

Proposed Multi-Mode Home Node-B Air Interface Protocol Stack Architecture

Ajaegbu C Omotosho O.J Awodele O Ogbonna A.C
Department of Computer Science, Babcock University

Abstract
A Multi-mode Home NodeB (MHNB) is a system that can offer cellular service(s) to more than one different generation technology. The Universal Mobile Telecommunication System (UMTS) technology using NodeB as its transceiver station was developed to offer a high frequency range of 5MHz and because of this, the signal from the NodeB dilutes faster once reaching indoor. Studies showed that the idea of Home NodeB system by Third Generation Partnership Project (3GPP) came as a means to boost the diluted indoor signals. The challenge with this system is that it can only accommodate small number of subscribers as its Close Subscriber Group (CSG) without allowance for expansion. This study seeks to address the small capacity issue of the existing HNB by proposing a system that will accommodate wider capacity range and also, modify its operation from a single network mode to a Multi network mode technology. This will also offer great benefit to developing countries through extension of their GSM coverage and will also create a uniform platform for all cellular generation technologies.
Keywords: Home NodeB, Multi-mode Home NodeB, Third Generation Partnership Project and Close Subscriber Group

1. Introduction

Home Node-B is a customer's home and hotspot device, enabling communication within UMTS core network to UMTS mobiles and HNB Gateway through Uu interface and Iuh interface respectively (Cisco ASR 5000 Series 3G Home NodeB Gateway Administration Guide, 2010).

Studies revealed that most phone calls are made indoor and that the signal of UMTS gets weak for indoor users. The idea of HNB system came as a result to boost UMTS signals for indoor users. The HNB device at the customers end, was closed to accommodate only a small number of subscribers (ranging from 1-4) simultaneously (Chandrasekhar and Andrews, 2008).

HNB has the abilities of standard Node B except for its design principles, which makes it smaller in capacity, size, range of coverage and its peculiarity with small cell structure. These exceptions brought its transceiver classification to a mini-base station transceiver.

For any HNB device to be compatible with any technology, it has to be built to accommodate the protocol features of the technology.

Although, there have been advancements in cellular generation technologies, the large roll-out of the second generation technologies (GSM and CDMA) will still be in existence in 2020 (Sorelius, 2014). In the light of this, operators in developing countries, deploying UMTS technology for data transmission and GSM technology for voice, need additional benefit from the HNB system such that when deployed, the coverage area extending to the uncovered area of their GSM signal, can also serve as coverage extension to their GSM users thus maximizing their resources with minimal deployment cost.

Therefore, this study seeks to address the small capacity issue of the existing HNB through proposing a system that will accommodate wider capacity range and also, modify its operation from a single network mode to a Multi network mode technology. This will offer great benefit to developing countries through extension of their GSM coverage and will also create a uniform platform for all cellular generation technologies.

2. Review of HNB Related Works

Claussen, Lester and Samuel (2008), opined that the quest for a private bandwidth for data services by users, led to the concept of femtocells and piconet. However, the initial idea of the deployment of these devices with secondary frequency bands was observed to degrade spectral efficiency per area thus the idea of co-channel deployment of macrocells and femtocells on the same frequency emerged as a solution to this challenge. This technique standing to improve the spectral efficiency, also pose the challenge of interference issues. Hence, there study looked at the hierarchical architecture and manual cell planning processes of macrocell as not being an effective practice in the deployment of millions of femtocell. The main objective of their study was to propose the deployment of femtocells using a base station router (BSR) flat Internet Protocol (IP) cellular architecture. Thus the specific objectives were as follows: to present an auto-configuration and self-optimization concept for the proposed architecture; to investigate the technical feasibility of co-channel deployment of femtocells. In order to achieve their aim, the proposed BSR combined all the functions of radio access network and the core network into a single network entity where, all the wireless access specific functions are carried by a cognitive access node and the core network access still remains independent. Their study showed that the deployment of home base stations can provide a major financial advantage both now and the nearest future with the widespread adoption of high data rate mobile services.

Shin.jo, Mun, Moon and Yook (2009), opined that limiting cross-tier interference from femtocell users at a macrocell base station (BS) is an important attribute for deployment of femtocell. Some of the studies in this area required site specific engineering in which the parameters are manually tuned and optimized by technicians. Hence, such methods can be used for femtocells designed to carry-out automatic self-configuration of radio resources. The main aim of the study was to propose two interference mitigation strategies in which femtocell users adjust the maximum transmit power using an open-loop and a closed-loop technique. Thus their specific objectives were: to look at the system model based on an ITU and COST231 path loss model; to propose an open-loop control for maximum transmit power; to propose a close-loop control for transmit power. The researchers employed an analytic procedure of the open and close loop control mechanism in order to: determining the Signal-to-Interference-and-Noise Ratio (SINR) of a particular transmission, the broadcast information on the average power level of the noise/ interference at the base station and required uplink transmission power (in order to control the cross-tier interference caused by femtocell users). The study showed that both scheme can effectively compensate the uplink throughput degradation of the macrocell BS and that the closed-loop control scheme offered better femtocell throughput as regards to the open-loop control at a minimal cost of macrocell throughput.

Chandrasekhar and Andrews (2009), argued that irrespective of the frequency reuse factor and spreading technique, cross tier interference causes unacceptable outage probability. Their main aim was to develop an uplink capacity analysis and interference avoidance strategy for such a Code Division Multiple Access two-tier cellular network. Their specific objectives were as follows: to study the uplink capacity in a typical macrocell with randomly scattered femtocells; to study the effect of femtocell hotspot density, macrocell-femtocell power ratio and femtocell size on a network; to look at the benefit presented by interference avoidance using antenna sectoring and time hopping in CDMA transmission. Their work employed a stochastic geometry framework for modelling the random spatial distribution of users/femtocells. Their work showed a higher user capacity for a shared spectrum network by enforcing higher spatial frequency reuse through small femtocells and interference avoidance by way of antenna sectoring and time hopping CDMA (TH-CDMA) in each tier.

Shetty, Parekh and Walrand (2009), argued that from the inception of femtocell idea till 2009, economic studies have focused on the financial aspects of femtocell in the direction of network deployment costs. Thus, there is a need to focus on determining the network operator's optimal pricing choices and the resulting users' motivations for femtocell adoption. The main aim of their work was to study the impact of the complex interplay of interference and service pricing on user's adoption of femtocells. Thus, their specific objectives focused on: the study of the impact of implementing a split spectrum scheme; the impact of adopting a shared spectrum scheme by operators. The researchers modelled a monopolist wireless network operator offering two mobile service options to a population of users with a fixed amount of spectrum for deployment. The instantaneous throughput of users was measured in terms of position, time of access and the congestion in the network; where users throughput valuation were distributed using a cumulative distribution function. Their result showed that the optimal pricing scheme always charges a higher price for the femtocell service. Also, if the degradation coefficient is sufficiently low, revenues from the common spectrum are always higher than that with the split spectrum scheme. Again, when the macrocell capacity is low, the revenues from common spectrum schemes are comparable to the split spectrum even when macrocell capacity is heavily degraded.

Perez, Ladanyi, Juttner and Zhang (2009), opined that interference avoidance has never been a trivial task neither in macrocell deployments nor in femtocell networks. Most studies have centred much on Wide-band Code Division Multiple Access (WCDMA) networks and have not considered mitigating interference through sub-channel allocation. This in regards is an important feature of Orthogonal Frequency Division Multiple Access (OFDMA) systems. The main aim of their study was to proffer a self-organizing approach for frequency assignment within femtocells. Thus their specific objectives were: to show that using self-organization leads to better system performance than using random assignment; to present two novel approaches for the self-organization of OFDMA femtocells. In order to propose the self-organization approaches, the researchers employed a method based on broadcast message (where the femtocell estimates the probability of usage and interference intensity) and measurement reports sent from a user to the serving femtocell. In accordance with their study, dynamic system-level simulations confirmed that their methods may improve user's throughput by around 26% and 34% respectively compared to the random assignment. Also, an efficient resource assignment algorithm must consider circumstances at the user environment in order to efficiently mitigate interference as well as the behaviour of the traffic.

Andrews, Claussen, Dohler, Rangan and Reed (2012), opined that despite the good deeds of femtocells, they pose disruption to the well-planned and structured cellular network. Also the cross-tier interference, spectrum allocations and co-channel deployments for femtocells remains an on-going challenge for wireless operators. The main aim of their work was to examine the performance and deployment of various small cells (pico, femtocell) from past, present and future. Thus their specific objectives were: to trace the origin of femtocells; to examine their benefits to macrocell and macrocell users; to examine the challenges posed by femtocells and the various proposed mitigation techniques. The researchers gave a historical background of femtocells, identified their benefits while their existing and expected challenges were also examined. At the end of the study, the researchers took a position that

> *"there is nothing fundamental preventing very dense femtocell deployments and that the economic and capacity benefits, femtocells provide, appear to justify the optimistic sales forecasts".*

Wang, Yu and Huang (2013), pointed out that the form of heterogeneous network where macrocell and small cell are overlapped, using the same frequency spectrum, incurs interference between macrocell and small cell (femtocell). Also, because femtocells are self-organized, femtocell nodes need to have the capability to identify the transmission environment and adjust their configurations intelligently. The main aim of their work was to propose a cognitive radio that will be able to enhance interference coordination for femtocell networks. Thus their specific objectives were: to study the likely occurred interference in a femtocell network; to propose two cluster-based dynamic frequency reuse; to propose an opportunistic cognitive relay enhanced interference coordination. Their work adopted the analytical research method where some of the cognitive radio inspired approaches to enhance interference coordination were also employed. The work when benchmarked with some existing techniques like relay-disabled system, relay-aided secondary system and relay-aided primary system, showed better performance in handling cross-tier interference coordination for femtocell networks.

From the review, it has been observed that studies have been in areas of interference mitigation of HNB deployment while less attention has been paid towards modifying the existing Home NodeB (femtocell) into a Multi-mode radio system that will expand the CSG of HNB and also benefit developing countries that still operates with GSM infrastructure.

3. HNB Architecture along with its air interface protocol stack

The architecture of HNB follows the same structure as that of a UMTS architecture where, the NodeB was replaced with HNB and the Radio Network Controller (RNC) was replaced by the HNB Gateway (see fig 1).

A cellular network air interface is the established link that facilitates communication in wireless communications. In cellular world, it is the portion of radio frequency that forms the route between mobile user and base station transceiver and between base station transceiver to base station controller.

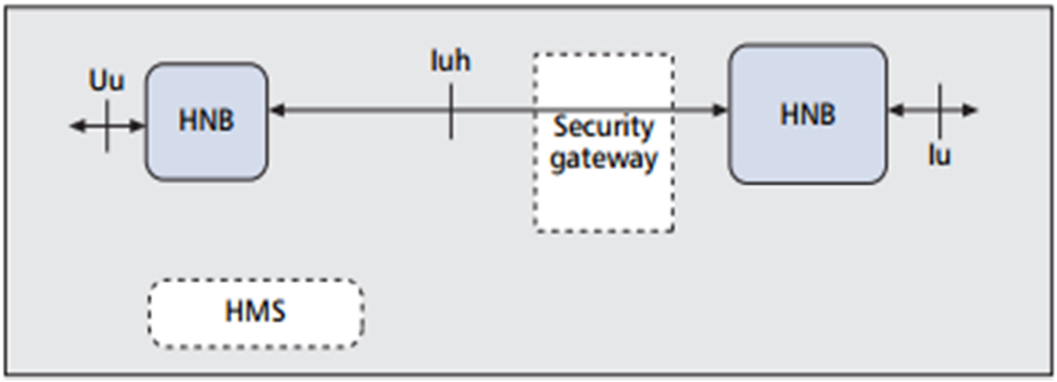

Figure 1: Architecture of the Existing HNB System

(Source: knisely et al, 2009)

The air interface protocol stacks for HNB architecture consist of the UMTS Uu interface between UMTS mobile user and the HNB device, Iuh interface between HNB device and HNB gateway system.

The Uu interface of femtocell is same as that used between UMTS macro cell (Node B) and UMTS user (see fig 2). Although, some minor modifications were included in order to accommodate HNB device specific needs such as Close Subscriber Group (CSG), (Knisely, Yoshizawa and Favichia, 2009), the call processing and packet transmission still remain similar to that between UMTS user and Node-B. The air-interface protocol between HNB and HNB gateway were further modified with two new protocols known as Radio Access network Application Protocol (RANAP) User Adaptation (RUA) and HNB Application Protocol (HNBAP), (Knisely, Yoshizawa and Favichia, 2009). The introduction of these two new protocols led to the air interface name luh (see fig 3) thus, formed the differential attributes from Iu interface between Node-B and Radio Network Controller (RNC).

Radio Resource Control
Radio Link Control
Media Access Control
Wide Code Division Multiple Access

Figure 2: Uu air-interface protocol stack used between user equipment and HNB

Radio Access Network Application Protocol	Home NodeB Application Protocol
RANAP User Adaptation	
Stream Control Transmission Protocol	
IP	
L2	
L1/PHY	

Figure 3: Iuh air interface protocol stack of femtocell

4. Proposed Multi-Mode Home Node-B Air Interface Protocol Stack Architecture

Multi-mode Home Node-B is a technology that is meant to incorporate more than one air-interface protocol stack into one device. MHNB technology should also offer better performance as compared to the existing HNB, in terms of speed, coverage distance and capacity.

The concept is meant to address the inability of existing HNB; to accommodate more number of subscribers and more than one air-interface protocol stack. The essence of such technology is to create allowance for the future and also to enable telecommunication firms in developing countries that are still carrying their voice services with GSM, to also benefit from the deployment of MHNB, through extending the GSM service, to areas that are not within the reach of the GSM coverage, but within the reach of MHNB (see fig 4)

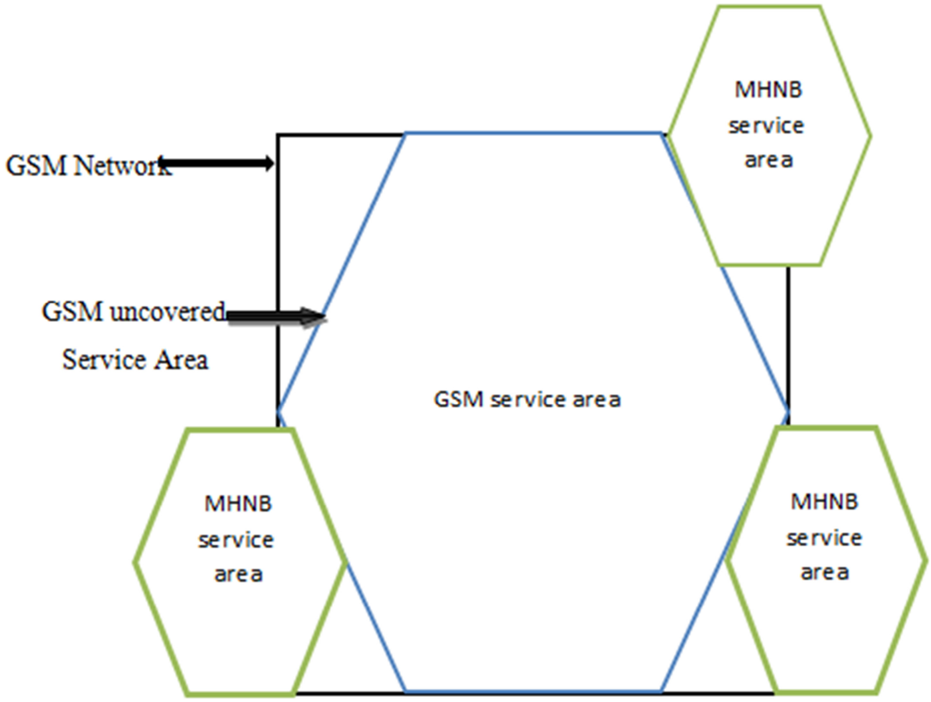

Figure 4: Illustration of GSM deployment and MHNB deployment

In figure 4, the spaces between black and blue border, represent the uncovered service area of GSM network. The space within the blue hexagonal shape represents the service area of GSM network while the light green hexagonal shape represents the service area of the MHNB. A user migrating from the service area of GSM network to the service area of the MHNB automatically will be handed over to the services of MHNB thus, retaining its access to GSM services.

The MHNB proposed technology could be achieved by integration of the *Uu* interface and Um interface into an IP network, while the *luh* interface will be integrated along with the *Abis* interface in what will be known as MHNB gateway. The IP network was achieved using high end router thus, replacing the HNB device (see fig 5).

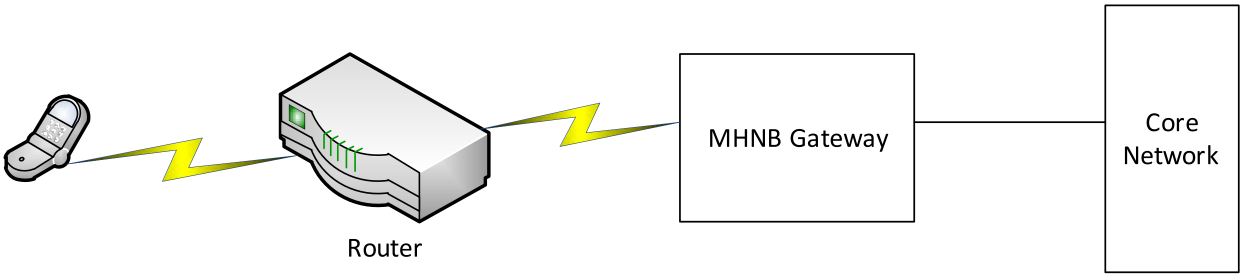

Figure 5: Block Architecture of MHNB System

The access network of MHNB that is from either UE to the MHNB was made to be carried over an IP network where the subscriber's identity, identified by the network prefix was mapped to various subnets created from the router's network address.

5. Conclusion

In conclusion, the idea of HNB as standardized by the Third Generation Partnership Project (3GPP), has added value to operators and subscribers in terms of service operation and quality of service respectively. Although, its introduction was a means of encouraging further advancement in cellular technology, the cellular technologies in developing countries should not be treated as a trivial issue and also the idea of unifying its platform in order to accommodate any generation technology when deployed should also be putting into due consideration.

This proposed system will offer greater benefit in comparison with the existing HNB in the areas of accommodation of more users, extension of network coverage and will also help developing countries to embrace the idea further because of its benefit in accommodating more than one air-interface protocol stack.

The technique, operation and the deployment success rate of this proposed system will be explained further in our upcoming papers.

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