**Article**

**Data Rate Maximization in RIS-Assisted D2D Communication with Transceiver Hardware Impairments**

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**Abstract:** We maximize the transmit rate of device-to-device (D2D) in a reconfigurable intelligent surface (RIS) assisted D2D communication system by satisfying the unit-modulus constraints of reflecting elements, the transmit power limit of base station (BS) and the transmitter in a D2D pair. Since it is a non-convex optimization problem, the block coordinate descent (BCD) technique is adopted to decouple this problem into three subproblems. Then, the non-convex subproblems are approximated into convex problems by using successive convex approximation (SCA) and penalty convex-concave procedure (CCP) techniques. Finally, the optimal solution of original problem is obtained by iteratively optimizing the subproblems. Simulation results reveal the validity of the algorithm that we proposed to solve the optimization problem and illustrate the effectiveness of RIS to improve the transmit rate of the D2D pair even with hardware impairments.

**Keywords:** reconfigurable intelligent surface (RIS); device-to-device (D2D) communications; hardware impairments; block coordinate descent (BCD); successive convex approximation (SCA)

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**1. Introduction**

Device-to-device (D2D) communication has already been taken as a potential paradigm to support proximity-based applications [1]. By using D2D communication technique, proximity users in communication system can exchange information with each other without access to the base station (BS). It can reuse the spectrum of conventional cellular user to improve the spectral efficiency (SE) of communication systems by carefully suppressing interference [2,3]. On the other hand, it also can use unlicensed spectrum bands to communicate with each other, which can effectively alleviate inband spectrum needs. Authors in [4,5] investigated power-saving D2D communication based on WiFi interface. The resource allocation about unlicensed based D2D communication was discussed in [6,7]. Moreover, D2D communication is also very useful for communication devices that are far away from the BS [8–11].

Existing studies have shown great performance gains for communication system by using D2D communication. Mode selection strategies have been proposed by considering power and quality-of-service (QoS) requirements in the literature [12,13]. Efficient energy resource allocation in D2D communications assisted cellular communication systems have been considered in [14,15]. Furthermore, the minimization of total computing delay in RIS-assisted D2D communication by optimizing the task assignment, BS’s transmit power, bandwidth of the system and phase beamforming of reconfigurable intelligent surface (RIS)
was investigated in [16]. However, most of the existing works conducted investigations by assuming perfect hardware. In reality, hardware impairments such as phase noises and amplifier non-linearity cannot be ignored because they are not ideal for communication devices, which generally limit system performance [17]. Existing works have demonstrated that hardware impairments severely affect the system performance of the multiple-input multiple-output systems [18,19]. On the other hand, D2D communication still encounters some challenges such as limited communicating distance, severe interference and complicated communication environments, which can reduce the performance of D2D user. Hence, recent techniques include RIS as one of the promising methods that can provide extra communication channel to improve the communication environment. It is composed of many programmable reflecting elements that are able to control the reflections of impinging wireless signals [20,21]. Moreover, an RIS was deployed to assist the devices in their communication when direct communication channels are blocked by buildings or walls in [22]. Hence, RIS also can be used to improve the performance of D2D communication.

In this paper, we discuss maximizing the transmit rate of D2D in RIS-assisted D2D wireless communication system with hardware impairments subjecting to the transmit power constraints of BS and D2D pair and the unit-modulus constraints of RIS. It is very challenging to obtain optimal solutions due to the non-convexity of the problem. However, it can be decoupled into three subproblems by adopting the block coordinate descent (BCD) technique. Furthermore, by using owing successive convex approximation (SCA) and penalty convex-concave procedure (CCP) techniques, these subproblems are transformed into convex optimization problems. Then, we obtain optimal solutions in an iterative manner.

2. System Model and Problem Formulation

2.1. System Model

We investigate an RIS-assisted D2D wireless communication system, which is composed of one BS, one RIS, one user equipment (UE) and a D2D pair that is made up of a D2D-transmitting UE (DTUE) and a D2D-receiving UE (DRUE). The system model is shown in Figure 1. The BS is equipped with \( N \) antennas, the RIS has \( M \) passive reflecting elements and UE has single antenna. In this paper, we take hardware impairments of transceiver into the considered system. Specifically, the transmit signal from the BS to the cellular UE can be expressed as follows:

\[
s_u = w x_u + z_b, \quad (1)
\]

where \( w \in \mathbb{C}^{N \times 1} \) denotes transmit beamforming that is used for transmitting symbol \( x_u \) to the UE and \( x_u \sim \mathcal{CN}(0, 1) \). \( z_b \) denotes the distortion that is caused by hardware impairment of the BS. In particular, it includes zero-mean Gaussian variables, and the variance of the \( k \)th entry of \( z_b \) is proportional to the signal power of the \( k \)th antenna and \( z_b \sim \mathcal{CN}(0, \kappa_b \text{diag}\{ww^H\}) \), where \( \kappa_b \in [0, 1] \) denotes the hardware impairment coefficient of the BS.

For the DTUE in D2D, its transmit signal \( s_d \) to DRUE can be expressed as follows:

\[
s_d = x_d + z_{dt}, \quad (2)
\]

where \( x_d \) is the desired signal from DTUE to DRUE, and \( \mathbb{E}\{|x_d|^2\} = p_d \) is the transmit power of DTUE. \( z_{dt} \) is the hardware impairment distortion that caused by DTUE and \( z_{dt} \sim \mathcal{CN}(0, \kappa_{dt} p_d) \), where \( \kappa_{dt} \in [0, 1] \) describes the hardware impairment coefficient of DTUE.

The received signal of UE can be modeled as follows:

\[
y_u = (h_{du}^H + h_{ru}^H \Phi H)s_u + (g_{du} + h_{ru}^H \Phi g_{dt})s_d + n + z_u = \tilde{y}_u + z_u, \quad (3)
\]
where $h_u \in \mathbb{C}^{N \times 1}$, $h_{br} \in \mathbb{C}^{N \times 1}$ and $H \in \mathbb{C}^{M \times N}$ represent the communicating channel from the BS to the UE, DRUE and RIS, respectively. $\Phi = \text{diag}\{\phi_1, \ldots, \phi_i, \ldots, \phi_N\}$ is the reflection coefficient matrix, where $\phi_i = e^{j\theta_i}$, and $\theta_i$ denotes the phase shift parameter of the $i$th reflecting element of the RIS, and $h_{ru} \in \mathbb{C}^{M \times 1}$, $g_{dt} \in \mathbb{C}^{1 \times M}$ and $g_{du} \in \mathbb{C}$ denote the channels from the DTUE to DRUE, RIS and UE, respectively.

$z_u$ denotes the distortion noise at UE, which is independent from the input signal $\tilde{y}_u$. Note that $z_u$ obeys zero-mean Gaussian distribution, and its variance is proportional to the received power of the undistorted signal, i.e., $z_u \sim \mathcal{CN}(0, \kappa_u \mathbb{E}\{|\tilde{y}_u|^2\})$, where $\kappa_u \in [0, 1]$ is the hardware impairment coefficient of UE.

**Figure 1.** RIS-assisted D2D communication model.

Then, we have the following:

$$
\mathbb{E}\{|\tilde{y}_u|^2\} = f^H \left(ww^H + \kappa_u \text{diag}\{ww^H\}\right)f + (1 + \kappa_{dt})p_d \sigma_1^2 + \sigma^2. \quad (4)
$$

where $f^H = h_u^H + h_{ru}^H \Phi H$ and $S_1 = g_{du}^H \Phi g_{dt}$.

The signal to interference plus noise ratio (SINR) of the cellular UE can be written as follows:

$$
\text{SINR}_u = \frac{|f^H w|^2}{\kappa_u f^H w w^H f + (1 + \kappa_u) (1 + \kappa_{dt}) \sigma_1^2 + (1 + \kappa_u) \sigma^2}. \quad (5)
$$

where $S_1 = +(1 + \kappa_u)(1 + \kappa_{dt})p_d \sigma_1^2 + (1 + \kappa_u)\sigma^2$.

When DRUE receives signal $s_d$ from the DTUE, the received signal can be expressed as follows:

$$
y_{dr} = (g_d + g_{du}^H \Phi g_{dt}) s_d + (h_{ru}^H + g_{du}^H \Phi H) s_u + n + z_{dr}
\quad = \tilde{y}_{dr} + z_{dr}, \quad (6)
$$

where $z_{dr}$ is the hardware impairment coefficient of DRUE; $z_{dr} \sim \mathcal{CN}(0, \kappa_{dr} \mathbb{E}\{|\tilde{y}_{dr}|^2\})$, in which $\kappa_{dr}$ denotes the power proportional coefficient of DRUE.
According to (6), the variance of $z_{dr}$ can be formulated as follows:

$$
\mathbb{E}\{\|\tilde{y}_{dr}\|^2\} = h_1^H \left(ww^H + \kappa_b \text{diag}\{ww^H\} \right) h_1 + (1 + \kappa_{dt}) p_d S_2^2 + \sigma^2.
$$

where $S_2 = g_d + g_d^H \Phi g_d$ and $h_3^H = h_3^H + g_d^H \Phi H$. Then, we can formulate the SINR of DRUE that is based on (6), which can be written as follows:

$$
\text{SINR}_{d} = \frac{pd S_2^2}{(1 + \kappa_{dt}) h_1^H (ww^H + \kappa_b \text{diag}\{ww^H\}) h_1 + S_2}.
$$

where $S_2 = [\kappa_{dr}(1 + \kappa_{dt}) + \kappa_{dt}] p_d S_2^2 + (1 + \kappa_{dt}) \sigma^2$.

### 2.2. Problem Formulation

In this section, our goal is to maximize the transmit rate of the D2D pair with hardware impairments by optimizing the BS’s beamforming vector, the minimum data rate requirement of cellular UE and the passive beamforming at the RIS. This problem is formulated as follows:

$$
P_0 \max_{w, \phi, p_d} \log_2 (1 + \text{SINR}_d)
$$

s.t. \( \log_2 (1 + \text{SINR}_u) \geq r_u \), (8b)

$$
\|w\|^2_2 \leq P_{u\text{max}}
$$

$$
p_d \leq P_{d\text{max}}
$$

$$
|\phi|^2 = 1, j = 1, \cdots, M
$$

where $\phi = [\phi_1, \cdots, \phi_M]^T$ collects all the diagonal elements of $\Phi$, $P_{u\text{max}}$ and $P_{d\text{max}}$ denotes the maximum transmit power of the BS and the DTUE, respectively.

### 3. Joint Optimizing the Transmit Rate of the D2D Pair

Due to the coupled variables and the non-convexity of Problem (8), we exploit the BCD technique to depart coupled variables in Problem $P_0$ into three tractable subproblems. Then, after solving each subproblem, an alternative algorithm is proposed to obtain the optimal solutions of Problem $P_0$.

#### 3.1. Optimizing the Transmit Beamforming of BS

With fixed $\phi$ and $p_d$, the original problem $P_0$ is simplified as follows.

$$
P_{1-1} \max_{w} \log_2 (1 + \text{SINR}_d)
$$

s.t. \( \log_2 (1 + \text{SINR}_u) \geq r_u \), (9b)

$$
\|w\|^2_2 \leq P_{u\text{max}}
$$

By invoking equality $a^H \text{diag}\{bb^H\} a = b^H \text{diag}\{aa^H\} b$, (7) can be transformed as follows:

$$
\text{SINR}_d(w) = \frac{pd S_2^2}{(1 + \kappa_{dt}) w^H Tw + c_1}.
$$

where $T = h_1 h_1^H + \kappa_b \text{diag}\{h_1 h_1^H\}$, $c_1 = [\kappa_{dr}(1 + \kappa_{dt}) + \kappa_{dt}] p_d S_2^2 + (1 + \kappa_{dt}) \sigma^2$. 
After introducing slack variable $\lambda$ and using the Dinkelbach’s transform [23], Problem $\mathcal{P}_{1-2}$ can be transformed as follows:

$$
\mathcal{P}_{1-2} \quad \max_w \quad p_d S_w^2 - \lambda [(1 + \kappa_{dr})w^H Tw + c_1] \\
\text{s.t.} \quad w^H Fw - c_2 \geq 0, \\
\|w\|_2^2 \leq P_{\text{max}},
$$

(11a)

where $S_w = 2^n - 1$, $F = \frac{1 - \tilde{r}_u}{\tilde{r}_u - \kappa_u} - (1 + \kappa_u)\kappa_L |f|^2$, and $c_2 = (1 + \kappa_u)(1 + \kappa_{dr})p_d S_w^2 + (1 + \kappa_u)\sigma^2$.

This problem is still non-convex because the convex part of $w^H Fw$ in (11b). Then, we use the following SCA proposition.

**Proposition 1.** $w^H Fw$ is a convex function for $w$, which can be approximated by the following:

$$
w^H Fw \geq -w^{(t)}H Fw^{(t)} + 2\text{Re}\{w^{(t)}H Fw\},
$$

(12)

where $w^{(t)}$ denotes the optimal value of $w$ at the $t$th iteration.

According to Proposition 1, Problem $\mathcal{P}_{1-2}$ can be approximated by the following.

$$
\mathcal{P}_{1-3} \quad \max_w \quad p_d S_w^2 - \lambda [(1 + \kappa_{dr})w^H Tw + c_1] \\
\text{s.t.} \quad 2\text{Re}\{w^{(t)}H Fw\} - w^{(t)}H Fw^{(t)} - c_2 \geq 0, \\
\|w\|_2^2 \leq P_{\text{max}},
$$

(13a)

This problem is a convex optimization problem, which can easily obtain optimal solutions by using CVX. Furthermore, the slack variable can be iterated by the following.

$$
\lambda = p_d S_w^2 / [(1 + \kappa_{dr})w^{(t)}H Tw^{(t)} + c_1].
$$

(14)

### 3.2. Optimizing the Phase Shifts of RIS

We show the optimization of phase shifts for a given transmit beamforming matrix $W$ and the transmit power of $p_d$. According to Problem $\mathcal{P}_{0b}$, the phase-shift optimization subproblem is formulated as follows.

$$
\mathcal{P}_{2-1} \quad \max_{\phi} \quad \text{SINR}_{\text{d}}(\phi) \\
\text{s.t.} \quad |\phi_j|^2 = 1, j = 1, \ldots, M. \\
(9b),
$$

(15a)

This problem is still very challenging to solve because of the non-convexity of constraints. By substituting $S_d = S_d + \phi^H \text{diag}(g_{dr}^H) g_{di}$ and $h^H_{b} = h^H_{br} + g_{dr}^H \Phi H$, the objective function of this problem can be approximated by the following:

$$
\text{SINR}_{\text{d}}(\phi) = \frac{p_d [S_d^2 + 2\text{Re}\{\phi^H p\} + \phi^H A \phi + 2\text{Re}(\phi^H q) + e]}{\phi^H A \phi + 2\text{Re}(\phi^H q) + e},
$$

(16)

where $p = S_d \text{diag}(g_{dr}^H) g_{dr}$, $c = (\kappa_{dr}(1 + \kappa_{dr}) + \kappa_{dr})p_d$, $G = c \text{diag}(g_{dr}^H) g_{di} + S_d \text{diag}(g_{dr}^H)$, $d = (1 + \kappa_{dr})(1 + \kappa_d)$, $A = G + d \text{diag}(g_{dr}^H) HWH^H HWH^H \text{diag}(g_{dr}^H)$, $q = d \text{diag}(g_{dr}^H) HWH_{br} + e p$, $e = c g_d^2 + d h_{br} HWH_{br} + (1 + \kappa_{dr})\sigma^2$.

Similarly, the constraint in (15b) can be reformulated as follows:

$$
\phi^H S \phi + 2\text{Re}\{\phi^H t\} + l \geq 0,
$$

(17)
where \( t = c'\text{diag}(h_{ru}^H H W h_u + d'g_{du} \text{diag}(h_{ru}^H)g_{dt'}) \), \( d' = (2^u - 1)(1 + \kappa_u)(1 + \kappa_{dt'})p_{dt'} \), \( l = c' h_{ru}^H W h_u - d' g_{du}^2 - (2^u - 1)(1 + \kappa_u)\sigma^2 \), \( c' = 1 - (2^u - 1)[\kappa_u + (1 + \kappa_u)\kappa_{du}] \), and \( S = \text{diag}(h_{ru}^H (c'H W H H - d'g_{du}g_{dt'}) \text{diag}(h_{ru}) \).

Hence, Problem (15) can be transformed as follows.

\[
\mathcal{P}_{2-2} \max_{\phi} \frac{p_d}{\phi^H A \phi + 2Re(\phi^H q) + \epsilon} \quad \text{s.t.} \quad \phi^H S \phi + 2Re(\phi^H t) + l \geq 0, \\
|\phi|^2_j = 1, j = 1, \cdots, M. \tag{18c}
\]

This problem is still difficult to solve because of the intractable form of the objective function and the constraints (18c). Firstly, we can exploit the Dinkelbach’s transform to reformulate the objective function of this problem [23]. Secondly, CCP can be used to deal with non-convex constraints (17c). Specifically, they can be rewritten as \( 1 \leq |\phi|^2_j \leq 1, j = 1, \cdots, M \). Then, the non-convex parts of the reformulated constraints are further rewritten as \( |\phi|^2_j - 2Re(\phi^H \phi) \leq -1, j = 1, \cdots, M \), at the \( t \)th iteration value \( \phi^{(t)}_j \). Then, this subproblem can be reformulated as follows:

\[
\mathcal{P}_{2-3} \max_{\phi} \text{Tr}(B \tilde{\Phi}) + 2Re(\phi^H r) + p_d g_{du}^2 - \lambda e \\
\text{s.t.} \quad \text{Tr}(S \tilde{\Phi}) + 2Re(\phi^H t) + l \geq 0, \\
|\phi|^2_j \leq 1, j = 1, \cdots, M, \tag{19c}
\]

where \( \phi^H \preceq \phi^{(t)}H + \phi^{(t)}H - \phi^{(t)}H = \tilde{\Phi}, B = p_d G - \lambda A \) and \( r = p_d p - \lambda q \). \( \lambda \) is the auxiliary variable, which can be updated by the following.

\[
\lambda^{(t+1)} = \frac{p_d}{(\phi^{(t)}H)^{\dagger} A \phi^{(t)} + 2Re(\phi^{(t)}H q) + \epsilon}. \tag{20}
\]

After transformation, Problem \( \mathcal{P}_{2-3} \) becomes convex and easily obtains optimal solutions by using CVX toolbox.

### 3.3. Optimizing the Transmit Power of the DTUE

With given \( w \) and \( \phi \), the problem of optimizing the transmit power of the DTUE can be reformulated as follows:

\[
\mathcal{P}_{3-1} \max_{p_d} \log_2 \left( 1 + \frac{p_d g_{du}^2}{[\kappa_d(1 + \kappa_u) + \kappa_{dt'}]p_d g_{du}^2 + f} \right) \quad \text{s.t.} \quad \log_2(1 + \text{SINR}_u) \geq r_u, \tag{21b}
\]

where \( f = (1 + \kappa_{dt'}) h_{ru}^H (ww^H + \kappa_d \text{diag}(ww^H)) h_1 + (1 + \kappa_{dr}) \sigma^2 \).

Due to the second derivative of the function, \( f(x) = \log_2(1 + x) \) is smaller than zero, and we know that the objective function of Problem \( \mathcal{P}_{3-1} \) is concave. Moreover, the constraint set of this problem is convex, which is able to be effectively solved by adopting the CVX toolbox.

### 3.4. Proposed Algorithm and Its Convergence

Based on the results above, an algorithm according to the BCD technique to solve Problem (8) is proposed, and detailed progress is concluded in Algorithm 1. Furthermore, the convergence of Algorithm 1 is proved as follows.
The values of the objective functions of Problem (8), (13) and (19) are defined as $C(w, \phi, p_d)$, $C_{w,lb}(w, \phi, p_d)$ and $C_{\phi,lb}(w, \phi, p_d)$, respectively. Then, the following exists:

$$
C(w^{t-1}, \phi^{t-1}, p_d^{t-1}) \leq C(w^t, \phi^{t-1}, p_d^{t-1}) \leq C_{w,lb}(w^t, \phi^t, U^{t-1}) \leq C(A^t, P^t, U^t) \tag{22}
$$

where (a) is obtained due to Step 5 of Algorithm 1, and the optimal solution of (8) is obtained by solving its approximate problem (13) with fixed $\phi^{t-1}$ and $p_d^{t-1}$; similarly, (b) holds with fixed $w^t$ and $p_d^{t-1}$, and optimal $\phi^t$ can be obtained by solving Problem (21) of Step 6 in Algorithm 1. It is demonstrated that the transmit rate of DTUE cannot increase infinitely, and it has an upper bound. This reveals that proposed Algorithm 1 will converge after a few iterations.

4. Simulation Results

We illustrate the influence of the hardware impairments and the benefits of the proposed algorithm via numerical simulations in this section. Here, we set the BS’s antennas number as $N = 4$, the reflecting elements of the RIS’s number as $M = 6$, the minimum rate as $r_u = 1$ b/s/Hz, the bandwidth of the D2D communication system as $B = 10$ MHz. The BS’s and the DTUE’s transmit power limits are set as $sP_{\text{max}}^w = 10$ W and $p_{\text{max}}^d = 1$ W; the additional noise powers set $\sigma^2_k = \sigma^2_k = -174$ dBm; and non-linear EH parameters set as $a = 6400$, $b = 0.003$ [24], respectively. The simulation setup is shown in Figure 2, where the locations of the BS and the RIS are placed at $(0,0)$ m and $(50,20)$ m. D2D UEs are uniformly and randomly placed in a circle with radius of 5 m, which is centered at $(55,0)$ m. In this paper, all channels comprise large and small-scale fading [20–22], and large scale fading in dB can be modeled as follows:

$$
\text{PL} = \text{PL}_0 - 10\log_{10}\left(\frac{d}{d_0}\right), \tag{23}
$$

where $\text{PL}_0$ represents the path loss, which is referred at the distance of $d_0$, $\alpha$ denotes the path loss coefficient and $d$ is the communication distance. In the simulations, we set $d_0 = 1$ m, $\text{PL}_0 = -30$ dB and the path loss coefficients from the BS to the UE. The RIS to the UE (D2D UEs) is set as $\alpha = 4, 2.2, 2$, respectively. Small scale fading in all channels is assumed to be a Rayleigh fading distribution.
Figure 2. The simulated system setup.

Figure 3 presents the convergence character of the proposed algorithm. We readily know that the proposed algorithm converges rapidly, which demonstrates the effectiveness of the proposed algorithm. Moreover, we know that the hardware impairments of the BS and the D2D UEs still have huge impacts on the D2D pair’s transmit rate even with the help of RIS. For example, the D2D pair’s transmit rate with hardware impairments almost decreases 41% when compared with the situation of ideal hardware, which shows the importance of reducing the impact of hardware impairment on the wireless communication system.

Figure 3. Convergence behavior of Algorithm 1.

Figure 4 illustrates the relationship between the D2D pair’s transmit rate and the UE’s minimum transmit rate in RIS-assisted D2D communication system with different hardware impairments. It is obvious that hardware impairments severely decrease the transmit rate of the D2D pair. Specifically, when hardware impairment coefficients of D2D
UEs become large, the D2D pair’s transmit rate is much smaller than when the hardware impairment coefficients of the BS become large. This is because BS can compensate the influence of hardware impairment by using more transmit power. Furthermore, it also shows that UEs are much more sensitive to hardware impairment than the BS and need to be carefully concerned. On the other hand, we also know the effectiveness of RIS, which can decrease the effect of the hardware impairment.

![Figure 4. Minimum data rate of UE versus the data rate of D2D.](image)

### 5. Conclusions

In this paper, we have maximized the transmit rate of D2D pair in the RIS-assisted D2D communication system with hardware impairments by optimizing the beamforming vector of RIS, the transmit power of BS and transmit UE of D2D pair. The optimization problem cannot be solved directly because of the non-convexity of the objective function and constraints. Hence, we have decoupled these three variables into three subproblems by using BCD technique. Furthermore, these subproblems were transformed into convex form by using SCA and CCP, and each of the variables has been solved by fixing the others. Finally, we can obtain optimal solutions of the original problem in an iterative manner. The convergence property of the proposed algorithm have been proved, and simulation results show that the data rate of D2D is severely impacted by the hardware impairment coefficient of D2D and UE. However, by adding RIS into the system, the influence caused by hardware impairment can be effectively alleviated.

### Author Contributions

Conceptualization, H.Z. and X.L.; methodology, H.Z. and X.L.; software, H.Z.; validation, H.Z., Y.Y., X.L.; formal analysis, H.Z.; investigation, H.Z.; resources, H.Z.; data curation, H.Z., Y.Y., X.L., and C.Z.; writing—original draft preparation, H.Z., Y.Y. and X.L.; writing—review and editing, Y.Y., X.L. and C.Z.; visualization, C.Z. and C.H.; supervision, Y.Y.; project administration, X.L.; funding acquisition, X.L. All authors have read and agreed to the published version of the manuscript.

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