Towards 1000x Capacity Challenge via Resource Allocation and Interference Management

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by

Konjeti Viswanadh

201232614

konjeti.viswanadh@research.iiit.ac.in

International Institute of Information Technology

(Deemed to be University)

Hyderabad - 500 032, INDIA

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International Institute of Information Technology

Hyderabad, India

CERTIFICATE

It is certified that the work contained in this thesis, titled "Towards 1000x Capacity Challenge via Resource Allocation and Interference Management" by Konjeti Viswanadh (201232614), has been carried out under my supervision and is not submitted elsewhere for a degree.

Date Advisor: Prof. G Rama Murthy

Dedicated to

To My Family and Friends

Acknowledgment

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Abstract

The data rates have seen a phenomenal increase from 2G with 9.6 kbps per time slot to LTE-Advanced with 1Gbps. It is more than a thousand fold increase. Even this huge data rate is not going to cater the needs of present day era of smart phones and tablets. Wireless Internet has exploded to 100 petabytes of data transfer per day. This clearly suggests that the capacity of the wireless networks has to be increased many fold, failing which will cause an internet slow down.

Heterogeneous networks (HetNets) are an attractive means of expanding mobile network capacity. A heterogeneous network (HetNets) is typically composed of multiple radio access technologies, architectures, transmission solutions, and base stations of varying transmission power. Combining such a variety of technologies together enables the best option to be chosen for a given area, but it also presents problems in terms of ubiquity and operation with such a variation of technologies and approaches. Nevertheless, mobile operators are looking to adopt the heterogeneous cellular network, HetNets approach to enable them to meet their goals for coverage and capacity as much greater demands are placed on mobile networks

In this thesis, the main objective is to increase the capacity of the wireless networks by enhancing the performance of HetNets from three different directions: Resource Allocation, Interference Mitigation and employing the latest techniques such as beam forming.

Channel is the most important resource in wireless networks more so in the case of HetNets as it contains the combination of many different wireless technologies. Although Channel Allocation is a widely studied problem in literature, there is still a scope of improvement when it comes to the latest HetNets technology. In this work, Predictive modeling technique such as regression model is used for effective utilization of the channels by the means of proper allocation.

Interference Mitigation in HetNets is a very complicated problem because of the heterogeneous nature. Femtocells. Pico cells, Wifi, Macrocells, all these different technologies have to coexist in one area which creates huge interference challenges to each other. In this work, we proposed intelligent power adaptive strategy and beam control strategies to mitigate the interference in highly dense femto cell deployment scenario.

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Nomenclature

MIMO – Multi Input Multi Output

SINR – Signal to Interference plus Noise Ratio

SNR – Signal to Noise Ratio

HetNets – Heterogeneous Networks

VNI – Visual Network Index

HSPA – High Speed Packet Access

LTE – Long Term Evolution

LTE-A – Long Term Evolution Advanced

CAGR – Compound Annual Growth Rate

TDD – Time Division Duplex

FDD – Frequency Division Duplex

UE – User Equipment

ITU – International Telecommunications Union

ASA – Authorized Shared Access

LSA – Licensed Shared Access

SDL – Supplemental Downlink

NSC – Neighborhood Small Cells

CapEx – Capital Expenditure

OpEx – Operational Expenditure

DL – Down Link

FCA – Fixed Channel Allocation

DCA – Dynamic Channel Allocation

HCA – Hybrid Channel Allocation

OHCA – Optimal Hybrid Channel Allocation

IFCA – Intelligent Fixed Channel Allocation

AP – Auto Regression

WSS – Wide Sense Stationary process

LPC – Linear Predictive Coding

GCD – Greatest Common Divisor

CFAP – Cognitive Femto cell Access Point

FAP – Femto cell Access Point

MBS – Macro cell Base Station

SBS – Small cell Base Station

RSS – Received Signal Strength

RF – Radio Frequency

CSI – Channel State Information

DoA – Direction of Arrival

MUSIC – Multiple Signal Classification

ESPRIT – Estimation of Signal Parameters via Rational Invariance Techniques

CLMS – Constrained Least Mean Square

CCI – Co Channel Interference

CGBF – Conjugate Gradient adaptive Beam Forming

RLS – Recursive Least Square

SB – Switched Beam

1. Introduction

1.1. Overview

Wireless Communications is a vast area, posing significant challenges in various directions. While there are many open research problems unsolved from many years, the technical revolution, we are witnessing with the explosion of number of smart phones usage has left the wireless research community with very interesting problems.

Engineers have been exponentially increasing the achievable wireless rate for a very long time. According to Cooper's Law [Martin Cooper, paraphrased]: "The data rate available to a wireless device doubles roughly every 30 months". But unfortunately the time period of 30 months is too slow. Already the industry is gearing up to 1000x capacity, which means the present capacity of wireless networks is to be expanded to 1000 times. Technological advancements in the hardware design, software design and core communication concepts, going in tandem can attempt to offer a solution to this tedious task.

This work focuses on resource allocation and interference management problems in wireless network. Both resource allocation and interference management are well investigated problems in this field. But due to advancements in communications systems, the definition and application of both the terms differ significantly. This work started with focus on age old channel allocation scheme from information theory perspective. In the next chapter, we proposed intelligent strategies to counter the interference problems in femto cell scenario. Later, applicability of MIMO and beam forming techniques is discussed in a dense small cell environment.

1.2. Problem Statement

A) Channel allocation problem in macrocell:

Channel allocation is one of the most important resource management schemes in macro cells. While this subject is heavily studied in literature, there is still scope for improvement. Traditional channel allocation cannot cater to the needs of dynamic signature of mobile traffic.

B) Interference Management in femto cells:

To solve the 1000x crisis, extreme densification of femto cells is an inevitable measure. But this densification on the large scale creates interference in multiple ways. This problem cannot be solved from a centralized viewpoint.

1.3. Contribution

<u>A) Resource Management in Macro cells</u>

In chapter 3, we used predictive modeling such as Auto-Regressive based channel allocation towards designing a more optimal channel allocation strategy with respective to channel utilization factor.

B) Interference Mitigation in HetNets

In a heterogeneous network with range expansion, in order for a user terminal to obtain service from a low-power base station in the presence of macro base stations with stronger downlink signal strength, the pico base station needs to perform both control channel and data channel interference coordination with the dominant macro interferers and the user terminals need to support advanced receivers for interference cancellation. In the case of femto base stations, only the owner or subscribers of the femto base-station may be allowed to access the femto base stations.

In chapter 4, a cognitive femto cell access point mitigates the interference caused by the dominant macrocell by employing a novel power control algorithm which depends on SINR ratio of femto cell access point.

C) Interference Management in HetNets

To meet the needs of 1000x, extreme densification of femtocells is almost inevitable. But this high scale densification creates significant interference to neighboring users. Thus the solution given in chapter 4 is not adequate.

In chapter 5, we improvised upon the fact that beam forming technique can be employed to manage the interference levels in HetNets. The efficiency of this solution can be improved by increase of number of antennas used in the femto cell access point.

1.4. Thesis Organization

The thesis is organized as follows:

Chapter 1 gives a brief introduction about 1000x capacity challenge and why we need it. Followed by, problem statement which divided into two parts and the contributions made in this thesis.

Chapter 2 presents the motivation behind this work. The challenges of rapid mobile traffic and 1000x challenges are presented in detail, followed by detailed solutions.

Chapter 3 depicts our novel channel allocation strategy by the usage of information related to traffic data to predict the traffic loads. This proved to improve the channel utilization factor compared to the traditional channel allocation strategies.

Chapter 4 talks about the novel algorithm to counter interference management using the power control with respect to the signal to interference and noise ratio. This makes the femto cell transmit power coverage area constant independent to the macro cell interference levels and try to minimize the neighboring interference.

Chapter 5 presents our work in which the MIMO and Beam Forming are employed to solve the interference challenges in the extremely dense small cell scenario.

2. Motivation

2.1. Introduction to Wireless Networks

The wireless-access networks of today will have to evolve in several ways in order to address the challenges and expectations of the future. New technology components will be introduced as part of the evolution of current wireless-access technologies, such as high-speed packet access (HSPA) and long-term evolution (LTE). However, additional components may also constitute future new wireless-access technologies, which may complement the evolved technologies. Examples of such new technology components are new ways of accessing spectrum and substantially higher frequency ranges, the introduction of massive antenna configurations, direct device-to-device communication, and ultra dense deployments.

Mobile wireless communication has come a long way since its introduction in the late 1970s: from analog voice calls to today's state-of-the-art technologies capable of providing high-quality mobile-broadband services with end-user data rates of several megabits per second over wide areas and tens, or even hundreds, of megabits per second locally. The enormous enhancements in terms of capabilities of mobile-communication networks, together with the introduction of new types of mobile devices such as smart phones and tablets, have generated an explosion of novel applications and use cases for mobile connectivity and a consequent exponential growth in network traffic. The transition into a fully connected, networked society has just begun where everything that can benefit from a wireless connection will be so connected. This article lays out our view on the future of wireless communication for 2020 and beyond [1]. The key challenges that will be faced by future wireless communication in enabling the networked society is the sudden surge in mobile traffic.

2.2. Mobile Data Traffic Analysis

Widespread adoption of wireless broadband and smart phones has resulted in tremendous growth in traffic volumes in mobile networks in recent years. With the introduction of the smart phone and tablets, mobile devices have evolved from being used predominantly for talking into a versatile communication companion. People spend more and more time on being connected to the internet over a mobile device [2].

The traffic growth will be driven by larger-screen devices and video rich tablets, machine-to-machine applications and soon, the connected vehicle and home. Research predicts that mobile data traffic will grow exponentially and video traffic will drive that growth. Not only does the video content consume more resources than many other applications, faster and bigger smart devices coupled with advanced wireless networks have led to increasing adoption of video content. According to Cisco Visual Networking Index (VNI), mobile video traffic is already over 50 percent of mobile data traffic, and is expected to account for 66 percent of global mobile data demand by 2017 [3].

According to Cisco VNI, the global mobile data traffic grew 70 percent in 2012 and is expected to grow steadily at CAGR of 66 percent from 2012 to 2017. This means there will be a 13-fold increase by the end of 2017. Ericsson Mobility Report shows that mobile data traffic already exceeded mobile voice traffic already in 2009 and that data traffic is growing at a steady rate whereas voice traffic growth remains moderate. In fact, the Ericsson report shows that mobile data traffic doubled in 2012 and is expected to grow with a CAGR of around 50 percent between 2012 and 2018. This entails growth of about 12 times by the end of 2018 [4].

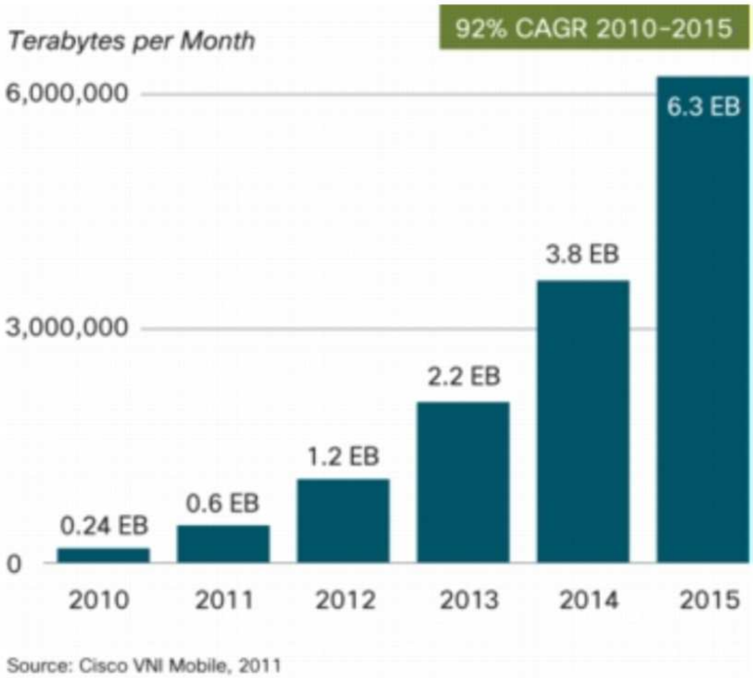

Figure 1. Global Mobile Data Traffic growth 2012 to 2017. [4]

All traffic growth predictions are suggesting that demand for mobile data could overwhelm wireless network resources due to finite and limited spectrum availability, even though technology evolution is improving the efficiency and capacity of the wireless networks. To be ready to accommodate this growth, the wireless industry needs additional spectrum and associated policy innovation. More than anything, there is a need for limitless capacity. The industry has started looking out enhancing the present capacity by 1000 times. This envisaged innovation is termed as “1000x” challenge.

2.3. Meeting the 1000x challenge

This presents the various technology enhancements that will help to meet the 1000x data challenge. This section provides the details of the several technological innovations that have been developed to drive the capacity to the fullest.

The first step towards meeting the 1000x challenge will be to derive most of the efficiencies from macro cells with new innovations so that operators can leverage their existing macro cellular network infrastructure network in a cost effective manner to increase capacity. There are several efforts currently underway in further enhancing the performance of 3G, 4G and Wi-Fi technologies in delivering higher capacity, data rates and user experience. The second would be the introduction of HetNets that includes small cells, micro cells and macro cells. It is clear that the indoor mobile traffic out beats the external mobile traffic. So the development of small cell seems inevitable. With the rapid proliferation of wireless devices, the frequency spectrum is fully occupied. The third and novel approach is the conservation and efficient utilization of spectrum resources. Cognitive Radio, Software Defined Radio and policy framework for regulating spectrum are the three efficient ways of doing it.

2.3.1. Technological Advancements

There are several untapped opportunities to enhance the network capacity and coverage of current macro cell deployment. Wireless researchers have found several methods to assist the macro cell operators. For example, as for 4G, the LTE technology that is currently commercial in several operators' networks is deployed in FDD up to 2x10 MHz bandwidth and 20 MHz in TDD. The LTE-Advanced technology allows deployment in much wider bandwidth with carrier aggregation across bands providing enhanced spectral efficiencies, sector throughput and user experiences. The next step in the evolution of 3G and 4G technologies is to incorporate smart network techniques to improve network efficiency and user experience and especially address the challenge of improving cell-edge data rates which continue to be lower than average. Multipoint HSPA is a new feature currently under study in 3GPP with an objective to address the imbalance of loading between adjacent sectors/cells and improve the cell-edge data rates while leveraging existing transceiver capabilities of the network and UEs.

Another important source of performance improvements comes from antenna enhancements which in the near future are going to play a key role in enhancing coverage, system capacity and user data rates without additional power or bandwidth. A MIMO system, irrespective of the technology (3G or 4G), consists of multiple transmit and receive antennas plus signal processing at both transmitter and receiver.

Irrespective of the technology, the spectrum allocated to the macro cell is getting more crowded and researchers started finding solutions to conserve the spectrum. International Telecommunication Union (ITU) gave more importance to spectrum policies than ever before.

2.3.2. Spectrum Regulatory Frameworks

While both licensed and unlicensed spectrum both play important roles in meeting the capacity needs, there is no substitute for licensed spectrum to deliver a predictable quality of service. However, it is increasingly difficult for governments to clear additional spectrum in order to make it available for licensed mobile broadband. For that reason, spectrum policy innovation is important. Authorized/Licensed Shared Access (ASA/LSA) is one of the authorization scheme designed to help meet the 1000x mobile data challenge. ASA/LSA allows sharing of underutilized spectrum on a non-interference basis with incumbents while permitting commercial offering of mobile broadband services with predictable quality of service. Another example of policy innovation is Supplemental Downlink (SDL). In the past, relatively small unpaired blocks of spectrum could not be used for mobile broadband due to the size of the band, channelization and compatibility with other services, among other factors.

With radio link performance fast approaching theoretical limits, the next performance and capacity leap is now expected to come from evolution of network topology by using a mix of macro cells and small cells in a co-channel deployment. Capacity gains of macrocells from using more spectrum and optimization and improved efficiency are unlikely to be enough to keep up with the traffic demand increase, so extreme cell densification will be needed too.

2.3.3. HetNets and Small Cells

To meet the 1000x challenge, effective solutions are required to bring new data capacity at a much lower cost. In this regard, small cells will play a quintessential role in serving the data needs over the coming years. Radio link performance is fast approaching theoretical limits. The next performance and capacity leap is now expected to come from a mix of macro cells and small cells in a co-channel deployment.

HetNet densification is clearly a way forward, i.e., many small cells are required and they will be deployed indoors, outdoors, at all possible venues such as residences, enterprises, in all technologies (3G, 4G, Wi-Fi), in all various mode such as indoor residential, enterprise, picos, relays, remote radio heads, distributed antenna systems, etc. The various types of small cells should complement the traditional macro networks, and allow denser use of spectrum. The introduction of Heterogeneous Network (HetNet) techniques in LTE-Advanced and HSPA, including intelligent interference coordination methods in the network, offers a more promising and scalable path to achieve tremendous growth in spectrum efficiency per unit area.

The new deployment concept, referred to as “Neighborhood Small Cells” (NSC), uses densely deployed open-access small cells and leverages existing premises and backhaul to greatly reduce Capital Expenditure (CapEx) and Operational Expenditure (OpEx).Figure 2 show NSC performance evaluated in terms of improvement in UE DL throughput or equivalently DL capacity in a deployment of 10 MHz macro + 10 MHz NSC relative to baseline macro-only (10 MHz) deployment. Performance is evaluated for different NSC penetrations {2,5,10,20,30,50} percent that correspond to {14,36,72,144,216,360} NSCs per macrocell, respectively[5]. The gain shown is for the DL median throughput for 25 and 200 active UEs simultaneously per macrocell. At 10 percent penetration level of NSCs, a DL median throughput gain of ~25x to 55x is achieved with an additional 10 MHz NSC carrier. Gains are attributed to cell splitting as well as improvement in SINR compared to macro deployment as users get closer to their serving NSC.

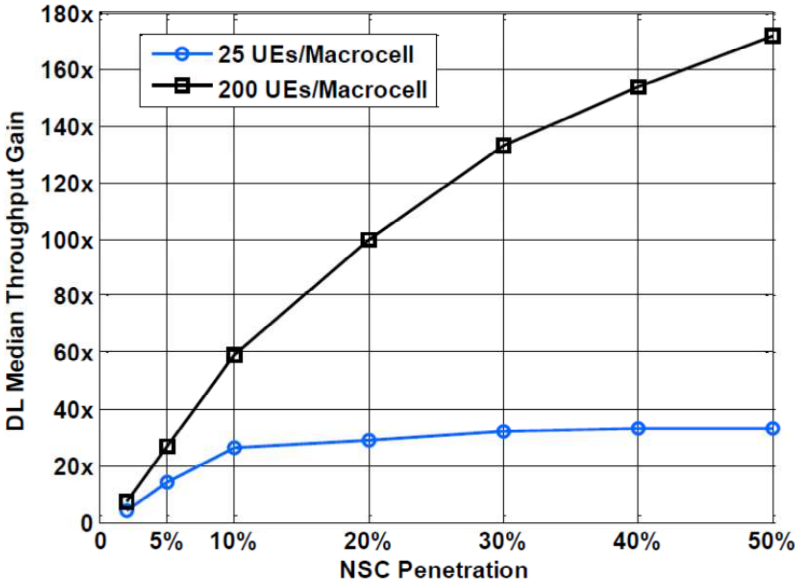

Figure 2: DL user throughput gains for a (10 + 10) MHz NSC deployment relative to 10 MHz macro carrier baseline for 25 or 200 active users per macrocell area [5].

2.4. Our Focus

All the technologies will undoubtedly address the high capacity demand of 1000x. But to bring them into reality is a different story because of the practical intricacies involved. Although there are many challenges, our work mainly deals with following challenges:

A) Resource Management in Macro cells

B) Interference Management in HetNets

C) Interference Mitigation in HetNets

A) Resource Management in Macro cells

Channel allocation is one of the most important resource management schemes in macrocells. While this subject is heavily studied in literature, there is still scope for improvement. Traditional channel allocation cannot cater to the needs of dynamic signature of mobile traffic. In chapter 3, predictive modeling based channel allocation is proposed towards designing a more optimal channel allocation strategy.

B) Interference Management in HetNets

In a heterogeneous network with range expansion, in order for a user terminal to obtain service from a low-power base station in the presence of macro base stations with stronger downlink signal strength, the pico base station needs to perform both control channel and data channel interference coordination with the dominant macro interferers and the user terminals need to support advanced receivers for interference cancellation. In the case of femto base stations, only the owner or subscribers of the femto base-station may be allowed to access the femto base stations.

In chapter 4, a cognitive femto cell access point mitigates the interference caused by the dominant macrocell by employing a novel power control algorithm which depends on SINR ratio of femto cell access point.

C) Interference Mitigation in HetNets

To meet the needs of 1000x, extreme densification of femtocells is almost inevitable. But this high scale densification creates significant interference to neighboring users. Thus the solution given in chapter 4 is not adequate.

In chapter 5, we improvised upon the fact that beam forming technique can be employed to manage the interference levels in HetNets. The efficiency of this solution can be improved by increase of number of antennas used in the femto cell access point.

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3. Optimal Hybrid Channel Allocation

3.1. Overview

Recent advances in cellular communication systems resulted in a huge increase in spectrum demand. To meet the requirements of the ever growing need for spectrum, efficient utilization of the existing resources is of utmost importance. Channel allocation has thus become an inevitable and well investigated research topic in wireless communications. In this chapter, we propose a novel channel allocation scheme called Optimal Hybrid Channel Allocation for an effective allocation of channels. We improvise upon the existing fixed channel allocation technique by imparting intelligence to the existing system by introducing the predictive modeling techniques such autoregressive process based technique to model the call traffic. Although our study is restricted to cellular networks, the same channel allocation algorithm technique can be extended to the channel allocation in various wireless environments such as WiFi, Femtocells and other wireless technologies. In chapter 4, we have applied this scheme for channel selection based on interference levels.

3.2. Introduction

Today's communication networks are being overwhelmed with the growth of bandwidth-intensive applications like streaming media. This has created a huge competition among the service-providers promising their customers with the speed improvement and other qualities of services. One of the most important challenges that these service providers always confront with is frequency scarcity. In fact frequency spectrum allocation and spectrum auction are of huge importance, when ergonomics and economic factors are taken into account.

In the age of spectrum drought, spectrum is regarded as one of the most important natural resources. With the number of users using smart devices exploding alongside with the emergence of concepts like "Internet of Things", the spectrum is getting heavily crowded and hence the need for utilizing the spectrum resources efficiently is of utmost importance. Frequency reuse is the basic strategy that has been employed over years to conserve frequency utilization. Channel assignment in cellular networks is fundamentally dependent on frequency reuse. The subject of channel assignment is well investigated. There are many existing channel allocation schemes such as fixed channel allocation (FCA) with borrowing [3], dynamic channel allocation (DCA) and its variants [5] and many hybrid channel allocation schemes (HCA) [6].

In this chapter, we focus on a novel hybrid channel allocation scheme called Optimal Hybrid Channel Allocation (OHCA) by introducing the concept of Intelligent Fixed Channel Allocation (IFCA). In addition, we model the call traffic as autoregressive process (AR model) to predict the future traffic. Here optimization is done with respect to channel utilization factor [12].

3.3. Previous work

A given radio spectrum (or bandwidth) can be divided into a set of disjoint or non-interfering radio channels by exploiting the physical characteristics of a radio wave. In cellular mobile communication systems design, the decision on channel assignment schemes is crucial [1]. The objective of any channel assignment scheme would be to enhance the received signal strength, minimize the carrier-to-interference ratio and decrease the co-channel reuse distance.

There are many ways in which the channel allocation schemes can be classified [2]. Based on the relation between the number of cells in a cluster and the number of allocated channels, channel allocation schemes are classified as follows:

- Fixed Channel Allocation
- Dynamic Channel Allocation
- Hybrid Channel Allocation

- <u>Fixed Channel Allocation (FCA):</u>

In this scheme, the number of channels that are allocated to a cell is fixed and is determined on the basis of co-channel reuse factors. Further we can classify FCA into uniform channel allocation and non-uniform channel allocation. In the uniform channel allocation scheme, as the name suggests, the number of channels assigned to each cell is uniform in channel allocation scheme [3]. But the temporal and spatial variations in traffic across the cell make the uniform channel scheme a ineffective one. So generally a non-uniform channel allocation scheme with different borrowing schemes would be employed [4].

- <u>Dynamic Channel Allocation (DCA):</u>

In this scheme, unlike the previous scheme, all the channels are placed in a central pool rather than hard-assigning of channels to each cell. The channels placed in the central pool are assigned dynamically to radio cells in accordance with the new calls that arrive to the system. After a call is completed, its channel is returned to the central pool [5]. Again based on the practical feasibilities and requirements, DCA can be further implemented in two ways: Centralized DCA and Distributed DCA. In centralized DCA, there would be a centralized controller that manages all the channel assignment operations. But this would lead to huge centralized overhead because of huge number of hand-shaking protocols that have to be followed before a link gets established. To avoid the centralized overhead, one can use the distributed DCA.

- Hybrid Channel Allocation (HCA):

This scheme employs the combination of both, fixed and dynamic channel allocation techniques. Out of the total number of available channels, some number of channels would be assigned to each cell in a manner similar to that of FCA, but the remaining number of channels would be placed in a channel pool and would be assigned to the cell based on the traffic, bandwidth and other factors [6].

Irrespective of the traffic load in a cell, there would be some fixed channels allocated to the cell. This led to inefficient channel utilization factor. This intrigued us to search for even better channel allocation scheme. Having realized the potency of machine learning, we have applied the auto regression technique to the estimate the traffic load, which in turn improvised the channel utilization factor.

3.4. Novel approach towards optimal HCA

To achieve (the optimal channel assignment), we propose a novel technique called intelligent FCA, that aims at improving channel utilization factor by employing non uniform channel allocation to each cell (discussed in detail in section 3.5). One of the parameters come from Autoregressive Model code, basic machine learning and optimization technique (discussed in section 3.5).The complete scheme coupling intelligent FCA scheme with machine learning techniques is presented in figure 3.

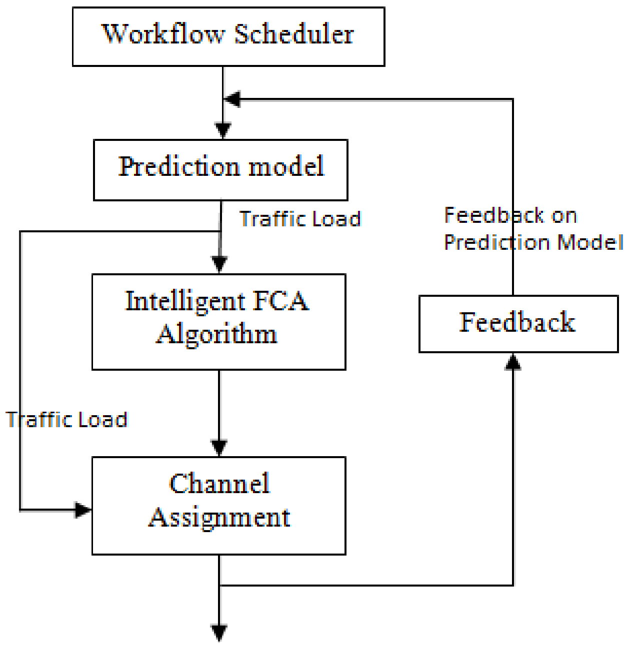

Figure 3: Work flow - Optimal Hybrid Channel Allocation

The implementation of our algorithm requires the following blocks:

- Workflow scheduler:

The workflow scheduler contains database and the scheduler that keeps the system intact, handling the synchronization issues of the design. Synchronization (here) refers to coordinating the functionalities such as the log management, triggering the machine learning block, managing the channel assignment issues etc. Traffic log is fed continuously by the feedback block updating the current traffic statistics. Typically the machine learning block (here the linear prediction model) is triggered periodically after a stipulated time frame. Channel assignment block deals not only with channel allocation but also maintains the record of channel information of all the cells of a cluster. Hence, with so many operations to be carried out, there has to be a component in the system that manages all these functionalities. Thus workflow scheduler is so designed to function as a coordinator.

- Prediction model:

In this schema, prediction of future call traffic is of utmost importance. To predict the future traffic, we employ a commonly employed tool time series analysis, autoregressive model (AR model). Although there are many other prediction techniques that can be applied in this context, a less complex basic AR-model is used in this chapter. Linear predictive coding of a random process reveals a model for the process, called the autoregressive (AR) model. This model is very useful both conceptually and for approximating the process with a simple model. The model is discussed in detail in section 3.5.

- Intelligent FCA algorithm:

In Intelligent Fixed Channel Allocation (IFCA) scheme, unlike the traditional approach, machine learning techniques are employed to study the traffic patterns of each cell. In traditional FCA, uniform channel allocation will be done to the cells in a cluster. Each cell is given a predetermined set of frequency channels and once allotment is done, the number of channels assigned to a cell remains fixed irrespective of the call traffic. Here we propose a novel scheme, IFCA in which channels are allocated to each cell based on the statistical information obtained from the prediction model**.** A cell with high traffic will be assigned more number of channels and a cell with less traffic will be assigned less number of channels. Various concepts such as probability of inverse packet count and idle time are introduced. The concept of intelligent FCA is discussed in length in section 3.5.

- Channel Assignment:

This is the final step in the schema. A cluster has a pool of channels, which are to be distributed among all the cells. The channels are then allocated accordingly with the results obtained from the above block.

- Feedback block:

The feedback block updates the database of the workflow scheduler with the current cell traffic information based on which the prediction model updates its data source. In the next section, the prediction model block and Intelligent FCA blocks are discussed in detail.

3.5. Prediction Model and Intelligent FCA Model

In this section, we discuss the prediction model presented in the implementation along with introducing a novel concept in FCA, as Intelligent FCA (IFCA). Later in this chapter, a system employing the combination of Intelligent FCA and DCA schemes is reasoned to be optimal HCA with respect to channel utilization factor**.**

3.5.1. AR model to predict traffic

The central idea behind this chapter is to estimate the channels required by the cell based on its past traffic statistics. Especially the focus will be on two parameters, idle time and packet count (defined in 3.5.2). These two parameters serve as inputs to the prediction model discussed in this section. A linear prediction model, autoregressive (AR) process is employed to model the call traffic. AR model is very useful both conceptually and for approximating the call traffic dynamics. Given a Wide Sense Stationary process (WSS) x(n) and if a Nth-order optimal predictor polynomial AR(z) is found, then represent the process can be modeled as

$$X(n) = \sum_{i=1}^{N} a_i X(n-i) + w(n)$$

Here '$w(n)$' is white noise (prediction error) and 'a_i' are AR model coefficients.

If the call traffic is modeled based on AR(N) WSS process, the advantage is that the AR coefficients a_i can be found simply by performing Nth-order LPC on the process x(n). We now discuss the computation of estimating the coefficients of a p^{th} order AR process.

$$X_t = \sum_{i=1}^{p} \psi_i X_{t-i} + \varepsilon_t$$

Where $\psi_i, \ldots\ldots, \psi_p$ are the parameters of the model, and ε_t is white noise. The parameters $\psi_i, \ldots\ldots, \psi_p$ are found using the Yule-Walker equations. The Yule-Walker equations are the following set of equations

$$\gamma_m = \sum_{i=1}^{p} \psi_i \gamma_{m-i} + \sigma_\varepsilon^2 \delta_{m,0}$$

where m = 0, ..., p, yielding ‘p + 1’ equations. Here γ_m is the auto-covariance function of X_t, σ_ω is the standard deviation of the input noise process, and $\delta_{m,0}$ is the Kronecker delta function. Because the last part of an individual equation is non-zero only if m = 0, the set of equations can be solved by representing the equations for m > 0 in matrix form, thus getting the equation

$$\begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \vdots \\ \gamma_p \end{bmatrix} = \begin{bmatrix} \gamma_0 & \gamma_{-1} & \gamma_{-2} & \cdots \\ \gamma_1 & \gamma_0 & \gamma_{-1} & \cdots \\ \gamma_2 & \gamma_1 & \gamma_0 & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ \gamma_{p-1} & \gamma_{p-2} & \gamma_{p-3} & \cdots \end{bmatrix} \begin{bmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \\ \vdots \\ \psi_p \end{bmatrix}$$

Which can be solved forall $\{\psi_m; m = 1, 2, ..., p\}$ The remaining equation for m = 0 is

$$\gamma_0 = \sum_{k=1}^{p} \psi_k \gamma_{-k} + \sigma_\varepsilon^2$$

Which, once $\{\psi_m; m = 1, 2, ..., p\}$ are known, can be solved for σ_ε^2. Thus by using end of the predictive modeling block, we obtain crucial parameters like idle time of a cell at a given instant and packet count etc. that will be used in IFCA (3.5.2). These are some other models to predict traffic data, which are studied in detail in [10].

3.5.2. Intelligent FCA: Concept

In the traditional HCA, the total number of channels will be divided into 3:1 ratio for fixed and dynamic channels respectively. One can infer that, the percentage of fixed channels clearly dominates the number of dynamic channels. Therefore it is important to focus on the technique which allocates the fixed channels such that the channels can be used more effectively.

In this section, we propose a new technique, “intelligent FCA”, employing which a sense of cognition is applied in the allocation of the fixed channels. In Intelligent Fixed Channel Allocation scheme, unlike the traditional approach, machine learning techniques are employed to study the traffic patterns of each cell. Based on the obtained traffic patterns, the channel allocation is made. This is different from the conventional FCA in a way that the number of channels in the conventional FCA is fixed and equal, while in intelligent FCA, the number of channels is fixed but not equal. This section describes two different approaches to implement intelligent FCA.

Before we discuss the schemes in detail, firstly we define two crucial parameters, idle time and packet count that will affect the number of channels that are to be allocated.

Throughout the chapter, we consider 'M' base stations namely $B_1, B_2, ..., B_M$, the idle time and packet count random variables are stated as $T_1, T_2, ..., T_M$ and $D_1, D_2, ..., D_M$ respectively and the corresponding probabilities be $P(T_i = t_i)$ and $P(D_i = d_i)$ respectively.

- Idle time: Idle time is defined as the total amount of time, for which a base station remains idle in a given time interval.

- Probability of idle time: Probability of idle time of i^{th} base station is the ratio of idle time of that i^{th} base station to the sum of idle times of all the base stations and is given by:

$$p(T_i = t_i) = \frac{t_i}{\sum_{i=1}^{M} t_i} \qquad (1)$$

- Packet count: Packet count is the total number of packets transferred by a base station in a given time interval.

- Probability of inverse packet count: Probability of inverse packet count of i^{th} base station is the ratio of the inverse of packet count that i^{th} base station to the inverse sum of packet count of all the base stations and is given by:

$$p(D_i = d_i) = \frac{\frac{1}{D_i}}{\sum_{i=1}^{M} \frac{1}{D_i}} \qquad (2)$$

Here the values of idle time and packet count are evaluated from the machine learning technique employed insection 3.5.1. After the evaluation, the probabilities of idle time and packet count can be calculated. These probabilities have a unique relation with number of channels allotted (n_i) to the cell (or base station). The relation is as follows,

As the probability of idle time for a base station increases, the required number of channels for that base station decreases.

$$\mathrm{n}_i \ \alpha \ \frac{1}{P(t_i)}$$

As the probability of inverse of packet count for a base station increases, the required number of channels for that base station decreases.

$$n_i \ \alpha \ \frac{1}{P(D_i)}$$

We can infer that the number of channels required for a base station is inversely proportional to the probability of either idle time or inverse packet count. The following equation represents the average number of channels allocated to the each cell (or base station),

$$\sum_{i=1}^{M} n_i p_i \qquad (3)$$

Subject to the constraint, $\sum_{i=1}^{M} n_i = L$.

For the effective utilization of resources (channels), the above value should be as minimal as possible. So our objective is to calculate the number of channels (n_i) such that the value depicted in equation (3) is as minimal as possible. To compute the number of channels (n_i) that reduce the average, we propose the following methods:

A) Integer Linear Programming and

B) Source Coding

A) Integer Linear Programming:

In the integer linear programming, the probabilities of each cell are to be sorted in descending order. Then the assigned number of channels of each cell has to be in ascending order to minimize the equation (3), as the increase of number of channels depends on the manner in which probabilities decrease. If we consider the number of channels to be in Arithmetic Progression, (satisfying the above condition), we consider the following three cases:

Case 1: In this case, we will assign an arithmetic progression numbers from 1 to M to the base stations in the descending order of their probabilities (simplest way with less complexity). Then the actual number of channels allocated to a base station is the constant 'c' times to the 1 to M. The scaling factor is given by,

$$c = \frac{L}{\frac{M^2 + M}{2}} \qquad (4)$$

From the equation (4) the assigned channels to the cells becomes c, 2c, 3c, 4c,….., Mc.

Case 2:In this case the number of channels allocated to M base stations are in Arithmetic progression "a, a+d, a+2d, ….., a+(M-1)d" where a,d are required. This situation is not practical as the number of channels allocated to a base station has a minimum value. thus we are lead to the following more realistic case.

In this case, we assign the AP series, “a, a+d, a+2d, ….., a+(M-1)d” number of channels to each cell, where a and d are the required variables, that are to be computed. The upper bound ($L_{\max}$) and lower bound ($L_{\min}$) on the allocable number of channels to any base station, can be determined from the machine learning techniques. When the difference between $L_{\max}$ and $L_{\min}$ is greater than the total number of cells (i.e. M), there would be a need for optimizing the allocation scheme since the distribution of number of channels to each cell would be non-uniform. This is not the case, when the difference is minimal as the channel distribution would be far more uniform than the previous case.

From the above statements, we can make a valid assumption that

$$a = L_{\min}$$

Then the integer variable d would be

$$d = \frac{L_{\max} - L_{\min}}{M}.$$

(Note that the right hand side is a non-integer value, would be rounded to the previous integer value since d has to be an integer because in this case it represents number of channels allocated to a base station).

Case 3: In this case we employ Linear-Diophantine equation based technique to get the parameters for channel assignment. Here also we consider an AP series “a, a+d, a+2d, ….., a+(M-1)d” as number of channels to each cell. Now the following procedure is employed to obtain ‘a’ and ‘d’. We know that, total number of channels of each cell adds to the available number of channels.

$$a + (a+d) + ... + (a + (M-1)*d) = L$$

LHS is in A.P. therefore,

$$M*a + (\frac{M(M-1)}{2})*d = L \qquad (5)$$

The equation (5) is in the form of Linear-Diophantine equation $ex + fy = g$ where e=M and f=$\frac{M(M-1)}{2}$ and g=L.

So, in accordance with Linear-Diophantine equation [7], for equation (5) to have a solution (probably infinitely many solutions), L should be an integer multiple of GCD of constants in equation (5) (i.e. GCD of M and $\frac{M(M-1)}{2}$ which is 'M' for 'odd' value of M. For 'even' value of M, we can find GCD using Euclidean algorithm [8]).

$$\therefore L = kM \qquad (6)$$

Here $'k'$ is an integer value. So L will be chosen in such a way that the equation (6) holds true. Now, from the solution of Linear-Diophantine equation the variables 'a' and 'd' assumes infinitely many solutions. But out of them only finitely many set of solutions are of interest to us. To find the unique set of values for 'a' and 'd', we consider all the solutions of 'a' and then compare with $L_{\min}$, then assign the value to 'a'(i.e. from the set of solutions), which is nearer to $L_{\min}$.

B) Source Coding

In this technique, the traditional "source coding" approach is applied to the channel allocation schemes, i.e. minimize $\sum_{i=1}^{M} n_i p_i$ subject to Kraft's inequality $\sum_{i=1}^{M} D^{-n_i} \leq 1$.The number of allocable channels is determined from ratio of probabilities of each cell. Huffman coding is one of the prominent techniques employed in source coding. In Huffman coding, the obtained code lengths are Kraft numbers, i.e. they satisfy Kraft's inequality [9].

So here we employ the concept of Huffman Coding in the channel allocation schemes. Firstly the probabilities of all the base stations are made known to every other base station. Then the process of Huffman Coding takes place at each base station. Then each base station sends its code word (which indicates number of channels assigned to each cell) to the central controller which handles the channel assignment schemes. So here, we can say that these number of channels allocated to the each cell would be a Kraft Number. If we assert the number of channels in a base station to be a Kraft Number, then the average number of channels in a i^{th} base station is given by,

$$\mathrm{n}_i = -\log_2 P_i$$

As the number of channels allocated to a base station be $n_1, n_2, n_3, \ldots\ldots, n_M$, then the ratios of the number of channels required for each base station is evaluated as follows,

$$n_1 : n_2 : \ldots\ldots : n_M = (-\log_2 P_1) : (-\log_2 P_2) : \ldots\ldots : (-\log_2 P_M) \qquad (7)$$

But $n_1 + n_2 + n_3 + ... + n_M = L$ (8)

From equations (7) and (8), we can compute the values of $n_1, n_2, n_3, ..., n_M$.

3.5.3. AR Model with IFCA : Optimal HCA

Optimal HCA is a hybrid channel allocation scheme that comprises of a combination of intelligent FCA with DCA. Thus, the concept of Optimal HCA is proposed by allocating channels to the each cell from the total number of available channels in the fixed channels division. (Determined from any of the above algorithms) If the channel requirement in a particular cell is more than the predicted (i.e. more than the allocated channels) then channels from the Dynamic pool will allocated to that cell.

Along the lines of above discussion, it is possible to consider average number of packets received as the criteria for optimization. With such criteria if the normalized probability in a base station is high the number of channels allocated should be high. Thus we are interested in maximization problem (formulated as an integer linear programming) and similar results as above can apply.

3.6. Simulation results

The main aim of the simulation is to compare the performance of FCA and OHCA algorithms under randomly generated non uniform traffic patterns in MATLAB. We have considered cellular system of 7 clusters with 7 cells in each cluster as shown in figure 4.

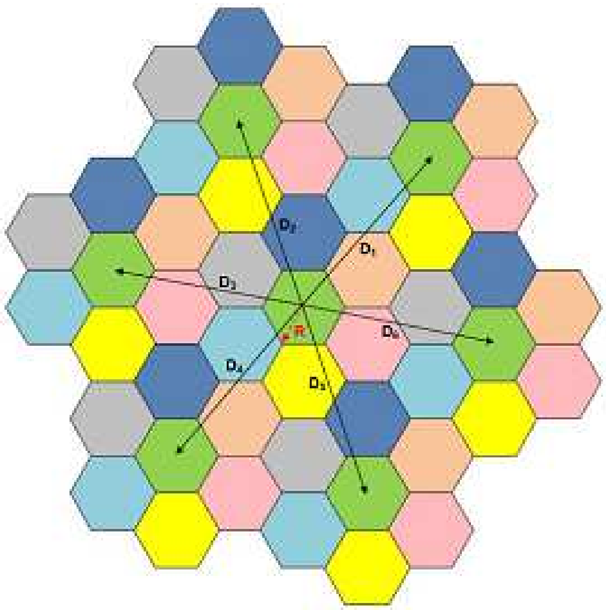

Figure 4:Hexagonal Cell arrangement

A plot of drop call probability versus traffic load is presented in figure 5. We can infer that the OHCA technique outperforms FCA and performs slightly better than DCA.

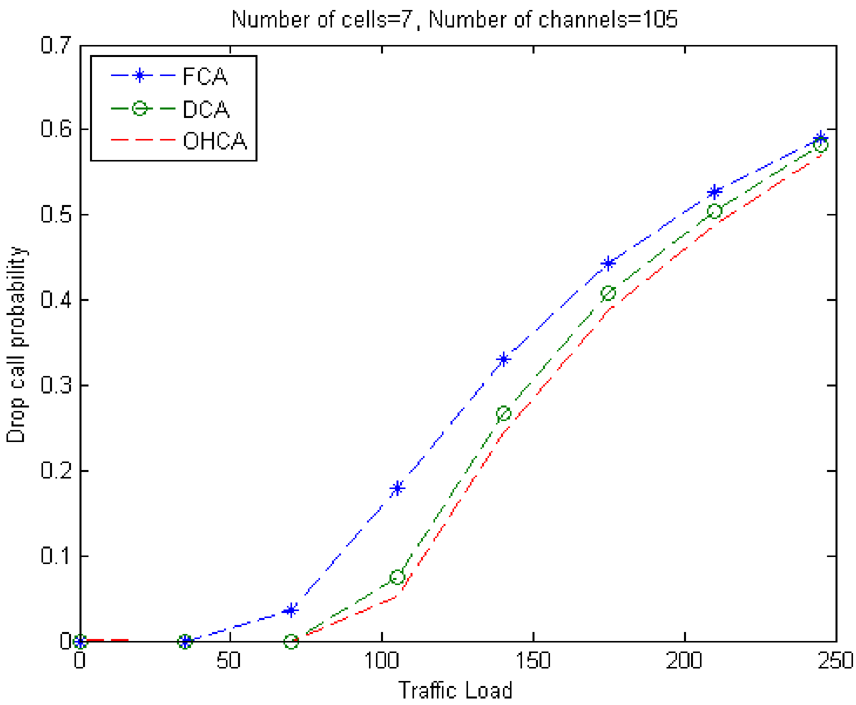

Figure 5: Drop call probability vs Traffic load

Our emphasis in figure 6 is to compare FCA and IFCA on the channel utilization factor [11] mapped on to the cells. It can be inferred from plot that the average channel utilization factor is optimized in the each cell in the case of IFCA compared to the FCA. In FCA some cells have better channel utilization factor and some have very poor where as in IFCA the channel utilization factor is achieved equally in each cell.

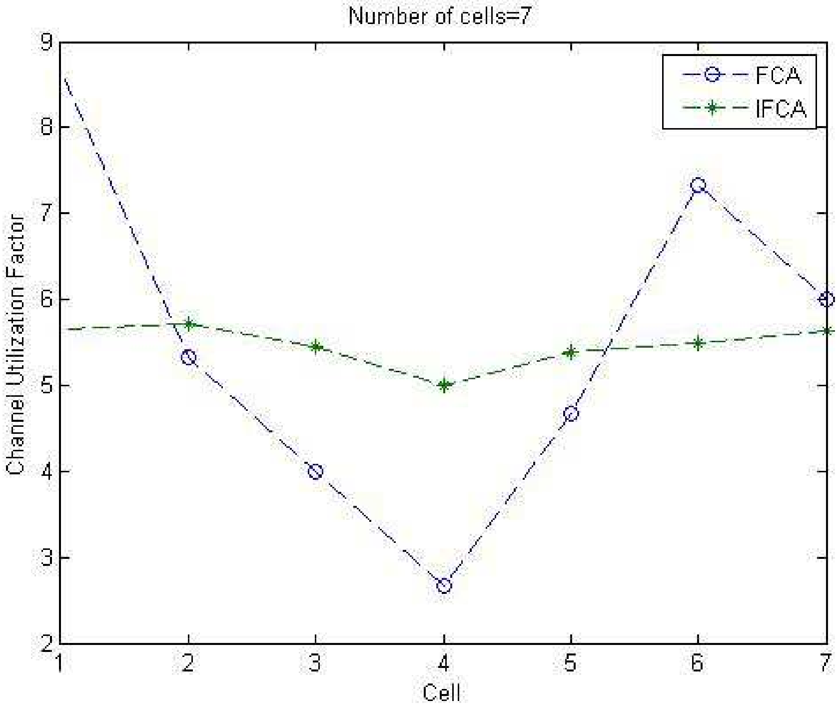

Figure 6: Channel Utilization Factor

3.7. Conclusion

The problem of efficient channel allocation or spectrum usage can be achieved by efficient channel allocation schemes rather than opting for the age-old techniques. This can be achieved by studying the pattern of traffic at each base station and by imparting a sense of cognition to channel assignment controller as employed in the case presented in the chapter.

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4. Interference management via Cognitive Power Control

4.1. Overview

Heterogeneous Networks (HetNets), a newly evolving paradigm has become a viable solution to the challenges posed by ever increasing traffic in the existing cellular networks. The deployment of a HetNet is a tedious task since it involves overlay of small cells onto macro cells. Given the nature of deployment, interference management is extremely crucial for HetNet deployment. In addition, interference issues multiply with multi tier architecture. In this work, cross-tier and co-tier interference is mitigated by introducing cognition femto cell access point (CFAP). CFAP will manage the co-tier and cross-tier interference without any information from macro cell base station.

4.2. Introduction

Smart phones and tablets have penetrated into every sphere of human life. With the advent of smart phones, the demand for high mobile internet speeds has begun to increase massively. Mobile traffic is growing exponentially by a factor of 80 percent every year. This ever-increasing demand for high speed data has forced many rapid changes in the cellular and other wireless technologies. Various cellular technologies are designed and continuously improved to meet the ever growing demand. Some of them include GSM, HSDPA, CDMA, CDMA2000, UMTS, W-CDMA and most recent being LTE-A [1]. Improving the link capacity and bandwidth with optimal spectrum resource allocation has always been the driving force behind this continuum of the advances made in cellular technologies. The concept of heterogeneous networks has been a recent addendum to the concept of cellular networks.

The term, "HetNets" may have many different senses and multiple meanings. In a broader sense, a HetNet is a multi-technology, multi-layer, multi-architecture, multi-tier and a multi protocol network in which various different standards will be supported and maintained at the same time [2].

The traditional way of building a cellular network is to use big macro cells, allowing good coverage of a particular area without the need for too many expensive cell sites. As the wireless data demand grows over the next decade, macro cell-splitting can become economically and logistically unfeasible as the cost of hardware, site acquisition and complexity of network planning can be beyond the practical limits. Operators are therefore looking to smaller form factor base stations which can be deployed in a wider range of locations. With reducing size, lower RF transmit power and thus shorter ranges, self-organizing small cells will play an integral role in cellular networks and enable operators to meet the 1000x demand challenge.

In this chapter, the term "HetNets" is viewed from the perspective that a HetNet is an overlay of femto cells over already existing macro cells shown in figure 7. Femto cell deployment brings in multiple advantages such as the increase in network coverage, network capacity, offloading, lowering the cost of delivering mobile broadband services etc [3].

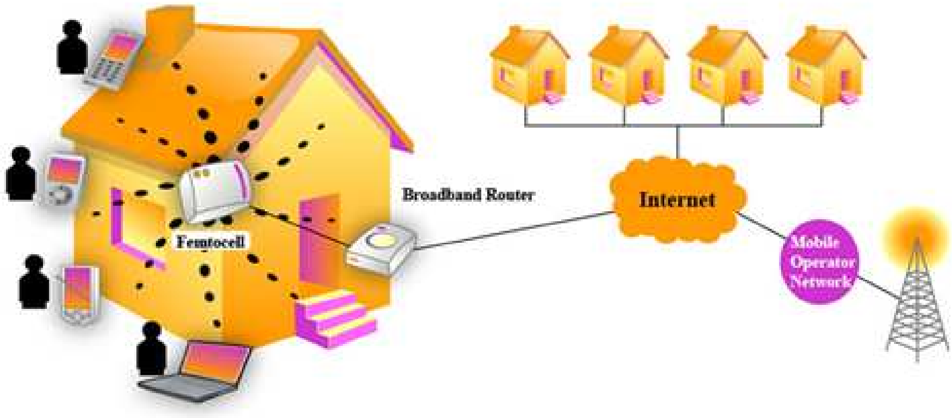

Figure 7. Femto cell connection to mobile operator [14]

Nevertheless, femto cell deployment confronts significant challenges [4] such as maintenance issues, deployment issues etc. Interference management among the femto cells and macro cells is one of the most significant challenges**.** In this chapter, we address a solution to the interference problem by introducing cognition to the femto cell access point. This cognitive FAP controls the power of the small cell base station in accordance with interference and noise levels. The concept is explained in section 4.4.

4.3. Back Ground

A small cell is a cell, introduced into an existing cellular network consisting of low power radio devices, whose transmission ranges are limited to a few kilometres to few meters. Small cellsinclude femtocells, picocells, microcells, and metro cells. Small cells bring in flexibility, cost effectiveness and ease of deployment unlike the complexities involved with the deployment of a macro cell. Small cells can also contain the self organization and sustenance capabilities as well. One of the key advantages of a small cell is that small cells serve as offloading spots to macro cells, thereby reducing the congestion in a macro cell.Traffic offloading in macro cell is achieved, when users are served by the small cell base station instead of macro cell base station. In this chapter we consider femto cell as the small cell.

In general users will connect to the network tier which has greater signal strength (received signal strength i.e. RSS). The association probability of the users connected to small cell can be stated as follows [12],

$$p_S = \mathrm{P}\{P_S T h_S r_S^{-\eta} > P_M h_M r_M^{-\eta}\} \qquad (1)$$

Here P_S represents SBS transmit power, P_M is the MBS transmit power, h_S is channel fading between user and nearest SBS, h_M is channel fading between user and nearest MSB, r_S is random distance between user and nearest SBS, r_M is random distance between user and nearest MSB, η path loss exponent, T is a control parameter used to bias users to connect to small cells. The probability of users to connect to MBS is $1-p_S$. The effect of the above parameters on association probability is studied in detail[5].

It has been empirically proved that a small cell is potentially an invaluable source that contributes to the macro cell to achieve its QoS requirements in hotspots. So it can be envisioned that, the number of small cells in a macro cell would substantially increase, since more the number of small cell in a macro cell, much easier it is to meet the QoS requirements of a macro cell. In other words the usage of femto cells will increase. Generally femto cells are deployed by the clients instead of service provider. The users are generally place the femto cell access point in their homes, offices, complexes, etc. Hence the deployment of femto cells confronts major challenges. Which are,

- Design of multi tier networks: When a macro cell is overlaid with a number of femto cells, it becomes a multi tier network, where the femto cells serves as a independent tier. This creation of new tier comes up with the challenges such as offloading related challenges,admission control and handoff management etc. This calls for a robust design of multi tier architecture.

- Interference management:Interference within a tier and among the neighbouring tiers of a network is a significant challenge.Challenges related to interference are further discussed in detail in section-3.

- Spectrum resource allocations:Spectrum is now seen as a scarce and diminishingcommodity. The concepts of software defined radio and cognitive radio have evolved to tackle the problem of spectrum drought. Especially in the case of HetNets, which survives on the spectrum reuse principle, the spectrum resource allocation is especially major problem to encounter with.

- Backhaul maintenance and related issues:The topology of theMBSs and the operator installed femto cell (FAP) is dynamic and volatile. A backhaul has to be designed so as to tackle the changes made in topology across the service area according to the capacity demand. Thus the deployment of femto cells and design of corresponding backhaul network is complicated [6].

4.4. Analysis

The objective of this chapter is to mitigate the interference related issues associated with the HetNets. Interference in femto cell is of two types [10]:

Cross-tier interference: This type of interference is caused by the network elements of different tiers. A MBS will affect the performance of any femto cell placed in its coverage region. Along with macro cell base stations, macro cell users will affect the performance of nearby femto cells. Similarly the femto cell access points will cause significant interference to the nearby macro cell users. Spectrum splitting and inter cell interference coordination are the generally employed techniques to mitigate cross-tier interference.

Co-tier interference: The network elements residing in the same tier results in this kind of interference. In femto cell environment, co-tier interference is caused by neighbouring femto cells. This kind of interference is more significant in the case of dense deployments.

Interference at point ‘y’ is given by,

$$I_y = \sum_{x \in T} P_x h_x (\llbracket y - X \rrbracket)^{-\alpha} \qquad (2)$$

Here, $x \in T$ where T is a complete set of transmitting nodes, P_x denotes the transmitted power, h_x represents the corresponding channel fading coefficient and $\llbracket y - X \rrbracket^{-\alpha}$ denotes the approximate distance between the transmitter and the place where interference is estimated.

Signal to Interference plus Noise Ratio (SINR) is also an important parameter in the small cell base station. SINR can be estimated as,

$$SINR = \frac{P}{I + N}$$

Where ‘P’ is the power of the incoming signal of interest, ‘I’ is the power of other signals in the network considered as interference power and ‘N’ is the noise. In case of femto cell, the SINR of ‘ i^{th} ’ femto cell access point can be calculated from,

$$SINR = \frac{P_{F_i} h_{x_i} \left\| x_i \right\|^{-\alpha}}{\sum_{j \neq i} P_{F_j} h_{x_j} \left\| x_j \right\|^{-\alpha} + \sum_i P_{M_i} h_{x_i} \left\| x_i \right\|^{-\alpha} + N} \qquad (3)$$

Here $\sum_{j \neq i} P_{F_j} h_{x_j} \left\| x_j \right\|^{-\alpha}$ represents interference caused by neighboring femto cells, $\sum_i P_{M_i} h_{x_i} \left\| x_i \right\|^{-\alpha}$ represents interference caused by macro cell and the neighbouring macro cells. And the total interference is $I = \sum_{j \neq i} P_{F_j} h_{x_j} \left\| x_j \right\|^{-\alpha} + \sum_i P_{M_i} h_{x_i} \left\| x_i \right\|^{-\alpha}$.

A comprehensive survey of interference mitigation techniques is presented [10]. In [11], overhead signalling strategies have been analyzed towards interference mitigation [8],[9]. But in all these techniques, interference mitigation is carried out in a centralized fashion. Such approaches may turn complicated when there is a large deployment of femto cells. In this chapter, we propose a cognitive femto cell access point which deals with the inference without any additional information or cooperation from macro cells or the neighbouring femto cells.

4.5. Proposed Work

The fundamental theory of the proposed algorithm is based on the fact that the power levels of MBS and FAP complement each other. This concept is further explained in detail using Fig. 2.The power levels of macro cell and femto cell against distance is plotted in Fig. 2.The primary use of femto cell is to provide the coverage to the indoor environment where the signal strength coming from MBS drops significantly. Typically the path loss incurred due to a brick wall is 6dB [13]. In Fig. 2, it can be observed that the MBS signal power drops significantly after passing through an obstacle, thus affecting the coverage. Femto cells are installed to provide service in such areas.

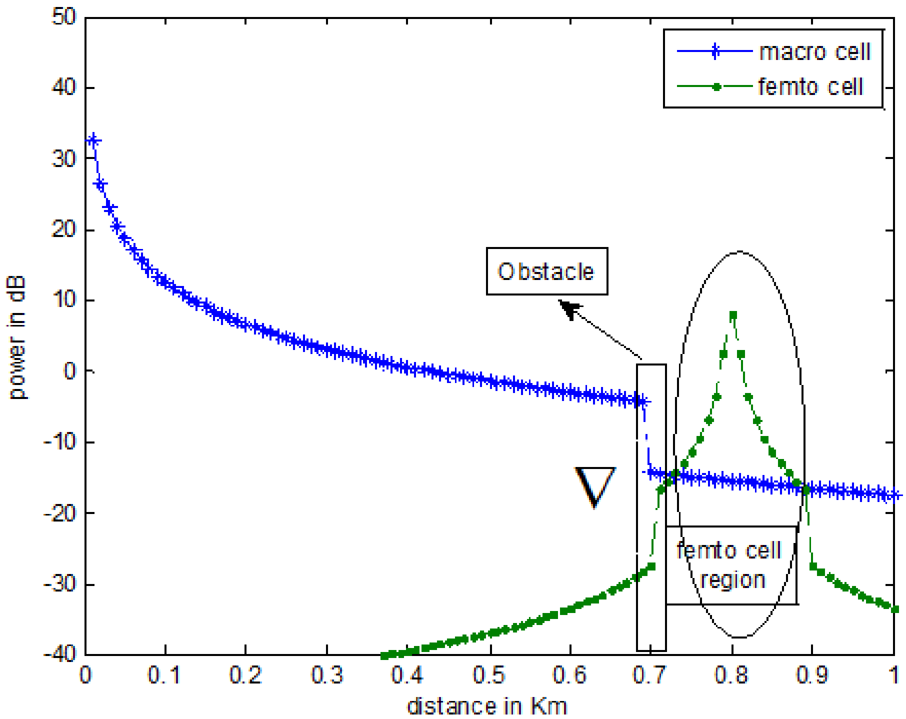

Figure 8. Macro cell and Femto cell Power levels vs Distance

(For the simulation purpose transmit power of macro cell base station is 200W and femto cell base station is 100mW.)

The most basic and simple method for interference mitigation is to adjust the power levels of the femto cell. This method is mainly constrained by '∇'. But as the power level of femto cell is increased, it would affect the neighboring users or femto cells. To address such problems, we propose a novel power control algorithm. To execute such a novel power control we incorporated cognition to FAP.

The proposed power control basically depends on the SINR value. As the SINR represents the quality of service, the maintenance of required SINR is important. From equation 3 the SINR is calculated as,

$$SINR = \frac{P_{F_i} h_{x_i} \|x_i\|^{-\alpha}}{\sum_{j \neq i} P_{F_j} h_{x_j} \|x_j\|^{-\alpha} + \sum_{i} P_{M_i} h_{x_i} \|x_i\|^{-\alpha} + N} \quad (4)$$

Here the denominator term represents interference and noise levels. So to maintain SINR we increase the transmit power at FAP 'P_{F_i}'. If this process takes place in all FAP then it will affect the value of $\sum_{j \neq i} P_{F_j} h_{x_j} \|x_j\|^{-\alpha}$ (neighboring interference). So we propose a threshold range rather than threshold level. This threshold range $Th_L < SINR < Th_U$ is defined as the lower bound 'Th_L' gives the minimum required SINR value, this allows to overcome the cross-tier interference and the upper bound 'Th_U' gives the maximum allowed SINR value. This upper bound is to tackle co-tier interference as it constrains the neighbouring interference power levels.The threshold range is as follows,

$$(I_M + N)SINR \leq P \leq (I_M + N)SINR(\frac{1}{1-\delta}) \quad (5)$$

Here δ is a constant depends on the density of femto cells. The range of δ is from 0.2 to 0.8 depending on the number of neighboring femto cells. CFAP follows the algorithm shown in Figure 9.

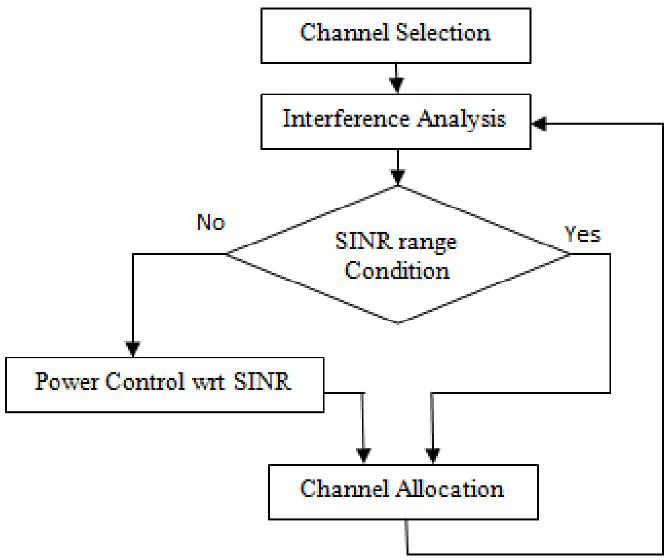

Figure 9. Algorithm flow chart

To mitigate the interference, the femto cell access point performs the following steps, depicted in Figure 9.

1. While allocating the channel to the users in the femto cell, CFAP first senses (energy detection or any simple spectrum sensing technique) all the channels available in the macro cell and allocates the channel with low interference and noise levels.

2. In this step the analyses of interference level is takes place. Which in turn estimates the value of SINR to a particular channel which is selected in step 1.

3. In this step the SINR value is compared to the range of the standard SINR value. If it satisfies it directly allocates the channel, otherwise the process goes to step 4 power control.

4. CFAP varies the transmit power level (Ps) such that the SINR level of that particular femto cell always remains in between the specified threshold range $Th_L < SINR < Th_U$. After varying the power level to attain the required SINR, the process will go to channel allocation.

5. In final step the channel allocation will takes place. After channel allocation the process is repeated through step 2, to continuously monitor the SINR values. If the SINR value changes it again varies the power in accordance.

Thus we introduced the cognition to the femto cell access point in the HetNets not only with respect to spectrum resources, but also with respect to SINR levels[7].

4.6. Simulation Results

In this section, we present simulation results, which are as follows:

In Fig.4, comparison of SINR values in a given small cell with and without employing cognition is presented. Here the range of small cell and interference ratio is limited to $90 \le \frac{I}{P_S} \le 190$. This variation of SINR is presented in Figure 10. We can infer that, in the case of without cognition, as interference levels increase, the SINR of the small cell decreases. In the case of with cognition, the value of SINR is independent of interference levels and is maintained above the given threshold level. That is, even with the increasing levels of interference, the level of SINR is held almost constant.

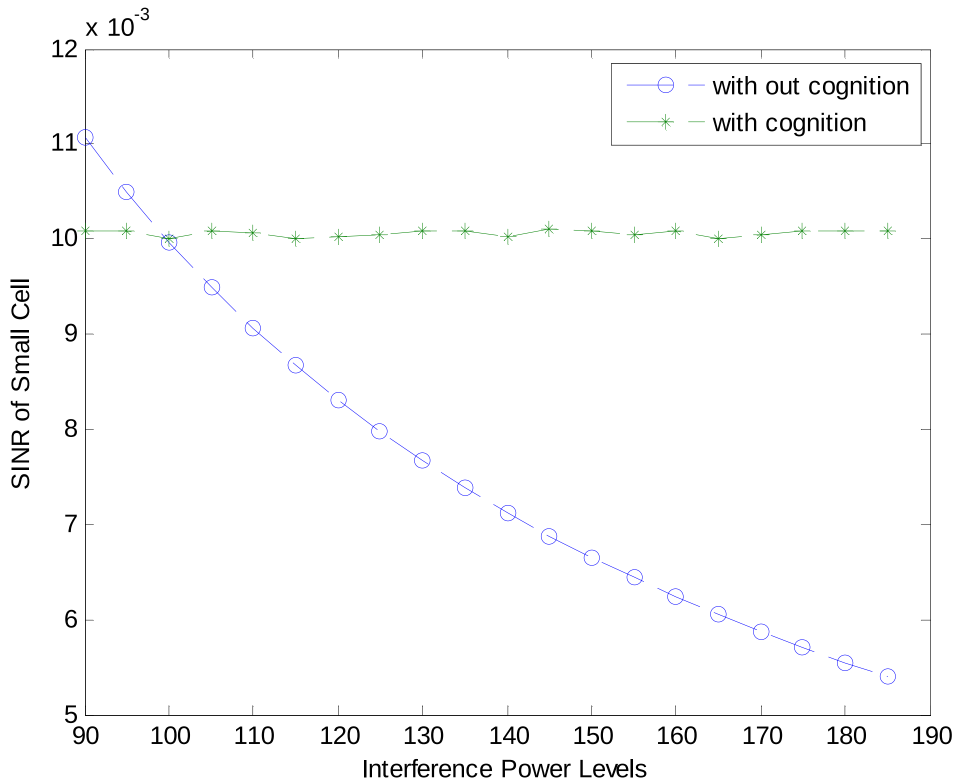

Figure 10. Comparison of SINR of small cell with and without employing cognition

The impact of transmit power variations of small cell on SINR neighboring small cells is shown in Figure 11. From the graph, it can be asserted that the impact of power level variations due to cognition does not affect the SINR of the neighboring small cell much, because of the upper bound on the SINR.

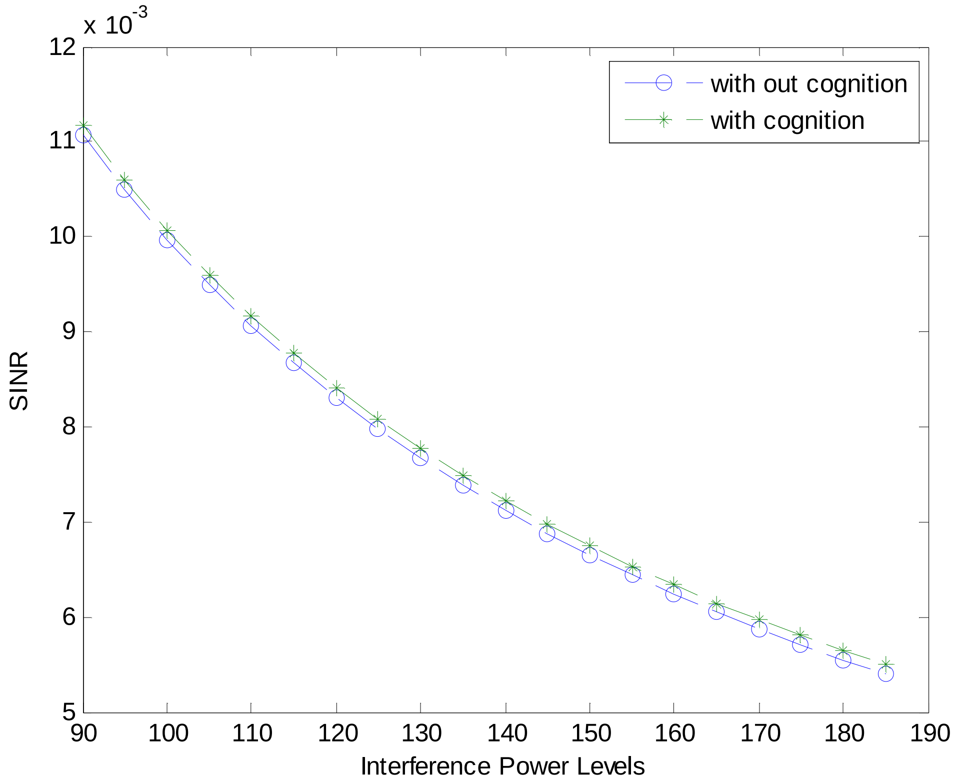

Figure 11. Effect of cognition on SINR of neighboring Small cell

4.7. Conclusion

From simulation results, it can be asserted that cognition with respect to power control is a better way to mitigate interference in the small cells. By this way, the amount of increase in power is controlled not to affect the interference of neighboring femto cells.

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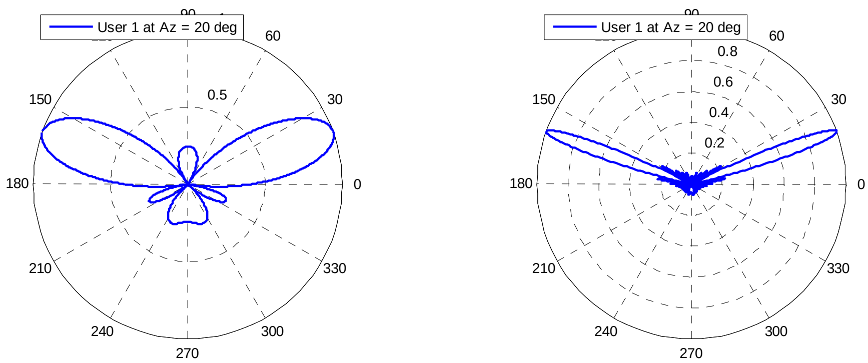
5. Beam forming

5.1. Overview

Femto Cells that are installed in macro cellular network forms a two-tier Heterogeneous network, yielding an interference problem between the two layers. The interference management is of a great concern to deploy femto cells. To address interference issue, we proposed an integrated technique of power control and beam forming without any requirement of channel state information (CSI). The beam forming is implemented by the use of direction of arrival (DoA) using adaptive antenna systems. Simulations show a clear improvement in mitigating the cross-tier interference.

5.2. Introduction

Densification of HetNets is an inevitable solution to meet the 1000x challenge. It creates all the possible types of interferences, due to very close proximity of the femto cell deployments. It is quite difficult to model the resultant interference analytically. If we employ the technique discussed in chapter 4, the solutions may not be adequate since it cannot solve all the types of interferences caused in this scenario. Meanwhile, the 4G (LTE and LTE-A) introduces multiple antenna technology (MIMO) which plays a big role in achieving coexistence of multiple users. The multiple antennas, also called smart antennas, have the capability to intelligently respond to the changing environment to change its radiation pattern to meet the desired need in wireless communication. Provided the users are well separated in space, the smart antennas are essentially helpful in forming nulls in the direction of interference and strong beams in the direction of the desired user [1-4]. This process is called adaptive array processing [4]. The architecture for adaptive array processing consists of an array of antennas (generally uniformly spaced) connected to a processor employing an adaptive algorithm (Fig-3). By knowing the direction of arrival (DoA) of the desired user, the processor adjusts the radiation pattern of antenna array such that it forms the beam in the direction of user.



Polar plot for the radiation pattern with beamforming having 4 antennas

Polar plot for the radiation pattern with beamforming having 16 antennas

Figure 12. Polar plot of Radiation Pattern with beam forming having 4 and 16 antennas

In this work, we employ the beam forming technique for interference management based on DoA and adaptive beam forming.

5.3. estimation Of DoA

In this section, the structure of antenna array (also called smart antenna) is briefly discussed followed by DoA estimation algorithm. There are many algorithms available in literature such as Capon's method, MUSIC, Root MUSIC and ESPRIT [3, 6-8], for calculating DoA using the smart antenna structure. Here, we have used Root MUSIC [3,7,8] algorithm which performs better than other algorithms with lesser computational overhead.

5.3.1. Smart antenna structure

The smart antenna structure consists of a uniformly spaced linear array of N elements presented in a homogenous medium in the far field of K uncorrelated users in the same operating frequency [4]. These N isotropic elements have uniform inter element distance of d. The angle with respect to the array normal at which the plane wave impinges upon the array is represented as Ψ, as shown in Fig.3. For the desired user, the wave front arrives at the antenna element $N'+1$ sooner than the element at N'. The beam pattern of an array is the product of the element pattern and the array factor of the selected known pattern [1,4]. The received input data vector at an N-element array can be expressed as linear combination of the K incident waveforms and noise:

$$X = As + n \qquad (2)$$

where $X=[x_1,x_2,\ldots,x_N]^T$ is a $N\ X\ 1$ vector; $s=[s_1, s_2, \ldots, s_K]^T$ is the $K\ X\ 1$ incident signal vector and $n=[n_1, n_2, \ldots, n_N]^T$ is the $N\ X\ 1$ random noise vector. $A=[\ a(\Psi_1), a(\Psi_2),\ldots, a(\Psi_K)]$ is the $N\ X\ K$ steering matrix such that $a(\Psi_j)$ represents array steering vector corresponding to the direction of arrival of j[th] user. In other words, $a(\Psi_j)$ is the $N\ X\ 1$ vector called spatial response of the array due to plane wave incident from Ψ_j direction and is given as [4]:

$$a(\Psi_j) = [1, e^{-j2\Pi\frac{d}{\lambda}\sin\Psi_j}, e^{-j2\Pi 2\frac{d}{\lambda}\sin\Psi_j}, \ldots, e^{-j2\Pi(N-1)\frac{d}{\lambda}\sin\Psi_j}]^H \qquad (3)$$

where λ is the wavelength.

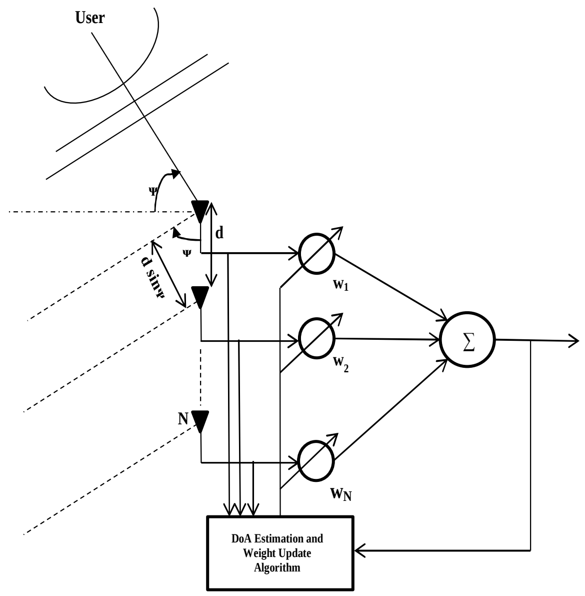


Figure 13: Adaptive Beam former Architecture using uniform linear antenna array with *N* elements and inter element distance *'d'*

5.3.2. Determining DoA by ROOT MUSIC algorithm

Here, we have focused on a class of Multiple Signal Classification (MUSIC) algorithm, i.e., Root-MUSIC algorithm for estimating DoA of the users. MUSIC is a high resolution multiple signal classification technique based on exploiting the Eigen structure of input covariance matrix (R_{XX}) which is given by [8]:

$$R_{XX} = AR_{ss}A^{H} + \sigma_{noise}^{2} I \quad (4)$$

where R_{ss} is the signal correlation matrix, i.e., $E[ss^H]$ and σ_{noise}^{2} is noise power.

Root-MUSIC algorithm is an improvement over MUSIC algorithm and exploits the rooting of the spectrum polynomial [8]. This is applicable for the case of uniformly spaced array. The following properties of the input correlation matrix form the basis for Root-MUSIC algorithm 1) the space spanned by its eigenvectors may be partitioned into two orthogonal subspaces, namely the signal plus noise subspace and the noise only subspace, 2) the steering vectors corresponding to the directional sources are orthogonal to the noise subspace. The detail derivation of Root-MUSIC algorithm can be found in [8, 9]. Assuming the number of users *K* is less than the number of array elements *N*, the MUSIC spectrum in all-pole form is expressed as:

$$P_{MUSIC}(\Psi) = \frac{1}{a^{H}(\Psi)V_{K}V_{K}^{H}a(\Psi)} \quad (5)$$

where V_K is the *N X (N-K)* matrix representing the noise subspace and have Eigen vectors, corresponding to the *N-K* Eigen values of R_{XX}, as its columns. The Eigen values are obtained by selecting last *N-K* elements of the Eigen values of R_{XX} when arranged in descending order [8,9]. The angle (Ψ) corresponding to the peak of the MUSIC spectrum gives the DoA of the users.

5.4. Adaptive Beamforming Model

With the advancement of 4G technology, it is now possible to use smart antennas to allow multiple users to coexist in the same spectrum. The smart antennas can be used to create strong beams in the direction of desired users and nulls in the direction of the interference. This process is called adaptive array processing [4]. The direction of desired user can be found by the process described in section 3. The system is called adaptive beamforming system. The array of antennas is connected to a processor which operates according to a adaptive algorithm[1-5]. The system is shown in the Figure 13. The array of antenna system, as compared to single antenna system with isotropic radiation pattern, has highly directed radiation pattern towards the user.

Using directed beams, the system allows multiple users to operate in the same channel without CCI. By knowing the direction of the desired user, the antenna array intelligently adjusts its radiation pattern by adjusting the weights in adaptive manner. Next, we have discussed the working model for the adaptive beamforming, describing the adaptive algorithm used to create beam in the direction of desired user.

The adaptive beamforming system consists of an array of antennas, which are designed to receive signals from the desired direction and attenuate signals coming from the direction of interfering sources. The weighted sum of the elements of array of antennas is calculated, shown in Fig.3, to produce the required directed beam and the adjustable nulls. The directed beam is designed to have constant gain in the desired direction. This is achieved by multiplying the output of each antenna element with the complex-weight calculated by the adaptive beamforming algorithm.

Adaptive beamforming algorithms such as RLS, SB, CGBF and CLMS have been discussed in [1,4]. In this chapter, we have discussed the Constrained Least Mean Square algorithm (CLMS) due to its computational simplicity. CLMS is a gradient based algorithm which minimizes the total processor output power [1], for a given direction of arrival of the desired signal, based on the look direction constraint. It adapts efficiently according to the environment and maintains desire frequency response in the look direction while minimizing output power of the array [1,4,10].

Let the complex weight vector, in the m^{th} iteration, of the proposed beamformer is given as:

$$W(m) = [w_0(m), w_1(m), ..., w_{N-1}(m)]^T \qquad (6)$$

and the weighted sum of these signals, in the m^{th} iteration is defined as:

$$y(m) = W^H(m)X(m) \qquad (7)$$

The expected output power of the array in the m^th iteration is calculated by:

$$E[|y(m)|^2) = E[W^H(m)X(m)X^H(m)W(m)] = W^H(m)R_{XX}W(m) \quad (8)$$

The CLMS algorithm for determining the optimal weight vector for the look direction is [1]:

$$W(m+1) = W(m) + 2\mu X(m+1)y^*(m) \qquad (9.1)$$

$$W^H a(\Psi_j) = 1 \qquad (9.2)$$

where $a(\Psi_j)$ is the array response on the desired look direction at Ψ_j. *W(m+1)* is the updated weight vector in the $(m+1)^{th}$ iteration. The variable μ refers to a positive scalar, called gradient step size, that controls the convergence rate of the algorithm.

The algorithm is similar to the traditional LMS algorithm except it has the extra property of being "constrained". The property refers to the fact that the weight vector satisfies the constraint of (9.2) at each iteration. This property is the principle behind tracking the mobile user. With the movement of the user, the desired look direction of the user changes and hence the corresponding array response of the antenna array changes. This results in update of weight vector according to (9.1), satisfying the constraint and thereby steering the directed beam along the direction of the desired mobile user.

5.5. Simulation Results

Following simulation are made to observe the interference caused by femto cell access point to the adjacent femto cell users or the just outside of the femto cell coverage macro cell users. In figure 14 we compared the probability of interference caused by the femto cell access point with only power control, beam forming with 4 antennas and beam forming with 8 antennas and the transmit power range is taken are standard range for a femto cell. It is observable that the probability of interference from femto cell access point is reduced by 89% by the usage of beam forming.

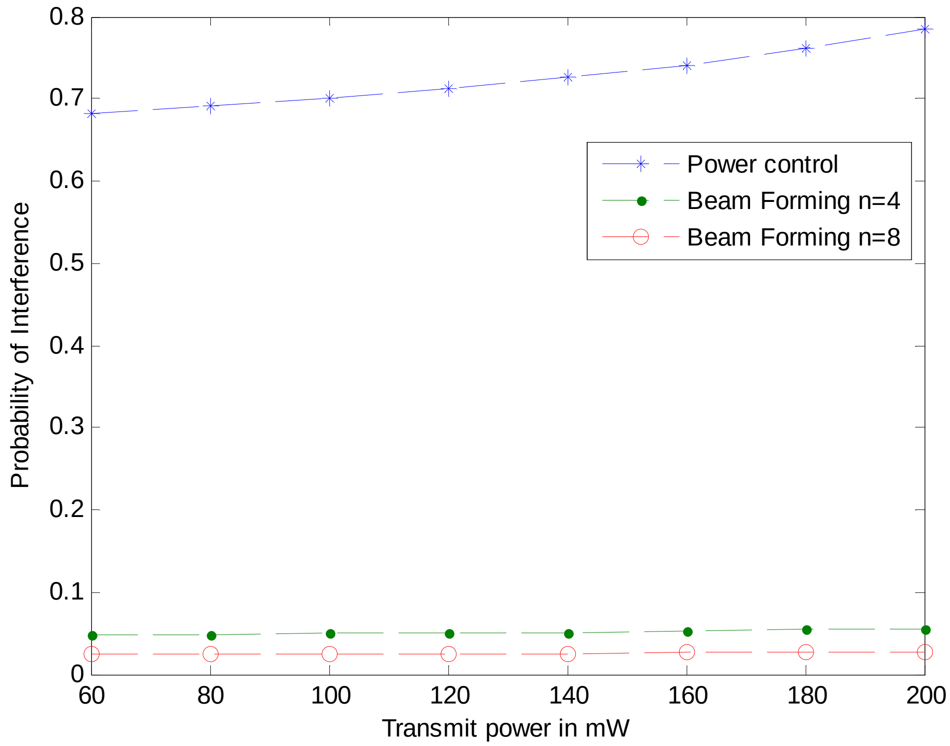


Figure 14: Femto cell access point transmit power vs probability of interference to nearby macro users

In figure 15, we calculated the probability of interference for the various number of antennas used for the beam forming. It can show that even at number of antennas are at 4 or 8 the probability of interference is considerably reduced.

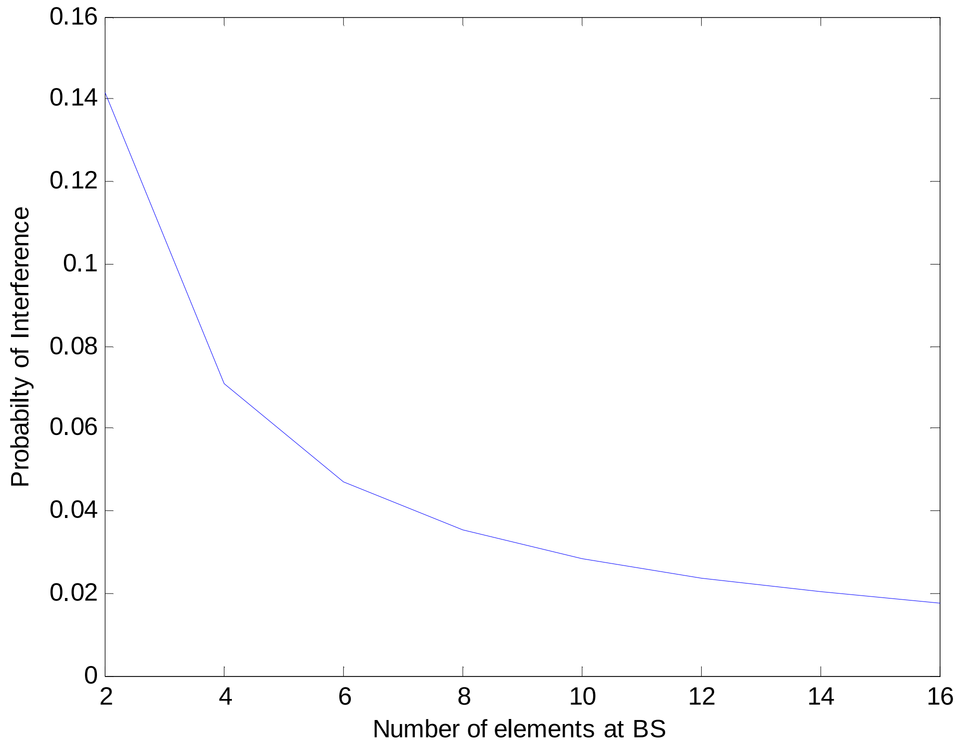


Figure 15. Number of antenna elements at femto cell access point vs probability of interference to nearby macro users

5.6. Conclusion

Hence it can be observed that employing Beam-forming techniques will go long way in solving the interference problems encountered in a densification scenario. In addition, Sensor Signal Processing for Defense Applications presents a range of important research contributions concerned with sensor array signal processing and, in particular, with the super-resolution beam formers fundamental to many civilian and defense applications. Overall, towards achieving 1000x capacity, it is inevitable to use beam forming techniques.

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6. Conclusion

With the challenges for operators increasing with users demanding improved performance and lower costs, this will require operators to use and ever wider number of technologies to ensure satisfactory operation of their networks in a variety of scenarios. To provide not only coverage, but the right form of coverage in terms of small and macro cells, operators need to deploy a variety of formats of base station, and also implement a heterogeneous format for the backhaul.

The solutions proposed in this work attempts solving some of the above problems. Especially Resource Allocation and Interference Mitigation techniques discussed in this work attempts to bring the HetNets into reality.

Related Publications

1. Viswanadh Konjeti, and Rama Murthy Garimella. "A Cognitive Femto Cell Access Point in HetNets to Mitigate Interference." Procedia Computer Science 46 (2015): 1417-1424.

2. K Viswanadh, G Rama Murthy, "Optimal Hybrid Channel Allocation: Based on Machine Learning Algorithms", IOCRSEM, 20 August-2014.

3. K Viswanadh, G Rama Murthy, "Interference Mitigation in HetNets using Power Control and Beam Forming", ICEIC 2015.