**International Conference of Science, Engineering & Environmental Technology (ICONSEET), 1(2): 8-14, 2016**
**ISSN 0794-9650**

www.repcomseet.org

# A Survey of Interference Challenges and Mitigation Techniques in 5G Heterogeneous Cellular Networks

Afolalu O.F[1], Petinrin J.O[2], Ayoade M.A[2]
[1]Department of Electrical Engineering, University of Cape Town, South Africa.
[1, 2] Department of Electrical & Electronics Engineering, Federal Polytechnic, Ede. Osun State.
dexlam2000@yahoo.com

**Abstract: The exponentially increasing demand for mobile broadband communications has led to the dense deployment of cellular networks with aggressive frequency reuse patterns. The future Fifth Generation (5G) networks are expected to overcome capacity and throughput challenges by adopting a multi-tier architecture where several low-power Base Stations (BSs) are deployed within the coverage area of the macro cell. However, Inter-Cell Interference (ICI) caused by the simultaneous usage of the same spectrum in different cells creates severe problems. ICI reduces system throughput and network capacity, and has a negative impact on cell-edge User Equipment (UE) performance. Hence, Inter-Cell Interference Coordination (ICIC) techniques are required to mitigate the impact of ICI on system performance. In this paper, a comprehensive survey and challenges of various cell association and power control methods used to mitigate ICI are presented. We thereafter proposed an efficient joint cell association and power control techniques that can be combined to make our proposed technique compatible with the evolving 5G cellular networks. It is expected that our approach will improve on the Quality of Service (QoS), user data rate, system throughput and traffic load balance of the evolving 5G cellular networks.**

***Keywords: Cell association, cellular networks, heterogeneous networks, inter-cell interference, power control.***

## 1. Introduction

The extreme densification of small cells is currently the big hope to resolve the unprecedented data challenge and to provide ubiquitous network coverage with an optimized Quality of Service (QoS) (Hossain & Hasan, 2015). This has made the fifth generation (5G) cellular network to become a hot research topic in telecommunication industries and academics (Ge, Tu, Mao, Wang, & Han, 2015). Small-cell heterogeneous networks (HCNs) represent a paradigm shift from the traditional centralized macrocell approach to a more self-organized solution, where small cells are deployed in conjunction with existing large cells at all possible venues, indoors and outdoors, and in all types and sizes (Hossain & Hasan, 2015; Lopez-Perez et al., 2011). Heterogeneous Network (HetNet), therefore, is an integration of cells of small coverage such as microcells, picocells, femtocells, relays and remote radio heads (RRHs) into the existing macrocells. The concept of heterogeneity and dense deployment of small cells in cellular networks has become an attractive solution recently in order to meet future demands for high data rates, reduced latency and enhanced coverage (Kaddour, Denis, & Ktenas, 2015), (Hossain, Rasti, Tabassum, & Abdelnasser, 2014). To accommodate the ever-increasing demand for mobile data, the wireless industry is faced with the urgent requirement of growing the capacity of mobile access networks by 1000 times. Today, users want to communicate with each other at anytime, anywhere and through any media, including instant messages, email, voice and video.

Globally, mobile data traffic has approximately doubled in each of the recent years and there are strong indications that this unprecedented trend will continue. According to the 2013 Ericsson Mobility Report (Ericsson mobility report, 2013), mobile data traffic has already surpassed voice traffic in 2009, and it is predicted to increase steadily whilst voice traffic only grows moderately. The report further shows that at the annual increase rate of 50%, the mobile traffic by the end of the year 2019 will be 10 times that of 2013. Moreover, in 2013 the traffic generated by mobile phones alone had exceeded that by all mobile PCs, mobile routers and tablets combined. Similarly, the 2013 Cisco Visual Networking Index (VNI) report (later reviewed in 2015) projected that the global mobile data traffic will go up at a compound annual growth rate (CAGR) of nearly 70% during the period 2012–2017 (up to 2015-2020) (Cisco VNI, 2013 & 2015), and a 13-time increase is expected by the end of 2017 with 11.2 exabytes generated per month.

The 5G networks will consist of nodes and cells with heterogeneous characteristics and capacities (e.g., macrocells, femtocells, picocells, radio relay heads (RRH) and D2D user equipments [UEs] etc.), which will result in a multi-tier architecture as shown in Fig.1. Due to increasing complexity in network management and coordination among multiple network tiers, the network nodes will have the capability of *self-organization* (e.g., autonomous load balancing, interference minimization, spectrum allocation, power adaptation etc.) (Hossain & Hasan, 2015). Also, a UE can have simultaneous active connections to more than one base station (BS) or access point (AP) using the same or different radio access technologies (RATs) (Ge et al., 2015).

Several objective functions can be defined to improve network performance, such as maximizing system throughput, spectral efficiency, energy efficiency or throughput fairness, while guaranteeing the minimum required QoS for all the UEs (Yassin, 2015; Lopez-Perez et al., 2011), (Hossain et al., 2014). Although cell densification provides significant benefits to both user and mobile operator, there is possibility for cross-tier and co-tier downlink interference that affects throughput and QoS of victim macrocell and small cell users. This leads to serious degradation in overall system capacity, and causes higher outage probability. Several state-of- the-art works have proposed various inter-cell interference (ICI) mitigation techniques for multiuser OFDMA networks such as Long Term Evolution (LTE). According to literature survey, none of the previous literatures fully reviewed all existing methods, their advantages and practical implementation challenges. This paper therefore presents a comprehensive survey on existing interference mitigation techniques, with open challenges and guidelines provided to modify the existing techniques in order to overcome these limitations and make them suitable for 5G HetNets. The rest of the paper is organized as follows: section II first outlines the need for interference management in HetNets. Then, cell association and power control techniques are described in sections III and IV respectively, followed by the conclusion in section V.

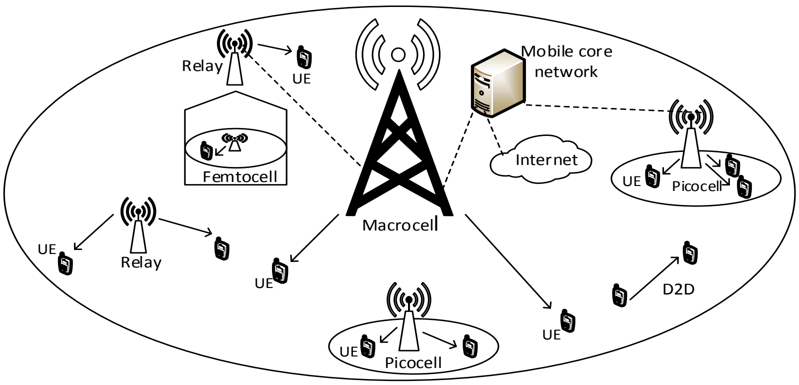


Fig. 1. A multi-tier network composed of macrocells, picocells, femtocells, relays and D2D links. Arrows and dashed lines indicate wireless links and backhaul connections respectively.

## 2. Interference Management in Heterogeneous Networks

One of the biggest challenges for muti-tier HetNets is to mitigate inter-cell and inter/intra-tier interferences, which becomes trickier in a dense deployment, with a more diffuse definition of aggressor cell and victim user (Soret, Pedersen, Jørgensen, & Fernández-López, 2015). Downlink interference can be mitigated from the network side by partially muting the interfering cells through a coordinated inter-cell algorithm. Another possibility is to let the UEs combat part of the interference by means of advanced receivers with interference cancellation (or suppression) capabilities (Kaddour et al., 2015). In any case, the choice of a proper interference management technique calls for a thorough study of the interference distribution between BSs and mobile users, where the interference sources for a UE are sorted from the strongest, the dominant interferer (DI), to the weakest. Unlike downlink, the transmission power in the uplink depends on the user's battery power irrespective of the type of BS with which users are connected. The battery power does not vary significantly from user to user, therefore, the problems of coverage and traffic load imbalance may not exist in the uplink. This leads to considerable asymmetries between the uplink and downlink user association policies (Ge et al., 2015).

In addition to heterogeneity and dense deployment of wireless devices, coverage and traffic load imbalance due to varying transmit powers of different BSs in the downlink make the interference management and resource allocation problems more challenging than those in conventional single-tier systems (Hossain & Hasan, 2015). Besides, different access restrictions (e.g., public, private, hybrid etc.) in different tiers lead to diverse interference levels. In addition, the introduction of carrier aggregation (CA), cooperation among BSs (e.g. by using coordinated multi-point transmission (CoMP)) as well as direct communication among users (e.g.D2D communication) may further complicate the dynamics of the interference (Hossain et al., 2014). Therefore, the optimal solutions for downlink cell association and power control problems may not be optimal for the uplink scenario due to the considerable asymmetries between the uplink and downlink user association policies. Consequently, it is therefore necessary to develop joint optimization frameworks that can provide optimal solutions for both uplink and downlink.

To deal with this issue of asymmetry, separate uplink and downlink optimal solutions are also useful as far as mobile users can connect with two different BSs for uplink and downlink transmissions, which is expected to be the case in 5G multi-tier cellular networks (Lopez-Perez et al., 2011). The above factors however translate into the following key challenges:

- Designing Optimized Cell Association and Power Control (OCAPC) methods for Multi-tier networks.
- Designing efficient methods for cooperation and coordination among multiple tiers.
- Designing efficient methods to support simultaneous association to multiple base stations (BSs).

## 3. Distributed Cell Association Schemes

**A. Reference Signal Received Power (RSRP) Scheme**: In the LTE system, a UE must detect and monitor the presence of multiple cells and perform cell selection or reselection to ensure that it is "camped" on the most suitable cell. A UE "camped" on a particular cell will monitor the System Information and Paging (SIP) of that cell, but it must continue to monitor the quality and strength of other cells to determine if handover or cell reselection is required. In other words RSRP is the average power of resource elements (REs) that carry cell specific Reference Signal (RS) over the entire bandwidth (Sangiamwong et al., 2011). RSRP is also used to estimate the path loss for power control calculations.

**B. Reference Signal Received Quality (RSRQ)**: In LTE, two types of cell selection methods are specified (Sangiamwong et al., 2011). The first one is the RSRP-based cell selection discussed previously while the other is the RSRQ, defined as the RSRP divided by the received signal strength indicator (RSSI).

$$RSRQ = \frac{RSRP}{RSSI} \propto \frac{S}{S+I+N} = \frac{SINR}{1+SINR} \tag{1}$$

where S, I, N and SINR represent the received power of the desired cell, interference power, background noise power and SINR respectively.

**C. Cell Range Expansion (CRE)**: Range expansion in HetNets increases the downlink coverage footprint of low-power nodes such as picocells by adding a positive bias to their measured signal strengths during cell association (Guvenc, 2011; Li, 2015) in order to address the problem of load imbalance in the downlink. Such base stations are referred to as biased BSs. With a larger range expansion bias (REB), more macrocell user equipments (MUEs) are off-loaded to picocells, at the cost of increased co-channel interference for range-expanded picocell user equipments (PUEs) in the downlink. According to Sangiamwong et al. (2011), the total number of small cells for the given REB of λ can be written as:

$$N_{pue} = argmax\ (\delta_i + \lambda) \tag{2}$$

such that $\delta_i + \lambda < 0$, where $N_{pue}$ and $\delta_i$ are the total number of PUEs and the difference between macrocell and picocell downlink signal-to-interference-plus-noise ratios (SINRs) for the *i*-th user, respectively. Therefore, the sum capacity of all the users connected to the desired macrocell for unit bandwidth as a function of the REB is given as:

$$C_{macro}(\lambda) = \sum_{i=N_{pue}+1}^{N_u} \frac{1}{N_u(1-F(\lambda))} \log_2(1+\rho i) \tag{3}$$

while for picocell within the desired macrocell is expressed as

$$C_{pico}(\lambda) = \sum_{i=1}^{N_{pue}} \frac{N_p}{N_u F(\lambda)} \log_2(1+\psi_i) \tag{4}$$

$$C_{total}(\lambda) = C_{macro}(\lambda) + C_{pico}(\lambda) \tag{5}$$

where $N_u$ denotes the total number of users within the coverage area of macrocell and its picocells, $N_p$, $F(\lambda)$, $\rho_i$ and $\psi_i$ are the respective co-channel picocells included in each macrocell's coverage, cumulative distribution function (CDF) of λ and the SINRs of the *i*-th user when connected to the macrocell and the strongest picocells. With (5), expanded-range PUEs may observe unfavourable SINRs, with increased (ICI) especially for large λ. In order to improve their performance, enhanced inter-cell interference coordination (eICIC) techniques that leave certain macrocell subframes blank are a considered in 3rd Generation Partnership Project (3GPP) Long Term Evolution Advanced (LTE-A) system (Guvenc, 2011; Okino, Nakayama, Yamazaki, Sato, & Kusano, 2011).

**D. Almost Blank Sub-Frame Scheme (ABS)**: The ABS technique uses time domain orthogonalization in which specific sub-frames are left blank by the unbiased BS and off-loaded users are scheduled within these sub-frames to avoid inter-tier interference. The purpose is that the cell that generates interference is prevented from transmitting user data during an ABS subframe giving the opportunity to the victim cell to transmit under reduced interference (Koutlia, Perez-Romero, & Agusti, 2014; Oh & Han, 2012). This improves the overall throughput of the off-loaded users by sacrificing the time subframes and throughput of the unbiased BS.

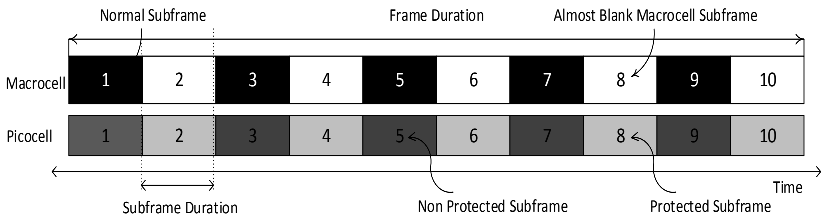


Fig. 2. Use of blank macrocell subframes in 3GPP for interference coordination.

Fig. 2 shows a scenario when 50% of macrocell subframes are silenced for the ABS (i.e., duty cycle $\beta$ = 0.5). In other words, macrocells do not allocate any users in even subframes, but only in the odd subframes while users connected to picocells are allocated in both frames. Therefore, the SINR of picocell *p*, selected by user *i* at subframe *n* can be represented by:

$$\gamma_{p,i}(n) = \begin{cases} \gamma_{p,i}^{\text{ABS}}, & \text{if n is ABS,} \\ \gamma_{p,i}^{\text{non ABS}}, & \text{otherwise.} \end{cases} \tag{6}$$

Numerous power control schemes have been proposed in the literature for single-tier cellular wireless networks. The schemes can be classified into the following four types according to the corresponding objective functions and assumptions (E. Hossain et al., 2014).

## 4. Distributed Power Control Schemes

**A. Target-SIR-tracking power control (TPC):** The TPC enables the UEs to achieve their fixed target-SIRs at minimal aggregate transmit power, assuming that the target-SIRs are feasible. However, when the system is infeasible all non-supported UEs (those who cannot obtain their target-SIRs) transmit at their maximum power, which causes unnecessary power consumption and interference to other users, and therefore increases the number of non-supported UEs (Foschini & Miljanic, 1993). Consequently, the iterative power update in the distributed TPC algorithm proposed by Foschini & Miljanic (1993) is given as:

$$p_i\,(t+1) = \frac{\Gamma_i}{\gamma_i(t)} p_i\,(t) \tag{7}$$

where $p_i(t)$, $\gamma_i(t)$ and $\Gamma_i$ denote the transmission power, achieved SINR, and a desired threshold for user *i* in iteration *t* respectively.

**B. TPC with gradual removal (TPC-GR):** To decrease the outage ratio of TPC in an infeasible system, a number of TPC-GR algorithms were proposed in which non-supported users reduce their transmit power (Rasti & Sharafat, 2011) or are gradually removed (Rasti, Sharafat, & Zander, 2011; Mehdi Rasti & Sharafat, 2011; Berggren, Jäntti, & Kim, 2001).

**C. Opportunistic power control (OPC):** This scheme allocates high power levels to users with good channels (experiencing high path-gains and low interference levels), and very low power to users with poor channels. In this algorithm a small difference in path-gains between two users may lead to a large difference in their actual throughputs (Leung & Sung, 2006). OPC improves the system performance at the cost of reduced fairness among users. In this case, the iterative power update strategy for the proposed OPC algorithm is also given as:

$$p_i(t+1) = \frac{\zeta_i}{R_i(t)} \tag{8}$$

where $\zeta_i = 1/(2\lambda_i)^2$ represents a non-negative control parameter.

**D. Dynamic-SIR tracking power control (DTPC)**: The DTPC algorithm was proposed to address the problem of system throughput maximization subject to a given feasible lower bound for the achieved SIRs of all users in cellular networks (Rasti, Sharafat, & Zander, 2010). In DTPC, each user dynamically sets its target-SIR by using TPC and OPC in a selective manner. It was shown that when the minimum acceptable target-SIRs are feasible, the actual SIRs received by some users can be dynamically increased (to a value higher than their minimum acceptable target-SIRs) in a distributed manner so far as the required resources are available and the system remains feasible. This enhances the system throughput at the cost of higher power consumption as compared to TPC (Hossain et al., 2014).

Although the above frameworks are distributed and optimal or suboptimal with guaranteed convergence in conventional networks, they may not be directly compatible with the 5G multi-tier networks. The interference dynamics in multitier networks depends significantly on the channel access protocols or scheduling, QoS requirements and priorities at different tiers (Saha, Saengudomlert, & Aswakul, 2016). Therefore, to effectively manage interference in cellular networks, a possible strategy would be to modify the existing power control schemes discussed in section IV. This will enable small cells limit their transmit power to keep the interference caused to macro users below a predefined threshold. To achieve this, cell association methods combined with prioritized power control schemes will be among the key enablers for evolving 5G cellular networks.

## 5. Conclusion

In this paper, a comprehensive survey on the cell association and power control methods associated with ICIC in HCN was carried out. Deployment of small cells over the existing macrocell network to improve the system capacity and indoor coverage leads to cross-tier and co-tier interference under co-channel spectrum allocation, which needs to be mitigated to effusively acquire the benefits of small cells. In this context, open challenges have been highlighted and guidelines have been provided to modify the existing schemes in order to make them suitable for 5G multi-tier networks. A promising direction for future research is to devise efficient joint cell association and power control methods that satisfy objectives such as maximizing system throughput, improving data rate and balancing traffic load.

## References

[1] Cisco, "Cisco visual networking index: Global mobile data traffic forecast update 2012–2017," Tech. Rep., Feb. 2013. [Online]. Available: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf

[2] Ericsson, "Ericsson mobility report," Tech. Rep., Nov. 2013. [Online]. Available: http://www.ericsson.com/res/docs/2013/ericsson-mobility-report-november-2013.pdf

[3] Berggren, F., Jäntti, R., & Kim, S.-L. (2001). A generalized algorithm for constrained power control with capability of temporary removal. *Vehicular Technology, IEEE Transactions on*, *50*(6), 1604–1612.

[4] Foschini, G. J., & Miljanic, Z. (1993). A simple distributed autonomous power control algorithm and its convergence. *Vehicular Technology, IEEE Transactions on*, *42*(4), 641–646.

[5] Ge, X., Tu, S., Mao, G., Wang, C.-X., & Han, T. (2015). 5G Ultra-Dense Cellular Networks. *arXiv Preprint arXiv:1512.03143*. Retrieved from http://arxiv.org/abs/1512.03143

[6] Guvenc, I. (2011). Capacity and Fairness Analysis of Heterogeneous Networks with Range Expansion and Interference Coordination. *IEEE Communications Letters*, *15*(10), 1084–1087. http://doi.org/10.1109/LCOMM.2011.082611.111387

[7] Hossain, E., & Hasan, M. (2015). 5G cellular: key enabling technologies and research challenges. *Instrumentation & Measurement Magazine, IEEE*, *18*(3), 11–21.

[8] Hossain, E., Rasti, M., Tabassum, H., & Abdelnasser, A. (2014). Evolution toward 5G multi-tier cellular wireless networks: An interference management perspective. *IEEE Wireless Communications*, *21*(3), 118–127. http://doi.org/10.1109/MWC.2014.6845056

[9] Kaddour, F. Z., Denis, B., & Ktenas, D. (2015). Downlink interference analytical predictions under shadowing within irregular multi-cell deployments. In *Communications (ICC), 2015 IEEE International Conference on* (pp. 1649–1654). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=7248561

[10] Kin-Kwong Leung, & Chi Wan Sung. (2006). An opportunistic power control algorithm for cellular network. *IEEE/ACM Transactions on Networking*, *14*(3), 470–478. http://doi.org/10.1109/TNET.2006.876148

[11] Koutlia, K., Perez-Romero, J., & Agusti, R. (2014). Novel eICIC scheme for HetNets exploiting jointly the frequency, power and time dimensions. In *Personal, Indoor, and Mobile Radio Communication (PIMRC), 2014 IEEE 25th Annual International Symposium on* (pp. 1078–1082). IEEE. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=7136327

[12] Li, Y. (2015). Spatial Interference Cancellation in Heterogeneous Networks with Biased Cell Association. In *2015 IEEE Globecom Workshops (GC Wkshps)* (pp. 1–7). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=7414216

[13] Lopez-Perez, D., Guvenc, I., de la Roche, G., Kountouris, M., Quek, T., & Zhang, J. (2011). Enhanced intercell interference coordination challenges in heterogeneous networks. *IEEE Wireless Communications*, *18*(3), 22–30. http://doi.org/10.1109/MWC.2011.5876497

[14] Oh, J., & Han, Y. (2012). Cell selection for range expansion with almost blank subframe in heterogeneous networks. In *Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on* (pp. 653–657). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6362865

[15] Okino, K., Nakayama, T., Yamazaki, C., Sato, H., & Kusano, Y. (2011). Pico cell range expansion with interference mitigation toward LTE-Advanced heterogeneous networks. In *Communications Workshops (ICC), 2011 IEEE International Conference on* (pp. 1–5). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5963603

[16] Rasti, M., & Sharafat, A. R. (2011). Distributed Uplink Power Control with Soft Removal for Wireless Networks. *IEEE Transactions on Communications*, *59*(3), 833–843. http://doi.org/10.1109/TCOMM.2011.122110.090711

[17] Rasti, M., Sharafat, A. R., & Zander, J. (2010). A Distributed Dynamic Target-SIR-Tracking Power Control Algorithm for Wireless Cellular Networks. *IEEE Transactions on Vehicular Technology*, *59*(2), 906–916. http://doi.org/10.1109/TVT.2009.2035627

[18] Rasti, M., Sharafat, A. R., & Zander, J. (2011). Pareto and Energy-Efficient Distributed Power Control With Feasibility Check in Wireless Networks. *IEEE Transactions on Information Theory*, *57*(1), 245–255. http://doi.org/10.1109/TIT.2010.2090210

[19] Saha, R. K., Saengudomlert, P., & Aswakul, C. (2016). Evolution Toward 5G Mobile Networks–A Survey on Enabling Technologies. *Engineering Journal*, *20*(1), 87–119.

[20] Sangiamwong, J., Saito, Y., Miki, N., Abe, T., Nagata, S., & Okumura, Y. (2011). Investigation on cell selection methods associated with inter-cell interference coordination in heterogeneous networks for LTE-advanced downlink. In *Wireless Conference 2011-Sustainable Wireless Technologies (European Wireless), 11th European* (pp. 1–6). VDE.
Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5898043

[21] Soret, B., Pedersen, K. I., Jørgensen, N. T., & Fernández-López, V. (2015). Interference coordination for dense wireless networks. *Communications Magazine, IEEE*, *53*(1), 102–109.

[22] Yassin, M. (2015). *Inter-Cell Interference Coordination in Wireless Networks*. Université de Rennes 1. Retrieved from https://tel.archives-ouvertes.fr/tel-01247157/.