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A Review of Uplink Power Control for Interference Mitigation in 5G-NR

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Abstract— ***Network densification in the fourth-generation long term evolution (4G LTE) network physical layer to improve capacity and the subsequent deployment of fifth-generation new radio (5G-NR) let to co-channel interference which affects the cell throughput. This co-channel interference is worst at the cell edge. The desire to increase capacity has been the driving force for moving from homogeneous to heterogeneous network infrastructures. This means having the Macro, Micro Pico, and the Femto-layers over-lapping each other at certain geographic space. The uplink power control is geared towards managing interference, improving data rates and by extension result in efficient energy utilization of the limited power source of the user equipment (UE). A lot of researches have sort to address the problem of inter-cell interference using different approaches guided by the frame and standards provided by the third-generation partnership program (3GPP). One of these approaches is the power control which leverages on either uplink or downlink interference mitigation. It focuses in power management, efficient utilization leading to overall energy minimization on the network, while meeting the everyday user data demands. In this review work, a look through works by different scholars, methods employed, schemes proposed and results obtained in uplink power control were carried out. It can be observed that power control plays a critical role in interference mitigation. Yet, much desired results are yet to be achieved, especially at the cell edge of a heterogenous network where resource management is essential.***

Keywords— ***interference mitigation, uplink power control, 5G-NR, information security, information system, security awareness, user behavior.***

I. INTRODUCTION

Interference has remained a challenge in mobile wireless networks, and some generally acceptable standards has been defined by organizations such as ITU and 3GPP. Approaches such as sub-channel scheduling, dynamic transmit power control, dynamic antenna pattern adjustment, and adaptive modulation and coding schemes has been proposed as seen in [1,2,3]. Therefore, review will focus on uplink power control techniques.

Power control in the field of mobile telecommunication became a focus in the code division multi-access (CDMA) network, in the bid to maintain fixed received signal strength of all user equipment (UE) within the network, the near-far problem which is critical in the CDMA network was addressed [4,5,6,7], but with increased inter-cell interference (ICI) at cell edge. The problem occurs in the absence of power control when all mobiles transmit at the same power levels, irrespective of their location and distance from their supporting base station (BS). In order to correct this problem, UE transmit at different power levels according to their distance away from their supporting BS so as to maintain same power levels at the BS[8]. This means higher transmission power for UE at cell edge to fully compensate for path loss and other losses such as channel fading, etc. It was observed that higher transmit power of users at cell edge degrades network capacity as intra-cell and inter-cell interference increased. The depletion of UE power was in the increase at cell-edges [2]. The intra-cell interference was resolved by the introduction of the single-carrier frequency division multi-access (SC-FDMA) scheme [4-9], which is a highbred of the orthogonal frequency division multi-access (OFDMA). The SC-FDMA is considered a better energy efficient scheme than the OFDMA and is now deployed in the uplink access in 4G LTE systems [4-11]. Every modification done today in the telecommunication network is geared towards efficient bandwidth utilization, and energy minimization as data rate requirement is on the increase [12-14].Hence the reason for the introduction of the fifth-generation new radio (5G-NR) access network. The 5G-NR as an upgrade of the LTE network is designed to meet expectations such as low latency, improved capacity, massive machine-type communication, etc [15-16]. To achieve this, some major network infrastructural adjustments must be undertaken. These and many more responsibilities has been committed to the third-generation partnership program (3GPP) to formulate and propose a universally acceptable framework for the implementation of the 5G service [17].

The expectations of high data rates, ultra-low latency in the service delivered by 5G network calls for stringent measures on schemes capable of managing interference in the network, while efficient energy utilization and management is also prioritized. An efficient scheme must be simple (not complex) and guarantee less signalling as it is going to be operated from the UE side of the network (uplink). The introduction of multi-tier network infrastructures to build

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capacity will aggravate the challenge of inter-cell interference [18-19]. Also, the plan of using frequency reuse factor of one (1) across all tiers is a thing of concern [20]. Therefore, addressing inter-cell interference from one end (downlink) will not do a lot of good. Instead, it will do better when these challenges are addressed from both ends (uplink and downlink) [21].

II. REVIEW OF RELATED LITERATURES

The idea of power control in mobile communication is centred on efficient energy utilization and minimization of overall power. The benefits of power control go beyond interference mitigation, signal to noise and interference ration (SINR) improvement which by extension improves data throughput to "RF exposure control" [22]. In [22], the power utilization of about 7000 devices were examined over a long period of time. This study was aimed at analysing the maximum power usage and duration to which this power was applied. This establishes the knowledge that the maximum transmit power used by the device was within the recommended range of values, and that the devices seldomly use its maximum transmit power. Meaning that the time at which these devices applied their maximum allowed power was short, implying that the extent of radiation exposure was also minimal.

The challenge of power control in uplink has been addressed by researchers using three major approaches, namely;

Analytical approach
Artificial Intelligence
Mathematical modelling, to achieve certain desired results.

A. Analytical approaches

In the analytical approaches, the focus thus far is to understand the open and closed loop power control (OLPC and CLPC) schemes as proposed by the 3GPP as the traditional scheme for both uplink and downlink operations [23][24]. These schemes are now modified to achieve an advantage based on the researcher's interest. The fractional power control (FPC) scheme is a typical example of the modified open loop power control scheme. This saves some power and reduce interference generated by cell-edge users, when the system no longer wants to fully compensate for path loss. This becomes an advantage of the FPC scheme over the traditional OLPC scheme [25-30].

From the network point of view, schemes such as joint scheduling with advanced receivers as presented by [31] bothered about the use of multiple approaches to advance the cause of interference management for 5G mobile networks. They proposed the use of advanced receivers with interference joint detection and decoding in the uplink side and interference management by joint scheduling at the network side (downlink).It showed that channel state information was a necessity to achieving gains especially to the cell-edge users.

Also, [32], in line with joint approaches, proposed the use of soft frequency reuse (SFR) scheme alongside power minimization in 5G network to mitigate interference. The interference contribution rate of neighbours was used to determine the interfering base state (BS). The BS with interference (downlink) above a set threshold is assumed to support less or no UE at all, therefore is shutdown. Scheme was focused on downlink power utilization/efficiency. Though the scheme achieved very little improvement in total power used by cell-nodes, but comparable rates was achieved using the SFR (standardized) scheme. It also achieved significant power efficiency but will definitely suffer from massive overhead signalling.

B. Open and Closed loop power Control Schemes

The OLPC and CLPC schemes were proposed by the 3GPP for power control in mobile telecommunication. As mentioned earlier, OLPC offers full path loss compensation as against the fractional power control (FPC) scheme that offers partial path loss compensation [25-30].

According to [1][27][30][33][34], the analysis of the performance of the OLPC and CLPC scheme were carried out and compared their performances in SINR and interference management in the uplink LTE network. According to the data presented by [27][33], FPC was said to support 20% increase in mean cell throughput by maintaining same cell-edge throughput. FPC was also shown to maintain lower interference levels better than those of OLPC, as FPC does not offer full path loss compensation thereby extending battery life [33]. Also, the conventional CLPC is said to have the flaws of targeting all users (UEs) to achieve same uplink SINR, thereby leading to significant reduction in mean cell throughput. This led to a recommendation that SINR target should be varied for UEs based on radio channel variations.

In [33], the analysis of the CLPC scheme combination with the FPC scheme was carried out. They also investigated the path loss compensation factor of the FPC for best set points that can best improve overall data throughput of the network. They came to a conclusion that the compensation factor of $\alpha = 0.7$ resulted in higher mean throughput but with degraded cell-edge performance to higher transmit power resulting in higher interference. The factor of $\alpha = 0.8$ was recommended for better value of path loss compensation as it resulted in low interference and improved/best cell-edge performance in throughput

[34] Successfully carried out a MATLAB simulation of a 4G LTE homogenous network, made comparison in performance between full compensation and fractional compensation. Performance analysis of OLPC and CLPC was simulated, and SINR relationship to cell capacity was compared. Also carried out is a mathematical analytics for SINR, based on distance of evolved Node-B (eNB), average SINR and average cell spectral efficiency. [29] worked on choosing or setting compensation factor in LTE network.

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They derived analytical equations for SINR based on distance of eNB, average SINR and average cell spectral efficiency. From data presented, compensation factor depends on path loss coefficient. It was also shown that FPC has gains over full path loss compensation scheme. In [30], a comparative analysis of the OLPC and CLPC scheme was performed. The open loop scheme leveraged on the FPC compensation factor, enabling trade-off between cell-edge data rate and capacity. Similarities showed that the FPC is advantageous over schemes with full path loss compensation and SINR balancing.

The achievable aim of the fractional power control schemes has remained low due to interference levels generated by the cell-edge users who face high path loss and other forms of channel fades. The reduced transmit power by a compensation factor by cell-edge users translate into improved SINR standings for the other users (cell centre). Thus, translating into better throughput in the cell and its neighbours.

C. Heterogenous Network (HetNet)

The network structure has been gradually modified to increase capacity due to high density of mobile users which led to network densification. In network densification, the base stations (eNB) are brought closer to the users, by increasing the number of eNBs within a given geographical area. Also, small cells are provided for highly crowded areas such as sports facilities, airports, rail station to provide reliable service. Other forms of small cells include those deployed by users (femtocells). This further complicate the forms of interference felt by the network which deserve serious attention. The HetNet environment is unique, making the interference experienced more complicated. Because in HetNet, we have multiple nodes with very different configurations hosting different users, largely on the same network. As proposed, macro and femtocells are to be deployed on the same frequency band as those of their respective operators, while the operators will be forced to using frequency reuse factor of one (1). As the power behaviour of UEs in a HetNet environment is challenged due to interferences generated, in [35], the analysis of the different UE transmit power (uplink) was carried out to determine the optimal UE transmit power levels in LTE small cell network, such that the ICI is controlled or kept minimal. It was resolved that 63.1mW was high-enough for the femto-user equipment (FUE), while the 199.52mW was accepted for the macro-user equipment (MUE) as this will checkmate interference between Femto-eNBs and Macro-eNBs. In [36], the authors analysed the power behaviour of UEs in a HetNet environment, using spatial Poisson point process. Their focus was on coverage probability and average achievable rates for both UE supported by the femtocells and macro cell.

Although there was no particular focus on cell-edge UEs and how the number of femtocells would affect the overall quality of service (QoS) of the network because it is an uplink-based analysis. It was noticed that the increase in FUE increases the amount of interference generated on the system thereby having a negative impact on the achievable rates of the network.

Other forms of power control schemes proposed are still based on either OLPC or the CLPC, and/or modified through FPC schemes. The power headroom report-based uplink power control (PHR-PERA) scheme in LTE-A HetNetwas proposed in [28]. It was observed from their work that resource block (RB) allocation must be controlled in order to control transmit power efficiency of UEs based on UE power capability using the power head-room report. Also, they employed the use of adaptive OLPC based on SINR and interference improvement. From data presented, significant improvement was achieved in throughput between femtocells and the macro cells as compared to FPC schemes. It was also reported that the OLPC scheme achieved additional gains based on received SINR. [25] also worked on the same HetNet environment proposed a self-powered fractional power control scheme for ICI mitigation. The authors also considered the interference between macro and femtocells by utilizing the dynamic power offset scheme to enhance FUE's performance within the small cells. This work achieved lower packet loss (BER) at lower transmit power. It was also shown that the increase in FeNB did not contribute to packet loss ratio in the network as against the work of [36].

Reuben Kurda's [25] work was able to keep interference lower than the Pmax of 23dBm allowed for UE class 3 devices. The fractional-self power control (FSPC) scheme showed that the throughput ratio was kept relatively higher than schemes operating with full path loss compensation factor. The increase in the number of FeNBs (translating to increase in number of users (UEs)) did not have as much impact on FSPC scheme as it had on other schemes operating with the full compensation factor.

Other parameters have been employed to give better response to channel variations beyond the previous. This is because there are other forms of losses in wireless channels other than path loss, while making efforts to maintain the QoS of the network, researchers such as [4-7][25][26] have moved to considerother parameters for power control schemes for optimum performance. [26] did some work on cell edge throughput improvement for LTE using combined uplink power control schemes. The FPC and the interference-based power control scheme (IBPC) was used in limiting transmit power of UEs based on interference limited threshold set. Although it achieved considerable results as compared to FPC scheme alone, but there was no consideration of HetNet but homogenous network.5G has been planned to be deployed in HetNet scenario and not homogenous. [37] worked on interference control in UTRAN LTE based on the overload indicator (OI). The work is based on using the OI signal for an automatic adjustment of the

OLPC parameters. This is to control interference levels in the network. From data presented, the uplink SINR remained competitively the same with the schemes operating on fixed received power (Po) while the interference over thermal (IoT) showed some shortfalls. In [6],an overload indicator-based uplink power control scheme for a HetNet environment was also worked on. The algorithm designed was said to be efficient for the network planning phase in the uplink power control. Simulated and calculated results showed some similarities and major discrepancy but followed some regular pattern of lower SINR with higher UEs in the network.

D. Artificial Intelligence (AI) Approach

Further researches into power control schemes led to the application artificial intelligence (AI). The analytical approaches make use of field data and real-time analytics to find solutions to present network challenges, but in programming, the system is trained on a set of data defining various network challenges beforehand. The AI approach has the advantage of fast and precise solutions after training. But require good amount of training data and extended training time to be able to provide meaningful outputs as solutions. Though they general also require retraining as the terrain changes as against [38] who stated that their scheme does not require retraining.

In [39], Random Neural Network (RNN) was applied to design a decision-making framework for optimized and autonomous power control in LTE uplink system. The RNN was applied to OLPC scheme, designed to address the uplink power control problem for LTE systems. The performance was compared to those of artificial neural network (ANN) and the FPC schemes in terms of capacity and coverage optimization. RNN was reported to achieve comparable results with faster adaptation in severe environment. Also, in [38], the reinforcement learning was applied for uplink power control optimization. The algorithm usesthe parameters generated from training data for its decision based on live network scenarios. Although it was stated that the network does not necessarily require retraining, the system was compared with FPC scheme with respect to throughput but without visible improvements in overall interference in the network.

E. Mathematical Approach

Mathematical theories from other fields have also been applied in this regard, this is in the bid to finding a more better scheme that will lead to better results in interference mitigation as the network gets more complicated while maintaining good QoS.

In [40], a utility function-based uplink power control algorithm in LTE-A network was proposed. They applied the LaGrangian method in solving a utility maximization problem. This approach is geared towards finding a point (optimum) where data rate is at its maximum while transmit power is kept at its minimum. On simulation, low interference was achieved by maintaining a low power profile. This approach though showed some gains in rate and power balancing but did not go through without suffering from low SINR regime on users allocated lowest transmit power, and the overall achievable rate was not presented. Also, [41] proposed an analytical modelling of interference aware power control for the uplink of HetNet. Using stochastic geometry, power control was achieved by keeping the generated interference within a given (set) threshold. The whole idea was to limit transmit power of neighbours so as to mitigate interference and average channel fading in other to maintain a fairly stable SINR approximation. Though the main aim was achieved; successfully limited UE transmit power, thereby improving bandwidth utilization. However, cell-edge UEs in the low SINR regime were not explicitly shown to have same significant improvements in data rates, neither was the outage probability indicated to have any improvement.

III. CHALLENGES

The reviews presented shows that some work have been done geared towards interference mitigation by power control. Many of the proposed schemes made some gains in specific areas of deployment, while others show strong applications in other areas. However, challenges faced in some of these schemes lies in its high computational requirement, high overhead signalling, some schemes are not friendly to HetNet environment. Also, some are not cell edge friendly while others are not specifically designed for power minimization, but efficiency.

IV. CONCLUSION

The review was classified into three categories namely; analytical, AI and mathematical approaches. All the three approaches showed some appreciable gains without any particular interest in cell edge user performance (mean throughput). Although, the analytical approach,while analysing the FPC scheme did make a spot-on cell centre UE SINR improvement due to low transmit power of the cell edge users, there was still no particular concern to improving the throughputs of the cell edge users.

In the HetNet environment, all the approaches reviewed did not clearly show the impact of femtocells to cell edge users who are served by the macro cell within their coverage region. As it believed by logical assumption that the deployment of femtocells at cell edge in closed user mode will greatly affect the cell edge UEs performance. The mathematical approach was applied to power minimization and rate maximization also without specifics to cell edge users who are most affected by interference in a wireless network.

The AI approach proved to be an efficient option in interference control. But not without the following concerns;

The retraining requirements of the program for effective and efficient decisions, as this may cause increase in required processing and new training data accumulation. May also lead to UE complexity.

Though [38] claimed scheme that does not require retraining, such schemes would have required large training data from different environments, which is obviously requiring big -data analytics. Therefore, such scheme may suffer from inefficient outputs (decisions) as adaptation becomes complicated with newly undefined environments.

V. RECOMMENDATION

Since the 5G NR will be best operated in a highly dense network environment, that is, the HetNet environment, the uplink power control schemes to be proposed must consider the impact on interference caused by most especially the femtocell which are user deployed (unplanned). The power control algorithms are also recommended to consider ways of improving cell edge user throughputs by considering the amount of interference generated by users served by different network structures within the same space. Such algorithms must not add to system processing, and or UE complexity.

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