# Intelligent core network for Tactile Internet system

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## ABSTRACT

Tactile Internet requires a round trip latency of 1ms, which considered being the main challenge with the system realization. Forced by recent development and capabilities of the fifth generation (5G) cellular system, the Tactile Internet will become a real. One way to overcome the 1ms latency is to employ a centralized controller in the core of the network with a global knowledge of the system together with, the concept of network function virtualization (NFV). This is the idea behind the software defined networking (SDN). This paper introduces a Tactile Internet system structure which employs SDN in the core of the cellular network and mobile edge computing (MEC) in multi-levels. The system is simulated over a reliable environment and introduces a round trip latency of orders of 1 ms.This can be interpreted by the reduction of intermediate nodes involved in the communication process.



## CCS Concepts

**• Network components → Wireless access points, base stations and infrastructure.**

## Keywords

Tactile Internet; 5G; latency; NFV; SDN; MEC.

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## 1 INTRODUCTION

Tactile Internet is expected to be a novel approach in the human-to-machine (H2M) communication by moving from the content delivery to the skill-set delivery. It will be a revolution in the area of information and communication technology with enormous applications in many fields [1]. Powered by the 5G cellular network, Tactile Internet will provide a way for the human to transfer their tough and actuation in real time form.

Designing Tactile Internet system and realizing it meets some challenges that are presented in [2]. The main challenge is the 1 ms round trip (end-to-end) latency. The round trip latency differ from the user plane latency and can be defined as the time duration starts from the transmission of a small data packet from the transmitter 's application layer and ends by the reception of the data by the receiver's application layer, including the response feedback dedicated by the communication process [3]. Thus the round trip latency depends on the number of network nodes involved in the communication process. In order to reduce the round trip latency and achieve the 1ms latency requirement for the Tactile Internet system, the number of network nodes involved in the communication process should be reduced and bring them as near as possible to the user equipment. This is can be achieved by employing SDN, NFV and MEC with the 5G cellular system.

SDN, NFV and MEC technologies provide a powerful solutions for the challenges associated with the design of 5G cellular system and Tactile Internet system, specially the 1ms latency. Thus the academia and the industry pay a great attention to the research and development in these areas. In today's cellular networks, the network services are handled by means of various network functions that are connected in static manner [4]. Thus, it isn't easy to add new services, this is because the cost, energy and integration difficulties of hardware required. To overcome these problems NFV and SDN are developed.

NFV provides the fixed network functions by means of software run on a virtualized environment which increases the flexibility of the overall system. NFV employs virtualization technologies on programmable hardware such as storage devices, general purpose servers and switches to separate the software implementation of network functions from the dedicated hardware. In another word, NFV set up the network functions by means of software virtualization techniques on commodity hardware [5]. Several projects are launched, for developing open source, commercial solutions and standardizations for NFV. The most important projects are the Service Programming and Orchestration for Virtualized Software Networks (SONATA) project and Management and Orchestration (MANO) project. SONATA is constructed with a vision of increasing the programmability and flexibility of 5G cellular system. It aims to make the service platforms easier and modular to be suitable for the requirements of the different service providers. Also it stands with the network function orchestration and provides a development model for the developers [6]. MANO is an open source project developed by European Telecommunications Standards Institute (ETSI) [7].

Software Defined Networking (SDN) is a new approach that provides a dynamic and cost effective network structure by the physical separation of data forwarding plane and control plane. The control plane is the network part that gives the appropriate decision to handle traffic [8]. The data plane is the other part of the network which forward traffic in respond to the control plane. The control signals moves from the control plane to the data plane by means of an open standard interface protocol such as OpenFlow protocol and ForCES protocol [9]. SDN allows the network operator to configure, control and mange the network through customized software known as application programming interfaces (APIs). SDN is mainly presented to simplify the network hardware and increase the network flexibility [10].

Dawn of the software networks is supported by the recent development in NFV and SDN technologies. NFV and SDN technologies are not reliant on each other but they complete each other [11]. Both technologies arise the advantage of employing in expensive programmable hardware. The early generations of SDN technology were corresponded with data centers, campus networks and private networks. By the time, SDN find its way to the core of cellular networks. On the other hand, NFV aims to replace the Middleboxes used in cellular networks from hardware appliance to software running on commodity hardware (i.e., less expensive general server hardware).

Employing SDN and NFV provides a way for performing the recent important concept of network slicing. The network slice may be viewed as a group of network functions worked together with a specific radio access technology (RAT) to achieve a certain use case of the network [12]. In another word, a network slice is a way of supporting communication service by means of a special connection. Network slicing allows network operator to set up multiple logical networks (each for a certain use case) on the same physical infrastructure [13].

One way to improve the cellular network efficiency is to offload network operations to cloud units employed at the edge of the cellular system. This is the idea behind the recent paradigm launched by the cellular network operators and known as MEC. MEC is the way of carrying cloud computing capabilities to the edge of the cellular network one hop away from the user equipment. European Telecommunications Standards Institute (ETSI) is one of the leading organizations in the research of MEC and the standardization of this technology. The latest progress in MEC platforms and their cellular uses are summed in [14]. The main benefit of employing MEC in cellular networks is the reduction of end to end system latency. Moreover, it provides a higher system bandwidth and reduces the network congestion by providing away for offloading data.

In this paper, we introduce a network structure for the Tactile Internet system employs SDN at the core of the network and enable NFV. The system uses MEC in multilevel hierarchical. In (Sec. 2) the related works to the proposed system is discussed. In (Sec. 3) the system structure is proposed. In (Sec. 4) the system is simulated over a reliable environment. Finally, (Sec.5) gives the conclusion.

## 2 RELATED WORKS

In [15], the authors present a SoftCell cellular system which enables the system operator to achieve service policies at high levels. The proposed system reduces the forwarding table's size and aggregates traffic in multiple dimensions at various switches in the network. The system employs an access switches at the base stations which are software switches. Access switches can classify packets arrived at the base station and handle the required state and bandwidth. SoftCell employs the components of the traditional Evolved Packet Core cellular network with a controller at the core network with certain functions. The controller installs the switch rules and implements the signaling rules used between hosts. The system is suggested for deployment to the core of LTE existing networks. The system improves the flexibility and scalability of the LTE cellular system. The main problem with the system is the capability of the core network controller and it is still mainly depends on the gateways (SGW, PGW) at the core network.

Recently, there are a number several approaches speak about employing SDN at the core network of cellular system. These are the most relates works. In [16], the problems and transport challenges to realize the 5G system. The authors suggested a structure for the core network based on SDN and employ the edge computing. In [17], a network coding is developed and employed with SDN to reduce Latency in 5G cellular system. The network coding is achieved through a software router that acts as a virtual network function. The main problem with the system is that they did not consider the MEC however they mainly concerned with the coding and SDN. The system is mainly introduced for 5G and the Internet of Things [28].

In [18], an optimized framework for a virtual network is introduced to reduce end-to-end delay in LTE-A cellular networks. A central controller is employed in the core network and used mainly for slicing the physical resources. The authors employ Virtual Network Embedding (VNE) algorithm to map the virtualized networks on substrate network. The system mainly concerned with the path optimization and network virtualization. The system achieves better latency performance and increase the user mobility. MEC is not involved in the structure and the system may be seen as a modification for the LTE-A cellular system.

In [19], a 5G based SDN architecture is introduced, with the dense deployment of small cells. Employing small cell concept raises the challenge of frequent handover and the latency dedicated with the handover process. The system introduces a system structure to overcome these challenges by using SDN controller at the core network. The system employs MEC and mainly concerned with the problem of latency of handover process.

## 3 PROPOSED WORK

Our Tactile Internet system may be generally viewed as a three layer system based on the proposed 5G system structure suggested by NGMN [3]. As illustrated in fig.1, the three layer system is based on the MEC, SDN and NFV. The whole structure is based on the 5G cellular system which decouples the hardware and software, and provides an APIs to facilitate the control and management of the system. The first layer is the physical hardware resource layer, which includes the cellular network infrastructure (5G/Tactile user devices, fiber cables, cloud units and networking nodes). User devices may be a master robot or a 5G smart phone which have enough capabilities to be configured in the network [20]. Cloud units are employed in levels, the first level includes Micro-clouds with small storage and processing capabilities connected to each cellular base station (eNB) [2]. The second level employs more efficient cloud units with higher processing and storage capabilities known as Mini-clouds. The final level of cloud units is main cloud unit with powerful storage and processing capabilities centered at the core network.

The second layer is the software deployment layer which maintains libraries for all functions needed in the network. These libraries are software functions and modules that can be used in the desired location in the network. Also, the radio access parameters and other configuration parameters of the network are located in this layer. The final layer is the application layer, which defines the services and applications required by system operators.

The three layers of the system are connected through the system management and orchestration interface. This interface is responsible for managing the operation of the first two layers based on the business application in the higher layer. The management and control tasks of the interface are performed through APIs. The management and orchestration interface is connected to the first layer through APIs to perform, the system configuration and monitoring of status and performance. Also the software and parameters of the second layer can be fetched at any time by the managing interface through APIs. The link between the application layer and the management and orchestration interface allows the interface to perform network slicing for each application or map it to an existing slice [3]. In

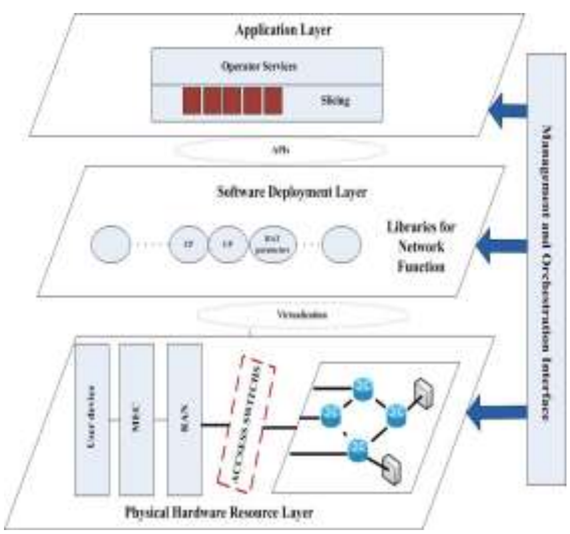



**Figure 1: System structure viewed as a three layer system.**

order to perform these critical and various tasks, the management and orchestration interface employs SDN/NFV technologies.

SDN technology is one way used to overcome the problem of one millisecond round trip delay concerned with the Tactile Internet system and the future 5G cellular system. Moreover, SDN provides efficient solutions for achieving network flexibility and efficiency. The core network of cellular network will be based on SDN technology [28]. SDN works based on the separation of the data plane and the control plane. The two plans are linked through OpenFlow interface protocol.

Figure 2 illustrates the end-to-end structure of our proposed Tactile Internet system. The end-to-end system structure consists of user device, RAN (eNB), cloud units, access switches, OpenFlow switches, Middleboxes and finally, SDN controller. Each base station (eNB) is connected to the network through an access switch which powerfully performs packet classification on traffic from user devices. The access switches is software switches such as Open vSwitch [21]. The whole network is connected through OpenFlow switches which manage data packets and forward traffic based on their flow tables. Middleboxes are commodity hardware that represents a way for the network operators to add extra functionalities such as firewall and network address translation. The major requirements of the functions and services introduced by these Middleboxes are the efficient use of resources and the system protection from attacks. All these elements represent the data plane of the network.

The last part of the system is the central controller (SDNC), which represents the control plane of the network. By means of programming and control logic, SDNC can execute functions and operations in the control plane. SDNC maintains the global information of the edge and core network devices include; OpenFlow switches, access switches, Middleboxes, RAN and cloud units. SDNC manages and controls the edge and core network devices mentioned through the OpenFlow protocol.

OpenFlow protocol is the signaling standard used for the communication between SDNC and OpenFlow switches. In other word, the instructions from SDNC to other network devices are transferred through the OpenFlow protocol [22]. OpenFlow switches build their forwarding tables and build the packet processing rules based on the instructions delivered from the SDNC. SDNC improve system performance in many terms such as system latency and user's mobility. One important aspect to reduce the round trip latency is to reduce the number of intermediate nodes involved in the communication process and this is introduced by employing SDNC. Moreover SDNC can foresee the user's mobility as it can access to all features of the user device (including; device type, location, billing information, etc), which improves the critical radio access processes such as handover. In other word, employing SDNC reduces the round trip latency, achieves handover process easily and also reduces the handover latency.

On way to illustrate the benefits of our system is to compare it with the latest traditional Evolved Packet Core cellular network [23]. In the traditional Evolved Packet Core networks, all data traffic flow through the Evolved Packet Core network including the Packet data Gateway (PGW) and the Serving Gateway (SGW). This represents a load on these gateways and leads to an increase in round trip latency. Unlike the traditional systems, our proposed system employs SDN, which removes this barrier and

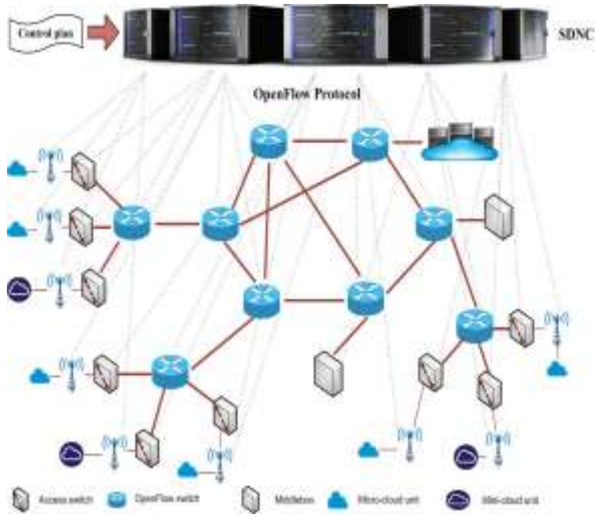
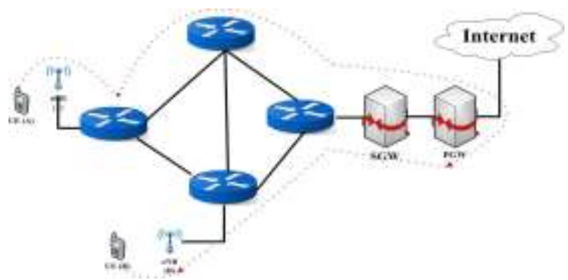
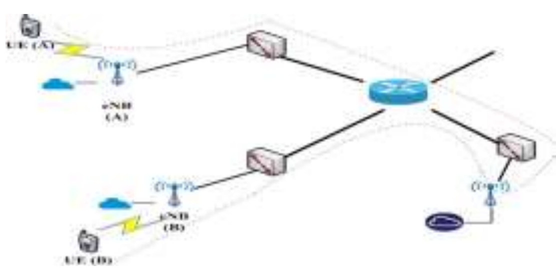


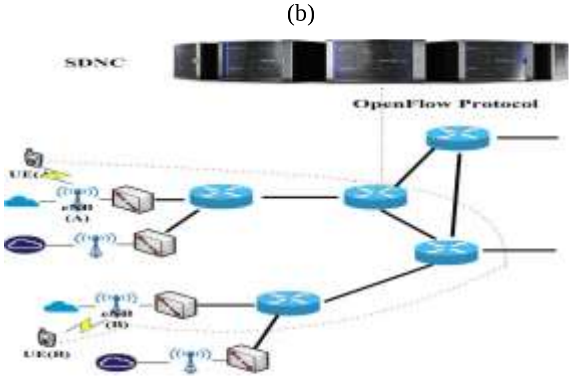

**Figure 2: End-to-end system structure.**




(a)




(b)




(c)

**Figure 3: (a) Evolved Packet Core cellular network (b) First case of proposed system. (c) Second case of proposed system.**

reduces the round trip latency by reducing the number of intermediate nodes involved in the communication process.

Figure 3 illustrates this comparison between two systems. While, in fig.3-b the two eNBs belong to the same Mini-cloud unit but in fig.3-c the two eNBs belong to different Mini-cloud units. Another important aspect is that the SDN structure allows and facilitates adding or changing network functions which isn't offered by the traditional systems. Moreover, network slicing can be done through the SDNC which will be the main feature of the Tactile Internet and 5G systems.

Summing up, the advantage of the proposed structure can be summarized in the following points:

1- The system is more flexible, as routing can be established easily through SDNC,

2- The system is reliable as it relay on the open flow protocol and other standardized technologies,

3- The network function virtualization can be easily implemented powered by the use of SDNC,

4- The requirements for achieving a certain quality of service (QoS) of the system can be supported by SDN. As the system can define and implement new rules through SDN switches and Middleboxes and

5- The system provides higher scalability than traditional packet core networks. This is because the SDNC takes into account the control process only and not involved in data flow.

## 4 SIMULATION AND RESULTS

In this section, the proposed structure for the Tactile Internet system is simulated in a reliable environment and the results are discussed.

### 4.1 Simulation environment and experiment set up

There are a number of efficient simulation environments and frameworks used to simulate and evaluate the performance and attributes of SDN and MEC based networks. One of the most efficient, reliable and powerful frameworks is the CloudSim environment and its related extension projects. CloudSim is a Java based simulation framework that enables simulation, experimentation and modeling for cloud based networks [24]. CloudSimSDN is a Java based simulation framework built on top of CloudSim. This framework is developed mainly for simulation purposes of SDN and cloud based systems.

In CloudSimSDN, the SDNC is programmable and it allows the testing of VM management policies and workload scheduling algorithms. Furthermore, the centralized controller is responsible for dynamically managing resources in data centers. Based on [25], the authors prove that CloudSimSDN simulator provides much features and facilities with better or at least the same performance as Mininet simulation environment. Also, it gives the ability for the modifications and extensions.

We consider two simulation cases with the topology illustrated in fig. 3-b and 3-c. In the first case, the two hosts belongs two different base stations (eNBs) but the two eNBs are connected to the same Mini-cloud. In the second case, the two hosts are in different cells and the cells are connected to different Mini-cloud units. The round trip delay is considered to be the performance of our system. The simulation process is repeated multi-times, with different bandwidth for each time but with the data size is the same in each case. All important simulation parameters used are illustrated in table1.

**Table 1: Simulation parameters**

| Simulation parameter | value |
|---|---|
| OpenFlow Switch processing delay | 5 µs |
| SDN Controller processing delay | 0.5 µs |
| Arrival rate of the Micro-cloud unit λi | 15 |
| The communication latency inside the cellular cell | 100 µs |
| Bandwidth | Variable |
| Micro-cloud RAM, Storage<br>Mini-cloud RAM, Storage | 1024Mb,1Gb<br>2048 Mb, 5Gb |

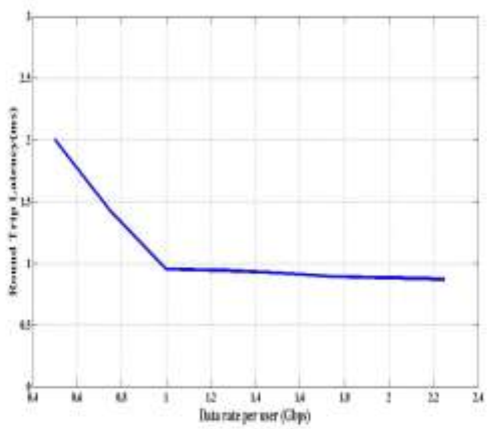



**Figure 4: Simulation results for the first case.**

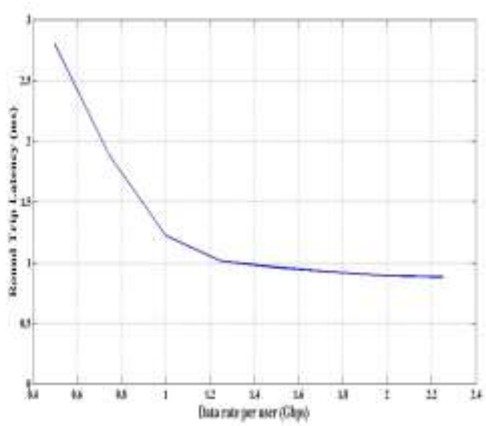



**Figure 5: Simulation results for the second case.**

## 4.2 Simulation results and analyses

Figures 4 and 5 illustrate the results for the first and the second simulation cases. From the simulations results, the round trip delay is decreased with the increase of the system bandwidth. For the second case; the round trip delay is higher than that of the first case, this is because the core network controller is not involved in the communication process as the Mini-cloud unit manages and performs the communication process. Based on [26],[3] the user bit rate for the future 5G cellular system will range from 1Gbps to 10 Gbps. For the least expected bit rate (1Gbps) the proposed tactile system affords a round trip delay of 0.95 ms for the first simulation case and 1.22 ms for the second case. Moreover, as the bit rate is raised above 1Gbps the round trip delay gets below the previous values which make the proposed structure get ride off the challenge of 1ms round trip latency.

# 5 CONCLUSIONS

SDN, NFV and MEC technologies are solutions to overcome the challenges associated with the realization of Tactile Internet system, specially the 1ms round trip latency. Employing SDN at the core network of cellular system reduces the latency and efficiently improves the system performance. This is because SDNC can efficiently manage and establish an efficient and flexible routing path between any two end points. Thus it can reduce the number of intermediate nodes involved in communication process. The proposed structure for the Tactile Internet system which employs SDN at the core of the network and multi-level cloud units poses a round trip latency of orders of ms. Thus, this structure is helpful and effective for building the Tactile Internet system.

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