FEMTOCELL: OPPORTUNITIES AND CHALLENGES OF THE HOME CELLULAR BASE STATION FOR THE 3G

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ABSTRACT

As indoor use of mobile phones is growing, there is increasing interest in a reliable solution to enhance indoor communications which often suffer from high signal attenuation leading to unacceptable call quality. The appearance of the dual-mode handset which supports cellular technology e.g. GSM, when the user is located outdoor and wireless technology e.g. WiFi, when the user is indoors, brings significant improvement. Moreover it allows indoor free calls by using internet software designed for phone calls, also referred to Voice over IP. This captivating technique constitutes a serious threat for cellular operators who are slowly loosing part of their profits. Recently, a possible solution, already imagined more than ten years ago, emerged. It consists in deploying a mini personal base station in each home called femtocell. The femtocell will be plugged to the fixed broadband connection already available in most households. Thus when someone enters their house, they would be able to make phone calls directly through their own femtocell instead of the overlaying macrocell. It results in a significantly improved signal quality and substantial cost savings. In this paper, we first introduce the background history that led to this new concept and then describe the femtocell technology in the context of 3G-based cellular networks. Then we present the remaining challenges and discuss the possible solutions. Finally we deal with the opportunities for users and operators and present further works.

KEYWORDS

Cellular, Femtocell, WiFi, 3G, Home Base Station

1. INTRODUCTION

A few months ago, the mobile world has celebrated its four billionth connections (GSMA 2009). Meanwhile 3G-based cellular networks continue to be deployed and 3.5G is already on the horizon. All these facts combined predict a comfortable future for operators, especially welcome in the context of the world financial crisis. For the end user, it also means that new and better services will become available. However, the problem of coverage and capacity is still open. This is even more severe for indoor users. Thus an improvement in this field should be meaningful especially when several surveys show that indoor traffic can reach more than 30% of the total traffic.

At the same, time wireless local area networks such as the so called WiFi networks are undergoing a frenzy increase in their deployment in homes. Users own dual-mode mobile phone, and when coming home they switch to their local wireless connection, and make free calls through Voice over IP software. Cellular operators interested in keeping their clients' loyalty have to find a competitive alternative. One of the considered solutions is the deployment of femtocells. A femtocell is a box quite similar in appearance to the classical WiFi router and plugged to the home wired access to the internet. This technology is being tested worldwide by manufacturers and operators and might be the long-awaited technology that will save cellular network operators.

The rest of the paper is organized as follows. Section 2 presents the background history, both from a technical and a commercial point of view. In Section 3 we detail how the femtocell is expected to work and briefly explain the overlaying 3G Code Division Multiple Access (CDMA) technique of multiple access. The technical challenges yet to be solved, that still prevent that technology from being widely adopted are described in Section 4 and the potential solutions being considered are then discussed in Section 5. Technical and economic opportunities are discussed in Section 6. In the conclusion (Section 7) we present some interesting further work.

2. HISTORICAL BACKGROUND

Literally the term femtocell in the context of cellular networks refers to the size of a cell covered by a Home Base Station (HBS). It's the logical following of the already existing sizes which are macrocell, microcell and picocell. Whereas a picocell is mainly intended for densely populated areas such as airports, malls, etc., a femtocell is a real Personal Base Station that can be deployed in each house.

It has been more than ten years since operators started to reduce the size of the cell covered by a base station (BS) to allow an increasing number of subscribers to perform phone calls. This became more critical when data oriented services were introduced, because such services require higher throughputs in order to be considered attractive. Even after the appearance of the CDMA technology which led to the third generation (3G) technology, the problem of throughput remains. In addition, as people use their cell phones more and more, the indoor use of mobile phones increases. This can be especially noticed as since 2002, mobile subscribers worldwide have outnumbered fixed-line subscribers (ITU 2003). The indoor environment is so challenging that users were rapidly dissatisfied and looked for an alternative.

Recent years have brought an exponential increase in the use of wireless access to the internet at home. As the deployment of wireless routers increased, and with the introduction of VoIP software, which allows for free phone calls, people wanted to mix these two opportunities. This gave birth to the famous Dual-Mode handset, which consists of a mobile device supporting both regular cellular technology standards such as GSM, and wireless local area network standards such as the IEEE 802.11 standard promoted by the WiFi alliance. This "smart" solution began to be, and still is, a real threat for cellular operators as some users no longer use outdoor cellular networks deployed by operators to make their indoor phone calls but instead use their cheaper access to the internet. That is why the concept of femtocell started gaining prominence about two years ago.

In fact the concept of femtocell (also called HBS) is not really new. It has already been proposed in the mid-90 by Silventoinen et al. with the GSM-based HBS (Silventoinen et al., 1996). It was thought of as a device that a GSM subscriber could buy and connect to his fixed telephone (PSTN) line. The innovation did not attract much attention then, but can now be considered as a seminal work of what we call femtocell. Actually this is seriously considered by operators who are struggling to keep their subscribers loyal.

3. DESCRIPTION

"To be considered as a candidate" to own a femtocell, a user must first of all have a broadband connection to the internet. The user then must buy a box similar in appearance to a regular Ethernet or WiFi router and simply plug it to the connection. It's important that a femtocell remains a simple Plug-and-Play device, as a complex installation process is likely to prevent clients from adopting it. When the user enters their home, the femtocell will detect the mobile handset and vice versa, and a connection will be established. Then all phone calls initiated by the mobile handset from indoors will be supported by the femtocell.

The underlying technology to be used can be theoretically one of the three last generations: 2G (e.g. GSM), 3G (e.g. UMTS) or 4G (e.g. LTE). The technical challenges are clearly different whether we choose 2G which is based on Time Division Multiple Access (TDMA), 3G based on CDMA or 4G based on Orthogonal Frequency Division Multiple Access (OFDMA). As 3G systems are currently deployed worldwide, we will focus here on this specific technology. In the context of 3G the HBS is called Home Node B where Node B stands for the classic macrocell BS. We will however refer to it further simply as femtocell. 3G technology is based on CDMA which means that all the users can transmit at the same time over the whole bandwidth. To distinguish between signals from different users, different spreading codes are used for each user. CDMA based systems have full frequency reuse which means that the same spectrum is reused in all adjacent cells. To overcome the problem of Co-Channel Interference, power control and scrambling codes which distinguish between downlink signals from two different base stations are used. When a mobile station (MS) moves closer to the edge of its current cell, the process of handover is triggered. The introduction of an additional tier in this already heavy loaded and complex cellular architecture system exhibits several challenges.

4. CHALLENGES

One of the main challenges of the femtocell technology is how to allocate spectrum to this "second tier" system. Two main approaches are possible: Spectrum splitting or spectrum sharing. In the first approach macro and femtocells are given orthogonal frequency bands. This approach seems to be the simplest one, as no cross-tier interference is expected. Thus both macro and femtocell tiers can be considered as totally separated networks. However in the context of 3G, this is not always possible, as operators do not own additional spectrum. The process of granting 3G spectra in Europe turned out to be a big auction, that cost operators amount a lot of money. Thus operators might not be able to allocate a separate set of frequencies for the use of femtocells. Also, it is not efficient to split the already allocated spectrum into two smaller ones, because this would imply lower throughput to macrocell users which is not desirable.

In the spectrum sharing approach the same spectrum is used by the macro and femtocell infrastructure, obviously this leads to the critical problem of co-channel interference. In fact, we can face the same problem in the already deployed macro/micro/picocells that share the spectrum. These systems are different as the operator sets them up manually, whereas femtocells are plug-and-play devices can be anywhere in the home without collaboration with neighbors' femtocells. In addition, the density of femtocells in a given area is expected to be higher than the pico or microcells density, which complicates the problem.

Several critical scenarios have to be considered. In the worst case we can imagine that the femtocell of a user is located for example on the first floor of a building near outdoor pedestrian users. Thus when a pedestrian user is walking on the road close to the private femtocell, the downlink signal transmitted by the femtocell will totally cover the active downlink signal between the pedestrian and its macrocell. Similarly the pedestrian signal can cover the uplink signal of the indoor user to its femtocell. This is likely especially if the pedestrian is far from its macrocell, so high transmission power is required to transmit in its uplink, very likely higher than the transmission power needed for the indoor user to transmit to its femtocell.

Another challenge consists of sharing the radio resource between femtocells. This problem is relevant even for the optimistic approach of spectrum splitting. The critical scenarios previously mentioned are likely to happen, especially in an environment where femtocells are densely deployed such as in big residential building containing small flats.

One can argue that this latter challenge also already existed with macrocells. Given a user U connected to a macrocell X, it can be disturbed by another user V connected to a macrocell Y but closer to user U than to its own macrocell Y. Although this problem already exists, it's managed through strong power control. However in the context of femtocells, that is not always possible, as we need to cover an indoor user everywhere in their home by their own femtocell, even if the user maybe in fact closer to the neighbour's femtocell.

5. OVERVIEW OF THE POSSIBLE SOLUTIONS

The radio resource management challenge previously detailed can be overcome in different manners. Spectrum splitting solves this problem, although it is a rare occurrence that an operator has multiple spectrum. This solution leads to spectrum efficiency loss. On the other hand spectrum sharing, which is more efficient, is more difficult to manage.

Some suggestions have already been considered to tackle the problem of downlink interference. One of them is to open the access of a personal femtocell to outside users which are strongly interfered in the downlink by the closest femtocell. As soon as a femtocell has been detected, the outdoor "victim" user being interfered could switch to the "aggressor" femtocell. Of course, this solution raises the question of security for the owner of the femtocell. In addition, if too many outdoor users connect to a single femtocell, the remaining resources for the owner of the femtocell might dramatically decrease. Thus, there is a tradeoff that requires an efficient algorithm of admission control. Finally, we have to deal here with a marketing challenge as we must convince a user to open the access to their femtocell to outdoor users. Some incentives such as cheaper rates or even money rewards per outdoor access allowed could be considered.

Another possibility is to share the resource in a TDMA fashion manner on top of the CDMA (Chandrasekhar and Andrews, 2007). Macrocell and femtocell will each transmit independently over one time slot and remain silent over other slots. This is referred to Time Hopped-CDMA (TH-CDMA). However it is in fact equivalent to splitting the resources in the time domain instead of splitting it in the frequency domain. As already said for the spectrum splitting, the loss of resource efficiency in an environment where radio resource is so scarce constitutes a major drawback.

6. TECHNICAL AND ECONOMICAL OPPORTUNITIES

There are still technical challenges on the way to the success of femtocells, but some opportunities are at our doorstep. Femtocells will bring better communication quality both for indoor and outdoor users. For the indoor user, a personal base station means higher signal power in the downlink, which implies higher throughputs. In the uplink, transmission power could be reduced and save battery power, which is still a challenge for 3G handsets where processing is greedy. Besides, the macrocell load will be lightened as every user will switch when possible to their personal femtocell when coming home. Lightened macrocells could provide much better conditions to outdoor users.

Compared to the dual mode handset, the femtocell enjoys advantages over its big competitor: WiFi. WiFi is not optimized for voice and the offered throughput decreases significantly as the number of users increases, even if the standard IEEE 802.11e which provide quality of service (QoS) is implemented (Haddad and Le Grand, 2007). Whereas femtocell is the natural technology for voice as it relies on cellular networks standards originally designed for voice communications.

From an economic point of view, it is no longer necessary to exchange the classical handset for a dual mode handset, to be able to perform calls indoor. This represents a substantial cost saving as it spares the user the purchase of a new device, especially as dual mode handsets remain expensive. Besides, some incentive measures to foster the technology by the operator could be for example, totally free calls when initiated from the femtocell. We have to keep in mind that the user will probably buy the femtocell so we need to find good reasons to encourage him to do so. Thus the user will probably enjoy a slimmed bill.

For the operator, the benefits are clear, as the client will continue performing their indoor calls via the cellular network. In addition as we mentioned, femtocells will lighten the load on the overlaid macrocell. This can lead to important savings as the infrastructure deployed is often very expensive. If femtocells are used, the operator will not have to deploy more macrocells to support more users or to offer higher throughput to its already existing users. The operation and maintenance costs will also probably decrease as the density of deployment could even be reduced.

7. CONCLUSION

The promising femtocell technology which is being extensively tested by operators is a step forward in the way to the Fixed-Mobile Convergence (FMC). However, several challenges are yet to be solved. Several solutions are already on the stage, but experimental analysis is needed to reveal if they are realistic and efficient. It would be interesting to perform comparisons also through theoretical performance analysis to compare between the two competitors: Femtocell versus WiFi. We presented in this paper the benefits for both end-users and operators in the context of a 3G network based on the CDMA scheme. It will further be interesting to understand how femtocells could be integrated in the context of the yet to be deployed 4G-based cellular networks.

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