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Framework for slicing 6G networks for efficient multi-tenancy

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ABSTRACT

6G Networks are going to be the reality in near future and are going to be used in all walks of life for multiple purposes. The network slicing facilitates optimum usage of the network resources cost-effectively by the service providers and major consumers. In this paper, prevailing slicing methodologies were analyzed and a better and efficient Artificial Intelligence based Network slicing framework is presented, for use in the upcoming 6G communication network technologies.

Keywords— *Artificial Intelligence, 6G Communications framework, Network Function Virtualization, Software defined network, Slicing*

1. INTRODUCTION

It is estimated that there are going to be 1.1 billion network connections approximately, in the world, by 2025 [1],[2]. The upcoming 6th Generation communication technologies would be adapting device centric architecture rather than base centric architecture to ensure reliable, low latency communication. The emergence of millimeter wave spectrum (mm wave) has come into picture in 5G for small cell backhaul and massive Multiple Input and Multiple Output (MIMO) for higher scalability [3].

The 5G and 6G networks also focus on device-to-device connectivity thus ensuring smart usage of devices [4]. Speed is the main difference between 4G and 5G networks. 5G networks are IoT compliant. The International Telecommunication Union has broadly outlined few use cases of 5G, which are Enhanced mobile broadband, Ultra reliable and low latency communication, Massive machine type communications and Fixed wireless access [5],[6]. On the other hand, 6G networking technologies are going to be very different from the previous ones.

2. BACKGROUND

The 6th Genesis research project was launched in Finland, which has drawn the attention of researchers and developers in the area of networking all over the world to take up R&D projects on 6G Networks. 6G networks are envisaged to provide networking services not only on ground like 5G, but under sea, in the air and space too. 6G networks are aimed at improving user experience with intelligence coupled with security and privacy apart from the speed to overcome the drawbacks of the earlier networks [7].

The technologies driving the 6G networks are Artificial intelligence, Molecular communications, Quantum communications, Tera Hertz (THz) technology and Visible light communication (VLC). 6G networks have to be IoE, Internet of Everything compliant. IoE involves incorporation of connectivity and intelligence to every device to enhance the functionality of the devices [8].

The 6G networks aims to support one micro-second latency in communications. As there is tremendous growth in the number of networked devices, in parallel, the persistent and robust connectivity requirements to the reliable higher bandwidth communication infrastructure are also increasing. This brings about a change in the network design, to accommodate larger networks. These requirements can be fulfilled by Software defined network s(SDNs), cloud computing, Network Function Visualization (NFV) in the 6G networks like in 5G networks [9].

2.1 Network Function Virtualization

Network function virtualization has transformed the way networking is done and how they are operated and managed. NFVs make use of information technology to virtualize network nodes such as routers, switches, firewalls on software virtual machines. The main advantages of NFVs are better network administration, cost reduction and programmability in the telecommunication systems. [10],[11].

2.2 Software Defined Networks

The Software defined networking facilitates network segregation into the data plane and control plane in terms of design, implementation and management in order to enable flexibility and controllability of the network, thereby ensuring seamless performance for the user. The data plane comprises of the network traffic, the data to be routed, whereas the control plane decides the routing traffic, network topology, etc., Apart from network virtualization and cloud computing, SDNs have a centralized operation-based intelligence which overlooks all the network management policies. Traffic management, reducing the complexity of network topology, optimal path selection for faster data transfer and communication, low cost and QoS are the key aspects in SDN [12].

2.3 Network Virtualization

The network virtualization is a framework of logical computational resources and network resources used to share the available physical networking infrastructure for multiple purposes, simultaneously. A specific instance of virtualization for a specific purpose is called network slicing [13].

2.4 Network Slicing

The Network Slicing technology enables creation of multiple sub-networks [13]. The advent of smart agriculture, smart healthcare, smart transportation, smart cities, Industry 4.0 technologies, require seamless, high-bandwidth connectivity with low latency. Network Slicing is a virtualization technology, where a single network connection is divided into multiple distinct autonomous connections. Each of the virtual connection caters to a specific user segment. Each segment comprises of a unique set of resources and network topology which differentiates one segment from the other broadly on speed, connectivity and capacity.

As discussed after the Slicing, each sliced network functions as independent network for all the practical purposes. Different network slices can share and use the common physical and logical infrastructure owned by different owners transparently. Thus, network slicing facilitates optimum usage of the available network in infrastructure. Network slicing also facilitates provisioning of networking services transparently for diverse uses in the world [14]. Generation Partnership Project (3GPP) has identified network slicing as one of the key technologies to achieve several new objectives in future networks [15] So, the Network Functions Virtualization and Software Defined Networks are essential technologies used for slicing the network [16].

2.5 The advantages of the network slicing

The main objective of network slicing is partitioning the available physical network into multiple virtual networks each designed for the optimal performance of a specified application/service. Keeping this objective in mind, I have proposed a framework which facilitates the slicing based on easily measurable metrics besides AI.

3. RELATED WORK

In the recent research literature, it has been reported that network slicing is one of the main techniques to be used in 5G and the upcoming 6G networks to serve a wide variety of devices with Quality of Service (QoS) in a seamless manner without human interference. The deliverables offered by 6G networks are more diverse so require more complex and variety of physical devices, better QoS performance and spontaneity. End to End network slicing stretching from user equipment/ devices to data centers is necessary to provide flexibility to the network [17].

3.1 Network Slicing Architectures

Several network slicing architectures have been proposed in the current literature. Network slicing consists of three layers: 1. Resource layer 2. Network slice instance layer 3. Service instance layer. The resource layer comprises of network resources and functions which are physical and virtual/logical. The network slice instance layer consists of slices which are required for the service instances. These slices may or may not run on the same network resources and functions. The service instance layer, the upper layer consists of service instances that are consuming the slices and are offered to customers. The slice management consists of a slice manager which monitors and regulates the life cycle of the slices and also interacts with the network functions and resources [17]. The other aspect which has been put forward is the packet core slicing and RAN slicing. Dynamic slicing takes place based on the service requirements and correspondingly MANO (Management and Network Orchestration) of the slices takes place for efficient slicing control [17],[18].

Costanzo et al., proposed a SDN based network slicing solution for sharing RAN (Radio access network) resources among eMBB (Enhanced mobile broad band) and IoT devices. They proposed a dynamic allocation algorithm with the help of SDN controller. This slicing algorithm makes use of 2 slices each for IoT traffic and eMBB traffic, and allocates the slice for enhanced mobile broad band services before the IoT traffic reaches its peak level. In their proposed network slicing framework, a SDN Slicing Controller exists in the control plane in order to allocate slices available in the radio spectrum and a Slicing Scheduler exists in the data plane to schedule the slicing controller operations. The slicing scheduler allocates slices based on the resource bases available to be used, duration of the slice and the target QoS [19].

In order to fully realize the vision of network slicing based multi-service software controlled 5G mobile network architecture, there are certain challenges which need to be considered. Few of the challenges include RAN virtualization, End to End slice management and Service composition [20].

Resource allocation and spectral allocation for RAN networks is essential in network slicing keeping in mind the user requirements. This results in overcoming the underutilization of the network resources. A resource allocation algorithm has been proposed to divide slices among enhanced mobile broadband (eMBB) and ultra-reliable low latency communication (URLLC) thereby improving the spectral efficiency [21].

Some researches presume that the peak loads of various segments do not coincide. This is a serious drawback at the stage of design itself. Because, the peak loads may sometimes coincide, in such a situation, if there is a drop in the QoS then it may result in huge losses. There exist various parameters such as low latency, high throughput, high reliability, high flexibility, high security and intelligent edge computing which need to be incorporated in 6G networks for smooth performance of the heterogeneous services. There by providing each service with an end-to-end communication path consisting of a logical network implementation using programmable network functions.

I have expanded the above services and categorized them based on Bandwidth, Mobility and Latency requirements. This segregation of applications makes it easier for network slicing to take place.

4. PROPOSED SLICING FRAMEWORK

As discussed, the network slicing framework proposed in the current research papers have not clearly mentioned pragmatic frameworks. Most of the frameworks are user or customer segment specific, such as Precision Agriculture, Digital Manufacturing, Smart Health Care Services, Smart City Applications etc., or theoretical architecture models were presented. The 6G networks apart from increasing the bandwidth are also going to be intelligent. So, the framework proposed should facilitate segmentation of the forthcoming 6G networks. To create the framework, the key network parameters required for various applications have been collected and tabulated as indicated in the table.1 [22],[23],[24],[25].

Table 1: Key network metrics

Application	Latency	Bandwidth	Mobility
Autonomous Vehicle	1 ms	10 Mbps	Mobile
UAVs	1 ms	10 Mbps	Mobile
Augumented Reality	1ms	150 Mbps	Mobile
Virtual Reality	1ms	800 Mbps	Fixed
Smart manufacturing	5 ms	1 Mbps	Fixed
Disaster management	10 ms	< 1 Mbps	Not Fixed
Multi-party video conference	50 ms	100 Mbps	Mobile
Mobile Broadband	20 ms	120-150 Mbps	Not Fixed
Monitoring sensor networks	100 ms	< 1 Mbps	Fixed
Device Remote Control	100 ms	1 Mbps	Fixed
Health monitoring system	1000 ms	< 1 Mbps	Fixed
Precision agriculture	1000 ms	< 1 Mbps	Fixed

It is clear that, there is an overlap of network parameters and associated physical resources in the case of certain use cases. So, if we create application segment specific use cases, then isolation of segments becomes difficult. Because, certain aspects of two different use cases may use same portion of the network spectrum and the physical resources. Even if two similar segments are created by appropriately allocating the physical resources, then it may not result in optimum utilization of available network resources. To overcome these problems, a standard measurable metrics driven AI based network slicing framework has been proposed.

4.1 Three Layered Architecture

The proposed architecture consists of three distinctly identifiable layers as depicted in figure 1. The first layer is the Physical Layer. It deals exclusively with the physical infrastructure. The physical infrastructure may consist of networking devices, antennas associated peripherals, accessories, energy systems.

4.1.1 Physical Layer: For efficient management, the Physical Layer is further sub-divided into three segments -1. Material Devices Segment 2. Medium Segment 3. MIMO Segment.

(a) The Material Devices Segment consists of end or edge devices, the Antennas and other physical devices used in the network. It also contains the details of the edge computing intelligent and last-mile devices used by the end-users for various services of the 6G networks.

(b) The Medium Segment, deals with communication medium. In case of wireless communication, it defines the frequency zone of the allocated and permitted spectrum bandwidths. In case of Quantum Computing and the light-based networking devices it contains the specifications and attributes of visible light zone.

(c) The MIMO segment deals with Massive Multiple Inputs and Multiple Outputs to ensure required bandwidth, etc., As the cell sizes are small in 6G networks Massive MIMO operations are going to be increasingly used in the 6G networks to ensure speed and to facilitate usage of available field infrastructure.

4.1.2 Artificial Intelligent Layer: The second layer or the middle layer is the Artificial Intelligent layer. This AI layer closely interacts with the other two layers i.e., first layer and third layer. The third layer which is Metrics Layer provides the inputs to the AI layer which act as target network slice parameters to ensure desired user experience. Based on these targets, AI layer computes and determines the optimum physical resources required and their best possible configurations to facilitate creation and management of the end-to-end network slices.

4.1.3 Metrics Layer: The third layer is the Metrics Layer. Its main function is to provide the performance metrics and the requirement schedules (i.e., required time of service) to the AI layer for creation of the required network slices. After analysis of various uses cases of the 6G networks, the metrics layer is carefully divided into Five (5) segments. These five segments are 1. Location, 2. Latency, 3. Speed, 4. User Density, 5. User Mobility.

Location Segment specifies the type of location where the 6G services are to be provided. i.e., Space, Air, Ground or Under Water. The underlying technologies differ for each of these location types in the 6G networks, so the location type is an important input to create the network segment.

4.2 Network Slicing Architecture

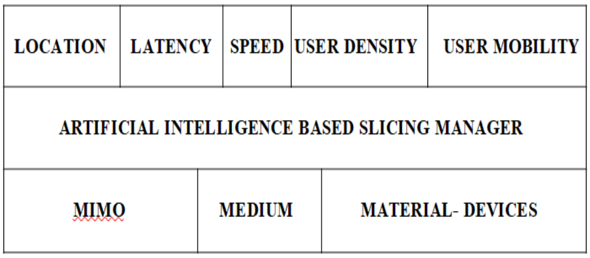

Fig. 1. Generic Network slicing architecture consisting of three layers. Layer one comprises of physical resources, spectrum, etc., layer two manages them taking into consideration the metrics of slices which are mentioned in the third layer.

(a) The Latency Segment keeps track of the latency requirements for various uses cases and provides the latency requirements to the AI layer. The network physical resources requirements various greatly based on the latency required, so this is another key segment of the Metrics layer.

(b) The User Density Segment keeps track of the number of users per square kilo-meter besides their usage type, at any given point of time in the network cell and provides this input to the AI layer. If the number of users per square kilo meter, increases suddenly then the number of antennas and MIMO operations, cell size have to be changed correspondingly.

(c) The User Mobility Segment function is to register, store and monitor the physical motion of the end user devices. The end user devices can be stationery like a Television Set, or Fixed Surveillance Camera or Refrigerator or Semi-Stationery, i.e., they can be at one location for some time and move to another location after some time like a Laptop, or Bio-medical Sensor, or Soil Moisture Sensor, or Environment Sensing Device etc., On the other hand the end device consuming 6G network services may be mobile like a mobile phone in the hand of a person walking in the street or park, or highly mobile like remote sensing devices in a moving auto-mobile, or a mobile phone inside a moving high speed vehicle, or a UAV, or a mobile phone in an aircraft, or a communication device in a space craft or a moving sub-marine vehicle. The mobility status of end user device determines the networking physical and logical network resources greatly. So, the speed of end user device is another key parameter for the AI layer.

4.3 Advantages of the Proposed Framework

The three-layered framework proposed is metrics based, so deterministic hence easily programmable. The solution proposed involves all the devices, equipment and elements in the network so it facilitates end to end slicing of the network resources to cater to the needs of all types of use cases. The AI layer takes into consideration the services requirement timings besides the key metrics to dynamically create the network slices. The AI layer can be configured to take into consideration the previous best practices and knowledge base to avoid unforeseen problems during dynamic slicing. Optimum usage of precious network resources is a big challenge. Slicing should not result in underutilization of resources or resources crunch. The proposed framework facilitates optimum utilization of available resources.

4.4 Network Slice Denotion As Set

In 6G networks there are a greater number of devices connected to the network as compared to 4G (LTE) Long Term Evolution. Thus, complexity of assigning slices increases at every stage of the end to end communication path. AI algorithms are used at every stage to allocate the slices dynamically based on the bandwidth, latency and traffic requirements. To facilitate this, I propose description of a slice as a set, whose elements represent various network slicing parameters. These parameters may include, the medium i.e., identity number and length of the fibre, dark fibre, coloured fibre, spectrum frequency, bandwidth, latency, the identity number of antennas, active and passive network devices, their performance, turning parameters, security parameters, the commercial parameters, exception handling parameters etc., of the devices involved in the entire network supply chain and value chain. i.e., the network devices involved in the entire end-to-end seamless network

connectivity from one device/ customer to the other device/ customer desired QoS.

In the 6G networks the number and variety of devices are much higher than those of earlier networks. So the number of elements representing a 6G slice shall also be much higher.

Hence, a 6G network Slice A with certain components can easily be represented as

Set A = <a1, a2, a3, a4, …,ap>.

Where p is the number of elements in the set A representing the 6G slice A. The size of set A is p.

Similarly, another 6G slice B with certain elements can be represented as

Set B = <b1, b2, b3, b4, …,bq>.

Let C is another 6G Slice with certain elements and let C be represented as

Set C = <c1, c2, c3, c4, …,cr>.

So if all the elements of set C are common to A and B then C becomes common sub-set of A and B as shown in the figure 2. Sometimes various network assets may be owned and locally managed by different users.

Optimum resources usage involves creation of a slice involving the network physical assets irrespective of their ownership.

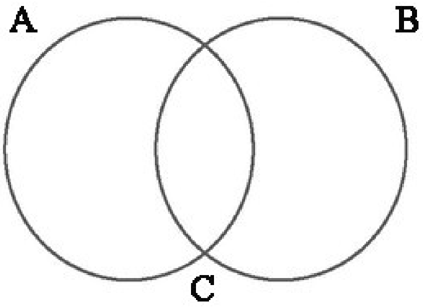

Fig. 2. Set A represents network slice A, Set B represents network slice B, then intersection set C is sub-slice of A and B, with common elements of set A and B.

So, the 6G network slice C becomes the sub-slice of network slice A as well as B.

For efficient and effective management of network devices which are identical, the common programs (program is a set of similar operations, projects) are preferable for creation, conservation, management and maintenance operations. As the desirable outcome metrics are same, the associated physical attributes and physical resources shall be same. So Slicing problem can be mainly viewed as creation of unique isolated sub-networks with certain distinctive elements from the given set of networks and ensuring their pro-active management based on historical data.

4.5 Sub-Slices and Sub-Sets

Fortunately, sub-slice C can be created easily with following typical algorithm.

The maximum number of elements in A are p. The maximum number of elements in B are q.

Sub-Slice C of common elements of A and B initially be null.

Compare p and q. If p > q then

Let Le[2][q] is the matrix to store result of two consecutive rows at a time.

```
Let CRow is the current row of the matrix. For i= 0 to p
For j=0 t q
Repeat following steps
{
if (i == 0 || j == 0) { Le[CRow][j] = 0;
}
else if (A[i - 1] == B[j - 1])
{
Le[CRow][j] = Le[1 - CRow][j - 1] + 1;
if (Le[CRow][j] > r) {
r = Le[CRow][j]; end = i - 1;

1.   For i=1to p
}
 (or if p < q then For i = 1 to q)
 else {
Le[CRow][j] = 0;
2.   Compare each element of A with each element of B
}
if A[i] == B[i]
```

If both elements are same, then update that as an element in the set C.

```
C[i] = A[i]

i=i+1

End of For loop
```

If r number of common elements if occurred, then maximum elements in C shall be r.
In this way the Set C = <c1, c2, c3, c4, …,cr> can be easily created with simple algebraic functions.

4.6 Slice is String of Network Element Attributes

Some extra efforts are required to represent the network parameters as set of elements, but they can easily be described as set of strings of text containing the various network elements and their attributes.

So, if a network Slice is described in terms of String A and network slice B is represented as string B, then optimization of the slicing resources of network involves determination of the longest common sub-string of the A and B.

Let C be the common sub-string of string A, string B. Let p is the length of A and q is the length of B.
Then C can be determined in following way. Let r is length of longest common substring C.
Let ‘Ae’is the ending point of longest common substring in A.
Make current row as previous row and previous row as new current row.

```
CRow = 1 - CRow;
}
```

If there is no common substring, print -1.

```
}
```

Longest common substring is from index, Ae -r + 1 to index end in A.

```
return A.substr(Ae -r + 1, r);
}
```

However, if a particular device is down, or if overloaded, then entire traffic has to be routed through alternative device(s). Such conditions can be incorporated heuristically in the algorithm such as the following.

In a path of network presume device di = Dn. If di functional status 0 implies if it is down,
i.e., if f(di) = 0 then use Device Dm i.e. di = Dm. Such practical knowledge has to be embedded in the 6G slicing algorithms to ensure successful slicing operations. Which is only possible with knowledge based expert systems driven slicing operations. Several text management AI systems are available readily at present.

5. CHALLENGES AND FUTURE WORK

The material segment consists of Antennas, Active and Passive Network components, Edge computing devices, sensors etc., To ensure high speeds, designing appropriate 3-Dimensional Antennas is a challenge in 6G networks. As 5G networks are just upcoming, lot of historical data is not available immediately, to feed the AI algorithms.

6. DISCUSSION AND CONCLUSION

An easily measurable metrics-based network slicing framework has been proposed. The framework takes into consideration the precious physical resources available right from the end device to the network / control and data centers intelligently. The frame work can be easily used to build intelligent 6G networks.

The AI component can be built based on diverse use cases, and knowledge associated with the best practices. So, the complicated slicing problem has been converted into problems of sets and strings to reduce the complexity and to use readily available AI tools. After simplification, the available or existing SDN systems can be used to create the slices. So, the outcome of the AI driven framework can be fed to the existing legacy SDN and NFV systems to builds the best network slices to serve the end users by optimally utilizing all the available resources. So the proposed framework though is based on disruptive AI technology, it do not disrupt the existing legacy systems, instead it provides the much required vital intelligent inputs to ensure the best performance of the existing legacy slicing systems.

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