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Successive Interference Cancellation for Ultra-Dense 5G Heterogeneous Network

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***Abstract*— Interference Cancellation (IC) is an emerging technique for interference mitigation and network performance enhancement. Successive Interference Cancellation (SIC) has prominence among existing IC Techniques due to architectural similarity with traditional hardware for reduced cost effects. Moreover, SIC supports the transition to Fifth Generation (5G) heterogeneous networks environment due to flexible hardware compatibility. Therefore, in this study, we cover a detailed analysis of SIC in a multi-tier heterogeneous network through the system and channel-level mathematical modeling. Moreover, we simulated the heterogenous network environment to evaluate SIC success probability based on the number of users and Signal-to-interference-plus-Noise Ratio (SINR). Our results depict SIC as a potential promising IC solution for a heterogenous network.**

Keywords—*Interference cancellation, successive interference cancellation, 5G, heterogeneous network.*

I. Introduction

5G framework surfaces unconventional challenges for Interference mitigation in multi-tier heterogeneous networks [1]. Moreover, the Internet of Things (IoT) [2] is adding catalytic effects to interference mitigation challenges in 5G heterogeneous networks such as drones [3]. Interference Cancellation (IC) is emerging as a suitable mechanism to reduce the effects of irrelevant signals. The primary functionality of IC techniques is to subtract the noise from the desired signal by regenerating the noise signal at the receiver end [4]. Several IC techniques are pursued such as Successive Interference Cancellation (SIC), Iterative Interference Cancellation (IIC), and Serial Interference Cancellation [5, 6]. Similarly, hardware complexity is a major advantage of SIC receiver architecture over traditional non-SIC. In SIC, the same decoder decodes the composite signal at processing stages and do not require complex decoders with multiple antennas. Therefore, SIC provisions the same hardware utilization with signal processing level upgrade. Moreover, the capability of SIC to optimize the broadcast and multiple access networks up to the Shannon capacity region limits. Due to outperforming other IC techniques, SIC is quickly adopted by commercial standards such as IEEE 802.15.4. However, existing publications primarily evaluate SIC for Ad-Hoc and mobile networks. But, the evaluation of SIC in heterogenous D2D-enabled cellular networks requires further analysis for heterogenous and complex interference scenarios, including, 5G based Macro-micro and femtocells [7]. In [8], the authors have approximated the infinite and finite SIC capabilities with successful probabilities transmission of network uplinks and D2D links in large-size D2D-enabled cellular communication. Here, the authors have proposed a scheme to match the two-tier interference to a single-tier interference with equivalent stochastic features. With this, they manage to produce a successful probability of transmission between D2D links and cellular links with both infinite and finite SIC performance. Yet, in their investigations, the SIC effect of D2D-enabled cellular network performances is still unknown. Next, the research has been extended in [8], where the authors have presented a stochastic geometry for unconditional IC and SIC, in large-scale D2D networks. Their proposed stochastic geometry enables the two-tier interference equivalence to be converted to single-tier interference, which expedites successful cellular uplinks and D2D networks. They have accelerated the network with the stochastic equivalence of the interference approach and demonstrated their results with analytical and numerical methods which outline the Unconditional Interference Cancellation (UIC) and SIC. Despite these promising results, their work has limited network analysis and can be extended to maximum level containing complex D2D heterogenous links. In [8], the authors have postulate that the SIC exploitation is limited MAC protocol. To overcome this challenges they have introduce a new model on user establish wireless network SIC-MAC protocol. They have configured the SIC-aware MAC protocol model system and it shows that it can increase SIC effectiveness with rapid throughput, Furthermore, with their introduced RAS-MAC system model, the users pair of rates is personalized through the optimal system throughput equilibrium point. Similarly in [9], the authors has proposed a statistical framework enabled SIC to analyze the IC in multi-tier heterogeneous networks. Their proposed system use interferences cancelation and signal decode with various Access Point (AP) of strongest signal and signal of interest respectively. With their model, the numerical results obtain deepen the comprehension of SIC role of in various policies association for multi-tier heterogeneous networks. Still, further research should be undertaken to expand the model including correcting the imperfect interference cancellation with reduce AP cost.

Full- Duplex (FD) countenances two directions of data which allows the users to transmit and receive signal simultaneously. In [10], the authors have been using EE of the FD two-way (FDTW) D2D communications model assisted with relay to intensify the spectral efficiency (SE). The model gives high efficiency of EE and SE which enhance the transmission power. By this, they are using a two-tier substitutive iteration optimization algorithm methodology to optimize the existing system. The existing D2D communication scheme has a poor quality of cellular users due to complex environmental interference, to address this issue, another research based on FD has been demonstrated in [11]. In their paper, the authors have used a two-antenna infrastructure for D2D relay to enhance SE, EE and throughput without the help of BS. They have applied an optimum power distribution algorithm for the base station (BS) and D2D relay to reduce the power consumption of D2D relay and minimize the cellular user's transmission rate. Meanwhile likewise in [12]), the authors have modeled Interference limited area (ILA) by lowering the boundary of ergodic capacity for FD D2D communications with misconfigured Self Interference Cancellation (SIC). With this model they have proved that the quantity of gain provided by FD D2D techniques is superior to the half-duplex (HD) techniques.

II. Successive Interference Cancellation Technique

Wireless networks are swiftly adapting the SIC technique for realistic interference cancellation. SIC functionality is based on the self-generation of interference signals for subsequent utilization for interference cancellation. Thereby, it results in a substantially improved desired signal Signal-to-Interference Ratio (SIR) corresponding to the desired signal. Initially, SIC approaches a highly interfering signal by considering it as noise. Further, it reproduces the decoded signal in analog format to employ in the Interference Cancellation process. Thus, the resultant signal is purified from the noise signal. Similarly, SIC functions iteratively for the next strongest noise signal until the desired signal has been extracted from the received signal. The overall functionality of SIC is shown in Figure 1.

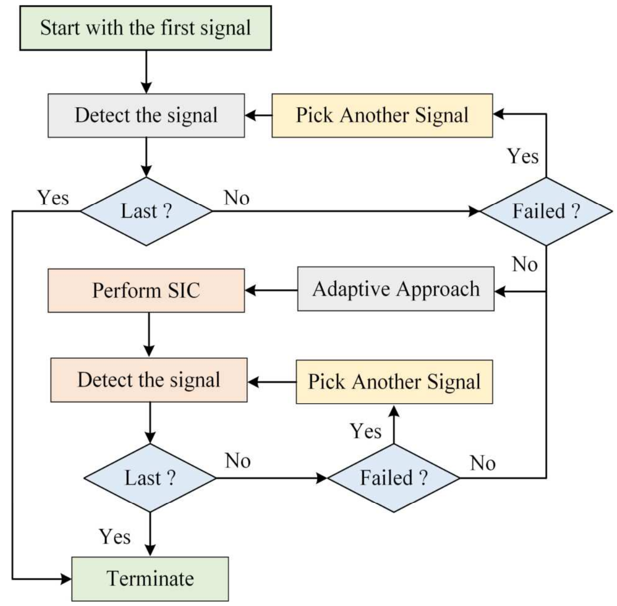

Fig. 1. SIC Technique

III. System Model

Our analysis is based on a D2D-Enabled Multi-Tier cellular network through system-level modeling, including a Base station linked with mobile cellular nodes through a relay node, as shown in Figure 2. The mobile cellular users, relay node, and D2D users are placed randomly based on stochastic geometry with the Poisson point process of ψ_R, ψ_{CU} and ψ_D, respectively. The transmission power function for base stations, relay nodes, cellular users and D2D users are defined as $\rho_{BS}\{|x_{BS}|^2\} = 1, \rho_R\{|x_R|^2\} = 1, \rho_{CU}\{|y_{CU}|^2\} = 1$ and $\rho_D\{|z_D|^2\} = 1$, respectively. Whereas the density of the relay nodes, cellular users and D2D users are stated as λ_R, λ_{CU} and λ_D, respectively. The system model includes a complete channel set for analysis i.e. $\|H_{BS_iR_i}\|$, $\|H_{R_jR_i}\|$, $\|H_{R_iR_i}\|$ and $\|H_{R_iCU_i}\|$, $\|H_{CU_jCU_i}\|$ and $\|H_{D_jCU_i}\|$ are experiencing Rayleigh fading $\sigma \sim exp(\sigma)$ with the path loss exponent γ. The fading factor for relay nodes, cellular users and D2D users are represented as $h \sim \exp(1)$, $f \sim \exp(1)$ and $g \sim \exp(1)$, respectively. In this network, we consider that each relay node is linked to the individual base station and all outside signals of non-linked base stations are taken as the noise. Likewise, each user is associated with a signal relay node; thus, all non-linked relay signals are considered noise. This scenario provides independent and identical distribution of all the entries in each matrix containing statistics with zero mean and variance Ω^2 based on complex Gaussian distribution. Network performance analysis critically depends on user location on origin in a random-access network. Therefore, we utilize the palm probabilities of Poisson processes to avoid errors in the statistical calculations due to the fixed location of receiving devices.

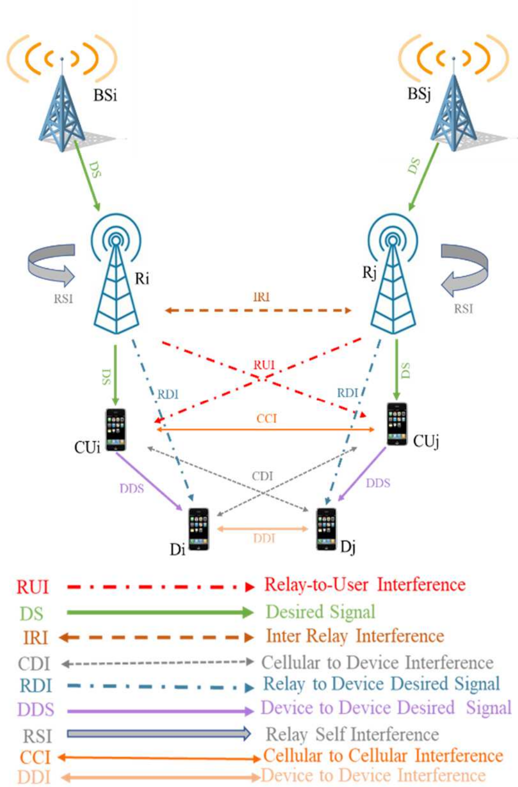

Fig. 2. D2D-Enabled Multi-Tier cellular network

IV. Channel Model

In the first tier in the network system model, the base station BS_i transmission signal x_{BS_i} is communicating with the relay node R_i, whereas the relay is also receiving other signals y_R, that encompasses Desired Signal (DS) from BS_i via channel $\|H_{BS_iR_i}\|$with path loss $P_{L,M}$, inter-relay interference(IRI) from R_j via channel $\|H_{R_jR_i}\|$ with path loss $P_{L,RR}$, Relay Self Interference (RSI) via channel $\|H_{R_iR_i}\|$ and it includes noise n_{R_i}. Likewise, for the Subsequent level, the user CU_i is receiving mixture of signals y_{CU_i}, which consist of DS x_{R_i} from R_i via channel $\|H_{R_iCU_i}\|$ with path loss $P_{L,O}$, the relay-to-user interference (RUI) from R_j having signal x_{R_j} via channel $\|H_{R_jCU_i}\|$ with path-loss $P_{L,O}$, cellular-2-cellular user interference (CCI) from CU_j having signal y_{CU_j} via channel $\|H_{CU_jCU_i}\|$ with path loss $P_{L,P}$, cellular user-to-device interference (CDI) from D_j having signal z_{D_j} via channel $\|H_{D_jCU_i}\|$ with path loss $P_{L,N}$ and the received noise are n_{CU_i}.

A. SINR Calculation

The overall signal at CU_i consist of DS from R_i plus noise received, plus the interference signals.

$$y_{CU_i} = \rho_{R_i} P_{L,O} h^{-\frac{\gamma}{2}} \|H_{R_iCU_i}\| x_{R_i} + n_{CU_i} + I_{CU_i} \tag{1}$$

Defining, the SINR at CU_i as

$$SINR_{CU_i} = \frac{\rho_{R_i} P_{L,O} {h_i}^{-\gamma} \|H_{R_iCU_i}\|^2}{I_{CU_i} + n_{CU_i}} \tag{2}$$

Here, I_{CU_i} is total interference at CU_i, which is RUI from R_j, CCI from CU_j and CDI from D_j.

$$I_{CU_i} = \sqrt{\rho_{R_j}} P_{L,O} h^{-\frac{\gamma}{2}} \|H_{R_jCU_i}\| x_{R_j} + \sum_{y_j \in \psi_{CU}} \sqrt{\rho_{CU_j}} P_{L,P} f^{-\frac{\gamma}{2}} \|H_{CU_jCU_i}\| y_{CU_j} + \sum_{z_j \in \psi_D} \sqrt{\rho_{D_j}} P_{L,N} g^{-\frac{\gamma}{2}} \|H_{D_jCU_i}\| z_{D_j} \tag{3}$$

B. Success Probability

The success of signal transmission for the cellular users is defined as the Complementary Cumulative Distribution Function (CCDF) of SIR_{CU_i} (neglecting the noise since it is very low as compared to interference) [12]. The system output for the uncorrelated case can be assumed as a bottom limit as Fortuin-Kasteleyn-Ginibre inequality [13].

We have evaluated the information transmission probability of the CU_i , which is considered as the probability of achieving desired SIR_{CU_i} at the user CU_i is denoted as

$$\wp_{SUC\,CU_i} \triangleq \wp\left(SIR_{CU_i} \geq \tau_{CU_i}\right) \tag{4}$$

Here τ_{CU_i} is the minimum SIR level necessary for successfully detecting the transmitted information, i.e., the determined threshold level satisfies a targeted SIR.

Theorem 1

The probability of successful transmission at CU_i is

$$\wp_{SUC\,CU_i} \triangleq \frac{\lambda_{CU}}{\lambda_{CU}(\nu+1) + \lambda_D \left(\frac{\rho_D}{\rho_{CU}}\right)^{\vartheta} \upsilon + \lambda_R \left(\frac{\rho_R}{\rho_{CU}}\right)^{\vartheta} \omega} \tag{5}$$

Where

$$\nu = \exp\left[-\lambda_{CU} \pi \frac{\vartheta}{1-\vartheta} \tau_{CU_i} \;\; F_1(1, 1-\vartheta; 2-\vartheta; \tau_{CU_i})\right]$$

$$\upsilon = \exp\left[-\lambda_D \pi \left(\tau_{D_i}\right)^{\vartheta} \Upsilon(1-\vartheta) \Upsilon(1+\vartheta)\right]$$

$$\omega = \exp\left[-\lambda_R \pi \left(\tau_{R_i}\right)^{\vartheta} \xi(\vartheta, 1-\vartheta)\right]$$

and $F_1()$,$\Upsilon()$ and $\xi()$are the Hypergeometric, Gama and Bessel functions, respectively.

V. Network with Successive Interference Cancellation Technique

The wholistic equivalent interferences at CU_i would consist of the RUI, CCI and CDI as presented in equation (3). Considering that the iterative cycle reaches up to k[th] strongest interference regeneration, therefore in mathematical demonstration through equation (2), the SIR level estimation at user end is denoted as.

$$SIR^k_{CU_i} = \frac{\rho_{R_i} P_{L,O} {h_i}^{-\gamma} \|H_{R_iCU_i}\|^2}{I^k_{CU_i}} \tag{6}$$

Where,

$$I_{CU_i}^{k} = \sum_{y_{CU_j} \in \psi_{CU-INTF}^{eq}} \rho_{CU_j} P_{L,P} f_j \left\| y_{CU_j} \right\|^{-\gamma} \qquad (7)$$

Where $I_{CU_i}^{k}$ is the cumulative interferences at the cellular user CU_i, and as the following equation (4), the successful probability of obtaining $SIR_{CU_i}^{k}$ at the user CU_i can be expressed as

$$\wp_{SUC_{CU_i}}^{k} \triangleq \wp\left(SIR_{CU_i}^{k} \geq \tau_{CU_i}\right) \qquad (8)$$

VI. Simulation Parameters

The theoretical analysis of IC is validated through numerical simulation of a multi-tier heterogeneous network and throughput gain is considered as a parameter for evaluation. The SIC model has been used as an interference cancellation technique. We have considered the power transmission of BS and relay as 23 dBm and 43 dBm, respectively. An area of 10km x 10 km with a reference receiver at the origin has been used in a multi-tier environment. SIR verification is performed from -15 to 10 dB through Monte-Carlo simulation for a sample of 5000 apprehensions. The coverage area includes a uniform placement of users. The model considered users as mobile entities in a specified coverage region, whereas Macro-cells are located at static points with coverage 40 m in radius. The simulation model consists of one macrocell and a number of femtocells, picocells and users uniformly distributed in the coverage area of the macrocell as shown in Figure 3. Mobility is the primary issue in 5G dense small cell environments [14]. The mobility model of the users follows a random waypoint model. The simulation specification is listed below in Table 1.

TABLE1: SIMULATION SPECIFICATION

Spécifications	Values
Model area	10 km x 10 km
Numbers of cellular users	10 to 100
Placement of cellular end	Random Distribution
Count of access points	2
Path loss exponent for outdoor	4
SIR threshold level	-15 to -5 dB
QoS threshold level for macro cell user	4.8 dB
QoS threshold level for D2D user	6 dB
Path loss exponent for Indoor	3
BS Transmission power	43dBm
Transmission power of D2D link	23dBm
Radius of Macro cell	40m
Antenna height	20 m
Antenna gain	14 dBi
Noise figure	5 dB

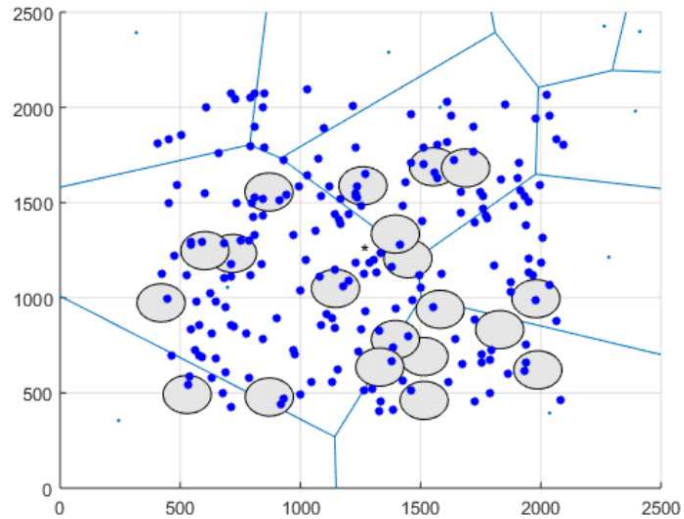

Fig. 3. Simulation model of a multi-tier heterogeneous network

VII. Results and Discussion

Success probability is considered the gaging parameter for the comparison of interference mitigation techniques [15]. Therefore, the experimental results are analyzed through the Success Probability level. The outcome is evaluated through graphs based on the number of users and SINR. The number of Users is one of the main driving factors in the majority of interference mechanisms. Various communication parameters start reaching limits by the increase in users, such as channel capacity, CDMA capacity, collision, etc. [16]. Similarly, SINR is the main parameter for the quality of communication link. 5G heterogeneous network operates on limits of SINR due to small cell sizes and low-power devices [17].

The Success Probability results for the number of users and SINR are shown in Figure 4 and Figure 5, respectively. To demonstrate our experiment, we used a graphical comparison of success probability with the number of users and SINR. For comparison, SIC results are plotted simultaneously with No SIC and ZF.

For performance analysis based on the number of users (Figure 4), we increased the number from 10 to 100 for a performance comparison of all three scenarios in the experimental ecosystem. The outcomes of SIC is better than both ZF and No SIC scenario. Similarly, ZF also out forms No SIC scenario. However, the performance of ZF is almost equivalent to No SIC for the number of users reaching 100.

Similarly, for analysis with respect to SINR (Figure 5), we performed a simulation from -5dB to 35dB. It is observed that the performance of all three scenarios (SIC, ZF and No SIC) remain the same till -3dB. However, SIC fairly outperforms the other two techniques from -3dB to 25dB. But from 25dB to 35dB the performance of all three scenarios is similar. Moreover, ZF remains better than No SIC in all SINR levels in the experiment.

The demonstration depicts the higher performance of SIC in a heterogenous interference environment as compared to non-SIC and ZF. This is due to the iteratively of SIC functions, which are used to eliminate the strongest unwanted signals, until the desired signal is extracted from the received signal.

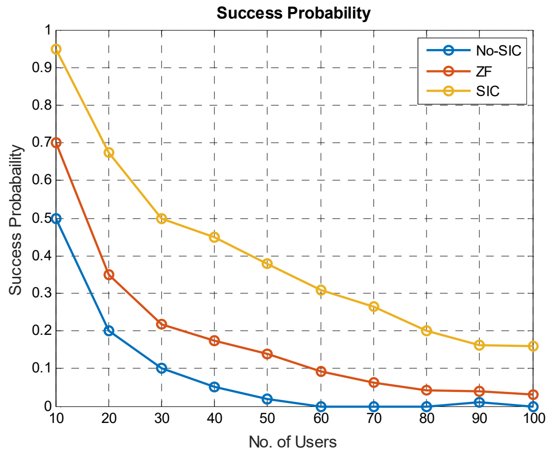

Fig. 4. Success Probability vs Number of users

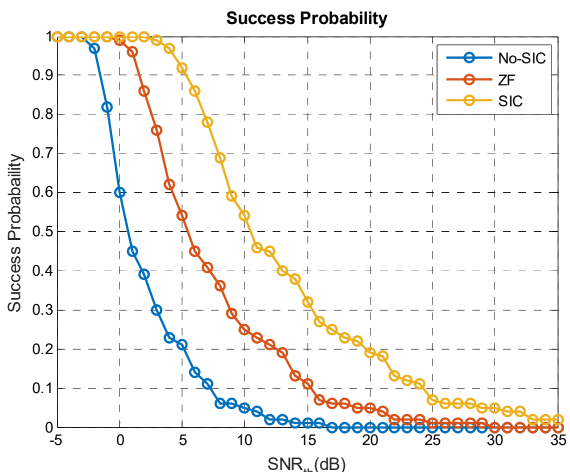

Fig. 5. Success Probability vs SINRth

VIII. Conclusion

SIC is considered suitable among existing IC Techniques due to compatibility with traditional hardware. However, SIC needs evaluation in 5G heterogeneous networks due to several nonconventional associated conditions. The heterogeneous nature of the interference signal tremendously increase the problem variables for noise signal classification and regeneration. Therefore, in this paper, we formulated a system-level model of 5G heterogeneous networking paradigm containing all possible interfering signals such as D2D and relay-to-relay including possible combinational links. Further, we conducted details mathematical and simulation-based analysis of SIC in a heterogeneous network containing multi-tier D2D links. We evaluated the probability of success with respect to the number of users and SINR. The simulation model included one macrocell and number of femtocells, picocells and users uniformly distributed in the coverage area of the macrocell. Our results indicate SIC as the preferable solution for interference cancellation in 5G enabled heterogeneous networks. Although, we considered user mobility through statistical functions. However, real-time analysis through mobile users may provision research openings for further improved results of SIC.

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References

[1] A. Gachhadar, R. K. Maharjan, S. Shrestha, N. B. Adhikari, and F. Qamar, "A 5G Framework and its Analysis of Interference Cancellation in Multi-Tier Heterogeneous Networks," in *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, 2021: IEEE, pp. 1-7.

[2] M. M. Rahman, M. Manavalan, and T. K. Neogy, "Artificial Intelligence in 5G Technology: Overview of System Models," *Asia Pacific Journal of Energy and Environment,* vol. 8, no. 1, pp. 17-26, 2021.

[3] S. H. A. Kazmi, A. Masood, and K. Nisar, "Design and Analysis of Multi Efficiency Motors Based High Endurance Multi Rotor with Central Thrust," in *2021 IEEE 15th International Conference on Application of Information and Communication Technologies (AICT)*, 2021: IEEE, pp. 1-4.

[4] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, and S. Vrzic, "Interference coordination and cancellation for 4G networks," *IEEE Communications Magazine,* vol. 47, no. 4, pp. 74-81, 2009.

[5] U. Noreen, L. Clavier, and A. Bounceur, "Lora-like css-based phy layer, capture effect and serial interference cancellation," in *European Wireless 2018; 24th European Wireless Conference*, 2018: VDE, pp. 1-6.

[6] J. G. Andrews, "Interference cancellation for cellular systems: a contemporary overview," *IEEE Wireless Communications,* vol. 12, no. 2, pp. 19-29, 2005.

[7] M. U. A. Siddiqui, F. Qamar, F. Ahmed, Q. N. Nguyen, and R. Hassan, "Interference management in 5G and beyond network: requirements, challenges and future directions," *IEEE Access,* vol. 9, pp. 68932-68965, 2021.

[8] C. Ma, W. Wu, Y. Cui, and X. Wang, "On the performance of successive interference cancellation in D2D-enabled cellular networks," in *2015 IEEE Conference on Computer Communications (INFOCOM)*, 2015: IEEE, pp. 37-45.

[9] M. Wildemeersch, T. Q. Quek, M. Kountouris, A. Rabbachin, and C. H. Slump, "Successive interference cancellation in heterogeneous networks," *IEEE transactions on communications,* vol. 62, no. 12, pp. 4440-4453, 2014.

[10] Y. Chang, H. Chen, and F. Zhao, "Energy efficiency maximization of full-duplex two-way relay-assisted device-to-device communications underlaying cellular networks," *EURASIP Journal on Wireless Communications and Networking,* vol. 2016, no. 1, pp. 1-19, 2016.

[11] H. Dun, F. Ye, and Y. Li, "Transmission power adaption for full-duplex relay-aided device-to-device communication," *Symmetry,* vol. 9, no. 3, p. 38, 2017.

[12] X. Hou, F. Liu, and Y. Liu, "Capacity gain analysis for underlaying full-duplex D2D communications with a novel interference management scheme," in *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2017: IEEE, pp. 1-5.

[13] R. Vaze, K. T. Truong, S. Weber, and R. W. Heath, "Two-way transmission capacity of wireless ad-hoc networks," *IEEE Transactions on Wireless Communications,* vol. 10, no. 6, pp. 1966-1975, 2011.

[14] C. M. Fortuin, P. W. Kasteleyn, and J. Ginibre, "Correlation inequalities on some partially ordered sets," *Communications in Mathematical Physics,* vol. 22, no. 2, pp. 89-103, 1971.

[15] M. U. A. Siddiqui, F. Qamar, M. Tayyab, M. Hindia, Q. N. Nguyen, and R. Hassan, "Mobility Management Issues and Solutions in 5G-and-Beyond Networks: A Comprehensive Review," *Electronics,* vol. 11, no. 9, p. 1366, 2022.

[16] J. Blomer and N. Jindal, "Transmission capacity of wireless ad hoc networks: Successive interference cancellation vs. joint detection," in *2009 IEEE International Conference on Communications*, 2009: IEEE, pp. 1-5.

[17] W. Zhang, E. Pasalic, and L. Zhang, "Phase orthogonal sequence sets for (QS) CDMA communications," *Designs, Codes and Cryptography,* vol. 90, no. 5, pp. 1139-1156, 2022.

[18] S. Gulia, A. Ahmad, S. Singh, and M. D. Gupta, "Interference management in backhaul constrained 5G HetNets through coordinated multipoint," *Computers and Electrical Engineering,* vol. 100, p. 107982, 2022.