Research Journal of
Information Technology

ISSN 1815-7432

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Information Technology 6 (2): 101-109, 2014
ISSN 1815-7432 / DOI: 10.3923/rjit.2014.101.109

Analytic Hierarchy Process (AHP) for Autonomous Component Carrier Selection (ACCS) in Carrier Aggregation Systems

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ABSTRACT

Carrier Aggregation (CA) is one of the key technologies for Long Term Evolution Advanced (LTE-A) systems. Technology has been receiving enormous attention because of its numerous advantages particularly for bandwidth expansion to 100 MHz. One of the primary issues affecting the performance of the technology is effective component carrier selection. The selection processes become even more critical with introduction of heterogeneous network and thus require better techniques in order to reap the reality benefits of carrier aggregation. In this study, we proposed a new technique to ease the selection process for Component Carriers (CC) in an impromptu network deployment using analytic hierarchy process and Iterative water filling technique. Our simulation results show that user's throughput can be improved while maintaining low inter-cell interference among base stations.

Key words: LTE-advance, carrier aggregation, analytic hierarchy process, iterative water filling, background interference matrix, radio resource allocation table

INTRODUCTION

The scarcity of radio spectrum has continued to impair the deployment and cost of cellular and wireless communication systems. The concept of Carrier Aggregation (CA) has been proposed as a key technology for LTE-Advanced systems in order to extend the current limit of 20 MHz spectrum bandwidth obtainable in LTE to 100 MHz for LTE-A systems. CA enables multiple Component Carriers (CCs) to be aggregated to form a wider overall system bandwidth. Consequent to introduction of CA the peak data rate proposed by IMT-Advanced became feasible; however, this proposal is not flawless and thus need to be perfected by either service providers or equipment manufacturers. This perfection process has received attention with different techniques been offered through hardware design, software radio and scheduling among others. One of the schemes added to carrier aggregation in order to enhance its performance is Autonomous Component Carrier Selection (ACCS). The proposed ACCS scheme is meant to ease selection process for both primary and secondary component carriers in an autonomous manner for base stations herein refer to as eNBs in LTE terms. The selection process for a well-planned base stations deployment (e.g., static wireless field study presented in Yu *et al*. (2013) can easily be controlled or managed because the base station's locations and environmental scenario is known priori. On the other hand, in a quasi-static base station deployment like mobile base stations use for occasional gathering e.g., Olympic Games, international festivity and emergency convergence etc., the time for careful base station deployment may be limited; such types of deployment pose new challenges in terms of interference management and load balancing. As demonstrated in similar scenarios that are partly alike with this in (Lindbom *et al*., 2011; Li *et al*., 2011; Wang *et al*., 2009), the interference pattern is quite different in such an impromptu cases which eventually call for self-adjusting interference management techniques.

In LTE-A with CA, the optimal allocation of radio resources depend on several factors such as mutual interference coupling among eNBs and the offered traffic. Finding the optimal ratio of radio resources sharing between eNBs in a highly dynamic and partly chaotic environment is, in general a non-linear non convex NP-hard optimization problem (Garcia *et al*., 2009; Li and Yang, 2011).

In HetNet scenario, direct communication between eNB and UEs is usually mediated by Low Power Nodes (LPN) (Fig. 1). The HetNet scenario imposed new challenges on the radio resource management because interference becomes more prominent especially between LPNs and the eNBs.

In a CA based HetNet, interference between eNBs and LPNs must be controlled in order to achieve better performance and realize the benefits of multi carrier systems. For release10 UEs (UEs with carrier aggregation capability), this can be accomplished by cross-carrier scheduling (3GPP, 2011). The LPNs are considered for effective area coverage in cellular/wireless networks. They are also intended to serve the cell-edge users. However, uncoordinated deployment of base stations is capable of imposing more problems in terms of interference, especially to cell edge users. In addition to the cross-tier interference between eNBs and LPNs; intra-tier interference becomes more severe when the density of LPNs gets higher.

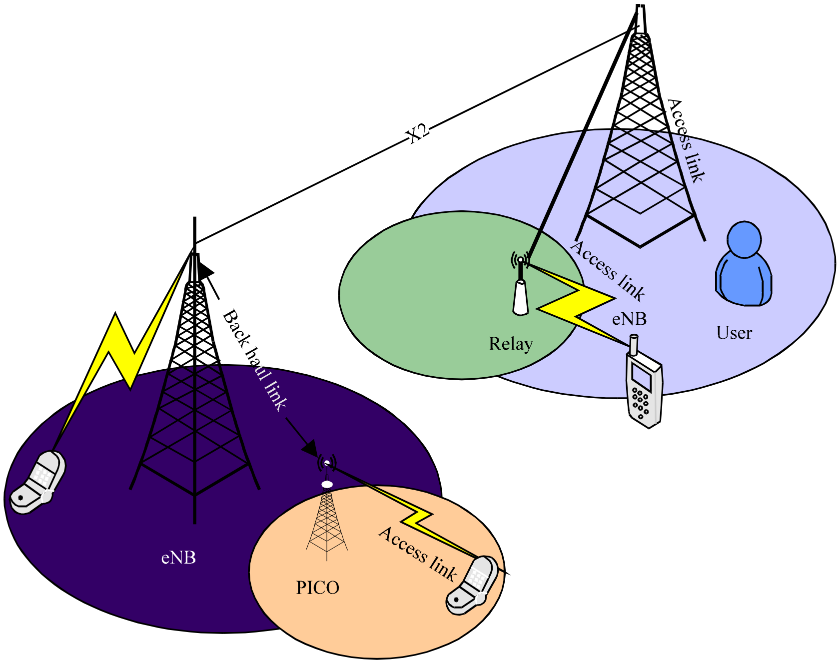

Fig. 1: Heterogeneous network deployment

COMPONENT CARRIER SELECTION

When multiple component carrier are available, each eNB is expected to select at least one active component carrier for its initial connection, camping, etc., designated as Primary Component Carrier (PCC). eNBs then continue to monitor the Quality of Service (QoS) on PCC, if the QoS on PCC is detected to be too low (depending on the preset threshold), a PCC reselection is triggered. As the traffic demand increases, an additional Secondary Component Carrier (SCC) can be dynamically allocated (Wang *et al.*, 2011; Yan *et al.*, 2011). Because PCC is to be used for control signaling the selection process must be made robust. Primary component carrier selection depend on certain metrics as explained in (Hong and Tsai, 2011). The ACCS process makes decisions based on two criteria namely; Radio Resource Allocation Table (RRAT) which specifies the current allocations of PCCs and SCCs belonging to the neighboring base stations within the network and (ii) the Background Interference Matrices (BIMs) which is determined by the standard physical layer measurements conducted by the UEs. The building of the BIMs can be initiated only after the selection of the PCC. Though, Yan *et al.* (2011) argued that the BIM-based method can result in significant signaling overhead, this is because the signaling overhead increases linearly proportional to number of network users and component carrier in a multi-user multi-carrier systems. Multi-criteria decision schemes for selection of primary and secondary component carrier can be found in (Garcia *et al.*, 2012; Wang *et al.*, 2010). The authors' proposed selection processes use different criteria such as eNBs' transmit power, offered traffic load and fairness.

In this study, we proposed a new scheme for autonomous component carrier selection, our approach is divided into two stages; stage one is primary component carrier selection-wherein an Analytic Hierarchy Process (AHP) is adopted for selection of the best component carrier while stage two involves using Iterative Water Filling techniques (IWF) for secondary component carrier selection. The purported benefit of our approach is to improve user's throughput while keeping the inter-cell interference overhead low.

SYSTEM MODEL

Here, we present the techniques for primary component carrier and subsequently the secondary component carrier selection process. We adopt the heuristic assumption that the spectrum configuration is known to all eNBs and each eNB always and only has one PCC at all time.

Primary component carrier selection procedure: To reduce signaling overhead, the analytic hierarchy process for autonomous component carrier selection algorithm makes decisions based on RRAT; Table 1 shows an example of a RRAT with five eNBs and five component carriers. In prudence for selection of primary component carrier we allot weighted percentage estimation for offered load ratio and carrier-to-interference C/I ratio designated as x_i and y_i, respectively, for each

Table 1: RRAT table

CC No.	eNB1	eNB2	eNB3	eNB4	eNB5
1	P		S		
2		S		S	P
3	S	P	S	P	
4			P		
5	S				

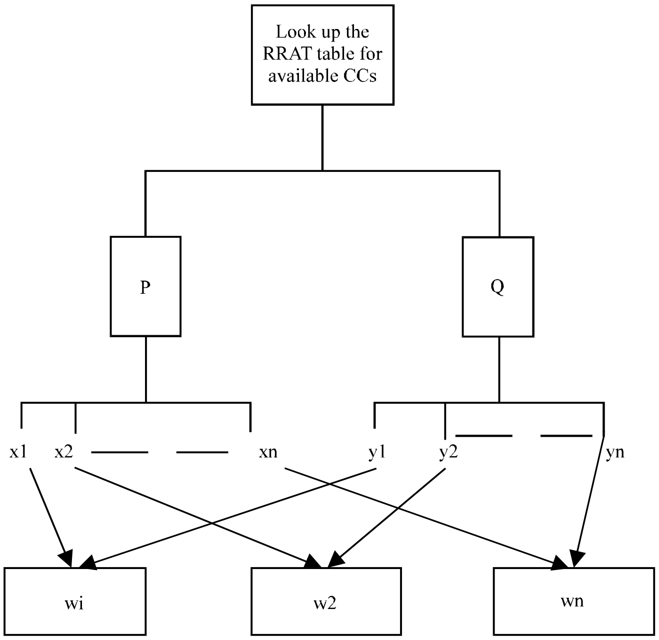

Fig. 2: Decision making process for selecting primary component carrier

component carrier i, for i = 1, 2....N (1≤N≤5), the rank of each component carrier from the standpoint of x_i and y_i is determined. The structure of the decision problem is summarized in Fig. 2. The problem involves single hierarchy (level) with two criteria (load and normalized C/I) and N decision alternatives (selecting from available CCs).

Assuming x_i is to be k times as important as y_i. The ranking of each component carrier is based on computing the composite weights as given in Eq. 1:

$$w_i = P.x_i+Q.y_i \tag{1}$$

where, P and Q are the respective importance level for x_i and y_i, respectively.

Based on these computations, the highest composite weight represents the best component carrier for the eNB. Secondary component carrier selection can be triggered if the need arises (e.g., increase in load) to compliment the performance of primary component carrier.

Secondary component carrier procedure using water filling technique: The eNBs are in an environment with noise and co-channel interference from other neighboring cells. Assuming each eNB is equally likely to use all available N component carriers. We designate this scenario as a Water Filling phenomenon (WF). The problem can be considered as optimization problem. We choose to perform optimization on the eNBs' transmit power. In this case, optimum user's throughput is to be achieved with less transmit power per eNB. The description of the scenario follows a characteristic deployment pattern depicted in Fig. 3. We assume each node can generate and transmit the inter-cell signaling and selects component carrier according to the received signaling messages. Figure 4 shows the resemblance of a signal level and interference model for 5 component carriers.

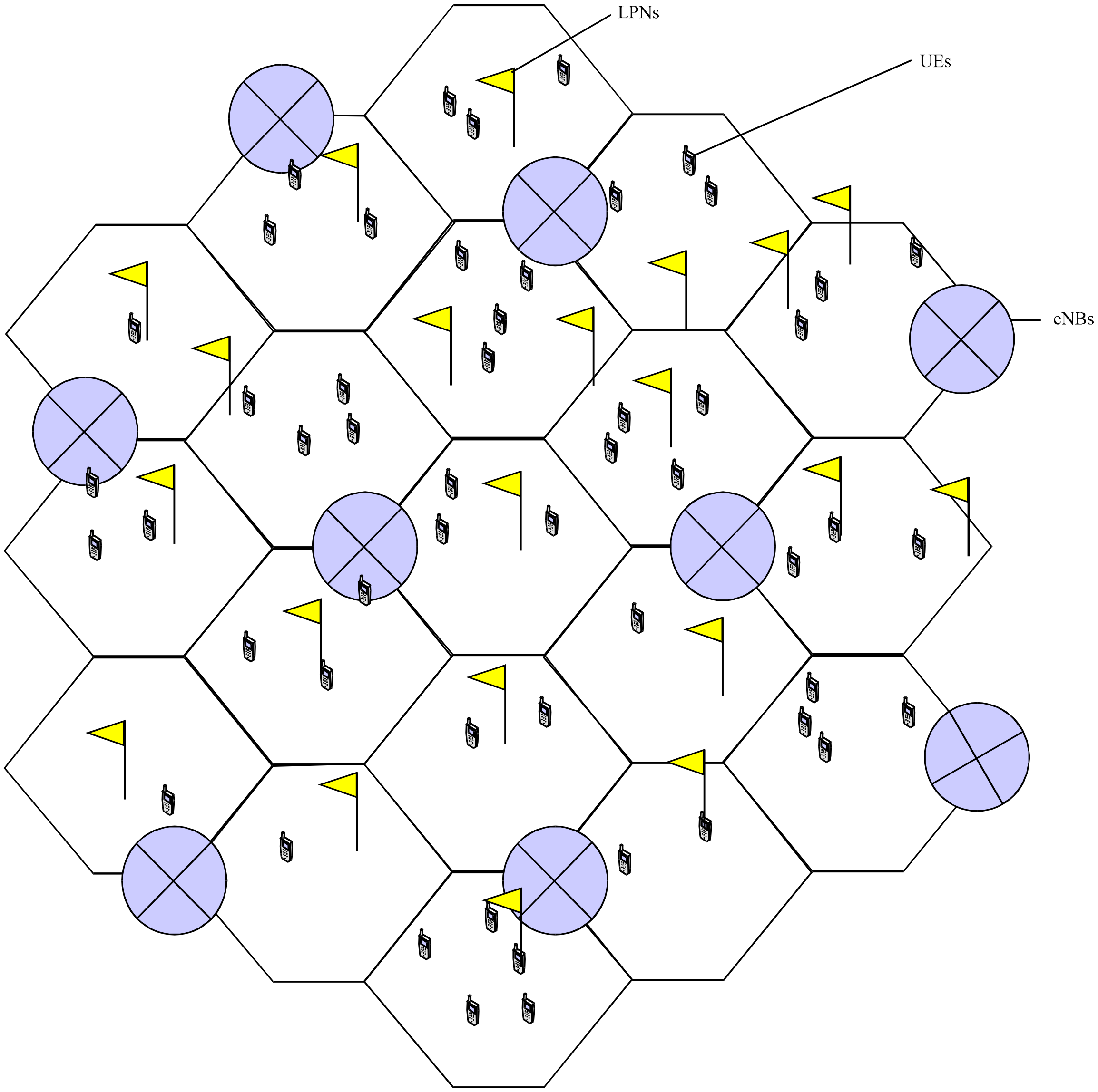

Fig. 3: Network deployment terrain

In the presents of interference the eNBs should guarantee optimal service to users through effective communication in both control and data channels. The problem is described by the following mathematical relation:

$$\begin{aligned} &\text{Minimise} \quad \sum_{i}^{N} P_i \\ &\text{Subject to:} \quad T \le R \\ &\text{With } R = \Delta\delta \sum_{i=1}^{N} \log_2\left(1 + \frac{P_i |\tau_i|}{\Gamma\sigma^2}\right) \end{aligned} \tag{2}$$

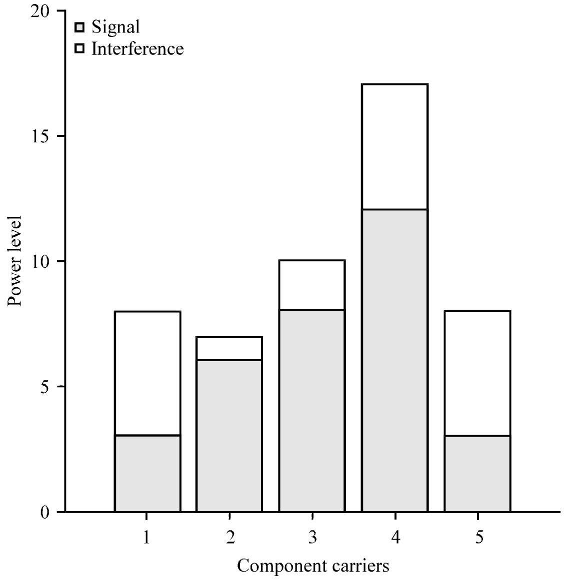

Fig. 4: Water level representing the combination of signal and interference in the system per component carrier

Table 2: Variables description

Symbol	Meaning
σ_i	Standard deviation for interference for CCi
Γ	SINR
τ_i	Channel state information
δ	Bandwidth per component carrier
R	Effective data rate for the network users
P_i	Relative narrowband transmit power for CC_i

The different variables in Eq. 2 are defined in Table 2. To relax the problem in Eq. 2, we use Lagrange multipliers. The Lagrange techniques begin with conversion of equality constrained model to an unconstrained form by weighting constraints in the objective function with Lagrange multipliers (Rardin, 2007). Expressing the problem in dual form:

$$L(1,T)=P_i-1\left(\Delta\delta\sum_{i=1}^{N}\log_2\left(1+\frac{P_i|\tau_i|^2}{\Gamma\sigma^2}-T\right)\right) \tag{3}$$

The (l) Lagrange multiplier was introduced to realize Eq. 3 with constrain of T. Partial derivative of Eq. 3 will normalize the constrain as follows:

$$\frac{\partial L(1,T)}{\partial P_i}=1-1\left(\Delta\delta\frac{|\tau_i|^2}{\Gamma\sigma^2\left(1+\frac{P_i|\tau_i|^2}{\Gamma\sigma^2}\right)}\right) \tag{4}$$

The value of P_i that solves:

$$\frac{\partial L(1,T)}{\partial P_i} = 0 \text{ is } P_i = \left[\frac{1}{1\Delta\delta} - \frac{\Gamma\sigma^2}{|\tau_i|^2}\right] \tag{5}$$

This gives the optimum solution for problem expressed in Eq. 2. Our water level is defined as:

$$\frac{1}{1\Delta\delta}$$

which can be compared with:

$$\frac{\Gamma\sigma^2}{|\tau_i|^2}$$

called normalized interference. Conclusively, when:

$$\frac{\Gamma\sigma^2}{|\tau_i|^2} \geq \frac{1}{1\Delta\delta} \Rightarrow P_i = 0 \tag{6}$$

On the other hand, if:

$$\frac{\Gamma\sigma^2}{|\tau_i|^2} < \frac{1}{1\Delta\delta} \Rightarrow P_i = \frac{1}{1\Delta\delta} - \frac{\Gamma\sigma^2}{|\tau_i|^2} \tag{7}$$

from Eq. 6-7 optimal power allocation configuration for optimizing the users' throughput among the eNBs is now feasible and tractable.

SIMULATION AND RESULT

Our proposed approach for effective ACCS in LTE-A is evaluated by means of Monte Carlo simulations that take into account the background interference metrics, transmit power and load for each component carrier. The scenario considers 5 eNBs with 20 UEs and five component carriers with equal bandwidth of 5 MHz each. Combined path loss and shadowing model described in (Goldsmith, 2007) was adopted for our simulation. The process for primary component carrier selection decision is internal to all eNBs and LPNs. Each nodes use the RRAT in Table 1 to estimate the weighting of each component carrier.

The secondary component carrier selection process begins with building of background information matrix. Explicit analogy of the measurements can be found in (Garcia *et al.*, 2012).Our target here is to achieve optimum users' throughputs using relation of Eq. 6-7. We assign variant transmit power levels per component carrier and varies the position of LPNs in different snapshots to evaluate the effectiveness of our proposed method.

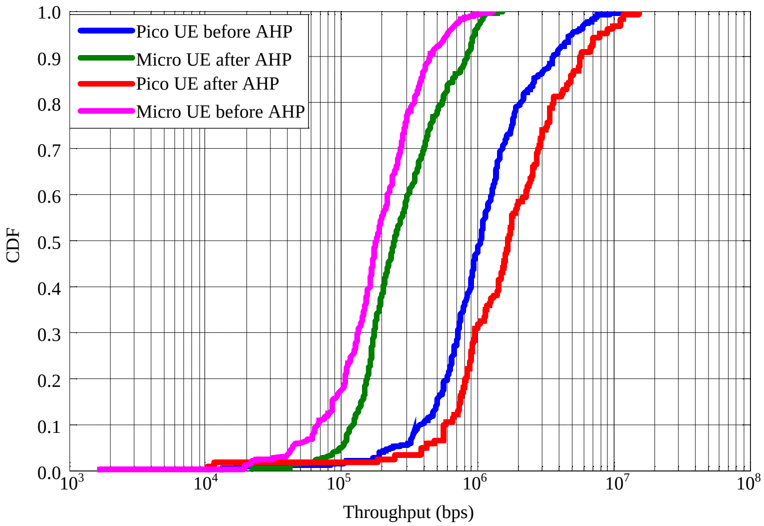

Fig. 5: Centre UEs throughput

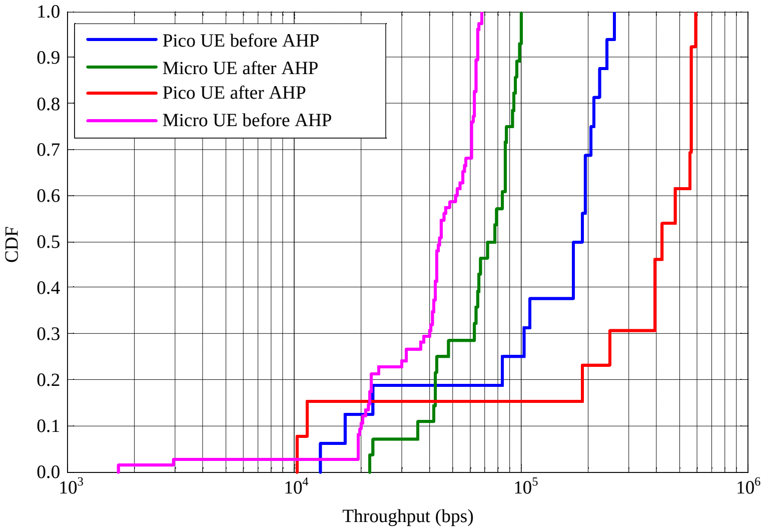

Fig. 6: Cell edge UE throughputs

Figure 5 and 6 shows the simulation results with clear comparisons in two scenarios and improvement achieved through application of proposed scheme.

CONCLUSION

This contribution introduced a new approach which enables autonomously component carrier selection whilst keeping the throughput optimal. The proposed method employed the use of analytic hierarchical process in selecting primary component carrier for eNBs and subsequently adopt iterative water filling procedure to regulate the transmit power of the nodes and provide better selection opportunity for choosing secondary carriers. We have considered an impromptu RF planning for evaluating our scheme, the simulation results delivers better performance.

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