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Orthogonal circular polarized transmission for interference control in femto–macro networks

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ABSTRACT

Multi-tier networks comprising of macro-cellular network overlaid with less power, short range, home-base station like femtocells provide an economically feasible solution for meeting the unrelenting traffic demands. However, femtocells that use co-channel allocation with macrocells result in cross-tier interference which eventually degrades the system performance. It is for this reason that, cross-polarized data transmission is proposed in this paper as a potential approach towards improving the spectral efficiency of cellular systems and at the same time permitting co-channel allocation. Here two independent information channels occupying the same frequency band can be transmitted over a single link. The paper evaluates a scenario where femtocell network makes use of right hand circular polarization (RHCP) and macrocell network makes use of left hand circular polarization (LHCP) for signal transmission. The polarizations being orthogonal to each other due to their sense of rotation ensure isolation between the networks and enable both of them to use the same spectral resources simultaneously. Analytical and simulation results prove that this opens the scope for an easily implementable, remarkable opportunity in the context of two-tier femto–macro network that can increase the system capacity. The paper closes by discussing the technical challenges involved in the implementation as well as the possible solutions to overcome the same.

1. Introduction

Wireless communication has always proved to be a fundamental driver of modern information infrastructure while its economic growth brings about exciting developments that makes the world a global village. The continuously galloping demand for bandwidth-hungry services with better signal quality constantly encourage the researchers to develop innovative designs for better communication networks with wider frequency spectrum allocation. A survey in Femtocell Europe and a study by ABI research projected that, 30% of business and 45% of household users experience very poor indoor coverage while more than 50% of voice calls and 70% of data traffic in the future is expected to originate from indoors [1]. At the same time, the revolutionary explosion of attractive mobile internet applications along with the proliferation of seamless connectivity devices drive the global mobile data traffic usage in the indoors to double every year through 2014, leading to a global compound annual growth rate of 108% [2]. This finally confronts the wireless industry with the demand for ubiquitous indoor wireless coverage to the customers which at the same time can transform into higher revenue and reduced churn for the network operators. In order to accomplish this significant network performance leap, the heterogeneous networks have been proposed as the next big step in future personal communication systems [3]. In this context, several industrial critics have also started to discover the hidden potential in the deployment of so-called home base stations or femtocells and its aggressive utilization [4–7].

Femtocell also known as Femto Access Point (FAP) is a low-power, low-cost base station, usually installed indoors to provide high speed data connection to subscribers and can be overlaid with the existing cellular network. This "plug and play device" which resembles a Wi-Fi router offers every cellular functionality to the end-user [4]. A study by Informa Telecoms and Media stated that by 2014, about 114 million mobile users will be accessing the cellular network through 50 million femtocells [5]. This increase in the number of cells demand efficient spectrum reuse in order to guarantee larger data rates. The question now is how quickly this fledgling femtocell technology can overcome significant challenges, on their way to increasing its credibility and making itself-the technology of choice for in-home wireless use.

The co-existing femto–macro architecture definitely improves the coverage and ensures capacity relief by offloading the traffic

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from the overburdened macrocell network. However, the unplanned ad-hoc deployment of femtocells in the macrocell network render the dynamic management of system resources a challenging task for the network operators. The system resource often being limited by the scarce and expensive frequency spectrum introduces interference between the femtocell and macrocell layer in co-channel operation, which degrades each other's performance [7]. Hence the co-existing femtocell–macrocell network demands efficient spectrum utilization backed by the need for better frequency reuse and orthogonal spectrum allocation techniques. Methods for optimizing the system capacity through intelligent frequency reuse must be figured out so as to overcome this challenge. Traditional frequency planning with higher frequency reuse patterns may result in wastage of limited available spectrum while a full frequency reuse within each sector of every cell may turn out to be an excellent solution. However, a full frequency reuse can result in co-channel interference (CCI) which may arise from concurrent inter-cell and intra-cell transmissions which can further degrade the Quality of Service (QoS) and hence the data-rate assured to the consumers. To cope-up with this cross-tier interference, several intelligent interference avoidance schemes were proposed, the most popular among them being spectrum splitting [7], limiting the number of femtocells [8] and introducing relaying techniques [9], orthogonal frequency allocation [10], power control [11], etc. Also the available literature for CCI reduction seem to be rich [11–16] too. Significant attention is given to scheduling algorithms [11–13] that is capable of organizing the total amount of interference.

In this technical standpoint, wireless radio bandwidth being expensive, prompts a close examination of the data channels available using electromagnetic waves. Since wireless communication utilizes polarization-sensitive electromagnetic (EM) medium for signal transmission, polarization could be explored as an independent domain for interference management. Even though the concept of polarization diversity is not a recent one, it remained under-utilized for the past several years and hence exploiting it for improving the spectral efficiency and system capacity seems to be the next logical step to undertake. Exploring polarimetric dimension is an exciting research direction and may bring revolutionary subversion, fundamentally for wireless communication. The concept of cross-polarization allocation is already introduced in systems operating under line-of-sight (LOS) conditions as a means of isolating the interfering signal from the desired signal [14]. The concept of a heuristic scheduling along with a terminal classification procedure for interference reduction is extended in [12], with a different scheduling algorithm for odd and even sectors. In [13] the scheme is further improved with the introduction of power shaping concept. The above concepts of combined scheduling of the intra-cell and inter-cell transmissions and cross-polarization allocation method has been integrated in [15] for minimizing the interference and hence improving the quality of service. On the other hand, an alternate polarization allocation scheme for Local Multipoint Distribution Service (LMDS) operating under LOS conditions is presented in [16]. A similar scheme for systems operating under non line-of-sight (NLOS) operation is proposed in [17] which gives due importance to the channel allocation policy and thereby reduce CCI. [18] addresses the potential benefits of dual-polarized antenna systems in wireless communication scenarios whereas the measurements and modeling of polarized transmission in indoor NLOS environments is analyzed in [19] which approves that a compact antenna system with lower inter-antenna correlation can be obtained with the help of perpendicularly polarized antennas.

In this paper, we propose an OFDM multiplexing transmission system that employs orthogonally polarized antennas for transmission in femto–macro systems. Most of the frequency reuse schemes available in the literature resort to spatial reuse with sub-channels used in one cell being banned in the neighboring cell. On the contrary, this paper investigates the application of cross-polarized wireless access (CPWA) to permit universal frequency reuse where all cells have the potential to access all available resources. This enables the same frequency carrier to be used for radio transmission by both networks simultaneously. Moreover, the orthogonal sense of rotation doubles the OFDM system capacity through proper interference mitigation between the femto–macro networks. Thus in co-existing femto–macro network, it provides an acceptable tradeoff and overall enhanced system performance. The paper also scrutinizes the impact that CPWA has on legacy macrocell network and concludes on the benefits that it brings along to enhance the overall system performance. Also due to the independence of the polarization states, the incorporation of polarization division multiple access (PDMA) and polarization modulation (PM), is expected to improve the spectrum efficiency too [20]. The scenario of interest for this work is explained in Fig. 1. Even though similar frequency reuse strategy is employed in satellite transmission systems, this is the first ever proposed for a femto–macro system to the best of our knowledge.

The rest of the paper is organized as follows. Section 2 discuss the reasons behind the polarization mode chosen and Section 3 demonstrates the CPWA frequency allocation strategy adopted in two-tier femto–macro network for interference reduction. Section 4 carries out the system analysis that gives insight on the capacity improvement and increased coverage probability achieved through this method. This analysis is further used for extensive simulations carried out in Section 5 for performance evaluation. Section 6 highlights the design and implementation challenges and Section 7 finally concludes the paper.

2. Choice of polarization for improved Qos

In order to ensure orthogonalization and enable frequency reuse, we make use of orthogonality in signal polarimetric dimension that can be employed in transmission schemes. Fig. 2 explains the different polarization states using a Poincare-spherical surface. It establishes one-to-one mapping between the polarization states

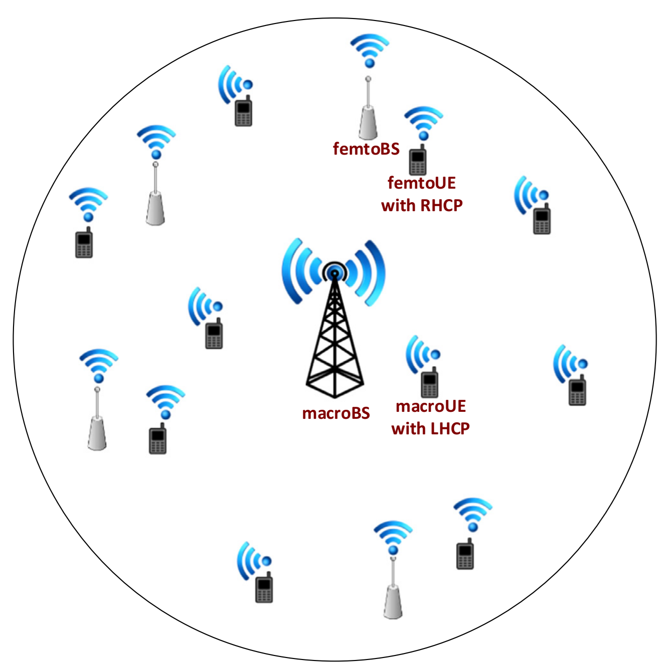

Fig. 1. Cross-polarized transmission in femto–macro network.