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Femtocell Technology: A Viable Indoor Coverage Solution

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Abstract: It has been generally observed that cell phone users in most developing countries possess more than one phone largely due to poor quality of service (QoS). This is becoming intolerable for indoor mobile phone users who account for the greater population of patronage compared to outdoor users, especially in Africa. This growing population have increased exponentially requiring high data rates due to user migration from voice centred communications to data centred_communications for non-real and real time applications like email/text messaging and live streaming events. As a result, most existing network Infrastructures are strained of their resources (bandwidth and frequency/time slot) to meet users perceived QoS. Capacity expansion through cell size reduction accounts for the greater improvement besides the combined contributions of wider spectrum, spectrum splitting and modulation techniques. Femtocell technology provides the road map to achieving an all Internet Protocol (IP) based network which is the future of mobile communication. Therefore, in this paper an overview of Femtocell as a viable solution to the stated challenges is presented. An outline of its choice with respect to energy consumption, some of its deployment challenges including interference management, timing and synchronization, mobility management, and QoS over internet backhaul are presented. These challenges are seen to vary based on the Channel type deployment and access method used.

Keywords: *Femtocell, Quality of Service, Capacity, Cell, Channel, Access*

1. Introduction:

The emergence of cell-based mobile radio system of Bell Laboratories in early 1970s and its commercial application in 1980s began with large transmitters covering large areas of approximately 35Km cell radius (McGraw-Hill, 2004). This is called a macrocell in which a mobile and its serving base station transmit and receive signals. Over time the drive for capacity improvement has given rise to smaller cell sizes as shown in Table 1. Cells with coverage area of less than 1km could be classified as Small Cells (Small Cell Forum, 2012). The emergence of these smaller cells is due to the success of mobile wireless systems, which consequently brought about increase in number of users over the years, demanding high data rate for good quality voice/video/text services.

Table 1: Cell Variations in Telecommunications

Cell type	Coverage area	Application
Macrocell	3-35Km	rural
Microcell	100m – 1Km	urban
Picocell	10m- 1Km	rooftops
Nanocell	1 – 10m	below rooftops
Selective , Sectorized or tiered cells	Less than 360°	tunnels – 120°
Umbrella cells	Overlays several small cells	reduce frequent handoffs
Femtocells	20 -30m	indoor

Femtocell is a data driven cellular technology aimed at improving indoor voice and data quality by exploring the possibility of a reduced transmit and receive distance for high quality link and frequency re-use (Chandrasekhar, V. Andrews, J. and Gatherer, A., 2008).

The effect of distance (d) and expected higher operating frequencies (f) at reduced cell size can be expressed from radio propagation theory:

$$P_r = P_t(\frac{\lambda}{4\pi d})^2 G_b G_m \quad (1)$$

Where:

$P_r = received\ power$

$P_t = transmitted\ power$

λ=wavelength$(\frac{speed\ of\ light, c}{\text{carrier frequency}, f})$

G_b and G_m are both base station (transmitter) and mobile (receiver) antenna gains respectively.

Reduced cell size usually requires less power for transmit and receive signal normally called the 5 bar coverage. It implies prolonged battery life. However, challenges exist due to decentralised planning.

A rapidly developed rural–urban transformation with a single macrocell is met with the challenge of network expansion to build the required capacity that accomodate these exponential increase in high data rate demands.

Table 2: Options for network expansion (Similarities and differences)

Infrastructure/Device For network expansion	Access point/ Node	Location	OP & M Cost	Operating frequency/ Technology	Intelligence	Link to MSC/CN
Macrocell	Yes	Outdoor	High	Licensed/Cellular	Yes	Radio/RNC
Microcell/Metrocell	Yes	Outdoor	High	Licensed/Cellular	Yes	Radio/RNC
Picocell	Yes	Outdoor	High	Licensed/Cellular	Yes	Radio/RNC
Relay	Yes	Outdoor	Medium	Licensed/Cellular	No	Radio/RNC
Distributed Antenna MIMO,SIMO,MISO	Yes	Out-/In-door	High	Licensed & Unlicensed	Yes	Radio/RNC
Femtocell	Yes	Indoor	Low	Licensed/Cellular	Yes	IP/UNC
WiFi	Yes	Indoor	Low	Unlicensed/WLAN	No	IP/UNC
Satellite	Good for data transmission, intolerable round trip delay of 500ms for voice					

Available microization options range from additional Macrocells, Microcells, Picocells, Distributed Antennas, Relays, WiFi /WiMax technology, Satellite and Femtocell technology. These options and their relative costs are shown in Table 2.

An indoor mobile station (MS) communicates with a femto device using a radio link. The device, in turn, communicates with the IP network from an ISP using Digital Subscriber Line (DSL), Ethernet or wireless broadband link.

The IP network is connected to the cellular network in one of three ways. Firstly, the IP network connects to the serving GPRS support node (GSN)/Mobile Switching Centre (MSC) via standard Iu PS/CS interface respectively. Here each Femto Access Point (FAP) is seen as a Base Station (BS) plus Radio Network Controller (RNC); this limits the number of Femto access points (FAP) per GSN/MSC to between tens and hundreds. Secondly, the IP network connects to the cellular network by placing a Femtocell network side by side with all existing macrocell network infrastructure which may serve unlimited number of femtocells but draw high maintenance cost in managing both core networks. Thirdly, the IP network connects to cellular network's MSC using a single gateway called Unlicensed Mobile Access (UMA) Network Controller (UNC). See Figure 1 and 2.

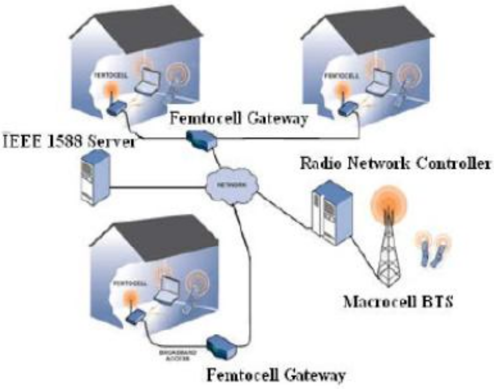

Fig. 1: Femtocell network's fundamental entities. Source: Hasan, M. K. *et al*, 2011.

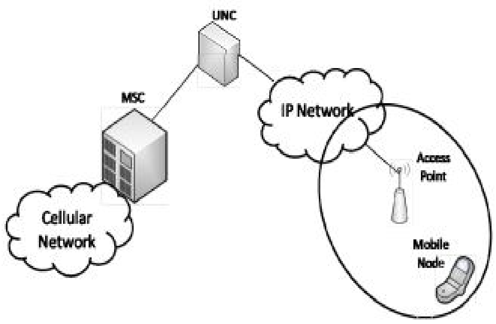

Fig. 2: Cellular/WLAN convergence architecture. Source: Hasan, Siddique and Chakraborty, 2009.

The rest of this paper is structured as follows: Section 2 presents a detailed review of related works in Femtocell development. Section 3 concludes on the direction of future research.

2. Review of Related Works:

The absence of a centralized planning of resources (frequency/time slot and IP backhaul) due to its user-deployed nature posses challenges such as: interference management, mobility management, timing and synchronization, including Quality of Service (QoS) over internet backhaul. These challenges are explained below.

(i) Interference management: A femtocell communicates with a macrocell overlaying it, in a cross tier scenario. If both layers share the same frequency channel (co-channel deployed) and operate in a closed access manner where unrecognized mobiles do not have access, the Femto Access Point (FAP) experiences a high noise rise due to interfering unrecognised user. Similarly, unrecognized users experience degraded demodulation performance due to interfering FAP. Within the same cell, same tier scenario, and operating adjacent-channel (different frequency) femtocell deployment, raises the issue of an optimal splitting policy so as to maximize the number of deplorable FAPs. This area has been extensively researched (Xia, P., and Andrews, J. G., 2012).

(ii) Mobility management: This is typical of 2G and 3G systems (Liu, C. 2004). The macrocell infrastructure was not designed with this technology in mind. As underlying femtocells increase within a macrocell, hand off protocols to handover service from macrocell to femtocell layer becomes more challenging when the femtocell operates in an open access scenario that permits roaming users to use the FAP. A macrocell is limited to 64 neighbour list of indoor/outdoor base station (BS) for effective hand off of its users (Järvinen, M., 2009). Low complexity algorithms have been proposed considering velocity threshold (Yeung, K.L. and Nanda, S., 1996), auto-configuration of received signal strength (Ho, L.T.W. and Claussen, H., 2007), adaptive power control (Kishore, S., Greenstein, L.J., Poor, H.V. and Schwartz, S. C., 2006), and remain open for further research.

(iii) Timing and synchronization: Femtocell synchronization over IP broadband network is needed to avoid harmful interference and incorrect handover decisions arising from traffic decentralized coordination system (Chandrasekhar et al., 2008). Research is ongoing to scale down signal processing capabilities related to location management and traffic bottlenecks (Hasan, M. K. et al., 2011).

(iv) QoS over internet backhaul: User throughput rate in open and closed access would be limited by uplink bandwidth over secure tunnel (Chandrasekhar et al., 2008), insecurity in open access due to communication over public infrastructure Femtocell/femto gateway (Chen, J. et al., 2010) and interoperability between network providers due to licensed frequency operation arise in this area (Shin, D., 2012).

It was observed that channel type (co channel-CDMA or adjacent channel-OFDMA) and access method (closed, open or hybrid) affect performance greatly. While co channel takes advantage of universal frequency reuse, there exists greater cross tier interference unlike in adjacent channel which is bandwidth limited. The type of access method is important considering the fact that owners of the device would not need to be starved of its resources (bandwidth and frequency/time slot). In open access, resources have to be shared with non-paying passerby-user of the device, which also introduces the problem of frequent handoffs. In closed access, however, resources are at the control of the owner but introduce interference issue especially at the downlink (Jo, Xia, and Andrews, 2012). As a solution to this conflicting demand, a hybrid, in form of Shared access control, has been proposed in literature with analytical results. While hybrid access have been suggested in these literatures, most users still prefer closed access for privacy and security at the expense of strong interfering neighbours. The provision of a hybrid femtocell solution that accommodates the security concerns of home users is an open issue.

3 Conclusion

In this paper background knowledge on Femtocell is presented. This is followed by presenting a possible area of application and the general challenges faced. Observations have been made on major factors of these challenges. It was found that channel type and access method are key influencers to the performance of femtocells. In addition users prefer a monopoly of their device. Further work is intended: a technical solution in the form of ‘hybrid access scheme using fuzzy logic systems’ to provide similar QoS Obtainable in closes access scheme.

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