HOW TO BUILD A DOCKER IMAGES TO RUN FEDERATED LEARNING ON KUBEEDGE ENVIRONMENT

Download the Federated Learning project using gdown:

$pip install gdown

$gdown 1eACMOFfHPakqQ_JUb4AV37cJgmTfmsK5

$unzip FL_project_latest.zip

Content of fashion-mnist-aggregator.Dockerfile:

Content of fashion-mnist-client.Dockerfile:

cd FL_project_latest/fashion-mnist/Dockerfile

Build the docker file:

sudo docker build -f fashion-mnist-aggregator.Dockerfile -t kubeedge/fashion-mnist-aggregator:v1.0.0 --label FL_project_latest=fashion_mnist/federated-learning ..

```
cloud@cloud:~/FL_project/Dockerfile$ sudo docker build -f fashion-mnist-aggregator.Dockerfile -t kubeedge/fashion-mnist-ag
gregator:v1.0.0 --label FL_project=federated-learning ..
[sudo] password for cloud:
Sending build context to Docker daemon  22.53kB
Step 1/8 : FROM tensorflow/tensorflow:2.6.0
 ---> 94fc08a3795e
Step 2/8 : RUN python -m pip install --upgrade pip
 ---> Using cache
 ---> b221892db032
Step 3/8 : RUN pip install flwr
 ---> Using cache
 ---> 5418597dba98
Step 4/8 : RUN pip install tensorflow
 ---> Using cache
 ---> 1c20f1264375
Step 5/8 : WORKDIR /home/work
 ---> Using cache
 ---> c2725df32100
Step 6/8 : COPY federated-learning/tensorflow_fashion_mnist /home/work/
 ---> 5805e4b144a2
Step 7/8 : ENTRYPOINT ["python", "server.py"]
 ---> Running in 8f31c8f808cf
Removing intermediate container 8f31c8f808cf
 ---> 35b177f11e5a
Step 8/8 : LABEL FL_project=federated-learning
 ---> Running in 7b83dfac0ef6
Removing intermediate container 7b83dfac0ef6
 ---> 34f0c6504574
Successfully built 34f0c6504574
Successfully tagged kubeedge/fashion-mnist-aggregator:v1.0.0
```

sudo docker build -f fashion-mnist-client.Dockerfile -t kubeedge/fashion-mnist-client:v1.0.0 --label FL_project_latest=fashion_mnist/federated-learning ..

```
cloud@cloud:~/FL_project/Dockerfile$ sudo docker build -f fashion-mnist-client.Dockerfile -t kubeedge/fashion-mnist-client
:v1.0.0 --label FL_project=federated-learning ..
[sudo] password for cloud:
Sending build context to Docker daemon  22.53kB
Step 1/8 : FROM tensorflow/tensorflow:2.6.0
 ---> 94fc08a3795e
Step 2/8 : RUN python -m pip install --upgrade pip
 ---> Using cache
 ---> b221892db032
Step 3/8 : RUN pip install flwr
 ---> Using cache
 ---> 5418597dba98
Step 4/8 : RUN pip install tensorflow
 ---> Using cache
 ---> 1c20f1264375
Step 5/8 : WORKDIR /home/work
 ---> Using cache
 ---> c2725df32100
Step 6/8 : COPY federated-learning/tensorflow_fashion_mnist /home/work/
 ---> Using cache
 ---> 5805e4b144a2
Step 7/8 : ENTRYPOINT ["python","client.py"]
 ---> Running in a30a31d8a50e
Removing intermediate container a30a31d8a50e
 ---> aba994e4a46e
Step 8/8 : LABEL FL_project=federated-learning
 ---> Running in 35f8b222c2a3
Removing intermediate container 35f8b222c2a3
 ---> 38f0e2cee5c8
Successfully built 38f0e2cee5c8
Successfully tagged kubeedge/fashion-mnist-client:v1.0.0
```

Check the docker images on cloud:

sudo docker images

```
cloud@cloud:~$ sudo docker images
REPOSITORY                                TAG        IMAGE ID       CREATED             SIZE
kubeedge/fashion-mnist-client             v1.0.0     38f0e2cee5c8   2 minutes ago       2.92GB
kubeedge/fashion-mnist-aggregator         v1.0.0     34f0c6504574   About an hour ago   2.92GB
kubeedge/edgemesh-server                  latest     a4812893d5c0   7 days ago          50.6MB
kubeedge/edgemesh-server                  <none>     1244970211b6   12 days ago         50.6MB
k8s.gcr.io/kube-apiserver                 v1.21.8    a5a584eef959   2 weeks ago         126MB
k8s.gcr.io/kube-scheduler                 v1.21.8    4cd11f55d2ec   2 weeks ago         50.9MB
k8s.gcr.io/kube-controller-manager        v1.21.8    74e3bdf53cd3   2 weeks ago         120MB
k8s.gcr.io/kube-proxy                     v1.21.8    f70621d55c05   2 weeks ago         104MB
calico/node                               v3.21.2    f1bca4d4ced2   4 weeks ago         214MB
calico/pod2daemon-flexvol                 v3.21.2    7778dd57e506   4 weeks ago         21.3MB
calico/cni                                v3.21.2    4c5c32530391   4 weeks ago         239MB
calico/kube-controllers                   v3.21.2    b20652406028   4 weeks ago         132MB
tensorflow/tensorflow                     2.6.0      94fc08a3795e   4 months ago        1.32GB
k8s.gcr.io/pause                          3.4.1      0f8457a4c2ec   11 months ago       683kB
k8s.gcr.io/coredns/coredns                v1.8.0     296a6d5035e2   14 months ago       42.5MB
k8s.gcr.io/etcd                           3.4.13-0   0369cf4303ff   16 months ago       253MB
```

How to send fashion-mnist-client images to edge node:

sudo apt-get install openssh-server

At Cloud Node:

sudo docker save -o client.tar 38f0e2cee5c8

sudo scp client.tar edge1@192.168.27.129:/home/edge1

sudo scp client.tar edge2@192.168.27.130:/home/edge2

At Edge Node:

sudo docker load -i client.tar

sudo docker image tag 38f0e2cee5c8 kubeedge/fashion-mnist-client:v1.0.0

sudo docker images

```
edge1@edge1:~$ sudo docker images
REPOSITORY                                TAG        IMAGE ID       CREATED          SIZE
kubeedge/fashion-mnist-client             v1.0.0     38f0e2cee5c8   3 hours ago      2.92GB
kubeedge/edgemesh-server                  latest     a4812893d5c0   7 days ago       50.6MB
kubeedge/edgemesh-agent                   latest     9d055bb5d3ee   7 days ago       61.9MB
kubeedge/edgemesh-server                  <none>     1244970211b6   12 days ago      50.6MB
kubeedge/edgemesh-agent                   <none>     b5569b947f1c   12 days ago      61.9MB
k8s.gcr.io/kube-apiserver                 v1.21.8    a5a584eef959   2 weeks ago      126MB
k8s.gcr.io/kube-controller-manager        v1.21.8    74e3bdf53cd3   2 weeks ago      120MB
k8s.gcr.io/kube-scheduler                 v1.21.8    4cd11f55d2ec   2 weeks ago      50.9MB
k8s.gcr.io/kube-proxy                     v1.21.8    f70621d55c05   2 weeks ago      104MB
calico/cni                                v3.21.2    4c5c32530391   4 weeks ago      239MB
calico/kube-controllers                   v3.21.2    b20652406028   4 weeks ago      132MB
k8s.gcr.io/coredns/coredns                v1.8.0     296a6d5035e2   14 months ago    42.5MB
k8s.gcr.io/etcd                           3.4.13-0   0369cf4303ff   16 months ago    253MB
kubeedge/pause                            3.1        da86e6ba6ca1   4 years ago      742kB
```

STRUCTURE OF A YAML FILE TO RUN FEDERATED LEARNING PODS

cloud.yaml:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: fashion-mnist
  labels:
    app: federated-learning
spec:
  selector:
    matchLabels:
      app: federated-learning
  template:
    metadata:
      labels:
        app: federated-learning
    spec:
      nodeName: cloud
      containers:
      - name: federated-learning
        image: kubeedge/fashion-mnist-aggregator:v1.0.0
        resources:
          requests:
            memory: "2Gi"
            cpu: "2"
          limits:
            memory: "4Gi"
            cpu: "4"
        args: ["--rounds=5", "--sample_fraction=0.5", "--min_sample_size=2", "--min_num_clients=2", "--server_address=0.0.0.0:8888”]
        ports:
          - containerPort: 8888
      hostNetwork: true #false: provide IP for cloud pod, true: use its cloud IP
      dnsPolicy: Default
```

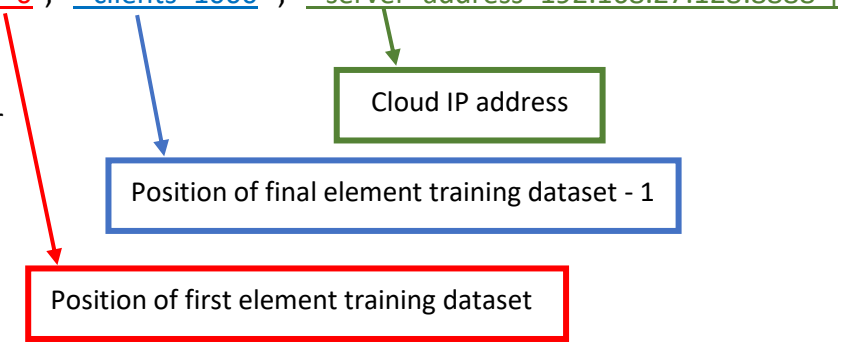
service.yaml:

```
###SERVICE###
apiVersion: v1
kind: Service
metadata:
  name: federated-learning-svc
spec:
  selector:
    app: federated-learning
  ports:
    - port: 12345
      protocol: TCP
      targetPort: 8888
```

client.yaml:

```
####EDGE 1####
apiVersion: v1
kind: Pod
metadata:
    name: fashion-mnist-edge1
spec:
    nodeName: edge1
    containers:
      - image: kubeedge/fashion-mnist-client:v1.0.0
        name: federated-learning-client
        args: ["--partition=0", "--clients=1000" , "--server_address=192.168.27.128:8888"]
    hostNetwork: true
    dnsPolicy: Default
    restartPolicy: Never

---
###EDGE 2####
apiVersion: v1
kind: Pod
metadata:
    name: fashion-mnist-edge2
spec:
    nodeName: edge2
    containers:
      - image: kubeedge/fashion-mnist-client:v1.0.0
        name: federated-learning-client
```



```
    args: ["--partition=2000", "--clients=4000" , "--server_address=192.168.27.128:8888"]
  hostNetwork: true
  dnsPolicy: Default
  restartPolicy: Never
```

Deploy:

$sudo chmod +x run-federated.sh

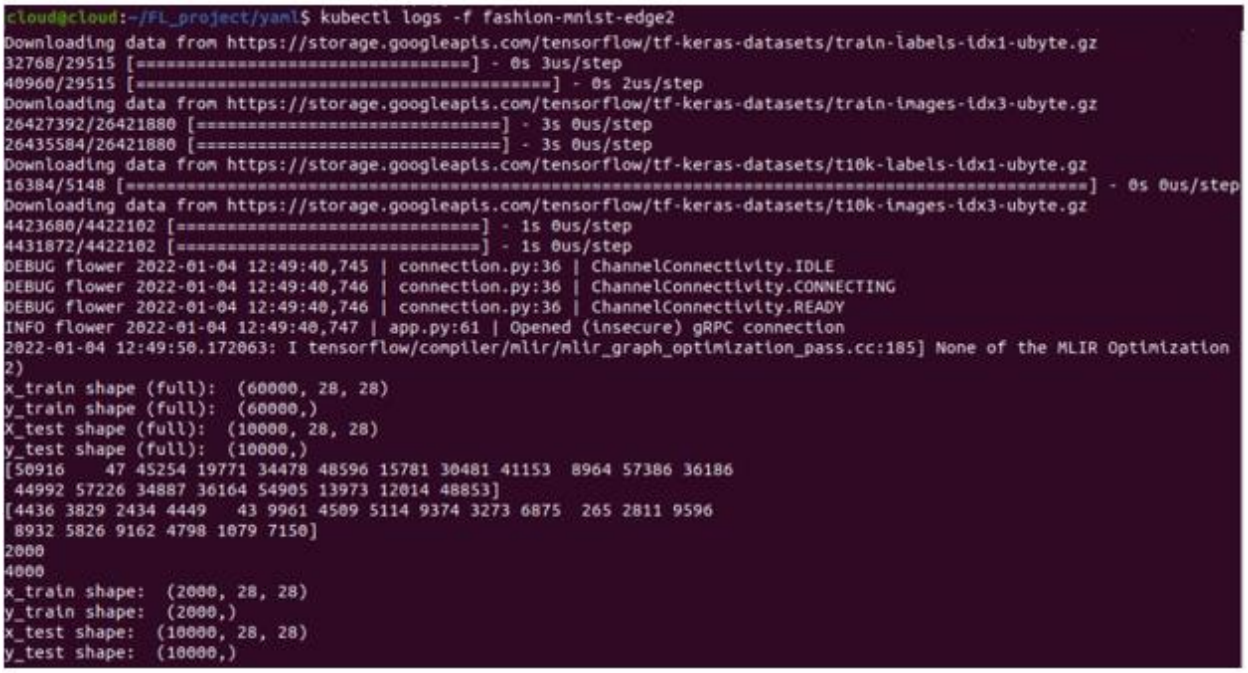
$sudo chmod +x stop-federated.sh

./run-federated.sh

Check results:

```
cloud@cloud:~/FL_project/yaml$ kubectl get pod -o wide -A
NAMESPACE     NAME                                READY   STATUS      RESTARTS   AGE     IP               NODE
default       fashion-mnist-6dcb58996c-r56dl      1/1     Running     1          2m14s   192.168.27.128   cloud
default       fashion-mnist-edge1                 0/1     Completed   0          2m4s    192.168.27.129   edge1
default       fashion-mnist-edge2                 0/1     Completed   0          2m4s    192.168.27.130   edge2
cloud@cloud:~/FL_project/yaml$ kubectl get svc -A
NAMESPACE     NAME                    TYPE        CLUSTER-IP      EXTERNAL-IP   PORT(S)                  AGE
default       federated-learning-svc  ClusterIP   10.108.46.5     <none>        12345/TCP                18m
default       kubernetes              ClusterIP   10.96.0.1       <none>        443/TCP                  13d
kube-system   kube-dns                ClusterIP   10.96.0.10      <none>        53/UDP,53/TCP,9153/TCP   13d
kube-system   metrics-server          ClusterIP   10.99.30.186    <none>        443/TCP                  5d18h
cloud@cloud:~/FL_project/yaml$ kubectl get ep -A
NAMESPACE     NAME                    ENDPOINTS                                                     AGE
default       federated-learning-svc  192.168.27.128:8888                                           18m
default       kubernetes              192.168.27.128:6443                                           13d
kube-system   kube-dns                192.168.41.4:53,192.168.41.5:53,192.168.41.4:53 + 3 more...   13d
kube-system   metrics-server          192.168.27.128:4443                                           5d18h
```

```
cloud@cloud:~/FL_project/yaml$ kubectl logs -f fashion-mnist-edge1
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/train-labels-idx1-ubyte.gz
32768/29515 [=============================] - 0s 2us/step
40960/29515 [=======================================] - 0s 2us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/train-images-idx3-ubyte.gz
26427392/26421880 [==============================] - 3s 0us/step
26435584/26421880 [==============================] - 3s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/t10k-labels-idx1-ubyte.gz
16384/5148 [===============================================================================================] - 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/t10k-images-idx3-ubyte.gz
4423680/4422102 [==============================] - 2s 0us/step
4431872/4422102 [==============================] - 2s 0us/step
DEBUG flower 2022-01-04 12:49:39,060 | connection.py:36 | ChannelConnectivity.IDLE
DEBUG flower 2022-01-04 12:49:39,061 | connection.py:36 | ChannelConnectivity.CONNECTING
INFO flower 2022-01-04 12:49:39,061 | app.py:61 | Opened (insecure) gRPC connection
DEBUG flower 2022-01-04 12:49:39,062 | connection.py:36 | ChannelConnectivity.READY
2022-01-04 12:49:50.179215: I tensorflow/compiler/mlir/mlir_graph_optimization_pass.cc:185] None of the MLIR Optimization
2)
x_train shape (full):  (60000, 28, 28)
y_train shape (full):  (60000,)
X_test shape (full):  (10000, 28, 28)
y_test shape (full):  (10000,)
[50916    47 45254 19771 34478 48596 15781 30481 41153  8964 57386 36186
 44992 57226 34887 36164 54905 13973 12014 48853]
[4436 3829 2434 4449   43 9961 4509 5114 9374 3273 6875  265 2811 9596
 8932 5826 9162 4798 1079 7150]
0
1000
x_train shape:  (1000, 28, 28)
y_train shape:  (1000,)
x_test shape:  (10000, 28, 28)
y_test shape:  (10000,)
```



To stop:
./stop-federated.sh

HOW TO ADD METRIC SERVER/HPA ON KUBEEDGE ON FL POD

sudo nano /etc/kubernetes/manifests/kube-apiserver.yaml
Add line: **- --enable-aggregator-routing=true** after kube-apiserver
Follow this instruction to install metric server.
https://kubeedge.io/en/docs/advanced/metrics/

Check results:

```
cloud@cloud:~/FL_project/yaml$ kubectl top node
W0106 21:38:38.435673 1534974 top_node.go:119] Using json format to get metrics. Next release will switch to protocol-buff
ers, switch early by passing --use-protocol-buffers flag
NAME     CPU(cores)   CPU%   MEMORY(bytes)   MEMORY%
cloud    722m         9%     4186Mi          54%
edge1    47m          2%     2428Mi          31%
edge2    42m          2%     2381Mi          30%
```

```
cloud@cloud:~/FL_project/yaml$ kubectl get pod -o wide -A
NAMESPACE     NAME                                       READY   STATUS    RESTARTS   AGE     IP               NODE
kube-system   calico-kube-controllers-6b9fbfff44-7k788   1/1     Running   7          7d8h    192.168.41.3     cloud
kube-system   calico-node-4gj8l                          1/1     Running   0          7d8h    192.168.27.128   cloud
kube-system   coredns-558bd4d5db-d2xz8                   1/1     Running   0          7d11h   192.168.41.1     cloud
kube-system   coredns-558bd4d5db-p9gsc                   1/1     Running   0          7d11h   192.168.41.2     cloud
kube-system   etcd-cloud                                 1/1     Running   0          7d11h   192.168.27.128   cloud
kube-system   kube-apiserver-cloud                       1/1     Running   0          6m      192.168.27.128   cloud
kube-system   kube-controller-manager-cloud              1/1     Running   2          7d11h   192.168.27.128   cloud
kube-system   kube-proxy-bmx9c                           1/1     Running   0          7d8h    192.168.27.128   cloud
kube-system   kube-scheduler-cloud                       1/1     Running   2          7d11h   192.168.27.128   cloud
kube-system   metrics-server-794f9b5fd-bwbb5             1/1     Running   0          9s      192.168.27.128   cloud
```

Check results while running FL pods:

```
cloud@cloud:~/FL_project/yaml$ kubectl top node
W0106 21:55:06.931525 1556057 top_node.go:119] Using json format to get metrics. Next release will switch to protocol-buff
ers, switch early by passing --use-protocol-buffers flag
NAME     CPU(cores)   CPU%   MEMORY(bytes)   MEMORY%
cloud    827m         10%    4483Mi          58%
edge1    194m         9%     2599Mi          33%
edge2    220m         11%    2542Mi          32%
```

```
cloud@cloud:~/FL_project/yaml$ kubectl get po -o wide
NAME                                READY   STATUS    RESTARTS   AGE   IP               NODE    NOMINATED NODE   READIN
ESS GATES
fashion-mnist-69c89966bb-x6k8g      1/1     Running   0          93s   192.168.27.128   cloud   <none>           <none>
fashion-mnist-edge1-879b848cd-ngkl6 1/1     Running   0          82s   192.168.27.129   edge1   <none>           <none>
fashion-mnist-edge2-8455d6df66-d52m6 1/1    Running   0          82s   192.168.27.130   edge2   <none>           <none>
```

Add HPA Autoscaling into FL pods running on edge1/edge2:

```yaml
###HPA AutoScaler###
apiVersion: autoscaling/v2beta2
kind: HorizontalPodAutoscaler
metadata:
  name: fashion-mnist-edge1
  namespace: default
spec:
  scaleTargetRef:
    apiVersion: apps/v1
    kind: Deployment
    name: fashion-mnist-edge1
  minReplicas: 1
  maxReplicas: 5
  metrics:
  - type: Resource
    resource:
      name: cpu #memory
      target:
        type: Utilization
        averageUtilization: 110 #Must higher than the CPU request resources of FL pod
  behavior:
    scaleDown:
      stabilizationWindowSeconds: 120
      policies:
      - type: Pods
        value: 5
        periodSeconds: 120
      selectPolicy: Min #Max
```

Check HPA status on FL pods (edge1/edge2):

```
cloud@cloud:~/FL_project/yaml$ kubectl get hpa
NAME                REFERENCE                          TARGETS         MINPODS   MAXPODS   REPLICAS   AGE
fashion-mnist-edge1   Deployment/fashion-mnist-edge1   <unknown>/60%   1         5         1          100s
fashion-mnist-edge2   Deployment/fashion-mnist-edge2   <unknown>/60%   1         5         1          100s
cloud@cloud:~/FL_project/yaml$ kubectl get hpa
NAME                REFERENCE                          TARGETS     MINPODS   MAXPODS   REPLICAS   AGE
fashion-mnist-edge1   Deployment/fashion-mnist-edge1   189%/60%    1         5         1          82s
fashion-mnist-edge2   Deployment/fashion-mnist-edge2   189%/60%    1         5         1          82s
cloud@cloud:~/FL_project/yaml$ kubectl get hpa
NAME                REFERENCE                          TARGETS     MINPODS   MAXPODS   REPLICAS   AGE
fashion-mnist-edge1   Deployment/fashion-mnist-edge1   189%/60%    1         5         4          94s
fashion-mnist-edge2   Deployment/fashion-mnist-edge2   189%/60%    1         5         4          94s
```

Desired Pods = ceil(current_pods * (current value/ target value))

= 1 * (1.89 / 0.6) = 3.15 ~~ 4 pods for each node.

```
cloud@cloud:~/FL_project/yaml$ kubectl get pod -o wide
NAME                                READY   STATUS    RESTARTS   AGE     IP              NODE    NOMINATED NODE   READ
INESS GATES
fashion-mnist-69c89966bb-pz784      1/1     Running   0          5m23s   192.168.27.128  cloud   <none>           <non
e>
fashion-mnist-edge1-59f96fc4cc-8kk4k   1/1     Running   0          10s     192.168.27.129  edge1   <none>           <non
e>
fashion-mnist-edge1-59f96fc4cc-bbgh6   0/1     Error     0          10s     192.168.27.129  edge1   <none>           <non
e>
fashion-mnist-edge1-59f96fc4cc-lj67b   1/1     Running   0          85s     192.168.27.129  edge1   <none>           <non
e>
fashion-mnist-edge1-59f96fc4cc-qkmxw   0/1     Error     0          10s     192.168.27.129  edge1   <none>           <non
e>
fashion-mnist-edge2-74c67b88cd-5kdld   0/1     Pending   0          10s     <none>          edge2   <none>           <non
e>
fashion-mnist-edge2-74c67b88cd-bjj2t   1/1     Running   0          85s     192.168.27.130  edge2   <none>           <non
e>
fashion-mnist-edge2-74c67b88cd-cthgs   0/1     Pending   0          10s     <none>          edge2   <none>           <non
e>
fashion-mnist-edge2-74c67b88cd-dw2nr   0/1     Pending   0          10s     <none>          edge2   <none>           <non
e>
```

Recheck after a couple of minutes:

```
cloud@cloud:~/FL_project/yaml$ kubectl get hpa
NAME                REFERENCE                          TARGETS   MINPODS   MAXPODS   REPLICAS   AGE
fashion-mnist-edge1   Deployment/fashion-mnist-edge1   19%/60%   1         5         5          12m
fashion-mnist-edge2   Deployment/fashion-mnist-edge2   19%/60%   1         5         5          12m
cloud@cloud:~/FL_project/yaml$ kubectl get pod -o wide
NAME                                READY   STATUS    RESTARTS   AGE   IP              NODE    NOMINATED NODE   READIN
ESS GATES
fashion-mnist-69c89966bb-pz784      1/1     Running   0          17m   192.168.27.128  cloud   <none>           <none>
fashion-mnist-edge1-59f96fc4cc-8kk4k   1/1     Running   0          11m   192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge1-59f96fc4cc-bbgh6   1/1     Running   1          11m   192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge1-59f96fc4cc-f924t   1/1     Running   0          11m   192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge1-59f96fc4cc-lj67b   1/1     Running   0          13m   192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge1-59f96fc4cc-qkmxw   1/1     Running   2          11m   192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge2-74c67b88cd-5kdld   1/1     Running   2          11m   192.168.27.130  edge2   <none>           <none>
fashion-mnist-edge2-74c67b88cd-bjj2t   1/1     Running   0          13m   192.168.27.130  edge2   <none>           <none>
fashion-mnist-edge2-74c67b88cd-cthgs   1/1     Running   2          11m   192.168.27.130  edge2   <none>           <none>
fashion-mnist-edge2-74c67b88cd-d7g6s   1/1     Running   0          11m   192.168.27.130  edge2   <none>           <none>
fashion-mnist-edge2-74c67b88cd-dw2nr   1/1     Running   2          11m   192.168.27.130  edge2   <none>           <none>
```

- ⇨ Check logs from every pods and all of them are working normal and all pods in 1 node are training synchronously (the same round).
- ⇨ Although the number of CPU percent is decreased, but the number of replicas is still unchanging. (it should be decreased??? – after 5 minutes for scale down).

https://kubernetes.io/docs/tasks/run-application/horizontal-pod-autoscale/

```
cloud@cloud:~/FL_project/yaml$ kubectl get hpa
NAME                REFERENCE                              TARGETS   MINPODS   MAXPODS   REPLICAS   AGE
fashion-mnist-edge1   Deployment/fashion-mnist-edge1   11%/60%   1         5         5          28m
fashion-mnist-edge2   Deployment/fashion-mnist-edge2   11%/60%   1         5         5          28m
```

It’s lead to high % CPU performance at each node because the HPA didn’t scale down:

```
cloud@cloud:~/FL_project/yaml$ kubectl top node
W0106 23:19:54.134390 1669618 top_node.go:119] Using json format to get metrics. Next release will switch to protocol-buff
ers, switch early by passing --use-protocol-buffers flag
NAME    CPU(cores)   CPU%   MEMORY(bytes)   MEMORY%
cloud   498m         6%     5097Mi          66%
edge1   1992m        99%    6092Mi          77%
edge2   2000m        100%   5015Mi          64%
```

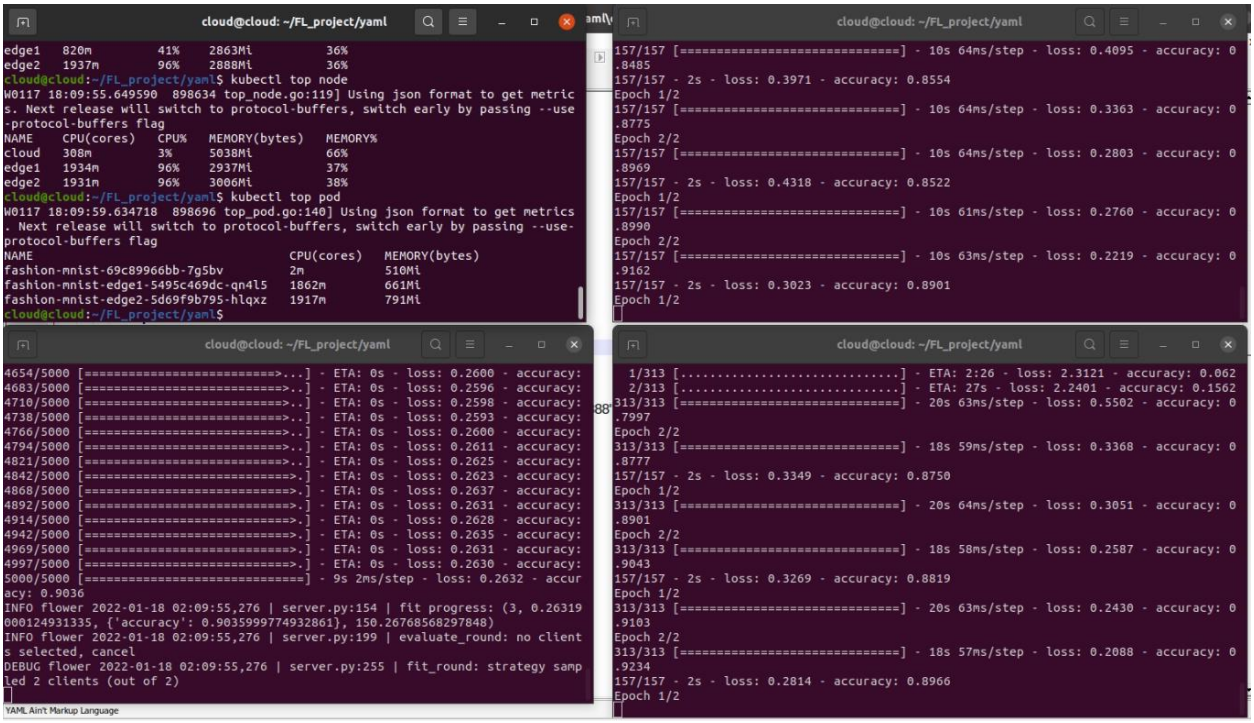
New results: now HPA can scale up and scale down.

```
cloud@cloud:~/FL_project/yaml$ kubectl get pod -o wide
NAME                                READY   STATUS    RESTARTS   AGE   IP               NODE    NOMINATED NODE   READIN
ESS GATES
fashion-mnist-69c89966bb-zzpwj      1/1     Running   2          28m   192.168.27.128   cloud   <none>           <none>
fashion-mnist-edge1-59f96fc4cc-rzszh   1/1     Running   4          28m   192.168.27.129   edge1   <none>           <none>
fashion-mnist-edge2-74c67b88cd-9rbvn   1/1     Running   1          15m   192.168.27.130   edge2   <none>           <none>
fashion-mnist-edge2-74c67b88cd-g65wz   1/1     Running   0          48s   192.168.27.130   edge2   <none>           <none>
fashion-mnist-edge2-74c67b88cd-n9phq   1/1     Running   1          15m   192.168.27.130   edge2   <none>           <none>
cloud@cloud:~/FL_project/yaml$ kubectl describe hpa fashion-mnist-edge2
Name:                                                  fashion-mnist-edge2
Namespace:                                             default
Labels:                                                <none>
Annotations:                                           <none>
CreationTimestamp:                                     Tue, 11 Jan 2022 17:36:14 -0800
Reference:                                             Deployment/fashion-mnist-edge2
Metrics:                                               ( current / target )
  resource cpu on pods  (as a percentage of request):  93% (930m) / 110%
Min replicas:                                          1
Max replicas:                                          5
Deployment pods:                                       3 current / 3 desired
Conditions:
  Type            Status  Reason              Message
  ----            ------  ------              -------
  AbleToScale     True    ReadyForNewScale    recommended size matches current size
  ScalingActive   True    ValidMetricFound    the HPA was able to successfully calculate a replica count from cpu resource
 utilization (percentage of request)
  ScalingLimited  False   DesiredWithinRange  the desired count is within the acceptable range
Events:
  Type     Reason                        Age                  From                       Message
  ----     ------                        ----                 ----                       -------
  Warning  FailedGetResourceMetric       28m (x2 over 28m)    horizontal-pod-autoscaler  failed to get cpu utilization: un
able to get metrics for resource cpu: no metrics returned from resource metrics API
  Warning  FailedComputeMetricsReplicas  28m (x2 over 28m)    horizontal-pod-autoscaler  invalid metrics (1 invalid out of
 1), first error is: failed to get cpu utilization: unable to get metrics for resource cpu: no metrics returned from resou
rce metrics API
  Normal   SuccessfulRescale             15m (x2 over 26m)    horizontal-pod-autoscaler  New size: 4; reason: cpu resource
 utilization (percentage of request) above target
  Normal   SuccessfulRescale             6m10s (x2 over 20m)  horizontal-pod-autoscaler  New size: 2; reason: All metrics
below target
  Normal   SuccessfulRescale             55s                  horizontal-pod-autoscaler  New size: 3; reason: cpu resource
 utilization (percentage of request) above target
```

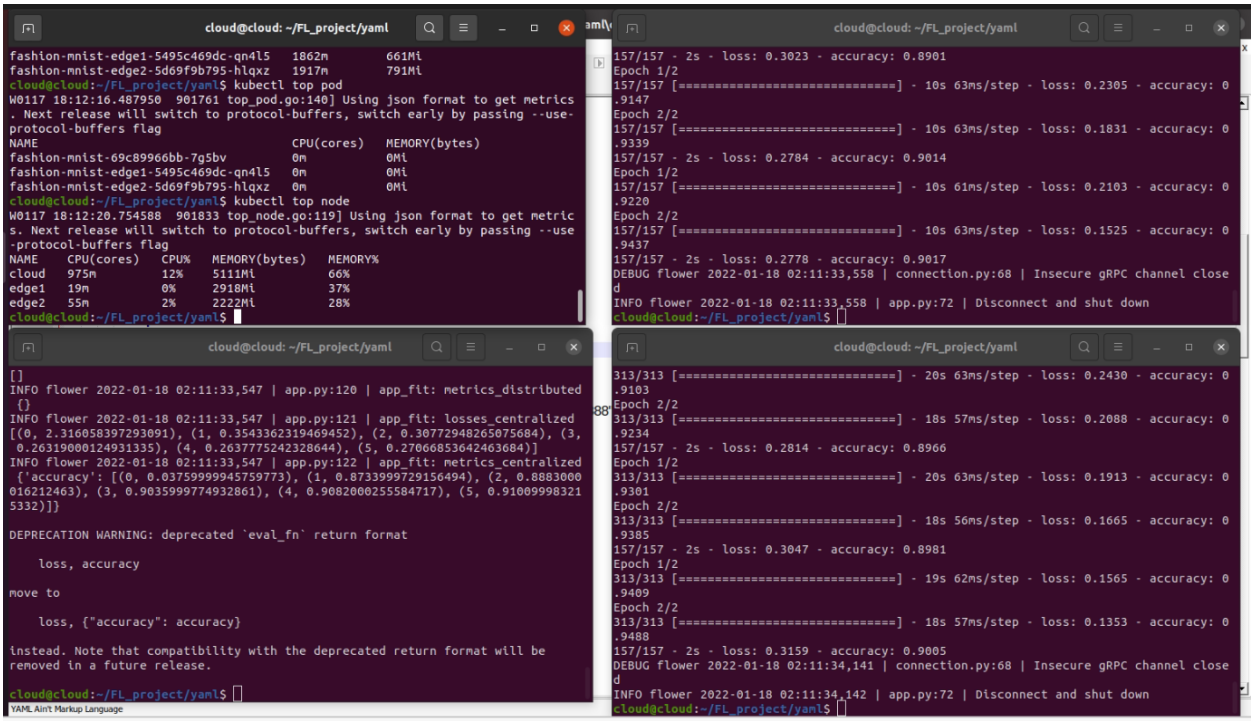
Testing CPU/Memory performance with HPA and without HPA:

Edge 1: 10K training samples, Edge 2: 20K training samples.

+ Without HPA: Check CPU/Memory performance on each pod/each node at end of round 3. (Cloud node completed in aggregation phase, edge nodes is training at round 4).

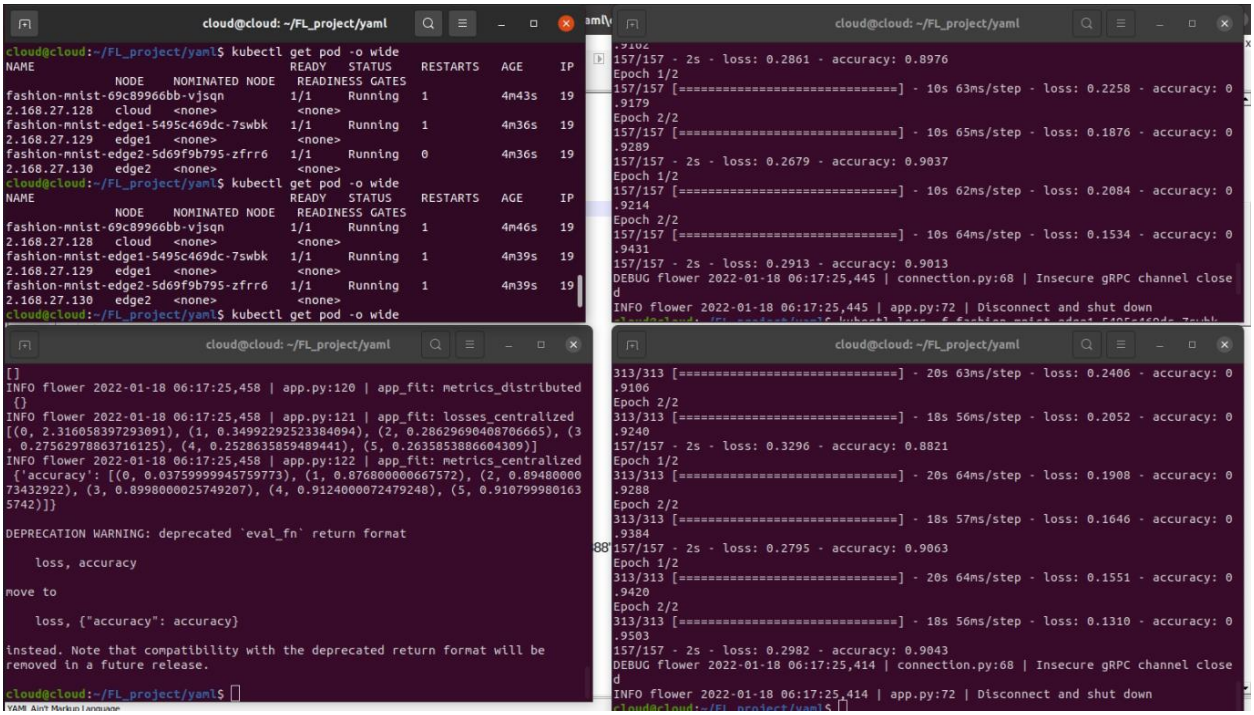


Check CPU/Memory performance on each pod/each node at end of a loop (1 loop = 5 rounds).



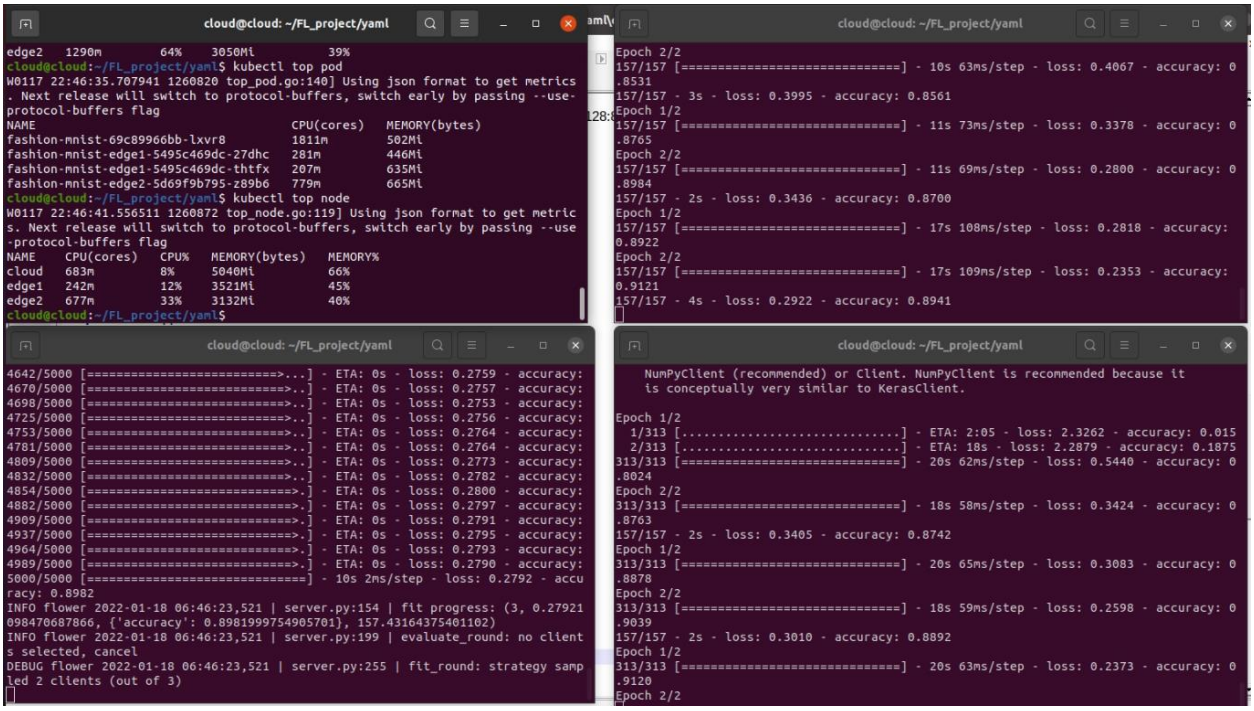
Training time:

Edge 1: 10K training samples, Edge 2: 20K training samples.

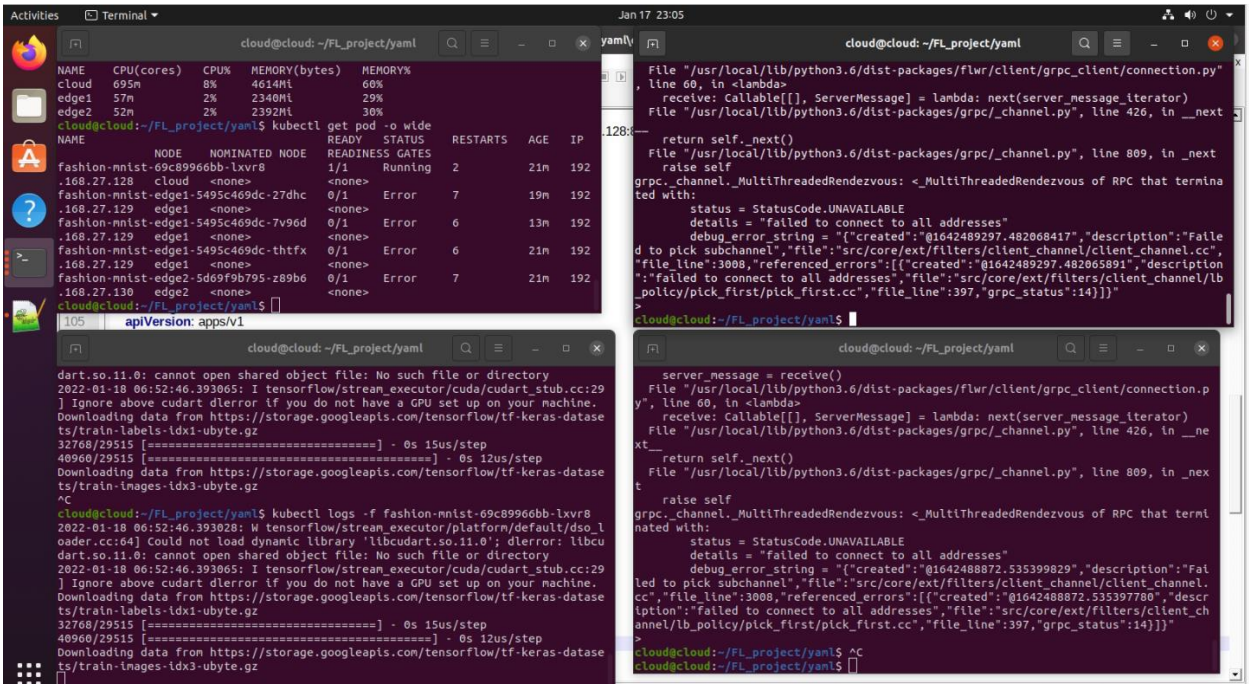


=> Training time on each loop: 4m39s

+ With HPA: Check CPU/Memory performance on each pod/each node.
Edge 1: 10K training samples, Edge 2: 20K training samples.
Test case: Apply HPA on edge 1, resources on edge 1 pod: (Request: 1 vCPU, 1Gi memory, Limits: 2vCPU, 2Gi memory), HPA info: (Min:1, Max: 5, CPU target: 120% ~ 1.2vCPU, scale down time: 120s).



Catch some errors since Cloud pod is still not ready but Edge pods have tried to connect => lead to failed to connect to all address (Cloud IP address).



Try Edge 1 & Edge 2 has the same amount of training data samples. HPA applied on Edge 2.

Problem 1: Incorrect pod which chosen to train

```
cloud@cloud:~$ kubectl top pod
W0118 00:08:14.522188   32135 top_pod.go:140] Using json format to get metrics
. Next release will switch to protocol-buffers, switch early by passing --use-
protocol-buffers flag
NAME                                CPU(cores)   MEMORY(bytes)
fashion-mnist-69c89966bb-t27rp      1m           444Mi
fashion-mnist-edge1-7b5dcf65f4-fqpww   3m        261Mi
fashion-mnist-edge2-5d69f9b795-mdj5c   988m      517Mi
fashion-mnist-edge2-5d69f9b795-qlf74   2m        562Mi
fashion-mnist-edge2-5d69f9b795-vl2lx   992m      652Mi
fashion-mnist-edge2-5d69f9b795-wvpbx   2m        292Mi
```

Picture 1: HPA scaling up and 2 FL training pods are running on the same node (Edge 2)

```
cloud@cloud:~$ kubectl top pod
W0118 00:17:29.237209   44687 top_pod.go:140] Using json format to get metr
ics. Next release will switch to protocol-buffers, switch early by passing
--use-protocol-buffers flag
NAME                                CPU(cores)   MEMORY(bytes)
fashion-mnist-69c89966bb-t27rp      1m           618Mi
fashion-mnist-edge1-7b5dcf65f4-fqpww   1908m     870Mi
fashion-mnist-edge2-5d69f9b795-crdfz   2m        261Mi
fashion-mnist-edge2-5d69f9b795-mcc9m   2m        268Mi
fashion-mnist-edge2-5d69f9b795-qlf74   1909m     850Mi
fashion-mnist-edge2-5d69f9b795-vl2lx   2m        690Mi
```

Picture 2: HPA scaling up and FL pod is running on the different node -> this is correct.

```
cloud@cloud:~$ kubectl top pod
W0118 00:28:37.982169   59401 top_pod.go:140] Using json format to get metr
ics. Next release will switch to protocol-buffers, switch early by passing
--use-protocol-buffers flag
NAME                                CPU(cores)   MEMORY(bytes)
fashion-mnist-69c89966bb-t27rp      1m           329Mi
fashion-mnist-edge1-7b5dcf65f4-fqpww   2m        261Mi
fashion-mnist-edge2-5d69f9b795-qlf74   993m      528Mi
fashion-mnist-edge2-5d69f9b795-vl2lx   990m      539Mi
cloud@cloud:~$ kubectl top node
W0118 00:28:49.256901   59642 top_node.go:119] Using json format to get met
rics. Next release will switch to protocol-buffers, switch early by passing
 --use-protocol-buffers flag
NAME    CPU(cores)   CPU%   MEMORY(bytes)   MEMORY%
cloud   245m         3%     3079Mi          40%
edge1   14m          0%     1314Mi          16%
edge2   1998m        99%    2141Mi          27%
```

Picture 3: HPA scaling down and FL pods are running on the same node (Edge 2)

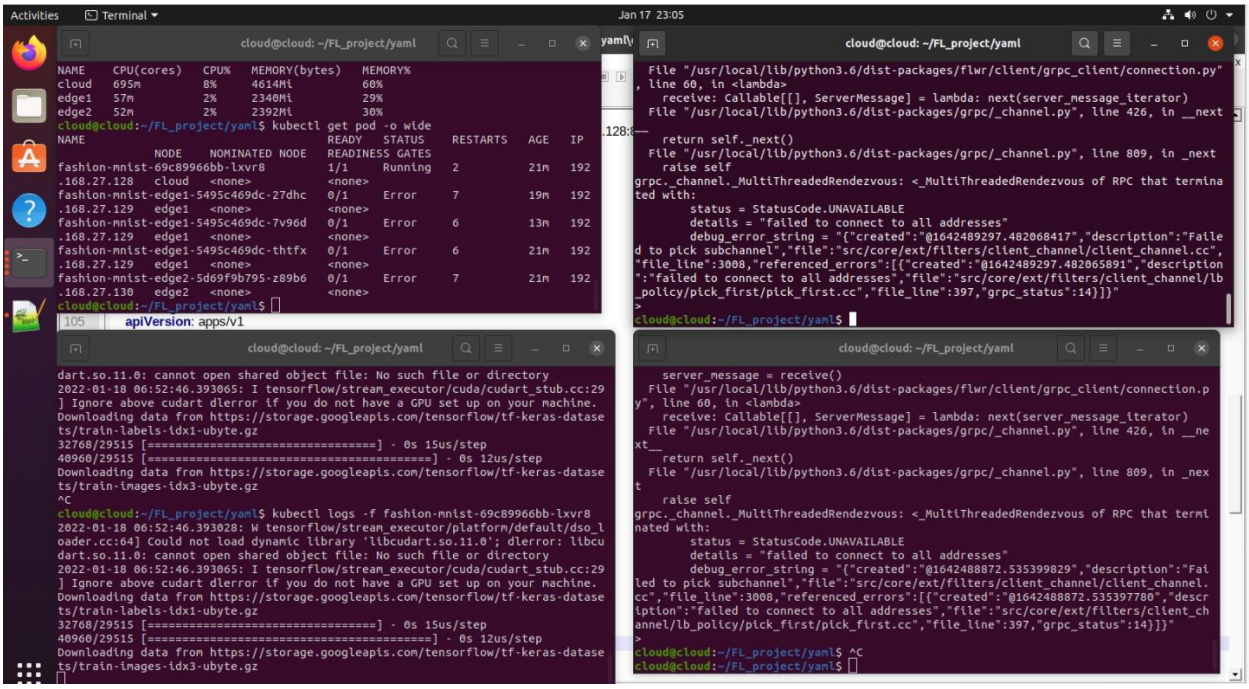
Why?

Because I set min_num_client = 2 so when the HPA scale up & scale down the number of pod, the FL application will understand that each pod will represent for each client, they just only choose at least 1 pair of pod and start training, the rest pods will wait or training in the next round.

This lead to the problem that FL_application may choose 2 pods in the same node like Picture 1 or different node like Picture 2.

=> Solution: Not yet.

Problem 2: Failed to pick subchannel/Failed to connect to all addresses on edge nodes



Why?

Because Cloud pod is still not ready state(Cloud pod still didn't finish the previous training loop but some pods in Edge 2 (HPA Pods) have already tried to connect => lead to failed to connect to all address (Cloud IP address).

Check logs on cloud: It was stuck at this step.

```
cloud@cloud:~$ kubectl logs -f fashion-mnist-69c89966bb-t27rp
2022-01-18 10:05:42.381730: W tensorflow/stream_executor/platform/default/dso_loader.cc:64] Could not load dynamic library 'libcudart.so.11.0'; dlerror: libcudart.so.11.0: cannot open shared object file: No such file or directory
2022-01-18 10:05:42.381764: I tensorflow/stream_executor/cuda/cudart_stub.cc:29] Ignore above cudart dlerror if you do not have a GPU set up on your machine.
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/train-labels-idx1-ubyte.gz
32768/29515 [==========] - 0s 2us/step
40960/29515 [==========] - 0s 2us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/train-images-idx3-ubyte.gz
```

Cloud logs at ready state should be:

```
cloud@cloud:~/FL_project/yaml$ kubectl logs -f fashion-mnist-69c89966bb-kxd54
2022-01-18 11:22:29.073117: W tensorflow/stream_executor/platform/default/dso_loader.cc:64] Could not load dynamic library 'libcudart.so.11.0'; dlerror: libcudart.so.11.0
: cannot open shared object file: No such file or directory
2022-01-18 11:22:29.073154: I tensorflow/stream_executor/cuda/cudart_stub.cc:29] Ignore above cudart dlerror if you do not have a GPU set up on your machine.
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/train-labels-idx1-ubyte.gz
32768/29515 [=============================] - 0s 2us/step
40960/29515 [=======================================] - 0s 2us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/train-images-idx3-ubyte.gz
26427392/26421880 [==============================] - 3s 0us/step
26435584/26421880 [==============================] - 3s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/t10k-labels-idx1-ubyte.gz
16384/5148 [===============================================================================================] - 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/t10k-images-idx3-ubyte.gz
4423680/4422102 [==============================] - 1s 0us/step
4431872/4422102 [==============================] - 1s 0us/step
INFO flower 2022-01-18 11:22:35,164 | app.py:80 | Flower server running (insecure, 5 rounds)
INFO flower 2022-01-18 11:22:35,164 | server.py:118 | Initializing global parameters
INFO flower 2022-01-18 11:22:35,164 | server.py:304 | Requesting initial parameters from one random client
```

Check HPA on both edge 1 and edge 2, the same training samples = 20K. (Below picture)
At first round, Cloud node received 3 parameters from clients, 1 failures, total 8 client (8 pods) are training, 4 pods for each node.
At second round, Cloud node received 4 parameters from clients, 0 failures, total 8 client (8 pods) are training, 4 pods for each node.

```
x_test shape:  (10000, 28, 28)
y_test shape:  (10000,)
5000/5000 [==============================] - 10s 2ms/step - loss: 2.3161 - accuracy: 0.0376
INFO flower 2022-01-18 11:32:47,595 | server.py:127 | initial parameters (loss, other metrics): 2.316058397293091, {'accuracy': 0.0375999994575977 3}
INFO flower 2022-01-18 11:32:47,596 | server.py:133 | FL starting
DEBUG flower 2022-01-18 11:32:47,596 | server.py:255 | fit_round: strategy sampled 2 clients (out of 4)
DEBUG flower 2022-01-18 11:33:32,148 | server.py:264 | fit_round received 2 results and 0 failures

DEPRECATION WARNING: deprecated `eval_fn` return format

    loss, accuracy

move to

    loss, {"accuracy": accuracy}

instead. Note that compatibility with the deprecated return format will be
removed in a future release.

5000/5000 [==============================] - 9s 2ms/step - loss: 0.3304 - accuracy: 0.8819
INFO flower 2022-01-18 11:33:41,581 | server.py:154 | fit progress: (1, 0.3304124176502228, {'accuracy': 0.8819000124931335}, 53.985757448001095)
INFO flower 2022-01-18 11:33:41,582 | server.py:199 | evaluate_round: no clients selected, cancel
DEBUG flower 2022-01-18 11:33:41,582 | server.py:255 | fit_round: strategy sampled 4 clients (out of 8)
DEBUG flower 2022-01-18 11:35:05,551 | server.py:264 | fit_round received 3 results and 1 failures

DEPRECATION WARNING: deprecated `eval_fn` return format

    loss, accuracy

move to

    loss, {"accuracy": accuracy}

instead. Note that compatibility with the deprecated return format will be
removed in a future release.

5000/5000 [==============================] - 9s 2ms/step - loss: 0.2717 - accuracy: 0.9038
INFO flower 2022-01-18 11:35:15,064 | server.py:154 | fit progress: (2, 0.2716974914073944, {'accuracy': 0.9038000106811523}, 147.46861769499992)
INFO flower 2022-01-18 11:35:15,064 | server.py:199 | evaluate_round: no clients selected, cancel
DEBUG flower 2022-01-18 11:35:15,064 | server.py:255 | fit_round: strategy sampled 4 clients (out of 8)
DEBUG flower 2022-01-18 11:36:37,739 | server.py:264 | fit_round received 4 results and 0 failures

DEPRECATION WARNING: deprecated `eval_fn` return format

    loss, accuracy
```

StatefulSet:

```
cloud@cloud:~/FL_project/yaml$ kubectl get pod -o wide
NAME                                READY   STATUS    RESTARTS   AGE    IP              NODE    NOMINATED NODE   READINESS GATES
fashion-mnist-7476c566c6-zj5gm      1/1     Running   21         163m   192.168.27.128  cloud   <none>           <none>
fashion-mnist-edge1-594865456c-ct9bf   1/1     Running   4          10m    192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge1-594865456c-dtftf   1/1     Running   4          10m    192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge2-0               1/1     Running   21         163m   192.168.27.130  edge2   <none>           <none>
fashion-mnist-edge2-1               1/1     Running   4          10m    192.168.27.130  edge2   <none>           <none>
```

Advantage: using StatefulSet can keep the original pod when applying HPA because the Statefulset will terminate pod by order from biggest to smallest during the scale down process. (The original pod won't be terminated by HPA because minReplicas is 1).

Disadvantage: if the original pod (fashion-mnist-edge1-0 || fashion-mnist-edge2-0) are in error state and they can't be running/ready state by themself, the system will be shutdown. In below picture, they meet **the problem 2** during training and the system can't be fixed by itself.

```
cloud@cloud:~/FL_project/yaml$ kubectl get pod -o wide
NAME                                READY   STATUS    RESTARTS   AGE   IP              NODE    NOMINATED NODE   READINESS GATES
fashion-mnist-7476c566c6-x4brh      1/1     Running   67         10h   192.168.27.128  cloud   <none>           <none>
fashion-mnist-edge1-0               0/1     Error     78         10h   192.168.27.129  edge1   <none>           <none>
fashion-mnist-edge2-0               0/1     Error     77         10h   192.168.27.130  edge2   <none>           <none>
```

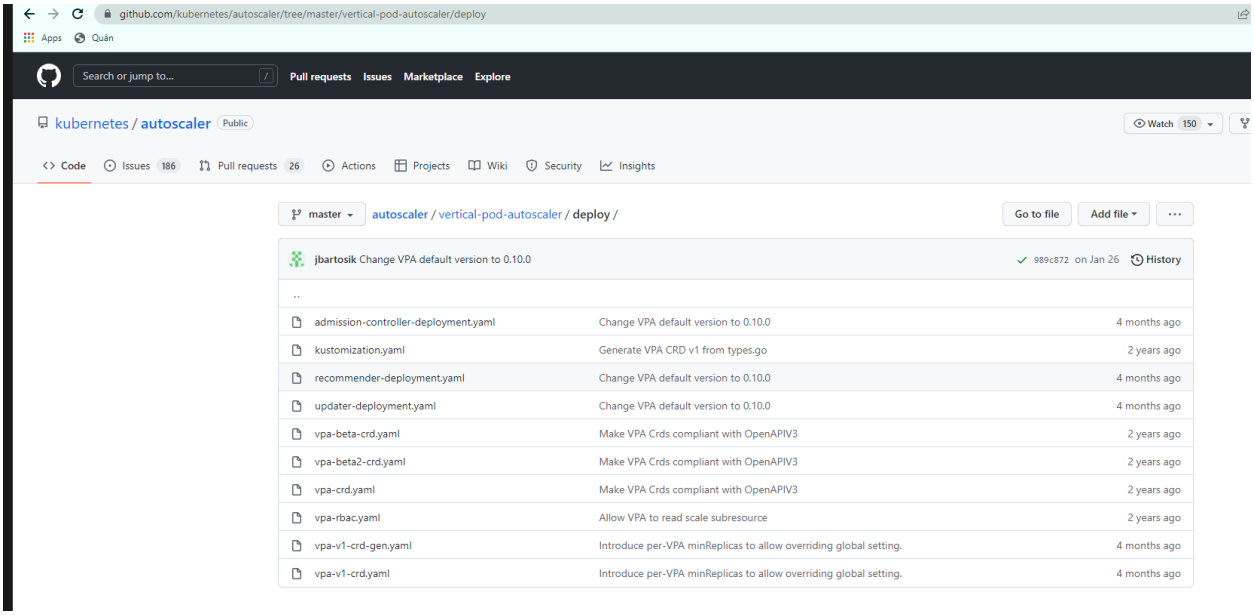
```
grpc._channel._MultiThreadedRendezvous: <_MultiThreadedRendezvous of RPC that terminated with:
        status = StatusCode.UNAVAILABLE
        details = "failed to connect to all addresses"
        debug_error_string = "{"created":"@1644196050.393040682","description":"Failed to pick subchannel","file":"src/core/ext/filters/client_channel
/client_channel.cc","file_line":3008,"referenced_errors":[{"created":"@1644196050.393038347","description":"failed to connect to all addresses","file"
:"src/core/ext/filters/client_channel/lb_policy/pick_first/pick_first.cc","file_line":397,"grpc_status":14}]}"
```

Below is 3 pods on each node, no autoscale, min_num_client = 6.

```
cloud@cloud:~/FL_project/yaml$ kubectl top pod
W0216 23:26:39.079657 2385976 top_pod.go:140] Using json format to
 metrics. Next release will switch to protocol-buffers, switch ear
y passing --use-protocol-buffers flag
NAME                     CPU(cores)   MEMORY(bytes)
fashion-mnist-cloud-0    1m           406Mi
fashion-mnist-edge1-0    2005m        1183Mi
fashion-mnist-edge1-1    2030m        1139Mi
fashion-mnist-edge1-2    2088m        1123Mi
fashion-mnist-edge2-0    2011m        1100Mi
fashion-mnist-edge2-1    2032m        1087Mi
fashion-mnist-edge2-2    2053m        1114Mi
```

```
cloud@cloud:~/FL_project/yaml$ kubectl top node
W0216 23:27:25.059295 2386929 top_node.go:119] Using json format to ge
t metrics. Next release will switch to protocol-buffers, switch early
by passing --use-protocol-buffers flag
NAME    CPU(cores)   CPU%   MEMORY(bytes)   MEMORY%
cloud   1950m        24%    4161Mi          53%
edge1   6111m        76%    5274Mi          67%
edge2   6270m        78%    5179Mi          66%
```

Install VPA:



Change nodeName: cloud