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Various Techniques of Interference Management in Heterogeneous Network : A Review

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ABSTRACT

Day by day evolution in the mobile networks is seen. As the number of mobile users are increasing, urge for data rate is also getting high. To satisfy these needs either the radio power can be increased or number of remote radio nodes can be increased. Due to tremendous development in the field of wireless communication there is a huge increase in the demand for spectrum. But the useful spectrum is limited. To deal with this, heterogeneous network is introduced. With Heterogeneous network, better data rate can be achieved at low power and with minimum spectrum. Heterogeneous network use small cells having low transmission power along with high transmission power macro cells. Small cells used in heterogeneous networks are femto, pico and micro cells. Using these small cells, increase the complexity of the network as well as interference in the neighbouring cells. The major issue in heterogeneous network is to mitigate interference which occurs between small cells such as femto and micro cells working on similar frequency band. In order to increase capacity as well as quality of service of the network interference management should be done. This paper presents a review on interference management techniques.

Keywords : Fractional Frequency Reuse, Heterogeneous Network, Interference Management, Small Cells.

I. INTRODUCTION

Number of mobile users and their demands has been increased exponentially over few years. Due to increase of mobile users traffic load is also increased which leads to bandwidth consumption applications such as multimedia data, video streaming etc. To deal with increased traffic proper network planning and optimization should be done. As the technologies developed, it leads to improvement in smart devices, tablets, laptops that support high end applications. Earlier the main concern of Radio Frequency engineers is to satisfy the customers need for voice services by doing proper frequency planning. That's why more efforts put on for proper frequency planning and improve radio spectrum utilization. According to latest research by cisco visual networking in 2021 mobile devices figure will reach up to 1.6 billion and there is a 53% increase in compound mobile data volume from 2016 to 2021. Mobile video will consume 60% to 78% of total data whereas mobile web consumes 14%, mobile audio consumes up to 5% and mobile file sharing consumes 2% of total data . The prime constraint in mobile network is the spectrum utilization and supporting higher data rates along with improved quality of services. Heterogeneous Network technology helps to provide high quality services. In this technology cells are partitioned into macro, micro and femto cells which have high and low power transmission base stations. To reduce interference, base stations with controlled transmission power are used in heterogeneous network [1].

Heterogeneous networks are widely used to enhance network capacity, quality of service, spectral efficiency and coverage in a cost effective way. Heterogeneous network consist of Macro cells having high transmission power, small cell such as Femto cell, Pico cell having low transmission power. These small cells help to handle offloading traffic from macro cells. It provides superior participation in connecting user equipment (UE) with small cells having low transmission power. This inlay between macro cell and small cells leads to inter-cell interference in the network [2].

Heterogeneous network consist of following components [3]:

1. A macro cell is the main base station having maximum coverage up to kilometres. It consumes maximum transmitted power.
2. A pico cell having small base station to serve less number of users. It consumes less transmitted power as well as less coverage than macro cells but helps to enhance the capacity of system.
3. A femto cell used for offloading data traffic and consume less power. Femto cells are also known as access points (AP). They serve to users in their particular home and offices. It has least coverage than above two cells.
4. Relays are used to enhance the signal strength when there is poor coverage environment like cell edge region.
5. Radio Relay Heads (RRH) is connected with macro base station through optical fibre. This element is compact in size, having less weight and consumes more power.

By reusing the spectrum in heterogeneous network, enhanced area spectral efficiency is achieved. According to the signal strength of the received signal, user selects its serving node. Signal having maximum strength is used by the user whereas other signals are treated as interference. The main limitation of using heterogeneous networks is interference which conduct reduction in signal to interference plus noise ratio (SINR). Parameters such as throughput, bit error rate and outage probability are directly related to SINR. That's why it is important to solve the interference problem and find out affective interference management techniques.

Other part of the paper is organized as follows: Section 2 discuss about the various types of interference occur in the heterogeneous networks, Section 3 discuss about various interference management techniques and Section 4 concluded the paper.

II. Interference

Heterogeneous network can be used with the original network to cope up with the increasing traffic [4]. To deal with increasing traffic, spectrum should be used wisely. Spectrum between the macro and femto cells can be allocated either by spectrum sharing or spectrum splitting. Pico cell, Femto cell and relays use the licensed spectrum which is owned by macro cell due to unavailability of spectrum [5]. Interference can be of two types i.e. co-channel interference which occurs between the users using same frequency band and adjacent interference which occurs between the users using adjacent frequency band [6]. Cell capacity can be enhanced by using frequency reuse technique [7, 8]. Inter-cell Interference Coordination (ICIC) scheme released by LTE to deal downlink interference problem. To reduce interference in the heterogeneous network

ICIC technique is used. Classification of interference is shown in below Fig.1.

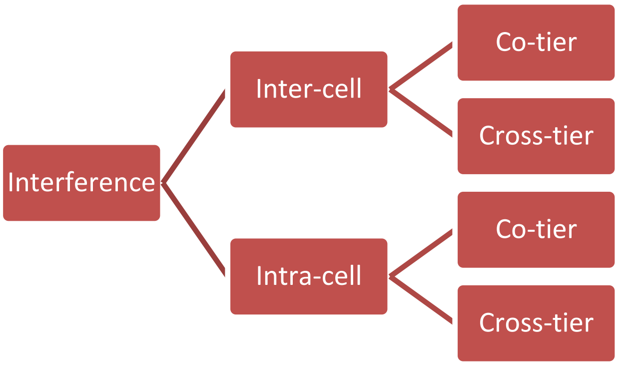

Fig.1 Classification of Interference

Heterogeneous networks are used because spectrum sharing becomes easy and frequency planning is also done but in certain conditions it introduces interference in the network. Cell Range Expansion (CRE) is the technique used in heterogeneous network to get all the benefits. CRE consist of small cells having low power and less coverage. The area of coverage of these small cells is enhanced so that traffic can be offload from macro cells to small cells which leads to interference. Users located in CRE area cause more interference in the downlink. In downlink two types of interference can be occur co-tier and cross-tier respectively. Between the two femto cells co-tier interference occurs whereas between macro and femto cells cross-tier interference occurs. Interference in heterogeneous network occur due to unplanned deployment, closed subscriber group access, power difference between the nodes and cell range expansion. It is easy to mitigate interference in indoor areas rather than outdoor areas. Interference mostly affects the cell edge region than the cell centre region.

III. Interference Management Techniques

Interference is one of the parameters which effect the performance of the heterogeneous network. So there are certain techniques developed which helps to mitigate interference. Interference management techniques can be categorized as time domain technique, frequency domain technique and power control technique. In case of network deployment, interference management techniques can be classified as

1. Decentralized Interference Management [9] has no coordination among the cells. It consists of fractional frequency reuse and static resource partitioning.
2. Coordinated Interference Management has adjacent cells which coordinate among themselves to reduce interference. It consists of coordinated multipoint communication (CoMP).
3. Resource Management based Interference Management [10, 11] allocate resources among macro cells and small cells. Perform different tasks such as handover management and packet scheduling.
4. Hardware based Interference Management [10] consist of antenna tilting and beamforming. It will select those channels which are less effected by the interference.

In this paper eight techniques are discussed which are shown in Fig.2 below.

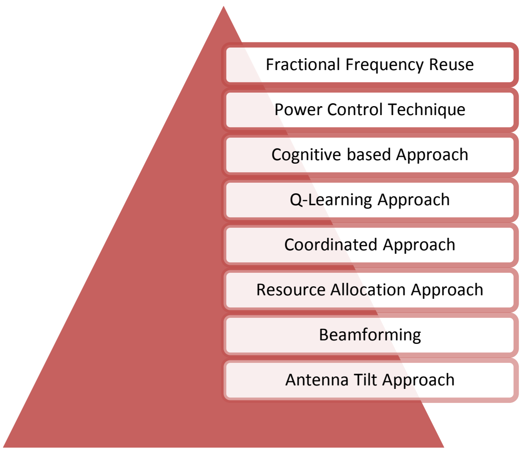

Fig.2 Classification of Interference Management Techniques.

3.1. Fractional Frequency Reuse (FFR)

Frequency reuse is the technique in which similar frequencies are used over the small geographic area on the transmitter side which are separated by small distance to reduce interference. Frequency reuse technique is used where limited bandwidth is available. With the help of this technique spectral efficiency, coverage and capacity of the network increases.

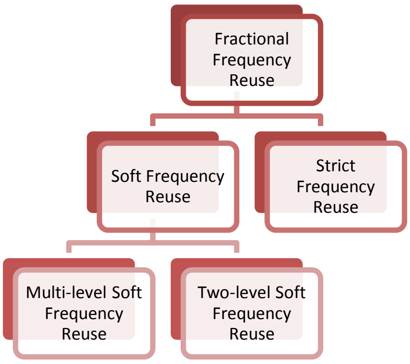

Fig.3 Types of Fractional Frequency Reuse (FFR)

FFR is the type of Frequency Reuse used widely in the wireless communication networks to mitigate interference. Here total available bandwidth is divided into sub bands and each sub band is allotted different frequency in a particular cell to avoid interference. Fractional Frequency Reuse is further divided into two parts such as soft frequency reuse and strict frequency reuse as shown in Fig. In soft frequency reuse technique, each cell is divided into two parts i.e. cell centre and cell edge region. Cell centre region can use all the sub bands if they are not used by cell edge region to avoid interference. Whereas in strict frequency reuse the frequency band is divided into segments i.e. primary and secondary. Primary segments are used by cell centre region whereas secondary segments are used by cell edge region. Author who implemented this approach is given in table.

Approach	Methodology Used	Inferences Drawn
Won-Lck Lee et al.[12]	• Hybrid Multiple Access (HMA). • Frequency Grouping (FG). • Intra-frequency group averaging (IFGA)	• In terms of service and mobility HMA is the best technique. • FG along with IFGA helps to reduce interference problem.
Romeo Giuliano et al.[13]	• Fractional Frequency Reuse.	• Overall system capacity is enhanced. • Interference is reduced.
Jaewon Chang et al.[14]	• Signal detection strategy. • Dynamic Frequency Reuse.	• Channel estimation error and shadowing effect is reduced.
Syed Hussain Ali et al.[15]	• Dynamic Fractional Frequency Reuse.	• Frequency reuse factor 1 is used. • Inter cell interference is reduced. • Trunking gain is increased.
A. Imran et al.[16]	• Self Organizing framework for adaptive Frequency Reuse and Deployment (SO-FRD).	• Analyse the effect of SO-FRD scheme on parameters such as frequency reuse, adaptive coding, and modulation.
Poongup Lee et al.[17]	• Fractional Frequency Reuse	• Cell edge throughput is increased. • Outage probability is reduced.

Thomas David Novlan et al.[18]	• Strict Fractional Frequency Reuse. • Soft Frequency Reuse.	• Coverage of cell edge users is improved.
Ju Yong Lee et al.[19]	• Fractional Frequency Reuse	• Using different sub-bands in femto cells will reduce the interference from macro cells.
Ioannis N. Stiakogiannakis et al.[20]	• Distance based approach. • SINR based approach. • Load balancing approach(LBA). • Fractional Frequency Reuse.	• LBA overcomes problem of resource management in SINR approach. • Blocking ratio and offered bit rates are improved.
Zhikun Xu et al.[21]	• Round Robin scheduling. • Maximum SINR (MSINR) scheduling. • FFR.	• Cell edge throughput increases. • Optimal distance threshold increases using MSINR along with FFR.
Lei Chen et al.[22]	• Generalized Fractional Frequency Reuse (GFFR).	• Cell edge throughput is enhanced.
Jiming Chen et al.[23]	• Adaptive Soft Frequency Reuse (ASFR).	• Enhanced spectrum efficiency. • Interference from the neighbouring cells gets minimized.
Zohreh Mohades et al.[24]	• Dynamic Fractional Frequency Reuse (DFFR).	• Throughput of system is enhanced using adaptive coding and modulation schemes.
Fan Jin et al.[25]	• Fractional Frequency Reuse (FFR).	• Spectrum Swapping Access technique is used to overcome near far problem. • Outage probability of femto cells in cell centre region and macro cells in cell edge region get reduced.
Haibo Mei et al.[26]	• Cell colouring based distributed frequency allocation approach (C-DFA). • Distributed dynamical fractional frequency allocation approach (DDFFA).	• Using C-DFA high frequency efficiency is achieved. • Using DDFFA high throughput and efficiency is achieved.
Nazmus Saquib et al.[27]	• Optimal static FFR (OSFFR).	• Better indoor coverage of users is achieved. • High quality of service. • High spectral efficiency is achieved.
David Gonzalez G et al.[28]	• Soft Frequency Reuse (SFR).	• Minimized inter-cell interference. • Better quality of service is achieved.

Qian Li et al.[29]	• Optimal Fractional Frequency Reuse.	• Convex dual problem is solved by using gradient descent method. • System capacity and coverage is also improved.
Wha Sook Jeon et al.[30]	• Fractional Frequency Reuse.	• System capacity is enhanced.
Dimitrios Bilios et al.[31]	• Fractional Frequency Reuse.	• Inter-cell interference is reduced.
Azwan Mahmud et al.[32]	• Fractional Frequency Reuse.	• Cell edge user's coverage is enhanced. • Interference in the neighbouring cells is minimized.
Hina Tabassum et al.[33]	• Fractional Frequency Reuse.	• Co-channel interference is reduced.
Wahyu Pramudito et al.[34]	• Soft Frequency Reuse.	• Quality of service and sum rate is improved by increasing the data rate per user.
Xuezhi Yang[35]	• Multilevel Soft Frequency Reuse (ML-SFR).	• Better interference pattern is achieved. • Cell edge throughput is improved. • Better data rates are achieved.
Manli Qian et al.[36]	• Adaptive Soft Frequency Reuse.	• Better cell edge throughput. • Enhanced system capacity.
Osianoh Glenn Aliu et al.[37]	• Adaptive distribution FFR scheme.	• Cell edge sum rate is improved.
Giovanni Giambene et al.[38]	• Soft Frequency reuse.	• Outage probability and average cell capacity is improved.
Suman Kumar et al.[39]	• Soft Frequency Reuse. • Fractional Frequency Reuse.	• FFR achieve higher coverage than SFR at SINR threshold.
Pochun Yen et al.[40]	• Fractional Frequency Reuse.	• Improved spectral efficiency.
Kemal Davaslioglu et al.[41]	• Fractional Frequency reuse.	• Enhanced energy efficiency. • Improved cell edge throughput.
Sok Chhorn et al.[42]	• FFR based overlap resource power control technique (FFR-OVER).	• System capacity as well as throughput of cell edge users enhanced. • Interference is reduced by using low power user equipment.
Cheng Chen et al.[43]	• Strict FFR. • Soft Frequency reuse (SFR).	• Average spectral efficiency is improved. • Cell edge user SINR is also improved.
M. S. Hossain et al.[44]	• Multi-layer soft frequency reuse (ML-SFR)	• Spectral efficiency at cell edge area is improved.

Hung-Bin Chang et al.[45]	• Directional FFR scheme. • Omni directional FFR scheme.	• Directional FFR scheme improve the throughput capacity as compared to omnidirectional FFR scheme.
Ahmed S. Mohamed et al.[46]	• Self organized dynamic resource allocation with enhanced FFR scheme ○(SODRA-EFFR).	• Improved cell edge performance is achieved.
Giovanni Giambene et al.[47]	• Iterative multi level soft frequency reuse (IML-SFR).	• IML-SFR solves non convex problem present in ML-SFR. • Better capacity, throughput and outage probability is achieved.
Se- Jin Kim et al.[48]	• Graph colouring based FFR (GC-FFR)	• High femto user equipment capacity is achieved.
Naser Al-Falahy et al.[49]	• Fractional Frequency Reuse.	• Enhanced capacity • Enhanced cell edge throughput • Enhanced average cell throughput • Enhanced peak data rate.
Jinjing Huang et al.[50]	• Coordinated soft frequency reuse (Co-SFR).	• Average cell edge throughput is increased. • Outage probability is reduced.

3.2. Power Control Technique

To reduce interference in the network, power control technique is one of the major aspects. The parameters used in power control technique are transmit power, throughput and outage ratio. The goal of this technique is to achieve a maximum throughput for the system. But in femto cells, if radiated power is reduced then it will also affect the throughput of the system. So there are various power control strategies to minimize interference. These are shown in Fig as below.

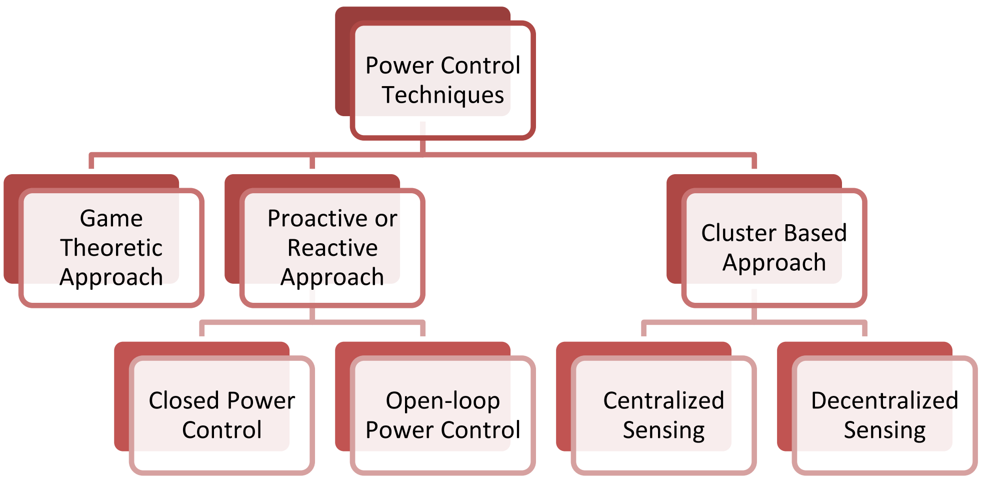

Fig.4 Types of Power Control Techniques

Power Control Techniques are partitioned into three categories i.e. Game theoretic, Proactive or Reactive and Cluster based Approach. Various power control techniques designed by game theoretic approach for femto cells to achieve better capacity in certain power constraints. The Proactive or Reactive approach mainly works on minimizing transmission power. It is further divided into open and closed loop power control respectively. Transmitted power is adjusted in the proactive manner in the open-loop power control method whereas transmitted power is adjusted in the reactive manner in the closed power control. The Cluster based approach is further of two types i.e. centralized and decentralized sensing. Centralized sensing tells about the number of active femto cells in the cluster by macro cell and also provide information about the maximum interference allowed for initial power setting whereas in decentralized sensing it tells about the number of active femto cells in the cluster by femto cell for initial power setting. Author who implemented this approach is given in table.

Author name	Methodology Used	Inferences Drawn
Carlos Ubeda Castellanos et al.[51]	• Fractional Power Control algorithm (FPC).	• To avoid inter-cell interference. • To improve SINR.
Mylene Pischella et al.[52]	• Downlink cooperation scheme.	• Enhanced throughput and fairness. • Better quality of service.
Tehseen Ul Hassan et al.[53]	• Adaptive Network Sensing Technique (ANS).	• ANS helps to reduce the cell edge interference as well as increase the throughput of the macro cells.
Zhaohui Yang et al.[54]	• Low complexity distributed power control and resource allocation algorithm.	• Low computational complexity. • Solved convex problem. • Better SINR and minimum interference.
Zhixin Liu et al.[55]	• Hierarchical game with a multiple-leader-multiple-follower model	• Cell edge throughput is increased.
Yanxiang Jiang et al.[56]	• Stackelberg Game Theory.	• Co-tier and Cross-tier interference is reduced.
Hristo Gochev et al.[57]	• Fractional Power Control Technique (FPC). • Interference based Power Control Technique (IBPC). • Power Spectral Density algorithm (PSD).	• PSD helps to improve the cell edge throughput. • Compensate the poor channel conditions.
Oleg Asenov et al.[58]	• Heuristic algorithm.	• Cell edge throughput is enhanced. • Inter-cell interference is mitigated.
Pavlina Koleva	• Open Loop Power Control	• Inter-cell interference is reduced.

et al.[59]	(OLPC).	• Average cell throughput is increased.
Zhixin Liu et al.[60]	• Power control algorithm based on Proportional-Integral Controller.	• Transient Response is adjusted. • Energy is saved. • Stability of power control algorithm is achieved.
Yongjun Xu et al.[61]	• Robust power algorithm.	• Lagrange dual decomposition method used to solve convex optimization problem. • Computational complexity is reduced. • Sensitivity is enhanced.

3.3. Cognitive-based Approach

The Cognitive based approach uses the concept of cluster based decentralized power control technique. This approach is used to handle co-tier and cross-tier interference. Cross-tier interference is minimized by sensing the free spectrum in the cognitive femto cells. Co-tier interference is minimized by using Gale-Shapley spectrum sharing method. Author who implemented this approach is given in table.

Author name	Methodology Used	Inferences Drawn
Shin-Ming Cheng et al.[62]	• Cognitive radio technology.	• Used to reduce interference.
Shin-Ming Cheng et al.[63]	• Cognitive radio technology.	• Indoor coverage is improved. • System capacity is increased. • Cross-tier interference is reduced.
Li Huang et al.[64]	• Cognitive radio technology.	• Intra- tier interference is reduced.

3.4. Q- Learning Approach

Q-learning approach is used for both interference management as well as cell association. Author who implemented this approach is given in table.

Author name	Methodology Used	Inferences Drawn
Meryem Simsek et al.[65]	• Reinforcement Learning Approach.	• Inter-cell interference is reduced.

3.5. Coordinated Approach

Coordinated approach deals with coordination among the cells. Coordination scheme can be of two type's i.e. dynamic and semi-static coordination as shown in Fig below.

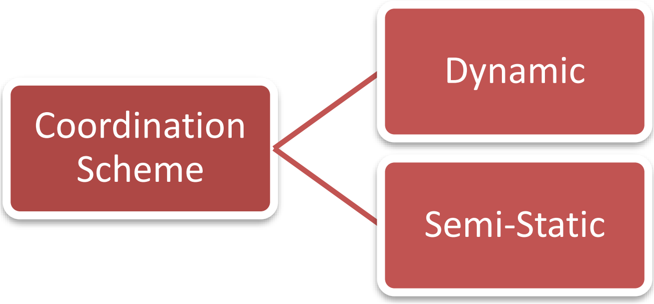

Fig.5 Types of Coordinated Approach

Dynamic coordination has larger flexibility than semi-static coordination that's the reason it enhance the performance of the system. But dynamic coordination has less coverage than the semi-static coordination. In order to mitigate interference this approach is used along with beamforming. Author who implemented this approach is given in table.

Author name	Methodology Used	Inferences Drawn
Zhu Han et al.[66]	• Distributive non-cooperative game approach.	• Transmitted power is minimized.
Hojoong Kwon et al.[67]	• Non-cooperative game approach.	• Resource allocation problem is solved. • Iterative algorithm is developed to solve co-channel interference.

3.6. Resource Allocation Approach

Resource allocation approach is used to mitigate interference in co-tier and cross-tier respectively. Its main focus is to work on downlink. Author who implemented this approach is given in table.

Author name	Methodology Used	Inferences Drawn
Sunil Kaimaletu et al.[68]	• Cognitive Interference Management.	• Average cell throughput is increased. • Outage probability decreases.
Lu Zhang et al.[69]	• Cognitive Interference Management.	• Indoor coverage problem is solved. • Improve network capacity. • Avoid spectrum allocation.
Holger Claussen [70]	• Distributed algorithm for self-deployment and load balancing.	• Enhanced network performance • Improved convergence speed.
Luis G. U. Garcia et al.[71]	• Autonomous Component Carrier Selection.	• System capacity as well as coverage of the network is enhanced. • Interference in cell edge user is minimized.

3.7. Beamforming

Beamforming is the hardware based approach in which beam shape of serving cell is considered in order to mitigate interference. To increase coverage and capacity of the cell correct phase angle and antenna pattern need to be selected. It also leads to increase throughput of the system. Author who implemented this approach is given in table.

Author name	Methodology Used	Inferences Drawn
Prasanth C.R et al.[72]	• Conventional Beam forming. • Adaptive Beam forming.	• Conventional beam forming done in time and frequency domain. • Adaptive beam forming used in noisy environment.
Barry D. Van Veen et al.[73]	• Beamforming	• Signals from different directions are analyzed in presence of noise and interference.
J. Bak et al.[74]	• Distributed Beam forming Technique.	• Computational complexity is reduced. • Interference in downlink is minimized.
Mika Husso et al.[75]	• Transmit Beamforming.	• Co-channel interference is suppressed. • Interference in downlink is also minimized by using multiple antennas.
Deyue Zhang et al.[76]	• Ajoint Femto Clustering technique. • Selective Beamforming scheme.	• Inference in uplink transmission is minimized. • To reduce in-cluster interference selective beamforming is used.
Obinna Oguejiofor et al.[77]	• Heuristic Beamforming Algorithm.	• Load distribution is enhanced. • Spectral efficiency is improved. • Interference in two-tier network is reduced.
Sungsoo Park et al.[78]	• Orthogonal Beamforming Technique.	• Cross-tier interference in femto cells is reduced. • System throughput is enhanced.

3.8. Antenna Tilt Approach

Antenna Tilt Approach is also hardware based approach in which antenna parameters are varied to achieve high quality of service. This approach is used because of less cost as well as complexity. Using this technique, helps to improve the SINR, average throughput of the system. Author who implemented this approach is given in table.

Author name	Methodology Used	Inferences Drawn
Osman N. C. Yilmaz et al.[79]	• Novel Method.	• Quality of service is enhanced. • SINR is improved.
Iana Siomina	• Automated Optimization of	• Common pilot channel transmit power helps to

et al.[80]	service coverage. • Radio base station antenna configuration.	increase coverage. • It also helps to reduce interference and increases the capacity of system.
Fredrik Athley et al.[81]	• Antenna Tilt Method.	• Inter-site interference is reduced. • Coverage and capacity of system is enhanced.
Jolly Parikh et al.[82]	• Antenna Tilt Method.	• Variations in antenna height and antenna tilt helps to increase the coverage as well as capacity of system whereas SINR of the system is also affected.
Ho-Shin Cho et al.[83]	• Antenna Beam Tilting Scheme.	• Interference in the neighbouring cells is reduced by using down tilting. • SINR is also improved.
Bahar Partov et al.[84]	• Antenna Tilt Method.	• Non convex problem is solved. • Convex optimization. • Maximum coverage.
Osman N. C. Yilmaz et al.[85]	• Self Optimization Method.	• Coverage and capacity of system is enhanced.
R. Razavi et al.[86]	• Self Optimization using Reinforcement Learning Approach.	• Used in the noisy environment. • Have self-healing properties. • Coverage of system improved using this technology.
Jingyu Li et al.[87]	• Self Optimization Method. • Fuzzy Q-learning Algorithm.	• Antenna down-tilt is optimized. • Coverage and capacity of system is improved.
Ajay Thampi et al.[88]	• Reinforcement Learning Approach.	• Algorithm is better than supervised as well as Q learning approach. • Coverage of system is improved using antenna tilting. • Self healing is also done. • Multiple coverage problems are also dealt.
Nikolay Dandanov et al.[89]	• Dynamic Self Optimization Antenna Tilt Approach.	• Interference in the neighbouring cells is reduced. • Signal reception is improved. • SINR and sum data rate is also improved.
Xiao Li et al.[90]	• Antenna Tilt Approach.	• With vertical beam width decreases, average throughput and spectral efficiency of the system increases.

IV. CONCLUSION

With the increase in traffic, high data rate's demand is increasing day by day. In order to fulfil this demand more spectrum should be there which is not possible. So there are number of techniques developed to reuse the spectrum. But there are certain limitations in reusing spectrum i.e. interference. Interference effect the quality of service as well as SINR. To get high data rate, capacity and efficiency there is need to maintain quality of service . So it is very necessary to mitigate interference from the network. Major issue of interference in heterogeneous network is solved by different interference management techniques discussed in the paper. Some of those techniques are hardware based which can be practically implemented. Different authors worked on different techniques and leads to different conclusions. In this paper eight interference management techniques are discussed and can be used depending on certain parameters.

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