Channel Capacity of Reflecting Intelligent Surface Enhanced Orthogonal Frequency Division Multiplexing with Index Modulation

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Abstract

This research suggests reflecting intelligent surface (RIS) aided orthogonal frequency division multiplexing (OFDM) with index modulation (IM) to improve the capacity of classical OFDM-IM. RIS controls the propagation environment and improves end-to-end communication by reflecting the transmitted signal towards the receiver. On the other hand, OFDM-IM provides two information units by partially activating the subcarriers through a predefined activation pattern. OFDM-IM with RIS is suitable for frequency selective fading due to narrowband subcarriers. RIS can enhance the coverage of traditional OFDM-IM by relaying the signal and increase capacity by improving the channel gain.

Ⅰ. Introduction

Reflecting intelligent surface (RIS) is an emerging technology in 6G wireless communication which controls the propagation of incident electromagnetic waves with the material coated on its surface [1]. The signal can be pointed towards a desired direction by adjusting the phase shifts of passive elements of RIS. The advancement in metamaterials has made it possible that the reflection coefficient of each element to be dynamically adjusted according to the real time channel conditions. Typically, the reflection coefficients are calculated at the base station and RIS controller gets it via a feedback link. Since RIS passively reflects the incident signal, it supports low implementation complexity. These lightweight meta surfaces can be installed on walls, ceilings, and so on. Moreover, it operates in full duplex mode with least self-interference and thermal noise, therefore capable of achieving high spectral efficiency (SE) compared of half duplex relays [2].

Orthogonal frequency division multiplexing (OFDM) with index modulation (IM) has achieved a good trade-off between SE and bit-error rate performance by activating a subset of subcarriers and sending additional bits virtually through the indices of these subcarriers [3-5]. The integration of RIS with OFDM-IM will provide an energy efficient system with enhanced coverage. The classical nature of OFDM subcarriers is robust against frequency selective fading channels and assistance of RIS improves channel gain to increase the channel capacity and communication coverage. Application of RIS is also useful when there is no line of sight available, however, this article considers both direct and indirect communication links. The proposed article compares the performance of classical OFDM-IM and RIS-OFDM-IM in terms of channel capacity for a multi-user scenario.

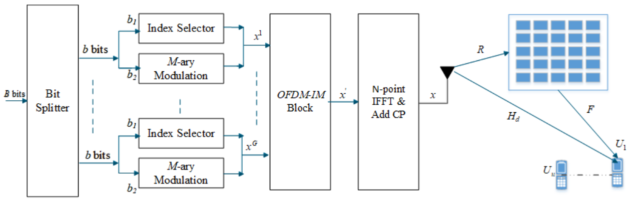

Figure 1. System block diagram for RIS-OFDM-IM

Ⅱ. Proposed Methodology

Consider a system model illustrated in Figure. 1 where a BS equipped with T antennas, transmits an OFDM-IM signal towards U single antenna users. The signal reached to the users via a direct link $\mathbf{H_d}$ and an indirect RIS assisted link. The indirect link consists of two paths $\mathbf{R}$ and $\mathbf{F}$ representing the BS-RIS channel and RIS-user channel, respectively. The RIS is considered with regularly distributed E elements. The reflection coefficient is considered same for each subcarrier such that $|\phi_{e,1}|,\cdots,|\phi_{e,N}|=1$ and $\angle\phi_{e,1},\cdots,\angle\phi_{e,N}$ where $|\phi_{e,N}|$ and $\angle\phi_{e,N}$ represent the amplitude and phase of e^{th} reflecting element for N subcarrier. The signal received for U users can be written as follows,

$$\mathbf{y}=(\mathbf{F^H}\boldsymbol{\phi}\mathbf{R}+\mathbf{H_d})\mathbf{x}+\mathbf{z}, \quad (1)$$

where $\mathbf{y}\in\mathbb{C}^{U\times 1}$ and $\mathbf{x}\in\mathbb{C}^{N\times 1}$ denote the received and transmitted signal vectors, respectively. $\boldsymbol{\phi}=\mathrm{diag}([\phi_{e,1},\cdots,\phi_{e,N}])\in\mathbb{C}^{E\times E}$ is a matrix of reflection coefficients. $z\in\mathbb{C}^{U\times 1}$ represents additive white Gaussian noise with mean zero and variance σ^2. The transmitted vector $\mathbf{x}$ is generated by an OFDM-IM method. The system contains N subcarriers divided into G groups for processing. Each group contains n elements such that $G=N/n$. For each user the k

subcarriers are activated according to a predefined activation pattern in an allocated bandwidth. The procedure is identical in each group. All groups are concatenated to form an OFDM-IM block which undergoes an N-point inverse fast Fourier transform (FFT). A cyclic prefix is inserted greater than the channel tap length to overcome inter-symbol interference in the received signal. The transmitted signal $\mathbf{x}$ is expressed as follows,

$$\mathbf{x} = \frac{1}{\sqrt{\tau}} \sum_{n=0}^{N-1} \mathbf{s} \times exp(j2\pi nt/\tau), \quad (2)$$

where τ indicates the symbol duration and $\mathbf{s}$ represents the vector of constellation symbols on the active subcarriers. The bits B transmitted by u^{th} user is calculated as

$$B = G \times \left\lfloor log_2 \binom{n}{k} \right\rfloor + k \times log_2 M, \quad (3)$$

where M is the modulation order of classical constellation used by the active subcarriers.

III. Result Analysis

The channel capacity equation for RIS-OFDM-IM is written as follows,

$$\mathbf{C} = \frac{G \times k}{n} log_2 \left(1 + \frac{|(\mathbf{F}^H \boldsymbol{\phi} \mathbf{R} + \mathbf{H}_d)\mathbf{w}_u|^2}{\sum_{i \neq u}^{U} |(\mathbf{F}^H \boldsymbol{\phi} \mathbf{R} + \mathbf{H}_d)\mathbf{w}_i|^2 + \sigma^2} \times \frac{n}{k} \right). \quad (4)$$

Where $\boldsymbol{w}_u$ is the beamforming vector. The capacity equation has signal power in the denominator and the numerator include interference term from the unintended users in the system and the noise power σ^2. Additionally, the signal to noise plus interference (SNIR) term is multiplied by a factor n/k, the gain in SNIR comes from the reduction in inter-carrier interference of OFDM-IM system due to partial activation.

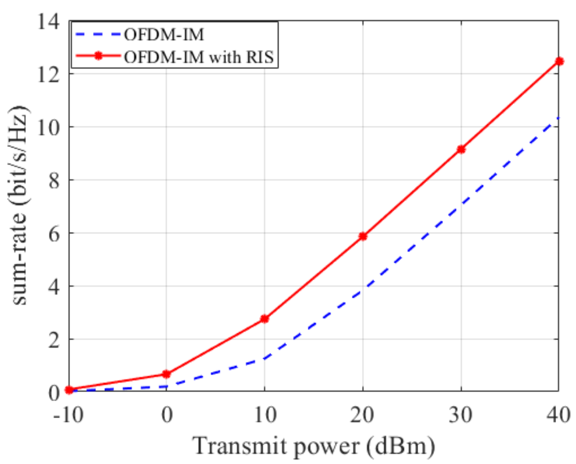

Figure 2. Capacity analysis of RIS-OFDM-IM

In Figure 2, a comparison of classical OFDM-IM is shown with RIS-OFDM-IM with parameters $n = 4$, $k = 2$, $N =$, $U = 2$, $T = 4$, $E = 16$, and each user is equipped with single antenna. The performance is shown for a single group of OFDM-IM only. RIS provides channel diversity in the proposed system and signal is received at a user from a direct path and a reflected signal from an indirect RIS channel. This improves the channel gain and RIS-OFDM-IM achieves approximately 16% capacity enhancement as compared to OFDM-IM.

IV. Conclusion and Future Work

This article has proposed RIS-OFDM-IM for frequency selective fading channels to improve the channel capacity of traditional OFDM-IM by improving the channel gain. By combining the direct channel between base station and users and indirect RIS channel the propagation environment was improved which led to enhance capacity. In future, the system can be analyzed for irregular distribution of RIS elements.

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