Transmit Beamforming in Dense NetworksA Review

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Abstract:*Communication technology has prospered in manifolds over the last decade. The scarcity of spectrum as well as the demand for higher data rates and increase in capacity has become a matter of concern. Newer technologies have evolved time and again, the latest of which is Long Term Evolution (LTE) and Long Term Evolution Advanced (LTE-A) systems more commonly known as 4G technology. The striking feature of LTE/LTE-A is the deployment of smaller cells (femto cells) in the vicinity of a large macro cells resulting in a dense network. As a result the data rate as well as capacity has increased in manifolds but the detrimental factor is the issue of interference between the various cells. Beamforming provides a solution in removing the issues of interference in dense networks. This paper focuses on the interference scenario in LTE dense networks and gives an overview of different beamforming methods that can provide a solution to the interference problem. Further, a review of several such methods so far proposed in available literature has been presented in this paper.*

Keywords:LTE/LTE-A, Dense Network, Interference,Beamforming

1. Introduction

The trend of increasing demand for better an efficient Quality of Service (QoS) at user equipment (UE), coupled with the scarcity of spectrum has been instrumental in development of newer wireless communication technology to ensure higher throughput, higher cell capacity as well as better quality of service. An efficient way to improve coverage and capacity in a wireless network is by use of smaller cells, where transmitter and receiver are closely spaced. This concept has been utilized in the recently developed LTE/LTE-A system where smaller (femto) cells are deployed in the vicinity of a large cell (macro cell) [1,2]. Such deployment known as heterogeneous or dense networks offers advantage of increased capacity due to better frequency reuse and spectrum sharing, improved coverage at cell edges and indoor environments and a higher QoS. But technical challenges lie in deployment of femto cells as because femto cells share the same spectrum dedicated to the macro cell and as a result interference issues come into picture. Interference mitigation has gained priority so as to provide good quality of service to the user in interference limited environment [3]. An advanced technique has been proposed in LTE/LTE-A system called beamformingfor interference removal which provides better efficiency than ad hoc techniques of cell splitting or cell sectoring [4].

In this paper, a review has been presented on different beamforming methods that have been proposed in literature for mitigation of interference in a dense cellular network. The rest of the paper is organized as follows section II describes some important theoretical concepts, section III describes beamforming, section IV describes review of some works done on various types of beamformer, section V describes the challenges facing during practical implementation of bamformers while section VI concludes the work

2. Theoretical Background

The demand for increase in capacity and achieving high data rates is increasing with the passage of time. High data rates require higher order modulation and coding schemes, which are currently being used in the LTE/LTE-A standards. LTE/LTE-A system is characterized by low latency and high throughput with carrier bandwidth (BW) of 1.4 MHz to 20 MHz and better spectral efficiency. It also has the capacity to support time division duplexing (TDD) as well as frequency division duplexing (FDD) on same and uses SC-FDMA in uplink transmission while OFDMA in downlink transmission as a result of which co-channel interference is mitigated to a large extent.

However, higher order modulation and coding schemes are more susceptible to noise in a given environment. On the other hand, capacity is generally increased by deploying larger number of channels per area (cell). This is possible by reducing the area of each cell thus increasing channel reuse. Classical approaches like Cell Splitting and Cell Sectoring are widely used in current wireless standards to increase system capacity. But it is to be noted that the call drop in indoor environment has been severely reported in recent times. A solution to this problem is to increase the power level towards an indoor user because power loss takes place due to penetration losses in the walls as well as fading effects. But directing high power towards indoor user leads to decrease in power for other users thereby decreasing system performance.

The solution to such an issue is that the transmitter and receiver can be placed close to each other and LTE/LTE-A has addressed on that issue. LTE/LTE-A systems have adopted a new methodology to increase system capacity, increase in number of users per cell as well as increase in data rate by incorporating various smaller cells like micro cells, femtocells as well as pico cells with less power in the vicinity of macro cell thereby allowing them to use the spectrum allotted to macro cell [3]. Few features of femtocells which are worth mentioning are discussed below:

2.1 Femtocell deployment modes

The deployment of femto cells in the vicinity of macro cell makes a two-tier network scenario called heterogeneous network or dense network. The mass deployment of femto cells increases capacity of indoor users but interference happens to be a matter of concern. The technical challenges lies in interference management between various femtocells deployed inside a macro cellular network or between a femto cell and a macro cell [5]. Deployment of femtocells in the vicinity of macrocell can take place in two different modes [6]:

2.1.1 Separate Channel Deployment*:* In a separate channel deployment mode, a specific channel is allocated for the femtocell network which is not used by the macrocell. This is done to avoid interference between femtocell and macrocell users.

2.1.2 Co-channel Deployment: In a co-channel deployment mode, the femtocell uses the same channels or spectrum that is assigned to the macrocell. This is much favoured by the operator because dedicating a certain portion of spectrum for femtocells might be expensive as spectrum is a precious and scarce commodity. The co channel deployment mode also increases the overall system capacity to a large extent but there is a greater risk of femtocell and macrocell users causing interference to each other.

2.2 Femto-cell access modes

Femtocell needs to be configured before they are interoperable with the existing macrocell. There are three ways of configuration to restrict their usage to certain number of user [7].

2.2.1 Open Access: In open access mode any user that enters the vicinity of femtocell base station (FBS) is served by the FBS and there is no restriction in service being rendered.

2.2.2 Closed Access: In closed access mode only a specific number of users are registered for a certain FBS and services are rendered to that specified group of users only. If any foreign user enters the vicinity of FBS range it doesn't receive any sort of service.

2.2.3 Hybrid access: Hybrid access mode can be defined as a combination of open and closed access mode where a user not registered under a FBS can enjoy the resources of that FBS only for a limited amount of time.

2.3 Femtocell Interference Scenario

The main aim of LTE/LTE-A system is to increase capacity of a cell with increase in data rate and also to mitigate the issues of call drop for an indoor environment. Deployment of femtocell in vicinity of macrocell has been helpful in increasing capacity as well providing coverage to indoor environment. But due to deployment of femtocell the issues of interference have risen and henceforth they need to be addressed. In a heterogeneousnetwork interference can be broadly classified in two ways.

2.3.1 Co-tier interference: Interference caused by elements of same layer of network is referred to as co-tier interference. Co-tier interference occurs between femtocells deployed inside same macro-cellular boundary. The interference experienced by a femo cell is generally caused by a nearby femto cell and as such to avoid interference proper cell-planning becomes a necessity. Now if due to interference the signal to interference plus noise ratio (SINR) falls below a certain threshold than communication links can't be established and the zone will be declared dead. The co-tier interference is more severe in closed access as compared to the open access. [3].

2.3.2 Cross-tier interference: This type of interference refers to the interference caused by network elements that belong to the different tier or layer of network. In this case co-tier interference occurs between femto-cells and macro-cell deployed inside same macro-cellular boundary.

So, it can be said thatalthough deployment of femto cell increases system capacity and data rate but interference stands as a hurdle. In order to mitigate the effect of interference the concept of beamforming has been addressed which acts as a tool for interference mitigation. Fig. 1 and Fig. 2 show the demarcation and interference scenario.

3. Beamforming

Beamforming is the method by which interference in cross-tier as well as co-tier interference can be removed by directing a beam in the direction of intended user and by providing nulls in all other direction.

Beamforming is an alternative name for spatial filtering where, with appropriate analog or digital signal processing, an array of antennas can be steered in a way to block the reception of radio signals coming from specified directions. While a filter in the time domain combines energy over time, the beamformer combines energy over its aperture, obtaining a certain antenna gain in a given direction while having attenuation in others. A beamformer may also be defined as a processor used in conjunction with an array of sensors to provide a versatile form of spatial filtering. Forming beams seems to indicate radiation of energy. However, beamforming is applicable to either radiation or reception of energy.

3.1 Classification of Beamformers

Of late beamforming has been instrumental in mitigating the adverse effect of interference whether that be co-tier or cross-tier interference. The main aim of a beamformer is to give a peak in the direction of intended user or the user to whom service is to be provided and null in all other direction. Beamformers can be classified as either data independent or statistically optimum, depending on how the weights are chosen. Beamformers can be broadly classified into four types:

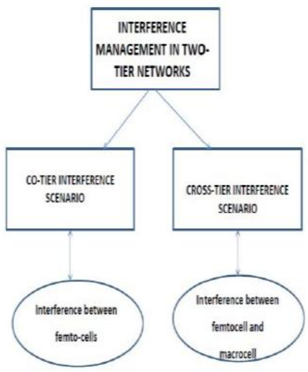

Figure 1: Demarcation of interference scenario

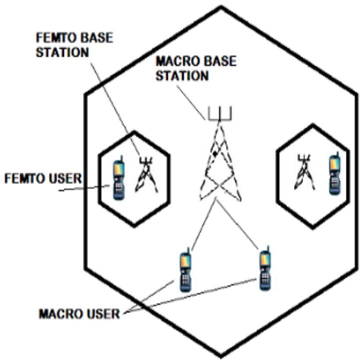

Figure 2: Interference scenario between femto-users as well as between macro-user and femto-user

3.1.1 Data Independent Beamforming: The weights of a data independent beamformer are designed so that thebeamformer response approximates a desired response independent of the array data or data statistics.

3.2.2 Statistically Optimum Beamforming: In statistically optimum beamforming, the weights are chosen based on the statistics of the data received at the array. Loosely speaking, the goal is to optimize the beamformer response so that output contains minimal contributions due to noise and interfering signals.

3.2.3 Adaptive Beamforming: The optimum beamformer weight vectors require knowledge of second order statistics. These statistics are usually not known, but with the assumption of ergodicity, they (and therefore the optimum weights) can be estimated from available data. Statistics may also change over time, e.g., due to moving interferers. To solve these problems, weights are typically determined by adaptive algorithms.

3.3.4 Partially Adaptive Beamforming: The concept of degrees of freedom is relevant to this discussion rather than considering the number of weights. The expression of degrees of freedom refers to the number of unconstrained or free weights in an implementation. An adaptive beamformer uses all degrees of freedom but a partially adaptive beamformer reduce degree of freedom thereby reducing computational complexity at the cost of performance as it degrades on reduction of degrees of freedom

4. Literature Review

The current trend of study is mainly focused on adaptive beamforming to support high data rate and providing un-interrupted service to an user whether it be stationary or mobile. A few methods of adaptive beamforming have been reviewed in this section. Some of the commonly used adaptive beamforming strategies are:

4.1 Zero-Forcing Beamforming(ZFBF)

Zero Forcing Beamforming is a spatial signal processing in multiple antenna wireless devices. In uplink, ZFBF algorithm allows a transmitter to send data to desired user together with nulling out in the direction where desired user is not present while in downlink it receives only from desired users while nulling in direction of interference users. Table 1 provides an overview of works done by various authors

Table 1: Zero-Forcing Beamforming

Paper	Salient Features
[8]	• Deals with ICI cancellation scheme for MISO channel • Partial CSI has been shared among BS. • Egoistic and Altruistic ZFBF has been discussed. • Output metric is throughput and it is compared with full CSI Monte-Carlo Simulation
[9]	• Comparison between Large Scale MIMO and Network MIMO. • Both use ZFBF for Orthogonality principle. • ZFBF is mainly used to remove inter-cluster interference in LS-MIMO and network MIMO
[10]	• Reduction in interference by exploiting angle dimension • Use of MUSIC algorithm to exploit angle information • Works on PRB basis and then DOA estimation using ZFBF • Comparison with conventional beamformer and BER is analyzed
[11]	• Emphasis on resource allocation and interference reduction using cognitive approach on the basis of DOA of signal. • Angular information is utilized that reduces interference and increses capacity. • BER comparison between AoA scheme and ZFBF

4.2 Minimum Variance Distortionless Response (MVDR) Beamformer.

It is a type of adaptive beamformer and when the weights of MVDR beamformer is applied to the elements of an array, they steer the response of sensor array in a specified direction of interest which is specified by the position of sensor array. Table2 provides an overview of the works done by various authors on MVDR beamforming techniques.

4.3Linear Constrained Minimum Variance (LCMV):

It is a type of adaptive beamformer. LCMV beamformer can be used to prevent null-steering which allows us to put multiple constraints along the target direction (steering vector).

Table 2: MVDR Beamforming

Paper	Salient Features
[12]	• Iterative Null steering approach has been proposed to reduce interference. • A macrocell to femtocell interference removal technique. • Comparative analysis between Constant Null Steering Technique (Non-

	Adaptive),Optimal Beam former (Adaptive Beam Former using MVDR technique), Iterative Null Steering
[13]	• MVDR and LCMV approaches are compared • Both depends on weight determination • Single M mobile users and one base station with 4-element antenna array are considered. • MVDR is not suitable in urban areas as it can't mitigate multipath effect but has greater application in rural areas. • Output metric is power level and comparative study shows MVDR shows better response than LCMV.
[14]	• Author has emphasized on advanced MVDR technique for interference cancellation by use of Clonal selection algorithm (Clonalg) of Artificial Immune System (AIS). • ULA has been incorporated • Output metric is received SINR and simulation shows that AIS assisted MVDR approach has better interference

It reduces the chance that the target signal will be suppressed when it arrives at a slightly different angle from the desired direction. In LCMV approach the array output is compared with reference signal, thus beams are produced in the direction of multipath signal that matches with reference signal unlike MVDR. Thus, LCMV beamforming is the optimum candidate for non-line of sight (NLOS) urban environment, as it not only reduces the interference but multipath fading is also mitigated. Table 3 provides an overview of the work done by various authors on LCMV beamforming techniques.

4.4 Robust Beamformer:

Robust Beamformer is also a type of adaptive beamformer. It is normally seen in many beamforming techniques especially in MVDR approach that if any mismatch occurs in direction of.

Table 3: LCMV Beamforming

Paper	Salient Features
[13]	• MVDR and LCMV approaches are compared • Both depend on weight determination • Single M mobile users and one base station with 4-element antenna array are considered. • LCMV is suitable in urban environment as it can remove multipath effect. • LCMV beamforming is the optimum candidate for NLOS urban environment, as it not only reduces the interference but also multipath fading is mitigated. • Output metric is power level and comparative study shows MVDR shows better response than LCMV
[15]	• Determination of outage probability using LCMV • Fading statistics of Rayleigh and Nakagami are used to characterize the desired signal and interferers are Rayleigh faded. • Outage performance of wireless systems with LCMV beamforming which cancels a number of dominant interferers. • The numerical results show that the outage probability of LCMV beamforming is very sensitive to the directions of the dominant interferers. • LCMV beamforming and conventional beamforming are also compared in terms of outage performance with considerations of the directions of arrivals of the dominant interferers.

arrival of signal of interest, then the signal cannot be properly estimated. Moreover as the beaamforming characteristics depends on weights so use of Minimum Mean Square Error (MMSE), Least Mean Square Error (LMSE) and Least Minimum Mean Square Error (LMMSE) methods are also employed to optimize the beam weights so as to have a peak in the direction of intended user and a null in the direction of interfering source. Robust Beamformers are extensively used in the field of wireless communication as well as marine application too. The papers related to Robust Beamformer have been studied in Table 4.

Table 4: Robust Beamforming

Paper	Salient Features
[16]	• Author has intermingled space time coding with OFDM to take advantage of space diversity. • To improve the robustness and uncertainty in DOAs of the MVDR method robust beamforming has been proposed and MMSE beamforming has been applied to STBC along with OFDM • Using MMSE DOA is not needed. • CCI is removed. • A comparative performance of STC-OFDM using adaptive beamforming with null deepening, STC-OFDM with null steering as well STC-OFDM scheme is shown.
[17]	• Robust beamformer which is modification of MVDR in presence of moving source. • The main aim is to broaden the main lobe in direction of signal of interest (SOI's) by computation of DOAs and placing broad nulls in the direction of interfering sources without even estimating them. • Resulting performances has been shown to constitute a trade-off between output SINR, computational complexity and

	sensitivity to source movement.
[18]	• Emphasis on resource allocation i.e deployment of femto cell in vicinity of macro cell. • Firstly the beamformer used formacrocell base station is maximal ratio transmission beamformer, and they determined the power allocation at the macrocell and all femtocell base stations. • Secondly for femtocell the beamforming is robust beamformer with imperfect CSI. • Robust optimization methodology has also been employed • The resultant metric is outage probability and it is seen that robust beamformer has better outage probability with respect to a pre-determined constraint"P".

5. Basic Challenges in Implementing Beamformers

Beamforming has proved to be an excellent tool for interference cancellation but some challenges are worth mentioning while implementation of beamformers. Some of them are listed below:

• Null steering beamforming has challenges that it is very easy to implement for single interference source but the computational complexity increases as the number of interfering sources increases. Moreover null steering beamformer has limitation as it cannot remove un-correlated noise. All these issues are removed in optimal beamforming also known as Minimum Variance Distortionless Response (MVDR) beamforming

• In Zero-forcing beamforming partial channel state information (CSI) is necessary to mitigate ICIC.

• The challenges of an adaptive beamforming lies in the fact that the training data are often limited in many practical scenarios, which may cause significant performance loss due to lack of sufficient training data that are needed to form a reliable covariance matrix estimate.

• Gathering CSI information requires a strong back-haul network and henceforth exchange of information results in consumption of bandwidth which is a major detrimental factor in some of the beamforming technique.

6. Conclusion

The constant endeavour to achieve higher data rate, higher capacity as well better QoS has paved the path for development of newer techniques to make communication better and faster and the latest addition to this technology is LTE. It aims at increasing data rate and capacity by deployment of smaller cells in the vicinity of larger cells leading to the development of heterogeneous networks or called dense network. But the prime detrimental factor happens to be the issue of interference that arises due to deployment of smaller cells in the vicinity of larger ones. So interference mitigation has gathered priority and the concept of beamforming came into being. A beamformer is a spatial array that gives peak in the directions of intended user while placing a null in other direction thereby reducing interference from any other user. Various types of adaptive beamformers are being discussed and choice of beamfomers may depend on practical scenario, ease of hardware implementation and complexity.

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