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Improving Device-to-Device Communication in Hybrid Microwave and Millimeter Wave Cellular Networks using Fractional Frequency Reuse Technique

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Abstract
Device-to-Device (D2D) communication is one of the most promising technologies to enhance user experience in 5G and beyond. The concept of enabling D2D in cellular network has encounters some challenges, despite the huge benefit anticipated. However, resolving these challenges promises improved service delivery, spectrum efficiency and reduced latency amongst other gains. Attempts to enable D2D in both microwave and millimeter wave network gained some traction in recent years in a bid to enable wider coverage and utilization of the technology. Some of the research attempts, challenges and prosects are discussed in this paper.

Keywords: Device-to-Device, Microwave, Millimeter Wave, Inter-cell Interference.

Introduction
The most promising solution to spectrum scarcity is the incorporation of emerging technology into the next generation of cellular network. These emerging technologies has the potential to improve spectrum efficiency, reduce latency, increase flexibility while also ensuring seamless transition from one cellular network generation to the next. One of the front runners of thew technology to help in spectrum management and improve user experience is Device-to-Device D2D communication. D2D enabled cellular network is reported to suffer intercell interference (Kuruvatti, Hernandez, & Schotten, 2019), thereby

degrading cellular network user service quality (Noura & Nordin, 2016). With the rapid deployment of millimeter wave and the existing microwave technology D2D finds application in a hybrid environment where it can be deployed to serve both microwave and millimeter wave network users without significant change in infrastructure, while also providing means of interference mitigation. Attempts have been put forward by researchers to enable D2D communication in 4G microwave cellular networks (Lien, Chien, Tseng, & Ho, 2016; Sanusi, Nasr, & Moessner, 2019) also for exclusive 5G millimeter wave networks (Qiao et al., 2015; Ramadhan & Nashiruddin, 2020; Sarma & Hazra, 2020), recent research geared towards use of D2D technology in hybrid 4G and 5G networks (Hussain, Jangsher, Arafah, Mao, & Li, 2019; Prado, Cardieri, & Brito, 2020; Roslee, Nizam, & Yusoff, 2020; Wang, Wang, Feng, & Xu, 2019).

Device-to-Device (D2D) Communication

Device-to-device communication generally refers to a form of technology that enables nearby devices to communicate directly with each other over the licensed cellular bandwidth with limited or no AP or BS involvement. D2D was proposed as part of 4G LTE-A network and was part of 3GPP LTE-A standard in Release 12 as ProSe (Proximity Service) (Lien et al., 2016). D2D communication has not been widely adopted by operators as part of communication networks in current communication systems. However, with the proliferation of new context-aware services and applications, and new trend in cooperative communication paradigm shifting from fixed terminal relaying to device relaying, D2D communication is expected to continue to evolve and play an important role in future 5G networks (Höyhtyä, Apilo, & Lasanen, 2018). D2D communication is broadly classified into Inband and outband communication, depicted in figure 1.

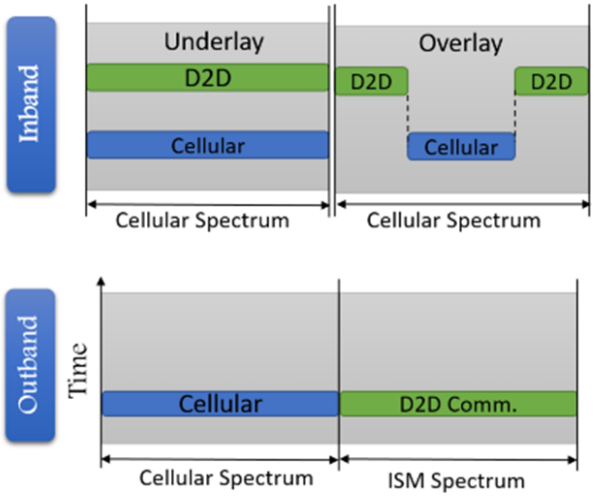


Figure 1: Inband and Outband D2D configurations (Asadi, Wang, & Mancuso, 2014)

D2D communication operates in basically three different configuration which are either Network controlled, Autonomous or Network assisted D2D communication (Song, Niyato, Han, & Hossain, 2015). Some of the major drawback of D2D communication are;

i. Interference Management: this is one of the most critical challenges of D2D as the interference between D2D equipment and cellular equipment. Several techniques have been proposed to mitigate interference amongst which is resource allocation technique (Dai & Gui, 2020; Guizani & Hamdi, 2016) and power control technique (Kuruvatti et al., 2019; Sanusi et al., 2019).

ii. Mode Selection: Mode selection can be described as the process of determining whether the D2D pair should communicate in D2D mode or if a cellular mode (CM). This is vital for the successful seamless implementation of D2D in hybrid network and improve user satisfaction. D2D operating modes can be classified as;

   a. Dedicated Mode - Here resources are assigned to D2D users, thereby preventing co-channel interference. Signal to Noise Ratio in DM mode is computed by;

$$\gamma_i^{dm} = \frac{\rho_i G_i^k}{N_0} \tag{1.1}$$

   and the throughput is obtained by the expression;

$$T_i^{dm} = w_B \log_2(1+\gamma_i^{dm}) \tag{1.2}$$

   where, ρ_i is the power of D2D transmitter $D2D_{tx}$ of pair i^{th} and G_i^k channel gain between $D2D_{tx}$ and $D2D_{rx}$.

   b. Reuse Mode: for Reuse Mode, D2D users share the Cellular user equipment channel, this however causes interference for users in of both tier. The SINR of the users $\{m,s,i\}$ under macro, small, and D2D tier communicating in the same Resource block (RB) k^{th} is describe mathematical by;

$$\gamma_m^k = \frac{P_{MB} G_{MB,m}^k}{N_0 + \sum_{j=1}^{d} y_j^k h_{j,m}^k p_j + \sum_{j=1}^{N} Y_{SB_j}^k h_{SB_{j,m}}^k P_{SB_j}} \tag{1.3}$$

   where, $\{G_{MB,m}^k, G_{SB,m}^k, G_i^k\}$ represents the channel gain between MB and m^{th} user.

D2D Communication System Model

Considering a sectored antenna array model, as reported in (Chevillon, Andrieux, Négrier, & Diouris, 2018), for both transmitter and receiver in mmWave, where ϕ_b and ϕ_u denotes half-power beamwidth of BSs and UEs respectively. Main lobe and side-lobe gain are represented by Gm_b and Gs_b respectively. Gm_u and Gs_u denotes receiving UEs main and side lobe gains respectively. Furthermore, assuming an $N \times N$ uniform planar square antenna array, with half-wavelength antenna spacing, the beamwidth ϕ, main lobe gain Gm and side lobe gain Gs are obtained as (Wu, Atat, Mastronarde, & Liu, 2018);

$$\phi = {1.732}/{N},\ Gm = N^2,\ Gs = \frac{1}{\sin^2}\left(\frac{3\pi}{2N}\right) \tag{1.4}$$

Antenna array gain g_i from an arbitrary $BS\ i$ to a typical cellular receiver is represented as;

$$g_i = \begin{cases} G_1 = Gm_b Gm_u, \text{ with probability (w.p.) } \frac{\phi_b}{2\pi}\frac{\phi_u}{2\pi}, \\ G_2 = Gm_b Gs_u, \text{ with probability (w.p.) } \frac{\phi_b}{2\pi}\left(1-\frac{\phi_u}{2\pi}\right), \\ G_3 = Gs_b Gm_u, \text{ with probability (w.p.) } \left(1-\frac{\phi_b}{2\pi}\right)\frac{\phi_u}{2\pi}, \\ G_4 = Gs_b Gm_u, \text{ with probability (w.p.) } \left(1-\frac{\phi_b}{2\pi}\right)\left(1-\frac{\phi_u}{2\pi}\right). \end{cases} \tag{1.5}$$

four possibly antenna gains are denoted for simplicity as $G_k = 1,2,3,4.$ where, $G_1 = Gm_b Gm_u$ is the boresight gain (Wu et al., 2018).

Using Poison Point Distribution (PPP), the LOS probability of two nodes separated by a distance d on the plane is obtained by (Wu et al., 2018);

$$\rho L(d) = \exp\left(-\eta\lambda_0\left(2\mathrm{E}[R]d + \pi E\left[R^2\right]\right)\right) \tag{1.6}$$

where λ_0 is the obstacle intensity, the random variable R denotes the obstacle radius.

$$\eta = 1 - \int_0^1 \int_{h_{\min}}^{sh_{Rx}+(1-s)h_{Tx}} f_H(d)dhds \tag{1.7}$$

η defined in equation (2.14) is the obstacle thinning factor.

To ensure effective mode selection and successful communication in D2D pair in either microwave or mmWave, it is vital that the interference caused by and suffered by the D2D equipment is mitigated efficiently. Some of the research focused on hybrid D2D interference management have put forward mechanisms such as Fractional Frequency Reuse (FFR) technique (Eslami, Mirjalily, & Davidson, 2020; Kim, Kim, Noh, & Cho, 2018; Ningombam, Pyun, Hwang, & Shin, 2017) or a variant of FFR (F. Tabassum, A. K. M. N. M. N. Islam, & M. S. Kaiser, 2020).

Future network will have to coexist with microWave and mmWave band infrastructure side-by-side thereby necessitating the need for developing mechanisms that can accommodate seamless transitioning between both bands. Figure 2, depicts a 5G network architecture comprising microWave, mmWave and massive MIMO.

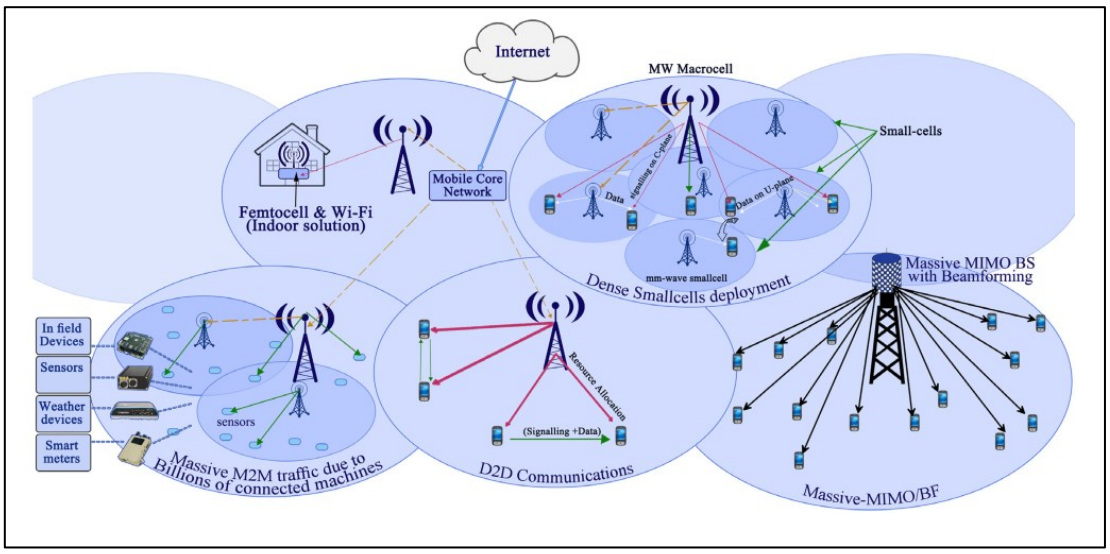


Figure 2: 5G Network architecture comprising microWave and mmWave bands.

Review of Papers on D2D deployment in Hybrid Cellular Network Environment.

D2D as an emerging technology for spectrum efficiency and user experience improvement, has gained interest in both academia and communication industry as a promising solution. However, hybrid cellular network environment is the future target for real world application as mmWave is gradually deployed across the globe where current microWave band still exists and serve massive number of users. Therefore, some research effort focused on proffering mechanism for seamless deployment and utilization of D2D communication in this network scenario are reviewed in this section.

A hybrid D2D discovery mechanism target for use in 5G cellular network infrastructure was proposed by **(Li & Tsai, 2018)**. The authors reported to have designed an efficient methodology for establish and using D2D communication

technology in a 5G network, comprising microWave and mmWave bands. The mechanism is based on both inband and outband techniques, leveraging on Wi-Fi direct protocol (Khan, Cherif, Filali, & Hamila, 2017) for outband communication, while requiring a full eNB control for inband D2D communication (Hayat, Ngah, & Zahedi, 2019). The authors proposed a two-phased approach, where phase one requires UE initiate request to communicate and the request is routed via the eNB and the Enveloped Pack Core (EPC), with confidential details of the requesting UE such as International Mobile Subscriber Identity (IMSI), location and distance to base station, the request is granted and controlled by the eNB if the identity, location and network constraints are met as judged by the EPC, for same cell devices or adjacent cell devices, otherwise, they are instructed to communicate via cellular network. The second phase of the hybrid mechanism is independent of the cellular network, here the intending source device sends request beacon to the intended destination and will transmit data only after a successful acknowledging beacon is received, in the event of failure, the beacon is resent at a predetermined interval for a set number of times before the communication attempt is abandoned as unreachable. The solution, though promising does not consider inherent mmWave network challenges like NLOS and beamforming.

For the work presented by **(Wang et al., 2019)**, a hybrid communication model for mmWave and microWave band D2D communication underlaying 5G cellular system is proffered. The approach proposed, ensures the establishment of D2D link either via mmWave band when available and unobstructed or microwave band otherwise. The beamforming assumption are that all eNBs and DUEs are equipped with directional antenna (Ghosh et al., 2012), with good array again. The mmWave is only available via a line-of-sight (LOS) scenarios (Kakkavas et al., 2019), otherwise it is assumed blocked. To ensure hybrid D2D communication, BS is informed of D2D communication intention by the source UE, the BS locates and broadcast D2D-link-setup-request to the UEs, the DUE pair receives request and setup beam alignment process (Hassanieh et al., 2018) in the microWave band, DUE_{TX} sends probing signals towards DUE_{RX} in a circular pattern, all received signals are recorded and compared and forwarded to the BS, the BS sends the information to DUE_{TX} to select the strongest signal received location for data transmission, in the case the received power does not reach pre-defined threshold, the data transmission between the DUE pair is performed via microwave.

Another hybrid D2D communication solution is proposed by **(Eslami et al., 2020)**. Here the authors considered co-tier and cross-tier interference in deployment of D2D communication link in hybrid mmWave and microWave network infrastructure. To provide a solution, all devices are allocated to access the spectrum either in reuse or dedicated mode, the mixed integer nonlinear nonconvex problem (Mahajan, Leyffer,

Linderoth, Luedtke, & Munson, 2020) is solved based on problem decomposition method, the matching problem is addressed using Kuhn-Munkres algorithm (Chen, Tian, & Wang, 2014). The authors report that the proposed strategy solves admission, power control problems optimally, including matching subproblems, by using heuristic suboptimal algorithm (Stern, Dreiman, & Valenzano, 2019) to allocate free sub-channels. The solution for interference is based entirely on a Modified Fractional Frequency Reuse scheme (F. Tabassum, N. Islam, & S. Kaiser, 2020) proffered by the authors, which is subject to minimum sum rate and transmission power constraints.

The work presented by **(Fahim & Samad, 2019)** attempts are made to provide a combined mechanism for mmWave and microWave band cellular network for implementing D2D communication for both indoors and outdoor scenarios, while considering rain and fog attenuation effect on LOS (Elmutasim & Mohd, 2021). In the work, the authors suggested band selection technique that is based on the Angle of Arrival (AoA) (Dong, Wang, Huang, & Huang, 2020) Peaks from mmWave band to the intending D2D transmitter, whereby the threshold for inconsistency is measured and mmWave is either selected or rejected for establishing the D2D link. While microWave band is reserved as redundant link establishing band, while computing the SINR for the mmWave band, considering the attenuation due to rain and fog before final link establishment is performed (Semiari, Saad, & Bennis, 2017).

Some of the work by researchers in this field covers hybrid network scenarios, while most proposed solution from literature are focused on either microWave or mmWave only. However, not all the Hybrid solution cover all the challenges expected on the Hybrid network scenario, especially interference and mmWave band peculiarities such as NLOS conditions. Table 1, presents a summary of some of the reviewed papers.

Table 1: Review Summary

Authors (Year)	Title	Proposed Solution and Challenges
Fahim and Samad, (2019)	Device-to-Device Communication with Weather Considered Combined Mechanism of Millimeter Wave and Microwave Band	Proposed a hybrid band selection mechanism applicable to indoor and outdoor transmission scenario, while considering weather effect. Does not cover interference management.
Li and Tsai, (2018)	Design and Evaluation of a Hybrid D2D Discovery Mechanism in 5G Cellular Networks	D2D communication using inband or outband techniques for mmWave and microWave band.

		Does not consider peculiar mmWave challenges like NLOS scenarios.
Wang et al., (2019)	A hybrid communication model of millimeter wave and microwave in D2D network	Developed a hybrid D2D link mechanism considering received power threshold and LOS availability in choosing mmWave or microWave band. Interference mitigation strategy was not presented.
Eslami et al., (2020)	Spectrum-Efficient QoS-Aware Resource Assignment for FFR-Based D2D-Enabled Heterogeneous Networks	Presented a mode selection strategy for D2D link establishment using either Dm or RM, interference mitigation is covered using a modified Fractional frequency reuse mechanism. No consideration for NLOS scenario in mmWave.

Challenges of D2D links in Hybrid Cellular Network

Some of the major challenges that researchers aim to solve in order to effectively deploy D2D communication link in Hybrid Network environment for 5G and beyond are;

i. Mode Selection: The challenge of selecting the most reliable link establishment mode either Dedicated Mode or Reuse Mode for continuous link between communicating D2D pairs.
ii. Band Switching: In the case of mmWave and microWave availability, the choice of selecting, establishing and maintaining D2D link and the threshold requirement for switching in the result of degradation, interference or blockage.
iii. Blocking and Deafness: Challenges of setting threshold values for acceptable deafness in mmWave band communication and development of reliable NLOS correction technique to counter blockage.
iv. Interference: Developing a robust interference management mechanism applicable to both mmWave and microWave band underlaid with D2D to improve cellular user QoS and ensure reliable D2D communication.

Some of these challenges are being solved, however, they are mostly solved as stand-alone solutions to improve performance where needed, such as mode selection for mmWave and microWave band network presented by (Feng et al., 2019) does not consider D2D communication link, likewise the work presented by (Moltafet, Mokari, Joda, Sabagh, & Zorzi, 2018) also suggest dual mode select scheme but does not consider D2D links, for band switching some promising research effort like the work by (Semiari et al., 2017).

Conclusion

D2D has been established to be beneficial technology in current and future communication network, however, there are challenges associated widespread adaptation in current cellular network. As a solution to future network spectrum scarcity and improved user service experience and quality, research efforts are geared toward developing mechanism for enabling D2D to coexist in hybrid mmWave and microWave cellular network bringing the benefits of D2D to both bands while also providing solution to mitigate interference and overcome inherent challenges in mmWave band that limits D2D utilization. This paper provided some key features of the D2D technology, state-of-the-art in the research field of D2D in hybrid bands and challenges being encountered.

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