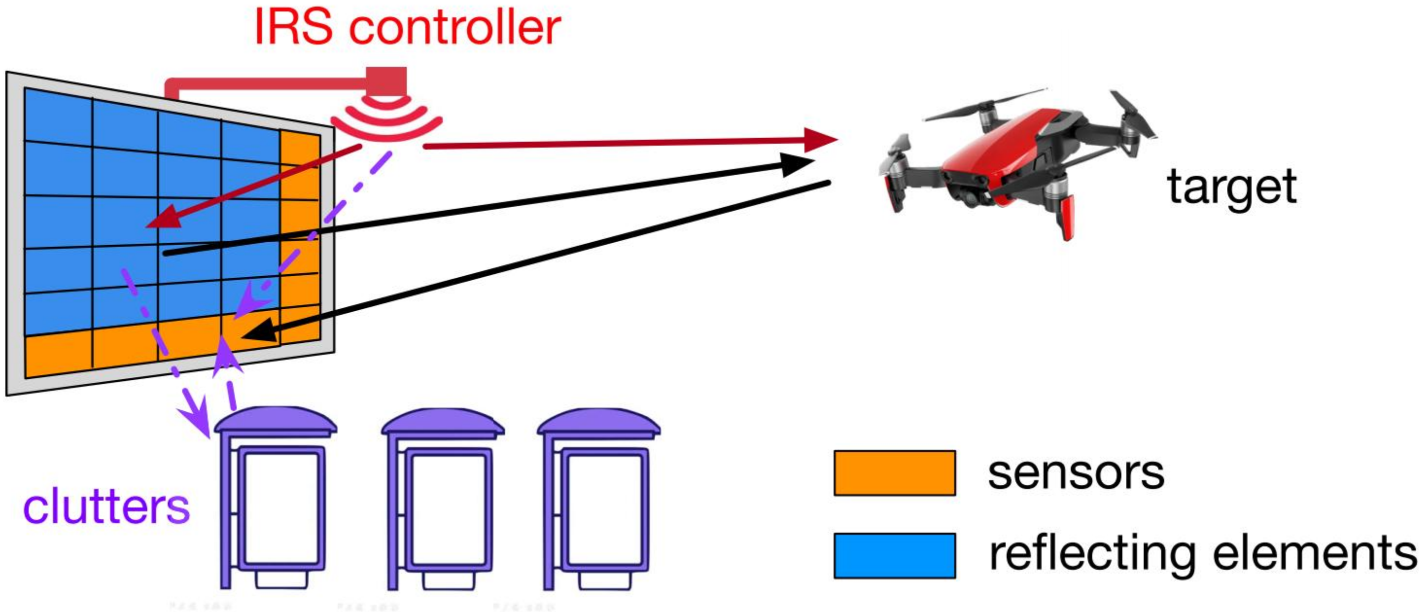
Target Sensing with Intelligent Reflecting Surface: Architecture and Performance



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Target Sensing With Intelligent Reflecting Surface: Architecture and Performance

IF 17.2 SCIE JCR Q1 计算机科学1区 Top EI

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Abstract:
Intelligent reflecting surface (IRS) has emerged as a promising technology to reconfigure the radio propagation environment by dynamically controlling wireless signal's amplitude and/or phase via a large number of reflecting elements. In contrast to the vast literature on studying IRS's performance gains in wireless communications, we study in this paper a new application of IRS for sensing/localizing targets in wireless networks. Specifically, we propose a new self-sensing IRS architecture where the IRS controller is capable of transmitting probing signals that are not only directly reflected by the target (referred to as the direct echo link), but also consecutively reflected by the IRS and then the target (referred to as the IRS-reflected echo link). Moreover, dedicated sensors are installed at the IRS for receiving both the direct and IRS-reflected echo signals from the target, such that the IRS can sense the direction of its nearby target by applying a customized multiple signal classification (MUSIC) algorithm. However, since the angle estimation mean square error (MSE) by the MUSIC algorithm is intractable, we propose to optimize the IRS passive reflection for maximizing the average echo signals' total power at the IRS sensors and derive the resultant Cramer-Rao bound (CRB) of the angle estimation MSE. Last, numerical results are presented to show the effectiveness of the proposed new IRS sensing architecture and algorithm, as compared to other benchmark sensing systems/algorithms.

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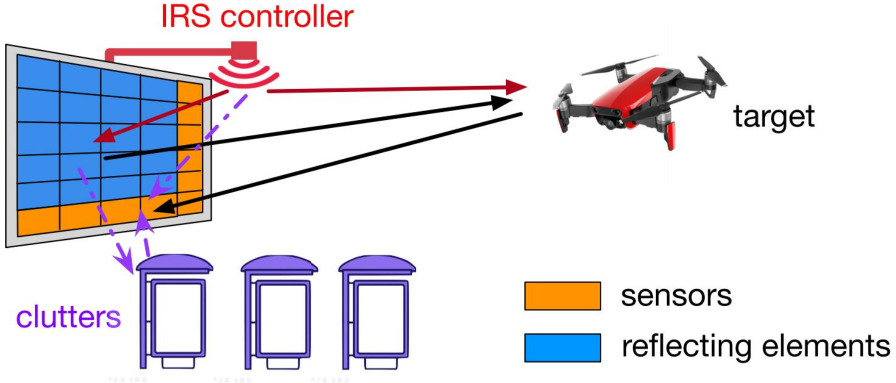
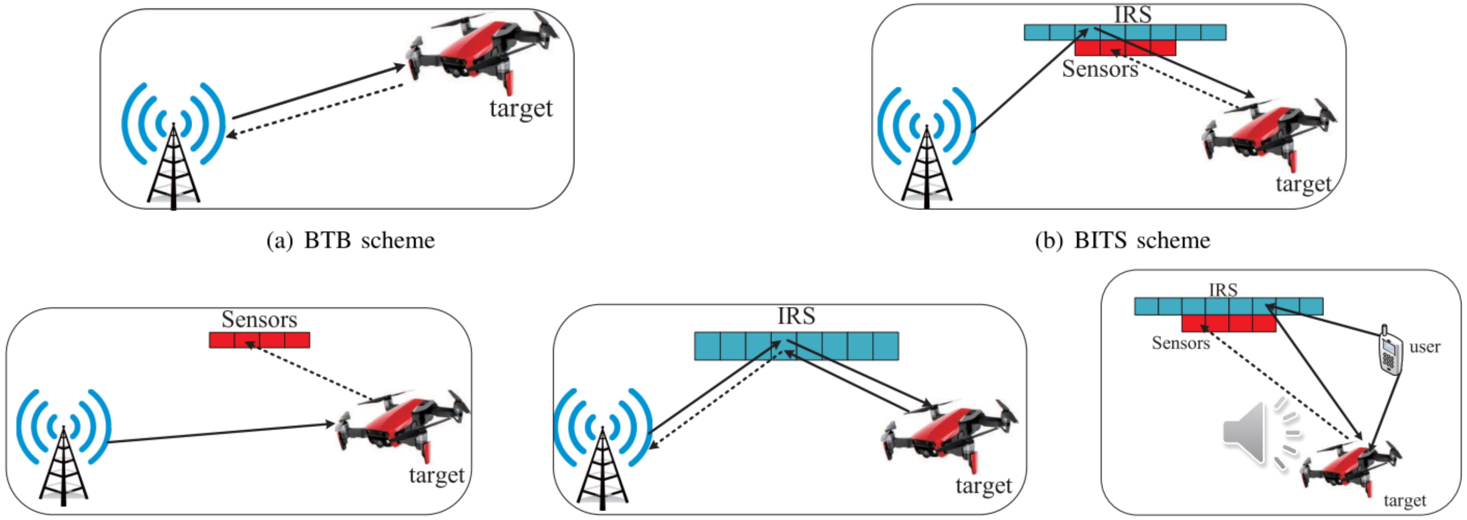
[1] X. Shao, C. You, W. Ma, X. Chen and R. Zhang, "Target Sensing With Intelligent Reflecting Surface: Architecture and Performance," in *IEEE Journal on Selected Areas in Communications*, vol. 40, no. 7, pp. 2070-2084, July 2022

介绍框架

- 背景/简要介绍
- 研究方法
- 实验结果
- 总结



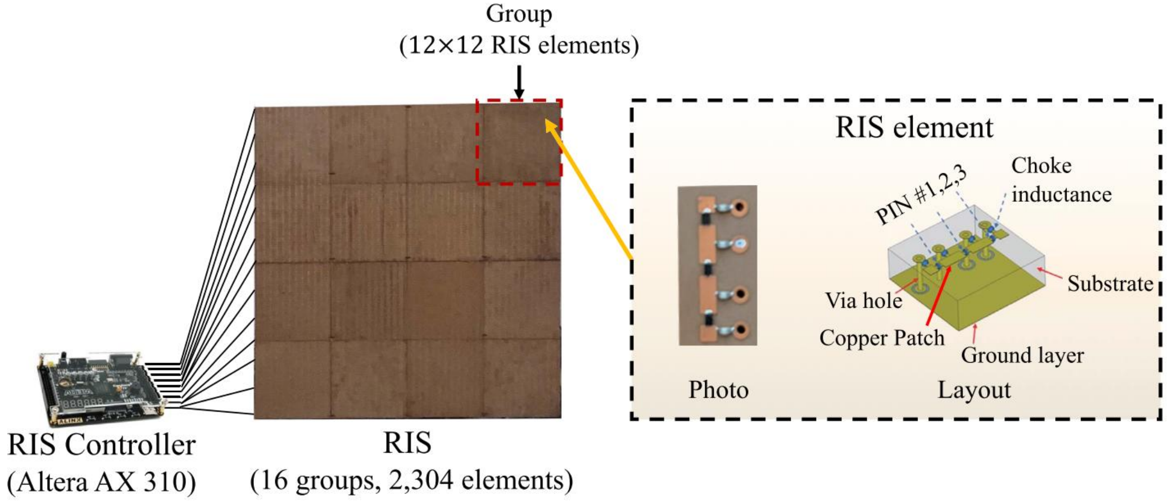


(a) BTB scheme
(b) BITS scheme
(c) BTS scheme
(d) BITIB scheme
(e) Mobile-user aided scheme (MUS)

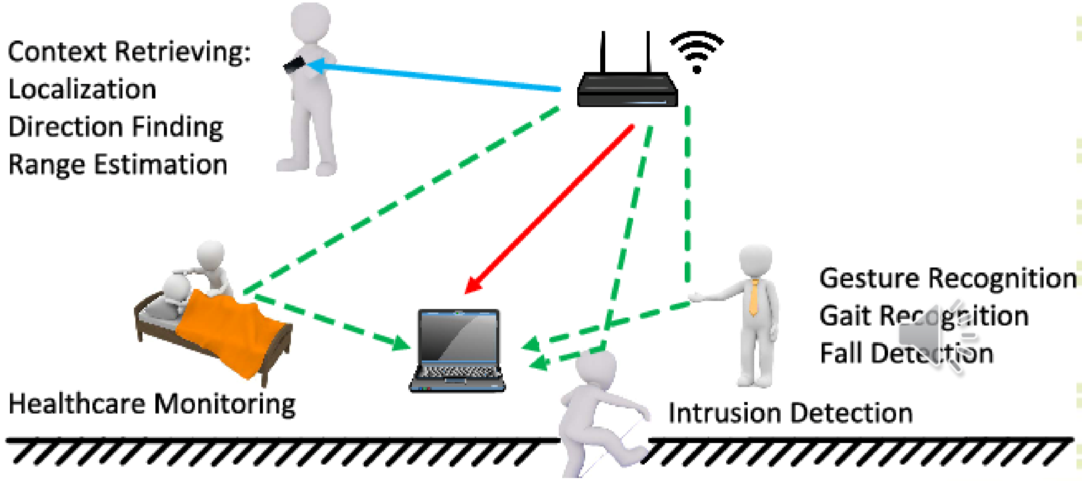
智能反射表面辅助的无线感知

- 什么是智能反射表面?
  - 一个由许多可重构单元组成的表面。
  - 可以让接收信号中包含更多环境信息

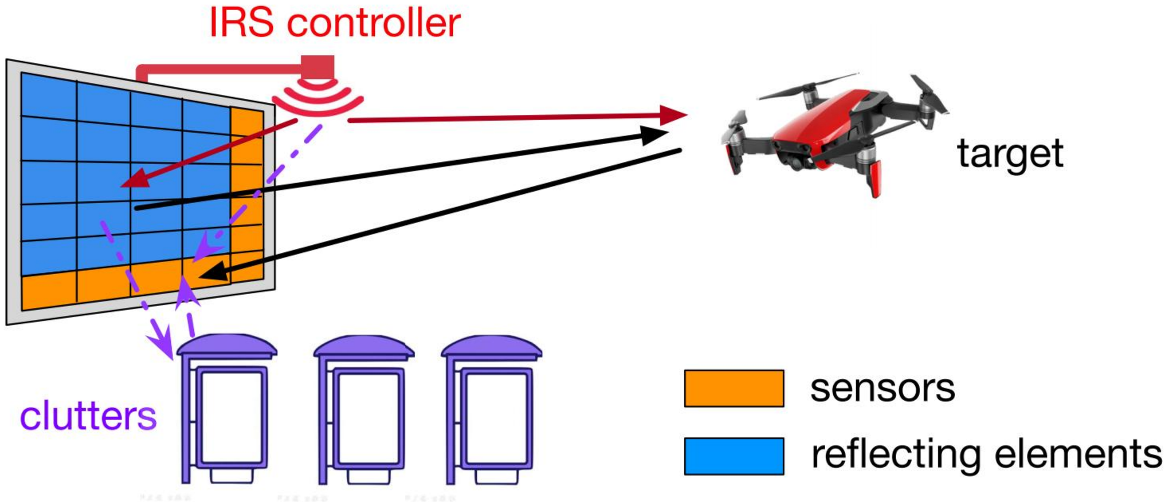
  → 对无线感知有很大的增益
  - 如何控制智能反射表面的被动波束成形?



- 什么是无线感知?
  - 通过收集无线信号来感知环境中的变化与活动。
  - 定位 (localization) /姿势识别 (gesture recognition)
  - 如何从接收信号中恢复出感知信息?



智能反射表面辅助的无线感知



- 被动感知
  - 感知目标与RIS之间的角度信息 （DOA）
- 发射端与接收端都部署在RIS附近
  - 减少路径损耗
- MUSIC算法估计角度信息，推导CRB分析估计误差

智能反射表面辅助的无线感知

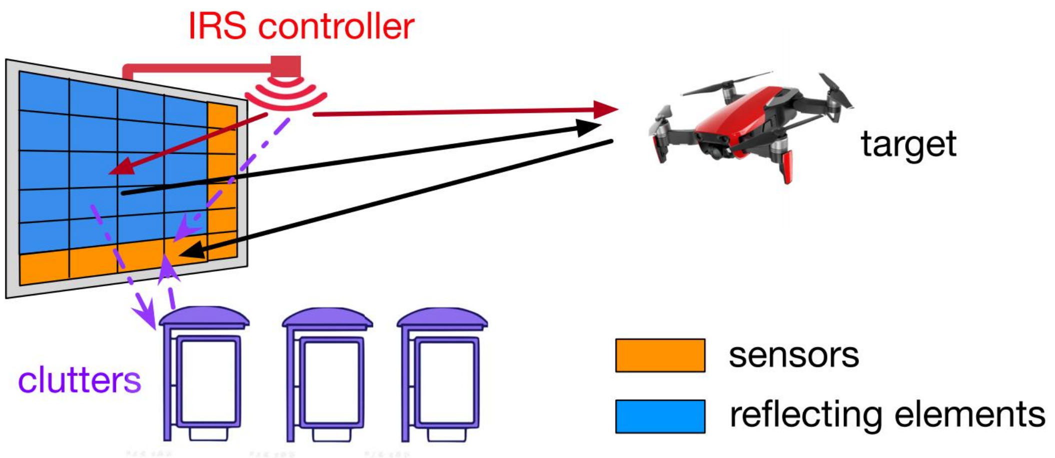
- 接收信号模型

经过环境物体的信道

$$\mathbf{y}_0[t] = \left(\underbrace{\mathbf{g}_{\mathrm{r}}[t] + \mathbf{g}_{\mathrm{d}}} + \underbrace{\sum_{\ell=1}^{L} (\mathbf{g}_{\mathrm{r},I_\ell}[t] + \mathbf{g}_{\mathrm{d},I_\ell}) + \mathbf{h}_{\mathrm{CS}}}_{\text{background channel}} \right) x[t] + \mathbf{z}_0[t], \quad t \in \mathcal{T}, \quad (7)$$

经过目标的信道

噪声



- 角度信息估计
  - MUSIC算法 (multiple signal classification)
  - CRB推导 (Cramer-Rao bound)

智能反射表面辅助的无线感知

- 角度信息估计 (MUSIC算法)

$$\mathbf{Y} = [\mathbf{y}[1], \cdots, \mathbf{y}[T]] = \mathbf{b}(\theta)[f(\boldsymbol{\varphi}[1]), \cdots, f(\boldsymbol{\varphi}[T])] + \mathbf{Z} \triangleq \mathbf{b}(\theta)\mathbf{f}^H + \mathbf{Z}, \quad (14)$$

导向向量(steering vector)

$$\mathbf{u}(\bar{\vartheta}, \bar{N}) \triangleq [e^{\frac{-\jmath(\bar{N}-1)\pi\bar{\vartheta}}{2}}, e^{\frac{-\jmath(\bar{N}-3)\pi\bar{\vartheta}}{2}}, \ldots, e^{\frac{\jmath(\bar{N}-1)\pi\bar{\vartheta}}{2}}]^T,$$

  - Sensor的数量需要大于感知目标数量
  - 相比DFT，需要的sensor数量没那么多
  - 需要扫描所有可能的角度，计算复杂度较高

- 智能反射表面状态设置
  - 最大化感知性能 → 最大化接收信号能量 去除环境散射信号
  - Max-min问题：在不同的时隙下，让RIS的反射波束扫描不同的角度

$$(\text{P1}): \max_{\{\boldsymbol{\varphi}[t]\}} \min_{\mathbf{B}} \operatorname{tr}(\mathbf{R}_{\boldsymbol{\varphi}}\mathbf{B})$$

$$\text{s.t. } [\mathbf{R}_{\boldsymbol{\varphi}}]_{n,n} = 1, \quad n \in \mathcal{N}, \quad (20)$$

$$\mathbf{R}_{\boldsymbol{\varphi}} \succeq 0, \quad \mathbf{B} \succeq 0, \quad (21)$$

$$\lambda_n(\mathbf{B}) \geq \epsilon, \quad n \in \mathcal{N}, \quad (22)$$

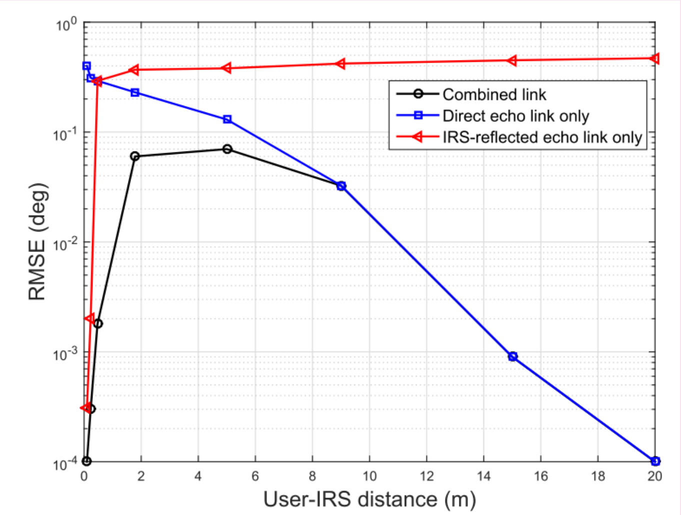
$$|[\boldsymbol{\varphi}[t]]_n| = 1, \quad n \in \mathcal{N}, \ t \in \mathcal{T}, \quad (23)$$

MUSIC算法: https://pdfcoffee.com/qdownload/gird-systems-intro-to-music-esprit-pdf-free.html

智能反射表面辅助的无线感知

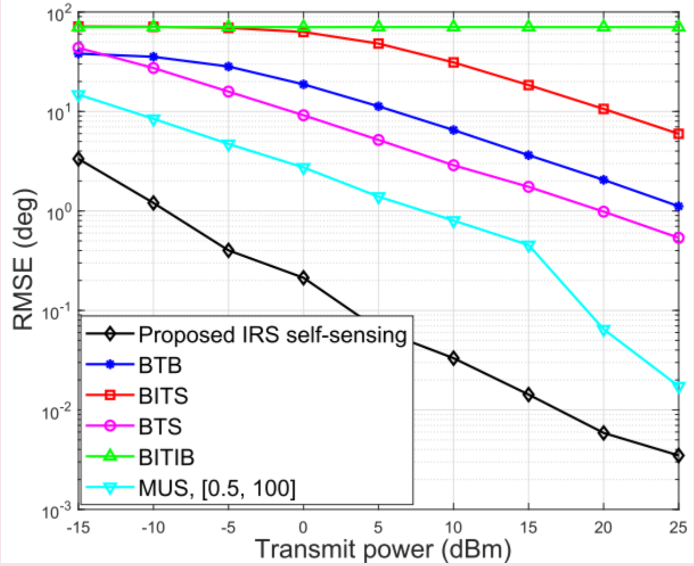
- 实验结果

1

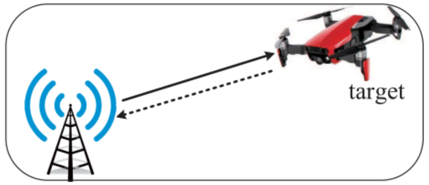


- RIS要么靠近目标物体，要么靠近发射端

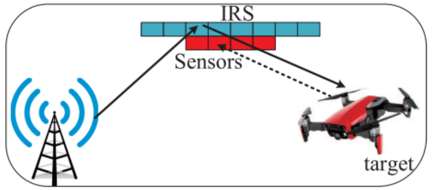
2



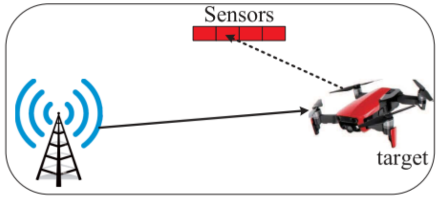
- 与其他方案的性能对比



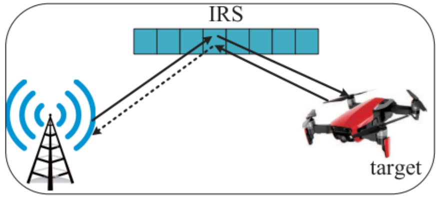
(a) BTB scheme



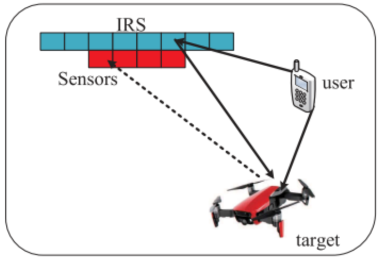
(b) BITS scheme



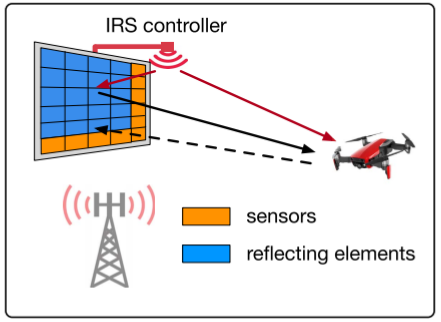
(c) BTS scheme



(d) BITIB scheme



(e) Mobile-user aided scheme (MUS)



Proposed scheme

基于通感一体化的移动网络框架

- 总结
  - 无线领域比较早期的智能反射表面辅助室外定位（角度信息估计）的工作
  - 将传统无线阵列DOA估计的理论应用到RIS辅助感知
  - 做了大量的理论推导做性能的定性分析，以及大量的试验结果来支撑

Intelligent Reflecting Surface Enabled Sensing: Cramér-Rao Bound Optimization IF 5.8 SCIE

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Xianxin Song; Jie Xu; Fan Liu; Tony Xiao Han; Yonina C. Eldar

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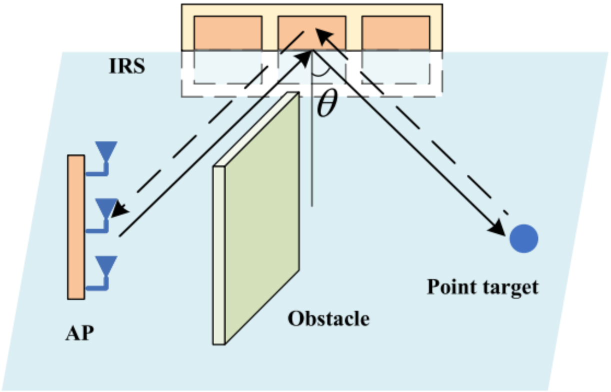
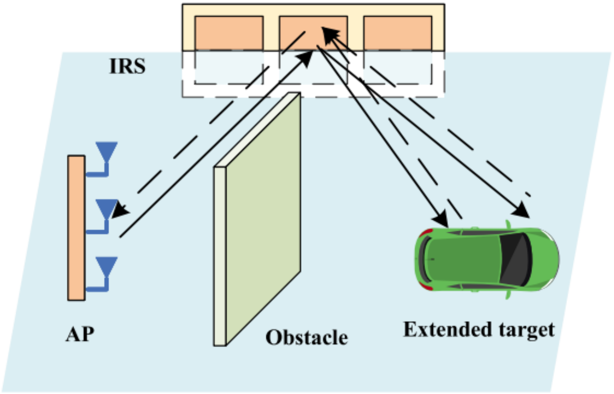


(a) Point target case



(b) Extended target case