Bandwidth Consideration for Cellular System Upgrade in Developing Countries

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ABSTRACT

This work looks into employing simulation-based approach to consider bandwidth aspects when designing/upgrading current/future cellular systems in developing countries. Bandwidth is an important resource that needs to be used optimally and plays a significant role in determining the maximum number users a system can accommodate. Bandwidth directly impacts both the capacity that can be supported and limiting end to end delay within acceptable ranges. This paper presents a scheme to maximize the use of bandwidth considering both capacity and delay aspects and helps to identify major parameters that influence system design.

KEYWORDS

Cellular systems, Bandwidth, End to end delay

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1 INTRODUCTION

5G networks provide higher quality of services and improve performance compared to previous cellular technologies. These considerations have raised the expectations on the possibility to support advanced networks and provide unprecedented levels of flexibility and adaptability that are necessary to support diverse set of services and applications [1] [2]. 5G technology has been marketed as an "all-in-one" communications solution for a variety of application scenarios that have strict requirements for the dependable real-time transmission of data packets and reliable low-latency communication such as Industrial automation, Internet of Things (IoT), E-Health, and self-driving vehicles [3]. Research works on this new generation of technology and beyond have been quite active in the past years. Thus, a number of EU-funded initiatives have made an effort to develop cutting-edge scenarios for determining the needs of 5G. Similar to this, other efforts like NGMN and standardization bodies like 3GPP and ITU-R have worked to identify fundamental requirements to guide ongoing research into how to fulfil future demands, and would enable significant economic and social values. This effort resulted in a number of scenarios that focusing on diverse requirements [4] [5] as follow:

- Extreme Mobile Broadband (xMBB).
- Massive Machine Type Communications (mMTC).
- Ultra-reliable Machine-Type Communications (uMTC).

This characterization was done based on the performance attributes of requirement with respect to usage, the eMBB relates to higher data rates and capacities while high reliable communication is needed for URLLC and mMTC as both are latency sensitive [6] [7].

Indoria [8], in their published study, listed the main challenges that developing countries could face with the implementation of 5G technologies. They particularly focused on their lack of infrastructure, which includes poor fiber construction, no proper mechanism to handle rapid increase in the number of users, low rates of data speed, high costs as well as political and security issues, thus hindering the development of the telecommunications sector. They also discussed the need for 5G and its applications given its advantages over 4G and the future prospects for its implementation. It is also important to look into the economic developments/costs associated with implementing 5G networks, for instance, Oughtona [9] in their published study indicated there will be a 90 percentage of data growth due to technology change from 4G to 5G. They also highlighted the techno-economic problem of deploying 5G. In this regard, they pointed to the large number of new components required to operate enhanced network infrastructure, including base station units and backhaul transmission, as well as the associated costs of site installation and operation, network optimization and maintenance. While Shin [10] focused on analyzing the 5G users and data traffic demand and how that demand would change based on several attributes including the content amount, additional monthly fees, and additional cost of devices. The study revealed a crucial foundation for mobile service providers' investment and marketing strategies that aim to maximize profits.

Maximizing the use of bandwidth is an important consideration for developing countries because of lack of existing infrastructure and the lack of ability to upgrade them to support future communication schemes to offer the benefits of 5G and beyond systems. It is

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Table 1: Communication Scenarios and Requirements

	End to end delay (DL) (ms)	Data rate (Mbps)
Broadband in the crowd	5	25
Wireless roadside	15	10
Medical monitoring	50	1

essential to provide the benefits to all so that developing countries do not lag behind other countries in this new digital age. This paper focus developing methods to maximize the use of bandwidth when designing or upgrading existing communication systems. A system level approach has been considered focusing on incorporating multiple nodes from Core to the user equipment (UEs). In general, the current communication infrastructure in most developing countries are set up using a Core – Layer 3 switches – base station equipment. This equipment is linked using communication links with specific characteristics to support the intended network performance.

Section II of this paper highlights the requirements and approaches taken to maximize the use of bandwidth and section III presents the system model employed to analyze performances and Section IV presents sample results and discussions. Finally, section V provides general conclusions from this work.

2 REQUIREMENTS AND APPROACH

5G and beyond communication systems specify high data rates and strict delay requirements to support various applications such as Industrial automation, Internet of Things (IoT), E-Health, and self-driving vehicles. For example, Broadband access in crowd: This scenario is typical for a stadium, it is considered as a challenging core scenario for operators to provide their services and build their brand and reputation by providing a reliable high capacity and low latency service [7]. Wireless roadside infrastructure backhauls: Several techniques have been put in place to handle traffic congestion and vehicular communications. These include self-driving cars, real-time location monitoring, road safety schemes, intelligent traffic lights, smart logistics, and trains [11]. Medical monitoring: High-bandwidth 5G enables sharing of 3D 4K pathological images of patients, and the low latency enabled services can support real-time multi-screen interaction where doctors can discuss and annotate in real time and output medical solutions in a timely manner. [12] [13]. The following table highlights these scenarios and requirements:

The above challenging requirements will need major backhaul and front haul upgrades and maximizing the use of bandwidth is essential in keeping system costs low. A general network scenario that is commonly employed in developing countries is shown Figure 1 [14]. This network scenario is based on core network, Backhaul Layer 3 switches connected to each other in a ring layout, gNBs connected to Layer 3 switches, and different number of UEs distributed randomly in each cell.

Different entities in this network scenario require communication links to connect them and it is essential to determine the requirements for these links. One simple way to decide the bandwidth requirements of these links is to consider the aggregated individual requirements of the expected maximum number of users to support the required capacity. However, this approach will result in wasting bandwidth resources as expected maximum number of users are not always present. Furthermore, link bandwidths also play an important part in end to end delays. A system approach considering Core to user analyzing number of user access and delay performances are required. A fractional bandwidth parameter can be utilized to analyze various random scenarios to maximize the bandwidth usage. The fractional bandwidth factor is defined as:

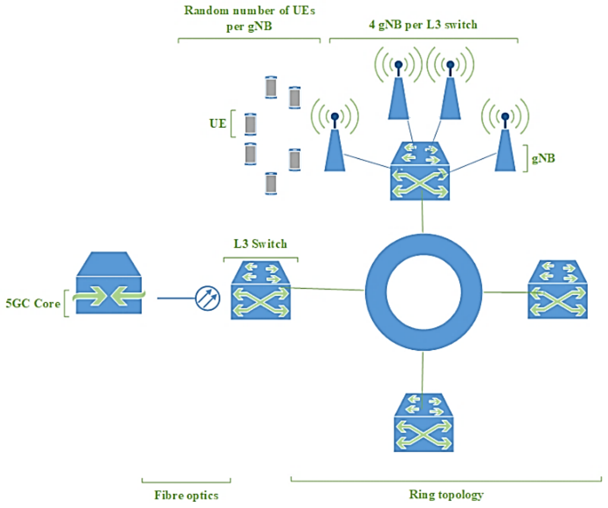

Figure 1: General network layout

$$Fractional\ Bandwidth\ Factor = \frac{Actual\ Link\ Bandwidth}{Aggregated\ max.\ number\ of\ user\ bandwidth} \quad (1)$$

It is required to establish appropriate bandwidth factors for the communication links to maximize the bandwidth factor.

3 MODELLING AND SIMULATIONS

A system model was formed based on Figure 1 with random number of users in each cell within an expected maximum number of users. For example, if the expected maximum number of users are 50 in a cell, the actual number of users in a cell can be a random integer between a minimum number and 50 users. A fixed number of Cells were connected directly to the Layer 3 switches and the Layer 3 switches were connected in a ring configuration. The ring of Layer 3 switches was connected to the core network. Each communication link between the entities in this configuration is characterized by a link capacity. A simulation model was formed based on data rate requirements of individual users and the model was employed to compute user access statistics and delay statistics based on available bandwidths in the links. The assumed actual link bandwidths were computed based on equation 1) for the communication links between Core and Layer 3 switches, Layer 3 switch interconnects and Layer 3 switch and gNB. Simulations were repeated for a fixed number of times and the results were averaged to have confidence in the results.

3.1 User access statistics based on available bandwidth

Data rate requirements of individual users served by a link are aggregated to find required capacity. Based on required aggregated capacity and the actual link capacity, the number of unserved users were calculated. The percentage of unserved users in the network was computed for different fractional bandwidth factors and different expected maximum number of users in a cell. This analysis will aid the decisions on appropriate link bandwidths based on the number of expected maximum users in a cell.

3.2 Delay statistics based on available bandwidth

The down link delay for providing service to a user, Core to UEs, were adopted based on the model described in [13]. This delay is expressed as the sum of the delay experienced by all the network's entities, the transport network delay ($T_{TRANSPORT}$), core delay (T_{CORE}), Layer 3 switch delay (T_{L3_SWITCH}), gNB delay (T_{gNB}), and end user delay (T_{UE}) as:

$$Total\ end\ to\ end\ delay\ \ (DL) = T_{TRANSPORT} + T_{CORE} + T_{L3\_Switch} + T_{gNB} + T_{UE} \tag{2}$$

The transport network (DL) delay in this work is considered as the sum of backhaul network delay and fronthaul delay. The transport network delay consists of queuing delay time (T_Q) of the packets in each network node, the transmission time (T_t) over the backhaul network from core toward the gNB and then to each user, and the propagation time delay (T_G) that takes a packet to travel through the links that interconnect the network's elements. The propagation time delay (T_G) depends on the total distance (D) that packets travel through the transport network, and the propagation speed V in the transport medium such as free space, fibre etc. The transport network delay is given by:

$$T_{TRANSPORT} = T_{TRANSIT} + T_G \tag{3}$$

$$T_{TRANSIT} = T_Q + T_t \tag{4}$$

In this work, to estimate the transit time delay, each entity in the network was modeled as an M/M/1 queue. The packet arrival was assumed a Poisson process with an average arrival rate, λ and an average service rate, μ. Using λ and μ the average transit delay when the packets pass through n network elements toward the end user is expressed as [15]:

$$T_{TRANSIT} = \sum_{i=1}^{n} \frac{1}{\mu_i - \lambda_i} \tag{5}$$

Where the λi and μi are the traffic arrival and service rates in the downlink channel for the transport network elements i, i = 1. . ., n. An excessive transit time of 10 ms was assumed when (μi -λi) < 0 to identify undesirable instances. Using the properties of the Poisson processes, the average arrival rate of the traffic that the element ***i*** has to dispatch through each of the m links for downlink is given by [15]:

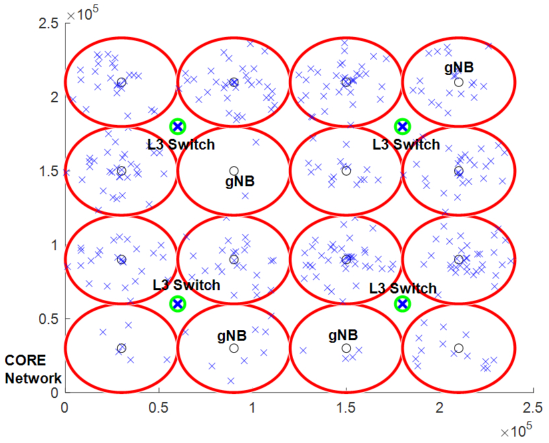

Figure 2: User distribution in the network with 16 cells

$$\lambda_i = N_i \times \left(\frac{B}{Packet\ Size} \right) \tag{6}$$

Where Ni is the number of users served by the element i in the network, B is the experienced data rate in bps, and Packet size is the message size that arrived for each 5G service or application in bits. All the packets arrival to network element i have to be dispatched to its destination through m links, the service rate of a transport network element i and the next element i+1 in downlink is computed as [15]:

$$\mu_i = \frac{Service\ fraction\ alpha\ \times C_i}{Packet\ size} \tag{7}$$

The Service fraction alpha is the fraction of the link capacity that allocated in a specific downlink and considered 1 for all the links in this work, Ci is the link capacity that connects the ith transport network's element in bps, and Packet size is the message size for each service or application in bits.

Eq. 6) and (7) are both used to calculate the transit time delay using Eq. 5), or the transmission and queuing time delay in the transport network. The propagation delay is calculated as:

$$T_G = \frac{D}{S} \tag{8}$$

Where D is the distance that the traffic traveled from sender to receiver in the network links, and S is the speed of signals in a link that the traffic will pass through.

The core delay (TCORE), Layer 3 switch delay (TL3_SWITCH), gNB delay (TgNB) and end user delay (TUE) are represented by the processing time delay (Tp): the time it takes for a packet to be received and correctly assigned it to an ongoing link. The following values were assumed in this work.

4 RESULTS AND DISCUSSIONS

MATLAB based simulations were carried out based on the parameters in Table 3. Fiber links were assumed in the backhaul with one-way communication in the ring for simplicity.

Random distribution of users in a specific run is shown in Figure 2. These are distributed with an expected maximum of number of

Table 2: Processing delays for different elements

Node	Core	L3_Switch	gNB	UE
Processing delay (ms)	0.05	0.001	0.1	0.1

Table 3: Simulation parameters

Number of runs for averaging	1,000
User Bit rate	10 MBits/s
Packet size	800 Bits
Velocity factor for fiber	0.8
Number of cells (gNBs)	16
Number of cells per L3 Switch	4
Min. no of users per cell	0
L3 switch locations – Centered around served cells	

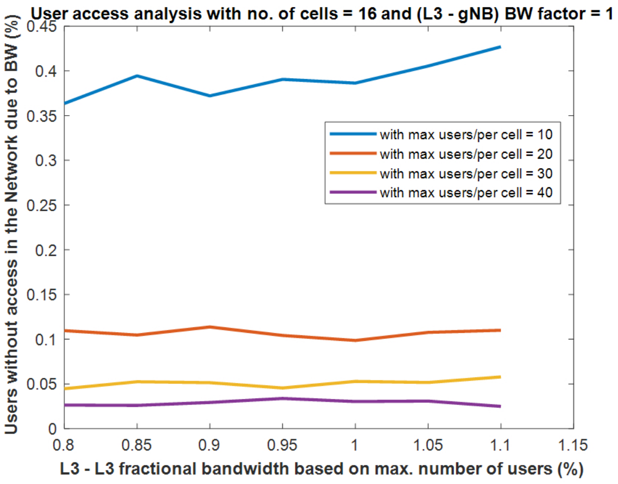

Figure 3: User access statistcs in the ntwork with warying fractional bandwidth between Layer 3 switches

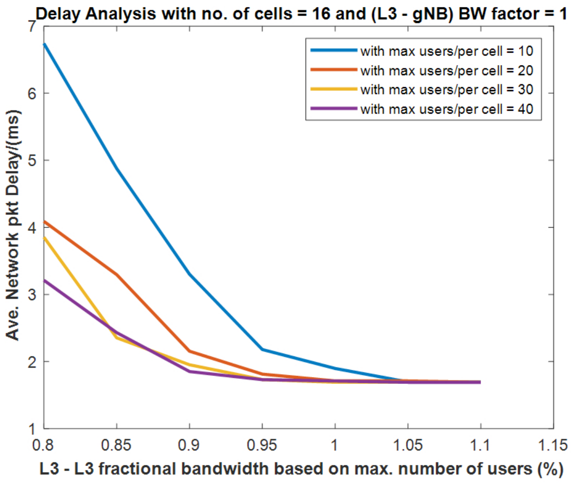

Figure 4: Computed average downlink delay between Core and the user with warying fractional bandwidth between Layer 3 switches

users of 40 in each cell. The same 40 maximum users were assumed for all cells in the network.

The fractional bandwidth factor between the Layer 3 switches were waried while keeping the fractional bandwidth between Layer 3 switches and the gNB at 1 and the Core – Layer 3 fractional bandwidth factor equal to the varied factor between Layer 3 switches. Figure 3 shows the average user access statistics based on available bandwidth and Figure 4 shows the computed average downlink delay between Core and the user. These statistics were initially avaraged by the number of users and then by the number of runs.

These results clearly show the importance of bandwidth with respect to user access and delay. Although lower fractional bandwidths can help to provide reasonably good user access, delay requirements might prevent using lower fractional bandwidths. For systems where delay is not an important requirement, system designs can focus on maximizing the use of bandwidths in these links. Dynamically varying the bandwidth allocation is also a possibility in these scenarios depending on the type of users in the system. Further analyses were also carried out to investigate transit delay and propagation delays and shown in Figure 5.

5 CONCLUSIONS

This paper looked into maximizing the bandwidth use in communication links associated with future cell-based communication systems. This methodology can be useful for developing countries where system upgrades present significant cost challenges. A MATLAB based model has been presented that can be used to maximize bandwidth use in communication links. Initial results from this work shows there are opportunities to maximize bandwidth allocations in cell-based communication systems.

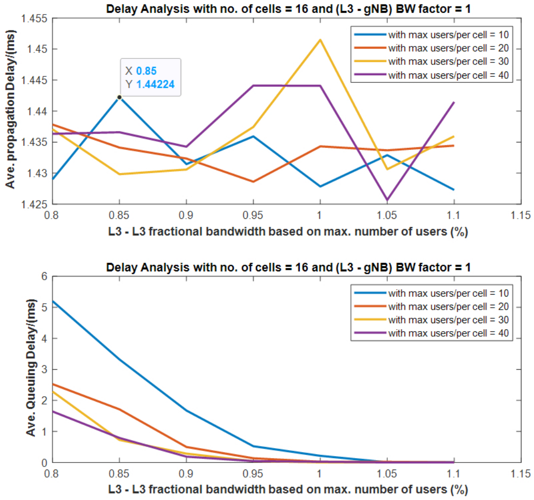

Figure 5: Computed average downlink transit and propagation delay between Core and the user with warying fractional bandwidth between Layer 3 switches

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