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Research Article

Inter Cell Interference Management Strategies in Dense Small Cell 5G Networks

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Abstract

As the number of smart and connected devices increases, the need to explore higher frequency bands in the radio spectrum also grows. While the existing wireless communication networks mostly employ carrier frequencies below 5 GHz, the future networks are expected to use the spectrum above 30 GHz. But above 30 GHz, the channel attenuation is several times higher than the attenuation for carriers less than 5 GHz. Moreover, as the frequency increases, multipath propagation reduces and line of sight propagation becomes more significant. To overcome these challenges, cell radius must be reduced and carrier frequencies must be reused more often. This will lead to interference between cells which are in close vicinity and which use same carrier frequencies. Most of the current interference management techniques are for sparse wireless communication networks. In this paper, we present various strategies to overcome inter cell interference in dense 5G small cell networks. These strategies are based on power allocation strategies, machine learning algorithms, game theory, convex optimization etc. These techniques can significantly reduce inter cell interference and reduce the probability of error in in future 5G networks. Finally, we present the summary of the discussion as conclusion and future scope.

Keywords: Small Cells, 5G Networks, Interference, Power Allocation

1. INTRODUCTION

Future wireless communication networks are expected to provide ubiquitous coverage and data rate of several Gb/S. Moreover, the future networks are expected to provide service for millions of connected devices per square kilometer [1]. Several techniques have been proposed to meet these requirements. Massive MIMO and millimeter wave technology are expected to be the game changers in future networks. But millimeter waves undergo several order of higher attenuation than centimeter waves. Moreover, as the frequency increases, line of sight propagation becomes more prominent and multipath propagation becomes insignificant. To overcome these challenges, small cells and network densification are going to be the key enabling technologies in future networks.

Network densification is not without its limitations. As the cell radius decreases, co-channel interference among the nearby cells also increases. Interference in dense small cells is different from sparse macro cells in several ways. As the devices are close by, the interfering signals are more likely to be correlated [1]. This makes it difficult for the receiver to distinguish between desired and undesired signals. The small cell networks are highly heterogeneous. As a result of this, the composition of the small cell networks keeps fluctuating rapidly. Therefore, it becomes

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challenging for the active nodes to estimate the interference.

Table 1. Classification of Inter Cell Interference Management Techniques

Class	Summary
Interference Avoidance	Power Control, Multiple Access, OFDM
Interference Cancellation	Interference Modeling and Subtracting
Interference Coordination	Coordination between cells and user devices, interference alignment

Several techniques have been proposed to overcome inter cell interference in dense small cells. Based on the approach they follow to manage interference, they can be broadly classified into three categories, namely interference avoidance, interference cancellation and interference coordination [1]. These techniques are summarized in Table 1. In long term evolution networks, orthogonal frequency division multiplexing (OFDM) has been widely used to avoid interference. Even though, OFDM has proved to be very efficient in avoiding interference, it has its limitations such as high peak-to-average power ratio, sensitivity to Doppler shift and decreased efficiency due to cyclic prefix. Interference cancellation techniques require accurate measurement of channel parameters. At the beginning of communication, a predefined set of signals can be transmitted and the received signals are observed. By doing so, the receiver can estimate the interference levels in the channels and try to model the interfering signals in the channel. Then, the estimated interfering signals can be subtracted from the received signal. However, these techniques are highly sensitive to channel measurement and interference estimation errors. Interference coordination methods are mainly based on beam forming techniques. By cleverly choosing the direction of main beam of the antenna towards the receiver and reducing the side lobes, interference can be minimized. But these techniques are limited by the presence of side lobes and due to the movement of communicating devices.

Over the years, several novel techniques have been proposed to mitigate interference in dense small cell networks. As the speed of computing devices is increasing and new algorithms are coming up in the niche fields such as machine learning, data science, these developments have also contributed to the development of solutions to several problems in wireless communication. In this paper, we present a survey of novel algorithms for the mitigation of interference in dense small cell 5G networks. We cover several signal processing based approaches, game theory based approaches and machine learning and data science based approaches.

The remainder of this paper is organized as follows. In section II, we present several techniques to overcome interference in small cells. We explain the advantages and disadvantages of various interference minimization strategies. In section III, we present the conclusion and future scope.

2. INTERFERENCE MITIGATION TECHNIQUES IN DENSE SMALL CELL NETWORKS

Future generation wireless networks are expected to contain numerous small cells to provide high speed data to customers. But as the cell radius decreases, the probability of interference among cells using same frequencies also increases. While most of the currently existing interference management techniques focus on reducing interference among sparse cells, several authors have proposed new techniques to overcome interference in dense small cells. Table 2 summarizes different approaches that can be taken to mitigate interference.

Table 2. Approaches for Interference Mitigation

Approach	Summary
Signal Processing Approach	Be aware of the environment, control power levels and chose the carrier intelligently
Channel Modeling Approach	Develop mathematical model for channel behavior and interference, develop algorithms to overcome interference
Data Driven Approach	Collect the data about cells, learn about environment, adapt to the environment
Game Theoretic Approach	Use optimization principles of game theory to arrive at equilibrium with the network and cooperate with other nodes

Hossain et al. outline the key requirements and features of interference management strategies [2]. To effectively manage interference, power control to and from the user equipment should be based on priority. Prioritization can be done based on channel condition and data rate requirement of the user. By doing so, we can reduce the outage probability but at the cost of system throughput. The authors also propose a novel algorithm for user equipment to connect to a base station based on resource availability. This algorithm combined with prioritization techniques are found to significantly increase the efficiency of the network. Ha et al present a novel power control algorithm for heterogeneous cellular networks [3]. The authors use the principles of game theory to update the power levels transmitted from the device. The algorithm was found to help the user equipment to achieve the required signal to interference ratio with a faster convergence rate. Gary et al. present several viable approaches to interference minimization with special emphasis to 4G LTE networks [4]. The authors compare multiple interference avoidance and management strategies based on complexity, efficiency and spectral throughput. The authors opine that there is no one strategy that can provide efficiency in terms of all parameters, but a combination of strategies are essential to reach the desired level of interference minimization. Adaptive power control along with intelligent frequency reuse may result in best utilization of the available resources along with minimizing interference. Pederson et al. discuss interference minimization in 3GPP LTE Advanced cellular networks [5]. The authors emphasize the need to establish a coordination among multiple base stations to avoid interference. The authors highlight the need to develop techniques based on the combination of intelligent, interference aware base stations and user equipment to overcome interference.

Zhang et al. present a novel interference minimization technique in highly dense networks by reducing interference minimization to a convex optimization problem [6]. The authors propose an iterative algorithm for power allocation and user association with base station to manage interference. The authors consider load balancing, energy harvesting and quality of service as the major parameters. The proposed algorithm outperforms the traditional algorithms based on signal to interference and noise ratio while maintaining an acceptable level of user experience. In [7], Soret et al. propose two new algorithms for downlink interference minimization in dense cells – one based on time domain approach and the other based on frequency domain approach. The time domain approach is based on the identification of victims and aggressors. If a small cell is causing too much interference with adjacent cells, then that cell can be classified as aggressor and that cell can be muted for some time. In frequency domain based approach, carrier frequencies causing interference are identified and base station is made to switch to a new carrier frequency to avoid interference. The algorithms are shown to improve user throughput by 25-40 percent. But the real challenge is the classification of devices as either victim or aggressor. In [8], Mahmood et al. explain the development of an interference minimization scheme for multi user MIMO scenarios depending on the measurement of channel state towards the desired user. Depending on channel state information, power allocation can be controlled to minimize interference. The proposed technique is found to offer significant improvement in performance at less computational complexity. In [9], Mahmood et al. discuss various link management strategies for 5G dense small cells with special emphasis on energy efficiency and latency reduction specifically for small and dense cellular networks. Through simulation results, the authors show that up to 63% gain in latency and up to 84% reduction in latency can be achieved in 5G networks by intelligent interference minimization strategies. In [10], Bhushan et al. outline the key benefits and challenges of networks densification in future networks. The authors believe that the benefits of network densification can be fully exploited only through backhaul densification and by using intelligent user equipment capable of cancelling interference. But this requires a lot of computational power in the user device. The authors conclude that millimeter wave communication along with massive MIMO are believed to be the major enabling technologies for future networks. However, the upper bound for the throughput of a user in a cellular system is given by

$$R < C = m\left(\frac{W}{n}\right)\log_2\left(1+\frac{S}{I+N}\right) \quad . \; . \; . \qquad (1)$$

where, W is the signal bandwidth at the base station, n is the load factor, m is the spatial multiplexing factor, S is the power in the desired signal, I is the interfering signal power, N is the noise power.

Rasti et al. propose a dynamic power allocation algorithm to minimize interference and improve system throughput [11]. The authors show that instead of setting a fixed target signal to interference ratio, a variable target signal to interference ratio gives better throughput. Specifically, if the actual interference level is much lower than the maximum acceptable level, then the target level can be decreased. If the actual interference level is much higher than the maximum acceptable level, then the target level can be increased. By doing so, the device may set an optimum threshold iteratively and allocate power levels intelligently. The simulation results show that this dynamic approach can outperform static approach by a significant factor. Zhang et al. present a novel interference mitigation technique for cognitive small cells [12]. The authors develop power allocation and control schemes based on spectrum sensing. The power allocation is considered as a non-convex optimization challenge. The proposed iterative algorithm is found to be effective in interference minimization with minimum data rate overhead. In [13], Lopez et al. propose a centralized interference mitigation strategy. Through simulation results, the authors show that centralized approaches can be more efficient than interference cancellation at the receiver. It is shown that an increment up to 80% can be obtained in the 5th percentile throughput with the proposed strategy. The authors conclude that the future works may investigate interference cancellation at the receiver along with scheduling and power control at the base stations. Gesbert et al. discuss a new iterative power control strategy to minimize interference in small cells [14]. The proposed algorithm starts with On-Off strategy with each cell measuring the signal to interference noise ratio and deciding whether to remain on or off for the next iteration. To increase the probability of remaining on for the next iteration, the cells can adopt power control and scheduling policy, thus optimizing the available resource. Min et al. propose a new strategy to manage interference in a small cell device to device communication scenario [15]. The proposed algorithm does not allow multiple devices in the same vicinity to use same resources. Their algorithm can significantly minimize interference with negligible loss in cellular capacity.

Orthogonal frequency division multiple access (OFDMA) is widely used in 4G systems to provide access to the channel. However, the capacity of OFDMA systems is mainly limited by inter cell interference. Kosta et al. present a new strategy to mitigate inter cell interference in OFDMA systems [16]. The proposed algorithm is based on coordination between cells in 3GPP/LTE cells. The authors opine that the future cells must be able to self-organize themselves to avoid interference. The authors show that the full frequency reuse performs better than the classical frequency reuse in an interference limited cell. Qian et al. present power control strategies for non-orthogonal multiple access (NOMA) networks [17]. NOMA is considered to be one of the major techniques in future networks to avid bottlenecks in OFDM systems. The authors develop an algorithm by combining convex optimization and game theory. The authors show that the proposed algorithm will converge to an optimal solution in finite time. The algorithm requires that the user equipment be associated with right base station and transmit power be minimized in the uplink.

Classical interference avoidance strategies require mathematical models to design power allocation strategies. But this can be highly computationally demanding and sometimes not tractable. Recent developments in niche areas such as data science and machine learning have had their applications in many related areas as well. In [18], Meng et al. propose a new power allocation strategy based on deep learning algorithms. The algorithm does scheduling and power control based on dynamically learning about the cellular network composition. The proposed algorithm is found to avoid the need to have accurate channel models and network models. In [19], Wang et al. present strategies for dynamic cells to reorganize themselves to avoid interference. The devices and base stations are required to be aware of traffic and interference levels in the network. Based on rank ordering, the devices are made to adjust power levels to mitigate interference while maintaining a minimum quality of service. Such adaptive techniques can help the nodes to intelligently control their power levels in a dynamically changing small cell. But reducing the power levels below a threshold may cause degradation of service to the customers. To avoid this Wang et al. propose a victim-aware strategy to guarantee a minimum quality of service [20]. The proposed algorithm requires that the victim users be identified and compensated with higher priority while maintaining an acceptable level of fairness to other devices based on a fairness index.

Several other techniques have been proposed based on data driven approach to minimize interference [21-24]. They are all based on the ability of base stations and user devices to learn about the interference in the network. The interference aware transmitters can intelligently schedule and control their power levels in the network to avoid interference. Efficient learning methods and development of reward functions is the main area of study in the development of

such algorithms.
Cao et al. present a game theoretic approach for resource allocation in ultra-dense small cells [25]. Based on this approach, the users in close vicinity are allotted orthogonal carriers as much as possible to avoid interference. The authors show that their approach can converge to a stable state in finite iterations. Zheng et al. also propose a game theoretic approach to manage interference in dense small cells [26]. The authors develop an iterative algorithm based on Game theory for the networks to arrive at Nash equilibrium which is the optimal solution to the problem. The small cells can be made to cooperate with each other to mitigate interference by designing an appropriate utility function. Further, the authors suggest that base station switching and channel switching can be incorporated to improve the throughput.

3. CONCLUSION AND WAY FORWARD

As the faster and efficient algorithms are developed in the niche fields such as machine learning, data science, they have also contributed to several fields related to communication and signal processing. Moreover, computing devices are becoming faster, smaller, more efficient and less power hungry. All these developments have made implementation of complex algorithms possible. But, as the number of smart and connected devices grows, interference also increases and it becomes increasingly challenging to manage interference. The future devices and networks are expected to be well aware of their environments and take measures to avoid or mitigate interference. Apart from being intelligent, future networks are also expected to be green and leave less carbon footprint.

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