

RIS-assisted Scheduling for High-Speed Railway Secure Communications

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Abstract—With the rapid development of high-speed railway systems and railway wireless communication, the application of ultra-wideband millimeter wave band is an inevitable trend. However, the millimeter wave channel has large propagation loss and is easy to be blocked. Moreover, there are many problems such as eavesdropping between the base station (BS) and the train. As an emerging technology, reconfigurable intelligent surface (RIS) can achieve the effect of passive beamforming by controlling the propagation of the incident electromagnetic wave in the desired direction. We propose a RIS-assisted scheduling scheme for scheduling interrupt flows and improving quality of service (QoS). In the proposed scheme, an RIS is deployed between the BS and multiple mobile relays (MRs). By jointly optimizing the beamforming vector and the discrete phase shift of the RIS, the constructive interference between direct link signals and reflected link signals can be achieved, and the channel capacity of eavesdroppers is guaranteed to be within a controllable range. Finally, the purpose of maximizing the number of successfully scheduled flows and satisfying their QoS requirements can be practically realized. Extensive simulations demonstrate that the proposed scheme has superior performance regarding the number of completed flows and the system secrecy capacity over four baseline schemes in literature.

Index Terms—High-Speed Railway (HSR), mmWave band, QoS requirement, RIS-assisted, secrecy capacity.

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I. INTRODUCTION

IN recent years, high-speed railway (HSR) has gradually evolved from informatization to intelligence. Diversified data-intensive services have higher and higher demand for railway high-capacity communication, such as high-definition video surveillance, onboard broadband internet services, and the railway Internet of Things (IoT) service. According to current researches, the transmission rate of each train carriage is about 40 Mbps, and it may increase to 0.5~5Gbps in the future [1]. This is a great challenge for the existing railway wireless communication system.

With huge bandwidth from 30 to 300 GHz, millimeter wave (mmWave) can provide multi-gigabit communication services, such as high definition television (HDTV) and ultra-high definition video (UHDV) [2]. Massive Multiple Input Multiple Output (MIMO) wireless communication refers to equipping base stations (BSs) and receivers with a large number of antennas. Massive MIMO has been shown to potentially improve spectral and energy efficiency [3]. Massive MIMO and mmWave can well support the demand of large data traffic and bandwidth-intensive applications, and solve the challenge of HSR communication. However, using a large number of active antennas in massive MIMO and mmWave implies considerable hardware costs, power consumption, and computational complexity. In addition, in a mmWave communication system, the propagation environment is not controllable. When the line of sight (LoS) link between the BS and user equipments (UEs) is blocked by the HSR carriage, a large amount of penetration loss is generated and the quality of service (QoS) is significantly reduced, which brings many design challenges.

Notably, due to the broadcast nature of wireless communication, eavesdropping has always been an important security risk to users' privacy and data security. To alleviate this problem, many studies have developed various effective authentication and encryption algorithms. However, the high-speed mobility and frequent handover of HSR bring great challenges to identity authentication. Moreover, both authentication and encryption require additional overhead and reliable third-party authentication. Fortunately, the Physical Layer Security (PLS) technology can achieve secure transmission only by using the dynamic characteristics of wireless channels to increase the capacity difference between legitimate users and illegitimate users. Moreover, the high-speed mobility of HSR makes the channel change rapidly, which brings abundant channel resources to PLS. Therefore, we implement secure flow (i.e., the traffic data transmitted between the transmitter and receiver

[4]–[6]) scheduling with PLS in this work.

In recent years, reconfigurable intelligent surface (RIS) has attracted extensive attention of scholars as an innovative and revolutionary technology. RIS is a plane containing a large number of passive reflective elements, each of which can independently induce controllable amplitude and/or phase shift to the incident signals [7]. By densely deploying RIS in a wireless communication system and subtly adjusting its parameters, it is possible to improve communication performance by increasing the expected power gain of the received signal and destructively reducing interference. As a two-dimensional implementation of metamaterials, RIS naturally has the outstanding characteristics of low cost, low complexity and easy deployment, which can well solve the challenges in intelligent HSR communication scenarios [8], [9].

At present, many studies have considered RIS-assisted high mobility scenarios [10]–[14]. However, almost all of these studies focus on vehicle or UAV, and few studies focus on the RIS-assisted HSR communication. Vehicles tend to be densely distributed and have variable directions, while UAVs have more flexible three-dimensional trajectories. HSR not only moves faster, but also has a definite running direction and a regular running trajectory. These characteristics can bring both advantages to HSR communication. Using RIS to increase the coverage of mmWave BS can reduce the number of HSR handovers and improve the practicality of mmWave in HSR communication. Integrating RIS into HSR mmWave communication is challenging and very little research is currently done on this topic. Xu *et al.* [15] investigated the problem of jointly design transmission beamforming at the BS and phase shifts at the RIS for spectral efficiency maximization in RIS aided mmWave HSR networks. But he took a deep reinforcement learning approach and didn't consider the eavesdroppers. While RIS also enhances the eavesdropping signal while providing diversity gain. This is detrimental to the communication security of the HSR. In addition, the vast majority of existing researches on RIS-assisted work aim at maximizing system capacity or secrecy capacity. But our ultimate goal is to maximize the satisfaction of users, which requires optimizing the order of serving users based on their requests and system capacity. In this case, not only the coupled beamforming vector and the RIS phase shift matrix, but also the 0-1 variable indicating whether to schedule or not, are among the optimization variables. How to design the optimization variables well is important but difficult.

In this paper, we consider the communication between HSR and the ground BS, introducing mmWave and RIS to improve the communication quality. Due to the penetration loss of the train carriage, we consider deploying multiple mobile relays (MRs) as communication relays on the rooftop of the train. MRs can serve passengers through the access points (APs) inside the carriage. We study a downlink RIS-assisted HSR communication system scenario where MRs request the BS to schedule a certain number of flows for them. Each flow has its own minimum throughputs requirements (i.e., minimum transfer rate requirements), referred to as its QoS requirement in our paper. Due to the quality of communication links and the existence of eavesdroppers, the flows may fail to be scheduled

for not meeting the QoS requirements or too low security capacity. We propose a RIS-assisted scheduling algorithm, which aims to maximize the number of successfully scheduled flows under the constraints of QoS, secure transmission and power budget.

The contributions of this paper are summarized as follows.

- In order to improve the security capacity of the HSR communication system and meet the service requests of passengers to the greatest extent, we use the huge bandwidth of mmWave to schedule flows with different QoS requirements. We consider the communication between the BS along the track and multiple MRs on the roof. Due to the high-speed mobility of the train and the small coverage of mmWave, we deploy a RIS to provide reflection paths to enhance the received signal strength, and reduce the eavesdropping capacity of a random eavesdropper.
- We formulate a maximization problem for the number of safely scheduled flows, with the goal of optimizing the beamforming vector, the RIS phase shift matrix, and the 0-1 binary variable indicating whether to be scheduled or not, while ensuring that BS power budget, RIS phase shifts, and minimum secrecy capacity constraints. Since the optimization variables are coupled, it is difficult to optimize them at the same time. Moreover, the problem is a mixed integer non-convex nonlinear problem, so it is challenging to solve.
- We propose a low-complexity alternating optimization algorithm. The optimization problem is decomposed into three sub-problems to solve, namely beamforming, discrete phase shifts and scheduling selection optimization. The beamforming subproblem is equivalent to a Rayleigh quotient problem, which can be solved by the MRT method. The discrete phase shifts optimization subproblem employs a local search algorithm to find the optimal phase shifts. The two are alternately optimized and updated iteratively. Finally, a heuristic algorithm is developed to optimize the scheduling decisions.
- In addition, we also evaluate the proposed RIS-assisted security scheduling scheme for mmWave HSR networks through extensive simulations. The simulation results show that RIS can improve the security communication efficiency of HSR communication and expand the coverage of the cell. And our proposed algorithm has much better performance than the baseline schemes.

The rest of the paper is organized as follows. In Section II, we summarize some related works. In Section III, we establish the system model, including the description of the investigated system and communication channels. In Section IV, we formulate the problem of maximizing the number of successfully scheduled flows, and decompose it into a power allocation subproblem and a discrete phase shift optimization subproblem. Next, in Section V, the optimization algorithms are designed for the two subproblems respectively. Then the optimal solution is obtained by jointly optimizing the two subproblems. In Section VI, we conduct a performance evaluation and compare the proposed algorithm with other

benchmark algorithms. Finally, we conclude this paper in Section VII.

II. RELATED WORK

The rapid development of railway transportation systems has greatly enriched railway wireless services and raised the demand of wireless transmission. In order to achieve high data transmission rate, the application of ultra-wideband millimeter wave is a popular trend [16]. To promote the application of mmWave in HSR, many works have explored the propagation and fading characteristics of in HSR [17]–[22]. This provides empirical propagation models for our research on mmWave applications. In order to ensure the stable and reliable transmission of railway mmWave signals, have made various effective beamforming schemes. Yin *et al.* [23] proposed an mmWave-based adaptive multi-beamforming scheme. Multiple beams with different beamwidth were adopted by the BS simultaneously to improve the capacity of HSR wireless networks. Cui *et al.* [24] proposed a novel optimal nonuniform steady mmWave beamforming scheme, to guarantee the network reliability under an interleaved redundant coverage architecture for HSR wireless systems. Whereas, Cui *et al.* [25] considered that the strong line-of-sight of the HSR propagation channel leads to high channel correlation, which makes MIMO less effective in HSR scenarios. They proposed a hybrid spatial modulation beamforming scheme operating at mmWave frequency bands for HSR wireless communication systems. The narrow beam of mmWave and the high mobility of the train make beam alignment extremely difficult. Yan *et al.* [26] took advantage of the periodicity and regularity of trains' trajectory and proposed a fast bear alignment scheme. Gao *et al.* [27] investigated the beam tracking strategies for mmWave HSR communications, and proposed a dynamic beam tracking strategy by adjusting the beam direction and beam width jointly. In order to meet the challenges of mmWave application in HSR, Song *et al.* [28] redesigned the multiple access technology and the frame structure of OFDM and single carrier, presented train–trackside network architectures based on different MIMO techniques. The Doppler shift caused by high-speed mobility can damage HSR wireless signals. Gong *et al.* [29] conducted the modeling of the Doppler effect for mmWave in HSR communications, and designed data-aided Doppler estimation and compensation algorithms based on the new model. However, the mmWave channel has some well-known characteristics, such as high propagation loss, high penetration loss of building materials and rough-surface scattering [30]. Yalçın *et al.* [31] used relay-assisted transmission to resistance the path loss and link blocking in mmwave communication. Other wireless access technologies, such as LTE, WiFi, etc., can be adopted for the communication inside the carriage. Therefore, we focus on the mmWave communication between the BS and MRs.

The research on millimeter wave scheduling algorithm has made relatively mature progress, including time division multiple access (TDMA) [32], spatial time division multiple access (STDMA) [33] and QoS awareness [34]. Among these, TDMA is a common millimeter wave scheduling scheme, and

its related studies cover different types of link scenarios, such as wireless access and backtrip networks [35]–[37]. Therefore, in this paper, we also use TDMA scheme for millimeter wave scheduling. Millimeter wave has serious propagation loss and easy to be blocked. In order to solve the problem, beamforming in high-speed railway scenarios has been extensively studied. Gao *et al.* [38] and Zhang *et al.* [39] modeled vehicle-ground communication and used optimization methods to achieve high network throughput. Xu *et al.* [40] proposed a low-complexity iterative optimization approach of power allocation in time-varying HSR environment. Yin *et al.* [41] proposed a location-fair based mmWave stable beamforming scheme under the interlaced redundant coverage architecture to decrease the fluctuation of data rate. Xu *et al.* [42] developed an experience-driven power allocation method by leveraging multi-agent DRL, to maximize the achievable sum rate (ASR) for smart railway. However, the above work doesn't change the propagation environment, but only alleviate the dilemma of millimeter wave transmission through appropriate resource allocation and management.

RIS can dynamically modify the propagation environment by adjusting its own reflection coefficient. Sun *et al.* [43] proposed a three-dimensional (3D) RIS-assisted MIMO channel model based on a 3D cylinder model. At present, there have been many related studies on the optimization problem in RIS-assisted communication. Fu *et al.* [44] and Wu *et al.* [45] studied the minimum BS transmission power optimization problem in a MISO system and a MIMO system, respectively, but they all adopted continuous RIS phase shifts. In fact, RIS's phase shift is realized by adjusting the switching state of the PIN diode. One PIN diode can realize two-phase shift. Therefore, due to the limitation of element size, continuous phase shift is unrealistic. Di *et al.* [46] studied a downlink multi-user system, in which considered the achievable rate under the practical case where only a limited number of discrete phase shifts can be realized by a finite-sized RIS. Chen *et al.* [47] established a problem of maximizing the sum rate of multiple D2D links by jointly optimizing the transmission power and RIS discrete phase shifts of all links. Di *et al.* [48] proposed a hybrid beamforming scheme where the continuous digital beamforming and discrete RIS-based analog beamforming were performed at the BS and the RIS, respectively, and showed that the RIS-based system can achieve a good sum-rate performance by setting a reasonable size of RIS and a small number of discrete phase shifts. Considering the difficulty of deploying continuous phase shift in reality, we use discrete RIS phase shift in our paper. RIS can also get a good auxiliary effect in high-speed mobile scenes. RIS was considered to be deployed in a railway wireless communication system (RWCS) for the first time to improve the anti-interference ability of RWCS communication [49]. Chen *et al.* [50] studied the fast time-varying mmWave vehicular communication, and proposed RIS-assisted sum rate maximization algorithms for single vehicle user and multi vehicle users with imperfect CSI. Chen *et al.* [51] studied RIS-aided high-speed vehicular communication. By jointly optimizing transmission power, multi-user detection matrix, spectrum reuse and RIS reflection coefficient, they solved three major problems: spectrum shar-

ing, imperfect CSI and QoS performance guarantee. Makarfi *et al.* [52] deployed a RIS-based access point at the source and a RIS-based relay on buildings respectively, and studied the utility of these two methods for V2V security communication. Guo *et al.* [50] studied RIS-assisted mmWave communication under imperfect CSI. At the same time, RIS phase shift, UAV active beamforming and flight trajectory are optimized to ensure the maximum security capacity with multiple eavesdropping. Ren *et al.* [51] optimized the similar indicators as [53], but they were committed to minimizing the UAV energy consumption. While HST is very different from vehicles and UAV. HST tends to be located in suburban, mountainous and other fields, and has fixed routes and smooth speed. What's more, there are almost no two HSTs at the same time. Based on this, HST communication is quite different from the Internet of Vehicles and UAV communication. Therefore, it is of great significance to study RIS-assisted HSR communication. But so far, only Xu *et al.* [15] have studied the performance of RIS in HSR communication. However, in these studies, the existence of eavesdroppers and the scheduling of traffic flows are not considered.

Due to the broadcast characteristics of wireless communication, it is very vulnerable to be eavesdropped and attacked [55]. In recent years, PLS (Physical Layer Security) has received extensive attention [56]–[58]. PLS uses the dynamic characteristics of wireless channel to realize secure communication without complicated encryption and decryption process. At the same time, the advantage of RIS is to change the channel propagation environment. Therefore, RIS can be used to enhance the performance of PLS. Zhang *et al.* [59] derived the key indicators of RIS-aided communication, such as the secrecy outage probability, the probability of nonzero secrecy capacity, and proved that RIS can provide good performance for PLS. Zhang *et al.* [60] studied the impact of RIS on secure communication in the four cases of internal eavesdropping, external eavesdropping and with/without channel state information (CSI) of eavesdroppers. Makarfi *et al.* [61] and Gu *et al.* [62] respectively studied the influence of the location of RIS and Eve on the security performance. Dong *et al.* [63] proposed a new design of active RIS, which can amplify the signal strength and achieve better security performance gain than passive RIS. As a key infrastructure, the security of high-speed railway wireless communication is very important. Xu *et al.* [64] described the security attacks faced by HSR communication and the practical dilemma of the application of traditional security technologies in high-speed mobile scenarios. Therefore, we hope to take advantage of the rapid change of wireless channels caused by the high-speed mobility of HSR, and use RIS-assisted PLS to achieve security and effective traffic flow scheduling.

III. SYSTEM MODEL

A. System Description

We consider a single cell scenario of the mmWave HSR communication shown in Fig. 1. A BS equipped with M antennas is fixed beyond the railway track. There are N MRs deployed on the rooftop of the train. An RIS is deployed to

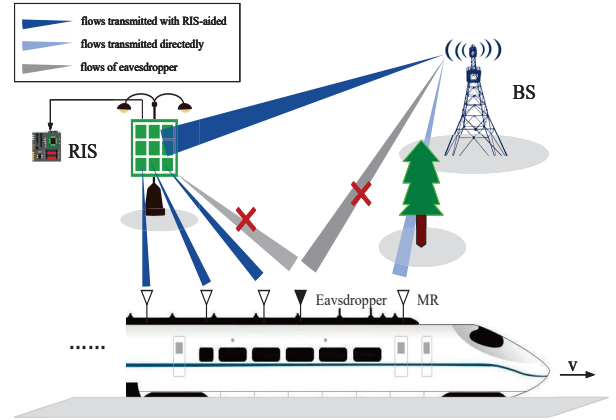


Fig. 1: The mmWave HSR communication system.

assist the communication between the BS and MRs, which is composed of a controller and a great quantity of programmable elements. It reflects signals that impinge on the surface and emits them in the desired beamform. Specifically, the controller tunes the voltage-controlled PIN diodes of each RIS element in real time by changing their switching state, and then the amplitude and phase of the incident wave will be adjusted to expected value. By using this reconfigurable property and combining with channel estimation, the legitimate channel capacity can be improved, and the eavesdropping channel can be suppressed. The BS and RIS are located in fixed positions on the same side of the track, and all MRs are within the coverage of the BS and RIS assistance. There are two kinds of links in the system, the one is the direct transmission links from the BS to MRs, as shown in the light blue link in Fig. 1, and the other one is the RIS-assisted reflection links, as shown in the dark blue link in Fig. 1. There is also an eavesdropper in the system that eavesdrops illegally on signals messages, as shown in the gray link in Fig. 1.

In our investigated system, the RIS is a uniform planar array consisting of L elements. The range of phase shifts of each element is constrained in $[0, 2\pi]$. Considering the realities of hardware configuration, we just take finite discrete values with equal quantization intervals with the valid range. We assume that the number of quantization bits is e , and then the phase shifts of each element can be represented as $\phi_l = \frac{2m_l\pi}{2^e - 1}$, where $l = 1, 2, \dots, L$, $m_l = \{0, 1, \dots, 2^e - 1\}$. In our system, time is divided into a series of non-overlapping superframes, each of which consists of the scheduling phase and the transmission phase. The scheduling phase is the duration of collecting requested services and MRs' QoS requirements. There are F flows need to be scheduled between the BS and MRs, and each flow can be directly received from the BS to MRs or assisted with RIS's reflection. Since the moving direction and velocity of the train can be known a priori and is predictable, the doppler frequency shifts of the signals received by the MRs are assumed to be known and can be eliminated with some existing technologies.

At present, there are many studies on CSI estimation of RIS-assisted channel. Various practical approaches have

been proposed. For example, Nadeem *et al.* [65] proposed a minimum mean squared error based channel estimation protocol, and Wang *et al.* [66] established a novel three-phase pilot-based channel estimation framework. Tang *et al.* [67] developed free-space path loss models for RIS-assisted wireless communications for different scenarios by studying the physics and electromagnetic nature of RISs. It pointed out that the free space path loss of BS-RIS-User channel is proportional to $(d_{R,2}d_{n,3})^2$ in RIS assisted far-field communication. Chen *et al.* [47] used Rice fading as the small-scale fading model. Since our research focuses on resource allocation, channel estimation is beyond our research content. Therefore, in our paper, we assume that we have perfect channel state information, and channel modeling refers to the empirical models of [67] and [47].

B. Path Loss Model

We use $d_{n,1}$ and $d_{n,3}$ to denote the distance from MR n ($n = 1, 2, \dots, N$) to the BS and RIS, respectively. And the distance between the BS and RIS is denoted by $d_{R,2}$. Then the path loss of the LoS link from the BS to the MRs, RIS, and from the RIS to MRs [67], respectively, are

$$L(d_{n,1}) = Cd_{n,1}^{-\alpha_1}, \quad (1)$$

$$L(d_{R,2}) = Cd_{R,2}^{-\alpha_2}, \quad (2)$$

$$L(d_{n,3}) = Cd_{n,3}^{-\alpha_2}, \quad (3)$$

where C is the path loss intercept, α_1 is the path loss exponent in the LoS case, and α_2 is the path loss exponent in the NLoS case.

C. Small-Scale Fading

In order to construct a practical RIS framework, We assume that the small-scale fading of each link follows the Rician distribution with a β_l Rician factor. The channel correlation between RIS elements may exist because the electrical size of RIS's reflecting elements is between $\lambda/8$ and $\lambda/4$ in principle, where λ is a wavelength of the signal [68]. The small-scale fading matrices between the BS and MRs are defined as

$$\mathbf{Q}_{n,1} = [q_1^{n,1}, q_2^{n,1}, \dots, q_M^{n,1}], \quad (4)$$

where $\mathbf{Q}_{n,1}$ is a $1 \times M$ matrix. The elements in $\mathbf{Q}_{n,1}$ are represented by Rician factor β_l and the random variables q_m^{ray} follow the Rayleigh distribution [47], i.e.,

$$q_m^{n,1} = \sqrt{\frac{\beta_l}{\beta_l + 1}} + \sqrt{\frac{1}{\beta_l + 1}} q_m^{ray}. \quad (5)$$

Similarly, we use the matrix $\mathbf{Q}_{R,2} \in \mathbb{C}^{L \times M}$ to denote the small-scale fading of the link from the BS to the RIS, and use matrix $\mathbf{Q}_{n,3} \in \mathbb{C}^{1 \times L}$ to denote the small-scale fading of the link from the RIS to the MRs. They are, respectively, defined as

$$\mathbf{Q}_{R,2} = \begin{bmatrix} q_{1,1}^{R,2} & \dots & q_{1,M}^{R,2} \\ \vdots & \ddots & \vdots \\ q_{L,1}^{R,2} & \dots & q_{L,M}^{R,2} \end{bmatrix}, \quad (6)$$

$$\mathbf{Q}_{n,3} = [q_1^{n,3}, q_2^{n,3}, \dots, q_L^{n,3}]. \quad (7)$$

Therefore, the channel coefficients of the BS-MRs links, the BS-RIS link, and the RIS-MRs links can be denoted as $\mathbf{d}_n \in \mathbb{C}^{1 \times M}$, $\mathbf{G} \in \mathbb{C}^{L \times M}$, $\mathbf{h}_n \in \mathbb{C}^{1 \times L}$,

$$\mathbf{d}_n = \sqrt{L(d_{n,1})} \mathbf{Q}_{n,1}, \quad (8)$$

$$\mathbf{G} = \sqrt{L(d_{R,2})} \mathbf{Q}_{R,2}, \quad (9)$$

$$\mathbf{h}_n = \sqrt{L(d_{n,3})} \mathbf{Q}_{n,3}. \quad (10)$$

D. Achievable Rate and Secrecy Rate

In the DL transmission, the complex baseband transmitted signal at the BS can be expressed as

$$x_n = \mathbf{w}_n s_n, \quad (11)$$

where $\mathbf{w}_n = [w_n^1, w_n^2, \dots, w_n^M]^T$ is the beamforming vector, satisfying the constraint of $\|\mathbf{w}_n\|^2 \leq P_{max}$, and s_n ($n = 1, \dots, N$) are i.i.d. random variables (RVs) with zero mean and unit variance, denoting the informationbearing symbols of users.

For MR n , a binary variable a_n^k is defined to indicate whether its request is scheduled in the k th time slot. If it is scheduled, $a_n^k = 1$; otherwise, $a_n^k = 0$. Then the signal received by MR n in the k th time slot can be obtained

$$y_n^k = a_n^k (\mathbf{d}_n + \mathbf{h}_n \Phi \mathbf{G}) \mathbf{w}_n s_n + N_0, \quad (12)$$

where $\Phi \triangleq \text{diag}[e^{j\phi_1}, e^{j\phi_2}, \dots, e^{j\phi_L}]$ is a diagonal matrix considering the effective phase shifts introduced by all elements of the RIS. N_0 denotes the additive white Gaussian noise, which is modeled as a realization of a zero-mean complex circularly symmetric Gaussian variable with variance σ_N^2 . Accordingly, the SNR of the signal received in the k th time slot of MR n is

$$\Gamma_n^k = a_n^k \frac{|(\mathbf{d}_n + \mathbf{h}_n \Phi \mathbf{G}) \mathbf{w}_n|^2}{\sigma_N^2}. \quad (13)$$

According to the Shannon's capacity formula, the corresponding achievable rate received by MR n in the k th time slot is given as

$$R_n^k = \log_2 \left(a_n^k \frac{|(\mathbf{d}_n + \mathbf{h}_n \Phi \mathbf{G}) \mathbf{w}_n|^2}{\sigma_N^2} \right). \quad (14)$$

Then the throughput achieved by MR n in a superframe can be obtained as

$$R_n = \frac{\sum_{k=1}^K R_n^k \cdot \Delta T}{T_s + K \cdot \Delta T}, \quad (15)$$

where T_s is the duration of the scheduling phase and ΔT is the duration of every transmission phase.

Similarly, in the k th time slot, the signal eavesdropped by the eavesdropper is

$$\begin{aligned} y_e^k &= a_n^k (\mathbf{d}_e + \mathbf{h}_e \Phi \mathbf{G}) \mathbf{w}_n s_n + N_0 \\ &= a_n^k \left(\sqrt{L(d_{e,1})} \mathbf{Q}_{e,1} \right. \\ &\quad \left. + \sqrt{L(d_{R,2})L(d_{e,3})} \mathbf{Q}_{e,3} \Phi \mathbf{Q}_{R,2} \right) \mathbf{w}_n s_n + N_0, \end{aligned} \quad (16)$$

where $\mathbf{d}_{e,1}$ represents the LoS distance from the BS to the eavesdropper, $\mathbf{Q}_{e,1} \in \mathbb{C}^{1 \times M}$ represents the small-scale fading from the BS to the eavesdropper. Then the SNR of the signal received by the eavesdropper in the k th time slot is

$$\Gamma_e^k = a_n^k \frac{|\mathbf{d}_e + \mathbf{h}_e \Phi \mathbf{G}| \omega_n|^2}{\sigma_N^2}. \quad (17)$$

The eavesdropping channel capacity in the k th time slot can be obtained on the basis of the Shannon's capacity formula

$$R_e^k = \log_2 \left(a_n^k \frac{|\mathbf{d}_e + \mathbf{h}_e \Phi \mathbf{G}| \omega_n|^2}{\sigma_N^2} \right). \quad (18)$$

Then the throughput achieved by the eavesdropper in a superframe can be expressed as

$$R_e = \frac{\sum_{k=1}^K R_e^k \cdot \Delta T}{T_s + K \cdot \Delta T}. \quad (19)$$

The secrecy capacity is an important physical layer security performance evaluation metrics which can be used to determine the feasibility of the schedule scheme. For MR n , its security capacity is given by

$$C_n = [R_n - R_e]^+, \quad (20)$$

where $[x]^+ \triangleq \max(x, 0)$.

There are F flows come from N MRs ($F \leq N$). Each flow has its own QoS requirement q_f , which is the minimum throughput required for its actual transmission. δ_f is defined to express whether flow f is successfully scheduled, if so, $\delta_f = 1$; otherwise, $\delta_f = 0$. The value of δ_f is related to the quality of service requirement q_f and the actual throughput of the link.

IV. PROBLEM FORMULATION

In this section, we first formulate our optimization problem based on the above system model, and then decompose the complex optimization problem into three sub-problems in order to obtain a sub-optimal solution efficiently.

A. Scheduled Flows Maximization Problem Formulation

we consider the joint optimization of transmission scheduling, power controlling and RIS phase shifts, to maximize the number of scheduled flows successfully.

$$\max \sum_{i=1}^F \delta_f = \sum_{n=1}^N \left(\left(\sum_{k=1}^K a_n^k \right) \neq 0 \right), \quad (21)$$

where $\sum_{k=1}^K a_n^k$ represents the sum of a_n^k in K time slots for MR n . $(\sum_{k=1}^K a_n^k) \neq 0$ is a judgment statement. If $(\sum_{k=1}^K a_n^k) \neq 0$ is established, then its value is 1, which proves that the requested flow f of MR n is successfully scheduled, otherwise it equals to 0. Then all N MRs are summed to obtain the total number of successfully scheduled flows.

Due to the existence of the eavesdropper, the confidentiality of transmission must be guaranteed. RIS can not only improve the data transmission rate of legitimate MRs, but also reduce the data rate of the eavesdropper, so as to increase the difference between the two rates. We guarantee that the security capacity is at least 10% of the legal channel capacity. The security capacity constraint of MR n is given by the following formula

$$C_n \geq 0.1 \cdot R_n, n \in \mathbf{N}. \quad (22)$$

Moreover, since there are K time slots available for scheduling in each superframe, the total number of time slots scheduled for all users should not be greater than K , which can be expressed by the following formula

$$\sum_{n=1}^N \sum_{k=1}^K a_n^k \leq K. \quad (23)$$

Therefore, the problem of maximizing the number of scheduled flows in limited time slots can be expressed as the following optimization problem

$$\begin{aligned} &\max_{\mathbf{w}_n, \Phi, a_n^k} \sum_{f \in F} \delta_f \\ \text{s.t. } &(a) \|\mathbf{w}_n\|_2^2 \leq P_{max}, \\ &(b) [\Phi]_{l,l} = e^{j\phi_l}, \phi_l = \frac{2m_l\pi}{2^e - 1}, \\ &\quad l = 1, \dots, L, m_l \in \{0, 1, \dots, 2^e - 1\}, \\ &(c) R_i^k = \log_2 \left(1 + a_n^k \frac{|\mathbf{d}_i + \mathbf{h}_i \Phi \mathbf{G}| \omega_n|^2}{\sigma_N^2} \right) \\ &\quad R_i = \frac{\sum_{k=1}^K R_i^k \cdot \Delta T}{T_s + K \cdot \Delta T}, i = \{e, n\}, n = \{1, \dots, N\}, \\ &(d) C_n = R_n - R_e > 0.1 \cdot R_n, n = 1, \dots, N, \\ &(e) \sum_{n=1}^N \sum_{k=1}^K a_n^k \leq K, \\ &(f) \delta_f = \begin{cases} 1, & \frac{q_f \times (T_s + K \cdot \Delta T)}{R_n \times \Delta T} \geq T_{rem} \cap R_n \geq q_f, \\ 0, & \text{otherwise,} \end{cases} \end{aligned} \quad (24)$$

where constraint (a) indicates that the maximum BS transmission power is limited to P_{max} ; constraint (b) is the phase shift of RIS elements; constraint (c) is the legal/illegal capacity; constraint (d) is the security capacity limit of the link; constraint (e) indicates that the total number of time slots scheduled by all users in a superframe cannot be greater than the number of time slots K of the superframe; constraint (f) defines the value of δ_f , T_{rem} is the time slots remained, only when the current system capacity meets the QoS requirements

of flow f and the flow f can be scheduled within the remaining time slots, $\delta_f = 1$, otherwise $\delta_f = 0$.

B. Problem Decomposition

For the joint optimization problem, since only one flow is considered to be scheduled at the same time, we can firstly optimize each flow to find the corresponding optimal beamforming vector and phase shift matrix, and then schedule them in the priority order calculated based on the number of required slots. Whereas, it worths pointing out that the joint optimization of the beamforming vector and phase shift matrix for each flow is coupled, and so it is difficult to optimize them at the same time. Therefore, we consider optimizing them individually. Specifically, the local search algorithm is used to traverse all possible phase shifts firstly. Next, for each phase shift selection, the BS transmit power beamforming vector is designed to maximize the security capacity of the legitimate channel while minimize the channel capacity of the eavesdropper. Finally, the phase shift matrix with the largest security capacity and the corresponding beamforming vector will be selected.

1) *Transmit Beamforming Design*: The sub-problem is allocating the appropriate transmission power within the power constraint to maximize the capacity of all MRs. When the phase shift variable Φ is fixed, the problem with respect to the beamforming vector \mathbf{w}_n in (24) can be written as

$$\begin{aligned} & \max_{\mathbf{w}_n} \sum_{n=1}^N C_n \\ & \text{s.t.} \quad \|\mathbf{w}_n\|_2^2 \leq P_{max}, \end{aligned} \quad (25)$$

where $C_n = [R_n - R_e]^+$. The operator $[\cdot]^+$ has no effect on the optimal solution, and so it can be omitted for the sake of simplification in the following paragraphs.

2) *Discrete Phase Shifts Optimize*: The sub-problem is to select the optimal phase shift in the finite discrete phase shifts on the basis of satisfying the security capacity constraint, so as to maximize the MRs' channel capacity. When the beamforming vector \mathbf{w}_n is fixed, the optimizing problem about the phase shift matrix Φ in (24) can be written as

$$\begin{aligned} & \max_{\Phi} \sum_{n=1}^N C_n \\ & \text{s.t.} \quad [\Phi]_{l,l} = e^{j\phi_l}, \phi_l = \frac{2m_l\pi}{2^e - 1}, \\ & \quad \quad l = 1, \dots, L, \\ & \quad \quad m_l \in \{0, 1, \dots, 2^e - 1\}. \end{aligned} \quad (26)$$

3) *Scheduling Sequence Organize*: The sub-problem is to sort the flows to be scheduled according to the known maximum security capacity of each user, after optimizing the transmission beamforming vector and phase shift matrix. At this point, calculate the number of required slots scheduling each flow on the basis of their minimum throughput requirements. In addition, the flows are sorted in order of the number of slots from least to most. Then the sequential flows are scheduled to meet the goal of maximizing the total number of successfully scheduled flows.

V. DESIGN OF SECURE RIS-ASSISTED WIRELESS SYSTEM

In this section, we propose a RIS-assisted scheduling scheme. Each flow can be transmitted directly and reflected by RIS simultaneously, and all RIS elements have a limited number of discrete phase shifts. Therefore, the proposed scheme should first determine the optimal transmission beamforming vector and the phase shift matrix, and then plan all related links that need to be scheduled. Ultimately the goal of maximizing the number of scheduled flows can be achieved.

A. Transmit Beamforming Subproblem Algorithm Design

We first study the optimization of the beamforming vector \mathbf{w}_n with the fixed phase shift matrix Φ . According to (14), (18) and (20), (25) can be deformed. The design problem of the deformed beamforming is given by the following formula [69]

$$\begin{aligned} & \max_{\mathbf{w}_n} \sum_{n=1}^N \frac{1 + \frac{1}{\sigma_N^2} \left| (\mathbf{d}_n + \mathbf{h}_n^H \Phi \mathbf{G}) \mathbf{w}_n \right|^2}{1 + \frac{1}{\sigma_N^2} \left| (\mathbf{d}_e + \mathbf{h}_e^H \Phi \mathbf{G}) \mathbf{w}_n \right|^2} \\ & \text{s.t.} \quad \|\mathbf{w}_n\|_2^2 \leq P_{max}. \end{aligned} \quad (27)$$

The optimal solution is given by the following lemma.

Lemma 1. *Given the phase shift matrix Φ of RIS, the optimal solution of the beamforming vector \mathbf{w}_n is given by the following formula*

$$\mathbf{w}_n^* = \sqrt{P_{max}} \lambda_{max}(\mathbf{X}_e^{-1} \mathbf{X}_n), \quad (28)$$

where

$$\mathbf{X}_i = \mathbf{I}_M + \frac{P_{max}}{\sigma_N^2} [(\mathbf{h}_i \Phi \mathbf{G} + \mathbf{d}_i)^H (\mathbf{h}_i \Phi \mathbf{G} + \mathbf{d}_i)], i \in \{n, e\}. \quad (29)$$

Proof. It was shown that [70], in MISO channels, the beamforming vector at the transmitter is optimal to allocate all transmission power to the legal receiver, that is: $\|\mathbf{w}_n^*\|^2 = P_{max}$. Therefore, the numerator and denominator of the objective function (27) can be rewritten as

$$\begin{aligned} & 1 + \frac{P_{max}}{\sigma_N^2} |(\mathbf{d}_n + \mathbf{h}_n \Phi \mathbf{G}) \mathbf{w}_n|^2 \\ & = \widetilde{\mathbf{w}}_n^H \widetilde{\mathbf{w}}_n \\ & \quad + \frac{P_{max}}{\sigma_N^2} \widetilde{\mathbf{w}}_n^H [(\mathbf{h}_i \Phi \mathbf{G} + \mathbf{d}_i)^H (\mathbf{h}_i \Phi \mathbf{G} + \mathbf{d}_i)] \widetilde{\mathbf{w}}_n \\ & \triangleq \widetilde{\mathbf{w}}_n^H \mathbf{X}_i \widetilde{\mathbf{w}}_n, \end{aligned} \quad (30)$$

where $\widetilde{\mathbf{w}}_n = \mathbf{w}_n / \sqrt{P_{max}}$ is a unit vector. Substituting (30) into the objective function in (27), we can get

$$\begin{aligned} & \max_{\mathbf{w}_n} \sum_{n=1}^N \frac{\widetilde{\mathbf{w}}_n^H \mathbf{X}_i \widetilde{\mathbf{w}}_n}{\widetilde{\mathbf{w}}_n^H \mathbf{X}_e \widetilde{\mathbf{w}}_n} \\ & \text{s.t.} \quad \|\mathbf{w}_n\|_2^2 \leq P_{max}, \forall n. \end{aligned} \quad (31)$$

In this way, we transform the power optimization sub-problem (27) into a generalized eigenvalue problem, and the optimal solution is given by (28). ■

B. Discrete Phase Shift Optimization Subproblem Algorithm Design

When the transmitting beamforming vector is fixed and scheduling subproblem is not considered, the power constraint and scheduling constraint are removed, and the optimization objective is shown in (26). The objective function and constraint on Φ are still nonconvex. In addition, Φ contains a series of discrete variables, and the range available for each phase shift depends on RIS quantization bits e . Considering the complexity, we use a local search method as shown in Algorithm 1 to solve this problem. Specifically, for each element, we traverse all possible phase shifts while keeping the other $L - 1$ phase shifts unchanged. Then, the corresponding optimal beamforming vector is calculated by (28), and the optimal value is selected according to the target of maximizing the security rate. Then, this optimal solution ϕ_l^* is used as a new value of Φ to optimize other phase shifts, until Φ is fully optimized.

Algorithm 1 Local Search for Phase Shift

Require: the number of quantization bits: e

Ensure: Φ^*, ω^*

- 1: **for** $l = 1 : L$ **do**
 - 2: Assign all possible values to ϕ_l , and use (28) to find the corresponding optimal beamforming vector ω ; select the value maximizing the secrecy rate, denoted as ϕ_l^* ; $\phi_l^* = \phi_l$;
 - 3: **end for**
-

Algorithm 2 The RIS-Assisted Scheduling Algorithm

Require: $F_1 = F, F_2 = \emptyset, N_F = 0, \delta_f = 0, \forall f \in F,$
 $T = 0, q_f, R_n, \forall n \in [1, 2, \dots, N], \Delta T, T_s, K$

Ensure: N_F

- 1: Calculate the priority values of the flows in F_1
 - 2: Sort the links in F_1 in decreasing order by priority values
 - 3: **for** flow $f \in F_1$ **do**
 - 4: $t_f = \frac{q_f \times (T_s + K \times \Delta T)}{R_n \times \Delta T}$
 - 5: **if** $T + t_f \leq K$ **then**
 - 6: $\delta_f = 1, F_2 = F_2 \cup f, N_F = N_F + 1$
 - 7: **else**
 - 8:
 - 9: **end if**
 - 10: **end for**
-

C. Scheduling Sequence Optimization Subproblem Algorithm Design

In this subsection, we consider the resource scheduling optimizing problem in the RIS-assisted system. Based on the above two subproblem optimization algorithms, we obtain the optimal transmission beamforming vector, the phase shift matrix, and the maximum security capacity. Then, since we only serve one flow once a time, we consider the scheduling order of all flows. Define the parameter $\tilde{\omega}_f$ to determine the priority of the flow f , which is the reciprocal of the number

of slots that it needs in a frame to meet its QoS requirement. For flow f requested by MR n , the priority value $\tilde{\omega}_f$ can be expressed as

$$\tilde{\omega}_f = \frac{R_n \cdot \Delta T}{q_f \cdot (T_s + K \cdot \Delta T)}. \quad (32)$$

The less time it takes to complete a flow, the more flows can be completed in a given amount of time slots. In order to complete as many users' requests as possible, we sort the flows according to their priority. The less slots it requires, the higher priority it has, and the earlier it will be scheduled. Algorithm 2 summarizes the scheduling subproblem algorithm based on the quality of service.

D. Complexity Analysis

The complexity of the sum scheduling flows maximization algorithm is not only related to the complexity of the power allocation subproblem and the phase shift optimization subproblem, but also related to the complexity of scheduling subproblem. For the former one, for each RIS element l , the local search algorithm keeps the remaining phase shifts unchanged, selects the best one among 2^e phase shifts, and updates a value for ϕ_l . Since there are L elements, the complexity of this part is $\mathcal{O}(N \times 2^e)$. Once updating an element, we calculating the best beamforming vector for ϕ_l , its computing complexity is derived from formular (28) and (29), and equals to $\mathcal{O}(M^2 \times L^6)$. So the computing complexity of the former part is $\mathcal{O}(M^2 \times L^6 \times N 2^e)$. For the scheduling part, we need to the above operations for the all flows, so the complexity of this part is $\mathcal{O}(F)$. Therefore, the complexity of the proposed algorithm can be given by $\mathcal{O}(FNM^2L^62^e)$.

VI. SIMULATION RESULTS

In this section, we evaluate the performance of our RIS-assisted wireless resource scheduling scheme. By comparing with other benchmark algorithms, we get numerical results under different representative parameters, verify the effectiveness of our proposed scheme, and study the impact of different parameters on the system performance.

A. Simulation Setup

We consider a mmWave HSR system. The train has eight carriages with a total length of 200 meters. There are 24 MRs evenly deployed on the rooftop of the train. So, each carriage is equipped with 1 or 2 MRs, and the distance between two adjacent MRs is 8.33m. The vertical distance between the BS and the track is 75m. The shortest distance between the BS and the MRs is 75m, and the longest distance is 213.6m. In addition, there is an eavesdropper randomly distributed around the MRs on the rooftop. All communication links in the system are transmitted within the communication range allowed by the transceiver. The number of flows need to be scheduled between the BS and MRs is less than the number of MRs. The QoS of each flow is evenly distributed between 5Mbps~100Mbps. The other parameters set in the simulation are shown in Table I.

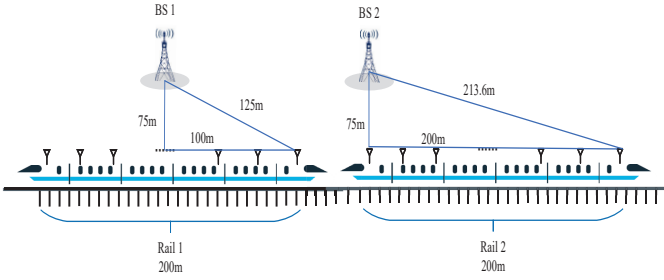


Fig. 2: Distance between the BS and MRs.

TABLE I
SIMULATION PARAMETERS

Parameter	Symbol	Value
Carrier frequency	f	28GHz
Bandwidth	W	100MHz
Max distance between BS and MRs	$d_{n,1}$	213.6m
Min distance between BS and MRs	$d_{n,1}$	75m
Distance between BS and RIS	$d_{R,2}$	50m
Distance between RIS and MRs	$d_{n,3}$	30m
Path loss intercept	C	-61.3dB
Path loss exponent in the LoS case	α_1	2.5
Path loss exponent in the NLoS case	α_2	3.6
Number of BS transmit antennas	M	4
Number of RIS elements	L	30
Noise power spectral density	N_0/W	-134dBm/MHz
Maximum transmission power	P_{max}	23dBm
Beacon period	T_s	850us
slot time	T	18us
The number of slots	K	2000
Rician factor	β_l	4
Number of flows	F	15

During the evaluation study phase, we compare the following indicators to evaluate the performance of the **Proposed-algorithm** and the benchmark algorithms:

- 1) **The number of scheduled flows:** the number of schedulable flows that meet their QoS requirements. If the QoS requirements are not met, the corresponding scheduled flows are not counted as completed flows.
- 2) **System security capacity:** the link secret capacity of the legal MRs. This metric is the difference between the throughput of the legitimate user link and that of the eavesdropper link in the network.
- 3) **Total scheduled time slots:** the total number of time slots required by all scheduled flows. The actual value of this metric must be less than the total number of slots in the frame.

In order to show the system performance of the **Proposed-algorithm**, we compare it with the following algorithms:

- **Without-RIS:** this scheme does not use RIS to reflect the signal, and so the receiver can only receive the signal through the direct link. The same power allocation algorithm is used to reduce interference and eavesdropping.
- **Manifold optimize:** this algorithm considers continuous RIS phase shifts. A manifold optimization algorithm is then used to iteratively optimize the power allocation of P_{max} and the continuous phase shift matrix.
- **Random Phase Shift (RPS):** the algorithm randomly selects a feasible phase shift for each RIS element and

keeps these phase shifts unchanged. Then, the optimal beamforming vector at the transmitter is obtained by using the same power allocation algorithm as the proposed RIS-assisted algorithm. Then the goal of maximizing the number of schedulable flows is discussed.

- **Average Power Transmission (APT):** the scheme allocates the same transmit power to all transmit antennas, and then uses the local search algorithm to find the RIS phase shift that maximizes the security capacity of each link. Then it discusses the goal of maximizing the number of schedulable flows.

B. Performance Analysis

In Fig. 3, we set the number of RIS elements $L = 30$, the number of quantization bits $e = 3$, and draw the curves of the number of schedulable flows of these four schemes as the number of requested flows changes from 2 to 18. It is observed that the trend of all five schemes increases as the number of requested flows increases, which indicates that the more requested flows in the HSR network, the more flows can be scheduled on a limited scale. The number of the flows that the proposed-algorithm can schedule is larger than the other four schemes. In particular, it is 185% larger than that of without RIS. It shows that the system capacity of communication links can be improved by RIS's reflection, and more flows can be scheduled within the same time slots. The APT scheme achieves much less flows than the other four schemes. This is because the average transmit power does not take into account the channel capacity of the eavesdropper as low as possible. In the case of confidentiality, the number of schedulable flows is correspondingly small. In addition, compared with RPS, the proposed RIS-assisted scheduling scheme has more schedulable flows, which shows that choosing the appropriate RIS reflecting element phase shift can also increase the channel capacity. It is worth mentioning that, considering continuous RIS phase shifts, the performance optimized with the manifold optimization algorithm is shown by the yellow line in Fig. 3. Although it successfully schedules more flows than the Without-RIS algorithm, it is much less than our proposed-algorithm. Because in this case, although the RIS can provide a certain reflection gain, the manifold optimization only obtains a suboptimal solution of the constrained variables. While our algorithm obtains the optimal closed-form solution. Moreover, manifold optimization takes many iterations to converge to the suboptimal solution, which is more complex than our proposed-algorithm. In short, when the number of requested flows is 18, the performance of the proposed RIS-assisted algorithm is 1.2288, 5.1221, 2.8585 and 1.7520 times that of RPS, APT, without-RIS and manifold optimization, respectively. Therefore, compared with the other four schemes, the proposed-algorithm has the best performance in the number of completed flows.

In Fig. 4, we also set $L = 30$, $e = 3$, and the number of requested flows is 18. We plot the number of schedulable flows and the number of time slots used under different time slots per frame. It can be seen that when the number of slots increases, the numbers of schedulable flows of the five schemes vary

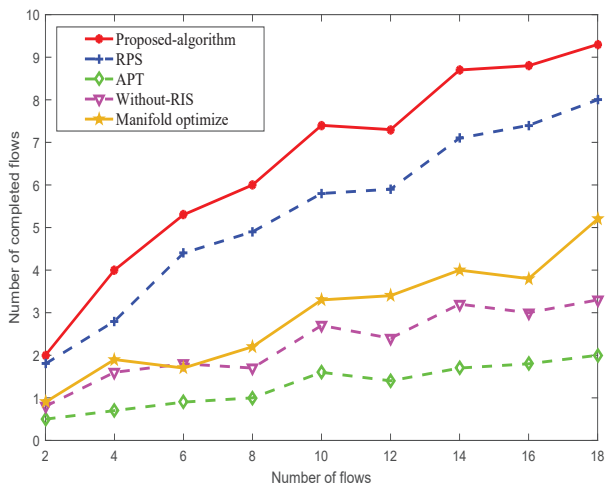


Fig. 3: Number of completed flows vs different numbers of requested flows.

little and are almost flat. Therefore, the number of time slots does not need to be increased indefinitely. High performance can be achieved by setting an appropriate number of time slots according to the number of requested flows and corresponding QoS requirements. The number of flows that can be scheduled in the proposed RIS-assisted scheduling scheme is 1.2293, 5.3819, 2.6575 and 1.6932 times that of RPS, APT, without-RIS and manifold optimization schemes, respectively. The number of time slots used is close to that of the other three schemes. It indicates that the proposed RIS-assisted scheduling algorithm has better performance in transmission efficiency.

In Fig. 5, we set $e = 3$ and $F = 18$. We draw the curve of channel security capacity as the number of requested flows changes when $L = 20$, $L = 40$ and $L = 60$. It can be seen from the figure that the number of schedulable flows of the proposed RIS-assisted scheduling scheme is the largest than the other schemes. Moreover, as the value of L increases, the amount of secrecy capacity also increases gradually. This illustrates that an appropriate increase in the number of RIS reflective elements can effectively enhance channel quality.

In Fig. 6, we set $L = 30$ and plot the change of channel secrecy capacity as the number of requested flows changes, with the phase shift quantization number of RIS reflection elements e set to 1, 3 and 4. It can be seen from the figure that the larger the quantization number of RIS reflection phase shift is, the larger system secrecy capacity can be obtained. This is because with the increase of e , the RIS elements can adjust the phase more accurately, and a more optimal phase shift can be found through the local search algorithm, so as to obtain a better secrecy capacity.

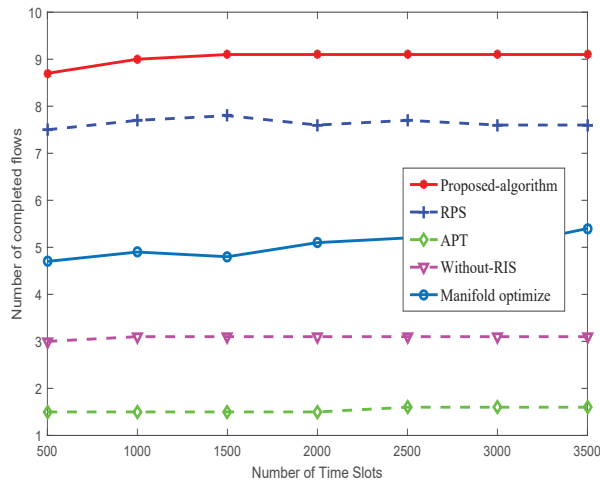
In Fig. 8 and Fig. 9, we set $L = 30$ and $e = 4$, and we plot the impact of where RIS is deployed on system secrecy capacity. Specifically, in Fig. 8 we only change the distance between RIS and MRs to observe the change in performance. It can be seen that as the distance of RIS-MRs increases, the security capacity decreases gradually. This is because as the reflection distance increases, the double fading effect of the RIS also increases gradually. This makes the auxiliary function

of RIS weakened, so that the security capacity is gradually reduced. In Fig. 8 we change the deployment location of RIS in another way. As shown in Figure. 7, we establish a three-dimensional coordinate system centered on the position of the BS. Fix other parameters unchanged, only gradually increase y_r from a negative value to a positive value. In this way, the distance changes of BS-RIS and RIS-MRs can be reflected simultaneously. Fig. 9 shows that as y_r increases from a negative value to 0 and then to a positive value, the security capacity firstly increases gradually and then tends to be stable. This is because as the distance of BS-RIS-MRs gradually decreases, the double fading effect of RIS gradually weakens, and the security capacity of the system gradually increases. But when the RIS gradually approaches the MRs from the vicinity of the BS, the security capacity no longer changes significantly. This is because the distance change of BS-RIS-MRs does not change much, and on the other hand, the improvement of system performance caused by RIS gradually tends to be saturated. In general, even if RIS is a little far from the BS and MRs, the performance is slightly impaired, but compared with the situation without RIS, it still greatly improves the security capacity.

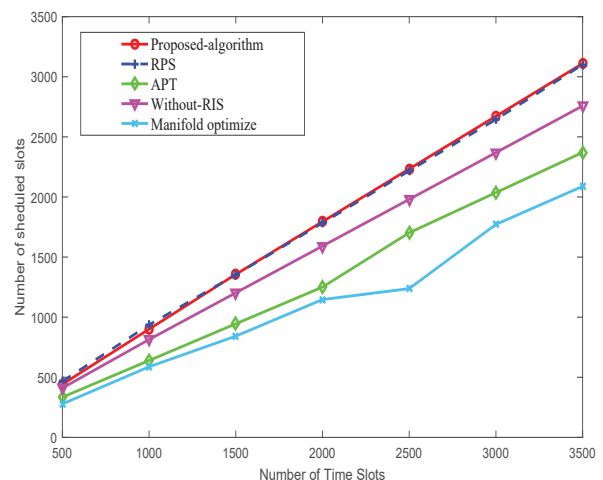
In Fig. 10, we set $L = 30$ and $e = 4$ to plot the influence of the BS transmitting power on the system secrecy capacity. As can be seen from Fig. 10, when the transmitting power is small, the system secrecy capacity of the RIS-assisted scheduling scheme increases gradually as the increase of the BS transmitting power, which indicates that the increase of transmitting power can effectively improve the system secrecy capacity. However, when P_{max} increases to a certain extent, as shown in Fig. 10 is about 40dB, the system secrecy capacity of the proposed RIS-assisted scheduling scheme drops sharply. This is because when P_{max} increases to a certain extent, although the system capacity of the legitimate receiver increases, the system capacity of the eavesdropper also increases to the point where it is difficult to suppress, leading to the secrecy capacity very small. Therefore, the transmission power is not the bigger the better, it should be reasonable set to maximize the system secrecy capacity.

VII. CONCLUSION

In this paper, we have focused on the problem of scheduling flows with diverse QoS requirements in the mmWave HSR communication scenario. Under the constraints of maximum transmit power, discrete phase shift and minimum secrecy capacity, we joint the power allocation design, the RIS' phase shift optimization and scheduling order problem to maximize the number of successfully scheduled flows. Extensive simulations have showed that the proposed RIS-assisted algorithm outperformed the other three baseline schemes on the number of completed flows and achievable secrecy capacity. In the future work, we will consider RIS-assisted multi-cell HSR communication to reduce the number of handovers and improve the handover success rate. We will also consider adopting the FDMA scheme, using RIS to enhance the useful signal, and achieve the purpose of reducing interference at the same time, so as to maximize the utilization of frequency resources.



(a)



(b)

Fig. 4: (a) Number of completed flows vs Number of TSs. (b) Number of scheduled slots vs Number of TSs.

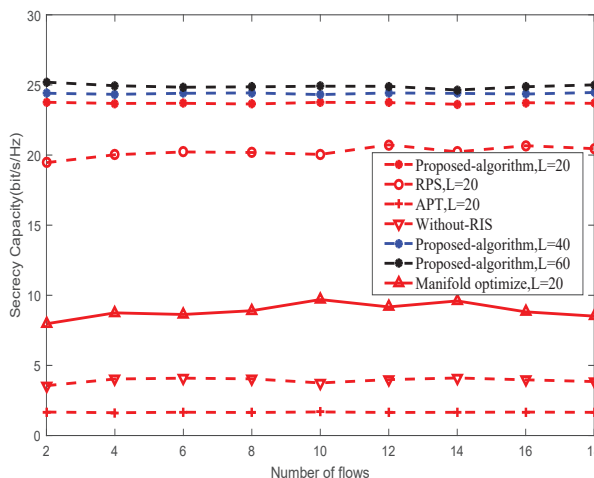
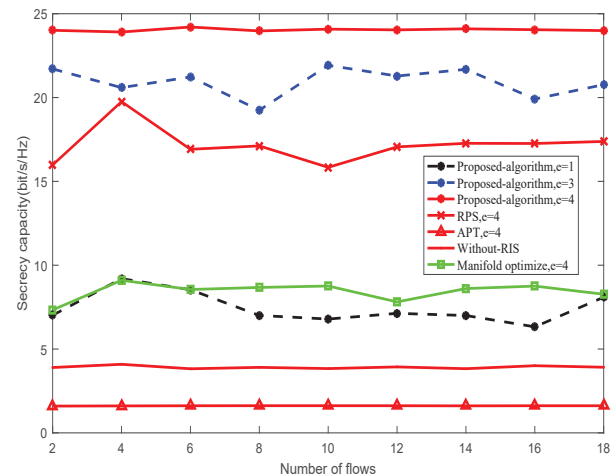
Fig. 5: Secrecy capacity vs the number of RIS elements L .

Fig. 6: Secrecy capacity vs the number of quantization bits.

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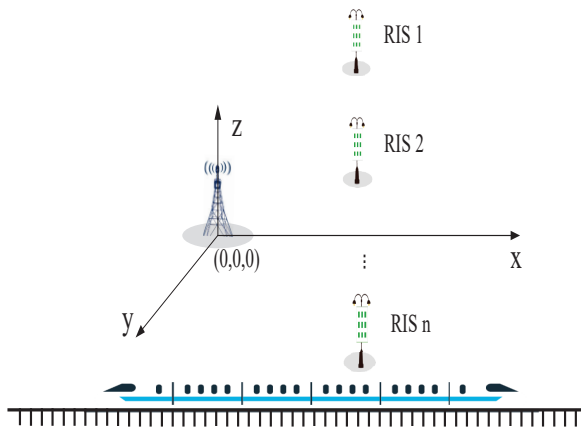


Fig. 7: The three-dimensional coordinate system.

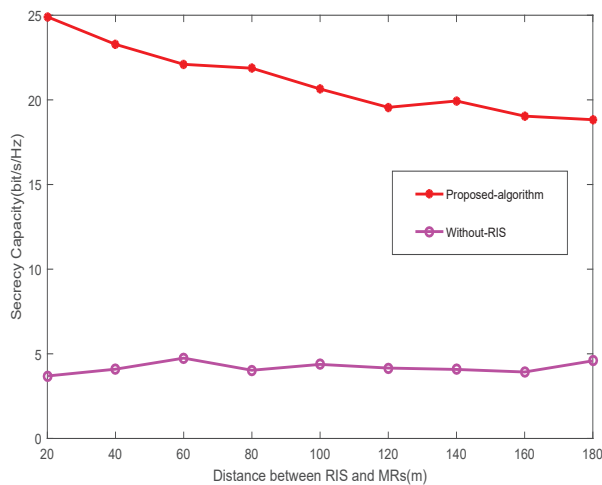


Fig. 8: Secrecy capacity vs the distance between RIS and MRs.

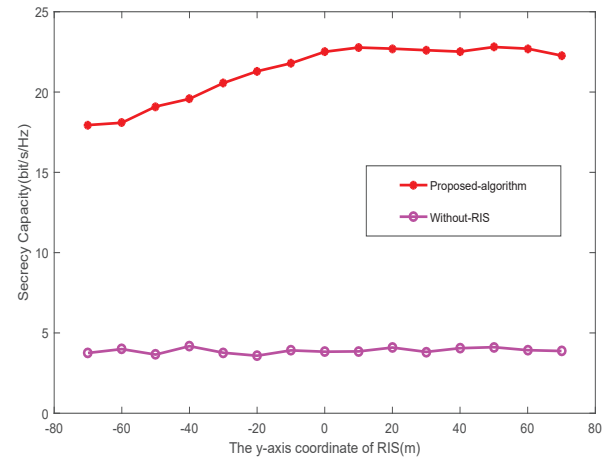


Fig. 9: Secrecy capacity vs the position of RIS.

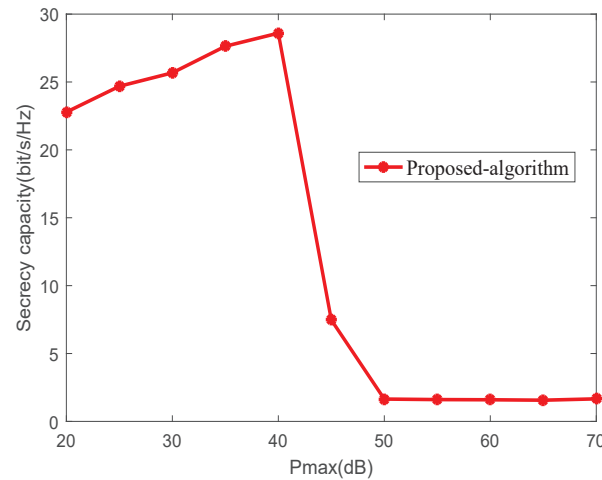


Fig. 10: Secrecy capacity vs transmit power Pmax.

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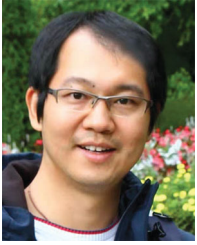


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