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# From Federated to Fog Learning: Distributed Machine Learning over Heterogeneous Wireless Networks

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Abstract

Computer processing ability keeps on going stronger. The AI training is not only by the supercomputer. Federated Learning is one of the choices to develop the Machine Learning model for our daily life. However, the Federated Learning has some disadvantages. In this paper, it will share ideas on how to improve the Federated Learning based on paper [1].

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# 1 Background and Motivation of the paper

## 1.1 Federated Learning

Federated Learning is a decentralized Machine Learning. The main idea is to cooperate using mobile devices to learn a share prediction model. The learning data will not only be store in the phone, but also in the cloud. Therefore, the mobile device can upload the data to the cloud for learning, rather than the cloud sever to learn by itself.

For the standard Federated Learning there has a sequence i.e. Local learning and Global aggregation, to train an Machine Learning model. Local learning will collect dataset from the device and use them to train the model. After this, the local model will be uploaded to the sever to update the global model for development for an aggregated version.

The local model is more like a specified model for users, and the global model is an average model made from all local models to make a new model suitable for every new user.

The most important point of the Federated Learning is that it will not share the data to outer-layer devices and servers. In other words, it has a higher security and lower communication demand when compared with other learning systems.

## 1.2 Fog Computing

Fog Computing is a part of cloud computing. It is mainly used to preprocess the data from the user. If the data is short enough, the Fog Computing can finish the job locally. Generally, people are using cloud computing to resolve the problem due to the lack of resource in local computation. However, some of the computations are not that necessary to use that strong computation from cloud computing. Therefore, the Fog Computing was presented. The Fog Computing has similar job compare with

the cloud computing, but the computation is not from the internet that far away from the user, it is from the local computer or some network which is close to the user, even a mobile phone can do the job.

## 1.3 Machine Learning

Machine Learning is a self-developed program, commonly used in different fields such as face recognition system, image processing, graphic processing etc. Even the iPhone contains a neural engine on the processor for Machine Learning.

## 1.4 Motivation

Machine Learning has already formed part of our life. Training efficiency and high privacy for the user are the key targets to improve the Machine Learning system. Federated Learning is a trend to reduce the training cost of the Machine Learning. However, the Federated Learning has some problems that need to be solved, such as, high power consumption, high transfer probability and limited spectrum for communication etc. Therefore, by joining the Fog Network into the Federated Learning can improve the efficiency and performance.

## 2 Technical Contribution of the paper

### 2.1 Idea between Fog Computing and Federated Learning

The authors have provided a brand-new idea or how to maximize the performance for Federated Learning. By using Fog Computing, the Federated Learning can share the training material (heterogeneity). In addition, it has mentioned in the introduction of the paper that the Machine Learning will use the wireless system for model development [2], such as 5G, 6G, WIFI 802.11be, which the Federated Learning is possible to work on a wireless network. This can make the Fog Computing deployment more easily.

### 2.2 Design consideration for network aware

In paper [1], the authors have pointed out some of the topics that need to be consider when using the Federated Learning. For example, Communication heterogeneity, computation of the device and storage, Privacy and Security etc.

### 2.3 Showing limitation of Federated Learning to prove the usefulness of Fog Learning.

In the view of limitation of the Federated Learning , the Fog Computing will be a useful tool to solve the problem.

### 2.4 How the Fog Learning can Collaborative in a Multilayer Structure

In paper [1], the authors have used the P2P technique as the body of the Device to Device communication. This technique enables people to decentralize the Machine Learning more efficiently.

The authors have also presented a Fog Computing architecture in a logical tree graph. The graph shows how the Federated Learning can be

worked as the bottom leaves of the tree by using the technique Device to Device. It can assist the horizontal communication.

From the result of the paper, after the Fog Computing was used the power consumption can reduce 50 percent and the symbol required to transfer was decreased 80 percent. In addition, it also can decrease 50 percent of total device processing by using fog computing.

## 2.5 Advantage from Fog Learning

The paper [1] has explained why the Fog Computing is necessary for the Federated Learning. The advantages include reducing the network translation, lowering the power consumption for the overall communication system, Efficient Spectrum usage etc. It concludes that the Fog Computing is good for the Federated Learning.

## 2.6 Further Research Topics

The author has suggested several research topics for readers interacted in the subject to do further research.

# 3 Detail description of the result

## 3.1 Design consideration

### 3.1.1 Communication Heterogeneity

The Federated Learning needs to communicate frequently to get the up-to-date data. Therefore, there will be a large amount of communication between the Internet of Things (IoTs). To avoid a busy network traffic, the designer has to consider which data can be transferred or compressed to transfer more efficiently.

### 3.1.2 Computation and Storage Heterogeneity

Updating efficiency will vary by using different device. Therefore, it needs to be considered the availability of the resource to avoid sending the instruction during the device is busy.

### 3.1.3 Privacy and Security

The introduction of the federation learning has high privacy because the raw data is not necessary to send for analysis in another machine. But it does not mean that the data will totally be hidden, because if the processed data was caught by someone, they are still having a chance to get the raw data by reverse engineering.

## 3.2 Limitation in Federated Learning

There will have some disadvantages by using the Federated Learning from the Network, privacy etc.

### 3.2.1 Data Transfer

For the Federated Learning, the data gathering only happens in device itself or in the main server. This will require a large amount of power to transfer the data from the end device to the base station.

### 3.2.2 Overloading Heterogeneous Network Resource

The cellular base stations and roadside units are not designed for a lot of devices to upload their data at the same time. However, the model uploading activities of the Federated Learning are so frequent that will overload the network.

### 3.2.3 Raw Data Privacy

For Federated Learning, the device can only process its own raw data. In other words, the device cannot cooperate with other devices to compute the raw data, which will increase the processing time significantly even if the end user has a resource rich device for computation.

## 3.3 Federated Learning to Fog Learning

As a result of the above, the paper [1] has proposed a new learning concept called Fog Learning. By using the Fog Learning, the Federated Learning can transfer the data from Device to Device, share the data in a smart way, use the multilayer network to do the job etc.

For the Federated Learning, some research have been done for the wireless network [3]. Also, Edge computing is used to help the Federated Learning performance [4]. The Fog Computing can serve as a connection between edge computing and Federated Learning. In addition, the Fog Computing with Device to Device communication can make the system more efficient.

### 3.4 Multilayer network for the Fog Learning

Fog Learning use the Fog Network to achieve multilayer learning architecture. As this is a multilayer learning, the end user will not transfer the data straight to the main sever. Instead, the data will be transferred layer by layer, form the Federated Learning device to the Fog Network device, then to the edge computing network and finally, to the main server.

As the multilayer learning system does not require the main sever to send the instruction or data to all devices concurrently, this can lower the delay for the system.

In addition, because it is a multilayer system, the result from the lower layer can be combined with the upper layer for further analysis, and which will give a better data grouping for upstream device.

### 3.5 How Fog Learning improves the Performance of the System

In this section, it will share about the advantage by using Fog Learning.

#### 3.5.1 Reduce Transmission between Layers

For the multilayer learning system, the Fog Learning is able to divide the data that need to be transferred, because there is one more layer to split the pressure form each layer device.

#### 3.5.2 Lower the Power Consumption

For the Fog Learning, it can provide the Device to Device transmission for the end user communication. Therefore, the end user can do the data transmission to the Fog Learning device with a short range, rather than sending the signal to the base station and then to the other devices.

### 3.5.3 Customize Spectrum Usage

The fog device can set to the suitable spectrum for the end user, it is not necessary to be fixed to a specific spectrum such as the spectrum of LTE, 5G, WIFI.

### 3.5.4 Resource Sharing

For the inter-layer devices, the data can be transferred between each other, so that one device is resource hungry, the data can be transferred to the resource rich device for computation.

## 3.6 Open Research Topics

From paper [1], it has provided some open research topics for further consideration. Below are two possible research topics.

### 3.6.1 Error Propagation Analysis

The wireless communication will get error from noise easily, especially when transferring the data in Device to Device form. Therefore, doing analysis on how to avoid those noise will be a good direction for improving the Fog Learning.

### 3.6.2 Smart Data Sharing

From the section 3.5.4 mentioned, some resource hungry devices may need to share their data for faster processing speed. Therefore, to consider some insensitive data can share to stronger computation with their own device will give a better performance for the system.

## 4 Comment on the paper

### 4.1 Overall

This paper gives a good overview on what will happen when the Fog Network was applied to the Federated Learning. In addition, it has detailly explained in why the Fog Computing should be add into the Federated Learning. User are encouraged to do research about the Fog Network and the Federated Learning.

### 4.2 Easy to Read

The paper is prepared for publication at a magazine. The authors use simple language to explain the concepts clearly instead of precenting them by showing formulas. It is not a technical report and everyone interested in this field can read and understand the paper. This also allow me to have a deeper understanding on the topic.

### 4.3 Compare

The paper is not only talking about the fog computing, they also have provided the experiment parameter when Federated Learning combined with the Fog Network, which is good for the researcher can locate the performance of this idea rapidly.

# Reference

[1] Hosseinalipour, Seyyedali, Brinton, Christopher G, Aggarwal, Vaneet, Dai, Huaiyu, & Chiang, Mung. From Federated to Fog Learning: Distributed Machine Learning over Heterogeneous Wireless Networks (2020).

[2] S. Ali et al., “6G White Paper on Machine Learning in Wireless Communication Networks,” arXiv preprintarXiv:2004.13875, 2020..

[3] S. Luo et al., “HFEL: Joint Edge Association and Resource Allocation for Cost-Efficient Hierarchical Federated Edge Learning,” IEEE Trans. Wireless Commun., 2020.

[4] M. S. H. Abad et al., “Hierarchical Federated Learning Across Heterogeneous Cellular Networks,” Proc. IEEE ICASSP, 2020, pp. 8866–70.