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Energy Efficient Underlaid D2D Communication for 5G Applications

Lalitha Nagapuri [1], A. V. Prabu [2], Suresh Penchala [1], Bashir Salah [3,*], Waqas Saleem [4], G. Sateesh Kumar [5] and Amira Sayed A. Aziz [6]

1 Department of ECE, Kamala Institute of Technology & Science, Singapur, Karimnagar 505468, India
2 Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram 522302, India
3 Industrial Engineering Department, College of Engineering, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia
4 Department of Mechanical and Manufacturing Engineering, Institute of Technology, F91 YW50 Sligo, Ireland
5 Department of ECE, Aditya Institute of Technology and Management, Tekalli, Srikakulam 532127, India
6 Digital Media Department, Faculty of Computers and Information Technology, Future University in Egypt, New Cairo 11835, Egypt
* Correspondence: bsalah@ksu.edu.sa

Abstract: With the increasing importance of reduced-energy wireless communication in 5G networks, maximizing the energy efficiency of device-to-device (D2D) communication has gained a lot of research interest. But so far, the methods have only been able to address the single-cell scenario. This paper proposes an algorithm to improve the non-convex problem in underlaid D2D communication for multiple band scenarios. In 5G wireless communications, device to device is one of the methods used for achieving better energy efficiency. It also reduces the throughput latency. The optimization problem is formulated with a derivative algorithm and proposed modified derivative algorithm. Both the algorithms are compared, and this comparison shows that the modified derivative algorithm is more efficient than the derivative algorithm.

Keywords: 5G; D2D communication; energy efficiency; optimization; derivative algorithm

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1. Introduction

In conventional cellular communication, the cellular user uses communication to uplink and downlink via the base station. Whereas in underlay D2D communication, the cellular users and D2D users share frequency sub-channels; this increases frequency reuse. However, it also causes interference to one another. The cellular users cause interference to D2D users and the D2D users cause interference to cellular users. This decreases the signal-to-interference noise ratio. which consequently decreases the transmission rate of the users. Device-to-device communication draws extensive attention in industry, scademia, and standardization bodies with the sudden increase in the demand for higher data rates. Device-to-device communication without the base station (BS) facilitates direct wireless communication between two transceivers. It is used to increase energy efficiency (EE) and to consume less power while transmitting information without loss and it is a key technique for 5G networks. It connects the devices directly and it also improves the quality of the network, as well as itsthroughput, and reduces the latency. It can achieve improved spectral efficiency and energy efficiency. It also uses the same frequencies as cellular networks which pull down the network quality as extra interference will occur [1–7].

To have better performance, D2D underlaying cellular networks are considered and focused on energy efficiency maximization. The existing technologies work only on a single-cell scenario. More attention was paid to a single-cell scenario, rather than the multiple bands because in multiple bands it takes a lot of power; so research is focused on how to increase energy efficiency with less power consumption. An uplink or a downlink is taken into consideration to transmit and receive the information [8]. Whenever there is a need for maximum energy efficiency, the usage of energy efficiency optimization is required. The solution to the energy efficiency optimization problem for getting maximum EE (energy efficiency) is given in [9,10]. The branch and bound (BB) algorithm is a conventional algorithm used for energy optimization in wireless networks [11]. After achieving maximum energy efficiency, interference will occur due to which the information may be lost and not be in a position to send the packets through the transmitter. So, to overcome this, transmission probability and average sum rates are used to find the average sum of values to obtain the maximum value [12–14]. By considering data rate, energy usage, and battery lifespan, the RICA (A Radial Basis Function (RBF) Iterative Construction Algorithm) algorithm with fixed power provides superior performance [15]. A dynamic reward approach with deep reinforcement learning, a novel iterative power allocation algorithm, and robust power allocation (PA) solution achieve a much higher EE [16–20]. Due to higher spectral efficiency, underlaid is considered superior to overlaid. The different topologies of underlaid communication by using the same frequency channels as cellular and D2D users is explained in [21–23]. The improved data rate, efficient bandwidth use, power control, and energy-efficient methods are used [24–30].

The main purpose of implementing D2D in cellular networks is to reduce the data traffic in the network. Underlaid D2D communication is considered to achieve spectral efficiency by reusing the cellular resources as well as to achieve better link quality [31]. D2D underlaid communication improves spectral efficiency and provides more incentives for local coverage compared to pure cellular networks. Here, centralized management schemes are proposed [32]. The dynamic power control mechanism is studied to control D2D cellular interference by controlling D2D power [33]. Power control methods are discussed in this paper [34]. D2D enables the communication between two approximation distant devices without the help of a base station. It reduces the delay and increases spectral efficiency. But the distance between the two device users greatly affects the performance of D2D communication [35]. Among the emerging technologies, D2D communication and massive MIMO are key enablers in achieving 5G targets [36]. The possibilities and challenges are discussed here [37]. Advanced wireless techniques, energy efficiency optimization, and non-convex problems are also discussed [38,39] as well as the SWIPT-based EE optimization challenge for D2D communications supporting IoT networks with UAV assistance [40,41]. In addition, a joint resource management approach that ensures the quality of service (QoS) of both cellular and D2D communications while improving the overall energy efficiency of D2D communications is discussed in this paper [42].

The objective of this paper is to develop an algorithm for high-energy efficient device-to-device communication.

The remainder of this paper is set out as follows. The system model is explained briefly in Section 2. The proposed modified derivative algorithm is explained in Section 3. The simulation findings are summarized in Section 4. The comparison of simulation results is summarized in Section 5. The conclusion of the paper is given in Section 6.

2. System Model

Figure 1 shows the whole network underlaid with D2D communication. The D2D users and the cellular users share the same bandwidth in the uplink direction. Here, the base station is used to allocate the resources to the whole network underlaid with D2D communication [24].

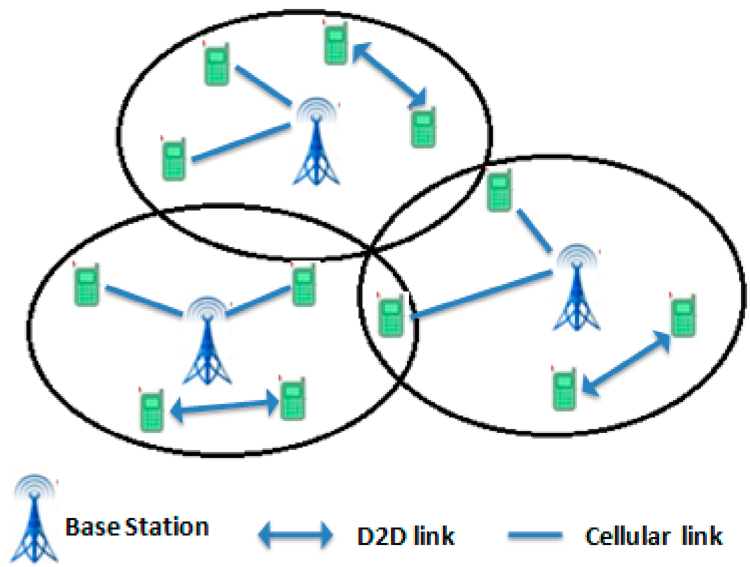

Figure 1. The system model of underlaid with D2D communication.

At present, the existing works were based on a single-cell scenario, but in this paper, we tried to work on multiple bands which means that at a specific time it transfers the data to various devices. The total bandwidth of the ith band is Wi and it is divided into M sub-bands. The bandwidth of each sub-band is Wi, i = 1, 2, 3, . . . , M, having these parameters the channel fading may vary and the power transmission is adjustable and it also improves energy efficiency [24,25]. Both cellular and D2D are divided into sub-bands so they can use these sub-bands with the density λc,i, λd,i. For each, there is a different density and if we use more bandwidth for both users, the multiple users are allowed to transmit and the density also increases.

The transmission power allocation for the ith band for cellular users is $C_{p,i}$ and the total transmission power C_p.

$$\sum_{i=1}^{k} C_{p,i} = C_p \tag{1}$$

Similarly, the transmission power for the ith band for D2D users is $D_{p,i}$ and the total transmission power for D2D is D_p.

$$\sum_{i=1}^{k} D_{p,i} = D_p \tag{2}$$

We considered the channel model as a channel path loss and small-scale channel fading, which represents the Rayleigh fading. To observe the performance of cellular and D2D communication of the whole network, we focused on the typical receiver without loss, the typical receiver for D2D communication, and the typical base station for the cellular network [26]. The received power for both devices obtained by considering small and large-scale fading is expressed as

$$R_p = T_p \delta R^{-\alpha} \tag{3}$$

where T_p represents power transmission, δ indicates Rayleigh fading, R is for the distance between transmitter and receiver, R_p represents the power received for cellular and D2D users and α represents the path loss exponent.

To obtain a better quality of communication, the probabilities should be less than the threshold values.

$$1 - \Pr\,(\mathrm{SIRc,i} \geq \mathrm{Tc,i}) \leq \theta\mathrm{c,i}, \tag{4}$$

$$1 - \Pr\,(\mathrm{SIRd,i} \geq \mathrm{Td,i}) \leq \theta\mathrm{d,i}, \tag{5}$$

where θc,i and θd,i are the probabilities for cellular transmission and device to device communication for the ith band. But the power transmission for D2D can't hold interference for very long, in which case the network is complicated to coordinate. In that situation, the base station reduces the number of D2D users to access until the probabilities become small.

The power in the ith band should not be less than zero and it should not be greater than the upper bound and it is represented as $D_{p,i,up}$. Then we get

$$0 \le D_{p,i} \le D_{p,i,up} \quad (6)$$

The optimal resource allocation is mainly used to maximize energy efficiency; finally, we obtain the maximum EE.

Any optimization issue where the objective or any of the limitations are non-convex is referred to as a non-convex problem. Such a problem may have several possible zones, each with several locally optimal points.

$D_{p,i,inf}$ and $D_{p,i,sup}$ are used to represent the lower limit and upper limit of the feasible area of $D_{p,i}$. We have $D_{p,i,inf} = \max\left\{0, D_{p,i,low}\right\}$ and $D_{p,i,sup} = \min\left\{D_{p,i,up}, D_{p,i,high}\right\}$.

$$\max_{D_{p,i}} EE_d = \sum_{i=1}^{k} EE_{d,i} \quad (7)$$

$$D_{p,i,inf} \le D_{p,i} \le D_{p,i,sup}$$

$$\sum_{i=1}^{k} D_{p,i} = D_p \quad (8)$$

The goal function of our optimal solution is the total EE of D2D communication (EE_d). EE of the ith band D2D communication is $EE_{d,i}$. It achieves the description of the optimization process to maximize the EE across the entire cellular network using D2D communication.

3. Proposed Modified Derivative Algorithm

The difference between a derivative algorithm and a proposed modified derivative algorithm is a computational complexity. In the proposed modified derivative algorithm, computational complexity is less when compared with the derivative algorithm; this is explained clearly from Step 8 to Step 10 and in the corresponding flow chart for the proposed modified derivative algorithm. Here we considered the parameters of both the methods the same because with those parameters the proposed modified derivative algorithm produced better performance when compared to the exiting method. Here we plotted both the method's performance graphs.

We proposed a modified derivative algorithm as shown in Figure 2. The maximum value of $f_i(D_{p,i})$ can be obtained by $D_{p,i} = D_{p,i,max}$. Where $D_{p,i,max}$ denotes the global maximum point of $f_i(D_{p,i})$ on the interval [$D_{p,i,inf}$, $D_{p,i,sup}$]. The EE_d achieves the maximum value when every $EE_{d,i}$ achieves the maximum value in the feasible region. This is obtained when every $D_{p,i}$ is mutually independent. Here every $D_{p,i}$ is mutually independent when the equality constraint $\sum_{i=1}^{k} D_{p,i} = D_p$ is removed. We can calculate $D_{p,i,max}$ for I = 1, 2, . . . , K; the least reduction in EE_d can be achieved by adjusting the value of $D_{p,i}$ to meet the equality constraint $\sum_{i=1}^{k} D_{p,i} = D_p$.

Step 1: Initialize the threshold value.

Step 2: Calculate the power transmission of D2D users for ith band.

Step 3: After calculating we get the maximum $D_{p,j}$

$$D_{p,i} = D_{p,i,max}$$

Step 4: To achieve the least reduction in EE, the value of $D_{p,j}$ needs to be adjusted to meet the equality constraint.

Step 5: Consider "n" as the parameter that checks the balance between performance and computation. Hence, according to practical requirements, we can adjust the value.

Step 6: We consider the der_i variable to set a value to save. It is used to select an appropriate value for $D_{p,j}$ in further steps.

Step 7: To exit the loop, we used a threshold value instead of a counter. Because if $D_{p,j}$ was chosen in the latest iteration, it will surpass the global optimum; in this case, we had to choose another $D_{p,j}$ iteration to modify. This situation is unpredictable and iterations are not determined either.

Steps 8 and 9: After all adjustments in $D_{p,j}$, if it was overstepping the feasible region, we set der_j to infinite, preventing j from being chosen. As a result, we avoided the occurrence of an infinite loop.

Step 10: In this, we updated the der_j variable instead of every der_i variable since for i = 1, 2, 3, . . . , k & not equal to j, der_i remains unchanged after adjusting $D_{p,j}$.

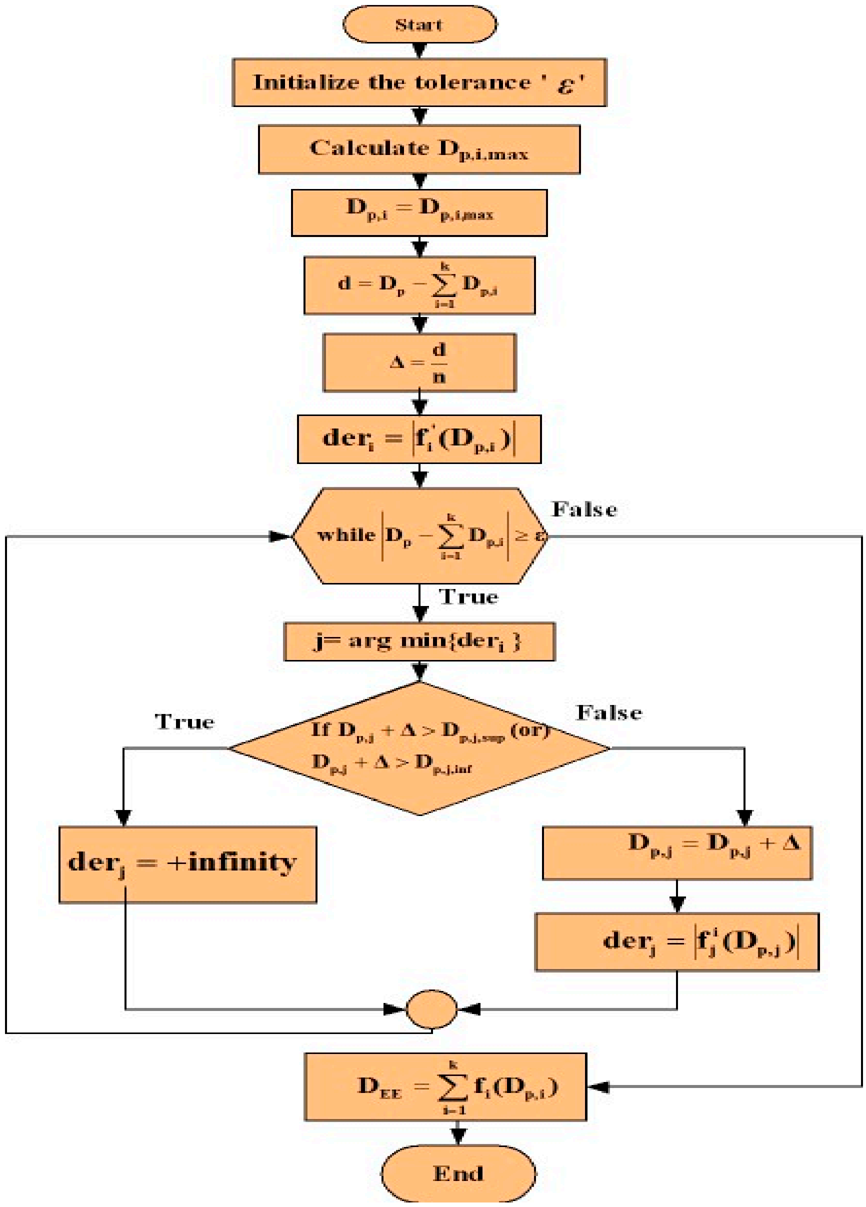

Figure 2. Flow chart for the proposed modified derivative algorithm.

4. Simulation Results

Table 1 presents the main simulation parameters by using the derivative algorithm.

Table 1. Simulation parameters by using the derivative algorithm.

Parameter	Value
K (no of bands)	5
Wi (bandwidth of ith band)	20 MHz
α (Path loss exponent)	4
θc,i (cellular probability for ith band)	0.1
Θd,i (D2D probability for ith band)	0.1
Tc,i (cellular threshold for ith band)	0 dB
Td,i (D2D threshold for ith band)	0 dB
$[R_{c,00,1}, R_{c,00,2}, \ldots, R_{c,00,5}]$	[50,60,70,80,90] m
$[R_{d,00,1}, R_{d,00,2}, \ldots, R_{d,00,5}]$	[10,20,30,20,10] m
$[\lambda_{c,1}, \lambda_{c,2}, \ldots, \lambda_{c,5}]$	$[10,1,10,10,10] \times \lambda_{c,ref}$
$[\lambda_{d,1}, \lambda_{d,2}, \ldots, \lambda_{d,5}]$	$[10,1,10,10,10] \times \lambda_{d,ref}$
D_p (total transmission power of D2D users)	60 mW
$D_{p,i,up}$	20 mW
ε (tolerance)	1×10^{-3}

Figure 3 shows the energy efficiency of D2D users with the reference density of D2D users by using the derivative algorithm. We assumed an uplink environment where 5 multiple bands of spectrum with bandwidth 20 MHz are shared by cellular and devices users. As the D2D users increase the EE rises, and then it slowly decreases; if the cellular user's transmission power is 325 mW, 375 mW, and 425 mW are fixed. This is a result of the increasing distortion brought on by cellular transmission. We also observed that the EE decreases with the increase of cellular power because the increase in cellular power creates interference.

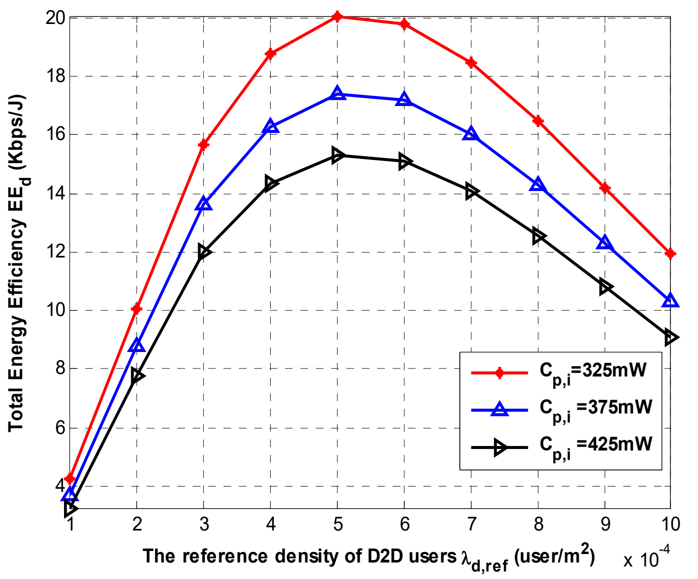

Figure 3. The Energy Efficiency of D2D users with the reference density of D2D users by using the derivative algorithm.

Figure 4 shows the energy efficiency of D2D users with the reference density of cellular users by using the derivative algorithm. We assumed an uplink environment where 5 multiple bands of the spectrum with a bandwidth 20 MHz are shared by cellular and device users. We can observe that the EE decreases with the increase in the reference density of cellular users if the D2D user's reference distances of 15 m, 20 m, and 25 m are fixed. We are aware that the severity of the channel fading worsens with distance, causing a fall in signal-to-interference ratio. As a result, the average sum rate declines, which lowers the EE.

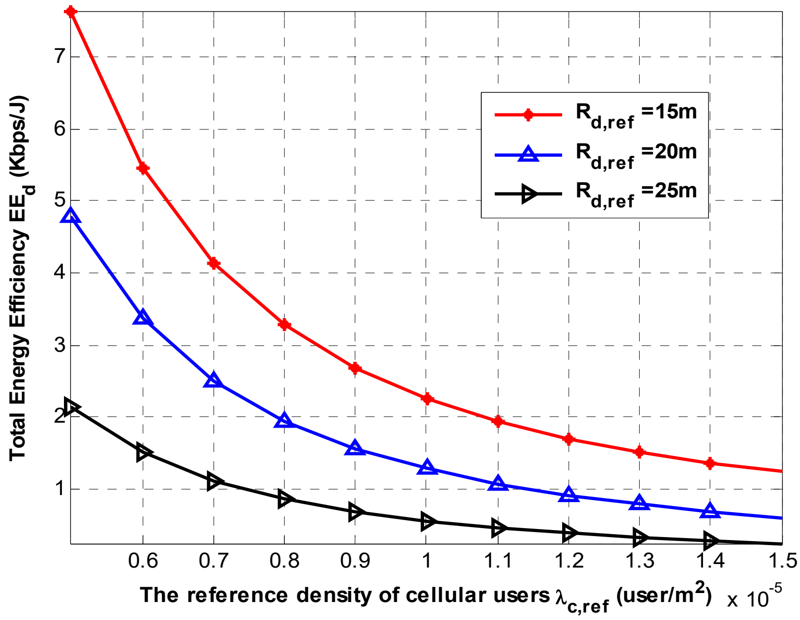

Figure 4. The energy efficiency of D2D users with the reference density of cellular users by using the derivative algorithm.

Table 2 presents the main simulation parameters by using the modified derivative algorithm.

Table 2. Simulation parameters by using the modified derivative algorithm.

Parameter	Value
K (no of bands)	5
Wi (bandwidth of ith band)	25 MHz
α (Path loss exponent)	4.1
θc,i (cellular probability for ith band)	0.1
θd,i (D2D probability for ith band)	0.1
Tc,i (cellular threshold for ith band)	0 dB
Td,i (D2D threshold for ith band)	0 dB
$[R_{c,00,1}, R_{c,00,2}, \ldots, R_{c,00,5}]$	[60,80,100,120,140] m
$[R_{d,00,1}, R_{d,00,2}, \ldots, R_{d,00,5}]$	[20,20,20,20,20] m
$[\lambda_{c,1}, \lambda_{c,2}, \ldots, \lambda_{c,5}]$	$[10,1,10,10,10] \times \lambda_{c,ref}$
$[\lambda_{d,1}, \lambda_{d,2}, \ldots, \lambda_{d,5}]$	$[10,1,10,10,10] \times \lambda_{d,ref}$
D_p (total transmission power of D2D users)	65 mW
$D_{p,i,up}$	25 mW
ε (tolerance)	1.5×10^{-3}

Figure 5 shows the energy efficiency of D2D users versus the reference density of D2D users by using the modified derivative algorithm. We assumed an uplink environment where 5 multiple bands of the spectrum with a bandwidth 25 MHz are shared by cellular and device users and the total transmission power of D2D users is 65 mW, $\lambda_{d,ref} = 10^{-4}$, $\lambda_{c,ref} = 10^{-5}$. As the D2D users increase, the EE rises and then it slowly decreases if the cellular user's transmission power is 325 mW, 375 mW, and 425 mW are fixed. This is a result of the increasing distortion brought on by cellular transmission. We also observed that the EE decreases with the increase in cellular power because the increase in cellular power creates interference.

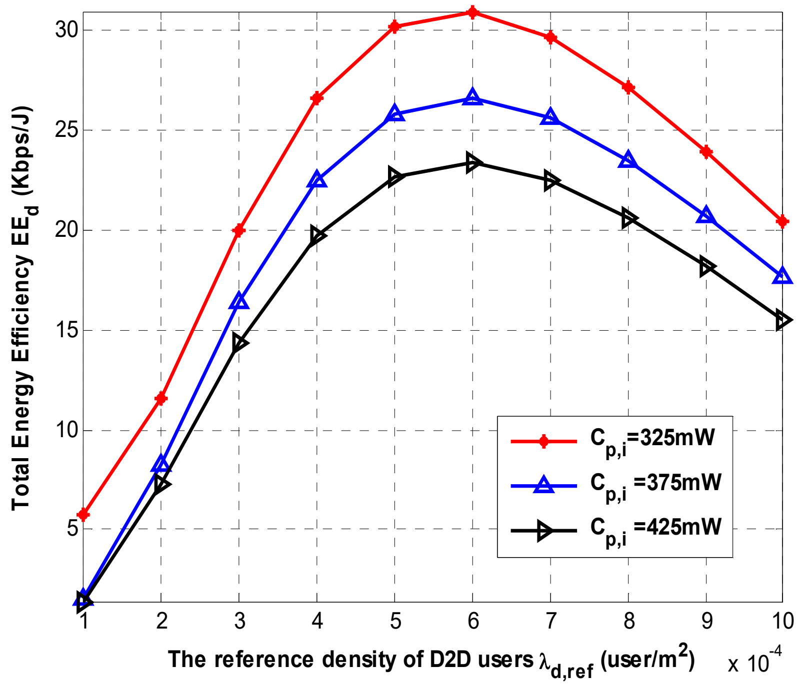

Figure 5. The energy efficiency of D2D users versus the reference density of D2D users by using the modified derivative algorithm.

Figure 6 shows the energy efficiency of D2D users versus the reference density of cellular users by using the modified derivative algorithm. We assumed an uplink environment where 5 multiple bands of the spectrum with a bandwidth 25 MHz are shared by cellular and device users and $\lambda_{d,ref} = 10^{-4}$, $\lambda_{c,ref} = 10^{-5}$. We were able to observe that EE decreases with an increase in the reference density of cellular users if the D2D user's reference distances of 15 m, 20 m, and 25 m are fixed. We were aware that the severity of the channel fading worsens with distance, causing a fall in signal-to-interference ratio. As a result, the average sum rate declines, which lowers the EE.

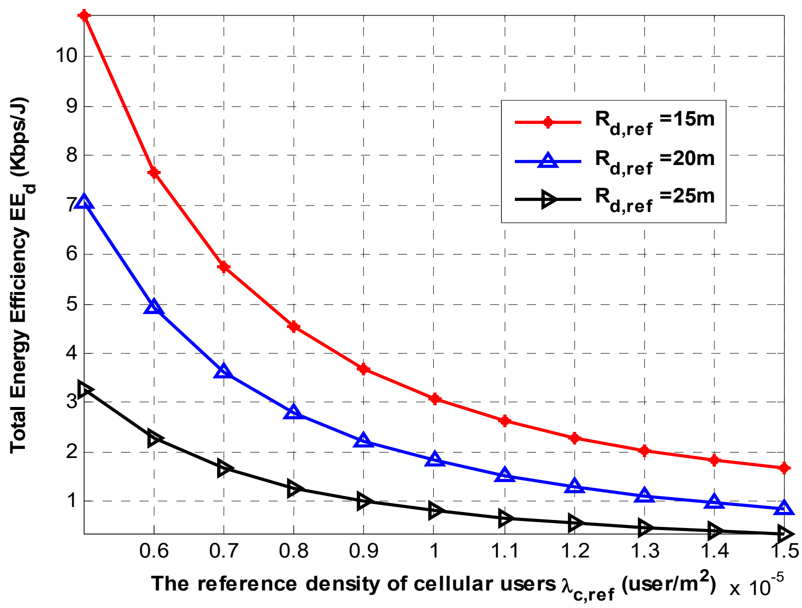

Figure 6. The energy efficiency of D2D users against the reference density of cellular users by using the modified derivative algorithm.

Table 3 Presents the simulation parameters by using the modified derivative algorithm with different parameters.

Table 3. Simulation parameters by using the modified derivative algorithm with different parameters.

Parameter	Value
K (no of bands)	8
Wi (bandwidth of ith band)	25 MHz
α (Path loss exponent)	4.1
θc,i (cellular probability for ith band)	0.1
θd,i (D2D probability for ith band)	0.1
Tc,i (cellular threshold for ith band)	0 dB
Td,i (D2D threshold for ith band)	0 dB
$[R_{c,00,1}, R_{c,00,2}, \ldots, R_{c,00,5}]$	[50,60,70,80,90,100,100,90] m
$[R_{d,00,1}, R_{d,00,2}, \ldots, R_{d,00,5}]$	[10,20,30,20,10,10,10,10] m
$[\lambda_{c,1}, \lambda_{c,2}, \ldots, \lambda_{c,5}]$	$[10,1,10,10,10,10,10,10] \times \lambda_{c,ref}$
$[\lambda_{d,1}, \lambda_{d,2}, \ldots, \lambda_{d,5}]$	$[10,1,10,10,10,10,10,10] \times \lambda_{d,ref}$
D_p (total transmission power of D2D users)	65 mW
$D_{p,i,up}$	25 mW
ε (tolerance)	1.5×10^{-3}

Figure 7 shows the energy efficiency of D2D users versus the reference density of cellular users by using the modified derivative algorithm with different parameters. From Figure 7 we assumed an uplink environment where 8 multiple bands of the spectrum with a bandwidth of 25 MHz are shared by cellular and devices users and $\lambda_{d,ref} = 10^{-4}$, $\lambda_{c,ref} = 10^{-5}$; we were able to observe that EE decreases with an increase in the reference density of cellular users if the D2D user's reference distances of 15 m, 20 m, and 25 m are fixed. We were aware that the severity of the channel fading worsens with distance, causing a fall in signal-to-interference ratio. As a result, the average sum rate declines, which lowers the EE.

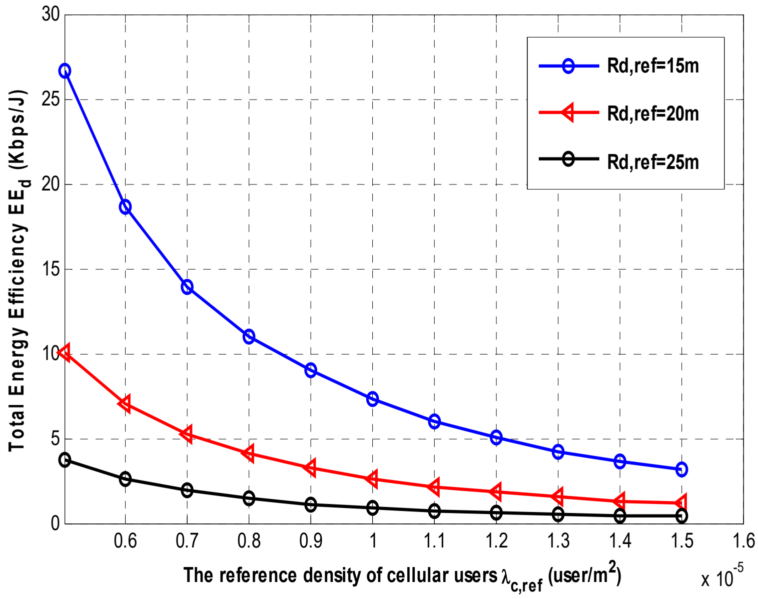

Figure 7. The energy efficiency of D2D users against the reference density of cellular users by using the modified derivative algorithm with different parameters.

Figure 8 shows the energy efficiency of D2D users versus the reference density of D2D users by using the modified derivative algorithm with different parameters. We assumed an uplink environment where 8 multiple bands of the spectrum with a bandwidth 25 MHz are shared by cellular and device users and $\lambda_{d,ref} = 10^{-4}$, $\lambda_{c,ref} = 10^{-5}$. As the

D2D users increased, the EE rose and then it slowly decreased if the cellular user's transmission power is 325 mW, 375 mW, and 425 mW are fixed. This is a result of the increasing distortion brought on by cellular transmission. We also observed that EE decreases with the increase in cellular power because the increase in cellular power creates interference.

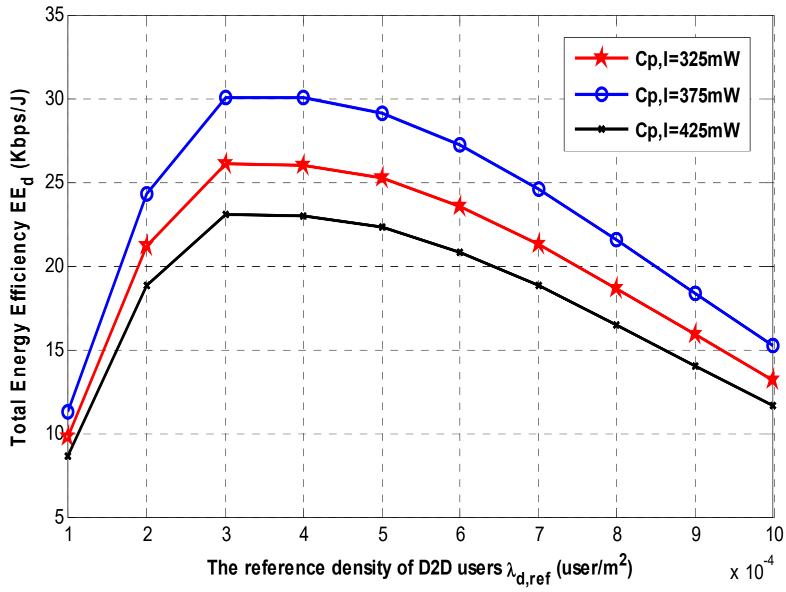

Figure 8. The energy efficiency of D2D users versus the reference density of D2D users by using the modified derivative algorithm with different parameters.

Figure 9 shows the graph between D2D power and EE. We observed that initially, EE rises with D2D power until the maximum point after which EE decreases with D2D power. In Figure 9, the feasible area lies to the left of the dashed line. Then $f_i(D_{p,i})$ grows steadily in the feasible area, hence $f_i(D_{p,i})$ reaches its highest value at $D_{p,i} = D_{p,i,sup}$ which results from $D_{p,i,max} = D_{p,i,sup}$, and the feasible area lies to the right of the dashed line, then $f_i(D_{p,i})$ uniformly drops in the feasible area.

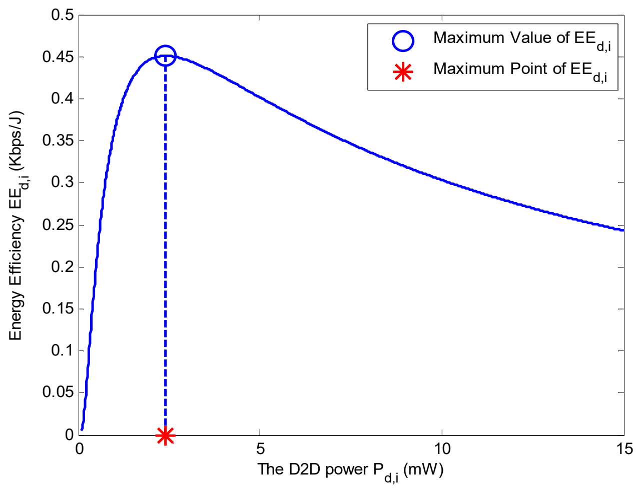

Figure 9. EE against D2D power.

5. Comparison of Simulation Results

Tables 4 and 5 show the comparison of EE of the proposed derivative algorithm with the conventional derivative algorithm for both D2D users' density and cellular users' density, respectively. We observed that the EE of the proposed derivative algorithm is better than the conventional derivative algorithm.

Table 4. Comparison of energy efficiency with the D2D density users (users/m^2).

D2D User Density (user/m^2)	Total Energy Efficiency (Kbps/J) with $C_{p,I}$ = 325 mW		Total Energy Efficiency (Kbps/J) with $C_{p,I}$ = 375 mW		Total Energy Efficiency (Kbps/J) with $C_{p,I}$ = 425 mW	
	Derivative Algorithm	Modified Derivative Algorithm	Derivative Algorithm	Modified Derivative Algorithm	Derivative Algorithm	Modified Derivative Algorithm
1×10^{-4}	4.230	5.750	3.683	1.564	3.252	1.398
2×10^{-4}	10.056	11.573	8.766	8.262	7.750	7.265
3×10^{-4}	15.664	20.004	13.604	16.373	11.980	14.393
4×10^{-4}	18.772	26.609	16.289	22.486	14.330	19.766
5×10^{-4}	20.064	30.182	17.403	25.811	15.305	22.688
6×10^{-4}	19.803	30.981	17.174	26.640	15.101	23.417
7×10^{-4}	18.445	29.718	15.994	25.629	14.062	22.529
8×10^{-4}	16.450	27.148	14.263	23.453	12.539	20.616
9×10^{-4}	14.187	23.904	12.300	20.673	10.813	18.172
1.0×10^{-3}	11.915	20.451	10.330	17.699	9.081	15.558

Table 5. Comparison of energy efficiency with the cellular density users (user/m^2).

Cellular User Density (user/m^2)	Total Energy Efficiency (Kbps/J) with $R_{d,ref}$ = 15 m		Total Energy Efficiency (Kbps/J) with $R_{d,ref}$ = 20 m		Total Energy Efficiency (Kbps/J) with $R_{d,ref}$ = 25 m	
	Derivative Algorithm	Modified Derivative Algorithm	Derivative Algorithm	Modified Derivative Algorithm	Derivative Algorithm	Modified Derivative Algorithm
0.5×10^{-5}	7.644	10.851	4.780	7.045	2.153	3.278
0.6×10^{-5}	5.460	7.669	3.366	4.912	1.505	2.271
0.7×10^{-5}	4.138	5.760	2.509	3.632	1.113	1.666
0.8×10^{-5}	3.277	4.526	1.949	2.802	0.857	1.275
0.9×10^{-5}	2.684	3.682	1.563	2.234	0.681	1.007
1×10^{-5}	2.258	3.079	1.285	1.827	0.554	0.816
1.1×10^{-5}	1.942	2.635	1.077	1.525	0.459	0.674
1.2×10^{-5}	1.702	2.298	0.917	1.294	0.387	0.566
1.3×10^{-5}	1.516	2.038	0.791	1.113	0.330	0.481
1.4×10^{-5}	1.369	1.833	0.690	0.969	0.285	0.414
1.5×10^{-5}	1.251	1.670	0.607	0.851	0.248	0.360

6. Conclusions

Device-to-device communication is paving the way for many future realities such as the Internet of Things and smart cities. This improves the spectrum efficiency and energy efficiency, reduces the latency, and enhances the network throughput. In this work, a modified derivative algorithm was proposed to optimize the energy efficiency of the entire cellular network underlaid with device-to-device communication. We developed the model for the derivative algorithm and the modified derivative algorithm in a MATLAB and we compared the energy efficiency with the cellular density users and energy efficiency with the D2D density users of both the models. From our simulation results, we assumed an uplink environment where 5, 8 multiple bands of the spectrum with bandwidth 25 MHz are shared by cellular and device users. The modified derivative algorithm energy efficiency improved when compared with the derivative algorithm. Numerical results confirmed the proposed algorithm's nearly ideal performance. It is possible to look at the optimal D2D user and cellular density for each band as well as the associated trade-off analyses. We concluded that this algorithm can be used for 5G applications due to its high energy efficiency.

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References

1. Tehrani, M.N.; Uysal, M.; Yanikomeroglu, H. Device-to-device communication in 5G cellular networks: Challenges, solutions, and future directions. *IEEE Commun. Mag.* **2014**, *52*, 86–92. [CrossRef]
2. Lin, X.; Jeffrey, A.; Amitava, G.; Rapeepat, R. An Overview on 3GPP Device-to-Device Proximity Services. *IEEE Commun. Mag.* **2014**, *52*, 40–48. [CrossRef]
3. Liu, J.; Kato, N.; Ma, J.; Kadowaki, N. Device-to-Device Communication in LTE-Advanced Networks: A Survey. *IEEE Commun. Surv. Tutor.* **2014**, *17*, 1923–1940. [CrossRef]
4. Wei, L.; Hu, R.Q.; Qian, Y.; Wu, G. Enable device-to-device communications underlaying cellular networks: Challenges and research aspects. *IEEE Commun. Mag.* **2014**, *52*, 90–96. [CrossRef]
5. Datsika, E.; Antonopoulos, A.; Zorba, N.; Verikoukis, C. Greenco-operative device-to-device communication: A social-aware perspective. *IEEE Access* **2016**, *4*, 3697–3707. [CrossRef]
6. Feng, D.; Yu, G.; Xiong, C.; Yi, Y.; Li, G.; Feng, G.; Li, S. Mode Switching for Energy-Efficient Device-to-Device Communications in Cellular Networks. *IEEE Trans. Wirel. Commun.* **2015**, *14*, 6993–7003. [CrossRef]
7. Wei, L.; Hu, R.Q.; Li, Q.C.; Wu, G. Energy-efficiency of multi-hop device-to-device communications underlaying cellular networks. In Proceedings of the 2014 IEEE International Conference on Communications (ICC), Sydney, NSW, Australia, 10–14 June 2014; pp. 5486–5491. [CrossRef]
8. Wu, Y.; Wang, J.; Qian, L.; Schober, R. Optimal Power Control for Energy Efficient D2D Communication and Its Distributed Implementation. *IEEE Commun. Lett.* **2015**, *19*, 815–818. [CrossRef]
9. Abrol, A.; Jha, R.K. Power Optimization in 5G Networks: A Step towards GrEEn Communication. *IEEE Access* **2016**, *4*, 1355–1374. [CrossRef]
10. Jiang, Y.; Liu, Q.; Zheng, F.; Gao, X.; You, X. Energy-Efficient Joint Resource Allocation and Power Control for D2D Communications. *IEEE Trans. Veh. Technol.* **2015**, *65*, 6119–6127. [CrossRef]
11. Zhou, Z.; Dong, M.; Ota, K.; Wu, J.; Sato, T. Energy Efficiency and Spectral Efficiency Tradeoff in Device-to-Device (D2D) Communications. *IEEE Wirel. Commun. Lett.* **2014**, *3*, 485–488. [CrossRef]
12. Hoang, T.D.; Le, L.B.; Le-Ngoc, T. Energy-efficient resource allocation for D2D communications in cellular networks. In Proceedings of the 2015 IEEE International Conference on Communications (ICC), London, UK, 8–12 June 2015; pp. 2251–2256. [CrossRef]
13. Ye, Q.; Al-Shalash, M.; Caramanis, C.; Andrews, J.G. A tractable model for optimizing device-to-device communications in downlink cellular networks. In Proceedings of the 2014 IEEE International Conference on Communications (ICC), Sydney, NSW, Australia, 10–14 June 2014; pp. 2039–2044. [CrossRef]
14. Shalmashi, S.; Bjornson, E.; Kountouris, M.; Sung, K.W.; Debbah, M. Energy efficiency and sum rate when massive MIMO meets device-to-device communication. In Proceedings of the 2015 IEEE International Conference on Communication Workshop (ICCW), London, UK, 8–12 June 2015; pp. 627–632. [CrossRef]
15. Mahfoudhi, M.; Hamdi, M.; Zaied, M. Distributed Resource Allocation Using Iterative Combinatorial Auction for Device-to-Device Underlay Cellular Networks. In Proceedings of the 15th International Wireless Communications & Mobile Computing Conference (IWCMC), Tangier, Morocco, 24–28 June 2019; pp. 2043–2049. [CrossRef]
16. Ji, Z.; Kiani, A.K.; Qin, Z.; Ahmad, R. Power Optimization in Device-to-Device Communications: A Deep Reinforcement Learning Approach with Dynamic Reward. *IEEE Wirel. Commun. Lett.* **2020**, *10*, 508–511. [CrossRef]
17. Hmila, M.; Fernández-Veiga, M.; Rodríguez-Pérez, M.; Herrería-Alonso, S. Energy Efficient Power and Channel Allocation in Underlay Device to Multi Device Communications. *IEEE Trans. Commun.* **2019**, *67*, 5817–5832. [CrossRef]
18. He, C.; Tian, C.; Zhang, C.; Feng, D.; Pan, C.; Zheng, F.-C. Energy Efficiency Optimization for Distributed Antenna Systems with D2D Communications Under Channel Uncertainty. *IEEE Trans. Green Commun. Netw.* **2020**, *4*, 1037–1047. [CrossRef]

19. Chen, R.; Shi, F.; Zhao, C. A Novel Energy-Efficient Power Allocation for D2D Communications Underlaying Cellular Network. In Proceedings of the 11th International Conference on Wireless Communications and Signal Processing (WCSP), Xi'an, China, 23–25 October 2019; pp. 1–6. [CrossRef]
20. Yu, X.; Wang, G.; Teng, T.; Li, N.; Wang, H. Energy Efficiency Optimization for D2D Communication Underlaying Distributed Antenna System. *IEEE Trans. Green Commun. Netw.* **2018**, *3*, 26–36. [CrossRef]
21. Hashad, O.; Fouda, M.M.; Eldien, A.S.T.; Mohamed, E.M.; Elhalawany, B.M. Resources Allocation in Underlay Device-to-Device Communications Networks: A Reduced-Constraints Approach. *IEEE Access* **2020**, *8*, 228891–228904. [CrossRef]
22. Penchala, S.; Nayak, D.K.; Ramadevi, B. Survey on Massive MIMO System with Underlaid D2D Communication. In *Intelligent System Design*; Advances in Intelligent Systems and Computing Book Series; Satapathy, S., Bhateja, V., Janakiramaiah, B., Chen, Y.W., Eds.; Springer: Singapore, 2021; Volume 1171.
23. Nagapuri, L. A Review on Massive MIMO for 5G Systems: Its Challenges on Multiple Phases. In *Intelligent System Design*; Advances in Intelligent Systems and Computing Book Series; Satapathy, S., Bhateja, V., Janakiramaiah, B., Chen, Y.W., Eds.; Springer: Singapore, 2021; Volume 1171.
24. Zhang, Y.; Yang, Y.; Dai, L. Energy Efficiency Maximization for Device-to-Device Communication Underlaying Cellular Networks on Multiple Bands. *IEEE Access* **2016**, *4*, 7682–7691. [CrossRef]
25. Haenggi, M. *Stochastic Geometry for Wireless Networks*; Cambridge University Press: Cambridge, UK, 2012. [CrossRef]
26. Akhtar, I.; Kirmani, S.; Ahmad, M.; Ahmad, S. Average Monthly Wind Power Forecasting Using Fuzzy Approach. *IEEE Access* **2021**, *9*, 30426–30440. [CrossRef]
27. Devi, A.; Ramya, K.C.; Kumar, K.S.; Ahmad, S.; Kadry, S.; Park, H.J.; Kang, B.G. Energy aware metaheuristic optimization with location aided routing protocol for MANET. *CMC Comput. Mater. Contin.* **2022**, *71*, 1567–1580.
28. Sathish Kumar, L.; Ahmad, S.; Routray, S.; Prabu, A.V.; Alharbi, A.; Alouffi, B.; Rajasoundaran, S. Modern Energy Optimization Approach for Efficient Data Communication in IoT-Based Wireless Sensor Networks. *Wirel. Commun. Mob. Comput.* **2022**, *2022*, 7901587. [CrossRef]
29. Khalaf, O.I.; Abdulsahib, G.M. Energy Efficient Routing and Reliable Data Transmission Protocol in WSN. *Int. J. Adv. Soft Comput. Appl.* **2020**, *12*, 45–53.
30. Khalaf, O.I.; Abdulsahib, G.M.; Sabbar, B.M. Optimization of Wireless Sensor Network Coverage using the Bee Algorithm. *J. Inf. Sci. Eng.* **2020**, *36*, 377–386.
31. ElSawy, H.; Hossain, E.; Alouini, M.-S. Analytical Modeling of Mode Selection and Power Control for Underlay D2D Communication in Cellular Networks. *IEEE Trans. Commun.* **2014**, *62*, 4147–4161. [CrossRef]
32. Wen, S.; Zhu, X.; Lin, Z.; Zhang, X.; Yang, D. Optimization of interference coordination schemes in Device-to-Device(D2D) communication. In Proceedings of the 7th International Conference on Communications and Networking in China, Kunming, China, 8–10 August 2012; pp. 542–547. [CrossRef]
33. Gu, J.; Bae, S.J.; Choi, B.-G.; Chung, M.Y. Dynamic power control mechanism for interference coordination of device-to-device communication in cellular networks. In Proceedings of the 2011 Third International Conference on Ubiquitous and Future Networks (ICUFN), Dalian, China, 15–17 June 2011; pp. 71–75. [CrossRef]
34. Lee, N.; Lin, X.; Andrews, J.G.; Heath, R.W. Power Control for D2D Underlaid Cellular Networks: Modeling, Algorithms, and Analysis. *IEEE J. Sel. Areas Commun.* **2014**, *33*, 1–13. [CrossRef]
35. Jameel, F.; Hamid, Z.; Jabeen, F.; Zeadally, S.; Javed, M.A. A Survey of Device-to-Device Communications: Research Issues and Challenges. *IEEE Commun. Surv. Tutor.* **2018**, *20*, 2133–2168. [CrossRef]
36. Al-Falahy, N.; Alani, O.Y. Technologies for 5G Networks: Challenges and Opportunities. *IT Prof.* **2017**, *19*, 12–20. [CrossRef]
37. Lin, X.; Heath, R.W.; Andrews, J.G. The Interplay Between Massive MIMO and Underlaid D2D Networking. *IEEE Trans. Wirel. Commun.* **2015**, *14*, 3337–3351. [CrossRef]
38. Lin, Z.; Niu, H.; An, K.; Wang, Y.; Zheng, G.; Chatzinotas, S.; Hu, Y. Refracting RIS Aided Hybrid Satellite-Terrestrial Relay Networks: Joint Beamforming Design and Optimization. *IEEE Trans. Aerosp. Electron. Syst.* **2022**, *58*, 3717–3724. [CrossRef]
39. Lin, Z.; Lin, M.; Champagne, B.; Zhu, W.-P.; Al-Dhahir, N. Secure and Energy Efficient Transmission for RSMA-Based Cognitive Satellite-Terrestrial Networks. *IEEE Wirel. Commun. Lett.* **2020**, *10*, 251–255. [CrossRef]
40. Su, Z.; Feng, W.; Tang, J.; Chen, Z.; Fu, Y.; Zhao, N.; Wong, K.-K. Energy Efficiency Optimization for D2D Communications Underlaying UAV-assisted Industrial IoT Networks with SWIPT. *IEEE Internet Things J.* **2022**. [CrossRef]
41. Su, Z.; Tang, J.; Feng, W.; Chen, Z.; Fu, Y.; Wong, K.-K. Energy Efficiency Optimization for D2D communications in UAV-assisted Networks with SWIPT. In Proceedings of the 2021 IEEE Global Communications Conference (GLOBECOM), Madrid, Spain, 7–11 December 2021; pp. 1–7. [CrossRef]
42. Zhang, R.; Qi, C.; Li, Y.; Ruan, Y.; Wang, C.-X.; Zhang, H. Towards Energy-Efficient Underlaid Device-to-Device Communications: A Joint Resource Management Approach. *IEEE Access* **2019**, *7*, 31385–31396. [CrossRef]