# Secure and Reliable Transmission via Intelligent Reflecting Surface Integrated on Unmanned Aerial Vehicle

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**Abstract.** Wireless communication environment becomes more and more complex especially when facing vicious eavesdroppers and external jammers. Intelligent reflecting surface (IRS) can provide secure or anti-jamming communication approaches via passively reflecting with low power consumption and high cost efficiency. Unmanned aerial vehicle (UAV) also can be used to cooperatively transmit useful signals of legitimate users with vicious attackers. Carrying IRS on UAV can add new cooperative strategies, such as trajectory or height of UAV, numbers of reflecting elements or phase shift of IRS, to improve secure and anti-jamming performance of legitimate users. Two cooperative transmission schemes assisted with UAV and IRS are proposed to confront passive eavesdroppers or smart jammers in this paper. The first kind of cooperation is to select UAV relay or IRS reflecting strategy to improve energy efficiency of system with passive eavesdroppers. The second kind of cooperation is to jointly optimize phase shifts of IRS and trajectory of UAV to enhance transmission capacity with smart jammers. Simulation results show that, with the help of the cooperation of UAV and IRS, secure and reliable communications can be realized and system performance can be improved compared with no cooperation scheme or only one kind of cooperation with UAV or IRS scheme.

**Keywords:** UAV · IRS · cooperative transmission · physical layer security · smart jammers

## 1 Introduction

The electromagnetic environment becomes more and more terrible as numbers of wireless communication devices increasing dramatically, while vicious eavesdroppers and external jammers make matters worse. To countermeasure external jammers or vicious eavesdroppers in civil and military communications, traditionally, appropriate design of transceivers, such as pre-coding or artificial noise generated in transmitters, interference avoidance or elimination used in receivers, or cooperative relay and friendly jamming introduced by intermediate nodes [1] were adopted. Although these technologies above are available for enhance anti-jamming or anti-eavesdropping performance of legitimate users, extra devices and energy are consumed. Therefore, it is necessary to search


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some more economical approaches to guarantee secure and reliable communications of legitimate users in complicated electromagnetic environment.

Intelligent reflecting surfaces (IRSs) can realize programming or reconfiguration of wireless spectrum environment by modifying electromagnetic parameters via reflecting coefficients or phase shifts [2, 3]. On one hand, IRSs just reflect the received signals passively, don't need to add extra devices, consume huge forward energy or increase signal processing costs, since it can improve cost efficiency, spectrum efficiency and energy efficiency [4, 5]. On the other hand, as introduced with IRSs, a new degree of freedom of optimization strategies for wireless communication performance is increased. IRSs can modify their reflecting coefficients to enhance transmission rates or achievable security rates through magnifying useful signals of legitimate users and weakening vicious jamming signals, or reducing leakage of secrecy information in the wiretapping direction. In other words, as IRSs introduced, wireless spectrum environment become a new optimizable strategy to confront jammers or eavesdroppers. Usually, IRSs are always deployed on the outside surface of fixed buildings or on motionless aerial platforms. It makes adjustable strategies of IRSs being limited, and can't cope with serious effects on mobility of legitimate users and block of tall buildings.

Unmanned aerial vehicles (UAVs) can play the roles of aerial base stations, aerial users or relay nodes in the future mobile communication systems. They have been drawn extensive attentions since there exists distinct line of sight (LOS) communication links between UAVs and terrestrial users with lower deployment and hover costs, and they can adjust their position and trajectory flexibly [6–9]. Integrated IRSs on UAVs in the cellular networks on the next generation mobile communications can promote communication performance, since it can not only make IRSs configure spectrum environment more flexible, but also increase probabilities of LOS with obstacles.

## 2 Review of Secure Anti-jamming Cooperative Transmission with IRSs and UAVs

Based on the characteristic of wireless spectrum environment reconfiguration of IRSs, there are many works studying anti-eavesdropping and anti-jamming problems with the help of IRSs. Furthermore, concurrently considering flexible mobility of UAVs and wireless spectrum environment reconfiguration of IRSs, several works discuss secure and anti-jamming cooperative transmission on UAV-borne IRS systems. In this section, we will survey on the anti-eavesdropping and anti-jamming transmission technologies under IRS-only and integrated IRS to UAV scenarios.

### 2.1 Secure Anti-jamming Cooperative Transmission on IRS-Assisted Wireless Systems

There are a series of works [10–16] consider physical layer security problems with the help of IRSs. For instance, in [10], on the situation that one receiver and one eavesdropper were in the same direction and the eavesdropper was closer to the transmitter than the receiver, both beamforming of the transmitter and reflecting coefficients of IRS were optimized to maximize the minimum secrecy achievable rate. In [11], supposed that the global channel state information (CSI) can be acquired by the access point (AP) and IRS, the beamforming coefficients were designed to transmit or reflect the useful signals to maximize the secrecy achievable rate. It was reasonable to suppose that the CSI related with the eavesdropper was available, since the eavesdropper was the inner user but not be trusted by the legitimate receiver. In [12], phase shift of the IRS, beamforming of the transmitter and pre-code parameters were jointly optimized to reach a tradeoff between energy efficiency and secrecy performance of legitimate users.

While in practice, it is impossible for legitimate users to acquire eavesdropping related CSI easily. Therefore, there were another series of works considering robust and secure communications on IRS-aided wireless systems without perfect CSI. In [13], supposed that there were multiple eavesdroppers with multi-antenna and their wiretapping CSI couldn't be achieved perfectly, considering the robust and secure communication of an IRS-aided multiple-input-single-output (MISO) system. On the condition that the maximum information leakage was lower than a threshold, both artificial noise beamforming of the transmitter and phase offsets of IRS were optimized to maximize system sum rate. Authors in [14] also considered an IRS-assisted massive antenna system with the statistic CSI, to maximize the ergodic spectrum efficiency, proposed an optimal phase offsets scheme. In [15], with errors of statistic CSI, to minimize the transmission power, the variance matrix of the artificial noise, beamforming of the transmitter and phase offsets of IRS were jointly optimized, and a robust and secure wireless communication scheme with the assistance of IRS was designed. Then in [16], without CSI of the eavesdropper, the physical layer security performance of the MISO communication system was studied, the secrecy rate was enhanced in the way of minimizing transmission power of the transmitter and optimizing power beamfoming of other devices to interfere eavesdroppers.

Since most of anti-eavesdropping problems on IRS-assisted wireless communication systems were not convex problems induced by joint optimization of phase offsets design of IRSs and beamforming of transmitters, there were some numerical optimization technologies were used [17, 18]. In [17], secure transmission problem of a multiple antenna system with the assistant of IRSs was considered, the active beamforming and passive phase offsets were jointly optimized to maximize the secrecy achievable rate. Authors in [17] made this non-convex optimization problem into a convex problem via semi-definite programming (SDP) relaxing and solved it by CVX tool in Matlab. And in [18], IRS was applied on physical layer security, supposed that a system model with a transmitter with multiple antenna, an eavesdropper and a receiver with single antenna, secrecy achievable rate was optimized by phase offsets of IRS and beamforming of the transmitter. The minorization maximization (MM) and block coordinate descent (BCD) approaches were used to obtain the suboptimal solution of the non-convex problem.

There are lots of researches on IRSs at the present, but most of them focus on transmission rate or secrecy achievable rate improvement, there are few researches on confronting smart jammers. Smart jammers, which are a kind of jammers can destroy legitimate communication while can conceal its position and modify its jamming strategies dynamically. On this situation, it is difficult for legitimate users to countermeasure them. In [19] and [20], authors employed deep reinforcement learning algorithms to enable legitimate users to obtain fast or optimal communication strategies without any characteristic of smart jammers.

## 2.2 Secure Anti-jamming Cooperative Transmission on UAV-Borne IRS Systems

It is benefit to deploy IRSs on the UAV. Firstly, it is probable to decrease transmission with obstacles on UAV communications. By integrated IRSs, multiple LOS channels can be generated through reflecting signals passively, communication between UAV and terrestrial users is enhanced. Secondly, IRSs can work on the full duplex mode without any self-interference. Thirdly, deploying IRSs on the UAV, the air-to-ground link sustains much lower channel fading than the ground-to-ground link, it means that energy consumption can be decreased drastically. Besides, the mobility of UAV can enable IRSs to adjust its deployment, and dynamic environment can be fully used to bring communication performance improvement of legitimate users.

In this section, some works on cooperative transmission scheme where IRSs is deployed on UAV are given. In [21], a new method was proposed to enhance communication performance of mmWave network by integrating IRSs on the UAV, the Q learning and neural network-based approaches were used to modify reflecting coefficients of IRSs and location of UAV to maximize downlink capacity. Simulation results showed that, deploying IRSs on UAV, both the average transmission rate and LOS communication probability had a large promotion compared with still IRSs. In [22], power allocation of the base station and passive reflecting coefficients of IRS were jointly designed to fulfill communication requirement of legitimate users. However, when users move dynamically, the fixed deployment of IRSs can't play a perfect role for anti-jamming. Therefore, instead dynamic deployment of static deployment, fixing IRSs on UAV and planning UAV's trajectory can enhance the anti-jamming performance further. Then in [23], with the imperfect CSI of eavesdropping link, trajectory of UAV, passive reflecting beamforming and active transmission power of legitimate users were jointly designed to improve the physical layer security performance. Authors in [24] thought that it was effective to confront passive eavesdroppers and smart jammers via integrating IRSs on UAV through their cooperation. On one hand, part of reflecting cells of IRS can adjust their phase offsets to generate counteractive reflecting signals to minimize eavesdropping signals at special position. On the other hand, the distance can be shortened through the free mobility of UAVs, and reflecting signals can be superimposed to the source signals through adjusting phase offsets of other IRS cells, eventually improve signal-to-noise-ratio (SNR) of legitimate users. In [25], on the constraint of sum transmission power budget, the secrecy achievable rate was maximized via jointly optimizing beamforming weight of the transmitter, reflecting coefficients of IRS and position adjustment of IRS brought by the mobility of UAV.

Several cooperative methods of UAV and IRS were discussed in [26] and three modes were proposed, they were only UAV as for relay node, only IRS as for reflecting node, and both UAV and IRS working as help nodes. In the third mode, the number of reflecting elements of IRS and height of UAV were jointly optimized to maximize spectrum efficiency and energy efficiency. In [27], the deployment height and distance to the base station of IRS were adjusted to enlarge coverage of cellular networks and throughout of UAV users. Authors in [28] investigated that dynamic mobility of UAV and software-controlled IRS could be used to enhance security performance, and maximize the secrecy rate via jointly optimizing phase offsets of IRS and transmission power and position of UAV.

Because it is hard to find close expressions of optimization problems on IRS integrated UAV wireless system, machine learning methods are usually used. To enhance the secrecy achievable rate with smart jammers on an IRS-assisted communication system, authors in [22] designed a fuzzy win or learn fast-policy hill-climbing (WoLFCPHC) algorithm to meticulously design the transmission power of the base station and the reflecting coefficients of IRS. In [29], based on proximal policy optimization (PPO), a deep reinforcement learning framework was proposed to learn the activity randomness of internet of thing (IoT) devices, phase offsets of IRS and communication schedule were jointly optimized to minimize expected sum AoI (ESA). And in [30], a novel deep reinforcement learning enabled method was proposed to deploy UAV with IRS to promote downlink transmission performance in mmWave networks.

## 3 Cooperation Mechanism Designs and Numerical Results Discussion

We have mentioned that it was benefit for cooperative transmission with IRS-integrated UAV systems above. Therefore, we discuss the scheme that IRSs are deployed on the UAV, and furthermore they can cooperate with each other to improve secure and reliable communication performance of terrestrial mobile users. In this section, we introduce two cooperation mechanisms of UAV and IRS.

### 3.1 Cooperation Mode Design of IRS and UAV

The first one is cooperation mode design, such as relaying of UAV and reflecting of IRS. As shown in Fig. 1, considering that there is a base station, a terminal user, a passive eavesdropper and a UAV-carried IRS. There are two modes for communication enhancement, such as UAV relaying and IRS reflecting. On one hand, UAV relaying can obtain higher gains compared with IRS reflecting, while may bring the probability of being wiretapped. On the other hand, IRS reflecting only consumes lower power with passive reflecting elements to bring higher energy efficiency. Therefore, it is available to cooperate with UAV and IRS to forward the source signals to enhance security performance and energy efficiency simultaneously.

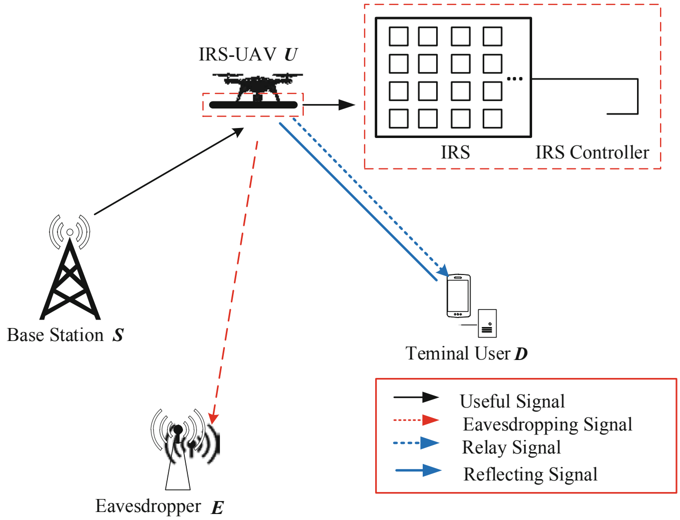


**Fig. 1.** System model of secure cooperative transmission with a passive eavesdropper on IRS-integrated UAV system

Specifically, through two cooperation mode design, such as UAV relaying and IRS reflecting, two joint strategies optimization, such as transmission power of UAV and numbers of IRS reflecting elements, energy efficiency of the system is maximized under the secrecy capacity constraint.

We set that the base station is located on the original point, the terminal user and the eavesdropper are located on coordinates with [1000, 0] and [2000, 0] respectively, and the height of UAV is 150 m for simulation. Suppose that the air-to-ground link suffers LOS pass-loss with a probability and Rician channel fading related to the urban environment, and the related wireless environment parameters are obtained by [31–33]. In Fig. 2 and 3, we can see that the energy efficiency first increase as transmission power of UAV and numbers of IRS reflecting elements, then decrease. Therefore, there exists an optimal transmission power of UAV and optimal number of IRS reflecting elements. As shown in Fig. 4, we can see that through jointly designing both of them, energy efficiency of system will be boosted enormously.

### 3.2 Cooperative Strategy Optimization of IRS and UAV

The second cooperative scheme is considering UAV as a carrying tool and IRS as the reflecting device, cooperating UAV and IRS in another way to realize secure and reliable communications for legitimate users. As shown in Fig. 5, we suppose there exists a smart jammer, a base station, a terminal user and an IRS carried on the UAV. We jointly optimize phase offsets of IRS and the trajectory of UAV to improve anti-jamming performance of terrestrial users. Since the attacking strategy of the smart jammer can't be obtained by legitimate users, we formulate the optimization problem as a Markov decision process and solve it via a 3-DQN multi-step learning algorithm in [34].

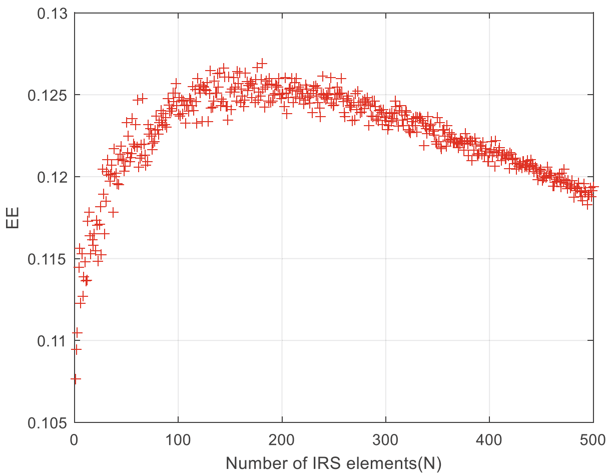


**Fig. 2.** Energy efficiency versus numbers of IRS elements with a passive eavesdropper

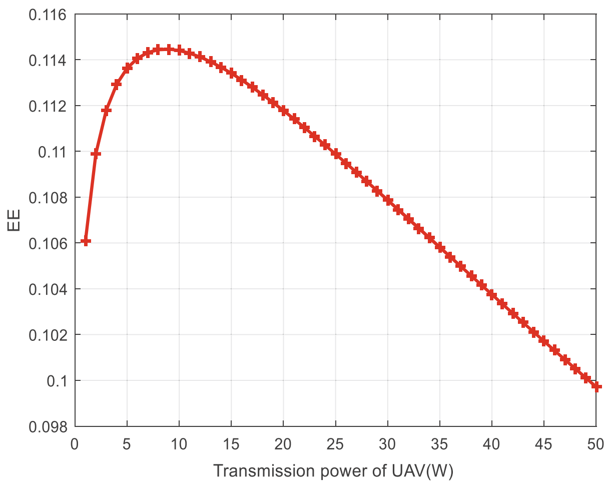


**Fig. 3.** Energy efficiency versus transmission power of UAV with a passive eavesdropper

As illustrated in Fig. 5, we consider that the base station and the terminal user are located on the original point and [1000, 1000], while there are three position sets of the smart jammer, such as [200, 500], [500, 500], and [800, 500], respectively. Depending [35], we suppose that our scenario meets the requirement of large-IRS far-field free space model. We compare the anti-jamming performance of joint optimization versus jamming

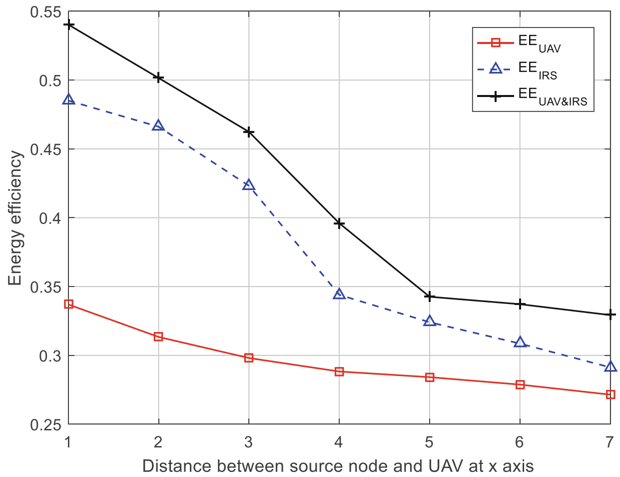


**Fig. 4.** Energy efficiency under different algorithms with a passive eavesdropper

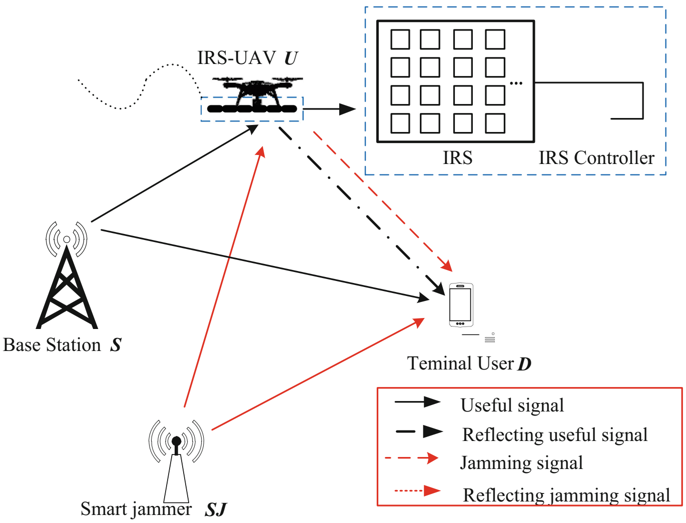


**Fig. 5.** System model of reliable cooperative transmission with a smart jammer on IRS-integrated UAV system

power and versus three different positions of the smart jammer in Fig. 6 and Fig. 7. In Fig. 6, we can see that the achievable rate under the algorithm we proposed outperforms the ones under other compared algorithms. It is verified that, by jointly designing phase shifts of IRS and trajectory of UAV, the performance for confronting smart jammers can be improved. And in Fig. 7, it is shown that whether the position of the smart jammer is, our proposed algorithm always has the best performance comparing to other strategies.

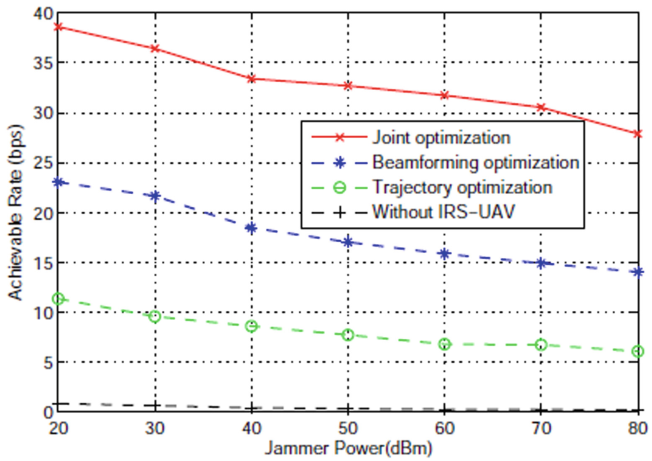


**Fig. 6.** Achievable rate under different algorithms versus jammer power of the smart jammer

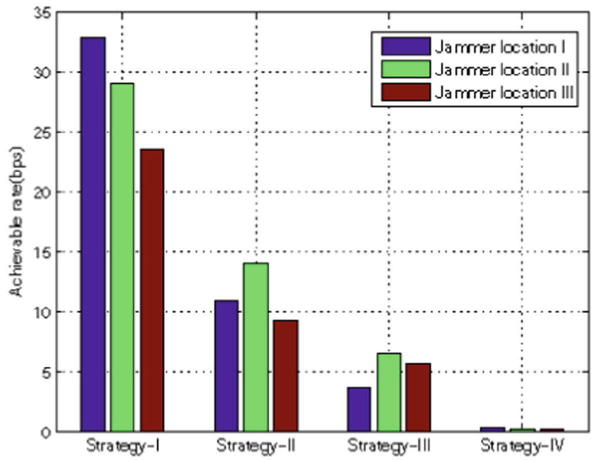


**Fig. 7.** Achievable rate under different algorithms versus position of the smart jammer

## 4 Future Research Directions

We have surveyed some works on IRS-assisted wireless system and IRS-integrated UAV communication system, and provide two cooperative schemes for IRS and UAV with passive eavesdroppers and smart jammers. We find that researches on anti-eavesdropping and anti-jamming problems with UAV and IRS are still in infancy, there are many open issues should be deeply studied.

**Joint Optimization Designs of UAV and IRS:** Some works have considered that mobility of IRS deployed on UAV, while the influence on strategy adjustment of IRS is rarely involved. Part of works mentioned that carrying IRS on UAV could increase adjustment flexibility of reflecting coefficients, and other works optimized phase offsets of IRS and the trajectory of UAV independently to improve anti-jamming performance. However, there exists some coupling relationship between position adjustment of UAV and deflection of IRS, it is not suitable to optimize their strategies individually. Therefore, their coupling relationship should be studied further, and the influence on cooperative communication of IRS brought by mobility of UAV should be revealed, and enhance secure and reliable communication performance of legitimate users.

**Practical Cooperation Mechanisms of UAV and IRS:** Cooperative mechanism of UAV and IRS hasn't been fully explored. In [26], two cooperative communication modes, such as UAV relay and IRS reflecting, were discussed and their effects on cellular network throughout has been compared. While most of researches consider UAVs as carriers used to deploy IRSs, their cooperative transmission abilities have not been mentioned. In fact, on some conditions, the UAV, works as the cooperative relay, can bring much more performance gain than reflecting IRS. Hence, it is valuable to unlock the potential of cooperative approaches of UAV and IRS, analyze the cooperative transmission effect on system capacity and physical layer security and jointly optimize cooperative strategies of UAV and IRS.

**Intelligent Countermeasure for Active Eavesdroppers and Smart Jammers:** At the present, most of works focused on transmission capacity or throughout improvement via integrated IRS on UAV, and few works studied physical layer security problem on the same scenario. Although mobility of IRS has been mentioned, flexibility and intelligence of eavesdroppers or jammers hasn't been expressed. Therefore, it is significant to research the cooperative transmission of UAV and IRS with active eavesdroppers or smart jammers.

## 5 Conclusion

We introduce the characteristics of UAV-assisted and IRS-assisted communication for anti-eavesdropping and anti-jamming, analyze the research results of IRS-assisted communications on fixed platforms and on mobile UAV scenarios in this paper. We also provide two use cases of secure and reliable cooperative communications on IRS-integrated UAV system for confronting passive eavesdroppers and smart jammers. Numerical results verify that cooperative mode design and cooperative strategy optimization can effectively enhance secure and reliable communication performance of legitimate users. Finally, open issues and conclusions are drawn.

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