures with heavy traffic loading seen around hot spots. To achieve high spectrum efficiency, serious traffic blocking problems usually emerge in such architecture if the network resource is not well managed. Based on a normal graph framework, we propose a fully-distributed dynamic channel assignment algorithm for hierarchical cellular systems using antenna arrays. Utilizing the available mobile station location information, the proposed algorithm defines soft-information to reflect the local traffic distribution. The soft-information is then iteratively exchanged among mobile stations and base stations to significantly increase system capacity.

## 1. INTRODUCTION

With increasing demands for wireless communication services and with limited channel bandwidth resource, increasing spectrum efficiency becomes an important issue. Higher spectrum efficiency, and thus system capacity, can be achieved through sectorization, cell splitting, and reuse-factor reduction while limiting interference to maintain signal quality. In addition, one recently popular technique to significantly increase capacity is to adopt a multiple-input-multiple-output (MIMO) multiuser scheme, which utilizes an antenna array at each base station (BS) and each mobile station (MS) to serve multiple users in the same frequency simultaneously. It has been shown that the MIMO multiuser scheme can reduce the cochannel interference (CCI) and dramatically improve the system capacity [1]. In the MIMO multiuser scheme, generally speaking, users in different angular positions can be served with the same channel if the angular separation between them is large enough.

On the other hand, after the service area is divided into small cells with a low frequency reuse factor and after the MIMO multiuser scheme is employed, channel assignment starts to play an important role in system capacity. Based on the strategy of CCI elimination, various channel assignment strategies for the conventional cellular systems can be roughly categorized as fixed channel assignment (FCA), dynamic channel assignment (DCA), and hybrid channel assignment (HCA) [2]. In the FCA strategies, each cell is allocated a predetermined set of channels (frequencies). The FCA schemes are simple, but it performs poorly if traffic is either non-stationary or uneven. In the conventional DCA, all channels in the universal set can be assigned to any service-requesting mobile station (MS) as long as the criterion on the carrier-to-inference ratio (CIR) requirement is met. However, the conventional DCA suffers high system complexity and may require a large amount of feedback on channel state information. To balance the trade-offs between the complexity and the performance, the HCA is suggested as something in-between. A major drawback of the HCA and the conventional DCA strategies stems from their capability to work properly only for cellular systems with identical cells. Unfortunately, in order to provide service to heavy traffic around hot-spots, most existing cellular systems possess a microcell/macrocell overlaying architecture. Furthermore, at a receiver, the CIR is difficult to measure [5] and a high CIR does not directly account for better service quality before antenna beamforming and frequency equalization. To alleviate the problems described above, by utilizing the available MS position information, we propose a novel DCA strategy to adaptively and efficiently allocate the channel resource in a fully distributed way. Based on a normal graph [3] framework, soft-information, which carries the stochastic properties of the traffic distribution, is created and is exchanged among the MSs and the BSs in a hierarchical cellular system to iteratively optimize the channel resource allocation.

## 2. THE ALGORITHM

To proceed, we first model the DCA problem in terms of a normal graph in Section 2.1. The detailed local rules in the

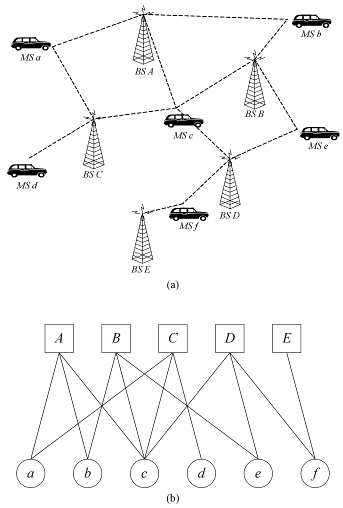


**Fig. 1**. (a) An example network scenario for dynamic channel assignment and its corresponding (b) normal graph.

normal graph are described in Section 2.2 and the calculation of soft-information at each node is explained in Section 2.3.

### 2.1. Normal Graph Modeling

A normal graph, consisting of nodes and edges, is a graph representation for a group of mutually-interactive check rules. Nodes and edges are respectively corresponding to local rules and variables. As long as we can describe a problem with a normal graph and specify all the local rules enforced by all the nodes, the problem can then be easily solved with a standard procedure, the soft-information-passing sum-product algorithm. Normal graph modeling for the DCA problem is realized through the following two steps: 1) Let us define two types of nodes: The square nodes represent the BS's and the circular nodes represents the MS's. Take the wireless network scenario described in Fig.1(a) as an example. Nodes *A*, *B*, *C*, *D*, and *E* represent five BSs nodes and nodes *a*, *b*, *c*, *d*, *e*, and *f* represent six MS nodes. In the US for example, the Federal Communications Commission (FCC) has made it a mandatary requirement for the wireless service suppliers to provide accurate MS location information [4]. 2) In Fig. 1(b), an edge is connected from a BS node to a MS node whenever the MS is detectable to the BS. These edges altogether represent a codeword. Each edge is associated with a codeword bit, which can be either one or zero, where one means that desired signals are transmitting through the link between the corresponding MS and BS, zero means that the edge is an interference link. We define $B(i)$ as the set of BS nodes that are connected to *MS* $i$ and define $M(j)$ as the set of MS nodes that are connected to *BS* $j$.

In other words, each codeword intends to describe a DCA solution. We just need to decide the best codeword according to the local constraints. In order to faithfully describe the network scenario, we have to impose the local constraints at each node, as will be described next.

### 2.2. Local Constraints

Let us first start with the local constraints associated with the MS nodes, since they are relatively much simpler. For simplicity reason, we assume a system with single-rate data transmission, i.e., an active MS receives service only from one BS and the service is restricted to a single channel, either a time slot or frequency band depending on the system multiplexing scheme. In that case, the constraint rule for each MS node is to make sure there is only a single "one" in the codeword bits among all the related edges (or codeword bits) connected to each MS node. However, this rule can be easily extended to a multi-channel system transmitting multi-rate data just by allowing more "one" in the codeword bits.

Now, let us turn to the local constraints associated with the BS nodes. We can make use of the available MS location information to define a mobile exclusive region (MER) for each MS. When an MS is activated, an MER is defined and is off-limits to the other MSs connecting to the same BS. Note that an MER is not effective for the MSs connecting to the other BSs due to angle selectivity of the MS channels in a MIMO system. For a MIMO uplink scenario, the MER for each MS looks like a sector with its vertex at the corresponding BS. The angle span of the sector is inversely proportional to the angular resolution of the antenna array at the corresponding BS; the radius extension of the sector is proportional to the distance between a MS and corresponding BS. With angle and distance protections, the communication quality can be guaranteed. Notice that we intentionally avoid to use the CIR measurement, the standard conventional approach for the DCA problem. This is because accurate CIR measurement is difficult to obtain at the receiver's very front end [5]. In addition, especially for system with antenna array, the CIR measurement before beamforming is basically useless.

Next, the definition of the local constraints for each BS can be obtained through MER. Take five MSs, *MS a*, *MS b*, *MS c*, *MS d*, and *MS e*, connecting to *BS A* as an example. Scenario 1: If *MS a* and *MS c* are very close in angle; therefore, these two MSs cannot be assigned channel links to the same BS at the same time, therefore the illegal codewords for *BS A* in this scenario will be $\{1 \times 1 \times \times\}$, where

"$\times$" means "don't care". Scenario 2: If the signals of *MS b*, *MS c*, and *MS d* come from the same angle, the illegal codewords for *BS A* will be $\{\times 111\times, \times 110\times, \times 101\times, \times 011\times\}$. Similarly, the BS can claim other codewords illegal according to the distance distribution of the associated MSs. We define the codebook that keeps the illegal codewords (or the local traffic restrictions) for *BS j* as $R(j)$.

### 2.3. Soft-Information Calculation

In this subsection, we explain how to convert the MS location information into its associated soft-information and how to calculate soft-information at each node as follows.

**1. Initialization:** With the location information of *MS i*, we define the initial SI that *MS i* pass to *BS j* as the probability that *MS i* will be served by *BS j*

$$\begin{aligned} \mathrm{SI}\,(MS\ i, BS\ j, 1) &= 1 - \mathrm{SI}\,(MS\ i, BS\ j, 0) \quad (1) \\ &= \exp\left(\lambda \cdot \frac{d_{ij}}{R_j}\right), \end{aligned}$$

where $\mathrm{SI}\,(x, y, s)$ denotes the soft-information passed from node $x$ to node $y$ with the codeword bit associated with the edge connecting the two nodes being $s$, $d_{ij}$ is the distance between *MS i* and *BS j*, $R_j$ is the coverage radius of *BS j*, and $\lambda$ is a normalization factor that makes the probability $\mathrm{SI}\,(MS\ i, BS\ j, 1)$ one half when *MS i* is located at the edge of the *BS j* cell.

**2. From BS to MS:** After each BS receives SIs from its associated MSs, it calculate its output SIs based on its codebook and pass the SIs back to the associated MSs. According to the sum-product algorithm, the SI passed from *BS j* to *MS i* can be expressed as

$$\begin{aligned} &\mathrm{SI}\,(BS\ j, MS\ i, s) \\ = \quad &\lambda_{ji}\left(1 - \sum_{\substack{\mathbf{r}\in C(j)\\ r_i = s}} \prod_{l \in B(j)\backslash i} \mathrm{SI}\,(MS\ l, BS\ j, r_l)\right) \quad (2) \end{aligned}$$

where $\lambda_{ji}$ is a constant to make sure $\mathrm{SI}\,(MS\ i, BS\ j, 0) + \mathrm{SI}\,(MS\ i, BS\ j, 1) = 1$. Note that (2) is identical to the SI calculation for a function node in the decoding of an LDPC code [3]. With such a decoding algorithm, optimal performance is guaranteed for the LDPC code if there is no cycle in its corresponding normal graph.

Take the two scenarios in Section 2.2 as examples. In scenario 1, $\mathrm{SI}\,(BS\ A, MS\ a, 1) = \lambda_{Aa}$, $\mathrm{SI}\,(BS\ A, MS\ a, 1) = \lambda_{Aa}\,(1 - \mathrm{SI}\,(MS\ c, BS\ A, 1))$, while $\mathrm{SI}\,(BS\ A, MS\ b, 1) = \mathrm{SI}\,(BS\ A, MS\ b, 0) = 0.5$. We can calculate the SI from *BS A* to *MS c*, *MS d*, and *MS e* in a similar way. In scenario 2, $\mathrm{SI}\,(BS\ A, MS\ a, 1) = \mathrm{SI}\,(BS\ A, MS\ a, 0) = 0.5$, while $\mathrm{SI}\,(BS\ A, MS\ b, 1) = \lambda_{Ab}\,(1 - \mathrm{SI}\,(MS\ c, BS\ A, 1) \cdot \mathrm{SI}\,(MS\ d, BS\ A, 1) - \mathrm{SI}\,(MS\ c, BS\ A, 1) \cdot \mathrm{SI}\,(MS\ d, BS\ A, 0) - \mathrm{SI}\,(MS\ c, BS\ A, 0) \cdot \mathrm{SI}\,(MS\ d, BS\ A, 1))$; $\mathrm{SI}\,(BS\ A, MS\ b, 0) = \lambda_{Ab}\,(1 - \mathrm{SI}\,(MS\ c, BS\ A, 1) \cdot \mathrm{SI}\,(MS\ d, BS\ A, 1))$. If there are a large number of MSs connected to a BS, *BS j*, we can always further break $C(j)$ into independent simpler constraints so that the application of (2) can always stay very low complexity. Breaking down of $C(j)$ will be elaborated in another paper.

**3. From MS to BS:** In order to complete an iteration loop, each MS needs to calculate its output SIs with 1) the output SIs from its associated BSs, and 2) its data rate request. If we assume single rate for simplicity reason, the SI passed from *MS i* to *BS j* is given by

$$\begin{aligned} \mathrm{SI}\,(MS\ i, BS\ j, 1) &= \lambda_{ij} \prod_{l \in M(i)\backslash j} \mathrm{SI}\,(BS\ l, MS\ i, 0), \\ \mathrm{SI}\,(MS\ i, BS\ j, 0) &= \lambda_{ij} \sum_{k} \mathrm{SI}\,(BS\ k, MS\ i, 1) \\ &\quad \times \prod_{l \in M(i)\backslash j \backslash k} \mathrm{SI}\,(BS\ l, MS\ i, 0). \end{aligned}$$

**4. Convergence check:** At the end of each iteration, we calculate the likelihood of each codeword bit. For the codeword bit between *MS i* and *BS j*, it is temporally decided as 1 if

$$\begin{aligned} &\mathrm{SI}\,(MS\ i, BS\ j, 1) \cdot \mathrm{SI}\,(BS\ j, MS\ i, 1) > \\ &\quad \mathrm{SI}\,(MS\ i, BS\ j, 0) \cdot \mathrm{SI}\,(BS\ j, MS\ i, 0) \qquad (3) \end{aligned}$$

and decided as 0 otherwise. If all the temporal decisions meet all the local constraint rules, then the algorithm is considered converges. However, there is no guarantee that the proposed algorithm will always converge in any scenario, since a viable solution may not even exist for some heavily overloaded systems. Nevertheless, while staying very low complexity, the proposed algorithm can almost always provide a better solution than the existing DCA algorithm in non-trivial scenarios, as will be shown next.

## 3. SIMULATION RESULTS AND DISCUSSION

Conventional DCA approach in space-division multiple acess (SDMA) is the switched multibeam, where multiple beams are used to cover the entire coverage of the BS and the beam with the strongest signal power for the desired MS is selected to serve the MS. Simulation are conducted to confirm the performance improvement of the proposed DCA strategy. The criteria for performance measurement considered here is the system capacity subject to a pre-determined blocking rate. For comparison, we also test some conventional schems, the omni-directional and the conventional 3 sectors, 4 sectors, and SDMA schemes. The simulation scenario, shown in Fig. 3, is a microcell and macrocell overlaying architecture, where the radius for the macrocell and the macrocell are 5 km and 1 km, respectively.

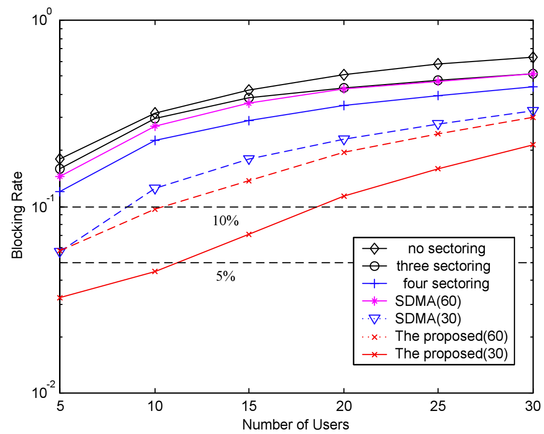


**Fig. 2**. Simulation results on the outage probability.

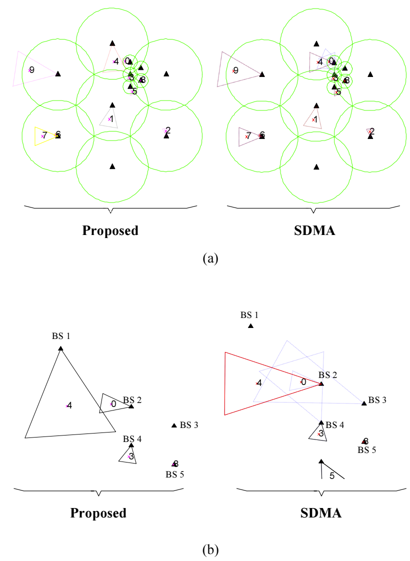


**Fig. 3**. (a) An example system layout and its channel assignment. (b) is zoom-in view on the hot spot of (a).

In the simulation, we assume a single-frequency scenario for simplicity. However, it can also be easily extended to multi-frequency scenarios. With different level of blocking rates in the system, Fig. 2 plots the number of the sustainable users in the system for various DCA schemes. It is observed that: 1) As expected, when the blocking rate in the system increases, the total number of users of all the schemes also increase; 2) the proposed normal-graphic-based algorithm always outperforms all the other schemes. This is because the the proposed algorithm automatically distributively and iteratively coordinates the channel assignments among new arrival users and the users who are already in the system whenever a new arrival user is admitted to the network. This procedure sometimes results in channel re-assignment of the users who are already in the system, which release the original channels to the new arrival users. With this, it is more probable to reach the overall optimal channel assignment and the distance is only resticted to the region around the new arrival user. However, the conventional schemes do not have this mechanism. That is, incorrect order of channel assignments may easily result in a waste of network resources in the conventional schemes, since it is likely that sometimes some early-assigned users may consume most of the network resources. In Fig. 3, we demonstrates a channel assignment example to show channel assignment carried out by both the proposed algorithm and the conventional scheme, where the *MS 1*, $\cdots$ , *MS 9* is the users who are already in the system and *MS 0* is the new arrival user. After applying the proposed scheme, the *MS 4* releases its channel and pass it to the *MS 0* and builds up new connection with *BS 1*. However, the conventional scheme fails to assign channel after trying all the three candidate BSs.

## 4. CONCLUSION

A new DCA strategy based on the MS position location is proposed. The proposed algorithm efficiently utilizes the location information by exchanging soft-information among MSs and BSs in a normal graph to increase system capacity. From simulation results, we found that the proposed algorithm always outperforms the conventional ones. In addition, the proposed algorithm is fully distributed, i.e. the proposed scheme does not increase much the network loading for feedbacks of various channel state information and required little computation power at each distributed site.

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