A Cloud-Based Traffic Flow Framework for Tactile Internet using SDN and Fog Computing

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***Abstract*— Tactile Internet (TI) is an emerging area of research which is still in its infancy, and facing many issues and challenges. One of the main challenges in TI is to achieve a round trip time (RTT) or latency of 1ms or less. This RTT consists of transmission time, processing time (operator's end), and acknowledgement time (controlled environment end). In this paper, we first present a system framework of the multilevel structure of cloud units incorporating Software-Defined Networking (SDN) and Fog Computing (FC) for TI. We then propose an efficient traffic flow framework that can avoid unnecessary processing and waiting times at each cloud units. The SDN and FC approaches are used to control the traffic flow in the system. As FC-empowered edge nodes, fog nodes (FNs) are placed close to the end-user devices, consequently, the communication paths are reduced and minimised RTT is achieved. The system performance is evaluated by iFogSim simulation. Results demonstrate the superiority of the proposed traffic flow framework than edge, cloud, and cellular networks. The findings reported in this paper provide some insights into Tactile Internet that can help network researchers and engineers to contribute further towards developing the next-generation Internet.**

Keywords—Tactile Internet, Fog Computing, SDN, 1ms challenge, end-to-end delay.

I. Introduction

Tactile Internet (TI) is relatively a new concept where human beings communicate with each other, thus allows us to transmit the sense of touch and actuation over a long distance in real-time.

The TI is an innovation which facilitates the interaction between human beings (possibly over a distance) with visual presence [1]. A unique challenge for accomplishing this communication feature is to minimise the latency in the round trip of the signal to 1ms (end-to-end). Once these difficulties are fulfilled, numerous applications can be achieved. By using the concept of TI, it can be applied in the areas of ICT, defence, medical industry, education, etc. It could play a crucial role in eradicating the socio-economic boundaries of society [1].

To have an option to guarantee a transparent experience, the most challenging factor is to achieve a round trip delay of 1ms [2]. The motion sickness (delay) that occurs while performing any activity in one place, and the other person perceives it in another place is called lag [3]. For haptic communication, various examinations demonstrate that lag will be observable if it is higher than 1ms [4]. If this lag is perceptible, it contrarily influences transparency.

Fig. 1. The evolution of tactile internet from cellular mobile internet

One of the principle factors that affect the lag is a round trip delay for haptic communication happening in the network. The elements that add to the end-to-end delay are queuing, processing, encoding, transmission and its delays. The speed of light restricts a standout amongst the most constraining elements for end-to-end delays. For example, if a packet takes more than 10ms to propagate through the media. To overcome the challenge of 1ms, the propagation delay should be 1ms or less and is suitable for short-range communications. The Fig. 1 shows the evolution of Tactile Internet.

The end-user device and server station should place close to each other to get rid of the challenge of 1ms. So that the workload or request information can be executed immediately and acknowledgement can be sent as feedback. Therefore to avoid any delay, the control servers ought to be profoundly dependable and ought to handle all the request information.

Subsequently, the round trip time (RTT) relies on the number of nodes (sensor and actuators) present in the network to have a flow of traffic in the TI. To meet the challenge of 1ms, the number of nodes present in the network ought to be diminished and place them close to the end-user device or in the vicinity of the end-user device. This challenge can be achieved by employing Software-Defined Networking (SDN), Mobile Edge Computing (MEC) and Fog Computing (FC) by enabling Network Function Virtualisation (NFV) with 5G communication framework. Due to technological advancements such as SDN, MEC and FC, these can facilitate useful answers that help to meet the challenge of 1ms.

Coming to the origin of FC, it was first proposed by Flavio Bonomi, vice president of network device manufacturing organisation called Cisco in 2011 [5]. The FC is a higher virtualised platform where the network contains an enormous number of heterogeneous, pervasive and decentralised devices. They connect and correspond to other devices to provide computation, storage and to process requests/task. Besides, they facilitate networking services between devices and conventional cloud service stations, but not precisely at the edge of the networks without the interference of the third parties.

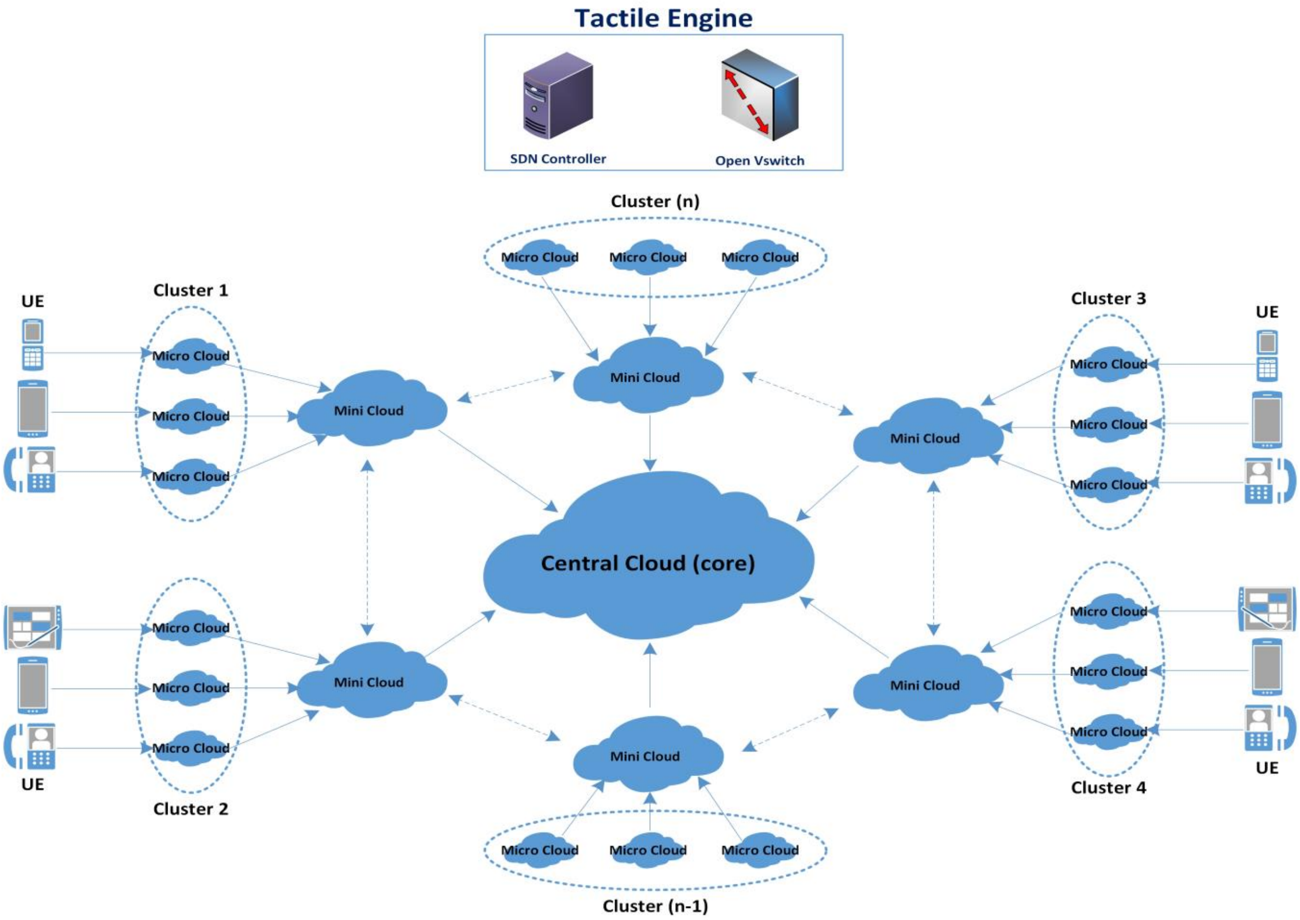

Fig. 2. The proposed framework for multilevel structure of cloud units

The capabilities of cloud computing and services are extended to FC, where routers, gateways and switches, can also be a part of the network having all properties of FC. It is fundamentally utilised for automating types of equipment since FC has a background of Internet of Things (IoT).

The FC has decentralised computing structure dependent on fog computing nodes (FCNs) and can be fixed at several locations of the architecture between the end-user device and the cloud. The FCNs that utilise devices such as machine-to-machine (M2M) gateways and wireless router, these FCNs are utilised to execute and save the information from end-user devices before sending to the cloud.

The main contributions of this paper are as follows.

- We present a framework of the multilevel structure of cloud units incorporating SDN, and FC approaches for Tactile Internet (TI).
- We propose an efficient traffic flow framework of tasks/workloads to avoid unnecessary processing and waiting times at each level of cloud units.
- We validate the system framework using iFogSim, a Java-based simulation toolkit.

The paper is organised as follows. Section II provides a review of literature on TI and related areas. The system overview is presented in Section III. The results and simulation scenario validation are discussed in Section IV. A brief conclusion in Section V ends the paper.

II. Related Work

Christian Grasso et al. [6] have proposed an architecture for UAV-based video surveillance with Tactile Internet constraints. The Markov chain model is developed, and the drone-based solution is investigated.

There are various methodologies that talk about utilising SDN at the central network of the cellular framework. In [7], the author mentioned about the issues and transport difficulties in understanding the 5G structure, and proposed a framework for the central network dependent on SDN and utilise the edge computing. In [8], development of the need for coding the system is incorporated with SDN to minimise the end-to-end latency in 5G framework. A software router within the network is encrypted and acts as a virtual network function. Here they are mostly worried about the coding and SDN, but they have not taken MEC into account. This framework is predominantly presented for 5G as well as Internet of things [9].

A 5G based SDN infrastructure is presented in [10] with massive deployment of small cells. Hence by having an idea of small cells incurs the difficulties of continuous handover and the delay occurred during the handover process. Here the authors facilitate a framework to defeat these difficulties by incorporating SDN controller at the central system. The controller allocates the radio access resources and satisfies the difficulties that are related to the incorporation of different radio access advancements. The

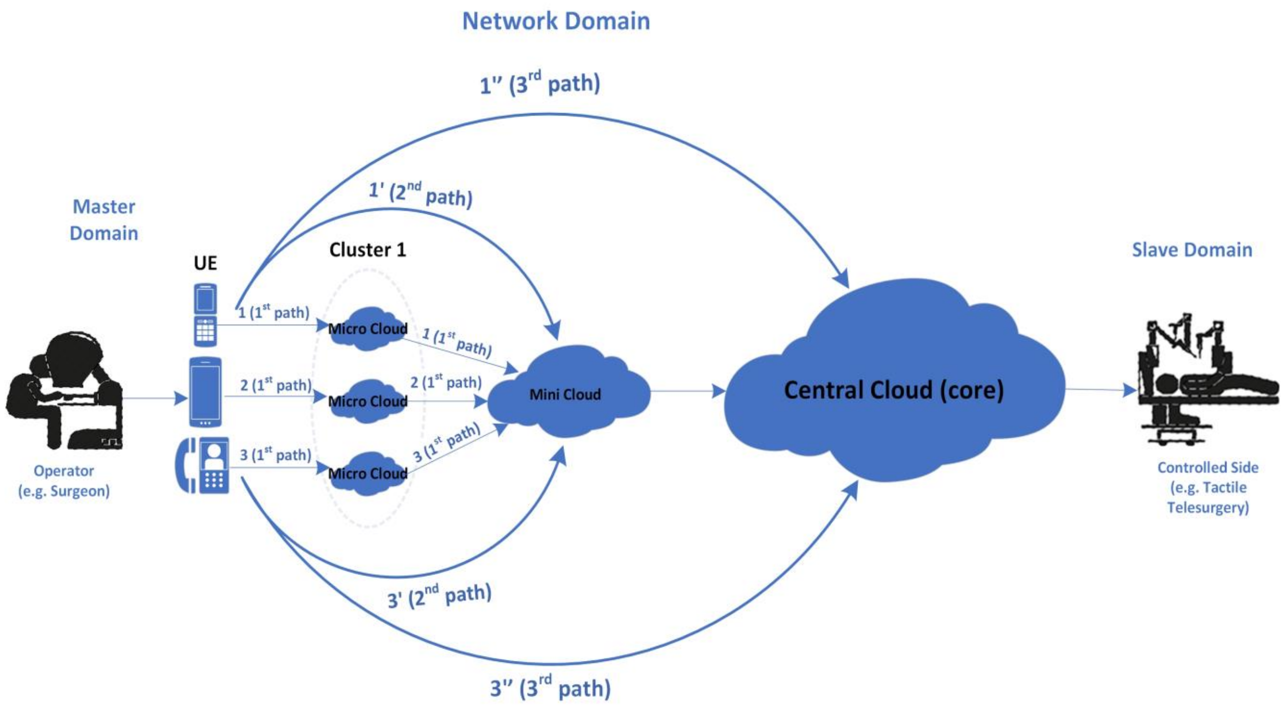

Fig. 3. The proposed paths adopted by the traffic (workload or request) in cloud multilevel structure

framework is fundamentally worried about the issue of delay occurred during the handover process. By the deployment of SDN controller, the framework is ready to anticipate that the end-user or a client is moving, and subsequently can deal with the handover process in less time; by characterising three sorts of program interfaces.

Previous work utilises a controller at the central network for specific working or properties. These properties empower the framework by increasing the system efficiency as far as bit rate and end-to-end latency are concerned. Since the fundamental thing of TI framework is to meet 1ms round trip time, i.e. ultra-low latency, the cognitive control ought to be conveyed at the central network to accomplish desired end-to-end latency.

As far as the architectural aspects of FC are concerned, Bonomi et al. [5] exhibited one of the primary tasks on FC surveying the appropriateness of FC for the IoT. It mentions about the necessities of developing the application as far as user real-time communication, awareness of the location and requirement for geo-distributed end nodes, and FC attends these problems. The authors give more knowledge into the appropriateness of FC for IoT applications with a couple of utilisation cases, including smart wind farm and intelligent traffic light system in the accompanying paper [11]. On the contrary, the authors in [12] facilitate an outline of the fog framework and exact meaning of the fog nodes, and their workings and capacities.

The work in [13] has utilised the services of the fog layer to execute and find the optimal parking spot, where the aggregated data was gathered from different fog devices, thus having the concept of the distributed idea of fog devices. In [14], the authors have presented FC architecture with the consumer-centric approach with application case situation of connected vehicles.

In [15], the authors have featured the benefits of FC over conventional cloud computing. The authors in [16] have worked on the programming model for mobile FC to provide services to many IoT applications. The investigation has been carried out on the resource allocation within the FC at the fundamental level. Krishnan et al. [17] have implemented an application based on FC by utilising Raspberry Pi. However, they did not focus on the FC architecture and implementation aspect. Misra et al. [18] proposed a sensor cloud model and virtualisation methods for cloud manufacturing systems.

III. System Overview

Tactile Internet (TI) requires the competencies of having high reliability, high availability and ultra-low latency. To work system as tactile, the end-to-end delay should be of 1ms or less. This delay consists of processing delay and communication delay. As a result, the action and the response time should happen within 1ms than human reaction time [19].

To overcome the limitations of cloud computing (CC) such as lack of proper allocation of network bandwidth, pushing huge data chunk to the cloud resulting in high latency, and all-time dependency on internet connection, FC approach can be used as it facilitates a decentralised architecture and provides services as an extension to CC. This is achieved by incorporating one or more fog node devices, thus giving more options to offer services.

The FC-enabled edge nodes (cloud units) are structured to utilise edge node resources, solve the restrictions over cloud computing and optimise the usage of network bandwidth.

The cloud units are deployed close to the end devices based on the concept of FC. We develop a framework of the multilevel structure of cloud units for TI, as shown in Fig. 2. This multilevel structure of cloud units adopts the idea of decentralised distributed cloud units. The first level incorporates micro clouds with limited processing capabilities and storage. This first level includes three micro cloud units as one cluster, where every cluster will receive workload coming from the cellular base station

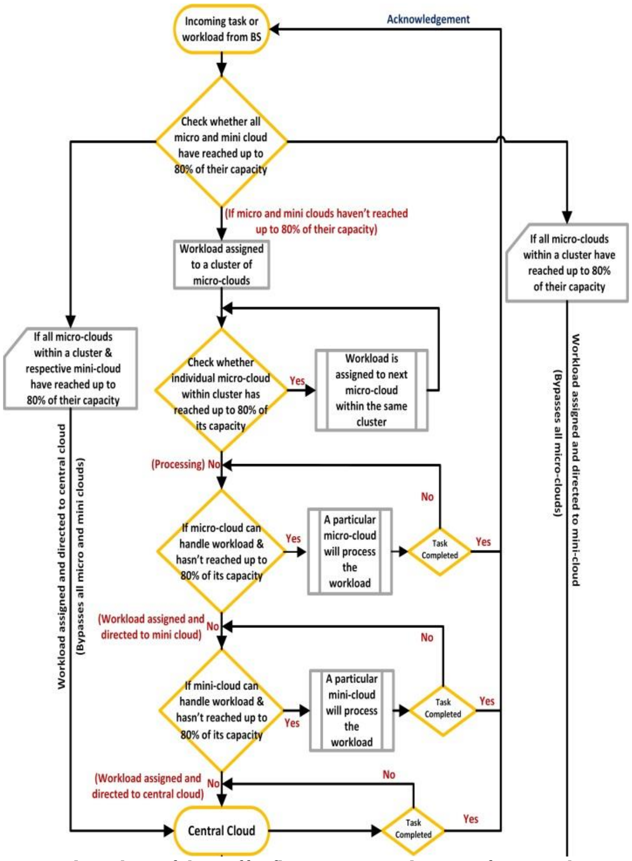

Fig. 4. Flow chart of the traffic flow in proposed system framework

(BS). The second level incorporates mini clouds units which are connected to every cluster of micro cloud units. These cloud units have more processing capabilities and storage than micro cloud units. Finally, the mini cloud units are connected to the central cloud, which have even more processing and storage capabilities than mini cloud units. This central cloud controls and monitors all mini cloud units, which is deployed far-away from end devices. Subsequently, the traffic flow of the workload or request is controlled by the SDN controller and switches.

By incorporating multilevel cloud structure in the TI system using FC, this system provides the following benefits. The network congestion is reduced due to the efficient management of traffic flow in which the client/server is a single hop away. Consequently, reduced end-to-end delay is achieved. Better services can be delivered by getting system parameters through BSs. It facilitates offloading data from the BS of the end-users efficiently.

In the proposed framework, we make efficient use of cloud space and cluster in the network. The objective is to minimise end-to-end delays and data saving and to provide efficient traffic flow within the cloud structure to avoid unnecessary processing and waiting times. The efficiency is achieved by utilising SDN approach. The proposed flow of traffic is depicted in Fig. 4.

Each cloud unit on each level is threshold with cloud capacity value (e.g. 80%), and the SDN controller will keep the track for the cloud capacity and data per second coming to the particular cloud for each request or task.

Table 1. Simulation parameters

No. of micro-cloud units	9
No. of mini-cloud units	3
No. of central cloud unit	1
No. of users	18
No. of VMs (micro, mini and central)	5
Bandwidth of micro-cloud units	1000Mbps
Bandwidth of mini-cloud units	2000Mbps
Bandwidth of central-cloud unit	4000Mbps
Micro-cloud RAM, Storage	512Mb, 1Gb
Mini-cloud RAM, Storage	2048Mb, 2Gb
Central-cloud RAM, Storage	4096Mb, 4Gb
Simulation time	60 secs

If a particular cloud unit is utilising 80% of its capacity, the following operation takes place (Fig. 3):

- The incoming task will bypass the existing cloud and will direct to another cloud of the same cluster of micro cloud units. In this framework, we have three micro cloud units within a cluster. If the second unit of micro cloud within the cluster is also occupied with 80% of the capacity, then it bypasses the existing cloud and directed to the third micro cloud unit.
- If all the micro cloud units within the same cluster are full with 80% of the cloud capacity, the incoming task bypasses the complete cluster of micro cloud units and is passed on to mini cloud unit which is connected to its respective cluster of micro clouds.
- Subsequently, if the respective mini cloud unit is crossing the threshold value of the cloud capacity (i.e. 80%), the incoming task will bypass both clusters of micro cloud unit and mini clouds. Now the incoming tasks will be directed to the central cloud that is the core cloud for processing of the workload.

The main purpose of bypassing and directing the cloud units is to minimise end-to-end delays and to achieve energy efficiency.

A. *How is end-to-end delay minimised?*

- When the incoming task is assigned to a particular cloud unit, it will incur some processing time. If the existing cloud is bypassed and the workload is directed to the next level of cloud unit (e.g. mini cloud from the micro cloud), the processing time and data will be saved at an existing cloud.
- If the incoming task is directly assigned to the central cloud (core), the processing time will be saved at the micro cloud and mini cloud units level. Subsequently, the end-to-end delays will be minimised.

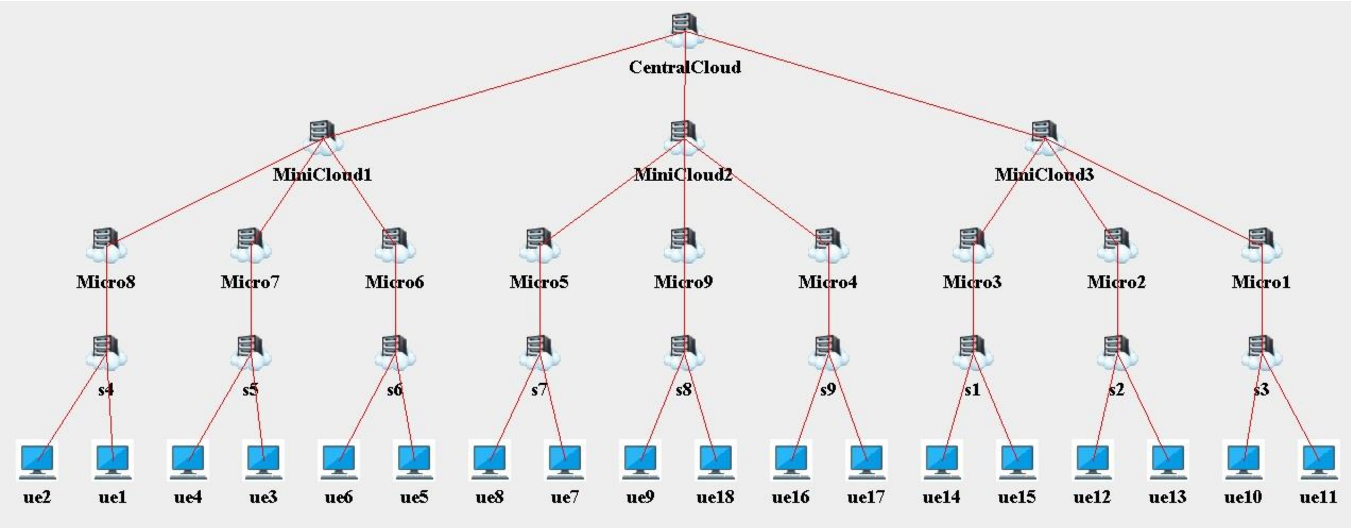

Fig. 5. Network scenario for multilevel cloud units

IV. Simulation Results and Validation

The proposed framework is evaluated by iFogSim simulator, a Java-based simulation toolkit used as an extension of CloudSim framework. We have selected this iFogSim because it is a credible simulation tool.

All simulation results reported the steady-state behaviour of the network and were obtained with a relative statistical error ≤5%, at the 95% confidence level. Each simulation run lasted for 60 minutes of simulated time, where the first minute was the transient period. The observations collected during the transient period are not included in the final simulation results. We measure throughput and end-to-end delay.

A. Simulation Scenario

We develop a simulation model for the proposed framework comprising of 18 end-user devices, 9 open Vswitches, 9 micro clouds, 3 mini clouds, and 1 central cloud (Fig. 5). All user-end devices are connected to the micro cloud via switches and thus forming micro cloud clusters. Subsequently, all the user-end devices are connected to the mini cloud and finally, connect to the central cloud. Fig. 5 shows the simulated network topology. Here, fog nodes should be placed close to end-user devices, but not necessarily far from each other. These fog nodes are geo-distributed nodes spread across some geographical region. These nodes are placed such that the distance between them is more than 150km in a specific geographical region.

We compare the performance of the proposed traffic framework/network with edge network, cloud network, and cellular network. We observe that the proposed framework is efficient than the edge, cloud, and cellular networks. Table 1 lists the simulation parameters used in the system simulation.

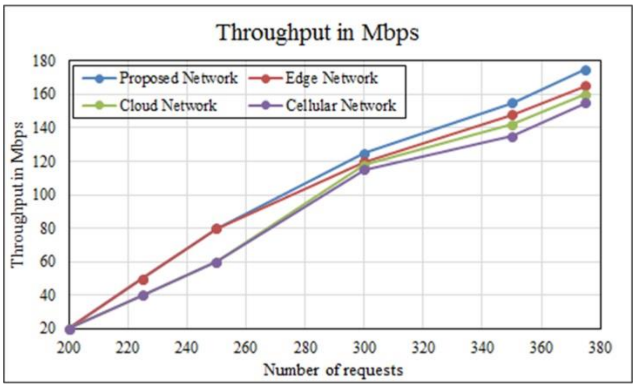

Fig. 6. Throughput vs Number of requests

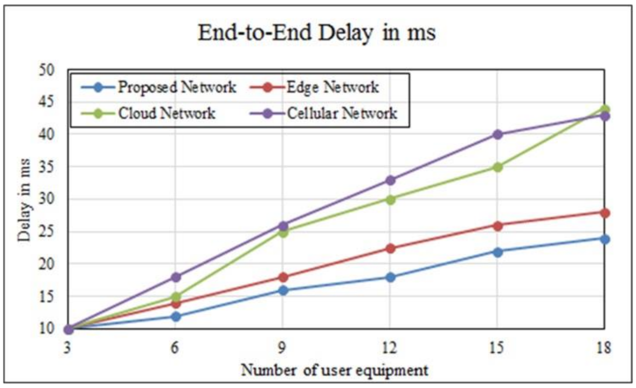

Fig. 7. End-to-end delay vs Number of user equipment

Fig. 6 shows the effect of increasing the number of requests on throughput performance. We observe that the throughput of the proposed network is 20% higher than the edge network, cloud network, and cellular networks.

In Fig. 7, we plot the number of user equipment against end-to-end delays. One can observe that the proposed network offers 20% lower end-to-end delays than the edge, cloud, and cellular networks. From Figs. 6 and 7, the main conclusion is that the proposed traffic framework with Fog Computing provides optimised results than the edge, cloud, and cellular networks.

B. Simulation results validation

Although iFogSim is one of the credible simulation tools, it may produce invalid results if the simulation parameters are incorrectly configured. First, we checked simulation log files to ensure that there were no errors and the simulation scenarios run smoothly. Second, we compared our results with similar work in the literature to ensure that we are on the right track [13, 14].

V. Conclusion

In this paper, we presented a framework of multilevel structure cloud units incorporating SDN and Fog Computing approaches for Tactile Internet. To meet the end-to-end delay requirements (≤ 1ms) at each cloud units, we proposed an efficient traffic flow in proposed system framework. Our preliminary results obtained have shown that the proposed network/framework offers up to 20% lower delays and also up to 20% higher throughput than the edge, cloud, and cellular networks. This is encouraging findings which provide an insight into the field of Tactile Internet contributing to 5G and beyond. Developing a robust analytical model for the proposed traffic flow simulation framework is suggested as future research.

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