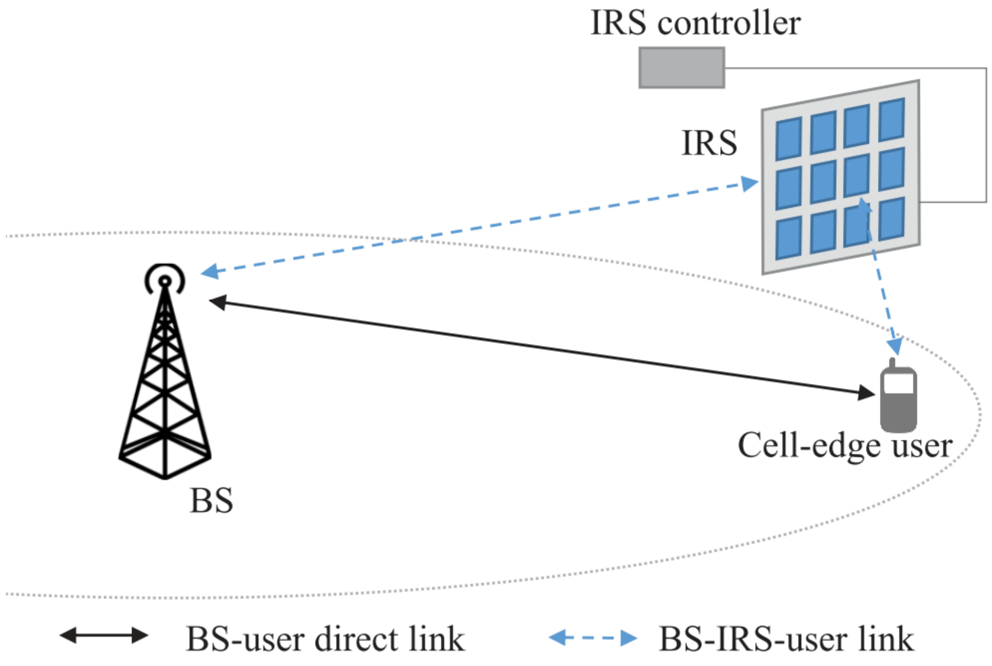
Intelligent Reflecting Surface Meets OFDM: Protocol Design and Rate Maximization



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Intelligent Reflecting Surface Meets OFDM: Protocol Design and Rate Maximization

IF 8.3 SCIE JCR Q1 计算机科学2区 Top EI

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Abstract

Document Sections

I. Introduction

II. System Model and IRS Elements Grouping Design

III. Transmission Protocol With IRS Elements Grouping

IV. Achievable Rate Maximization via Joint Power Allocation and Reflection Coefficient Optimization

V. Numerical Results

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Abstract:
Intelligent reflecting surface (IRS) is a promising new technology for achieving both spectrum and energy efficient wireless communication systems in the future. However, existing works on IRS mainly consider frequency-flat channels and assume perfect knowledge of channel state information (CSI) at the transmitter. Motivated by the above, in this paper we study an IRS-enhanced orthogonal frequency division multiplexing (OFDM) system under frequency-selective channels and propose a practical transmission protocol with channel estimation. First, to reduce the overhead in channel training as well as exploit the channel spatial correlation, we propose a novel IRS elements grouping method, where each group consists of a set of adjacent IRS elements that share a common reflection coefficient. Based on this method, we propose a practical transmission protocol where only the combined channel of each group needs to be estimated, thus substantially reducing the training overhead. Next, with any given grouping and estimated CSI, we formulate the problem to maximize the achievable rate by jointly optimizing the transmit power allocation and the IRS passive array reflection coefficients. Although the formulated problem is non-convex and thus difficult to solve, we propose an efficient algorithm to obtain a high-quality suboptimal solution for it, by alternately optimizing the power allocation and the passive array coefficients in an iterative manner, along with a customized method for the initialization. Simulation results show that the proposed design significantly improves the OFDM link rate performance as compared to the case without using IRS. Moreover, it is shown that there exists an optimal size for IRS elements grouping which achieves the maximum achievable rate due to the practical trade-off between the training overhead and IRS passive beamforming flexibility.

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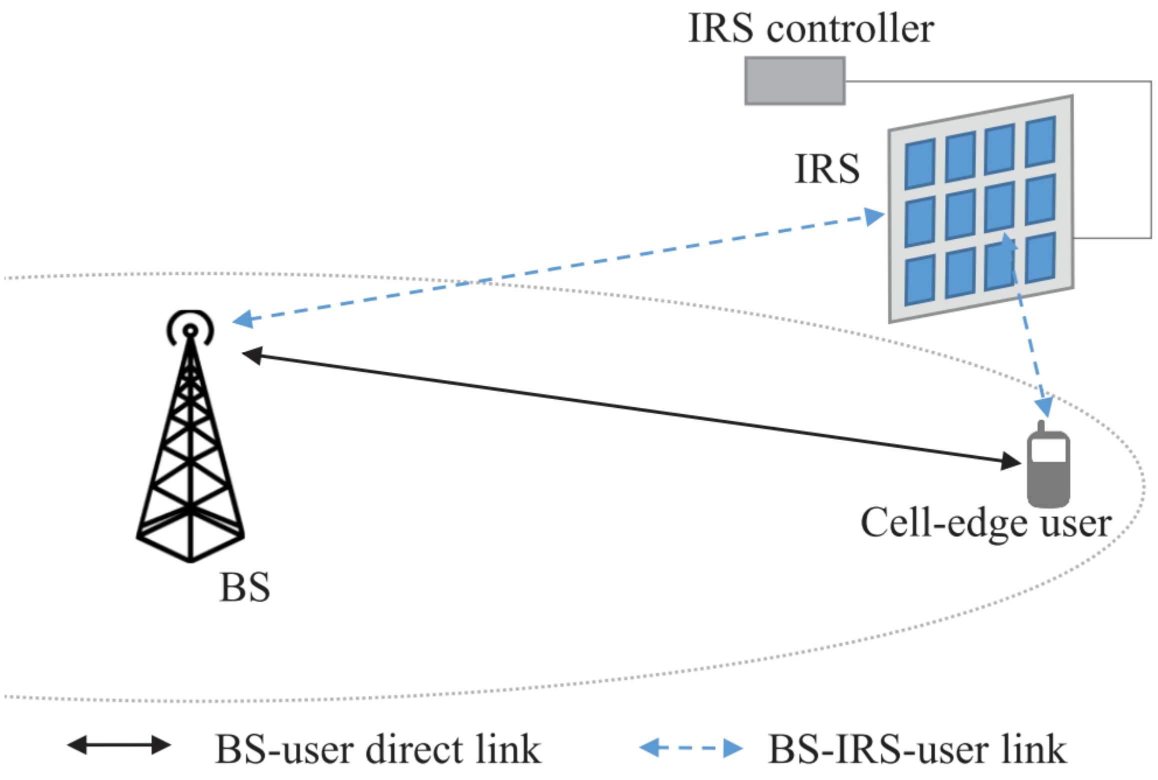
https://arxiv.org/abs/1906.09956

[1] Y. Yang, B. Zheng, S. Zhang and R. Zhang, "Intelligent Reflecting Surface Meets OFDM: Protocol Design and Rate Maximization," in IEEE Transactions on Communications, vol. 68, no. 7, pp. 4522-4535, July 2020, doi: 10.1109/TCOMM.2020.2981458

介绍框架

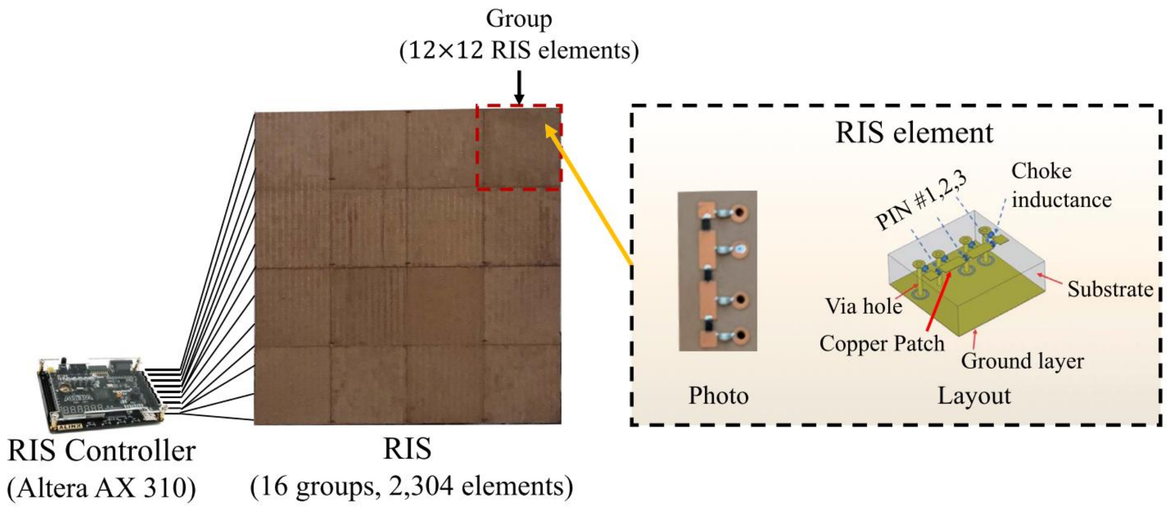
- 背景/简要介绍
- 研究方法
- 实验结果
- 总结



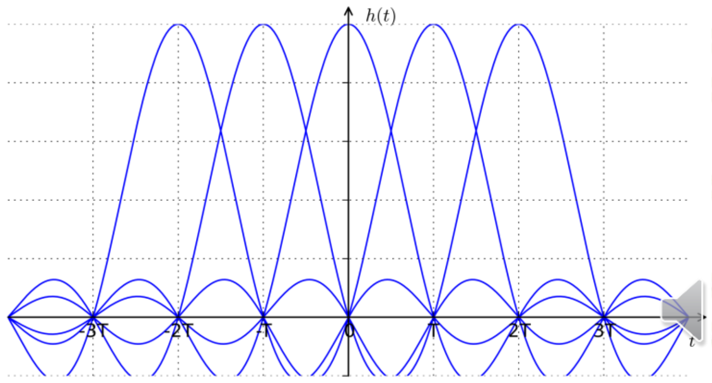
智能反射表面辅助的无线通信

- 什么是智能反射表面?
  - 一个由许多可重构单元组成的表面
  - 可以额外建立一条可控的通信路径

  → 对提升接收信号SNR有很大的增益
  - 如何控制智能反射表面的被动波束成形?

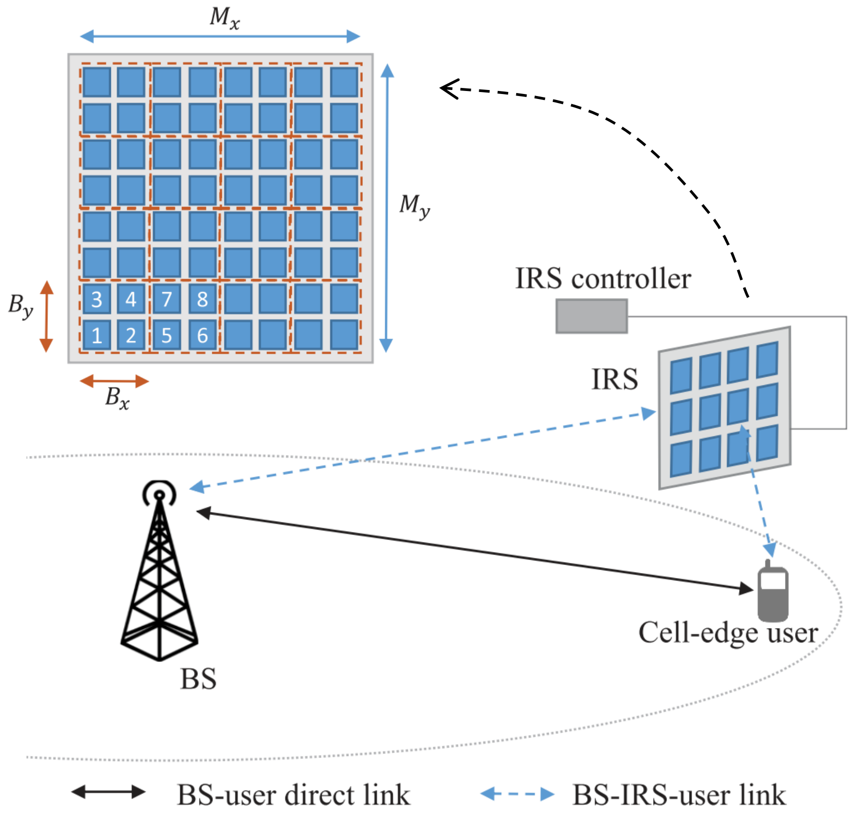


- 什么是OFDM?
  - 适用于宽带通信系统（频率选择性衰落信道）
  - 切分出多个子载波，将信号在这些子载波上平行的传播
  - 有效解决了符号间串扰(inter symbol interference, ISI)问题



[2]https://zhuanlan.zhihu.com/p/678429235

智能反射表面辅助的无线通信



- ## 总体性能
  - 基于OFMD，**单用户上行**通信系统
  - 考虑了RIS**信道估计**的开销对系统性能的影响
  - 提出了**单元分组策略**，以此来降低信道估计的开销
  - 通过优化在不同子载波上的能量分配，与RIS的被动波束成型来达到最优的信号传输速率

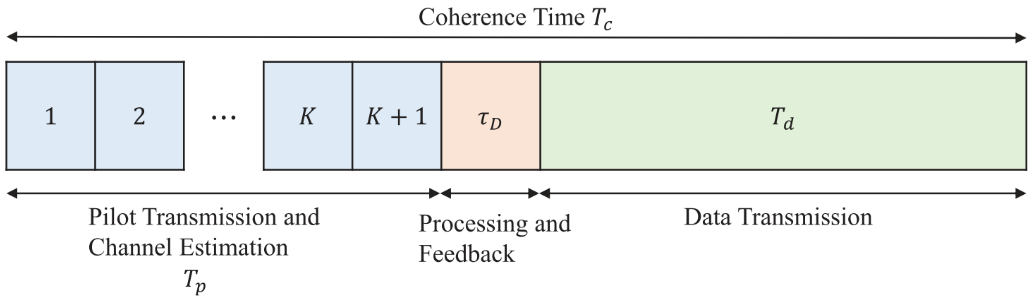
智能反射表面辅助的无线通信

- 信号模型

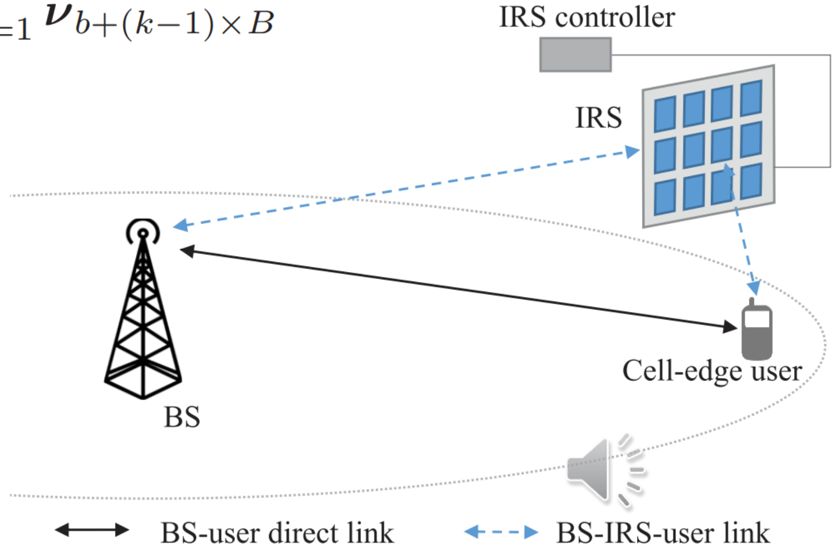
信道估计的开销

$$r(\boldsymbol{p}, \bar{\boldsymbol{\phi}} | \hat{\boldsymbol{h}}_d, \hat{\mathbf{V}}') = \left(1 - \frac{T_{\mathrm{p}} + \tau_D}{T_c}\right) \frac{1}{N + N_{\mathrm{CP}}} \times \sum_{n=0}^{N-1} \log_2 \left(1 + \frac{\left|\boldsymbol{f}_n^H \hat{\boldsymbol{h}}_d + \boldsymbol{f}_n^H \hat{\mathbf{V}}' \bar{\boldsymbol{\phi}}\right|^2 p_n}{\Gamma \sigma^2}\right),$$

经过RIS的反射信道



$$\boldsymbol{\nu}'_k = \sum_{b=1}^{B} \boldsymbol{\nu}_{b+(k-1)\times B}$$



- 通信系统性能优化
  - 同时优化能量分配与RIS的被动波束成形
  - 分析不同分组策略对传输速率的影响

智能反射表面辅助的无线通信

- 优化算法设计(能量分配与RIS波束成形)

$$\text{(P1)}: \underset{\boldsymbol{p},\bar{\boldsymbol{\phi}}}{\texttt{maximize}} \sum_{n=0}^{N-1} \log_2\left(1+\frac{\left|\boldsymbol{f}_n^H\hat{\boldsymbol{h}}_d+\boldsymbol{f}_n^H\hat{\boldsymbol{V}}'\bar{\boldsymbol{\phi}}\right|^2 p_n}{\Gamma\sigma^2}\right)$$

$$\texttt{subject to} \sum_{n=0}^{N-1} p_n \le P, \quad (15)$$

$$p_n \ge 0, \quad \forall n \in \mathcal{N}, \quad (16)$$

$$|\bar{\phi}_k| \le 1, \quad \forall k \in \mathcal{K}. \quad (17)$$

- 多变量优化问题→交替优化(alternating optimization)
- 如何选取变量的初始值?
  - 能量：均等分配
  - 波束成形：最大化接收信号强度

$$\text{(P2)}: \underset{\bar{\boldsymbol{\phi}}}{\texttt{maximize}} \quad \left\|\hat{\boldsymbol{h}}_d+\hat{\boldsymbol{V}}'\bar{\boldsymbol{\phi}}\right\|^2$$

$$\texttt{subject to} \ |\bar{\phi}_k|^2 \le 1, \quad \forall k \in \mathcal{K}. \quad (27)$$

子载波能量分配

$$p_n = \left(\frac{1}{c_u}-\frac{1}{c_n}\right)^+, \quad \forall n \in \mathcal{N},$$

- 注水算法(water filling)

RIS波束成形

$$\text{(P1.1)}: \underset{\bar{\boldsymbol{\phi}}}{\texttt{maximize}} \sum_{n=0}^{N-1} \log_2\left(1+\frac{|\boldsymbol{f}_n^H\hat{\boldsymbol{h}}_d+\boldsymbol{f}_n^H\hat{\boldsymbol{V}}'\bar{\boldsymbol{\phi}}|^2 p_n}{\Gamma\sigma^2}\right)$$

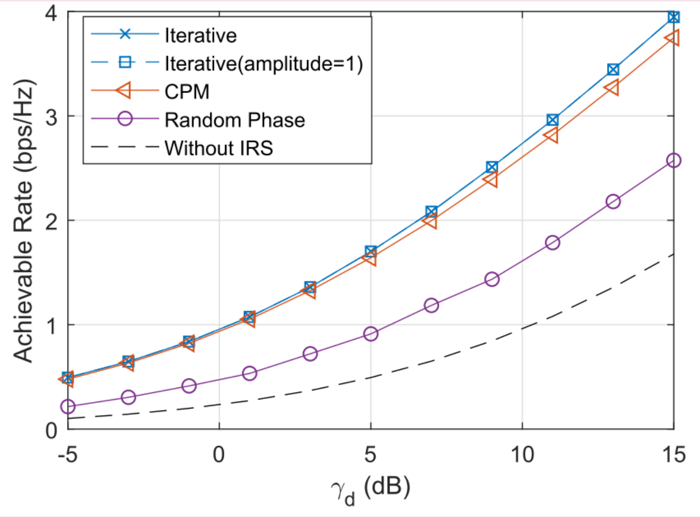
$$\texttt{subject to} \ |\bar{\phi}_k| \le 1, \quad \forall k \in \mathcal{K}. \quad (20)$$

- 逐次凸近似算法(SCA)

智能反射表面辅助的无线通信

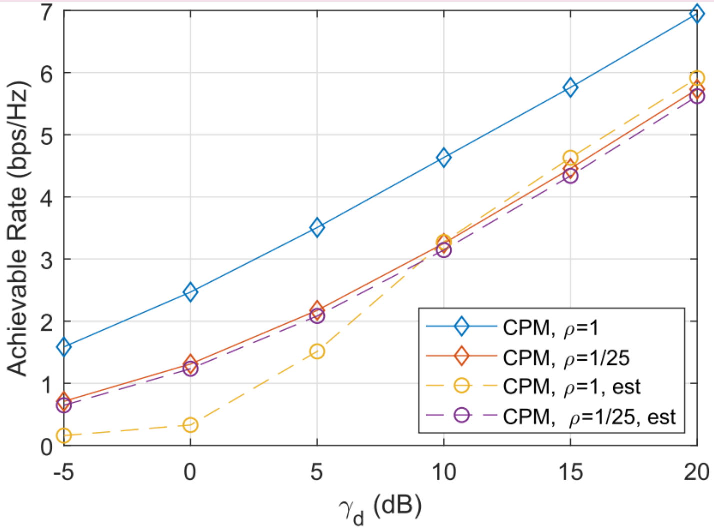
- 实验结果

1



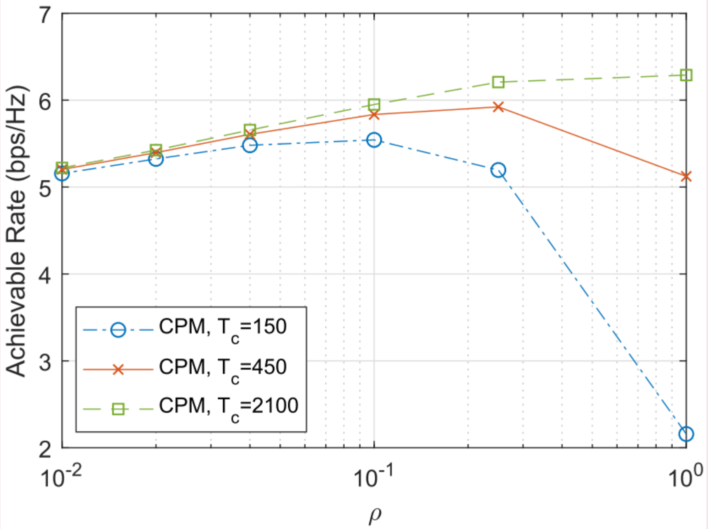
- 提出的方案可以取的最优的传输速率 → 验证方案的可行性

2



- 单元分组策略可以提升接收信号的SNR→降低信道估计的误差

3



- 把更多单元编为一组→信道估计开销↑，波束成形效果↓
- 分组单元数量存在trade-off

智能反射表面辅助的无线通信

- 总结
  - 智能反射表面领域最早提出单元分组策略(element grouping)的工作，启发了大量的后续工作
  - 探讨了智能反射表面应用的一个关键问题，信道估计的大量开销

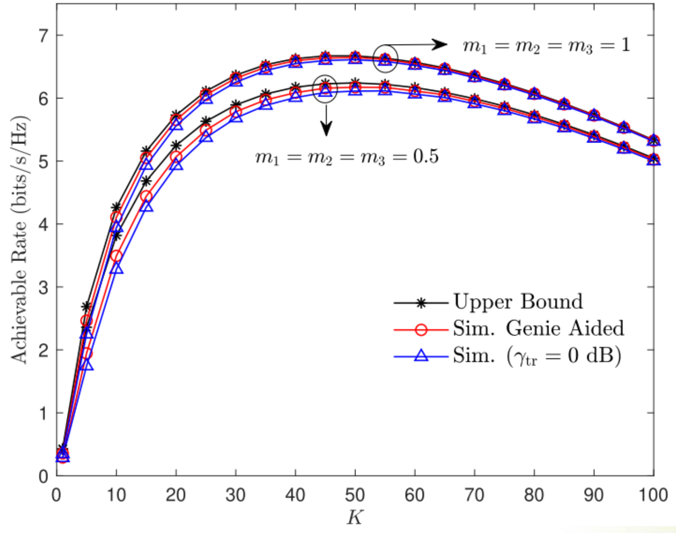
Optimal Grouping Strategy for Reconfigurable Intelligent Surface Assisted Wireless Communications IF 5.5 SCIE JCR Q1 计算机科学3区 EI 2022 Cited 21

Neel Kanth Kundu; Zan Li; Junhui Rao; Shanpu Shen; Matthew R. McKay; Ross Murch

IEEE Wireless Communications Letters

Year: 2022 | Volume: 11, Issue: 5 | Journal Article | Publisher: IEEE

Cited by: Papers (21)



An Optimal Channel Estimation Scheme for Intelligent Reflecting Surfaces Based on a Minimum Variance Unbiased Estimator 2020 Cited 335

Tobias Lindstrøm Jensen; Elisabeth De Carvalho

ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)

Year: 2020 | Conference Paper | Publisher: IEEE

Cited by: Papers (335)

$$\Phi = \begin{bmatrix} 1 & \mathbb{0}_K^T \\ \mathbb{1}_K & I_K \end{bmatrix} . \quad \Phi = F_{T,K+1}$$