A Resource Optimization Framework for Federated Learning Over Wireless Networks

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Abstract

In the past few decades, a significant increase in number of Internet of Things (IoT) devices has been observed which generate huge amount of data. This data can be used for the training of different machine learning models to make different applications smart. However, the traditional machine learning model has a disadvantage of moving the user data to a centralized server which causes serious privacy issues. Coping with this issue, federated learning (FL) is a promising scheme to enable machine learning without transferring the data to a centralized server. In this paper, we propose software-defined networking (SDN) based architecture for FL over wireless networks. We propose a framework that consider joint user association and resource allocation in a heterogeneous cellular network for improving the global FL model accuracy. Furthermore, we consider a hybrid control plane for SDN to offer scalability which will be one of the key requirement of future networks.

1. Introduction

A rapid rise in the Internet of Things (IoT) enabled smart environments has been witnessed recently [1][2]. These devices produce a significant amount of data that must be effectively used to train machine learning models for making the applications smart. Different machine learning schemes can be used to make these applications smart; however, traditional machine learning has serious privacy concerns. To tackle this challenge of privacy concern in traditional machine learning, we can use federated learning (FL). FL offers distributed learning which involves the training of local model at the devices and then sending the local model parameters of all the devices to a centralized server. The centralized server after global model aggregation sends back the global model parameters to the devices. This transfer of learning model parameters between the local devices and centralized serves takes place in an iterative manner until a certain level of accuracy has been attained [3][4].

Although FL offers significant advantages it uses significant communication resources during the training process. Therefore, it is necessary to optimize the communication resources for FL over cellular networks. On the other hand, the packet error rate has a proportional effect on the performance of FL [5]. Additionally, the significant increase in the number of IoT devices is expected in the foreseeable future. Software-defined networking (SDN) and network function virtualization (NFV) are considered to the basic building blocks for 5G and beyond networks. The operation of SDN is based on a separation of the control plane from the data plane and thus, enables efficient and easier management of the network [5]. NFV allows the use of generic hardware for implementing different network functions on virtual machines in a cost-effective way [6].

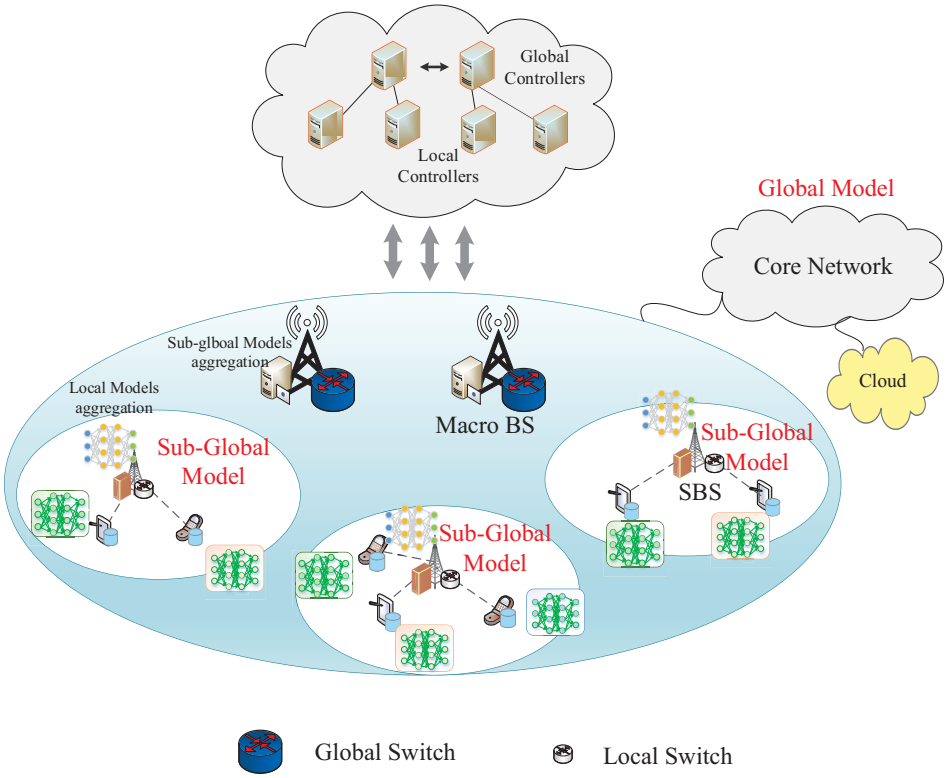

Fig 1: Proposed framework for federated learning

Motivated by the above-discussed factors, we propose an architecture based on SDN and NFV to enable effective FL for wireless networks in a resource optimized way.

2. Proposed Framework

Consider a heterogeneous cellular network consisting of macro-cell base stations (MBSs) and small cell base stations (SBSs). In [6], a hierarchical fashion of FL is adopted to enable resource-efficient operation. Similarly, we adopt the hierarchical fashion for learning for a global FL model. First of all, sub-global models are computed at every SBS in an iterative fashion which is followed by global model computation at the core network. On the other hand, the packet error rate significantly determines the performance of FL [5]. The SBS preferably will not consider the local learning models of the devices having a higher packet error rate. Therefore, it is necessary to reduce the packet error rate for improving the performance of FL over wireless networks [5]. Increasing the throughput of the devices involved in learning reduces the packet error rate and thus, can improve the FL model accuracy. One of the promising ways to improve the network throughput is through joint optimization of devices association with base SBS and resource allocation. For association and resource allocation, we can use iterative algorithms [7][8]. The iterative algorithms can further use matching theory and other heuristic algorithms specifically for association and resource allocation [9]. To improve the FL model accuracy over the wireless network, we propose a framework based on SDN as shown in Fig. 1. The proposed framework consists of a data plane and a control plane. The data plane consists of radio access networks, mobile devices, edge computing servers, cloud computing servers, and SDN switches. In our proposed framework, we use two types of SDN switches: Local switches and global switches. The local switches are placed near the devices at the SBS, whereas the global switches are positioned at the MBS and core network. Every global switch can be connected to multiple local switches. The local switches can communicate with each other through global switches, whereas global switches can communicate with each other directly.

In a control plane, there are two types of controllers: Global controllers and local controllers. The reason for

using two types of controllers is to enable scalability which is one of the primary design objectives of foreseeable future wireless networks. The job of the global controller is local switches management, radio resource management, cloud management, quality of service (QoS) management, among others. The most important role of global controllers in our proposed framework is to control joint devices association and resource allocation. All these functions are based on the requirement of global network-wide view information.

On the other hand, local controllers are used to control local switches that require only local information for their operation and do not need global network-wide view information. The local controllers manage the process of the local devices learning which is followed by sending of model parameters to SBS equipped with edge computing servers. The SBSs are connected using high-speed backhaul links to MBSs.

3. Discussion

We have proposed an architecture based on SDN to enable hierarchical FL for heterogeneous cellular networks in a resource optimized fashion. One of our main contributions is the use of a hybrid control plane to enable scalable operation. Using our proposed algorithm, we can achieve resource optimized and scalable FL over wireless networks to enable different smart applications.

4. Conclusions

In this paper, we have proposed an architecture that enables resource-efficient and scalable FL over wireless networks. It is concluded that SDN with a hybrid control plane can be used effectively in FL processes to offer effective FL in a resource optimized way. Furthermore, the hybrid control plane has the advantage of a more scalable operation for coping with the increasing number of users in the foreseeable future.

As future work, we can formulate an optimization problem for joint device association and resource optimization for hierarchical FL in heterogeneous cellular networks which will be followed by an appropriate solution.

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