LIS - Assisted Wireless Communications: A Tutorial

Abstract. Large Intelligent System (LIS) is a technology that allows for the customization of radio signal propagation in wireless networks, by intelligently tuning the signal reflection using a large number of low-cost active reflecting elements. LIS can dynamically change wireless channels to improve communication performance. As a result, it is expected that the new LIS-assisted wireless network, with active components, will be highly promising for achieving cost-effective sustainable capacity growth in the future. Despite its enormous potential, LIS faces new challenges in efficiently integrating into wireless networks, such as reflection optimization, deployment from the perspective of communications design, as well as complexity. In this paper, we provide a tutorial overview of LIS-assisted wireless communications to address the aforementioned issues and elaborate on its reflection and channel models, as well as various appealing wireless network applications. Furthermore, we highlight important directions that should be explored further in future work.

Keywords: LIS; 6G

1 Introduction

The architecture for the fifth-generation (5G) telecommunications networks have been developed and deployed. Given the growing customer interest in Internet of Things (IoT) adoption, it is necessary to upgrade the current functioning network to the sixth-generation (6G) [1]. It is anticipated that user needs will be considered as the new design is improved. It provides users with the highest Quality of Service (QoS), low implementation costs for operators, increased capacity, higher data rates, more bandwidth, and less interference [2,3].

Large Intelligent Systems (LIS) were introduced in wireless communications as a completely novel concept. It enables communications that require high energy efficiency and transmission stability, as well as a low sending and receiving delay, an appropriate data rate, and the ability to adapt to changing conditions. Because of the unprecedented concentration of energy in three-dimensional space, channel estimation, and abundant data transmission, it enables the realization of visions for 6G systems and the concept of IoT, in which many devices are expected to require adequate bandwidth and a secure network. LIS is essentially a type of beyond-massive MIMO (Multiple Input Multiple Output). A LIS could be used to create a programmable and controllable intelligent radio environment. As a result, a LIS generates, sends, and receives signals. Because of this, they can virtually infinitely control electromagnetic waves on the surface [4].

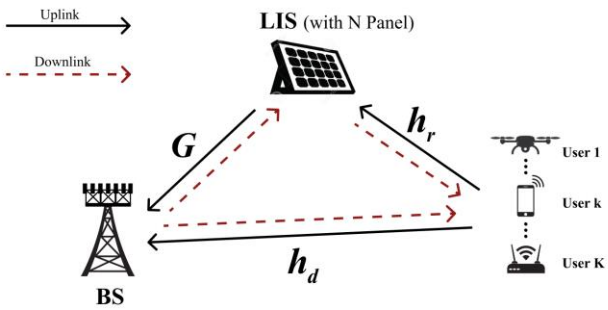

Fig. 1. Block diagram of an LIS-assisted communication system.

1.1 LIS versus Massive-MIMO

A LIS system differs significantly from massive MIMO. Massive MIMO systems use antenna arrays with hundreds of antennas to serve tens of terminals on the same time-frequency resource at the same time. Significant advantages are provided by the technology in terms of energy efficiency, spectral efficiency, robustness, and dependability [5]. However, a LIS system can send and receive signals through the surfaces of all man-made structures. Users can communicate with a LIS in close proximity, and their transmission power levels can be configured to be lower than those produced by large MIMO systems. Higher data rates are possible due to lower interference levels. A LIS also make channel estimation easier than in massive MIMO systems [6], where hundreds of antennas may require Channel State Information (CSI). The Line-of-Sight (LOS) path is strongly associated with large antenna-array systems based on LIS, allowing for greater precision and simplicity in channel estimation and feedback. Because the massive number of antennas may result in a significant overhead for CSI acquisition due to pilot training, this overhead can significantly degrade the performance of massive MIMO systems [7].

1.2 Objective and Organization of This Paper

The main purpose of this paper is to introduce the benefits of LIS while also attempting to demonstrate its disadvantages. This is done to better understand LIS and to find a solution for the improvement of the LIS systems.

The remainder of this paper is arranged as follows. Section 2 provides an overview of the LIS. In Section 3, we introduce the system model for LIS. Section 4 summarizes the article. Finally, Section 5 suggests future research.

2 Categorizing Recent Studies of Large Intelligent Surfaces

From a distance, the development of LIS has aided in wireless communications, signal placement, and signal control.

It is made up of a continuous radiating surface that is close to the users and can transmit and receive data (similar to the way base stations do) [8].

Once LIS functions as a radio access point, users can communicate with it directly. LIS employs a portion of the channel as an adjustable reflector between the base station and the user terminal (see Figure 1). LIS has full receivers and baseband processing capacity to acquire CSI from pilots transmitted by users (Figure 1). This allows for finding the required equalization matrix in LIS after precisely computing it [9].

2.1 LIS-assisted Communications with easy Deployment

When integrating new technology into wireless networks, deployment is an important design consideration. Appropriate LIS deployment can significantly improve LIS-aided communications system performance. Especially when there are LoS paths between the transmitter and the LIS, as well as the LIS and the receiver. Given the LIS's large physical size and the requirement for distributed processing near the antennas, the LIS system is commonly divided it into square units, or panels. Penalization allows the LIS to adapt to a variety of situations by adding, moving, or removing panels as needed [10].

2.2 Power consumption LIS-assisted Communications

Energy efficiency (EE) is a particularly attractive aspect of LIS, since optimum result depends on the user and the number of LIS elements in LIS-assisted communications systems. A new idea suggested using panel base LIS structure. Switching off parts of panels that receive weak channels makes power consumption more efficient [11].

Moreover, since the users are located very close to the LIS (near-field beamforming), the path loss is low, and the antenna gain is high, so the transmit power on both sides of the communication is expected to be low. This makes it possible for many low-cost and low-power analog components to be used [12].

2.3 Capacity/Data rate analyses of LIS-assisted Communications

LIS systems are great additions to traditional cellular networks. They make the data rate and capacity of these networks much faster and bigger [13]. A LIS can send and receive signals through all man-made structures' surfaces. This enables users in close proximity to communicate with a LIS, and their transmission power levels can be set to values lower than those produced by the LIS, resulting in reduced interference levels. As a result of the lower interference levels [14], higher data rates can be achieved when compared to massive MIMO systems. LIS works well and is great at keeping interference to a minimum in its panel-based structure, where there are more terminals [15]. As a result, it is a good choice for data transmission in communication systems that go beyond massive MIMO and increase capacity [16, 17, 18].

Table 1 demonstrates main contribution of recent research on LIS.

Table 1. Description of the recent research on LIS.

Reference	Main Contribution
1	The implementation issues relating to the LIS interconnection data rate will be covered in this study. Also considered were the system's capabilities and the cost of implementation given various design constraints. made proposals for the installation of the LIS.
3	One of the implementation's drawbacks is the complexity of LIS panels. The strategy for avoiding the complexity of controlling a group of activated panels is provided in this work.
6	It is shown that using smaller panels, which produce more outputs per square meter, is desirable when terminal density rises.
7	The capabilities of connecting single-antenna terminals to massive antenna arrays mounted on surfaces are examined in this study. In other words, the whole surface serves as an IRS array. The intersymbol interference (ISI) channel can accurately represent the received signal after matched filtering (MF) if the surface area is large enough.
8	With the help of traditional linear assignment problems (LAPs), which were created based on the LIS-Units' useful feature of effective inter-user interference suppression, the optimal user assignments may be quickly acquired.
11	Due to the higher effective noise level caused by the HWI, both the capacity and usefulness of the surface area are decreased. By dividing it into numerous smaller LIS units, you might want to put in place a distributed LIS system. The impacts of HWI can be significantly diminished because each unit has a smaller surface area.
12	Decentralized architectures and distributed algorithms are needed to reduce interconnection data rate and computational requirements. provide the sum-rate capacity for such an architecture and derive an algorithm to obtain the equalizer, which aims to maximize the sum-rate capacity.
13	Hardware defects, noise, and interference from non-line-of-sight and channel estimate mistakes become minor as the number of antennas rises. This study looked at the uplink rate under conditions like device-specific, spatially coupled Rician fading limitations.
15	In this work, coverage and posture are examined.
16	LIS presents a new physical layer technology for improving coverage and energy efficiency by intelligently controlling the propagation environment with accurate channel estimation.
17	Showed that the polarization mismatch should not be ignored since it has a non-negligible impact on spectral efficiency (SE)

3 System Model

A LIS system that aids communications between the users and the base station is shown in Figure 1. In order to increase communication between LIS with M antennas and K users with only one antenna, a communications system with N reflecting components added to a reflecting device is examined.

Let $G \in \mathbb{C}^{M\times N}$, $h_r \in \mathbb{C}^{N\times 1}$ and $h_d \in \mathbb{C}^{M\times 1}$ denote the equivalent channels of the (AP/BS <--> Reflector), (Reflector <--> user) with k link. Then, the received signal of the kth user can be expressed as [17]

$$Y_k = \underbrace{h_d^H X_k}_{Direct.Link} + \underbrace{h_r^H \phi G X_k + N_k}_{\text{Re}\,flected.Link} \quad (1)$$

where ϕ indicates a matrix of $N \times N$ diagonal reflection coefficient, which can be written as $\phi = diag(\varphi_1, \varphi_2, ..., \varphi_n)$, $\varphi_n = a_n \exp\left(j\phi_n\right)$, $a_n \in \left[0,1\right]$, $\phi_n \in \left(0, 2\pi\right)$ and N_k denotes the Additive White Gaussian Noise (AWGN) at the receiver of kth user, with zero mean and variance σ^2.

The *k*th user's received signal-to-interference plus noise ratio (SINR) can be stated as [12]

$$SINR_K = \frac{\left|h_d^H + h_r^H \phi^H G\right|^2}{\sum_{n=1}^{K} \left|h_d^H + h_r^H \phi_n{}^H G\right|^2 + \sigma^2} \quad (2)$$

The rate that can be achieved with such SINR, expressed in bits per second per Hz (bits/s/Hz), comes

$$R_k = \log_2(1 + SINR_k) \quad (3)$$

4 Conclusions

The LIS system was first used as a big active antenna array, which was similar to Massive MIMO, but was much bigger and more complicated. This is why the LIS is commonly known as beyond Massive MIMO. A LIS is responsible for producing, sending, and receiving signals. The arrays contain very small components as panels in addition to having high dimensions. These qualities enable them to practically continuously control electromagnetic waves over the surface. The channel estimation problem has also been resolved, while the capacity and SE have been improved.

5 Future Research

Future research will concentrate on low-complexity receivers, which present the challenge of achieving high quality with a low BER (Bit Error Rate). Block transmission and the highly effective low-density parity-check (LDPC) codes should be used in future studies.

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