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A case study on femtocell access modes

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ABSTRACT

Access mode of a femtocell network plays a crucial role in determining the service quality of femtousers and the revenue of network operators. The behavior of a femtocell is not only based on network density, orthogonal or non-orthogonal multi-access technique, frequency reuse strategy, but also on the access mode being adopted. The access mode selection directly influences the performance metrics like handover mechanism, security, resource management and co-channel interference management. In this paper, we analyze the behavior of femtocell networks in three different access modes. We examine the choice of access mode from the aspect of network operator and FC owner. Under various network scenarios, we identify the best access mode analytically in terms of ergodic rate, sum throughput and interference factor. Simulation results indicate that the performance of conventional cellular network can be improvised through proper selection of FC access mode. It indicates that the selection of a particular access mode strictly depends on the performance requirements of network operator and FC owner.

1. Introduction

Every day, there is a growing demand for higher data rate services and the conventional macrocell (MC) network is unable to provide better services to data-rate-hungry users [1]. To handle tremendous traffic burden, the recent heterogeneous network has emerged with an answer in the form of low power femtocell (FC) networks which bring the base station closer to the users. Deployment of many FCs offer higher throughput to network users and bring-down the traffic bottleneck at the MC network [2]. The configuration phase of FCs includes access mode selection as a fundamental task. In general, access mode is regarded as the ability of a femto-base station (FBS) to allow or restrict the nearby network user to access the core network [3].

The FCs or the FBSs can be flexibly configured in any one of the three access modes namely open access mode, closed access mode and hybrid access mode. Among them, the primitive access mode is closed access mode that evolved based on the Closed Subscriber Group (CSG), conceptualized by Release 8 of Third Generation Partnership Program (3GPP) [4]. In the conventional CSG based Home evolved Node B (HeNB), limited number of network users are grouped in an Access Control List (ACL) and only those registered users in the list are offered with a high quality service [5]. In Long Term Evolution (LTE) technology, the CSG is referred as FC and the HeNB is denoted as FBS. The network users in the ACL database are termed as femtousers (FUs), who are allowed to access FC's backhaul resource [6]. Hence, the FCs were initially designed and deployed in closed access mode to serve only certain set of registered users, rather than accepting a cross-tier macrouser (MU).

Subsequently with 3GPP release 9 specifications on inter-tier mobility [7] and security aspects [8], the open access mode has emerged in FC networks. The network operators viewed open access FCs as an attractive solution to extend the service to the MUs present in cell-edge, coverage hole and shadow regions. Hence, they deployed more and more number of open access FCs to support cross-tier users over limited FC's resource. However, in open access mode, FUs who really pay for the backhaul bill experience service outage on the unrestricted camping of cross-tier users [9]. In order to offer preferential access to registered FU, a new functionality was introduced in 3GPP TSG SA WG1 Release 9 [10] in the name of hybrid access mode. With a preferential treatment to the FUs, the hybrid access mode shares *limited amount* of resource with *selective number* of cross-tier users [11].

To define, closed access mode allows only the registered FUs to camp-in, thereby preventing the FBS from the public access. In open access mode, cross-tier MUs are unconditionally allowed to access the FC's resource along with the registered FUs. Hybrid access mode, on the other hand, combines the benefits of closed and open access modes through priority based service to FU and best effort service to MUs. Many literatures have viewed and analyzed the behavior of FC access modes with various schemes

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under different environmental conditions. The following discussion enumerates the challenges in access mode selection and the solution for the challenges. Golaup [12] discussed the access control strategy of FCs from the aspect of pre-release 8-Universal Mobile Telecommunication System (UMTS) network, pre-release 8 User Equipment (UE), Third Generation Partnership Project (3GPP) release 8 and LTE standards. In addition to periodic cell reselection method, Golaup proposed two methods namely, autonomous system information acquisition method and manual system information acquisition method for proper identification and selection of FC access mode. The inbound handovers in LTE and UMTS standards were also discussed in [12].

Xia [13] analyzed the uplink capacity of open and closed access FCs over orthogonal and non-orthogonal multiple access schemes. Based on the constraints like FC backhaul, user density and throughput requirement, the choice of access mode was examined. The analyses in [13] concentrated on open and closed access modes, whereas the choice and effects of hybrid access mode were not considered. In general, access mode selection greatly influences the level of interference in co-existing macro-femtocell networks. The closed access mode induces interference to the MU, whereas the open access mode affects the performance gain of the registered FUs. To overcome this performance conflict between access modes, Jia-Shi Lin [14] proposed the hybrid access mode based on pure Nash Equilibrium model. The function of all users was determined on the basis of channel quality, resource scheduling priority and service preference to subscribers, this model [14] offered service to cross-tier MUs. As per [6], hybrid access mode was more flexible as it used Game theoretical model that aided in selecting the appropriate network user to be its home user.

It is remarkable that an MU always chooses to become a home user of good signal quality FC, whereas an FBS always prefers to select an interference-aggravating MU, thereby protecting itself from cross-tier interference. Hence, to regulate the admission strategy in open and hybrid access modes, a Mutual Selection Admission (MSA) algorithm was modeled in [15]. Out of different levels of stability, MSA algorithm chose to serve a weak MU based on limited resource constraint. The MSA algorithm found the stable match using Nash's hard formulation, thereby yielding a rate gain to both MU and registered FU.

Flexible spectrum allocation in closed and open access FC networks was discussed in [16]. In a densely populated area, MUs and closed access FUs were assigned with disjoint set of subchannels, whereas in less populated area, joint set of subchannels were assigned to MUs and open access FCs [16]. The joint sub-channel assignment strategy in open access FCs provided higher throughput than the disjoint sub-channel assignment strategy in closed access FCs. Tarasak et al. [17] examined Inter-carrier Interference (ICI) between fixed number of MUs and FBSs. With fixed distance of separation between MBS and FBS, Tarasak [17] derived the closed-form expression for the probability of an MU causing ICI to the open access FCs. For a fixed number of FC deployment, their analyses showed that the probability of ICI in open access mode was lesser, whereas for the same number of closed access FCs, the probability of MU experiencing ICI was more.

Jo et al. [18] presented the mathematical model for zone-wise SINR distribution with respect to distance between FBS and MBS. For open and closed access FCs, the sum throughput of FU and MU were arrived in [18]. They proposed a shared access approach in which each FC had a time slot gap to serve between the FU and the MU. The optimal value of the time slot gap met the Quality of Service (QoS) requirement of home user, thereby maximizing the overall network throughput. The shared access approach yielded 80% better network throughput than open access mode and whenever the QoS requirement of home user was higher, the overall throughput of shared access approach degraded similar to open access mode.

Bernal [19] developed an analytical model to study the activity profile of FUs and MUs in open access FCs. In an uncommon way, Bernal assumed that the FUs as primary network users and MUs as secondary network users, where MUs were supposed to vacate the channel of interest on FUs' arrival. In addition, based on the experienced SINR, the attainable data rate of each channel was determined and from the data rate, the best channel was chosen for the operation of open access FCs [19].

The relationship between access policy and the performance contribution of access modes in overall network was explored in [20]. A specific attention was imposed on understanding the relationship between traffic burden and respective quality of service. Choi [21] presented the mutual interaction between mobile stations and nearby open access FCs. It was shown that the performance improvement was attained over closed and open access approaches with an adaptive FC access policy with respect to network load. The work presented in [22] discussed the benefits and the challenges of access methods from the business aspect. The technical impact of access mode in macro-femtocell networks was provided in [22], with an emphasis on the need for hybrid access mode.

The discussion of Lopez-Perez [23] presented a framework for the study of Worldwide Interoperability for Microwave Access (WiMAX) in comparison with macro-femtocell hybrid scenarios. An in-depth description of the necessary radio coverage prediction and system-level simulation for the above scenarios were introduced. Simulations and numerical results were presented in [23] for the downlink side communication with public (open) and private (closed) access methods. Ko [24] studied the resource sharing aspect over different FC access modes. Over an IP based network, FC's resource allocation algorithm [24] controlled the private traffic information of the FUs to travel through the secured gateway. Fair resource sharing was attained even in open access FCs, thereby guaranteeing high quality service to registered and non-registered users.

Many of the literatures dealing with FCs concentrate on proposing solutions for the challenges associated with each of the FC access modes. To understand the effects of FC access modes in the overall network performance, we examine all the three access modes under certain network and system operating conditions. We focus on studying the importance of appropriate access mode selection in an FC network. The subsequent sections are organized as follows. Section 2 elaborates on the three different access modes of FCs. We discuss the choice of access mode from the aspect of FC owner and the network operator in Section 3. Section 4 presents the mathematical formulation to analyze the consequences of not identifying proper FC access mode. Section 5 examines the performance of FC access modes and highlights the merits associated with each access modes. Section 6 briefs out the conclusion.

2. Types of femtocell access modes

In macro-femtocell heterogeneous networks, the service quality experienced by co-existing FU and MU is greatly dependent on FC access modes. The permissible number of network users and the level of service guarantee to the cross-tier users are purely based on access mode adopted by an FC [25]. The interests of registered FU and unregistered MU in selecting an access mode are conflicting, that is, the indoor FUs choose closed access mode and the outdoor MUs prefer open access mode [26]. To mitigate this conflict, hybrid access mode has evolved. The following discussion elucidates on the three access modes of FCs.

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