Self-optimization of Downlink Transmission Power in 3GPP LTE-A Heterogeneous Network

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Abstract **—Co-channel full-reuse transmission is an important property in LTE downlink, which will generate strong inter-cell interference (ICI), especially in case of heterogeneous networks. The current LTE standardization supports the control of PDSCH transmission power to some extent via radio resource control signaling. In this paper, we propose a self-optimized downlink power allocation algorithm to efficiently use the transmission power while minimizing the interference to other users, which utilizes the concepts of game theory and fuzzy logic inference system. The proposed algorithm is suitable for the flat system architecture in 3GPP LTE-A system through a distributed operation manner, and minimizes the required information exchange among eNBs by the usage of fuzzy logic. And the simulation results illustrate the system performance benefits of the proposal compared to the conventional distributed water-filling algorithm.**

Keywords – 3GPP LTE-A, Heterogeneous Network, Self-optimization,Transmission Power

I. INTRODUCTION

The exponential increase on demand of telecommunication services in wireless networks motivates a constant evolution in mobile communication technologies. New cellular standards, known as Long-Term Evolution (LTE) and Long-Term Evolution-Advanced (LTE-A) has been standardized by the 3GPP [1]. LTE and LTE-A are considered as evolutions of the current UMTS third-generation networks, providing higher data rates, better quality of service and more wireless applications.

To further enhance the system coverage and spectrum efficiency in 3GPP LTE-A system, heterogeneous network (HetNet) deployment is proposed with additional small stations such as pico and femto eNode B (eNBs). However, the large number of small stations and their unmanaged deployment deteriorates the interference conditions a lot, which is very difficult to be solved through the network planning method and indirectly increases operating expense (OPEX). To cover these problems, the concept of self-organizing network (SON) is proposed to reduce the complex and repeated work load. Self-optimization is one of the main objectives in 3GPP LTE-A, which covers many aspects of the system operation and optimization tasks, such as the resource management, transmission power adjustment, mobility-related parameter configuration adjustment, and etc. To achieve this self-optimization functionality, fuzzy logic is a very powerful tool. Many researches in wireless communication have been done by utilizing the fuzzy logic. The proposed algorithms in [2]-[4] talk about the vertical and horizontal handovers using fuzzy logic in the parameter adjustment. Furthermore, the ideas of [5]-[7] introduce the admission control algorithm. However, the answers to the problems in [2]-[7] are simply yes or no, i.e., handover or not, and access or not. Very little research talks about the application of fuzzy logic in solving the problem with multiple potential answers, i.e., transmission power allocation of 3GPP LTE-A downlink (DL) which helps to reduce co-channel interference. Conventionally, the optimum downlink transmission power can be obtained by water-filling algorithm, which can be realized in a centralized way or a distributed way by a central controller or excessive information exchange between eNBs [8] - [10]. However, neither of the above realizations is desired in a 3GPP LTE-A system.

In this paper, we propose a 3GPP LTE-A DL transmission power allocation method based on the game theory and fuzzy logic inference (TPA-GF), which works in a distributed and autonomous manner to fulfill the requirement of self-optimization in SON concept. Compared to the centralized and distributed water-filling algorithms, the central control unit and excessive channel information exchange between stations are no longer needed.

The remaining part of this paper is organized as follows. Section II formulates the downlink transmission power allocation problem using game theory. The proposed self-optimized algorithm is presented in section III. The simulation assumptions and results are given in section IV. Finally, conclusions are drawn in section V.

II. PROBLEM FORMULATION

In this paper, we consider a heterogeneous 3GPP LTE-A system, where pico eNBs are deployed in the coverage of macro eNB for the performance enhancement. Figure 1 shows the deployment scenario of the 3GPP LTE-A HetNet considered in this paper, where UEs suffer interference from both macro and pico eNBs.

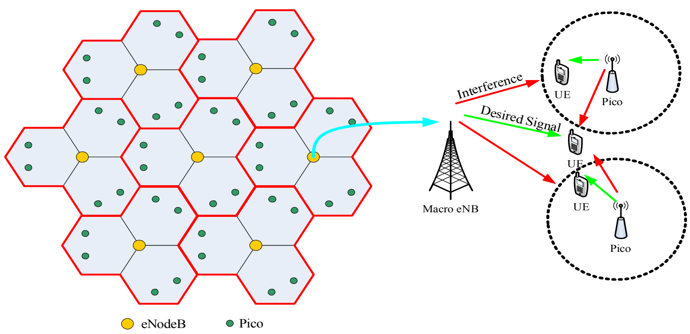

Fig. 1 Network topology and interference environment.

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To configure the proper link parameters, each UE should measure its channel environment based on the cell reference signals of its serving eNB and several strong interfering eNBs. Then, UE will feed them back to their serving eNB for the link adaptation. After obtaining the measurement report, the serving eNB can decide the initial modulation and coding scheme (MCS) for each UE. Contrary to the conventional equal transmission power configuration, this initial MCS decision is not sent to the UE via the radio resource control (RRC) signals in the proposed algorithm. Instead, the serving eNB will store this configuration for later power allocation calculation.

To utilize the concept of SON and make the algorithm suitable for the flat architecture of 3GPP LTE-A system with little information exchange through X2 interface, the concept of game theory is used here.

We can form a general non-cooperative game as

$$G = [\mathbf{N}, \{\mathbf{P}^n \times \mathbf{A}^n\}, \{u_n\}], \tag{1}$$

where $\mathbf{N} = \{1, 2, ..., N\}$ is the players of the game, which is the eNB in this case including both macro and pico, $\{\mathbf{P}^n \times \mathbf{A}^n\}$ is strategy space of each eNB, and u_n is the payoff function. Then, the non-cooperative game for the transmission power allocation can be formulated as

$$\max_{p^n \in P^n} u_n(p^n, P^{-n}, A^n), \text{ for all } n \in \mathbf{N} \tag{2}$$

The achievable signal-to-interference plus noise ratio (SINR) of the k-th UE served by eNB n on the m-th resource block (RB) given the transmission power set **P** can be calculated as

$$\gamma_{m,k}^n(\mathbf{P}) = \frac{G_{m,k}^n p_m^n}{\sum_{l=1, l\neq n}^{N} G_{m,k}^l p_m^l + \sigma^2}, \tag{3}$$

where $G_{m,k}^n$ is the effective channel gain for the k-th scheduled UE in eNB n on the m-th resource block including fast fading, path loss, shadowing and antenna gains; σ^2 is the additive white Gaussian noise (AWGN) power. Then, the achievable data rate can be calculated as

$$R_{m,k}^n(\mathbf{P}) = \frac{B}{M} \bullet \log(1 + \frac{\gamma_{m,k}^n(\mathbf{P})}{\Gamma}) \tag{4}$$

where B is the total system bandwidth; M is the total number of resource blocks; Γ is a parameter considering the block error rate requirement.

We further can calculate the total achievable data rate of user k with resource block allocation indication function $a_{m,k}^n$ as in (5).

$$R_k(\mathbf{P}, \mathbf{A}^n) = \sum_{m=1}^{M} a_{m,k}^n R_{m,k}^n(\mathbf{P}) \tag{5}$$

where $a_{m,k}^n = 1$ if resource block m is allocated to user k, otherwise $a_{m,k}^n = 0$.

III. Proposed Self-optimized Transmission Power Allocation Algorithm Using Fuzzy Logic Inference System

From Eq. (1)-(5), we find that the objective of the above transmission power allocation game is to maximize the system throughput while minimizing the effects of interference to other users, so we can set the utility function u_n as

$$u_n(\mathbf{P}, \mathbf{A}^n) = \sum_{k \in U_n} \mu_k R_k(\mathbf{P}, \mathbf{A}^n) - \sum_{m=1}^{M} c_m^n p_m^n \tag{6}$$

where μ_k represents the user k's quality of service (QoS) weight in the total system's utility; c_m^n represents the effects of the power adjustment on the co-channel interfered victim UEs with non-negative values, and larger c_m^n means the co-channel interfered victim UEs are very sensitive to the power adjustment on this RB.

According to the best response theory, the Nash Equilibrium on this power allocation problem can be obtained by applying the Lagrangian method and Karush-Kuhn-Tucker conditions. Then, the best response of eNB n on the m-th resource block is

$$[\mathbf{r}_n(\mathbf{P}^{-n})]_m = [\frac{B\mu_{k_m^{*n}}}{(c_m^n + \lambda^{*n})M \ln 2} - \frac{\Gamma(\sum_{l=1, l\neq n}^{N} G_{mk_m^{*n}}^l p_m^l + \sigma^2)}{G_{mk_m^{*n}}^n}]^+, \tag{7}$$

$$\lambda^{*n}(\sum_{m=1}^{M} [\mathbf{r}_n(\mathbf{P}^{-n})]_m - P_{\max,n}) = 0, \quad \lambda^{*n} \geq 0$$

In the conventional water-filling algorithm, the optimum variable of c_m^n can be derived from the serving and interfering path gains exchange among eNBs. In the centralized water-filling algorithm, all eNBs should report the serving and interference path gains to the central controller. While in the distributed water-filling algorithm, the information can be exchanged through X2 interface. Therefore, excessive information exchange overhead is required in both algorithms.

To avoid the above disadvantages in the conventional water-filling algorithms, the algorithm in [10] proposes to use a constant c instead of c_m^n to avoid information exchange between eNBs. But the constant c is not suitable to the fast varying interference environment and multiple measurement reports from UE to its serving eNB are still required. Instead of constant c value, the fuzzy logic is utilized here to obtain the suitable values of c_m^n, which enables the eNB to guess the optimum c_m^n autonomously with little information exchange overhead on the allocated transmission powers of the surrounding eNBs.

A linguistic variable is one of the key concepts in fuzzy logic. For example, power would be a linguistic variable in the control of transmission power allocation. It can take the linguistic value such as high, medium, and low. Such linguistic variables are embedded in the rules of a fuzzy controller and

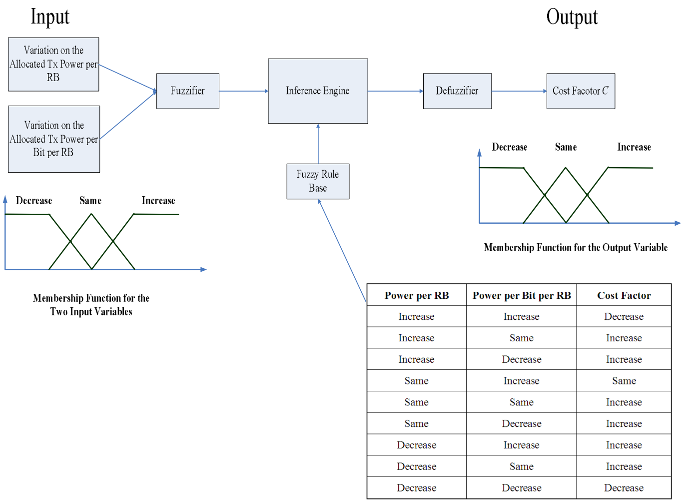

Fig 2. Structure of the fuzzy logic inference system utilized in the proposed algorithm.

allow human control expertise to be represented. A simple Fuzzy controller therefore consists of three elements: a rule base, a fuzzifier which converts measurements/observations into "fuzzy" variables, and a de-fuzzier which takes the results of reasoning and produces a new control setting. More sophisticated forms of controller may also have predictive abilities and time delay compensation. The rule base consists of the rules which dictate control actions and which have been derived from knowledge elicitation. The fuzzifier is the link between the measurements and the rules. Each measurement needs to be converted into a representation which can be used by the rules. After the rules have been processed, the de-fuzzifier takes the recommended control actions from all the rules that apply and combines them to give a new control setting.

Figure 2 shows the general structure of the fuzzy inference system adopted here, which is composed of the input, inference rule base, output, and membership functions. In the proposed fuzzy logic inference system, we use the variations on the absolute power (*w*) and the power efficiency (*bps/w*) as the input variables, and both are divided into {increase, equal, decrease} three levels. Similarly, the output variable which is the variation of c_m^n is also divided into {increase, same, decrease} for simplicity. Fuzzy rule base describes the knowledge about input and output linguistic variables. In this paper, the fuzzy rule base consists of nine fuzzy rules, which is shown in the table of Fig. 2. In addition, the center of area (COA) de-fuzzifier is applied here.

After obtaining the suitable c_m^n based on the fuzzy logic inference system in Fig 2, we can find the optimum parameter λ, using Eq. (7) and bi-section method considering the total transmission power constraint. Then, the optimum allocated power can be obtained.

IV. PERFORMANCE EVALUATION

1. Simulation Parameters

In this section, we compare the performance of the proposed method with the conventional equal power allocation

Table1. Detailed simulation parameters.

Parameter	Value	
HetNet scenario	3GPP downlink, outdoor Pico/Hotzone, configuration 1, model 1	
Cellular layout	Hexagonal layout with wrap around, 7 sites, 3 cells per site	
System frequency	2GHz carrier, 10 MHz bandwidth	
ISD	500m (case 1)	
Max MeNB Tx power	46 dBm	
Max Pico Tx power	30 dBm	
Number of Picos per cell	2, fixed at cell edge	
Number of UE per cell	25, uniformly and randomly distributed	
Traffic model	Full buffer	
Scheduling algorithm	Round Robin	
Scheduling delay	6ms	
Scheduling granularity	5PRBs	
Downlink HARQ	Asynchronous HARQ with CC, Maximum three retransmissions	
Channel model	SCM urban macro high spread for 3GPP case 1	
Number of MeNB antenna	1 Tx antenna	
Number of Pico/Hotzone antenna	1 Tx antenna	
Number of UE antenna	2 Rx antennas	
Antenna configuration	eNodeB antenna pattern: 14dBi antenna gain, sectorized $A_H(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right]$, where $\varphi_{3dB} = 70\text{degrees}, A_m = 25dB$ Pico antenna pattern: 5dBi antenna gain, Omni, $A(\varphi) = 0dB$ UE antenna pattern: 0dBi antenna gain, Omni	
Downlink receiver type	MRC	
Path-loss model	Macro to UE	L= 128.1+37.6log10(R), R in km
	Pico to UE	L= 140.7+36.7log10(R), R in km
Penetration loss	20dB for both macro to UE and Pico to UE	
Channel estimation error	None	
Control Channel overhead, Acknowledgements etc.	LTE: L=3 symbols for DL CCHs, overhead for demodulation reference signals	

method (referred as baseline) and distributed water-filling (DWF) algorithm. The detailed simulation parameters are outlined in Table 1 the same as those in [11]. UEs are associated to a macro or a pico eNB according to the best downlink reference signal receiving power. In addition to the data transmission, the HARQ re-transmission is also considered in the performance evaluation. To avoid further

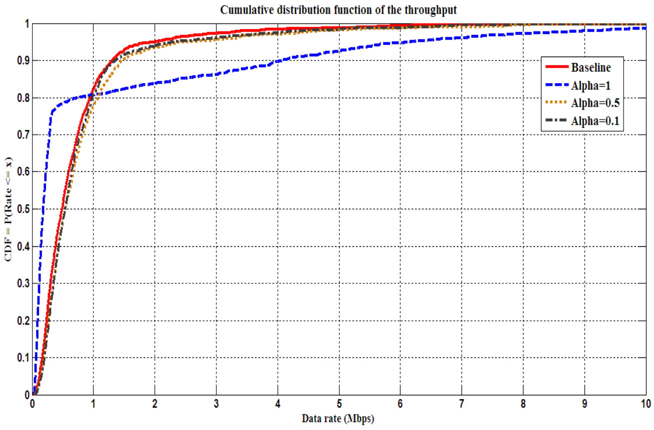

Fig 3. Comparison of CDF on average UE received data rate between baseline and the proposed algorithm.

data loss due to null transmission power allocated to the RB which performs the HARQ process, the amount of $(1-\alpha)P_{total}$ is allocated equally among RBs, and the remaining amount of αP_{total} is allocated using the proposed method, where P_{total} is the total transmission power of eNB and α is set as 1, 0.5, and 0.1 to examine the effects of power reallocation ratios on the system performance. Finally, the actual allocated power for each RB is the summation of the above two parts.

2. Evaluation Results

Figures 3 and 4 illustrate the cumulative distribution function (C.D.F.) curves of the UE received data rate corresponding to the cases of baseline, the DWF algorithm, and the proposed algorithm. Table 2 records the comparison of 5%-ile (cell-edge), and mean (cell-average per UE) user received data rate in Fig. 3 and 4. From the simulation results, we find that the configuration of parameter α can be used to balance the performance of cell mean and edge users. When all the eNBs' transmission power is allocated (i.e., α =1), most of the transmission power will be allocated to the central users due to their best channel environment and small effects to the co-channel interfered victim UEs, which also causes the performance degradation for the cell edge users because of near-null transmission power allocation. Comparing to the conventional distributed water-filling algorithm, the proposed algorithm outperforms the conventional DWF algorithm by 34.9 % and 5% in the aspects of cell mean and edge UE received data rate, respectively. When α decreases, the cell mean UE received data rate decreases while the cell edge data rate increases in the case of the proposed algorithm, because some eNBs' transmission power is equally allocated to all users to guarantee the HARQ process and cell edge users' performance. In addition, we observe that when α =0.5, we can get nearly equal gains on the system cell mean and cell edge UE received data rates.

3. Procedure of the Proposed Algorithm

In practice, the link adaptation parameters such as the transmission power and MCS should be transmitted to the UE

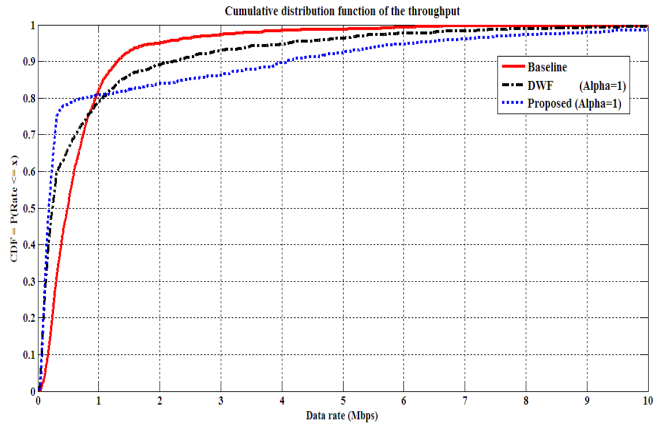

Fig 4. Comparison of CDF on average UE received data rate between the distributed water-filling algorithm and the proposed algorithm.

for the correct radio frequency signal reception and decoding at the UE side. Therefore, we can utilize the existing transmission power related parameters PA and PB in LTE to inform UE the updated transmission power with a limited parameter range extension [12]. Figure 5 shows the detailed realization procedure of the proposed algorithm in 3GPP LTE-A systems.

Table 2. Summarized performance comparison.

	Mean (kbps)	Gain over the Baseline	Cell Edge (kbps)	Gain over the Baseline
Baseline	737.9927		123.15	
α =1	1120.2	51.8 %	57.4577	-53.3 %
α =1 (DWF)	862.6549	16.9 %	51.3888	-58.3 %
α =0.5	876.2839	18.7 %	145.8266	18.4 %
α =0.1	830.9924	12.6 %	154.8073	25.7 %

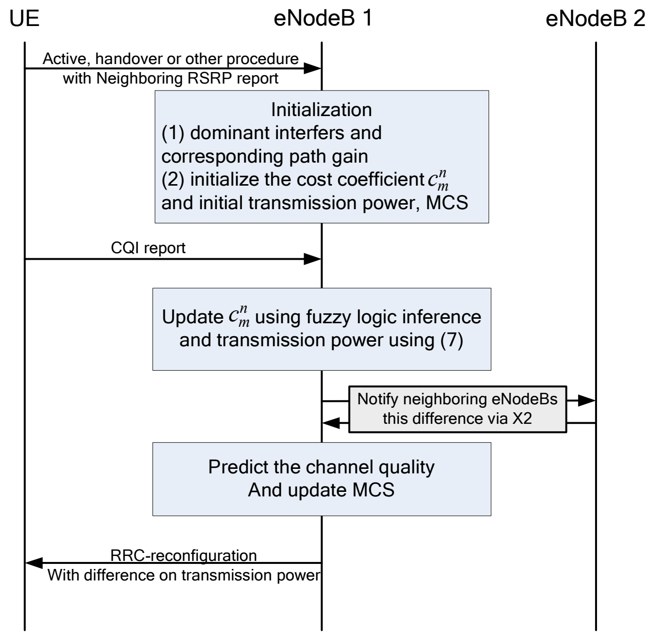

Fig 5. Practical procedure of the proposed algorithm in 3GPP LTE-A system.

V. CONCLUSIONS

In this paper, we propose an optimum power allocation algorithm for 3GPP LTE-A HetNet based on the combination of game theory and fuzzy logic inference, which utilizes the concept of self-optimization in SON and requires little information exchange among eNBs. The proposed algorithm solves the problems existed in the conventional centralized and distributed water-filling algorithms and carefully takes the co-channel interference effects into the consideration of the transmission power allocation procedure. From the simulation results, we observe that the proposed algorithm outperforms the conventional distributed water-filling algorithm by more than 30 % and the performance of cell mean and edge UE received data rate can be easily adjusted by the power-balancing parameter α in the proposed algorithm.

In addition, the proposed algorithm can be easily realized in the currently LTE-A specification using the existing RRC signaling to inform user the updated transmission power configuration, with a simple extension on the range of parameters.

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