Engineering, Financing, Medical care

Design of statistical signal processing for wireless communications

Division of Electrical, Electronic and Infocommunications Engineering, Graduate School of Engineering
Assistant Professor Takumi Takahashi
Researchmap https://researchmap.jp/takumi_takahashi?lang=en

Abstract

Large multi-user multi-input multi-output (MIMO) technology (Fig. 1), which spatially multiplexes information streams simultaneously transmitted by wireless terminals, is one of the essential physical layer technologies to meet the ever-increasing demand for wireless connectivity. However, to realize this technology, it is necessary to separate (detect) the spatially multiplexed signals at the base station receiver, and it is vital to develop advanced uplink signal detection algorithms. In the present study, we designed a beamforming algorithm based on long-term channel statistics according to the spatial arrangement of wireless terminals, and a novel signal detection algorithm based on belief propagation (BP) that operates in the beam domain after fully-digital beamforming.

Background & Results

In the vision of the future society proposed by Society 5.0, wireless communications are positioned as an information infrastructure that highly connects the real and virtual worlds. In particular, it is essential to upgrade the uplink communications that aggregate real-world information from countless sensor terminals. The conventional exclusive allocation of radio resources to each device has its limitations, and interference tolerant non-orthogonal multiple access (NOMA) is crucial for the next generation wireless communication system. The key to success is a receiver design that efficiently eliminates non-orthogonal interference and maximizes system performance.

In the case of large multi-user MIMO systems, advanced signal processing is required to detect the received multidimensional signals with low computational cost. The BP methods developed in the context of physics and (thermo-) statistical mechanics have attracted attention as promising candidates; however, it is difficult to create the ideal stochastic conditions for these algorithms in real wireless communications, and this has been a major obstacle to their practical application.

The contribution of this study is that we have incorporated this elaborate algorithm into the engineering problem, i.e., large MIMO detection, proposed an algorithm structure that can be practically used under non-ideal conditions, and paved the way for its utilization as a physical layer technology for 6G and beyond. Specifically, we designed a layered BP algorithm that is appropriate for the structure of beam-domain channels reduced in dimensionality by digital beamforming, and succeeded in realizing accurate signal detection under correlated fading environments. Computer simulations demonstrate that the performance approaching that of existing high-complexity detection state-of-the-art counterpart can be achieved with only a few percent of computational cost (Fig. 3).

Significance of the research and Future perspective

Cyber-physical fusion is a future framework that connects cyber space (virtual world) and physical space (real world) and provides an information infrastructure to solve all social problems such as poverty and hunger through efficiency, optimal allocation, and future prediction based on aggregated big data (Fig. 2). In this system, wireless communication technologies that can accommodate a large number of wireless/sensor terminals in the real world will be the key to connect the two spaces at a high level, and this study is the creation of such a foundation. The proposed framework is based on Bayesian inference, and it is compatible with the use of prior knowledge obtained from artificial intelligence (AI)-related technologies and the embedding of learning techniques into algorithms; hence, currently, we are also working on integration with machine learning.

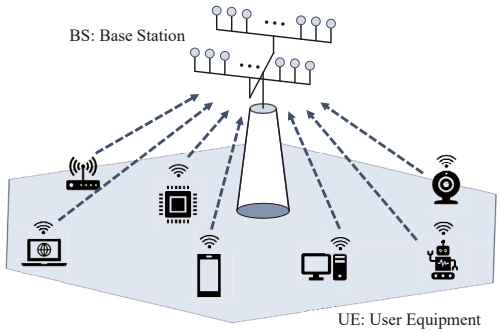

Fig.1: Illustration of large multi-user MIMO

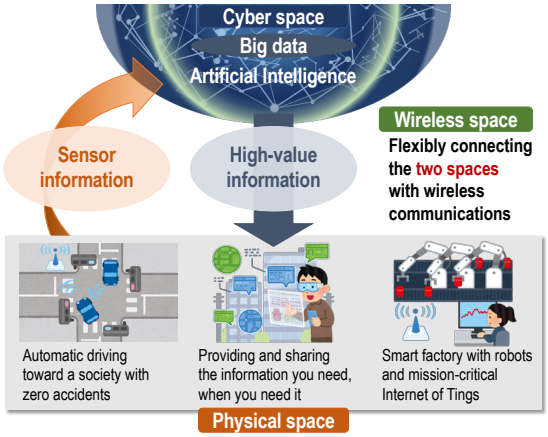

Fig.2: Cyber-physical fusion

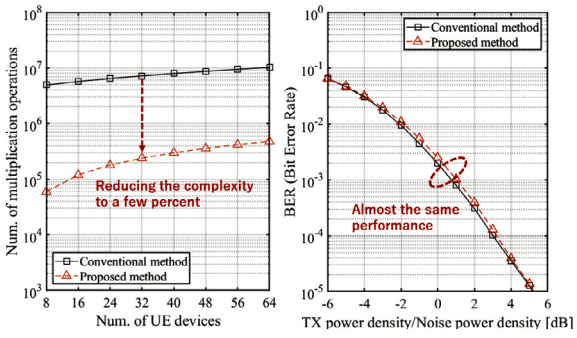

Fig.3: Comparison of performance and complexity

Patent	US11309991, US11627485
Treatise	Takahashi, Takumi; Tölli, Antti; Ibi, Shinsuke et al. Low-complexity large MIMO detection via layered belief propagation in beam domain, in IEEE Transactions on Wireless Communications. 2022, 21(1), 234-249. doi: 10.1109/TWC.2021.3094970 Takahashi, Takumi; Iimori, Hiroki; Ando, Keigo et al. Bayesian receiver design via bilinear inference for cell-free massive MIMO with low-resolution ADCs, in IEEE Transactions on Wireless Communications. 2023, 22(7), 4756-4772. doi: 10.1109/TWC.2022.3228326 Shirase, Daichi; Takahashi, Takumi; Ibi, Shinsuke et al. Deep unfolding-aided gaussian belief propagation for correlated large MIMO detection, in Proc. IEEE Global Communications Conference, Taipei, Taiwan. 2020, 1-6. doi: 10.1109/GLOBECOM42002.2020.9348087
URL	https://www.researchgate.net/profile/Takumi-Takahashi-4
Keyword	wireless communications, signal processing, bayesian statistics, coding theory, information theory