APSIPA Transactions on Signal and Information Processing, 2024, 13, e303

Original Paper

Joint Optimization for RIS Assisted Dual Functional Radar Communication in IoV

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ABSTRACT

Reconfigurable Intelligent Surface (RIS) has been recognized as the core technology for 6G. However, transmission signals may be blocked by obstacles due to mobility and complex transmission in vehicular scenario. In order to solve the above issue, this paper researches the RIS assisted dual function radar communication system (DFRC) in the Internet of Vehicles (IoV), and proposes an alternating optimization algorithm, named joint guaranteed

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*Corresponding author: Yaping Cui, cuiyp@cqupt.edu.cn. This work was partially supported by Natural Science Foundation of China (61901070, 61801065, 62271096, 61871062, U20A20157, 62061007), Science and Technology Research Program of Chongqing Municipal Education Commission (KJQN202000603, KJQN202300621), Natural Science Foundation of Chongqing (CSTB2022NSCQ-MSX0468, cstc2020jcyjzdxmX0024, cstc2021jcyjmsxmX0892, CSTB2023NSCQ-LZX0134), University Innovation Research Group of Chongqing (CxQT20017), The Chongqing Graduate Student Scientific Research Innovation Project(CYB22246), Youth Innovation Group Support Program of ICE Discipline of CQUPT (SCIE-QN-2022-04).

Received 30 August 2023; Revised 18 January 2024
ISSN 2048-7703; DOI 10.1561/116.00000060

radar communication (JGRC) algorithm, with sensed power and semidefinite relaxation to maximize the spectral efficiency of the communication vehicle while simultaneously ensuring the radar sensing performance of the target vehicle. Specifically, the proposed JGRC algorithm can be divided into two stages. Stage one, active beamforming of Base Station (BS) transmission is optimized with the power constraint of the sensed target vehicle. Stage two, the optimized active beamforming is applied, and the phase shift matrix is optimized. Then, RIS phase shift optimization problem is transformed into Quadratically Constrained Quadratic Programming (QCQP), and rank-1 non-convex constraint is relaxed by semidefinite relaxation, which can be transformed into a standard semidefinite programming solved by Matlab toolbox. Simulation results demonstrate that compared to the RIS element random reflection, the proposed algorithm achieves higher spectral efficiency by 9.5%.

Keywords: Internet of Vehicles, reconfigurable intelligent surface, dual function radar communication system.

1 Introduction

The sixth generation (6G) mobile communication system has been researched around the world. The deep integration of multiple systems such as communication system and sensing system has become a new trend of technology development, realizing a variety of new vertical application scenarios represented by the smart city and smart transportation [1]. The above vision requires communication devices and terminal devices to have the ability to intelligently sense the physical world [2, 3]. In order to meet intelligent transport, it is necessary to explore the new network architecture of integrated communication and radar system. Intelligent transport system (ITS) can sense vehicles and physical environment by integrating radar sensors into 6G wireless networks [4]. The integrated sensing and communications (ISAC) systems can be divided into two categories [5, 6]: the radar-communications coexistence (RCC) system and the dual-functional radar-communications (DFRC) system. The DFRC share spectrum, hardware platforms, and signal processing frameworks to simultaneously perform communications and radar tasks.

Reconfigurable intelligent surface (RIS), also called intelligent reflecting surface (IRS), is a programmable electromagnetic surface structure comprising plenty of passive reflecting elements [7–9]. Each RIS reflecting element can adjust the phase shift, amplitude, frequency and polarization of the incident signal [10, 11]. Through the dynamic regulation of electromagnetic wave by reflecting elements, RIS can adjust the beam to transmit signals in a specific direction and create a more favorable propagation environment [12–15]. Based on the above advantages, RIS is regarded as the key technology to realize the intelligent connection of everything in 6G network, which has been highly concerned by the industry and academia. In the application scenario of internet of vehicles (IoV) in intelligent transport system, the target vehicle in the area of none line of sight (NLoS) transmission has received great attention [16–18]. In the above urban environments, detecting NLoS vehicles at long distances is challenging, as vehicles may fall into the shadow areas (behind buildings) of the radar. In such cases, RIS is used to assist DFRC, and the reflection links of RIS can be used to assist base station (BS) and vehicle communication while detecting the target vehicle of NLoS.

The creation of line of sight (LoS) transmission link through RIS to assist sensing targets has been a concern of researchers. In [19], the IRS assisted radar system was researched to detect targets in the NLoS region, and minimize the cramer-rao bound (CRB) of the direction of arrival (DoA) by jointly optimizing active beamforming and passive beamforming. The multiple IRS assisted radar sensing system was researched in [20] to estimate the Doppler shift of moving targets, and proposed the alternate optimization algorithm to minimize CRB and improve the estimation accuracy of moving targets. In [21], the authors studied the IRS self-sensing system to sense the positioning target, estimated the DoA by installing sensors on IRS, and optimized the reflection coefficient matrix of IRS to derive the angle estimation CRB of mean square error. The prior works [19–21] mainly considered the RIS assisted the radar system. However, the communication system was not considered in these works. In [22], a RIS assisted ISAC system was researched to reduce the interference between users by design phase shift of RIS elements under the CRB constraint of target DoA estimation. In [23], the RIS assisted ISAC system was researched, BS can simultaneously perform communication functions and estimate the parameters of the target, and a maximize likelihood estimation scheme was proposed to estimate the speed and location of the target. In the research of RIS-assisted radar system and RIS-assisted ISAC system, CRB is used as an important performance indicator to measure the lower bound of the minimum variance of parameter estimation. However, the study of the perceived signal-to-noise ratio by joint optimized beamforming has also been extensively studied.

In [24], an IRS assisted ISAC system was considered where BS serves a single communication user and multiple sensing targets. The beam gain of sensing angle can be maximized through the joint optimization of BS transmitting beamforming and IRS reflecting beamforming. The IRS-assisted ISAC system was researched in [25], which used BS to transmit joint signals (the combination of communication signal and radar signal) to serve communication users and conduct target tracking at the same time, and minimizes the total transmitting power of BS in the system by jointly optimizing the sensing beamforming at BS and the reflected beamforming at IRS. In [26], the authors researched the RIS assisted DFRC system, and realized the maximization of signal to interference plus noise ratio (SINR) by jointly designing the transmission waveform of DFRC and the reflection beamforming of RIS. In [27], the authors researched the distributed IRS-assisted DFRC system to enhance the detection of NLoS targets, and maximized the radar SINR of user through the joint design of beamforming at BS and IRS phase shift matrix. In [28], the tradeoff between radar performance and communication performance in RIS assisted DFRC system was studied, and DFRC waveform and RIS phase shift matrix were jointly optimized by a proposed manifold optimization algorithm to minimize interference between users.

In [29], the problem of optimizing active beamforming and optimizing RIS phase shift is decomposed into several sub-problems, which can be alternately optimized by block coordinate descent (BCD) framework. Afterwards, efficient algorithms based on Dinkelbach's transform and majorization-minimization (MM) method are developed to solve these sub-problems. In [30], an efficient alternating algorithm based on the fractional programming, majorization-minimization, and manifold optimization methods is developed to convert the active beamforming and RIS phase shift optimization problem into two solvable sub-problems and iteratively solve them.

The research of RIS assisted DFRC system mainly focuses on the sensing performance. In the Internet of Vehicles, the signal is easily blocked by obstacles due to the moving characteristics of vehicles and the complex urban environment, thus affecting the stability of the link. Additionally, the explosive growth in wireless communication demands has resulted in increasingly scarce spectrum resources. The RIS-assisted DFRC system utilizes shared resources to achieve communication and sensing functions simultaneously. Spectrum and hardware efficiency are significantly improved. In practical scenarios within IoV, BS typically communicates with nearby vehicles while sensing distant vehicles. BS achieves this by sensing distant vehicles to gather information about traffic conditions and communicating with nearby vehicles. The communication vehicle can make appropriate adjustments to coordinate traffic situations.

Therefore, this paper researches the RIS-assisted DFRC system in the internet of vehicles, and the RIS assists BS to communicate with communication vehicles in short distance and sensing target vehicles in long distance. The main contributions of this paper are summarized as follows:

(1) This paper researches the RIS assisted dual-function radar communication system of IoV. Communicate with a short distance line-of-sight or non-line-of-sight vehicle via RIS assisted BS, while sensing a long distance line-of-sight or non-line-of-sight target vehicle. The spectral

efficiency of communication performance is maximized by the proposed algorithm while simultaneously ensuring the radar sensing performance of the target vehicle.

(2) The paper proposed the joint guaranteed radar communication (JGRC) algorithm, which solves the non-convex optimization problem by means of alternate optimization, so as to maximize the spectral efficiency of the communication vehicle. First, based on the sensed power required by the target vehicle, the active beamforming of the BS transmission is optimized. Then, the reflection phase shift matrix of RIS is optimized according to the optimized active beamforming. Specifically, the RIS phase shift matrix optimization problem is transformed into a QCQP problem, and the constraint is reduced by semidefinite relaxation to transform it into a semidefinite programming problem, and finally solved by convex optimization toolbox.

(3) The paper conducts a simulation to verify the effectiveness of the proposed JGRC algorithm with sensed power and semidefinite relaxation. The results show that the proposed algorithm guarantees the radar sensing performance, and improves the spectral efficiency of the communication performance. Compared with the RIS element random reflection, the proposed algorithm achieves higher spectral efficiency by 9.5%.

The rest of this paper is organized as follows: Section 2 presents the RIS-aided DFRC in IoV system model. Section 3 introduces the optimization problem of the paper, including objective function and constraints. The JGRC algorithm with sensed power and semidefinite relaxation is proposed to solve the problem in Section 4. Simulation results are presented to verify the effectiveness of the proposed JGRC algorithm in Section 5. Section 6 concludes this paper.

2 System Model

As shown in Figure 1, an RIS is deployed on the surface of the urban building to assist the DFRC system in IoV, and the BS can simultaneously transmit communication signal and radar signal. BS sends transmission signals to communication vehicles for communication service and senses the target vehicles blocked by obstacles. In an urban environment, radar sensing link and communication link are blocked by obstacles, which leads to link interruption or NLoS transmission, thus affecting communication quality and perception performance. In this paper, the RIS assists DFRC system to create a LoS link to ensure the performance of the communication link and sensing link. RIS is deployed on the surface of urban high-rise buildings that are not blocked

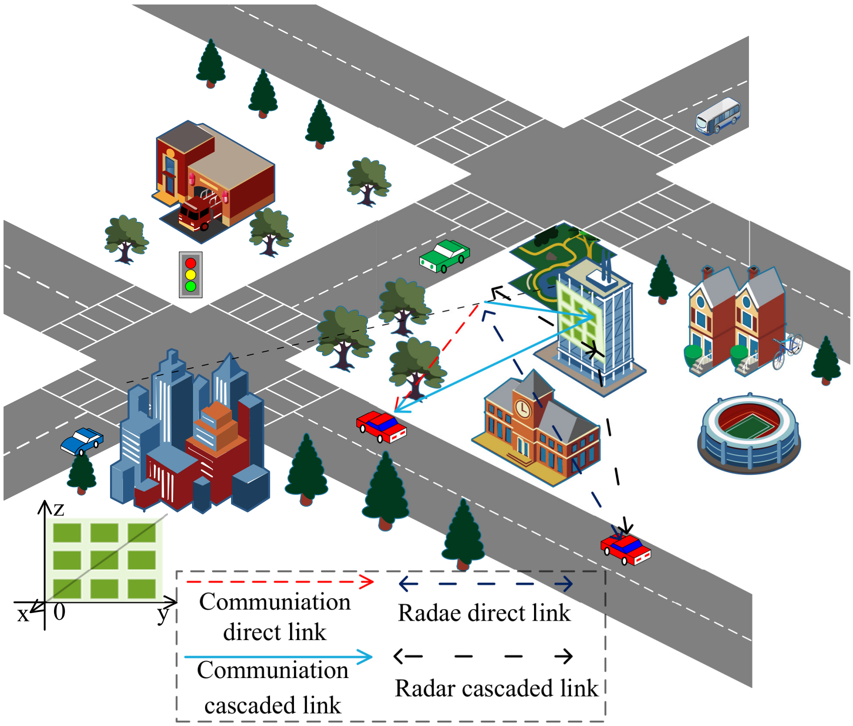

Figure 1: Network model.

by other obstacles, thus assisting BS to sense a vehicle which is blocked by obstacles.

2.1 Radar model

The communication vehicle and the target vehicle are equipped with a single antenna. The BS is equipped with M antennas. The RIS is modeled as a uniform linear array (ULA) with L elements in the y-z plane of the cartesian coordinate system. The radar model and the communication model of the system model are introduced respectively in the subsection.

Let $\mathbf{G} \in \mathbb{C}^{L \times M}$ denotes the channel for BS to RIS. RIS is deployed on the surface of a high-rise building that will not be blocked by obstacles between BS and RIS, therefore the channel $\mathbf{G}$ is mainly LoS transmission. The $\mathbf{G}$ follows Rician fading, and the expression can be written as

$$\mathbf{G} = \sqrt{\frac{k}{1+k}}\mathbf{G}_{LoS} + \sqrt{\frac{1}{1+k}}\mathbf{G}_{NLoS}, \tag{1}$$

where k denotes the Rician factor, $\mathbf{G}_{LoS}$ denotes the LoS component, $\mathbf{G}_{NLoS,n}$ denotes the NLoS component. The $\mathbf{G}_{LoS}$ follows the Rayleigh fading. The $\mathbf{G}_{LoS}$ can be expressed as

$$\mathbf{G}_{LoS} = \beta_G \kappa_R(\theta_R)\kappa_B^H(\theta_B), \tag{2}$$

where β_G denotes the path loss from the channel G_{LoS}, the $\partial_R(\theta_R)$. denotes array response vector of the RIS. The $\partial(\theta)$ is given by

$$\partial(\theta) = \left[1, e^{-j2\pi dsin(\theta)/\lambda}, \ldots, e^{-j2\pi d(t-1)sin(\theta)/\lambda}\right]^T, \tag{3}$$

where d denotes the element spacing of RIS. The element spacing can be defined as $d = \lambda/2$. The t denotes the antennas number of BS or the reflecting elements of the RIS.

Let $\mathbf{S} \in \mathbb{C}^{M\times M}$ denotes target response matrix of radar sensing channel and radar echo channel from BS to the target vehicle, the $\mathbf{S}$ can be expressed as

$$\mathbf{S} = \beta_v \partial(\theta_v)\partial(\theta_v)^H, \tag{4}$$

where β_v denotes the path loss of the radar sensing channel. Let $\mathbf{A} \in \mathbb{C}^{N\times N}$ denotes the radar response matrix between the RIS and the target vehicle, it can be expressed as

$$\mathbf{A} = \beta_{RV}\partial_{RV}(\theta_{RV})\partial_{RV}^H(\theta_{RV}), \tag{5}$$

where β_{RV} denotes the path loss of $\mathbf{A}$ between RIS to vehicle.

Let $\mathbf{\Theta}$ denotes the reflecting phase shift matrix of RIS assisted DFRC, the expressed is written as $\mathbf{\Theta} = diag(\beta_1 e^{j\varphi_1}, \ldots, \beta_n e^{j\varphi_n}, \ldots, \beta_N e^{j\varphi_N})$, where $\theta_n = \beta_n e^{j\varphi_n}$ denotes the nth reflecting element of RIS. β_n denotes reflection amplitude which set as 1 to maximize the reflected signal power. The $\varphi_n \in [0, 2\pi)$ denotes phase of the RIS reflecting element.

According to the channel analysis from (1) to (5), the radar model component of the overall system model can be expressed as

$$H = G^H \Theta A \Theta^H G + S, \tag{6}$$

Thus, the received signal at the BS is given as

$$y_r = \mathbf{H}\mathbf{w}x + n_r, \tag{7}$$

where x denotes the transmission signal by BS, $\mathbf{w} \in \mathbb{C}^{M\times 1}$ denotes the active beamforming of BS, $n_r \sim cn(0, \sigma_r^2)$ denotes the additive white Gaussian noise with the noise variance σ_r^2 at the target vehicle. According to (7), The SNR received at BS is expressed as

$$SNR_r = \frac{||H\mathbf{w}||^2}{\sigma_r^2}, \tag{8}$$

2.2 Communication model

In the system model of Figure 1, in addition to the sense model for sensing the target vehicle, there is also a communication model, and the channels in the communication model are analyzed next. Let $\mathbf{h}_r^H \in \mathbb{C}^{1\times L}$ and $\mathbf{h}_d^H \in \mathbb{C}^{1\times M}$ denote the channels for RIS to the communication vehicle, BS to the communication vehicle, respectively. Since RIS deployment position is not blocked by obstacles, therefore $\mathbf{h}_r^H$ is mainly LoS transmission. The channel $\mathbf{h}_r^H$ is modeled as Rician fading, the expression is given as

$$\mathbf{h}_r = \sqrt{\frac{k}{1+k}}\mathbf{h}_{LoS} + \sqrt{\frac{1}{1+k}}\mathbf{h}_{NLoS}, \tag{9}$$

where denotes $\mathbf{h}_{LoS}$ the LoS component of the channel $\mathbf{h}_r$, $\mathbf{h}_{NLoS}$ denotes the NLoS component. The $\mathbf{h}_{NLoS}$ follows the Rayleigh fading. The $\mathbf{h}_{LoS}$ expression can be written as

$$\mathbf{h}_{LoS} = \beta_h \partial_R(\theta_R), \tag{10}$$

where β_h denotes the path loss from RIS to the communication vehicle. The direct channel from the BS to the communication vehicle is modeled using Rayleigh fading since dense buildings in the city as well as other obstacles can block the communication link between the base station and the communication vehicle may lead to interruption of the link.

Therefore, according to the channel analysis in the radar model and the communication channel analysis in the communication model, the signal received at the communication vehicle can be expressed as

$$\mathbf{y}_c = (\mathbf{h}_r^H \boldsymbol{\Theta}\mathbf{G} + \mathbf{h}_d^H)\mathbf{w}\mathbf{x} + n_c = \mathbf{c}\mathbf{x} + n_c, \tag{11}$$

where $n_c \sim cn(0, \sigma_c^2)$ denotes the additive white Gaussian noise with the noise variance σ_r^2 at the communication vehicle, $\mathbf{x} = \mathbf{h}_r^H \boldsymbol{\Theta}\mathbf{G} + \mathbf{h}_d^H$. Thus, the SNR of the communication vehicle is expressed as

$$SNR_c = \frac{|\mathbf{c}\mathbf{x}|^2}{\sigma_c^2}, \tag{12}$$

3 Problem Formulation And Transformation

The objective function of this paper is to maximize the spectral efficiency of the communication vehicle by jointly optimizing the active beamforming $\mathbf{w}$ of BS and the phase shift matrix $\boldsymbol{\Theta}$ of RIS while simultaneously ensuring the radar sensing performance of the target vehicle. In this section, the objective function of the communication vehicle, which can be expressed as:

$$\begin{aligned} P(A) : & \max_{\mathbf{w},\Theta} \log_2(1 + SNR_c) \\ s.t. \quad & C_1 : 0 \le \varphi_n < 2\pi, \quad \forall n{=}1,\ldots n,\ldots,N, \\ & C_2 : ||\mathbf{w}||^2 \le P_T, \\ & C_3 : SNR_r \ge \alpha, \end{aligned} \tag{13}$$

where P_T denotes the transmit power of the BS, α denotes the sensed power of the sensing the target vehicle.

According to (13), the objective function can be equivalent to the SNR maximization problem received by the communication vehicle, thus the optimization problem can be rewritten as:

$$\begin{aligned} P(A1) : & \max_{w,\Theta} \quad |cw|^2 \\ s.t. \quad & \mathrm{C}_1 : 0 \le \varphi_n < 2\pi, \quad \forall n{=}1,\ldots n,\ldots,N, \\ & C_2 : \|\mathbf{w}\|^2 \le P_T, \\ & C_3 : |H\mathbf{w}|^2 \ge \alpha\sigma_r^2, \end{aligned} \tag{14}$$

In the next subsection, the objective function is solved by the proposed alternate optimization algorithm. This paper solves it by solving the following two subproblems iteratively. The paper first assumes a fixed $\mathbf{\Theta}$ and finds out the value of $\mathbf{w}$ that maximize the SNR of the communication. Then, according to constant $\mathbf{w}$, the phase shift matrix $\mathbf{\Theta}$ is optimized. In the rest of this section, we will specifically introduce the alternating optimization approach.

4 Joint Guaranteed Radar Communication Algorithm

In this section, the alternate optimization algorithm is proposed to solve problem (14). The proposed joint guaranteed radar communication algorithm is divided into two stages. In the first stage, based on the radar power that senses the target vehicle and the given RIS reflection phase shift matrix, the active beamforming is optimized. According to the relationship between radar power and channel power gain, the optimization of active beamforming can be divided into two cases. According to two cases, the corresponding active beamforming vectors are obtained by solving them in turn. In the second stage, given the optimized active beamforming to optimize RIS phase shift matrix, the original objective function is transformed into the quadratic constraint quadratic programming (QCQP) problem, and then the non-convex constraint is relaxed by the semidefinite relaxation (SDR) method to obtain convex objective function and constraint. Finally, the semidefinite programming (SDP) problem is obtained and solved by the convex optimization toolbox.

4.1 Optimize w with constant $\boldsymbol{\Theta}$

When the RIS reflection phase shift matrix is given, the range constraint of element reflection phase shift directly disappears and does not constitute a constraint on the solution of the objective function. After objective function conversion, the optimize problem expression (14) can be rewritten as:

$$\begin{aligned} P(A2) : & \max_{\mathbf{w}} |\mathbf{cw}|^2 \\ s.t. \quad & \mathrm{C}_1 : ||H\mathbf{w}||^2 \geq \alpha\sigma_r^2, \\ & C_2 : ||\mathbf{w}||^2 \leq P_T, \end{aligned} \tag{15}$$

Then, two constraints in objective function (15) are analyzed to derive the expression of active beamforming.

According to the constraint C_2 in (15), there exists the beamforming vector $\mathbf{w}_t$ that satisfies $||\mathbf{w}_t||^2 = P < P_T$, P is the power. Under the condition that objective function (15) and constraint conditions are satisfied, let $\mathbf{w} = \sqrt{P_T/P}w_t$, then the objective function (15) and the constraint C_1 in (15) can be rewritten as:

$$\begin{aligned} |\mathbf{cw}|^2 &= \frac{P_T}{P}|\mathbf{cw}_t|^2 > |c\mathbf{w}_t|^2 \\ |H\mathbf{w}|^2 &= \frac{P_T}{P}|H\mathbf{w}_t|^2 > \alpha\sigma_r^2 \end{aligned} \tag{16}$$

Equation (16) indicates that $\mathbf{w}$ will produce higher performance than $\mathbf{w}_t$ under the condition that the constraint is satisfied. Thus, the objective function (15) can be maximized by using the power constraint. If the power is not allocated to the sensing function, the solution can be obtained according to the power constraint, we can get $\mathbf{w}^* = \sqrt{P_T}\frac{\mathbf{c}^H}{||\mathbf{c}^H||}$. Since BS senses the target vehicle and transmits information to the communication vehicle, the communication vehicle only occupies the part of BS transmit power. In this case, according to constraint C_2 in (14), when $p|H\mathbf{c}^H|^2 > ||\mathbf{c}^H||^2\alpha\sigma_r^2$ is satisfied, we can get $\mathbf{w}^* = \sqrt{P}\frac{\mathbf{c}^H}{||\mathbf{c}^H||}$.

When constraint C_2 in (15) does not satisfy $p|H\mathbf{w}^H|^2 > ||\mathbf{w}^H||^2\alpha\sigma_r^2$, the active beamforming of the BS $\mathbf{w}$ can be constructed as:

$$\mathbf{w} = x_1\mathbf{w}_a + x_2\mathbf{w}_b, \quad x_1, x_2 \in \mathbb{C}, \tag{17}$$

where $||\mathbf{w}_a|| = ||\mathbf{w}_b|| = 1$, The projection of $\mathbf{w}$ onto the space $\{\mathbf{c}, \mathbf{H}\}$ is $\mathbf{w}_a \in \{\mathbf{c}, \mathbf{H}\}$, and $\mathbf{w}_b \perp \{\mathbf{c}, H\}$. Since the $\{\mathbf{w}_a, \mathbf{w}_b\} \in \{\mathbf{c}, \mathbf{H}\}$, the objective function (15) can be expressed as:

$$\begin{aligned} P(A3) : & \max_{x_1, x_2} |x_1\mathbf{cw}_a + x_2\mathbf{cw}_b|^2 \\ s.t. \quad & \mathrm{C}_1 : x_1|\mathbf{H}^H|^2 = \alpha\sigma_r^2, \\ & C_2 : |x_1|^2 + |x_2|^2 = P_T, \end{aligned} \tag{18}$$

According to C_2 in (18), the x_1 can be derived as $|x_1|^2 = \frac{\alpha\sigma_r^2}{|\mathbf{H}^H|^2}$, and $|x_2|^2 = P_T - \frac{\alpha\sigma_r^2}{|\mathbf{H}^H|^2}$. In order to maximize the objective function, x_1 and x_2 should be reciprocal of $\mathbf{cw}_a$, $\mathbf{xw}_b$. We can construct the $x_1 = \sqrt{\frac{\alpha\sigma_r^2}{|\mathbf{H}^H|^2}} \frac{\mathbf{w}_a^H \mathbf{c}}{|\mathbf{w}_a^H \mathbf{c}|}$, $x_2 = \sqrt{P_T - \frac{\alpha\sigma_r^2}{|\mathbf{H}^H|^2}} \frac{\mathbf{w}_b^H \mathbf{c}}{|\mathbf{w}_b^H \mathbf{c}|}$. Then, the active beamforming of the BS can be expressed as:

$$\mathbf{w}^* = \begin{cases} \sqrt{P}\frac{\mathbf{c}^H}{||\mathbf{c}^H||}, & \text{if } p|H\mathbf{c}^H|^2 > ||\mathbf{c}^H||^2\alpha\sigma_r^2 \\ x_1\mathbf{w}_a + x_2\mathbf{w}_b, & \text{otherwise} \end{cases}, \tag{19}$$

4.2 Optimize Θ with constant w

When the active beamforming at BS is given, the objective function (15) can be rewritten as:

$$\begin{aligned} &P(A4) : \max_{\varphi_n} \ ||\mathbf{h}_r^H \mathbf{\Theta G} + \mathbf{h}_d^H||^2 \\ &s.t. \quad \mathrm{C}_1 : 0 \le \varphi_n < 2\pi, \quad \forall n{=}1,\ldots n,\ldots,N, \end{aligned}, \tag{20}$$

In order to expand the analysis of (20), we let $v = [v_1, \ldots, v_n, \ldots, v_N]^H$, where $v_n = e^{j\theta_n}$. According to Euler formula, (19) can be converted to $|v_n|^2 = 1$. Thus, the objective function can be expressed as:

$$\begin{aligned} &P(A5) : \max_{v} \ \mathbf{v}^H\Phi\Phi^H\mathbf{v} + \mathbf{v}^H\Phi\mathbf{h}_d + \mathbf{h}_d^H\Phi^H\mathbf{v} + ||\mathbf{h}_d^H||^2 \\ &s.t. \quad \mathrm{C}_1 : |v_n|^2 = 1, \ \forall n{=}1,\ldots n,\ldots,N+1, \end{aligned}, \tag{21}$$

where $\Phi = diag(h_r^H)G$. Because of the unit modular constraint in the objective function C_1 in (21), the (21) is a non-convex QCQP problem. By introducing auxiliary variable x, the objective function can be expressed as

$$\begin{aligned} &P(A6) : \max_{v_a} \ v_a^H R v_a + ||\mathbf{h}_d^H||^2 \\ &s.t. \quad \mathrm{C}_1 : |v_n|^2 = 1, \quad \forall n{=}1,\ldots n,\ldots,N+1, \end{aligned}, \tag{22}$$

where $\mathbf{v}_a = [\mathbf{v}, x]^T$, $R = \begin{bmatrix} \Phi\Phi^H & \Phi\mathbf{h}_d^H \\ \mathbf{h}_d^H\Phi^H & 0 \end{bmatrix}$. Since the objective function (22) is not convex, this problem is still a non-convex optimization problem. In this case, (22) can be transformed into:

$$\mathbf{v}_a^H R \mathbf{v}_a = tr(R\mathbf{v}_a\mathbf{v}_a^H), \tag{23}$$

Then, the objective function can be expressed as:

$$\begin{aligned} &P(A7) : \max_{\mathbf{v}_a} \ \mathbf{v}_a^H R \mathbf{v}_a = tr(R\mathbf{v}_a\mathbf{v}_a^H) + ||\mathbf{h}_d^H||^2 \\ &s.t. \quad \mathrm{C}_1 : |v_n|^2 = 1, \quad \forall n{=}1,\ldots n,\ldots,N+1, \end{aligned} \tag{24}$$

In this section, let $\mathbf{V}_a = v_a v_a^H$. The $\mathbf{v}_a$ denotes the positive semi-definite matrix, which satisfies $\mathbf{v}_a \succ= 0$ and $rank(\mathbf{v}_a) = 1$. Since the constraint is non-convex when the rank is 1, SDR is used in this subsection to relax the constraint, and then the convex optimization problem can be obtained as:

$$\begin{aligned} &P(A8): \max_{V_a} \; tr(R\mathbf{V}_a) + ||\mathbf{h}_d^H||^2 \\ &s.t. \quad \mathrm{C}_1\colon V_{a,n} = 1, \quad \forall n{=}1,\ldots n,\ldots,N+1, \\ &\qquad\;\; \mathrm{C}_2\colon V_a \succ= 0 \end{aligned} \tag{25}$$

The objective function (25) is a semidefinite programming problem, which can be solved by using the convex optimization tool. In this section, an alternate optimization algorithm with sensed power and semidefinite relaxation is proposed to jointly optimize active beamforming and the IRS phase shift matrix. The proposed algorithm is divided into two phases. In the first stage, the JGRC algorithm optimizes the active beamforming at BS according to any given RIS reflection phase shift. In the second stage, the proposed algorithm optimizes the reflection phase shift vector of RIS according to the optimized active beamforming. In the first stage, the optimization of active beamforming is divided into two cases according to the radar power used by the sensed target vehicle. If $\sqrt{P_T}|H\mathbf{c}^H|^2 \geq ||\mathbf{c}^H||^2\alpha\sigma_r^2$ is satisfied, it can be deduced that the form of active beamforming is $\mathbf{w}^* = \sqrt{P_T}\mathbf{c}^H/||\mathbf{c}^H||$. If $\sqrt{P_T}|H\mathbf{c}^H|^2 \geq ||\mathbf{c}^H||^2\alpha\sigma_r^2$ is not satisfied, we can construct $\mathbf{w} = x_1\mathbf{w}_a + x_2\mathbf{w}_b$, where $\mathbf{w}_a \in \{\mathbf{c}, \mathbf{H}\}$ and $\mathbf{w}_b \perp \{\mathbf{c}, \mathbf{H}\}$.Then, the expressions of x_1 and x_2 are derived according to the objective function and constraints. In the second stage, the RIS reflection phase shift matrix is optimized according to the optimized active beamforming. The euler formula is used to transform the constraints, and the objective function and constraints are transformed into QCQP problem. Then the semidefinite relaxation is used to reduce the non-convex constraints. According to the objective function and the reduced constraints, the objective function is transformed into a semidefinite programming problem. Finally, the convex optimization toolbox is used to solve the transformed semidefinite programming problem. The proposed JGRC algorithm is summarized in Algorithm 1.

5 Simulations And Analysis

The effectiveness of the proposed JGRC algorithm is evaluated in this Section. The parameter settings are summarized in Table 1. Then, simulation results are presented and analyzed. We evaluate the system performance with the following three baseline schemes:

(1) Scheme 1: RIS only assisted communication system. This scheme considers that the RIS-assisted system only has communication function, and does not sense the target vehicle.

Algorithm 1 Joint Guaranteed Radar Communication Algorithm.

Initialize M,K,P_T,α
Input: RIS phase shift matrix θ_n,active beamforming w
Stage 1: Optimize w **with constant** $\boldsymbol{\Theta}$
if $\sqrt{P_T}|Hc^H|^2 > ||c^H||^2\alpha\sigma_r^2$ **then**
  $w^* = \sqrt{P}\frac{c^H}{||c^H||}$
else if $\sqrt{P_T}|Hc^H|^2 < ||c^H||^2\alpha\sigma_r^2$ **then**
  let $w = x_1 w_a + x_2 w_b$
  where$||w_a|| = ||w_b|| = 1$, $w_a \in \{c, H\}$, $w_b \perp \{c, H\}$
  Repeat:
  According to C_1 and C_2 in (18) to repeat x_1 and x_2
end if
Output: optimize$w$
Stage 2: Optimize $\boldsymbol{\Theta}$ **with constant** w
Repeat:
Convert (20) to QCQP problem
According to C_1 in (21) to repeat v
Auxiliary Variable x
Let $v_a = [v, x]^T$, $R = \begin{bmatrix} \Phi\Phi^H & \Phi h_d^H \\ h_d^H\Phi^H & 0 \end{bmatrix}$
The constraint C_1 in (24) is relaxed using SDR
until: obtain the convex function (25).
Output: optimized v

(2) Scheme 2: RIS element random reflection. This scheme considers the randomness of reflection phase shift in RIS assisted DFRC system.

(3) Scheme 3: Without RIS to assist DFRC system. This scheme considers the performance of DFRC systems without RIS assistance.

Figure 2 illustrates the RIS element number versus spectral efficiency. As shown in Figure 2, as the number of element number increases, the spectral efficiency of each scheme keeps rising. Since in scheme 1 research the RIS assisted communication system does not allocate power to the radar function to sense the target vehicle, all the transmitted power is used to communicate with the communication vehicle. The spectral efficiency achieved by the baseline scheme 1 is used as the performance upper bound. When N = 150, compared with scheme 2 and scheme 3, the spectral efficiency of the JGRC algorithm is increased by 7.7% and 13%, respectively. With the increase of the number of reflecting elements, the ability of RIS to regulate electromagnetic wave has been improved.

Table 1: Simulation Parameters.

Parameter	Values
Carrier frequency	5.9 GHz
Bandwidth	500 KHz
Vehicular speed	30 km/h
Transmit antennas number	4
RIS element number	100
Noise power	−80 dBm
Rician factor	10 dB
BS transmit power	15 dBm
Radar power	5 dBm
Doppler shift	400Hz

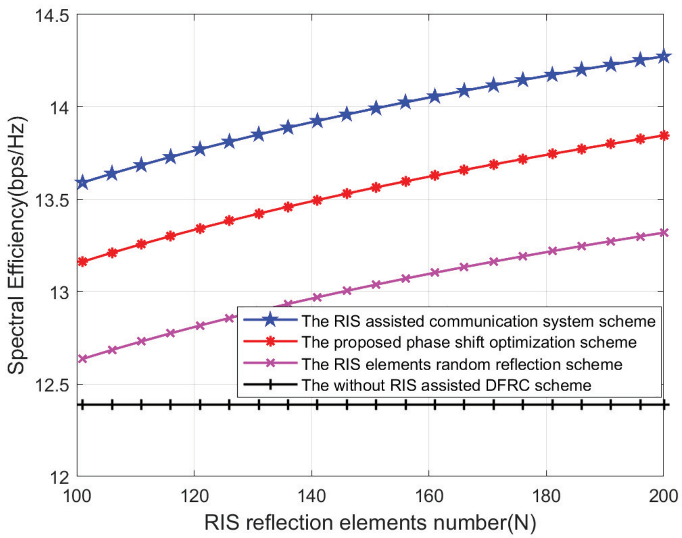

Figure 2: RIS element number versus spectral efficiency.

Figure 3 illustrates the transmit power versus spectral efficiency. It can be seen from Figure 3 that with the increase of transmission power, each scheme achieves higher spectral efficiency. When the transmission power is 15 dBm, the proposed JGRC algorithm achieves higher spectral efficiency than RIS element random reflection and without RIS to assist DFRC system, increasing by 7.1% and 10.4%, respectively.

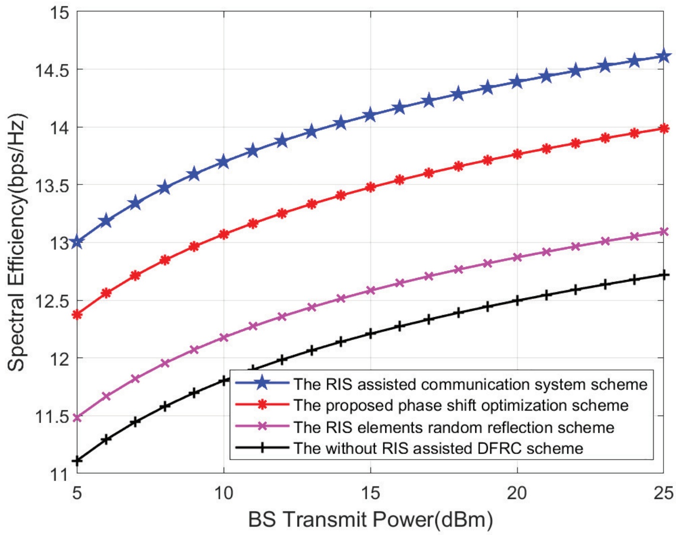

Figure 3: Transmit power versus spectral efficiency.

Figure 4 illustrates the spectrum efficiency achieved by different schemes under a different number of transmission antennas. It can be observed from Figure 4 that with the increase of the number of transmission antennas, both the proposed algorithm and the comparison schemes can achieve higher communication performance. When the transmission antenna is 5, compared with the RIS element random reflection and without RIS to assist DFRC system, the proposed scheme increases by 9.6% and 17.2%, respectively.

Figure 5 illustrates the proposed JGRC algorithm and the comparison schemes achieved spectrum efficiency versus different radar powers. It can be observed from Figure 5 that under the premise of constant total transmission power, when the system allocates more energy to the radar function, the spectrum efficiency achieved by the communication vehicle will decrease. When the radar power is 5dBm, compared with the comparison schemes, the proposed JGRC alternate optimization algorithm achieved spectral efficiency is increased by 9.5% and 21%, respectively. Compared with the radar power of 5 dBm, when the radar power is 10 dBm, the spectral efficiency achieved by the proposed algorithm and the comparison schemes is reduced by 0.9 bps/Hz, 1.2 bps/Hz and 1.35 bps/Hz respectively.

Figure 6 illustrates the RIS location versus the spectral efficiency. The RIS location is the distance between the RIS and the communication vehicle. It can be observed from Figure 6 that the spectral efficiency of all schemes

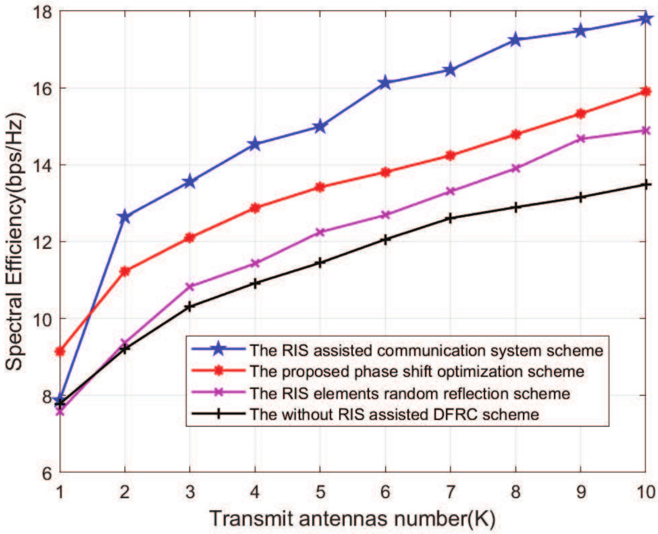

Figure 4: Transmit antennas number versus spectral efficiency.

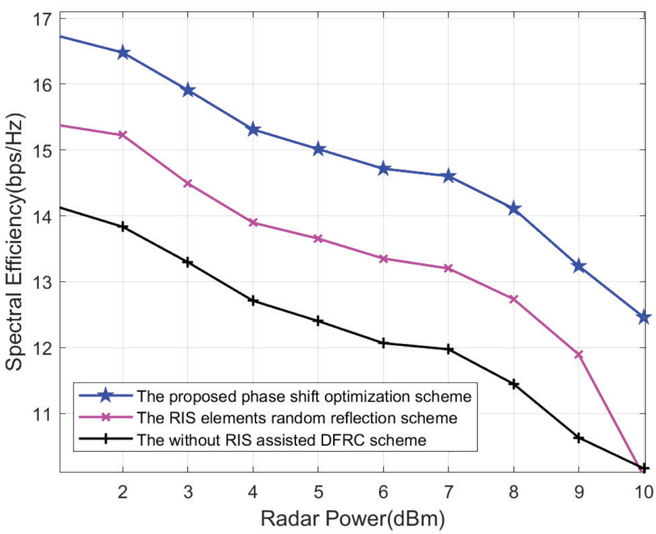

Figure 5: Radar power versus spectral efficiency.

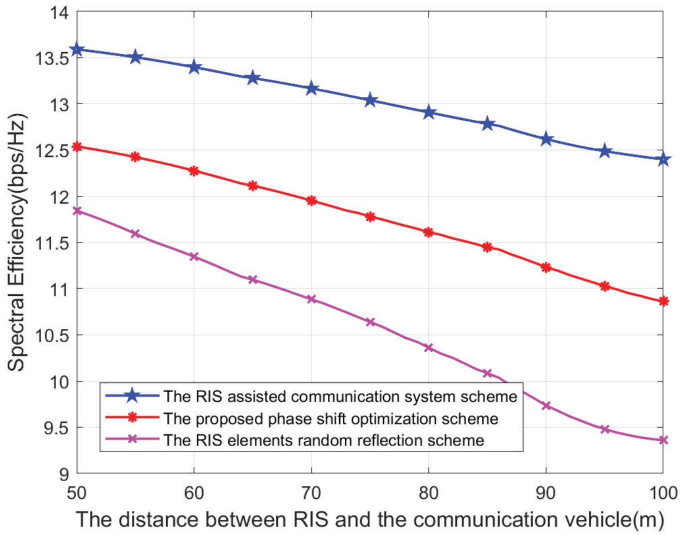

Figure 6: Spectral efficiency versus RIS location.

decreases as the distance between RIS and the communication vehicle increases. When the distance is 100 m, compared with 50 m, the spectral efficiency of all schemes is reduced by 8.7%, 13.% and 20.9%, respectively. In scheme 1, the RIS only assists communication vehicles, all power will be allocated to transmit information to communication vehicles. Thus, the performance of the proposed JGRC algorithm is slightly lower than scheme 1.

Figure 7 illustrates the convergence of the proposed JGRC algorithm versus a different number of iterations. As can be seen from Figure 7, with the increase of the number of iterations, the JGRC algorithm gradually achieves stable spectral efficiency. With the increase of RIS reflection elements and iteration times, the proposed JGRC algorithm can achieve higher spectral efficiency and eventually stabilize. When the number of reflection elements is small, the dimension of RIS reflection coefficient matrix is also low. Thus, when the number of reflection elements is 100, the inflection point of performance convergence appears first. When the RIS element number increases, the inflection point of performance convergence requires more iterations.

Through the above analysis, it can be seen that the proposed JGRC alternate optimization algorithm can effectively improve the communication performance while ensuring the radar sensing performance of the target vehicle. In scheme 1, the radar function is not considered to sense the target vehicle, and all the power is used for the communication service between BS and the

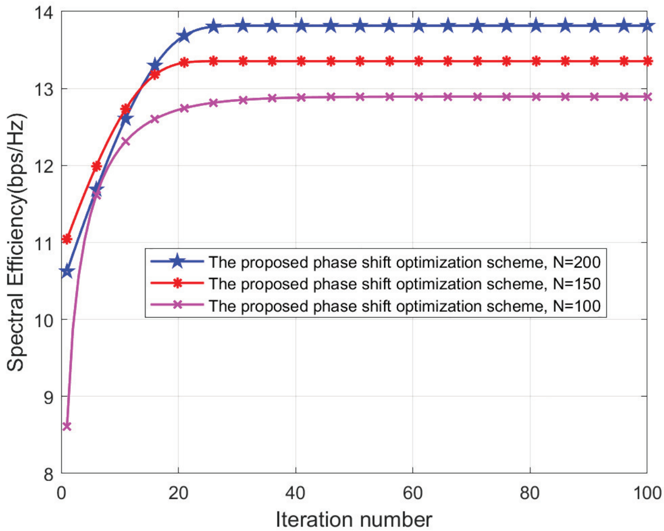

Figure 7: Spectral efficiency versus Iteration number.

communication vehicle. Thus, the performance of IRS assisted communication system scheme is higher than the JGRC algorithm. However, the proposed JGRC alternate optimization algorithm needs to allocate certain power to the radar function to sense the target vehicle, so the performance of the proposed algorithm is lower than scheme 1.

6 Conclusion

This paper studies the DFRC system in RIS-assisted vehicular networks, where RIS assisted BS in sensing the target vehicle and transmiting signals to communication vehicles. The proposed JGRC algorithm jointly optimizes the active beamforming of BS transmission and the reflection phase shift matrix of RIS in an alternate optimization way. The proposed algorithm improves the communication performance while ensuring the radar performance. Since the optimization problem is nonconvex, the problem is decomposed into two subproblems and solved by the alternate optimization method. When the reflection phase-shift matrix of RIS is fixed, the active beamforming at BS is optimized based on the required power for radar sensing of the target vehicle. Based on the optimized active beamforming, the optimization of the RIS reflection phase-shift matrix is transformed into a QCQP problem. Then the QCQP problem is transformed into the SDP problem according to the idea of SDR, and then solved SDP problem by CVX toolbox. The simulation results compare the performance of the proposed JGRC algorithm and the baseline schemes. In the case of sensing the target vehicle, the communication performance of the proposed algorithm is obviously better than the other two baseline schemes. In the future, the radar function of RIS assisted DFRC system in IoV will be studied, and the overall performance of the system will be improved through joint optimization of the active beamforming and passive beamforming.

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