Received July 31, 2018, accepted September 3, 2018, date of publication September 10, 2018, date of current version October 8, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2869151

Power Optimization Assisted Interference Management for D2D Communications in mmWave Networks

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This work was supported by the National Science and Technology Major Project of the Ministry of Science and Technology of China under Grant 2017ZX03001028.

ABSTRACT Aiming at the problem of aggravated interference caused by the increasing number of devices, a transmitting power optimization algorithm is proposed, which combines the device association and beamwidth selection. In the premise of guaranteeing, the authenticity of millimeter wave (mmWave) application scenario, an mmWave device-to-device (D2D) network model is introduced, which integrates the roll off feature of Gaussian directional antenna model and the reflectivity of two-ray channel model. Specifically, the device association performed through distributed framework, and the beamwidth scheme optimized by the particle swarm optimization (PSO) algorithm, solve the non-convexity problem of transmitting power optimization in mmWave D2D networks. Simulation results indicate that, compared with the existing interference management algorithms which ignore the transmitting power of devices, the proposed algorithm can effectively reduce the transmitting power and interference, and the superior performance can be achieved.

INDEX TERMS Millimeter wave, device-to-device, device association, beamwidth, power optimization.

I. INTRODUCTION

In recent years, wireless communications working in the millimeter wave (mmWave) band has emerged as one of the important means to circumvent the spectrum shortage problem in the future network [1]. The transmission in mmWave band is highly directional, but the large path loss and less multipath are serious issues in mmWave band [2]. Due to the smaller wavelength of mmWave, more antennas are installed in the same area. Therefore, both the transmitter and receiver can be equipped with a large number of antennas, which can achieve an efficient beamforming technology to compensate for the attenuation of higher frequencies [3]. In addition to mmWave communication, device-to-device (D2D) communication is another key enabler of the next-generation wireless network, which allows mobile devices to establish direct connections without traversing the base station [4], [5]. The goal is to reduce the traffic load and signaling overhead of the base station, increase the spectrum efficiency and improve the experience quality of the cell edge user. Therefore, D2D communication is conceived as an attractive additional function of mmWave networks for improving network capacity by establishing a connection between two mobile devices [6].

In general, the radiation pattern of a directional antenna is modeled in an idealized manner, namely a large constant antenna gain is produced by a narrow beam main lobe and the antenna gain that approaches zero is produced by the other side lobes [7]–[9]. However, only two constant gains are used to characterize the main lobe and the side lobe respectively in the sector antenna model, and there is no conversion between them. An obvious disadvantage of this idealized model is that the critical ''roll-off'' feature of the directional antenna's actual radiation pattern (the gradual attenuation from the main lobe to the side lobes) is not reflected and the resulting discontinuity may seriously affect the system performance evaluation [10]. Furthermore, it has been shown that, first-order reflections cannot be ignored in mmWave communications [11]–[13]. However, in most of preceding works (e.g., [14]–[16]), the effects of ground reflections (first-order reflections) are rarely included since it is widely and profoundly believed that ground reflections are not the dominant impact factor of performance evaluation.

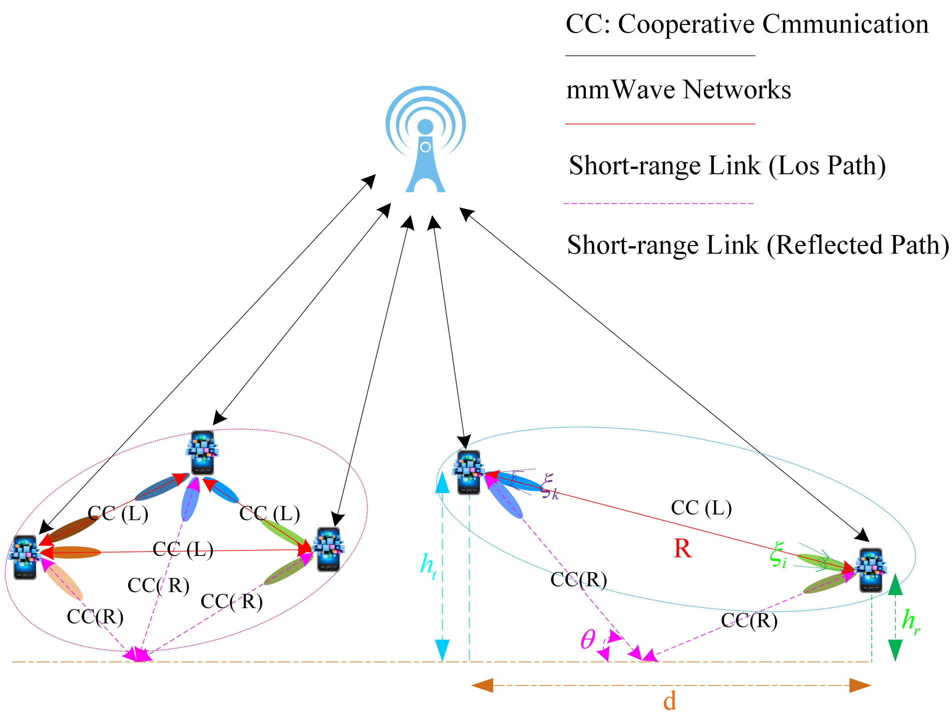

FIGURE 1. Network model.

Due to the omission of non-negligible (or destructive) effects of reflections, the traditional channel models for mmWave radios (based on the line of sight (LoS) path only) may result in a significant overestimation (or underestimation) in the performance evaluation [17].

Generally, a basic problem concerned with beamforming technology is to optimize the transmitting power under the signal to interference plus noise ratio (SINR) constraint of each device [18]. Nevertheless, it is commonly believed that the transmitting power of device is small. Hence the wastage of transmitting power is not considered under a mmWave D2D communications environment. However, as the number of deployed devices increases dramatically in the next generation networks, the interference increases accordingly, which would seriously affect the system performance without considering the wastage of transmission power. Meanwhile, as a means of accessing the network, device association connects the receiver to a suitable transmitter, which is a key process in cellular communications [19]. However, in most of preceding works (e.g., [20]–[23]), receivers and transmitters are associated with each other based on the maximum SINR, the maximum received power or random matching. These device association schemes do not consider the transmitter transmission power issue and utilize the centralized algorithm, which has high computational complexity and is difficult to implement.

In order to overcome the oversimplification of the traditional directional antenna model and the limitation of the mmWave traditional channel model, a mmWave D2D network model integrating a Gaussian directional antenna model and a two-ray channel model is established based on the above analysis, and a transmission power optimization algorithm based on device association and beamwidth selection is proposed. Particularly, the distributed framework is used for device association, and the particle swarm optimization (PSO) algorithm in swarm intelligence is used to search and select the optimal transmission and receiving beamwidth efficiently and quickly. Furthermore, the non-convexity problem of optimizing the transmitting power in mmWave D2D networks can be jointly solved by the above methods.

The rest of this paper is organized as follows. In Section II, we present the proposed mmWave D2D network model and scenario description. Section III describes the transmitting power optimization problem as an optimization problem and proposes a solution, and the proposed algorithm performance is analyzed in Section IV. Section V concludes this paper.

II. NETWORK MODEL AND SCENARIO DESCRIPTION

As shown in Figure 1, for mmWave D2D networks, it is assumed that all transmitters have the same height as h_t, all receivers heights are h_r, ξ_k is the transmission main lobe beamwidth of mmWave transmitters, and the beamwidth of the main lobe received by the receiver is ξ_i, θ represents the reflection with respect to the ground plane, R and d are the distance and horizontal distance between the transmitter and receiver, respectively. Considering that each transmitter is equipped with an N_t-element antenna array,

N_{RF} radio frequency (RF) chains serve multiple receivers, where an inherent constraint is $1 \leq N_{RF} \leq N_t$ and each RF chain serves only one receiver at a time, while the transmitters can serve multiple receivers simultaneously by using the different RF chains [24].

Usually, the directional gain of common sector antenna model is constant for all angles in the main lobe, and the side lobe gain is equal to a small constant in an ideal sector antenna pattern [25]. However, the real radiation pattern has the "roll-off" characteristics, but for the sector model, small disturbances and misalignments between the transmitter and the receiver will not affect the signal gain. As a result, a Gaussian directional antenna model which is similar to the sector antenna model is used in this paper [26], [27], but the model has the characteristic of smooth "roll-off". In this model, ω is set as the direction angle with respect to the boresight, and the antenna gain along this direction is expressed as follows

$$G_{i,k}^{tx/rx}(\omega) = \frac{2\pi}{S(\xi_m, \xi_h) + 2\pi - \xi_m} 10^{\frac{3}{10}\left[\frac{\xi_m^2 - 4\omega^2}{\xi_h^2}\right]_+}, \quad (1)$$

where $[*]_+ \triangleq \max\{*, 0\}$, ξ_h represents the half-power beamwidth, ξ_m denotes the main lobe beamwidth, and $S(\xi_m, \xi_h)$ is defined as

$$S(\xi_m, \xi_h) \triangleq \int_0^{\xi_h} 10^{\frac{3}{10}\left(\frac{\xi_m^2 - x^2}{\xi_h^2}\right)} dx. \quad (2)$$

In general, the mmWave two-ray model considers two major coexisting transmission paths, namely the LoS and the reflection paths [28]. By using Friis transmission formula, the received signal power is written as $P_r = P_t \cdot |h|^2$, where P_t is the transmitting power. Therefore, when the ground transmission is considered, the channel coefficient h is

$$h = \frac{\lambda(G(0) + G(\theta)\Psi(\theta)\cos(\theta)e^{-j\Delta\varphi})}{4\pi R}, \quad (3)$$

where λ is the length of the mmWave carrier, $G(*)$ represents the radiation pattern of a directional antenna, R is the distance between the transmitter and the receiver, $\theta = \arctan(\frac{h_t + h_r}{d})$ indicates the reflection angle with respect to the ground plane, $\Delta\varphi = \frac{2\pi}{\lambda}(\sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2})$ is the phase difference, $\Psi(\theta) = \frac{\sin\theta - \Lambda(\theta)}{\sin\theta + \Lambda(\theta)}$ represents the reflection coefficient. Meanwhile, with respect to vertical and horizontally polarized electromagnetic waves, $\Lambda(\theta)$ is denoted as

$$\Lambda(\theta) = \begin{cases} \varepsilon^{-1}\sqrt{\varepsilon - \cos^2(\theta)}, & \textit{verti.polarization} \\ \sqrt{\varepsilon - \cos^2(\theta)}, & \textit{horiz.polarization} \end{cases} \quad (4)$$

where ε denotes the dielectric constant of ground.

Next, the corresponding explanation will be given for the roles of the beam alignment process and the beamwidth selection in the proposed model. In general, both the transmitter and receiver establish mmWave D2D networks links with high directivity. Although the main lobe antenna gain of the beam pattern significantly improves the link budget, establishing a better mmWave D2D link between the transmitter and receiver nodes requires a time-consuming beam alignment process. Generally, a communication device finds the best sector-level beams through a series of pilot transmission signals firstly, and then the optimal beam is found within the selected sector area by searching at the corresponding nodes based on the current mmWave network technology standards.

As shown in Figure 2, $\theta_{i1,k1}^t$ and $\theta_{i1,k1}^r$ represent angles between the main lobe and the light-of-sight direction of transmitter k_1 and receiver i_1, respectively. $\xi_{i2,k2}^t$ and $\xi_{i2,k2}^r$ denote the transmission and receiving main lobe beamwidth of transmitter k_2 and receiver i_2, respectively. It is clear that the higher link budget can be achieved by using the narrower beams, which in turn leads to an excessive beam training overhead. It is shown that the beam-training overhead by tracking device sector-level can be greatly reduced over time [29]. Thus, without loss of generality, it is assumed that the transmitter has already known which sector the relevant receiver is located prior at the beam alignment phase.

In the phase of beam alignment, the corresponding node uses a set of pilot transmission signal vectors to align its beams by searching over all possible combinations of beam. Assume the T_p denoting the time required for a single pilot transmission of each combination. Therefore, using the exhaustive search method adopted by the existing mmWave standard [30], [31], the overall duration τ_{ik} of the alignment phase between the k-th mmWave transmitter and the i-th receiver can be expressed as

$$\tau_{ik} = T_p \frac{\psi_k^t \psi_i^r}{\xi_{ik}^t \xi_{ik}^r}, \quad (5)$$

where ξ_{ik}^r and ξ_{ik}^t are the receiving beamwidth of receiver i and the transmission beamwidth of transmitter k which transmits the data to receiver i, respectively, ψ indicates the sector-level beamwidth. After completing the beam alignment process, the optimal direction of data transmission and reception is determined, and a mmWave D2D networks link is established to start the data transmission phase. It is worth noting that the alignment time can not exceed the time slot duration T. Therefore, the feasible domain is constrained as follows

$$\psi_k^t \psi_i^r \frac{T_p}{T} \leq \xi_{ik}^t \xi_{ik}^r. \quad (6)$$

Since beam alignment occurs within the beamwidth at the sector level, there are

$$\xi_{\min}^r \leq \xi_{ik}^r \leq \psi_i^r, \quad (7)$$
$$\xi_{\min}^t \leq \xi_{ik}^t \leq \psi_k^t, \quad (8)$$

where $\xi_{\min}^r$ and $\xi_{\min}^t$ are the minimum possible operation beamwidth for the receiver and the transmitter, respectively, and they depend on the number of antenna elements implemented in the device and the antenna configuration.

Furthermore, the SINR of the i-th receiver is defined as

$$SINR_i = \frac{p_k^t G_k^t G_{k,i}^c G_i^r}{N + I_0}, \quad (9)$$

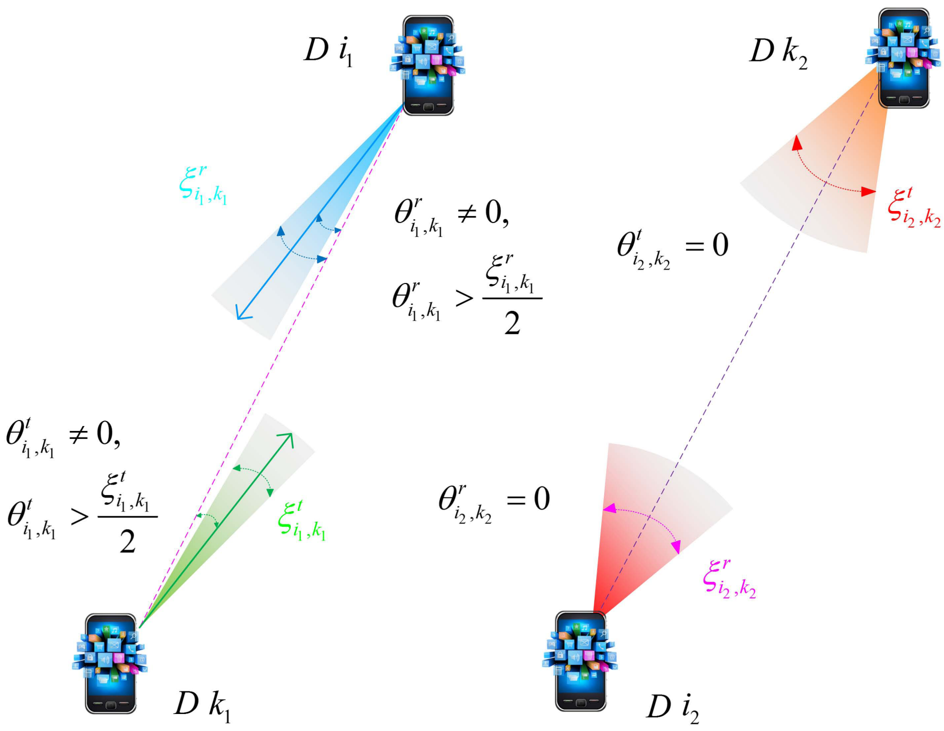

FIGURE 2. Beam alignment between transmitter and receiver.

where p_k^t is the transmitting power of the k-th mmWave transmitter, G_k^t and G_i^r are the gains of the transmitting antenna at the k-th mmWave transmitter and that of the receiving antenna for the i-th receiver, respectively. The channel gain $G_{k,i}^c$ from the k-th mmWave transmitter to the i-th receiver is defined as $G_{k,i}^c \triangleq |h_{k,i}|^2$, and $h_{k,i}$ is the channel coefficient from the k-th mmWave transmitter to the i-th receiver, I_0 represents the interference suffered by the i-th receiver, and N is the noise power.

Therefore, according to the Shannon formula, the maximum sum rate of the i-th receiver is

$$Rate_i = (1 - \frac{\tau_{ik}}{T})B\log_2(1 + SINR_i), \tag{10}$$

where B is mmWave bandwidth. Meantime, it can be noticed that the sum rate depends on the transmitting power, beamwidth and network topology. In addition, the narrow beamwidth of data transmission and reception improves the SINR of receiver. Nevertheless, the gain is achieved at the cost of increased adjustment overhead and less packet transmission time. Therefore, a trade-off between the time consumed by the beam alignment process and the effective rate needs to be made.

III. DEVICE ASSOCIATION AND BEAMWIDTH SELECTION

A. PROBLEM STATEMENT

In this paper, the problem of joint device association and beamwidth selection in mmWave D2D networks is considered. The optimization problem is to optimize the transmitting power of the transmitters in essence. The transmission power of each transmitter is optimized, and the energy can be saved in the mmWave D2D networks. Meanwhile, the interference can be suppressed. Thus, the optimization problem is constructed as

$$Minimize \left\{ \sum_{k=1}^{L} p_k^t \right\} \tag{11a}$$
$$0 \le p_k^t \le P_{\max} \tag{11b}$$
$$SINR_i \ge \gamma \tag{11c}$$
$$\xi_{i,k}^t \xi_{i,k}^r \ge \frac{T_p}{T} \psi_k^t \psi_i^r \tag{11d}$$
$$\xi_{\min}^t \le \xi_{ik}^t \le \psi_k^t \tag{11e}$$
$$\xi_{\min}^r \le \xi_{ik}^r \le \psi_i^r \tag{11f}$$

wherein the main optimized parameters are the transmitting power and the beamwidth. (11b) is a transmission power budget constraint for each transmitter, and Equation (11c) is the constraint that the SINR of each receiver must be higher than the threshold γ, which satisfies the quality of service (QoS) requirement to guarantee the basic communication. Furthermore, the constraint (11d) ensures that the search time in the beam alignment phase is less than the slot duration, the constraint described in (11e) limits the range of beamwidth transmitted by the transmitter, and (11f) limits the beamwidth range received by the receiver.

The feasible set of the optimization problem in (11) is non-convex, which is difficult to solve and calculate

TABLE 1. Device association algorithm.

The Proposed Device Association Algorithm	
1.	**Initialize** $p_k^{t,*} = \phi$, $p_k^t = 0$, $d_k^t = 0$ and $d_l^t = 0$;
	Repeat:
	Algorithm for each transmitter:
2.	Each transmitter collects receiver's location information;
3.	Each transmitter feedbacks the distance information d_k^t and d_l^t to the intra-class receivers and receivers of adjacent class respectively;
4.	Updates receiver's location information;
	Algorithm for each receiver:
5.	Each receiver collects the transmission power information p_k^t of transmitters that meet the conditions;
6.	Each receiver arranges the elements in the transmission power p_k^t of M transmitters that meet the conditions in ascending order to form a set $p_k^{t,*}$;
7.	Each receiver selects transmitter for the minimum transmission power $p_k^{t,*}(1)$ to pair;
8.	Updates transmitter's transmission power information;
9.	**Until convergence**

in general, especially in the environments with dense receivers and transmitters that require low complexity distributed solutions. Thus, the problem can be decomposed into two sub-problems: namely, device association and beamwidth selection. The device association is performed through a distributed framework, and a PSO algorithm in swarm intelligence is used to optimize the beamwidth.

B. DEVICE ASSOCIATION

In this section, in order to circumvent problem (11), a low complexity suboptimal algorithm for device association is proposed based on a distributed framework. The detailed process is illustrated in Table 1.

Transmitter side: The transmitter is only responsible for collecting the position information of the receivers. After the beamforming training operation is performed in advance, the receivers perform primary pairing with the beams of the transmitter in its own class and its adjacent classes. Although other association schemes, such as the highest received power and the maximum SINR, may be more favourable, they are performed at the expense of increased complexity and processing ability. Meanwhile, the device association of random matching scheme is uncertainty, resulting in a poor system performance. Moreover, a transmitter that is closer to the receiver is the least likely to suffer from the blocking, and it is most likely to provide the best received signal power. Therefore, the transmitter only needs to feed back its own receiver's distance information d_k^t and the distance information of the receivers in its neighboring classes d_l^t to the corresponding receivers.

Receiver side: The receiver is only responsible for collecting the transmission power information p_k^t of the transmitters. After completing the initial matching at the transmitter side, the transmission power information p_k^t is sent to the paired receivers. The elements in the transmission power p_k^t of the M transmitters that meet the conditions are in ascending order to form a set $p_k^{t,*}$. Specifically, $p_k^{t,*} = \left(p_k^{t,*}(1), p_k^{t,*}(2), \cdots, p_k^{t,*}(M)\right), p_k^{t,*}(1) < p_k^{t,*}(2) < \cdots < p_k^{t,*}(M)$, and then the transmitter with the smallest transmission power $p_k^{t,*}(1)$ is selected to be paired with the receiver.

C. BEAMWIDTH SELECTION

Once the transmitters and the receivers have completed the pairing with the above algorithm, the optimal transmission beamwidth and receiving beamwidth are selected by using the swarm intelligence method. The swarm intelligence approach relies on an interactive agent system governed by simple rules of conduction and the communication mechanisms among agents (such as those observed in certain insect and animal species) to effectively deal with convex and non-convex problems. This section will utilize the swarm intelligence's PSO algorithm [32] to optimize the search for the optimal transmission beamwidth and receiving beamwidth.

The PSO algorithm is an algorithm that simulates the foraging behavior of the flock of bees or birds. The basic idea is to find the optimal solution through the cooperation and information sharing among individuals in the group. Thus, assume that there are A candidate solutions $\{X^a\}_{a=1}^A$ in the method pool, a D-dimensional velocity vector $V_d^a = (v_1^a, \ldots, v_D^A)$, N nodes in the system and $D = 2N - 1$, and a set of particles is initialized at the beginning of the search process (solving the search problem for the optimal transmission and receiving beamwidth). First, a fixed beamwidth is pre-assigned for all the beams, and then a velocity vector is randomly and uniformly extracted in the range of $[0°, 90°]$ for each candidate solution. Next, each particle position is evaluated by the fitness criterion, i.e, the transmitting power minimization of the transmitter, so that a global optimum fitness value $f(X_d^{\perp})$ is searched according to the global optimum particle position $X_d^{\perp} = (x_1^{\perp}, \ldots, x_D^{\perp})$, and a single optimal position $X_d^{a,*} = (x_1^{a,*}, \ldots, x_D^{a,*})$ is also calculated for completing X^a. Based on the current velocity, the optimal position of the individual particles and the optimal position of the neighbor, the velocity is iteratively improved, and the specific process is described as follows

$$v_d^a = \delta v_d^a + \tau \Delta_\tau (x_d^{a,*} - x_d^a) + \sigma \Delta_\sigma (x_d^{\perp} - x_d^a), \quad (12)$$
$$x_d^a = x_d^a + v_d^a, \quad (13)$$

where δ is inertia weight, τ and σ are learning factors, the above parameters are used to control the search process of heuristic method. Δ_τ and Δ_σ are random variables following the uniform variation within [0, 1]. Meanwhile, $a \in \{1, \ldots, A\}$ and $d \in \{1, \ldots, D\}$ are satisfied. The search process repeats a fixed number of iterations I. The detailed process is shown in Table 2.

TABLE 2. Beamwidth selection algorithm.

The Proposed Beamwidth Selection Algorithm
Initialize v_d^a, and x_d^a;
set initial δ, τ, and σ;
Repeat
while $(i < I)$ **do**
for each particle $a = 1, \ldots, A$ **do**
if $f(x^a) < f(X_d^{a,*})$ **then**
$X_d^{a,*} = x^a$;
end if
if $f(X_d^{a,*}) < f(X_d^{\perp})$ **then**
$X_d^{\perp} = X_d^{a,*}$;
end if
end for
for each particle $a = 1, \ldots, A$ **do**
for each dimension d in D **do**
Update velocity: equation (12);
Update position: equation (13);
Update $X_d^{\perp}$ and $X_d^{a,*}$;
Evaluate objective function at the new location;
Find the optimal transmission and receiving beamwidth;
end for
end for
$i = i + 1$;
end while
Until convergence

IV. PERFORMANCE EVALUATIONS

In this section, the power optimization based mmWave D2D interference management algorithm is simulated and analyzed in mmWave D2D scenario. For better analysis, it is assumed that all receivers are in the same horizontal plane, the transmitters and the receivers have the same height. Assume that the mmWave radio characteristic is vertical polarization, and the maximum transmission power of the mmWave transmitter is $p_k^{\max} = 32$ mW, a fixed beamwidth $\xi = 15°$ is pre-allocated for all the beams by the PSO algorithm. Since the simulation is random, 1000 experiments are performed. Table 3 summarizes the detailed simulation parameters.

Figure 3 shows the variation of transmitting power of different devices under the PSO algorithm. Assume that there are two receivers in each class. Since this paper mainly considers the power optimization in a mmWave D2D scenario, the dimension of mW is used to represent the transmitter transmitting power instead of dBm, which can be easily observed and the result can not be affected. As can be seen from the figure, the power transmitted by the transmitter to each receiver is less than its maximum value $p_k^{\max}$ at first. Afterwards, the transmitting power from the transmitter to each receiver tends to decrease with the number of iterations increases. This is because the fitness criterion of the PSO algorithm is set to minimize the transmitter transmitting power, and the optimal transmission and receiving beamwidth are iteratively searched based on the criterion. Meanwhile, due to the position of receiver is random and the interference situation is different, the power decreasing status of each receiver transmitted by the transmitter is inconsistent according to the receiver's different conditions. In addition, when the number of iterations achieves about 10 times, the power transmitted from the transmitter to each receiver converges rapidly.

TABLE 3. Simulation parameters.

Parameter	Values
Radius of each class, r_{class}	15 m
Number of classes, L	3
Carrier frequency, f	60GHz
Bandwidth, B	1.5GHz
Wavelength, λ	0.005 m
Peak transmit/slot time, T_p/T	0.01
Sector-level beamwidth, ψ	45°
Transmitter/Receiver Height, h_t, h_r	5 m
Noise power spectral density	-174 dBm/Hz
Ground dielectric constant, ε	15
Initial population number, A	30
Inertia weight, δ	0.7298
Learning factor, τ, σ	1.4962
Number of iterations, I	30

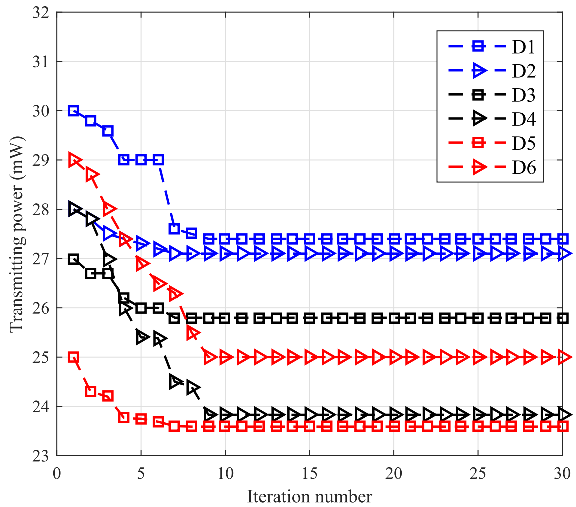

FIGURE 3. Variations of transmitting power of different devices based on the PSO.

Figure 4 considers the variation of SINR for different devices under the PSO algorithm. Assume that there are two receivers in each class and the SINR threshold of each receiver which meets the basic communication is set as $\gamma = 5$dB. It can be seen from the figure that the SINR of each receiver is greater than γ, which satisfies the minimum

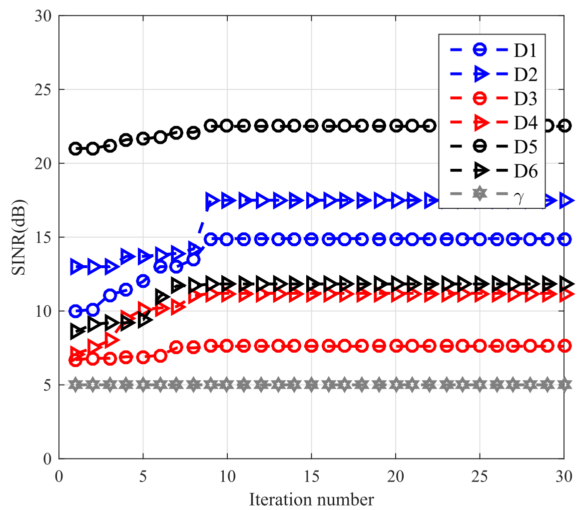

FIGURE 4. Variations of SINR for different devices based on the PSO.

SINR requirement and guarantees the receiver's basic communication. Secondly, with the increase of the number of iterations, the SINR of all receivers shows an upward trend. The reason is that in addition to ensure the basic services for each receiver, optimizing the transmission power of the transmitter can effectively suppress the interference to other receivers, so as to increase the SINR of receiver. However, due to the different interference situations of the receivers, the improved SINR by each receiver is different in the proposed algorithm.

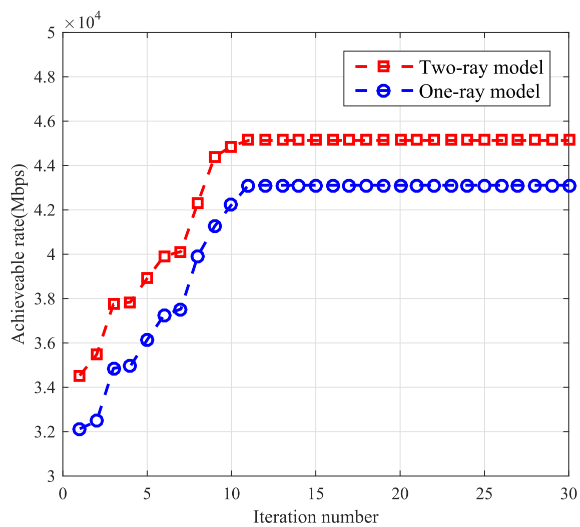

FIGURE 5. Effect of different channel models on the sum rate.

Figure 5 illustrates the effect of different channel models on the system sum rate. For convenient comparison, the one-ray channel model is used as a reference. This channel model only considers the LoS radiation from the transmitter to the receiver and the ground reflection is not included. Meanwhile, the model is considered as the traditional modeling method for mmWave D2D channel's LoS path. Assume that there are two receivers in each class. The figure shows that, the system sum rate of the two channel models increase with the number of iterations, and the sum rate converges when the number of iterations achieves about 10 times. Secondly, it can be seen that the sum rate of the proposed scheme exceeds that of the one-ray channel model, which is due to the influence of the ground reflection is considered. From formula (2), it can be seen that the channel coefficients are not only related to the direct path, but also affected by the ground transmission path. Since the class range is small in the mmWave D2D environment, the reflection component depends on the incident angle of the reflected signal, the radiation pattern of the directional antenna and the transmission distance. When the transmission distance is short, the ground reflection can affect the channel gain obviously, thereby the system sum rate of the mmWave D2D is improved.

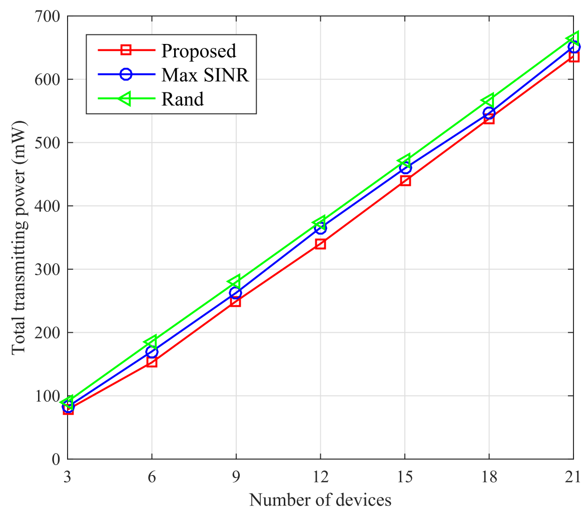

FIGURE 6. Total transmitting power with respect to the number of devices.

Figure 6 depicts the effect of different device associations on the total transmitting power. For comparison convenience, the maximum SINR and the random matching schemes are used as references, wherein the maximum SINR scheme is based on the receiver's maximum SINR to associate the transmitter with the receiver, and the random matching scheme performs random association between the receiver and the transmitter. As can be seen from the figure, with the number of receivers increases, the total transmitting power of the three device association schemes increases accordingly. Furthermore, from the perspective of total transmission power, in the case of the same number of receivers, random matching requires the highest total transmission power from the transmitters, the maximum SINR scheme requires less transmission power, and the proposed device association scheme requires the minimum transmission power. For the random matching scheme, it is possible for a receiver to randomly match a transmitter at a long distance. In order to ensure basic communication, the transmitter needs to transmit relatively large power to serve the receiver. This paper uses the fitness criterion set by the PSO algorithm to minimize the transmitter transmitting power, so that the sum of required transmitter transmitting power is the minimum in the same situation.

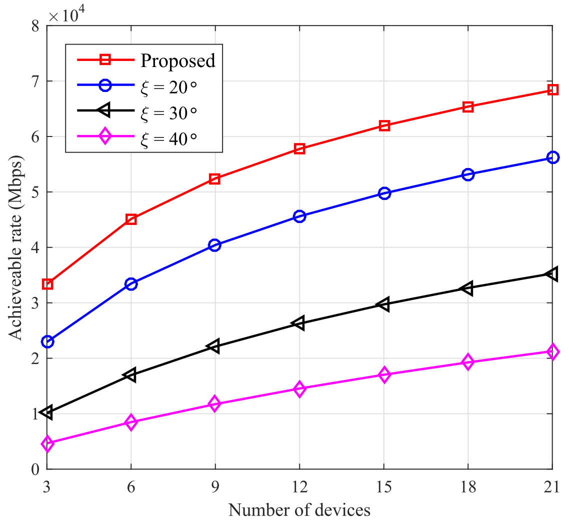

FIGURE 7. Influence of different beamwidths on the system sum rate.

Figure 7 describes the effect of different beamwidths on the system sum rate. The transmission beams of transmitter are set as different widths sequentially (e.g., $\xi = 20°, 30°, 40°$), and the transmission beamwidth of the transmitter is the same as the receiving beamwidth of the receiver. As can be seen from the figure, the system sum rate can also increase with the number of receivers. Meanwhile, it can be found that when the beamwidth decreases sequentially, the system sum rate increases in turn, and the proposed scheme presents the best performance. This is because the probability of interference caused by receiver beam overlapping decreases with the decrease of the beamwidth, and then the system sum rate increases in turn. The proposed scheme based on minimum transmitter transmitting power adaptive search for the optimal transmission and receiving beamwidth can suppress the interference and improve the system sum rate.

V. CONCLUSION

In this paper, aiming at the problem of aggravated interference caused by the increasing number of mmWave transmitters and receivers, a new algorithm based on device association and beamwidth selection is proposed to optimize the transmission power. The roll-off characteristic of the Gaussian antenna model and the reflectivity of the two-ray channel model are fully considered. In particular, the distributed framework is used for device association, and the PSO algorithm is used to effectively select the optimal transmission and receiving beamwidth, so as to jointly solve the problem of mmWave D2D transmitting power optimization. The simulation experiments show that, compared to the existing schemes, the proposed algorithm presents better performance in reducing the transmitter transmitting power, suppressing interference and increasing the system sum rate in mmWave D2D scenario.

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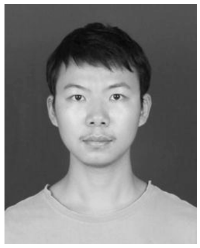

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