Advanced Inter-cell Interference Management Technologies in 5G Wireless Heterogeneous Networks (HetNets)

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***Abstract*— The future generations of mobile wireless systems such as the 5G technology are expected to be available due to huge demand on network capacity, better end-to-end performance, high mobility and high data rates. Inter-cell interference (ICI) management is one of the paramount issues that should be concerned in multi-tier Heterogeneous Networks (HetNets). Frequency reuse, successive interference cancellation techniques and coordinated multipoint transmissions (CoMP) are some of the popular interference cancellation schemes for mobile wireless networks. However, implementing these methods to the 5G standards with huge network size and capacity is a major challenge in the upcoming decades. In this paper, an extensive qualitative survey on different schemes of interference reduction is provided along with their performance, effectiveness and deficiencies. Key challenges and some guidelines to rework and overcome the shortcomings of the existing schemes are also discussed.**

Keywords— 5G, interference management, Heterogeneous Networks, HetNets, ICI.

I. INTRODUCTION

Modern wireless communication system has emerged to more advanced technologies in recent times. The 5G technology is soon to be deployed due to the huge demand for more capacity, high mobility and excellent end-to-end performance meeting the demand of a large number of users. As the spectrum resource is limited, the spectral efficiency has to be increased to support high data rate. Reuse of frequency spectrum in different cells is very common to increase the capacity. However, a major problem in this system is the Inter cell Interference (ICI) which is hindering the performance of the network. Assuming, by 2020, the number of device will be increased to 1000 times of the total world's population [1]. As the number of wireless device increase, more research work is needed to be implemented. For increasing the capacity, number of base stations along with the number of small cells has to be increased. As a result ICI is becoming more severe for large number of BSs and small cells. Heterogeneous Networks (HetNet) which is comprised of macro and small cells are supposed to have serious ICI too. In 5G HetNets, the dense small cell networks are used to increase the capacity and spectrum efficiency by creating more nodes in the given area. By deploying a large number of small cells in heterogeneous networks the capacity can be significantly increase. In that case interference management is a vital challenge for the better performance of the system. There are a number of traditional concepts in which the inter-cell interference is managed, among which frequency reuse and spectrum sharing techniques are the most popular. However, in 5G, the existing interference management scheme will not be sufficient to mitigate the Intercell Interference problem. As a necessity, advanced interference management techniques are developed in recent times. One of them is advanced coordinated multipoint (CoMP) technique which can convert a radio that is interference limited to a radio that manipulates interference for data transmission [3]. Another technology for interference mitigation is the massive MIMO system which is comprised of a large number of antennas at transmitter and receiver side. It is also used to enhance the spectrum efficiency as well as mitigate interference by employing linear pre coding and detection methods [4]. Software-defined Radio (SDN) paradigm is another advanced scheme for mitigation iter-cell interference which will be discussed later in this paper.

The main contribution in this paper is to analyze the different schemes of advanced interference mitigation techniques studied in recent times and compare them to obtain the potency and weakness of these technologies and to propose the future challenges in performing the interference management.

The rest of the paper is organized as follows. Section II discusses the work related to the interference management in various types of scenarios. A brief discussion on the proposed scheme is carried out in Section III. Finally, in Section IV the paper is concluded with scope and recommendation for future work.

II. INTERFERENCE MANAGEMENT TECHNIQUES FOR 5G TECHNOLOGY

In this section, a survey on the existing research works to mitigate the inter-cell interference in 5G wireless network is presented. Advanced schemes are proposed for different types

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of environment. Some of related works are discussed in this section are:

A. Reverse TDD HetNets

In reverse time division duplexing (TDD) method wireless backhaul is being used for data traffic in a heterogeneous network which is consisted of a macro base station with antennas and dense two-tier overlaid small cell access points (SCAs) [5]. The evaluation in [5] is the extension of the research work of [6] adding the wireless backhaul. Here, the user equipment terminals (UEs) with static and low mobility are linked with the SCAs and users with medium to high mobility are linked with the macro BS. Reverse time division duplexing protocol is used by both the tiers so that the base station can estimate the channel between the tiers and also within the single tier. The analysis result of optimization is used in the UL and DL of the base station in order to handle the macro user equipment terminals (MUEs) and provide wireless backhaul to SCAs. An integrated linear precoding technique is used by zero forcing (ZF) or regulated ZF at the BS to link with the MUEs and SCAs in DL whereas interference in SCAs in UL is nulled. The power consumption of the UL and DL transmissions is measured to check the performance under some specific assumptions including the fixed ratio of the number of the BS antenna and the network size. The result of this analysis gives a formula for such asymptotic UL and DL transmit powers and pre coding vectors. The analysis is conducted in different environment and comparing with other network architecture is accomplished to confirm the numerical results. However, there is a critical value in the imperfect CSI beyond which the network operation becomes worthless because of the divergence of the power. By developing scheduling algorithm the work can be modified and also analyzing with multi BSs the performance would have been better.

B. Effective CoMP Clustering

Effective CoMP Clusterng Scheme Co-channel interference and handover management are the most significant drawbacks in the heterogeneous cloud small cell network (HCSNet) where HCSNet is comprised of cloud radio network and small cells. There are four approaches for CoMP clustering scheme: dynamic selection, joint transmission, coordinated scheduling and dynamic blanking [12]. In joint transmission approach the remote radio heads (RRHs) form a cluster and they are conncted via fronthaul link with the cloud. To reduce fronthaul overhead, static dynamic, semi-dynamic and full-dynamic schemes can be applied [12]. However, static clustering has a very low throughput gain [13] and full-dynamic scheme provides high performance with a network of high complexity. Semi-dynamic clustering scheme made up of online and offline phases can provide both good performance and low network complexity by adopting CoMP clustering scheme using affinity propagation principle deployed in online phase to get maximum spectral efficiency [7].The figure shows the framework of semi dynamic CoMP for online and offline mode.

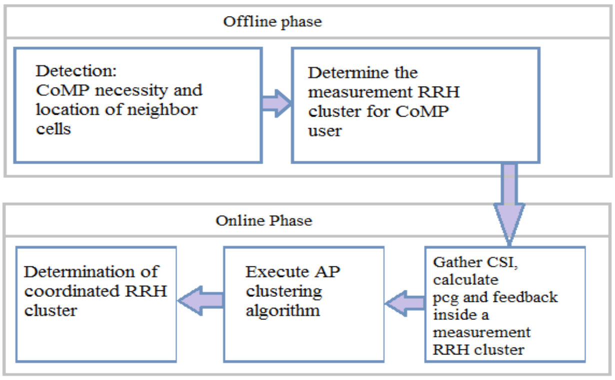

Figure 1. Framework for semi-dynamic CoMP

In this scheme, very limited CSI is required between the neighboring cells. This scheme mitigates interference especially for the cell edge users. The evaluation for the spectrum efficiency CDF curves shows that the spectrum efficiency of the CoMP scheme is higher than the non-CoMP schemes (figure). Results validate the increasing of the capacity of HCSNet and maintain QoS of the users including the interference. However, the proposed architecture with the aforementioned scheme would have been more convenient if HCSNet is self-controlled so that it can have self-optimizing power control.

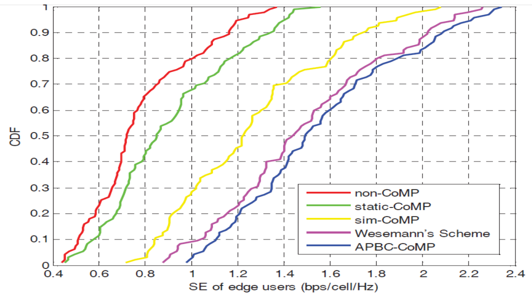

Figure 2. Effeciency spectrum CDF for CoMP and non-CoMP [7]

C. Interference Management Techniques Applied in Moving Network in Transportation

The interference reduction in urban dense public transportations is estimated by setting up moving base station on the vehicles [8]. The key challenge that is obstructing the efficiency of MNs in the vehicles is the inter-cell interference, especially due to urban canyon effect. By applying efficient interference management techniques with the MNs, like multi antenna suppression techniques and different interference coordination techniques, the Quality of Service (QoS) is significantly improved at the users in the transportation without largely affecting the regular outdoor users. There are several approaches such as time domain interference coordination and multi-antenna solution. In time domain coordination, BSs of three sectors are used for three types of macro UEs. First group is with high SINR that is less interference, second one is with comparatively high interference and the third group has the highest interference (figure). However, the MNs are assumed to be of constant speed ignoring the unwanted stoppages at various points. Moreover, this study was only limited to using simple multi antennas at the receiving side. More advanced multi antenna schemes could have been utilized at MNs for the better performance.

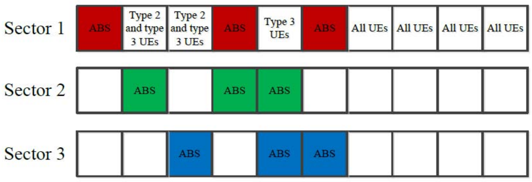

Figure 3. An example of frames with ABS configurations and scheduling restrictions at different macro sectors [8]

D. Using Advanced Receivers and Rank Adaptations

For inter-cell interference management in ultra dense small cell 5G networks, interference suppression receivers are expected to have better performance and a better alternative to traditional frequency reuse techniques [9]. This work evaluates the possibility of using this interference suppression technique as the main tool in the receiver to manage inter-cell interference problem. A system-level performance evaluation is done in three small cell dense indoor networks. The receiver model also has SIC and IRC as the supportive system. The outcome of the analysis shows that this model is a valid alternative to the frequency reuse technique. They achieve similar output data rate performance comparing to reuse strategies, even higher average and peak output is found. In the two scenarios, indoor hotspots (OSG access modes) and indoor office (OSG access modes), this technique is proved to be an alternative to frequency reuse. The results if the analysis shows that in this method, the performance is rather enhanced than the reuse method. However, in the third scenario in indoor office (SGC), the suppressed interference receiver is not compatible to reach the desired output when the network is loaded more than 50%. So in that case this method will not suffice and further research is needed to be conducted where its performance is improved.

E. Software defined Networking (SDN) Model

Fitting the software defined networking (SDN) paradigm to 5G mobile networks in order to reduce ICI is discussed in [10] along with a new proposal of using interference graph as an abstraction. For adjusting with the increase in the data traffic and for accommodating with the new technologies, 5G mobile network has to be compatible of efficient resource allocation schemes where interference is a major problem. Here the way of interference management is discusses by network controlling with SDN paradigm. In order to expose the lower layers to controller and its applications, this SDN approach is used. An output optimization tool is formulated which uses the interference graph as input. The analysis can be validated by varying the experimental condition.

F. SIC Applied in the Receiver

The performance of the interference cancellation receivers in 5G small network by using successive interference cancellation technique for reducing the interference is another technology used [11]. The evaluation result has been validated by implementing Monte Carlo simulation. Results show that the gain obtained from the IC techniques is dependent on the spatial density of the active interferes of the network along with the data rates. However, the theoretical calculation of gain is very high compared to the one in practice as the data rate and number of interferer increase, the SIC receiver's performance becomes similar to that of an ordinary receiver. Using SIC as the interference reduction technique is a very traditional and primitive way. Other advanced mitigation techniques need to be implemented such as the interference coordination and joint decoding etc for more better performance in the 5G network.

Table1. Comparison of the mitigation schemes

Name (year)	Approach	Strengths	Weaknesses/ Limitations
Sanguinetti, L.; Moustakas, A.L.; Debbah (2015)	Reverse TDD protocol used for Massive MIMO and dense tier SCAs with wireless backhaul.	1. Large system is investigated calculating power consumption of UL and DL 2. Results are used to form expressions for UL and DL powers and beamforming vectors	Beyond the critical value of imperfect CSI the network operation is unachievable due to divergence of all powers, resulting in decrease in the served rates.
Haijun Zhang; Chunxiao Jiang; Julian Cheng (2015)	Effective CoMP clustering scheme is used for HCSNet by using affinity propagation	The proposed scheme has proved to achieve higher output with a very low computational complexity.	The proposed scheme would have more convenient if it was self-controlled
Y. Sui, I. Guvenc,T. Svensson (2015)	Effective interference management techniques combining with Moving Networks (MNs) are deployed in transportation in urban areas.	1. Throughput is more improved at VUEs without affecting the regular outdoor UEs 2. Best performance by the IRC scheme is observed in all the states of experiment	1. The MNs are considered to be in constant speed, neglecting unwanted stoppage. 2. only limited to the users inside the vehicle
Tavares, Fernando M.L.; Berardinelli, Gilberto; Catania, Davide; Sorensen, Troels B.; Mogensen, Preben (2015)	Advanced receivers and rank adaptation	Proved to be an alternative of frequency reuse technique and even perform better in some cases compared traditional frequency reuse.	The throughput is not satisfactory in the third indoor office scenario when the network load is above 50%.
Gebremariam, A.A.; Goratti, L.; Riggio, R.; Siracusa, D.; Rasheed, T.; Granelli, F.	Software-Defined networking (SDN) model is implemented	Interference is successfully controlled with the proposed scheme	The work in at primitive stage. More advanced framework needs to be developed

(2015)			
Mahmood, N.H.; Uzeda Garcia, L.G.; Popovski, P.; Mogensen, P.E. (2014)	SIC technique is applied at the receiver	Analytical expression for success probability in practical case is derived and the results are validated by Monte Carlo simulation.	With the increase of the number of interferes, the receiver acts as an ordinary receiver

III. SUGGESTION FOR IMPROVEMENT

It is prominent that the theoretical analysis of interference management is far more accurate and attractive than that in practical case. The interference management should be reduced from heterogeneous 5G networks counting the real scenario without assuming the constant speed, mobility and data rates. For the upcoming new 5G technology, the advanced schemes and architectures of interference mitigation should be developed so that the spectrum efficiency is enhanced as well as the capacity of the network. One of the possible solutions can be the development of the macro tier heterogeneous network architecture where the gains of the MU MIMO can be utilized while operating in frequency division duplexing (FDD) system [5]. Another technique includes the combination of the three CoMP clustering schemes for HCSNet discussed in [7] which can be analysed in order to reduce the interference with less network complexity. As the number of wireless device increases, more possibilities of mobility are to go high. So the analysis of interference management is carried out in various types of urban environments so that all the possible situations are covered.

IV. CONCLUSION

The key concepts of the different ICI management technologies have been highlighted. With a very limited frequency spectrum, enhancing the spectral efficiency is very important for increasing the network capacity. At the same time ICI increase with number for frequency reused. The advanced ICI management schemes are being proposed to ensure excellent performance of the network. Future work may include to use self-controlled HCSNet for interference management such as using multi macro base stations and small cells in HetNets of 5G. Furthermore, joint decoding Cooperated Multipoint (CoMP) is also a very advanced method of interference management which is expected to give an improvement of performance.

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