# Chapter 70

# Federated Learning for 6G HetNets' Physical Layer Optimization:
## Perspectives, Trends, and Challenges

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## ABSTRACT

*This chapter presents a survey that focuses on the implementation of federated learning (FL) techniques in sixth generation (6G) networks' physical layer (PHY) to meet the increasing user requirements. FL in PHY perspectives are discussed, along with the current trends and the present challenges in order to deploy efficient (cost, energy, spectral, computational) FL models for PHY tasks. Moreover, the utilization of FL methods is, also, discussed when channel state information (CSI) is not guaranteed in a 6G scenario. In such conditions, the joint use of cell free (CF) massive multiple-input-multiple-output (mMIMO), reconfigurable intelligent surfaces (RIS), and non-orthogonal multiple access (NOMA) and FL methods is proposed. Finally, an FL-based scheme for relay node (RN) placement in 6G networks is presented as an indicative use case for FL utilization in modern era networks. Results indicate that the proposed FL scheme overperforms state-of-the-art centralized learning schemes concerning the trade-off between machine learning (ML) metrics maximization and training latency.*

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# 1. INTRODUCTION

## 1.1 The Need for Distributed AI/ML Models in 6G Networks

With the rapid growth of the Internet of Things (IoT), industry 4.0, augmented/virtual reality (AR/VR) applications, massive data volume is generated by end-user devices. In fact, according to Ericsson (Ericsson, 2022), the monthly global internet average per smartphone is expected to exceed 20GB at the end of 2023, while be 2027 all mobile data traffic growth will come from fifth-generation networks (5G), as the fourth-generation network's (4G) traffic will decline. On the same framework, by 2028, 5G's share of mobile data traffic is forecast to grow to 66 percent. Moreover, IoT and connected car applications are expected to be the most growing application type.

5G, which have been recently deployed around the world, support a wide range of trending applications by categorizing them in different usage scenarios. In this way, both enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), and Ultra-Reliable-Low-Latency Communications (URLLC) are supported. However, despite the numerous benefits of 5G networks, the large amount of generated data and the need for real-time responses by the network itself have raised the discussion in both industry and academia over a new generation of wireless networks, the sixth generation (6G). The main goal of 6G networks, as described in (Letaief *et. al*, 2019), is to provide the relevant technologies that can transform the "connected things" world (as expressed by the 5G-related worldwide wireless web (WWWW) and the service-based architecture (SBA) model) into the "connected intelligence" world by implementing data-aided models for diverse tasks, applications, and Open Systems Interconnection (OSI) levels.

It is already visible that to achieve the aforementioned revolution, user requirements should be even more demanding in 6G networks than the ones existing in 5G. As depicted in both (Letaief *et. al*, 2019) and (Wang *et. al*, 2023), these extended requirements are expected to be the following:

- Increased data rates around 1 Tbps.
- Energy efficiency (EE) as the primary Key Performance Indicator (KPI) to support dense connections and mass connectivity for energy/battery-saving IoT devices and Unmanned ground, air, surface or undersea Vehicles (UxVs).
- Enhanced low latency which is translated in less than 1ms end-to-end latency.
- Upper millimeter wave (mmWave) communication bands and Terahertz bands (e.g., 73GHz-140GHz and 1THz-3THz).
- Increased coverage by minimizing the disconnection probability.
- End-to-end Artificial Intelligence (AI) and Machine Learning (ML) capabilities.

It is significant to point out that 6G standardization is in its early phases currently (see also Fig. 1) and the expected International Mobile Telecommunications-2030 (IMT-2030) standard is to set all the 6G-relevant requirements and use cases. However, the need for new service types beyond the 5G ones (eMBB, uRLLC, mMTC) has been identified. As described in (Letaief *et. al*, 2019) and (Wang *et. al*, 2023) these are:

- **Computation Oriented Communications (COC)**, where distributed and in-network computation enabled by federated learning and edge intelligence, will provide the relevant service provisioning, and define the quality of service (QoS) flows to maximize also computational accuracy.

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