

Load Balancing with Transmission Power Control in Femtocell Networks

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Abstract— Femtocells applied in many existing systems, such as HSPA, 3GPP LTE, WiMAX, and etc, which cover a short range and offer an economically viable way to improve cellular system capacity, have caught world-wide researching interest nowadays. The primary purpose of femtocell solutions has been to improve indoor coverage in current cellular systems. Here, users that are moved to femtocells experience increased throughput due to shorter ranges, while using the cable backhaul to reach the network gateway. However, more importantly, the smaller size of femtocells increases the system capacity by enabling spatial reuse, whereby multiple femtocell transmissions can be executed on the same channel in a macro cell. But existing femtocell solutions only increase the network capacity without considerations of fairness of per femtocell user equipment (FUE) capacity.

In this paper, we propose a load balancing scheme with the optimal fairness of per FUE capacity on 3GPP systems, which is split into two steps named interference recognition and femtocell load balancing, respectively. In interference recognition step, the interference graph is created on the basis of the interference detection mechanisms consisting of user equipment measurement (UMR) and femtocell cooperation message (FCM). In femtocell load balancing step, we reallocate femtocell user equipments (FUE) to FAPs based on the interference relationship. By extensive simulations, it has been proved that the proposed scheme can effectively allocate FUEs to FAPs to increase the minimum capacity of FUE. This means that the proposed scheme leads the optimal FUE allocation in terms of fairness of per UE capacity.

Keywords— Load balancing, Femtocell network

I. INTRODUCTION

Femtocells provide cost-effective means of providing ubiquitous connectivity in future broadband wireless networks. There has been a significant impetus towards the deployment of these femtocell solutions by several cellular providers, namely Sprint, Vodafone, Korea Telecom, SK Telecom, etc [1-4]. The primary purpose of existing UMTS-based femto solutions has been to improve indoor coverage in current cellular systems. Here, users that are moved to femtocells experience increased throughput due to shorter

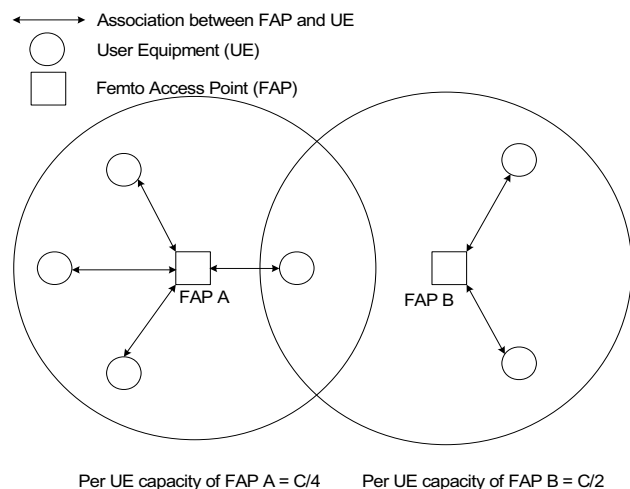


Figure 1. Example of unfair capacity usage in multi-femtocell environment

ranges, while using the cable backhaul to reach the network gateway. But more importantly, the smaller size of femtocells increases the system capacity by enabling spatial reuse, whereby multiple femtocell transmissions can be executed on the same channel in a macro cell. But existing femtocell solutions only increase the network capacity without considerations of fairness of femtocell user equipment (FUE) data rate [2-4]. This induces some FUEs are served with the low data rate because FUEs associated with the same FAP share the network capacity. However, in perspective of both network providers and users, FUE should be served with fair data rate. Thus, in this paper, we proposed load-balancing scheme to allocate FUEs to femtocell access points (FAPs) optimally in terms of fairness of per UE capacity. Through extensive simulations, we prove that the proposed scheme provide the optimal data rate for FUEs.

The reminder of the paper is organized as follows: In Section II, we describe the capacity unfairness problem in the multi-femtocell network. We develop the architecture for femtocell to achieve the fairness of per UE capacity in Section III. Section IV shows the description of the proposed load balancing

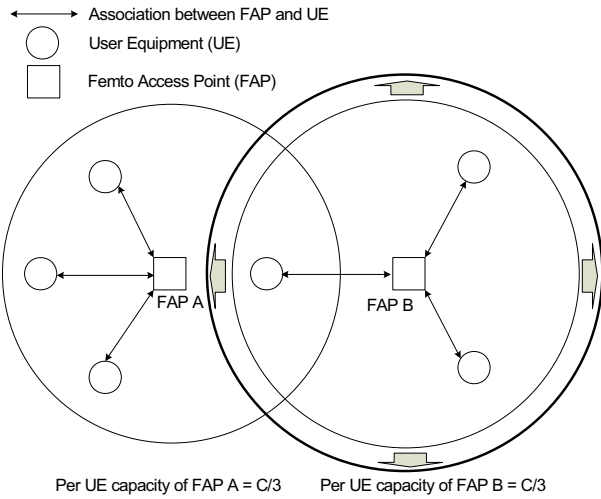


Figure 2. Example of fair capacity usage in multi-femtocell environment

scheme. Simulation results are mentioned at Section V. We conclude the paper in Section VI.

II. PROBLEM DESCRIPTION

For ease of installation, FAPs are typically installed by non-expert users. Non-expert users can not consider the network performance. They just connect a FAP to DSL (Digital Subscriber Line) and turn on the FAP. FAP self-organizes its radio parameters and system operational parameters [2-4]. A FUE within FAPs' coverage automatically tries to associate the FAP with strongest signal at the FUE. However, this FUE's mechanism leads unfairness in terms of per FUE capacity. As shown in Figure 1, there are 6 FUEs and 2 FAPs with unbalanced FUE associations. Per FUE capacity of FAP A is $C/4$, and Per FUE capacity of FAP B is $C/2$. If FAPs and FUEs cooperatively operate, then FUEs are optimally associated with FAPs. The example of optimal FUE allocation is in Figure 2. As shown in this figure, 6 FUEs are well distributed among 2 FAPs with $C/3$ of per FUE capacity. To resolve this unfairness problem, we propose the architecture for femtocell load balancing and devise the heuristic method for load balancing through allocating FUEs among FAPs.

III. PROPOSED ARCHITECTURE

To achieve the optimal fair capacity usage of FUEs with co-located FAPs, we proposed the architecture for femtocell load balancing which is described in Figure 3. FAPs connect with a backhaul network through DSL. The backhaul network can contain a femtocell gateway (FGW) and several entities of the core network. The new control frames are appeared in the proposed architecture.

The first on is UE measurement report (UMR) frame reporting measurement results about co-existing FAPs and path-loss relationship between them. For instance, FUE 1

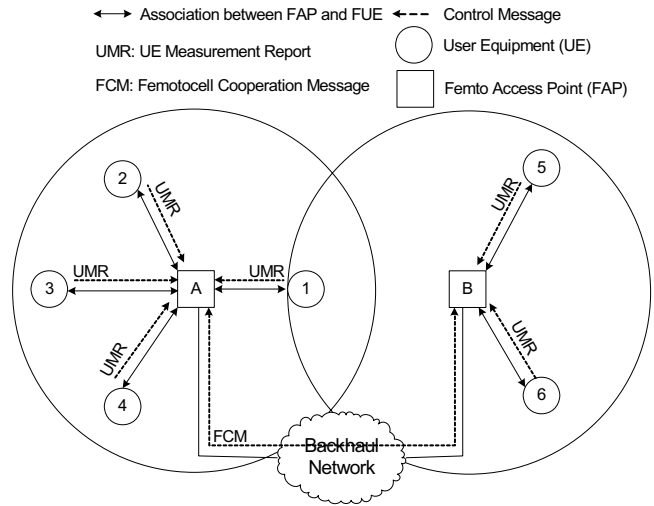


Figure 3. The proposed architecture for femtocell load balancing

measures the path-loss relationship from FAP B and reports. After receiving UMR from FUE 1, FAP A sends femtocell cooperation message (FCM) to FAP B, which co-located with FAP A and is related with FUE 1. In this example, FAP A and FAP B can cooperate to allocate FUE 1 with the optimal capacity usage. FUEs periodically measure the radio environment and report to the associated FAP through UMR transmissions. Also, a FAP shares the measurement results reported by its FUEs with co-located FAPs. Each FUE measures path-loss between FUE and co-located FAPs based on the following equation.

$$PL_u^f = R_u^f / P^f, \quad (1)$$

where PL_u^f is path-loss between FAP f and UE u ,

R_u^f is received signal power from FAP f , and P^f is transmit power of FAP f .

In this network configuration, FUE 1 measures the received signal power from FAP B (P_1^B), and estimates the path-loss between FAP B and FUE 1 (PL_1^B) based on (1). Then, FAP A transmits FCM containing path-loss information (PL_1^B) and traffic load information (= number of associated FUEs with FAP A) to FAP B. As a result, FAP B recognizes that it interferes with, and is interfered with FAP A and FAP A's FUEs. Thru these procedures (IGC), all FAPs share co-located FAPs information and their FUEs information.

IV. PROPOSED SCHEME

In this section, we describe the load balancing scheme to allocate FUEs to co-located FAPs optimally. To end this, we first identify candidate UEs, which receive the signals from 2 or more FAPs. By allocating candidate UEs over co-located FAPs, we can achieve the optimal load balancing in terms of fairness of per UE capacity. For ease of understanding, we assume that there are two co-located FAPs (FAP i and FAP j). The candidate UE ($u_{i,j}$) can associate with FAP i or FAP j . The

basic requirement of candidate UE ($u_{i,j}$) to be associated FAP I is expressed as following equation.

$$SINR_u^i = \frac{PL_u^i P^i}{PL_u^i P^j + I_u} > \Gamma_u, \quad (2)$$

where I_u is an overall interference (including noise) at UE u , Γ_u is the required SINR at UE u , and $u \in \{\text{Candidate UEs } (u_{i,j}) \text{ that make an association with FAP } i\}$

With a similar manner, the basic requirement of candidate UE ($v_{i,j}$) to be associated FAP j is expressed as following equation

$$SINR_v^j = \frac{PL_v^j P^j}{PL_v^j P^i + I_v} > \Gamma_v, \quad (3)$$

where I_v is an overall interference (including noise) at UE v , Γ_v is the required SINR at UE v , and $v \in \{\text{Candidate UEs } (v_{i,j}) \text{ that make an association with FAP } j\}$

We rearrange (2) and (3) in terms of transmit power of FAP i (P^i).

The equation below is rearranged formula of (2).

$$P^i > \frac{\Gamma_u PL_u^i P^j + \Gamma_u I_u}{PL_u^i} \approx \frac{\Gamma_u PL_u^i P^j}{PL_u^i} \quad (4)$$

for candidate UEs ($u_{i,j}$) that make an association with FAP i.

PL and P^j are dominant factors over I_u , thus we approximate the formula as (4). The rearranged formula of (3) can be expressed as following:

$$P^j < \frac{PL_v^j P^i - \Gamma_v I_v}{\Gamma_v PL_v^j} \approx \frac{PL_v^j P^i}{\Gamma_v PL_v^j} \quad (5)$$

for candidate UEs ($v_{i,j}$) that make an association with FAP j.

To meet basic requirements of FUEs, both (4) and (5) in terms of transmit power of FAP i should be satisfied. We can describe the feasibility condition for transmit power of FAP i (P^i) as one formula blow.

$$\begin{aligned} \frac{\Gamma_u PL_u^i P^j}{PL_u^i} < P^i < \frac{PL_v^j P^i}{\Gamma_v PL_v^j} \\ \rightarrow \frac{\Gamma_u PL_u^i P^j}{PL_u^i} < \frac{PL_v^j P^i}{\Gamma_v PL_v^j} \\ \rightarrow \max_u \frac{\Gamma_u PL_u^i}{PL_u^i} < \min_v \frac{PL_v^j}{\Gamma_v PL_v^j} \end{aligned} \quad (6)$$

for $u \in \{\text{Candidate UEs } (u_{i,j}) \text{ that make an association with FAP } i\}$

and $v \in \{\text{Candidate UEs } (v_{i,j}) \text{ that make an association with FAP } j\}$.

With a similar manner, (7) should be satisfied in terms of transmit power of FAP j (P^j).

$$\begin{aligned} \frac{\Gamma_v PL_v^j P^i}{PL_v^j} < P^j < \frac{PL_u^i P^j}{\Gamma_u PL_u^i} \\ \rightarrow \frac{\Gamma_v PL_v^j P^i}{PL_v^j} < \frac{PL_u^i P^j}{\Gamma_u PL_u^i} \\ \rightarrow \max_v \frac{\Gamma_v PL_v^j}{PL_v^j} < \min_u \frac{PL_u^i}{\Gamma_u PL_u^i} \end{aligned} \quad (7)$$

for $u \in \{\text{Candidate UEs } (u_{i,j}) \text{ that make an association with FAP } i\}$

and $v \in \{\text{Candidate UEs } (v_{i,j}) \text{ that make an association with FAP } j\}$.

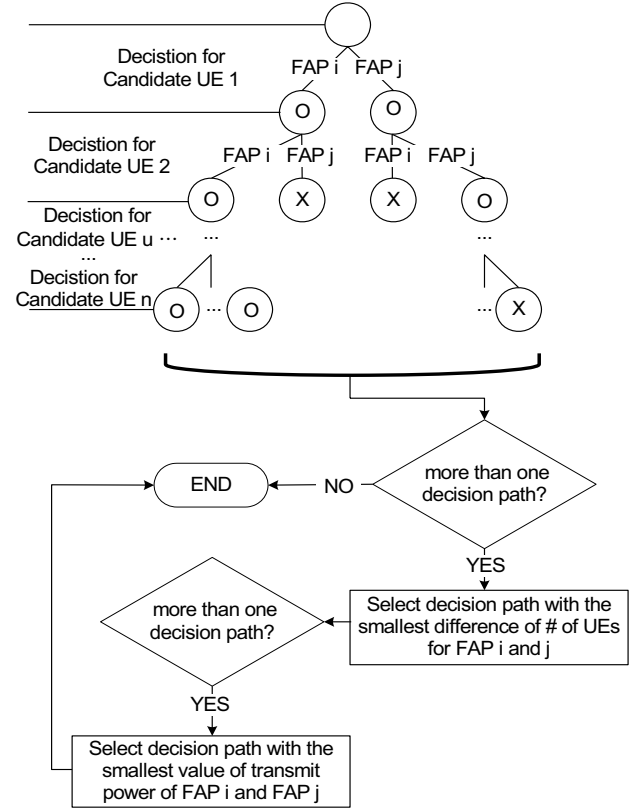


Figure 4. Decision tree for load balancing

Based on (6) and (7), we investigate the opportunity for load balancing.

The optimal load balancing scheme aspect of per FUE capacity is described in Figure 4. To ease of understanding, we assume there are two FAPs. As shown in Figure 4, each level means a decision for each candidate UE. At each level, we check the feasibility to association between a FAP and the candidate UE based on (6) and (7). If there is the feasibility for association, then we mark a node with 'O'. Otherwise, we mark the node with 'X'. For example, the candidate UE 1 can associate with FAP i and FAP j in Figure 4. Next, we traverse both branches and check the feasibility for candidate UE 2.

At this time, there are 4 decisions with the previous assignment of candidate UE 1. For instance, candidate UE 1 associates with FAP i and candidate UE 2 can associate with FAP i. However, candidate UE 2 can not associated with FAP j if candidate UE 1 associates with FAP i. We repeat traversing via only 'O' marked braches and checking the feasibility for

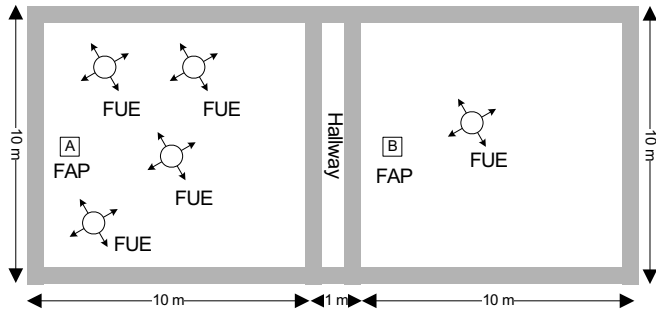


Figure 5. A typical Korean apartment model with femtocell networks

UE associations. Finally, all decisions for candidate UEs have done. If there is no available decision path, then the load balancing ends without changes. If there are more than one decision path, then we investigate the optimal decision path in terms of per UE capacity. Firstly, we find the decision path with the smallest difference of number of UEs for FAP i and j among feasible decision paths. By doing this, the optimal fairness of per UE capacity can be achieved. Additionally, FAPs select the decision path to minimize their transmission power.

V. PERFORMANCE EVALUATION

To evaluate the proposed load balancing scheme through FUE allocations, we implement C++ event-driven simulator based on femtocell path-loss model [5]. A typical Korean apartment model is selected to represent the femtocell networks [6]. The size of each apartment is 10m x 10m. There is a hall between two, with a width of 1m. The plane figure is in Figure 5. To make unfairness case in terms of per UE capacity, we deploy 4 FUEs in the left room and 1 FUE in the right room with uniform manner, respectively. Simulation and system parameters are taken mostly from [3, 5]. The key system parameters are shown in Table I. After applying the proposed scheme, the optimal configuration of FUEs and FAPs is checked. The optimal configuration of fair per UE capacity means that one FAP has 3 FUEs and the other FAP has 2 FUEs. The simulation results show that our proposed scheme allocates FUEs to make per UE capacity optimal in terms of fairness with 68% of total simulations.

VI. CONCLUSIONS

In this paper, we propose a load balancing scheme for femtocell networks to make per UE capacity optimal in terms of fairness. To obtain interference relationship between FAPs and FUEs, two measure and report mechanism are proposed. The first mechanism called UMR that recognizes path-loss relationship from neighboring FAP and FUE.

The other one named FCM is to exchange interference relationship and candidate UE information with co-located FAPs. Based on interference relationship and candidate UE information, the proposed load balancing scheme performs allocations of FUEs with checking feasibility conditions by

TABLE 1. System parameters for simulations

Propagation model	3GPP TSG-RAN WG3 R4-071617
FAP MIN/MAX Tx Pw	-10 dBm / 20 dBm
Required SINR	32 dB with spreading factor 16
Number Tx antennas femtocell	1
Femtocell antenna gain	0 dBi
Number Rx antennas UE	1
Antenna pattern	Omni-directional

traversing decision tree. The simulation results prove that the proposed load balancing scheme produces the optimal configuration of FUEs and FAPs in terms of fairness of per UE capacity with 68% of total simulations, which is well suitable for dense and skewed FUE distributions.

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