spatial radio resources management for Heterogeneous 5G Millimeter wave Networks

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***Abstract*—The availability of abundant Spectrum resources, power consumption and inter cell interference can be assumed as a bulky challenges towards meeting the high capacity demands and coverage resources expected in fifth-generation 5G technologies. By integrating Millimeter wave (mm-wave) into 5G technologies, allowing a huge number of links can be transmitted concurrently by reusing the same spectrum and providing a high density of access nodes. Also, flexible backhauling and access wireless links can be considered for heterogeneous access 5G technologies with a high directional antenna arrays. The scheme proposed in this paper can significantly enhance network throughput in mm-wave 5G heterogeneous networks by utilizing a genetic based algorithm GA for optimally power and radio resources management based on spectrum sharing with time and space-division multiple access. The proposed algorithm allows backhaul and access links with /without conflicting flows to be transmitted simultaneously without/with interference. Through a comprehensive simulations, we show that the proposed genetic algorithm achieves significant enhancement in terms of user throughput and resources utilization.**

Keywords—5G, mm-wave, heterogeneous network, backhauling, genetic algorithm.

I. INTRODUCTION

The rapid increase in the Demand on wireless communication services and application [1] like cellular traffic and services, multimedia, virtual reality, and internet of things (IOT) [2] become a critical issues during these years. In accordance with that, the major target of the future generation 5G technologies [3] is to fulfill such these requirements with huge capacity demands and rare radio resources. Due to this inability, 5G technologies are anticipated to address unmatched challenges to deal with a complicated degree of heterogeneity [4] with different set of demands such as network infrastructure, power and radio resources managements and huge user capacity with backhaul and access links and so on. To realize such demand, a huge amount of spectrum is needed, which leads to growing attention for introducing millimeter wave (mm-wave) band between 30 and 300 GHz [5] in cellular networks which , the available bandwidths are much greater than the utilized for a current cellular networks. However, mm-wave with higher carrier frequencies faces higher isotropic path loss, attenuation and shadowing [6]. For these reasons, mm-wave technology provides a large numbers of miniaturized antennas which can be added at both transceiver sides for a higher antenna gain and directional transmissions with exploitation of beamforming and spatial multiplexing gain [7]. Furthermore, mm-wave technology has the ability for spectrum sharing by simultaneous concurrent transmission using different access strategies like Space-Division Multiple Access (SDMA) technique, where a time slot can be allocated to multiple wireless links rather than Time Division Multiple Access (TDMA) Time division multiple access which each time slot is allocated to one link to improve spatial radio reuse [8]. So, it exploit more spatial multiplexing gain with relatively low multi-user interference which consequently reinforces network throughput. A lot of technologies with mm wave in 5G are under studies, where small cells with access connections and wireless Backhauling (BH) [9] exhibits a great potential in the way of exchange information and be a promising technologies that allow a large coverage extension and total network throughput expansion to fully exploit heterogeneity of the cellular networks without more heavy transmission traffic loads on access points (APs) and base stations (BSs).

The problem of radio resources utilization for BH and Access Link (AL) scheduling using mm-wave technologies in 5G HetNets has been investigated in different literature. Firstly, Enhanced inter-cell interference coordination (eICIC) scheme has been proposed in 3GPP LTE for time scheduling and interference reduction in HetNets [10] with a little throughput enhancement. In eICIC using HetNet concept, where a mix of remote radio heads (RRHs), macrocells and low-power relays, picocells and femtocells with larger number of nodes and cells are available. Therefore, radio resources can be improved due to more efficient spectrum reuse with higher link quality at lower distance.Without spatial multiplexing, a joint consideration of channel scheduling and power control is presented in [11] to improve total network throughput. Where, two schemes are proposed for interference estimation, based on underestimation and overestimation which aim to reuse and schedule the available spectrum that cause no interference in mmWave communication. In [12], multiple links are scheduled to transmit concurrently using spatial-time division multiple access (STDMA) to improve network throughput based on Quality of Service (QoS) and path selection metric. The proposed framework in [13] and [14] consists of a joint scheduling and resource allocation algorithm in mm-wave HetNets to enhance network throughput with low computational complexity and fully exploit spatial multiplexing gain. In this framework, Using Conflict graph that represent the conflicts among links (interfered links) and proposed maximum independent set (MIS)-based scheduling algorithm with SDMA to distribute maximum number of links that can be transmitted simultaneously without interference. Also using water filling algorithm to maximize power allocated to each link.

This paper proposes a joint power and radio resources allocation scheme in multi-Gbps mm-wave HetNets. Also, path selection criterion is designed to AL and BH transmissions for enhancement the total network performance and improvement spectrum utilization. The joint power and radio resources scheduling optimization problem has been systematically considered. Where efficient power optimization algorithm, spatial multiplexing scheduling for radio resource allocation scheme have been developed to enhance network throughput with minimum interference levels, ensuring QoS with considering both Line Of Sight (LOS) and NLOS transmission and efficiently radio resource management and utilization considerations for 5G mm-wave HetNets with BH and AL. Extensive simulations have been illustrated the effectiveness and efficiency of the proposed algorithm in achieving considerably high throughput gain in Compared with TDMA, eICIC scheme and heuristic scheduling based on conflict graph, water-filling and SDMA scheduling scheme.

The remainder of the paper is organized as follows. Section II presents the system model and Section III formulates throughput analysis and the joint optimization problem. Power optimization and concurrent radio resources transmission scheduling algorithm are proposed in Section IV. Performance of proposed algorithm is evaluated by extensive simulations in Section V, followed by a summary concluding the paper in Section VI.

II. System Model

We consider a 5G HetNet at mm-wave bands as illustrated in Figure 1 containing on a macro cell BS which provides wireless AL and BH links to service many user equipment (UE) for both uplink (UL) and downlink (DL) transmission.

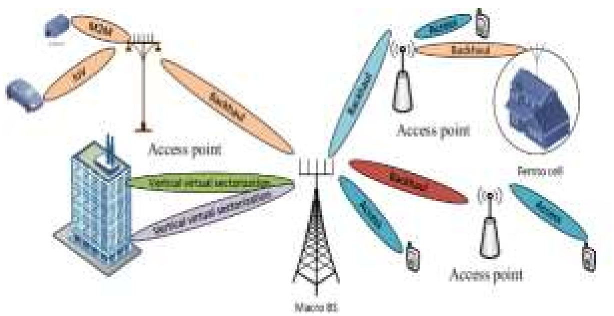

Fig. 1. Illustration of a 5G HetNet with mmWave wireless BH and access links

For capacity expansion a set of mm-wave APs are deployed. All these network components share the same air interface and equipped with high directional antennas and beamforming which can direct their beams in specific directions with minimum losses. The BS processes transmission link scheduling for concurrent transmission and adapts transmission duration and power for each flow and for all access links.

Figure 2 shows an example for the Concept of superframe as introduced in 802.15.3c draft standards operating at mm wave bands [15] and proposed in 5G HetNets. Here, the available channel access time is divided into superframes, and each superframe includes a beacon interval, a contention based access period (CBAP) and a channel time allocation period (CTAP).The beacon interval is established for BS control messages, broadcasting and synchronization. While CBAP and are set for sending transmission requests from user devices to BS. Finally, the last sector CTAP is available for data transmissions among all network elements and can be divided into several sequential intervals called time slots with the maximum number of slots is N based on TDMA scheme. In addition, during the period of each superframe, network topology and channel conditions are assumed unchanged but it can be changed in the next superframe.

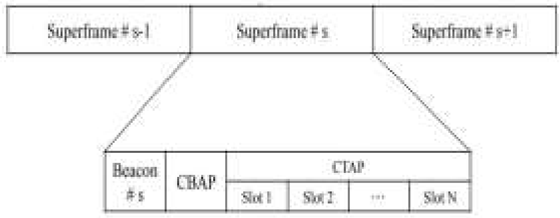

Fig. 2. Superframe structure of 802.15.3c.

Considering directional transmission at mm-wave bands for all AL and BH links. We allow concurrent transmissions for each time slot in CTAP which can be allocated to multiple flows and each flow can allocated more than one time slot to exploit more spatial multiplexing gain with specially enhancement in network throughput performance with interference management issue.

III. Throughput Analysis and Optimization Problem Formulation

A. Throughput Analysis

We assume that S concurrent transmission flows for AL and BH links are scheduled in a given superframe consists of N time slots. For AL and BH links, in each flow the total superframe time slots are allocated to K links, and the number of slots allocated to each link is denoted as $n_{k,S}$ and scheduled in flow The achievable data rate of link i from K link can be calculated according to Shannon channel capacity equation as

$$r_i = B\log_2\left[1+\frac{\partial_i P_i g_i L_i^{-1}}{\eta+\sum_j \partial_j P_j g_j L_j^{-1}}\right] \qquad (1)$$

Where P_i and P_j are the transmit power allocated to cellular (AL or BH) link i and j. The cellular link for this model is considered as the allowable access and BH connections between BS and AP, BS and UE and AP and UE, with LOS and NLOS transmission for both downlink and uplink traffic flows and also the link has similar modeling of high directional antenna gain as in [16]. Then, the g_i and g_j are defined as the channel power gain for ith and jth cellular links, respectively. B defined as system bandwidth and the activity of ith and jth cellular links can be determined by the resource sharing indicators ∂_i and ∂_j equal 1 if the link is active and use the spectrum band. We assumed perfect channel state information and η is considered as the Additive White Gaussian Noise (AWGN) power spectral density. Finally, L_i^{-1} and L_j^{-1} are the computed isotropic pathloss for cellular link i and j as illustrated and modeled in [17].

B. Optimization Problem Formulation

We formulate the joint scheduling and radio resources (transmission duration, concurrent flows and transmission power) sharing and allocation problem mathematically as a constrained optimization problem. Now, let us focus on how to maximize the total network throughput for all AL and BH links. In (2)-(4) we aimed to optimally select the best values for the maximum power allocated, maximum number of time slots and the maximum number of concurrent flows allocated for all AL and BH links in each flow for each superframe under three main different constraint. Firstly, in (5) the maximum power allocated to all network links must be limited to $P_{Max\ AL,BH}$ the maximum allowable power for AL and BH links. Secondly, in (6) the achievable rate for the AL and BH links must be exceeded the $r_{QoS\ AL,BH}$ minimum acceptable rate (minimum achieved QoS) requirement for AL, BH. Finally, in (7) the interference level at both of AL and BH links must not exceeded the interference threshold level $I_{i,TH_{AL,BH}}$ for AL and BH links ensure the required QoS for all user in this network.

$$\max_{p} \left(\sum_{i=1}^{K} \sum_{s=1}^{S} r_{i,s}\right) \tag{2}$$

$$\max_{n} \left(\sum_{i=1}^{k} \frac{r_{i,s}, n_{k,s}}{N}\right) \tag{3}$$

$$\max_{S} \left(\sum_{i=1}^{k} \frac{r_{i,s}, n_{k,s}}{N.S} . s_i\right) \tag{4}$$

S. t.

$$P_i \le P_{Max\ AL,BH} \tag{5}$$

$$r_i \ge r_{QoS\ AL,BH} \tag{6}$$

$$\sum_j \partial_j P_j g_j L_j^{-1} \le I_{i,TH_{AL,BH}} \tag{7}$$

The maximization problem indicated in (2)-(4) with constraints (5)-(7) is a mixed integer nonlinear programming (MINLP) problem [18]. So firstly, we consider radio resource scheduling as time and concurrent transmission flows in each superframe as possible to fully exploit the time and space multiplexing. Finally, coupling exists among the power limitation, interference reduction and the minimum required QoS constraints where power allocation relies on the results of concurrent flow scheduling. Hence, in the next section, we propose a heuristic radio resources scheduling and power allocation algorithm based on genetic algorithm aiming to solve the optimization problem efficiently with very low complexity. We have two different scenarios to indicate the maximum throughput achieved for each link in this model.

- Firstly GA based strategy, we stated to maximize the throughput for each link from AL and BH using power allocation technique based on genetic algorithm with concurrent transmission based on radio resources allocation and sharing scheduling without interfering links.
- Then we study interference GA based strategy, the same previous strategy but with interfering links to indicate the effect of interference on the throughput of AL and BH links.

IV. OPTIMAL POWER AND CONCURRENT TRANSMISSION FOR RADIO RESOURCES ALGORITHM

Genetic based algorithm is adaptive and intelligent heuristic computational technique based on Darwin's theory of evolution [19]. So, genetic algorithm is proposed as a heuristic search optimization technique seeking to find the best solutions for a given objective function in an optimization problem as in (2)-(4) to maximize the total throughput with minimum interference level and ensuring the required QoS for all AL and BH links in this model.

In first part of the proposed algorithm we started with identifying the locations for all users in this model, interference threshold level defined for all links, minimum acceptable rate for each link and the channels conditions. Then we determine the activity of AL and BH links to state if only one link allocate the channel or more than link share the same channel. Finally, Using GA we looking for optimal shared channel selection, optimal allocated time slots in each flow and the optimal number of concurrent flow scheduled for all AL and BH links while ensuring the QoS for all network links with minimum interference level as in the example shown in Figure 3. Then, based on results of radio resources scheduling and enabling concurrent flow, there will be multiple flows to be transmitted simultaneously. As a consequence, we apply the genetic algorithm to allocate power level for each link seeking to improve channel quality and maximize the user throughput under different constraints indicated in (5)-(7) with minimum interference level and achieve the required QoS for all links. The GA starts with an initial population of individuals or random chromosomes. Each individual represents a randomly candidate solutions called gens in search spaces which limited to the predefined constraints of the optimization problems in Eq. (5-7) for all links. Which are then initial throughput evaluated for each chromosome depending on the objective function (fitness function based on (1) to select good ones that are called Parents. From the parents, the chromosomes with best fitness value are called *Elite* and selected to continue in the next generation. Then the remaining chromosomes will subject to crossover where gens sites are exchanged thus creating an enhanced new chromosomes and then better chromosomes offspring by combining chromosomes and mutation insert random genes in the new chromosomes to maintain the diversity in the new generation and avoid being exhausted. Each new generation has more "better genes" and become better close to the optimal than the previous one.

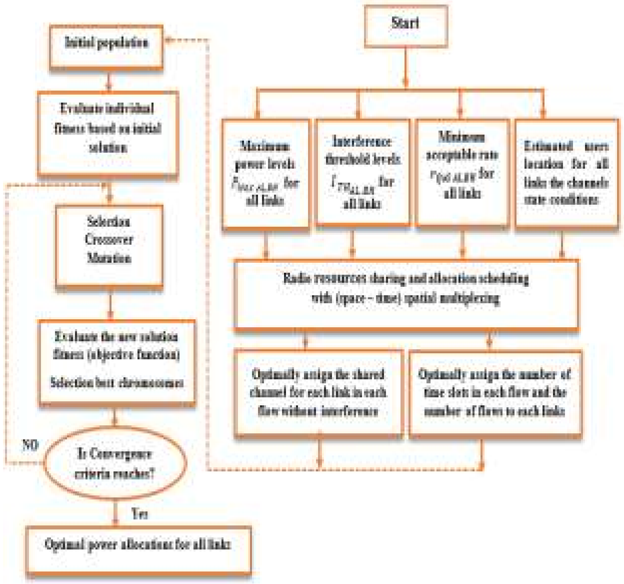

Fig. 3. Radio resources allocation scheduling for BH, access links

These steps are repeated until the specified maximum number of generations is reached or the optimum value of the fitness function is found where, the new generations don't having any significant difference than the previous populations, where the average change in fitness value is less than a small value that are called the Function Tolerance or convergence the population is ended. Now the algorithm generates a set of optimal values levels for all links in this system that achieve maximum throughput.

V. Results and Discussion

Here, we consider a 5G HetNet deployed under a single Manhattan Grid [14]. This network model is equipped with single BS and four APs are located at the crossroads where square blocks are surrounded by streets that are 200 meters long and 30 meters wide and 100 UEs for AL and BH are uniformly dropped in the streets. The simulation parameters are illustrated in Table 1, and the path loss model for LOS and NLOS is indicated in [20].

TABLE I SIMULATION PARAMETERS

Parameter	Value
Carrier frequency	28 GHz with 1 GHz bandwidth
Pathloss component	LOS: 2.1 and NLOS: 3.17
Shadowing	Lognormal:- zero mean 5.8 dB standard deviation
Inter-link interference threshold	1×10^{-8} W
Antenna array	(Vertical x Horizontal) 8x16 for AP/BS 4x4 for UE
Maximum transmission power	30 dBm for AP/BS 20 dBm for UE

In comparison with joint power and radio resources allocation based on SDMA with water filling power algorithm and conflict graph to identify the interfering nodes and solved using maximum independent set (MIS)-based scheduling algorithm, benchmark based on TDMA scheme and eICIC scheme our proposed algorithm based on GA provides appreciable enhancement in both average and edge user throughput for both UL and DL transmission as illustrated in Figure 4 due to exploiting optimal power allocation and intelligent spatial multiplexing which allocates more time radio resources with optimum power levels to each link by allowing many different links to transmit concurrently.

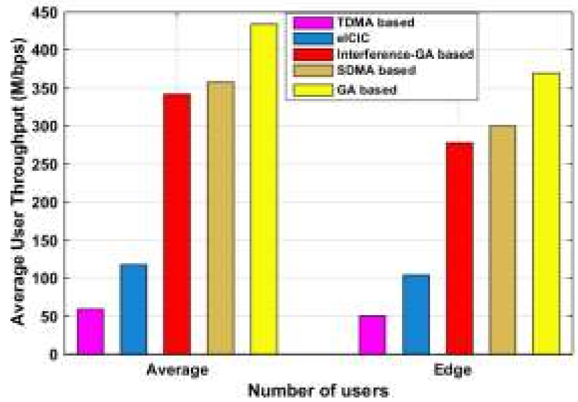

Fig. 4. Edge and average user throughputs for 100 users

The cell edge user throughput. Explained as The 5th percentile point of the cumulative distribution function (CDF) of user throughputs. Figure 4 shows that, the gain of our GA based scheme grows by 736%, 370% and 122% against benchmark TDMA, eICIC and SDMA with water filling power algorithm respectively in both average and edge user throughputs for 100 users. Furthermore, the edge and average throughputs for interference GA based strategy, our scheme grows by 580%, 290% against benchmark TDMA and eICIC.

Figure 5 shows the average user throughputs for different numbers of users such as 100, 200, and 300 users respectively. By increasing the number of users the average throughput for each user will be reduced due to fixed and limited system bandwidth. Also with higher number of users in this network, average user throughput for TDMA based schemes are limited with fixed number of system time slots. However, with the spatial multiplexing gain, our algorithm still achieves significant improvement in average user throughput in the case of heavy user density at 300 users. In this case, the achievable gain of our algorithm based GA than, benchmark based on TDMA scheme, eICIC and SDMA with water filling power algorithm scheme also grows by 811%, 348% and 125%, respectively. Also, the average throughputs for interference GA based strategy, our scheme grows to 628%, 295% against benchmark TDMA and eICIC.

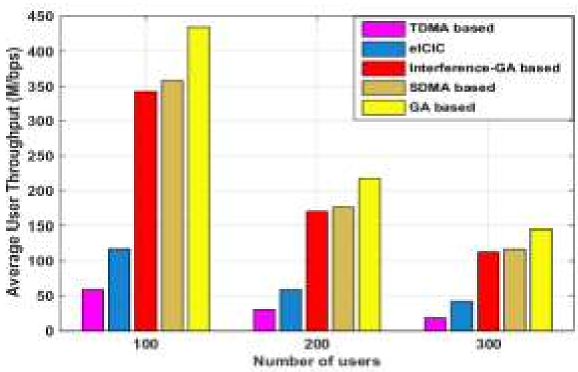

Figure 5 evaluating average user throughput with different user numbers

Therefore, GA based power, channel and time allocation technique with concurrent flow scheduling has better performance in increase system utilization and radio resources allocation, average throughput for all users in the network than the compered algorithms.

VI. CONCLUSION

In this paper, the problem of maximizing the average and edge user throughput and radio spectrum utilization via optimal transmission power allocation, concurrent transmission flows scheduling was addressed for mm-wave heterogeneous network considering backhaul and access connections. simple and low-complexity technique based on genetic algorithm were derived for enhancing average and edge user throughputs with minimum interference levels and ensuring QoS by exploiting optimal power allocation and concurrent transmission flows using a high directional antennas and spatial multiplexing gain in space/time/power resource allocation for all AL and BH links. Finally, Extensive simulations have been illustrated the effectiveness and efficiency of the genetic based proposed algorithm in achieving considerably high throughput gain for all network links in Compared with TDMA, eICIC and SDMA scheduling schemes.

REFERENCES

[1] Cisco "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2014-2019," Cisco, San Jose, CA, USA, White Paper, Feb. 2015.

[2] J. Ding, M. Nemati, C. Ranaweera and J. Choi, "IoT Connectivity Technologies and Applications: A Survey," in IEEE Access, vol. 8, pp. 67646-67673, 2020.

[3] O. O. Erunkulu, A. M. Zungeru, C. K. Lebekwe, M. Mosalaosi and J. M. Chuma, "5G Mobile Communication Applications: A Survey and Comparison of Use Cases," in IEEE Access, vol. 9, pp. 97251-97295, 2021.

[4] Y. Xu, G. Gui, H. Gacanin and F. Adachi, "A Survey on Resource Allocation for 5G Heterogeneous Networks: Current Research, Future Trends, and Challenges," in IEEE Communications Surveys & Tutorials, vol. 23, no. 2, pp. 668-695, 2021.

[5] A. N. Uwaechia and N. M. Mahyuddin, "A Comprehensive Survey on Millimeter Wave Communications for Fifth-Generation Wireless Networks: Feasibility and Challenges," in IEEE Access, vol. 8, pp. 62367-62414, 2020.

[6] S. Geng, J. Kivinen, X. Zhao and P. Vainikainen, "Millimeter-Wave Propagation Channel Characterization for Short-Range Wireless Communications," in IEEE Transactions on Vehicular Technology, vol. 58, no. 1, pp. 3-13, Jan. 2009.

[7] A. Adhikary et al., "Joint Spatial Division and Multiplexing for mm-Wave Channels," in IEEE Journal on Selected Areas in Communications, vol. 32, no. 6, pp. 1239-1255, June 2014.

[8] E. A. Jorswieck, P. Svedman and B. Ottersten, "Performance of TDMA and SDMA based Opportunistic Beamforming," in IEEE Transactions on Wireless Communications, vol. 7, no. 11, pp. 4058-4063, November 2008.

[9] M. Jaber, F. J. Lopez-Martinez, M. A. Imran, A. Sutton, A. Tukmanov and R. Tafazolli, "Wireless Backhaul: Performance Modeling and Impact on User Association for 5G," in IEEE Transactions on Wireless Communications, vol. 17, no. 5, pp. 3095-3110, May 2018.

[10] D. Lopez-Perez, I. Guvenc, G. de la Roche, M. Kountouris, T. Q. S. Quek, and J. Zhang, "Enhanced Intercell Interference Coordination Challenges in Heterogeneous Networks," IEEE Wireless Communications, vol. 18, no. 3, pp. 22–30, June 2011.

[11] H. Shokri-Ghadikolaei, L. Gkatzikis, and C. Fischione, "BeamSearching and Transmission Scheduling in Millimeter Wave Communications," in 2015 IEEE International Conference on Communications (ICC), June 2015, pp. 1292–1297.

[12] J. Qiao, L. X. Cai, X. Shen, and J. W. Mark, "STDMA-Based Scheduling Algorithm for Concurrent Transmissions in Directional Millimeter Wave Networks," in 2012 IEEE International Conference on Communications (ICC), June 2012, pp. 5221–5225.

[13] Y. Li, E. Pateromichelakis, N. Vucic, J. Luo, W. Xu and G. Caire, "Radio Resource Management Considerations for 5G Millimeter Wave Backhaul and Access Networks," in IEEE Communications Magazine, vol. 55, no. 6, pp. 86-92, June 2017.

[14] Y. Li, J. Luo, W. Xu, N. Vucic, E. Pateromichelakis and G. Caire, "A Joint Scheduling and Resource Allocation Scheme for Millimeter Wave Heterogeneous Networks," 2017 IEEE Wireless Communications and Networking Conference (WCNC), pp. 1-6, 2017.

[15] J. Qiao, L. X. Cai, X. S. Shen and J. W. Mark, "Enabling Multi-Hop Concurrent Transmissions in 60 GHz Wireless Personal Area Networks," in IEEE Transactions on Wireless Communications, vol. 10, no. 11, pp. 3824-3833, November 2011.

[16] Y. Li, J. Luo, M. H. C. Garcia, R. Boehnke, R. A. Stirling-Gallacher, W. Xu, and G. Caire, "On the beamformed broadcasting for millimeter wave cell discovery: Performance analysis and design insight," IEEE Transactions on Wireless Communications, vol. 17, no. 11, pp. 7620–7634, Nov. 2018.

[17] T. S. Rappaport, G. R. MacCartney, M. K. Samimi, and S. Sun, "Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design," IEEE Trans. Commun., vol. 63, no. 9, pp. 3029–3056, Sept. 2015.

[18] J. Lee and S. Leyffer, "Mixed Integer Nonlinear Programming". Springer Science & Business Media, 2011, vol. 154.

[19] K. Y. Lee; M. A. El-Sharkawi "Modern Heuristic Optimization Techniques: Theory and Applications to Power Systems" Wiley-IEEE Press, 2008.

[20] M. R. Akdeniz, Y. Liu, M. K. Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter Wave Channel Modeling and Cellular Capacity Evaluation," Selected Areas in Communications, IEEE Journal on, vol. 32, no. 6, pp. 1164–1179, 2014.