# Chapter 1
# MIMO Hybrid Beamforming:
## Performance Assessment in Macrocells and HetNets

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## ABSTRACT

*In mmWave massive MIMO, the required number of radio frequency (RF) chains becomes impractical due to the expensive and power-hungry components such as variable gain power amplifiers, filters, mixers, and analog-to-digital/digital-to-analog converters (ADCs/DACs). A promising solution to this problem is reducing the number of radiofrequency (RF) chains by partitioning beamforming operations between the digital and RF domains, known as hybrid beamforming (HBF), while still achieving the near-optimal performance of the fully digital beamforming systems with much-reduced hardware complexity. This chapter reviews different HBF techniques for massive MIMO in 5G and radar systems. The basic HBF structures and their algorithm design is presented in the context of a point-to-point MIMO hybrid beamforming system. Then, some recently proposed HBF techniques for 5G and beyond networks are investigated, followed by a discussion about the benefit of HBF in MIMO radar systems.*

## INTRODUCTION

Recently, millimeter-wave (mmWave) massive multiple-input multiple-output (MIMO) systems have emerged as a promising solution to enhance the network capacity and coverage of the new generation cellular networks (Marzetta, October 2010; Rusek, 2013; Hoydis, 2013; Busari, 2018). On the one hand, the mmWave can provide a considerable bandwidth; on the other hand, the significant gain of the massive arrays can compensate for the attenuation of the mmWave channel. Traditional MIMO-beamforming systems require a dedicated radio frequency (RF) chain for each antenna element to achieve optimal

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beamforming performance. However, in mmWave massive MIMO, the required number of radio frequency (RF) chains becomes impractical due to the expensive and power-hungry components such as variable gain power amplifiers, filters, mixers, and analog-to-digital/digital-to-analog converters (ADCs/DACs). A promising solution to this problem is reducing the number of radiofrequency (RF) chains by partitioning beamforming operations between the digital and RF domains, known as hybrid beamforming (HBF), while still achieving the near-optimal performance of the fully-digital beamforming systems with much-reduced hardware complexity (Sohrabi, F., Yu, W., 2016; El Ayach, O., 2014; Alkhateeb, A., 2014, 2015; Liang, L.,2014; Ni, W., 2017; Hefnawi, M., 2019; Kebede, T., 2022). In HBF, the RF analog beamformer is typically limited to applying phase shifters only to each array element, while digital beamforming with complex weighting vectors can be applied on each RF chain. Figure 1 shows a general hybrid configuration that connects $N_a$ antenna elements to $N_d$ RF chains, where $N_d$<$N_a$, using an analog RF beamforming matrix built from only phase shifters.

*Figure 1. Hybrid beamforming*

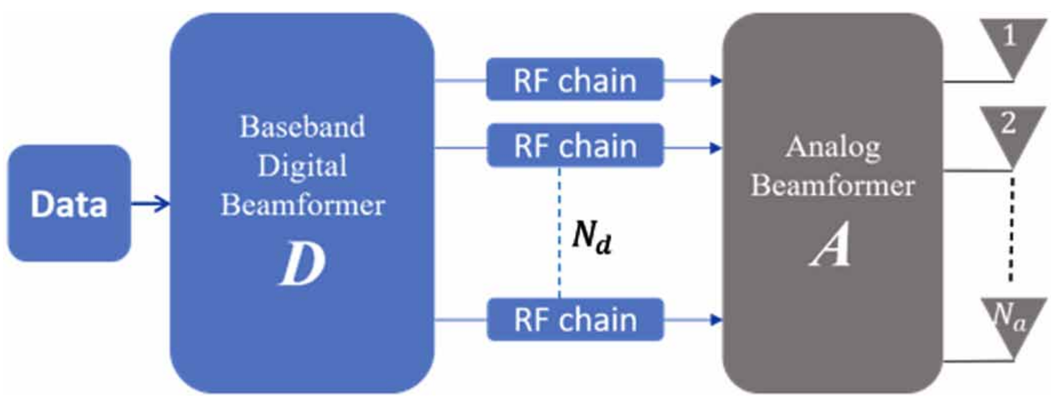


*Figure 2. Architectures of analog beamformers: (**a**) Fully-connected; (**b**) partially-connected*