

Graph based automatic centralized PCI assignment in LTE

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Abstract—Physical Cell Identity (PCI) is cell identifier on the physical layer which can be used to create synchronization signals. There is a mapping between synchronization signals and physical cell identity, and then User Equipment (UE) can search cells through this mapping. Traditionally, PCI was configured during network planning process. While with 3G Long Term Evolution (LTE) has been prevalent in the future network, auto configuration of radio parameters has become a necessity. This paper proposed an automatic centralized PCI assignment mechanism using OAM as central server to collect cell information of the network, and create an abstract graph using information given which reflects the relationship in real-world network. After that, an enhanced graph-coloring algorithm which can greatly reduce time complexity while keeping a high PCI utility ratio was provided to create a collision and confusion free PCI for the new cell.

Keywords—physical cell identity; LTE; graph-coloring

I. INTRODUCTION

LTE is well known for self-sensing, self-configuration, self-optimizing and self-healing without much human intervention and great operational expenditure (OPEX) and capital expenditure (CAPEX) reduction. In self-configuration phase, when a new evolved NodeB (eNB) is introduced into the network, a series of parameters such as antenna tilt, pilot power need to be configured. PCI is one of the radio parameters which ranges from 0 to 503 [1] and is used to scramble the data to help the mobile separate information from different transmitters. While in most cases, cells in a network are more than 504, the PCI need to be used more than once. During the assignment of PCI, it must fulfill both collision and confusion free with respective neighbor cells [2].

Several proposals in 3GPP for PCI allocation have been studied [3]-[4]. Finally, two main stream framework are agreed which are centralized and distributed PCI assignment algorithms [5]. Distributed PCI assignment algorithm often uses a temporary ID or X2 interface to obtain the neighbor cells information. However, it is usually insufficient and unsuitable for the network with neighbor cells changing together [3].

A similar paper was also mentioned to increase PCI utility using graph-coloring algorithm [6]. But it focused on the mathematical algorithm, no complete mechanism was put forward and the use of graph-coloring algorithm was also inefficient. This paper completed the PCI assignment with specific mechanism like scenarios, procedures and the

detailed implementation process, at the same time, improved the graph-coloring algorithm in depth-first search.

The following parts illustrate this centralized PCI allocation method from scenarios, procedures and the detailed implementation process respectively. After that, an evaluation is put forward and finally leads to the conclusion.

II. PCI ASSIGNMENT MECHNISM

A. Scenarios

Centralized PCI assignment mechanism is suitable in two scenarios. First, in initializing phase, when a new eNB is added to the network or a new cell is deployed, the cells of the new eNB supported or the new deployed cell need to be assigned with PCI automatically; second, in the operation phase, a collision or confusion occurred in the area or some other reasons can cause change of PCI.

B. Procedures

This section mainly discusses the initializing phase to explain the mechanism. Fig. 2 shows this procedure in detail.

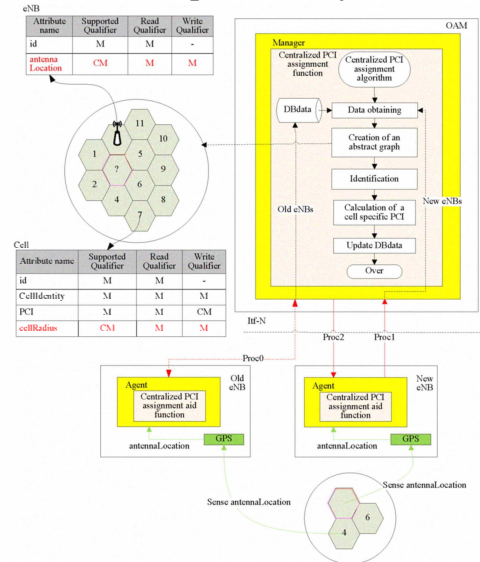


Figure 1. The OAM needs to implement the centralized PCI assignment algorithm. It acts as Manager and eNB acts as Agent. The information in OAM and eNB need to keep synchronized all the time.

Proc1 and proc2 represent the process of eNBs registration and configuration data download respectively.

The following steps elaborate on the process of OAM calculating an optimum PCI for the new eNB.

1) *Data obtaining*: Get information of old eNBs including antennaLocation, cellRadius and PCI of their supported cells from DBdata; get antennaLocation of new eNBs through GPS; get cellRadius of new eNBs through the detection of coverage optimization.

2) *Creation of an abstract graph*: Create an abstract graph to reflect the real-world network with the data obtained.

3) *Identification*: Identify direct neighbors and neighbors of direct neighbors of the new added cells of eNB.

4) *Calculation*: create an optimum PCI through the improved graph-coloring algorithm.

5) *Updating of DBdata*: update DBdata which includes adding a new cell and updating the Neighbor Relation Table (NRT) [5] of relevant direct neighbors of the new cell .

III. PCI ASSIGNMENT ALGORITHM

The algorithm is mainly consists of three parts which are 2, 3 and 4 steps in Section B of part II: First, translate the geographic position of eNB to plane coordinate location using Gauss projection. Second, identify the direct neighbors of the new added cell using M-tree and obtain the direct neighbors' neighbors through NRs of the known direct neighbors. Finally, pick a suitable PCI for the new cell. This part mainly discusses the last step.

TABLE I. CONCEPTS DECLARED

name	meaning
dNeighbors	List of cells in direct neighbors
iNeighbors	List of cells in neighbors of dNeighbors
Aset/Usset	All available/used PCI in the network
Sset	Direct neighbor PCI set of a cell
Mset	PCI set of neighbors of dNeighbors
Tset	PCI set of neighbors of one cell in iNeighbors
TargetSet	result set which PCI is choosing from
D _{cell}	Number of direct neighbors the cell has
C _{pci}	Number of times the PCI used
N _{cell}	Number of direct neighbors the new cell has

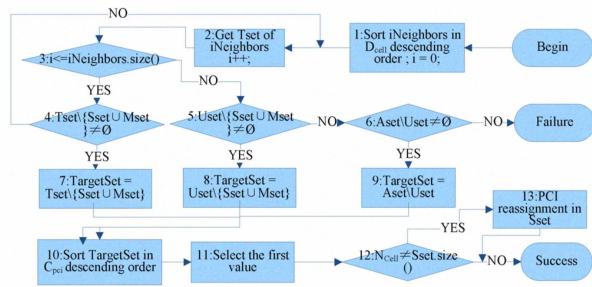


Figure 2. The flowchart of centralized PCI assignment algorithm. It should be noted that the sets mentioned above cannot be changed until the assignment process finished.

Such as the Figure 2 shows, first, identify and sort iNeighbors, and then find the Tset of cell in iNeighbors with the highest degree, if a PCI can be found from Tset while it

is not in Sset or Mset, then an optimum PCI is obtained. If no PCI can be found, then a new cycle need to be restarted from step 2 to find the cell with the second highest degree in iNeighbors until find an optimum PCI. Furthermore, when there is no cell in iNeighbors, PCI can be obtained from Usset, but the PCI must not appear in Sset or Mset. Finally, if no PCI can be found from the above conditions, PCI can be chosen from Aset which is not used by any cells.

However, If N_{cell} does not equal to the size of Sset, there are duplicate PCI values in Sset which means abnormal condition occurred, and then additional procedures need to be taken to change the PCI value of the cell with duplicate PCI using the same algorithm mentioned above.

- To every PCI in Sset, create a list contains the cell appeared in dNeighbors with this PCI;
- Sort the list in D_{cell} descending order;
- Change the cell's PCI from the second one in the list, which means to modify the cell with less neighbors.

IV. SIMULATIONS

A. Simulation process

In order to illustrate and analyze the behavior of the proposed PCI assignment algorithm, we consider simulations using scenarios in abnormal conditions.

The existing network is a virtual network in Fig. 3 which information is listed in TABLE II. NeighborCellList (NCL) is used to model the NRs of a cell. After a cell with location (9, 2.2) is inserted, the cells which ids are 4 and 13 with the same PCI 1 connect to each other. TABLE II is updated such as the blue part shows. Fig. 4 indicates the network change.

TABLE II. CELLS INFORMATION

id	PCI	X_Location	Y_Location	Radius	Degree	NCL
4	1	8	1	1	3+1	3,5,12,16
5	2	10	1	1	1+1	4,16
12	7	7.2	2.3	1	4	3,4,7,16
13	1->5	9.8	4	1	2	14,15,16
16	4	9	2.2	1.3	4	4,5,12,13

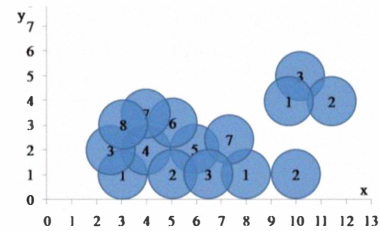


Figure 3. Two cell clusters in the network.

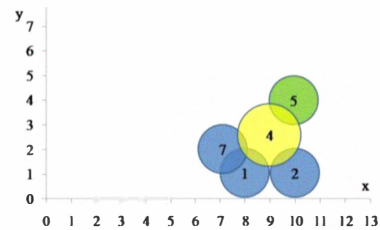


Figure 4. The yellow cell represents the new added cell; the green cell is the cell which changes its PCI.

B. Algorithm performance analysis

This part mainly analyzes the efficiency and PCI utility ratio of the algorithm. Compared to the algorithm mentioned in graph coloring based physical-cell-id assignment for LTE network [6] (short for algorithm B) in section 2.2, this algorithm (short for algorithm A) keeps high PCI utility ratio while reducing time complexity.

1) Time complexity analysis:

Assuming there is n (0, 1, 2...) cells in $dNeighbors$, m (0, 1, 2...) cells in $iNeighbors$ and one cell has t (t_n, t_m) neighbor cells (cells belonged to $dNeighbors$ have t_n neighbor cells and cells belonged to $iNeighbors$ have t_m neighbor cells). Algorithm A need to identity $iNeighbors$ and define the time complexity as $n * t_n$. Besides, based on the flowchart in section C of part III, A need to sort $iNeighbors$, and then define the time complexity of it as $m * \log_2 m$. At best times, A can search for only one cell in $iNeighbors$ to find the optimum PCI, and define the time complexity at best times as T_a .

$$T_a = n * t_n + m * \log_2 m + t_m. \quad (1)$$

While at worst times, A need to search for all the cells in $iNeighbors$ to find the optimum PCI, suppose the time complexity is $T_{a'}$.

$$T_{a'} = n * t_n + m * \log_2 m + m * t_m. \quad (2)$$

Contrast to algorithm A, algorithm B needs to get all the PCI of $iNeighbors$ ' neighbor cells except for $dNeighbors$ and $iNeighbors$. Suppose the time complexity of B is T_b

$$T_b = n * t_n * t_m. \quad (3)$$

Then time complexity comparison between algorithm A and B is presented in the following paragraphs in different conditions.

a) Condition 1: $n \neq 0, t_n = 0$, then $m = 0, t_m = 0$,

$$T_a = T_{a'} = T_b. \quad (4)$$

b) Condition 2: $n \neq 0, t_n \neq 0$, then $m \neq 0$,

If $n * t_n \leq s, m * \log_2 m \leq s, m * t_m \leq s, n * t_n * t_m < s$

$$T_a = T_{a'} = T_b. \quad (5)$$

Else $T_{a'} \geq T_a$, because so many parameters influence time complexity, in order to clearly explain the problem, suppose m, t_m, t_n are close to n , then

$$T_a = O(\max(n^2, n * \log_2 n, n)) = O(n^2). \quad (6)$$

$$T_{a'} = O(\max(n^2, n * \log_2 n, n^2)) = O(n^2). \quad (7)$$

$$T_b = O(n^3). \quad (8)$$

2) Time cost evaluation:

The following table shows time cost of the two algorithms for the same growth network. And their time cost analysis refers only to the core algorithm without including the cost of getting the data they need about neighbors.

TABLE III. TIME COST EVALUATION

$dNeighbors$	$iNeighbors$	Maximum degree of $iNeighbors$	Used PCI		Time cost (ms)	
			A	B	A	B
1	0	0	2	2	15~16	15~16
3	0	0	4	4	62~63	62~63
5	0	0	6	6	109~140	109~140
3	1	2	5	5	63~78	62~63
3	3	4	6	6	93~110	78~93
3	5	4	7	7	125~141	125~141
3	6	4	7	7	140~141	140~141
3	6	5	7	7	78~93	141~156
3	6	6	8	8	93~109	156~172

Time complexity of B is obviously higher than A from the analysis results (6), (7), and (8) of 1). And the time cost evaluation of part 2) also proved this.

V. CONCLUSION

A mechanism and the corresponding algorithm for automatic PCI assignment were presented. The mechanism brought OAM in the system acting as a central server to implement the centralized PCI allocation which can manage the whole network from the global view. The algorithm is an enhanced graph-coloring algorithm which can greatly reduce execution time and keep a high PCI utility ratio.

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