

Impact of scheduling algorithms on the performance of telemedicine traffic in cellular networks

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ABSTRACT

Efficient transmission of medical information is an emerging area of telecommunication engineering because it conveys critical data about a patient's state and vital measurements. Consequently, it is required that such transmissions be accelerated and errorless. This requirement is beyond the norm of only scheduling users at a Base Station but calls for the provisioning of guaranteed bandwidth for transmission of these critical medical data. To achieve this, there is a need to develop a scheduling scheme that will prioritize all forms of Telemedicine traffic over regular traffic at the Base Station. But there is also the need to measure, evaluate and quantify the impact of the developed scheduling scheme on telemedicine traffic transmission in cellular networks in terms of the throughputs attained. To address these problems, priority and non-priority based scheduling algorithms for telemedicine traffic transmission were developed and simulated using MATLAB 8.1.0 software and the impact of the developed algorithm on telemedicine traffic transmission was evaluated. The result represents a significant increase in telemedicine user's throughputs with a priority scheduling scheme. Over 20 rounds, the impact of packet sizes, traffic load conditions and codec rates on the average throughputs of telemedicine traffics were studied and discussed.

Keywords: Non-priority based, priority-based, scheduling algorithms, telemedicine traffic, throughputs.

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INTRODUCTION

One of the foremost causes of death in Nigeria is motor vehicle accidents. According to the Federal Road Safety Corps (FRSC), about 3,000 people died in road accidents between January and December 2011 in Nigeria and mortalities were recorded in 2,235 separate road accidents (Naijagists, 2015). According to Ugbeye (2010), the occurrence of deadly Road Traffic Accidents (RTA) peaks in developing countries and especially in sub-Saharan Africa. The yearly occurrence of trauma deaths in Nigeria alone was put at 1,320 per 100,000 people and remarkably, most of these deaths happened in the first hour of injury, mostly before the patient arrives at the hospital (Ugbeye, 2010). Basically, through voice communications in most cases, the emergency response teams providing the on-scene pre-hospital assessment takes the patients' vital signs measurements and transmit

the same to the main health care centres. Because it is mainly voice communication between the response teams and the physician at the main health care centre, assessments will be made based only on the verbal description but cannot monitor the patient through video communication, receive ECG images, X-ray images etc. Compounding that challenge is the issue of limited health care facilities, which are only located in the cities. Thus inadvertently increasing the time-lapse between incident and care, thereby worsening the outcome for the patients (Ugbeye, 2010). Unfortunately, mainly due to vehicular traffic congestion, the arrival of the patients to the main healthcare centre is always delayed. Across Nigeria, the arrival time to the hospital after road traffic accidents is put at 93.6 minutes on average according to a survey presented in Ugbeye (2010). It is therefore clear, that

telemedicine systems are necessary where the physician at the main health care centre can remotely monitor and observe the patient and also obtain real-time measurements of the patients' vital signs.

New possibilities in the field of telemedicine have been brought about as a result of advancements in mobile communication networks and the wide coverage provided by cellular networks with the ability to provide service even to moving vehicles. This increasing awareness and interest in telemedicine coupled with the advancements in telecommunications technologies have given rise to the many telemedicine applications successfully deployed (Fontelo et al., 2005; Holopainen et al., 2007; Maia et al., 2006; Olariu et al., 2004). The broad range of telemedicine applications includes (i) Teleradiology (ii) Teleconsultation (real-time, store-and-forward) (iii) Telesurgery (iv) Remote Patient Monitoring and (v) Health Care Records Management. In many of these studies, the efficient use of cellular network resources was vital to ensure errorless and accelerated transmission of all telemedicine traffic, that is, video, audio, data, etc., chiefly because of the criticality of the transmitted traffic and the limitations of bandwidth availability. The task of transmitting telemedicine data as soon as they get to the Base Stations goes beyond a scheduling task of a scheduler at the base station since the telemedicine user must have accelerated and expedient transmission, hence prioritized scheduling will guarantee bandwidth resources availability. Therefore, the prioritized or guaranteed transmission of telemedicine traffic is a quick fix to the challenge of accelerated and minimal end-to-end delivery delay. An approach includes reserving an amount of bandwidth solely for telemedicine users, but the direct consequence of this approach, firstly, is the violation of the Quality of Service (QoS) requirements of regular traffic users and secondly, when reserved bandwidth is left unused, it can result in bandwidth wastage.

While a lot of research work is ongoing in this field, a noteworthy observation is that most of these studies concentrate singularly on the transmission of telemedicine traffic over cellular networks, failing to note that regular traffic, which largely constitutes the bulk of traffic in a network also has strict Quality of Service (QoS) requirements as well. The combined transmission of regular traffic with the sparse but crucial telemedicine traffic poses a complex scheduling challenge. To appreciate this challenge, in Pavlopoulos et al. (1998), 27% of interruptions occurred during ECG data transmission in GSM principally due to congestion in the network. A quick fix to curb these interruptions is to give telemedicine traffic the highest importance, but this will create challenging disruptions to regular users already active in the given cell. Given the crucial and critical nature of telemedicine traffic, diverse nature of the QoS requirements, an appropriate scheduling scheme will be

necessary to cater for these diverse needs. The focus of the research, therefore, is to model, develop scheduling algorithms for prioritizing the transmission of the *urgent, critical and crucial* telemedicine traffic and to study and evaluate its impact and lack thereof on the throughputs of telemedicine traffic transmission in cellular networks.

Specifically, we are looking at the joint transmission of telemedicine traffics in the form of voice, real-time medical video, ECG signals, and medical images like X-ray scans in a multi-user cellular environment. We also considered the fact that only a little tolerance to loss and delay is acceptable in the delivery of medical videos in real-time and other urgent telemedicine traffic. An essential Quality of Service requirement in cellular networks is keeping the probability of handoff packet dropping below a specified limit so that mobile users can continue current sessions as they hand-off from one cell to the next, hence consideration is also given to handoff transmission in the research model. In the last few years, various telemedicine and M-health studies and test has been conducted with the ultimate goal of efficient use of cellular network resources and rapid transmission of all types of telemedicine traffic (video, audio and data). This is particularly so as only a limited amount of bandwidth could be devoted to the transmission of this crucial traffic type. In Garawi et al. (2006), the performance analysis of an end-to-end mobile robotic system over the third-generation (3G) mobile communications network was conducted with particular emphasis on the Quality of Service (QoS) issues measured in terms of average throughput, packet delays and jitter delay.

The system was tested on Vodafone, a U.K network, which is a 3G network. The study only focused on medical robotic systems and their end-to-end delivery of the generated medical data. It suggests the expected bandwidth required for the efficient transmission of the generated data without consideration to other medical traffic and 'regular traffic' in the network. The work in Navarro et al. (2006) was conducted to show the performance of a telemedicine system that is operating over 3G mobile networks. In design, medical personnel in an ambulance can communicate with specialists in a remote hospital through UMTS mobile access. In maximizing and ensuring efficient use of channel resources and maintaining good network performance, intelligent modules like information compression and coding were added to the system design. Some of the features of the system include simultaneous transmission of real-time medical data, medical videoconference. The approach in the work is that of using compression technology to ensure bandwidth efficiency. The system failed to consider the interaction of other types of users on the network and also did not preempt users entering the system. The objective of the study in Voskarides et al. (2003) is the practical evaluation of the performance of GSM and GPRS based systems in the end-to-end

transmission and reception of medical videos and X-ray images in emergency cases. Although the work presented achieved its set out objective of connecting remote clinics and specialized hospitals, a small fraction of the channel capacity is suggested to be reserved for the transmission. Better bandwidth utilization can be achieved with proper traffic prioritization and scheduling scheme.

The research works presented in Ganz (2004), Pavlopoulos et al. (1998) and Gallego et al. (2005), performance analysis of multiplexed medical data transmission for emergencies over 3G networks were considered. The research works were to investigate and demonstrate the feasibility of using technologies such as UMTS for emergency healthcare services on a high-speed ambulance and not the estimation of bandwidth and throughputs expected in the medical data transmission. The ultimate aim of these research works is how to use 3G networks to transmit medical data and not expedient delivery of such. Huang and Miaou (2001) in their work looked at ultimate bandwidth utilization in the transmission of ECG data over a next-generation mobile system. The work considered using a compression technique for the transmission of ECG data as a means of effectively using bandwidth, rather than creating a scheduling policy or prioritization of the ECG data in the midst of other traffics. In its approach to the transmission of vital signs (telemedicine data) in an ambulance over a limited bandwidth network, the work by Zubairi and Misbahuddin (2009) proposed data aggregation and reduction of ECG and blood pressure measurements before transmitting same over a 3G UMTS links as a means of effective bandwidth utilization. It assumed that the ambulance transporting the patient will be equipped with medical instruments that can be connected to the main hospital over a cellular network.

To achieve this aggregation and compression, a special packet format is used where these vital signs measurements are represented as 3-bits information. In Koutsakis (2011), in ensuring the efficient and errorless transmission of telemedicine traffic, while also guaranteeing efficient bandwidth utilization, it proposed a bandwidth reservation and scheduling scheme to handle the traffic but the performance of the scheduling scheme against the non-priority scheme was not discussed. Essentially, accelerated, errorless end-to-end telemedicine traffic transmission and maximizing channel capacity usage are QoS related problems. There are several QoS solutions available and can be implemented in ensuring efficient telemedicine traffic transmission. The choice of priorities in Bhargava et al. (2003) as shown in Table 1 is based on the importance that each of these traffic types currently has for medical care, while for regular traffic, prioritization is based on strictness of the QoS requirements for each traffic type. The research adopts these traffic types and the priority order for the

Table 1. Traffic types to be used arranged in descending order of priority.

Traffic types
Handoff ECG
Handoff X-ray
Handoff Telemedicine Image
Handoff Telemedicine Video
ECG
X-Ray
Telemedicine Image
Telemedicine Video
Handoff Video
Handoff Voice
Handoff Email
Handoff Web
Video
Voice
Email
Web

design of the Scheduling algorithms.

From the discussion of relevant works on telemedicine transmission over cellular networks and the various bandwidth reservation algorithms, it is observed that there is a challenge of resource (bandwidth) availability for the transmission of this crucial data type, coupled with the challenge of the maximization of channel capacity. This can lead to poor QoS, which is not desirable especially in an emergency that telemedicine represents. It is against this background that these problems were identified:

- The need for a scheduling policy to prioritize the transmission of telemedicine traffic.
- The need to evaluate the impact of scheduling algorithms on the performance of telemedicine transmission over cellular networks.

METHODOLOGY

Description of the system

The algorithm to be designed fits into any next-generation cellular system where channel capacity (data rates) is expected to be anything from 20Mbps and above (Bojkovic et al., nd). We are assuming a system that is TDM – FDD based, such that the Uplink and Downlink channels are on different frequencies. Therefore, the design is an Uplink Scheduling algorithm independent of the downlink. For simplicity, we have considered all mobile users under consideration to be within a cell i.e. one serving base station.

Structure of the channel

Based on the assumption that the system is TDM – FDD, the channel structure is such that it is divided into time bursts referred to as frames and the frames are divided into time slots of fixed duration. The frame duration and slot duration are obtained from the estimation of the parameters in Equations 1 to 5. The Channel rate used in the estimations is 20Mbps, with Packet Sizes of 305 bytes and 53 bytes. The Codec rate is 32Kbps.

Estimation of parameters

For a system that is TDM-based, the uplink channel is divided into frames and the frames are subsequently divided into time slots of fixed duration. Hence the parameters below needed to be computed for the uplink scheduling task.

Input parameters: Packet Size, Codec Rate, Channel Rate

Compute Frame duration

$$T_f = \frac{\text{Packet Size}}{\text{Codec Rate}} \quad 1$$

Compute Time Slot per frame (Slot duration)

$$T_s = \frac{\text{Packet Size}}{\text{Channel Rate}} \quad 2$$

Number of slots per frame

$$N_s = \frac{T_f}{T_s} \quad 3$$

Transmission time for a packet type

$$= \frac{\text{File Size} \times \text{Frame time}}{\text{Packet Size}} \quad 4$$

Number of bits accommodated per slot

$$= \frac{\text{Packet Size} \times \text{Slot duration}}{\text{Frame duration}} \quad 5$$

For this research work, the following parameters were used:

Channel Rate = 20Mbps
 Packet Sizes = 305 bytes and 53 bytes
 Codec Rate = 32Kbps

Overall block diagram

The overall conceptual structure was developed and represented in a block diagram as presented in Figure 1.

Figure 1 indicates the relationship between each section of the proposed algorithms. The first stage is the traffic or data generation (these include telemedicine data and regular data) from a random source which is considered digital and assumed to be formatted in a standard acceptable to next-generation cellular systems. In the second stage, the generated traffics/users are identified, classified and appropriate weights are assigned to indicate the priority order based on the QoS of the traffic types as described in Table 1. In the third stage, a contention resolution algorithm is applied to resolve contention among users of the same priority. The final block handles the scheduling of traffic and the allocation of time slots (bandwidth) according to the priority using a Time Division Multiplexing (TDM) approach. The details of the design and development of each of the blocks and the algorithms to achieve the set-out objectives is presented in the ensuing sections.

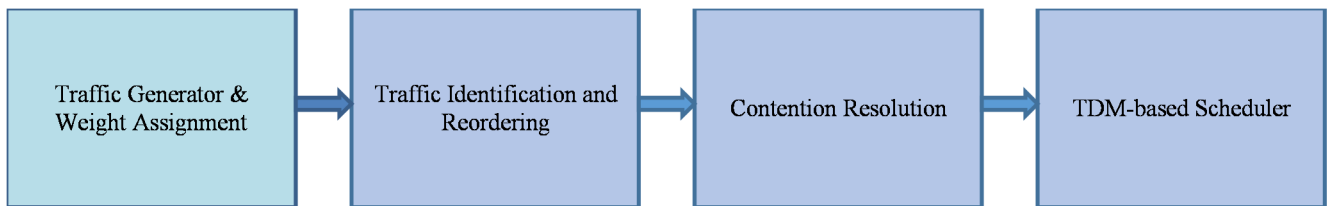


Figure 1. Overall block diagram of the system methodology.

Traffic generator

The number of mobile users *numusers* in the cell are fixed for a particular round (for simulation is fixed to 500 users) but the traffic or data type each user is transmitting is randomly assigned between 1 and 16. A uniform

random generator was used to ensure that each user has an equal probability of being assigned a *usertrafficclass*. Doing this ensured that users do not tend towards a particular class but can be evenly spread between all classes. The value assigned to each traffic type between 1 and 16 is as shown in Table 2.

Table 2. Traffic classes and their corresponding weights.

Traffic types	Weight assigned
Handoff ECG	1
Handoff X-ray	2
Handoff Telemedicine Image	3
Handoff Telemedicine Video	4
ECG	5
X-Ray	6
Telemedicine Image	7
Telemedicine Video	8
Handoff Video	9
Handoff Voice	10
Handoff Email	11
Handoff Web	12
Video	13
Voice	14
Email	15
Web	16

Although the research work is skewed towards telemedicine data types (i.e. 1 – 8), other forms of ‘regular traffic’ type are considered to simulate a scenario as close to reality as possible. The traffic (data) types are arranged in their order of priority with the highest priority assigned value 1 and the lowest assigned value 16. Hence, a traffic type belonging to a class is generated per user in each round.

Moreover, to further enhance the scenario to be close to real-life situations, we introduced a variable called *userchannelstate*, such that for each user, a random value between 3 and 1 was generated to represent the channel state. This was based on the three-state Markov model for channel conditions, where the channel condition is represented by three states of ‘Good’, ‘Bad’ and ‘Long Bad’ states. For simulation, value 3 denotes Good state, while value 2 denotes Bad state and value 1 denotes Long Bad state. This was done for 10 rounds and with 500 mobile users. The various factors contributing to the channel state of each user cannot be exhaustively dealt with in this work, but we assume that the packet delay at the Uplink Scheduler as a result of queueing is a significant factor.

Traffic generator algorithm and weight (priority) assignment

Inputs: Total Number of Users; N_U , Total Number of Rounds; R
 For $i = 1:R$; do
 Create a Null Vector of Size = N_U ; Users = $\{1, \dots, N_U\}$
 For $U = 1:N_U$; do
 Users (i,u) = Random number between 1 and 16;

 userfilesize (i,u) = Assign filesize based on traffic class
 End for
 End for

Outputs: A set of Users with different traffic types; Users with different file sizes. The flowchart is shown in Figure 2.

Traffic reordering

The block involves the re-ordering of the users in the order of priority. The algorithm to achieve this is outlined below:

For $i = 1:R$; do
 For $u = 1:N_U$; do
 Pusers (i,u) = Reorder values from lowest to highest;
 End for
 End for

Output: A set of users arranged according to the Priority of their Packets; Pusers

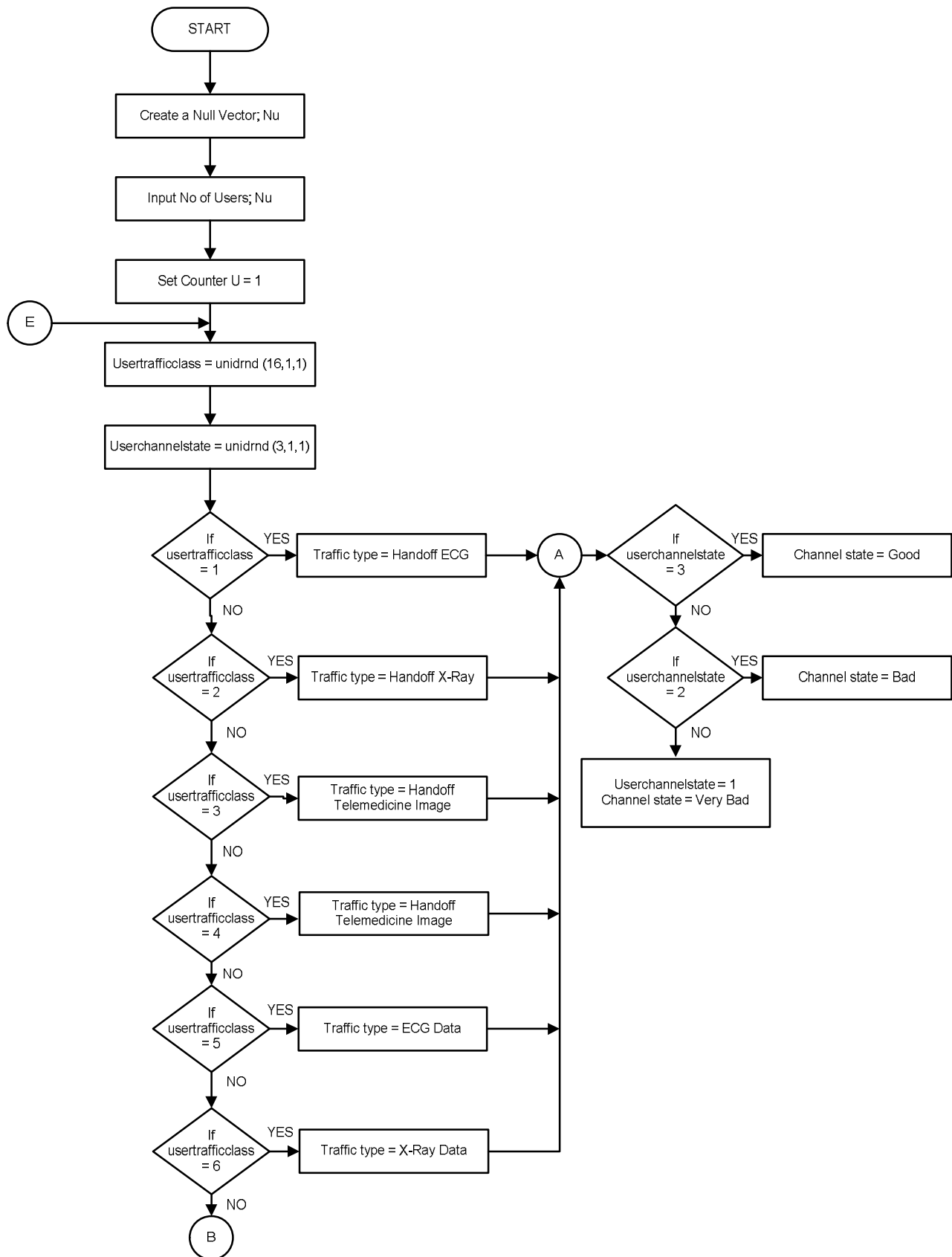
TDM – Based scheduler algorithm

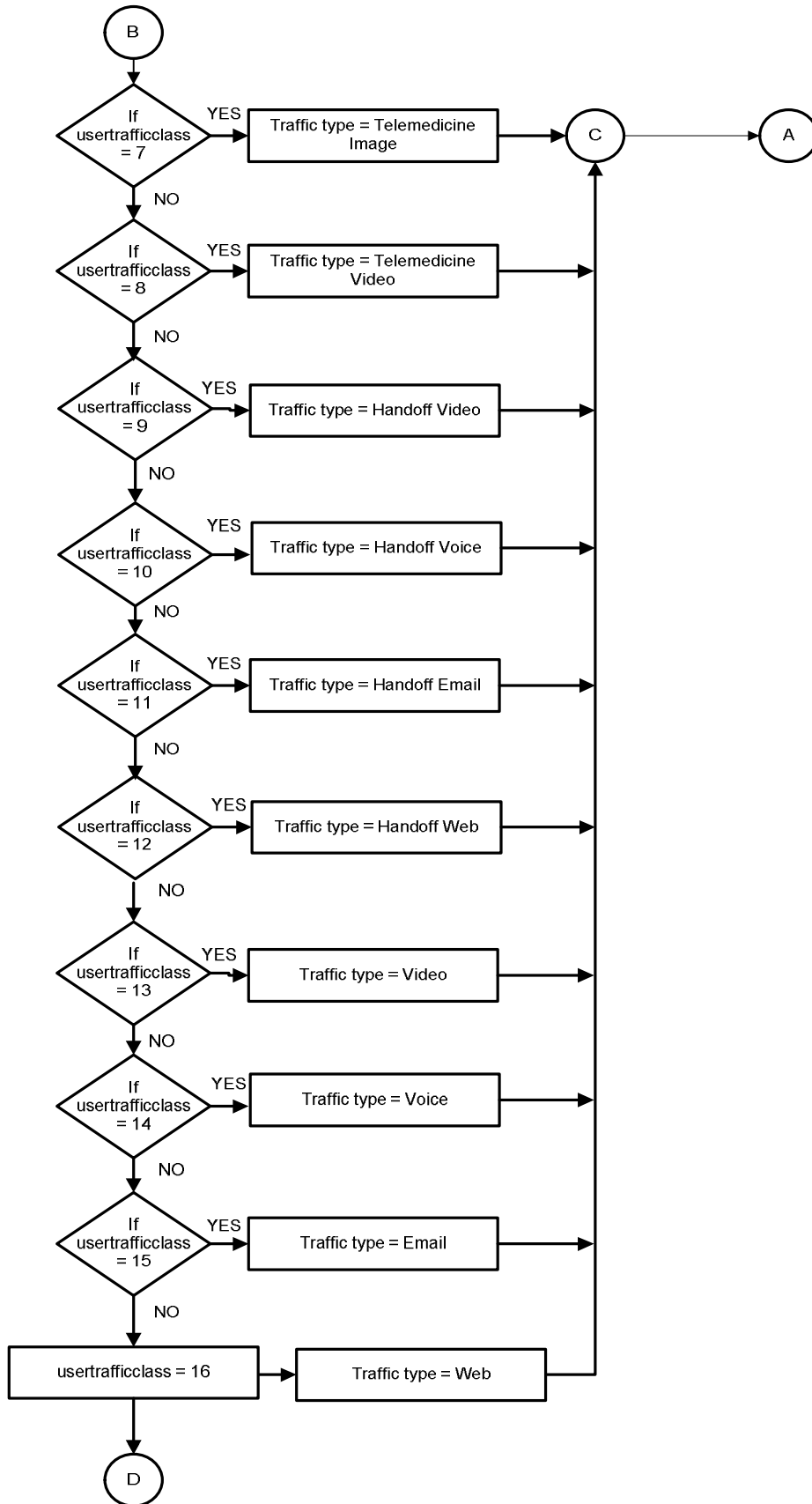
To fully evaluate the impact of priority-based scheduling on the throughput of telemedicine data classes, two algorithms were developed separately developed; non-priority based scheduling and priority-based scheduling schemes to observe the throughput of all the data classes without priority and secondly to note if there is a significant improvement on the telemedicine data classes after implementing the priority-based scheduling.

Contention resolution algorithm

The aim of the contention resolution module is to identify data streams from users of the same class arriving at the same time. To resolve the contention among users of the same class, the following algorithm is implemented:

$N_p = 16$; Number of Priority Class
 For $i = 1:R$; do
 For $P = 1:N_p$; do
 For $u = 1:N_U$; do
 PQ = Find all packets having P; PQ = Priority Queue
 If $PQ > 1$
 Execute two cell stack
 Else
 RePuser(i,u) = Pusers(i,u);
 EndIf
 Endfor
 Endfor





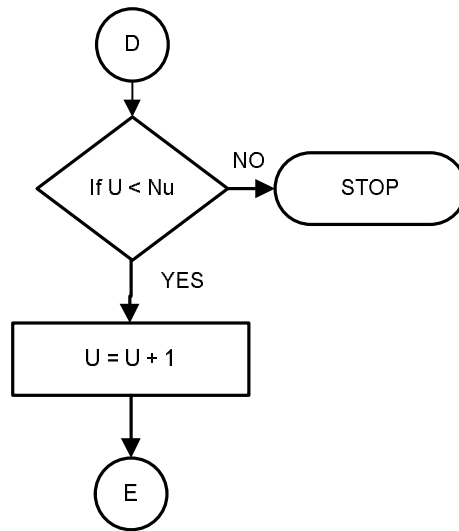


Figure 2. Traffic generator and weight (priority) assignment flowchart.

Endfor

Output: Reordered set of users based on Priorities

It is assumed in this work that a Two-cell stack algorithm for contention resolution was implemented within the algorithm and the output is a re-ordered set of users rearranged on the queue based on priority with all contention resolved. The flowchart is as shown in Figure 3.

RESULTS AND DISCUSSION

The scheduling without prioritization and strict priority-based scheduling algorithms were implemented in MATLAB 8.1.0 software and tested on various simulated input datasets. Data sizes to be transmitted (in Kb) were randomly assigned to the sixteen (16) traffic classes under consideration. Table 3 contains the traffic classes and the data size assigned. The assigned data sizes once assigned were held constant throughout the simulation process, this is because the data sizes do not have any significant impact on the throughput of the users.

A simulation case of traffic load of 500 users was conducted to ensure that all users traffic class will be available, and the various traffic classes were assigned in a uniform random distribution between 1 and 16 and the user channel condition was also a uniform random distribution between 1 and 3. This was to examine the performance of the scheduler algorithm with and without prioritization scheduling in a scenario that is close to a real cellular system.

The simulations were conducted first without the

scheduling scheme and thereafter with the scheduling scheme over 10 rounds while maintaining the distribution of the number of users and the channel states. This is done to quantify the difference in the average throughputs obtained. Table 4 shows the average throughput for all users in each class across 10 rounds without a scheduling scheme. Table 5 shows the average throughput for all users in each class over 10 rounds with a scheduling scheme in place.

Figure 4 shows the comparison of the average throughput of all users in each class, with priority scheduling and without priority scheduling. The average throughput when priority scheduling scheme was implemented over non-priority scheme for each traffic class shows 66.7% percentage gain for traffic class 1, 60.7% in traffic class 2, 53.8% in traffic class 3, 70.0% in traffic class 4, 73.1% in traffic class 5, 66.7% in traffic class 6, 73.7% in traffic class 7 and 68.5% percentage gain in traffic class 8. The results show a significant increase in the throughput of medically related traffic transmission with a priority scheduling scheme. The scheduling scheme thus impacts the throughput of telemedicine users.

To study the effect of traffic load conditions and packet sizes on the performance of the scheduling scheme as it affects telemedicine traffics, three different traffic load conditions with a standard packet size of 305 bytes were simulated: low traffic load, medium traffic load and full traffic load over 20 rounds. In the case of low load condition, the number of users in the system was chosen as 40, the medium traffic load was 70 users, while the full load condition was set at 100 users. The result is presented in Table 6 and the plot is shown in Figure 5.

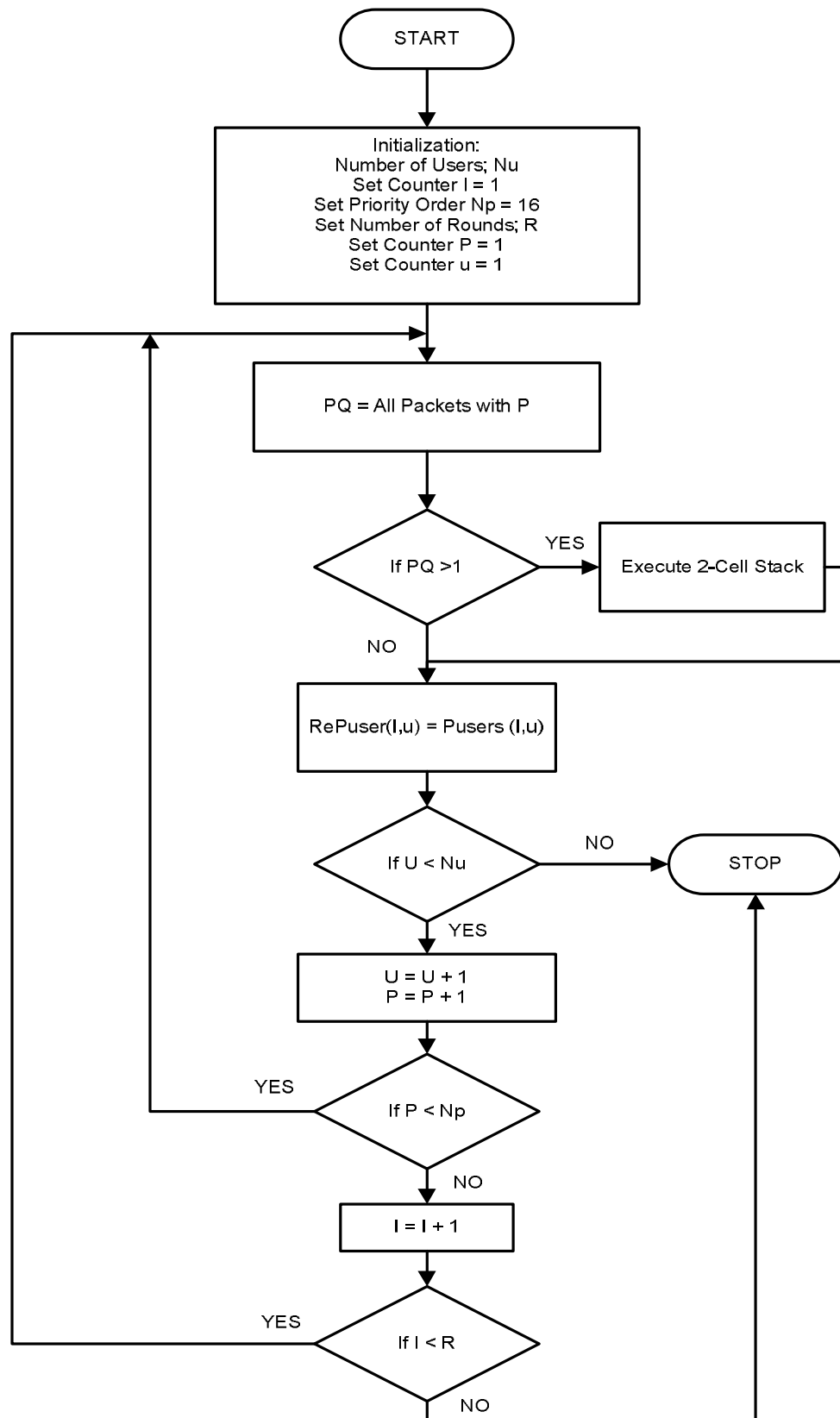


Figure 3. Traffic re-ordering flowchart.

Table 3. A sample of the data sizes corresponding to each traffic class.

Traffic types	Data size (KB)
Handoff ECG	1600
Handoff X-ray	1500
Handoff Telemedicine Image	1400
Handoff Telemedicine Video	1300
ECG	1200
X-Ray	1100
Telemedicine Image	1000
Telemedicine Video	900
Handoff Video	800
Handoff Voice	700
Handoff Email	600
Handoff Web	500
Video	400
Voice	300
Email	200
Web	100

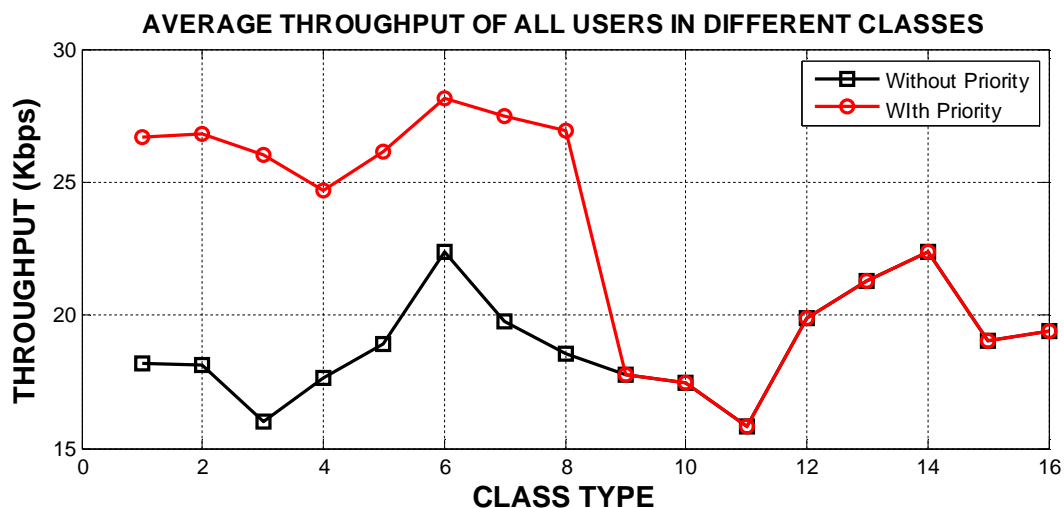


Figure 4. Comparison of the average throughput of users in the different classes with and without priority scheduling.

A comparison of the average throughputs of users after 20 rounds, with the packet size 305 bytes shows a percentage gain of 69.3% from full traffic load condition to medium traffic load condition and 51.7% from medium traffic load condition to low traffic load condition. The implication of this is that with low traffic conditions, the attained throughput increases.

The effect of reducing the packet size from 305 bytes to 53 bytes with the channel rate kept constant is investigated at various traffic load conditions, and is presented in Table 7 and Figure 6.

The consequence of transmitting the data bulk in packets of size 53 bytes as compared to transmitting in a packet of size 305 bytes is observable with average throughputs of users at various traffic load conditions significantly reducing. For low load traffic condition, 84.22% decrease in the average throughput when packet size is changed from 305 bytes to 53 bytes. When simulated with a medium traffic load condition, an 83.3% decrease in the average throughput is seen and an 82.27% decrease in the average throughput with full traffic load condition.

Table 4. Mean throughput (without priority-based scheduling) for traffic class 1 to 16 after 10 rounds.

Round No	Without Scheduling															
	Average Throughput (Kbps) of the various traffic types															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	18.7	18.9	21.1	19.8	16.0	16.9	19.9	16.6	17.6	18.7	17.5	18.3	19.6	20.3	20.8	21.3
2	18.0	23.1	20.9	17.2	20.1	20.9	19.3	19.6	17.1	19.0	18.2	21.1	21.8	18.4	19.5	19.2
3	15.6	15.8	17.7	18.9	23.4	18.4	19.1	18.4	22.6	17.3	16.9	20.3	21.2	20.1	18.3	23.0
4	16.7	17.0	16.2	18.4	19.4	20.3	21.4	17.3	15.5	19.8	20.6	20.7	19.8	16.2	21.1	19.2
5	19.1	18.8	18.5	18.5	20.6	18.8	15.7	19.8	17.6	20.8	17.3	17.9	17.8	18.1	21.7	14.1
6	22.5	21.5	21.3	16.8	18.9	17.3	18.8	16.7	14.4	18.8	20.1	15.0	17.3	17.5	17.7	18.1
7	17.5	20.4	18.7	17.1	16.6	19.9	18.8	18.9	16.0	19.5	15.8	17.3	18.4	21.4	17.8	21.4
8	20.5	18.1	18.8	19.6	17.9	20.0	17.1	15.0	22.7	19.5	18.8	18.8	17.5	17.6	17.0	18.8
9	22.3	20.0	15.0	20.9	17.3	18.9	16.8	16.7	19.5	18.7	21.5	22.6	19.2	19.3	23.0	18.7
10	19.4	16.7	17.6	19.6	14.3	21.7	19.3	19.7	18.4	18.8	17.9	18.3	20.4	19.2	22.2	17.9

Table 5. Mean throughput (with priority-based scheduling scheme) for traffic class 1 to 16 after 10 rounds.

Round No	Priority-based Scheduling															
	Average Throughput (Kbps) of the various traffic types															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	26.7	29.1	28.3	29.0	25.8	24.0	27.7	26.1	17.6	18.7	17.5	18.3	19.6	20.3	20.8	21.3
2	25.0	28.4	27.4	24.8	27.3	28.7	27.6	25.9	17.1	19.0	18.2	21.1	21.8	18.4	19.5	19.2
3	24.8	25.1	26.6	26.2	29.2	26.4	26.4	25.2	22.6	17.3	16.9	20.3	21.2	20.1	18.3	23.0
4	25.7	25.8	24.8	28.0	28.6	27.7	27.4	27.2	15.5	19.8	20.6	20.7	19.8	16.2	21.1	19.2
5	29.3	26.5	27.9	25.8	28.3	27.7	24.8	26.2	17.6	20.8	17.3	17.9	17.8	18.1	21.7	14.1
6	29.1	27.5	27.3	26.9	26.2	26.7	27.3	25.3	14.4	18.8	20.1	15.0	17.3	17.5	17.7	18.1
7	26.8	26.3	26.7	26.5	25.8	27.4	26.4	28.3	16.0	19.5	15.8	17.3	18.4	21.4	17.8	21.4
8	25.7	25.8	27.5	26.9	25.1	28.0	26.2	25.0	22.7	19.5	18.8	18.8	17.5	17.6	17.0	18.8
9	27.8	27.8	24.2	26.9	25.9	26.2	24.4	25.0	19.5	18.7	21.5	22.6	19.2	19.3	23.0	18.7
10	26.2	26.2	25.0	28.6	23.5	28.9	28.0	27.7	18.4	18.8	17.9	18.3	20.4	19.2	22.2	17.9

Table 6. Mean throughput for different traffic load conditions with packet size at 305 bytes.

Traffic load condition	Average throughput (Kbps)
Low load	1592.1
Medium load	822.6
Full load	570.1

From Figure 6, using a packet size of 305 bytes as compared to 53 bytes is justified as higher throughput rates are achieved. Hence for cellular networks with a high concentration of telemedicine traffic being transmitted, transmitting at 305 bytes packet size will guarantee high throughputs and compensate for the delay in queuing at the scheduler.

To investigate the impact of codec rates on the average throughputs at various load conditions, 20 rounds of simulation was conducted with standard codec rates of

32Kbps, 64Kbps and 128Kbps at different traffic load conditions with packet size 305 bytes and 53 bytes. At low load traffic condition and packet size of 305 bytes, the average throughputs obtained is represented in Table 8 and graphically presented in Figure 7.

At low traffic load condition, there is a 7.1% gain in the average throughput in transmitting at a codec rate of 64Kbps as compared to a codec rate of 32Kbps. Changing the codec rate from 64Kbps to 128Kbps shows no improvement in the average throughput. Hence at low

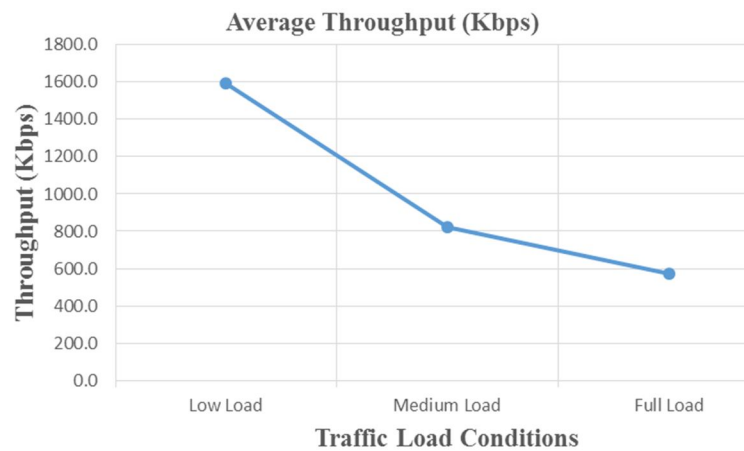


Figure 5. Average throughput at different traffic load conditions (with packet size 305 bytes).

Table 7. Comparison of mean throughput for different traffic load conditions with packet sizes of 53 bytes and 305 bytes.

Traffic load condition	Average throughput (Kbps) at packet size 305 bytes	Average throughput (Kbps) at packet size 53 bytes
Low load	1592.1	251.2
Medium load	822.6	136.6
Full load	570.1	101.1

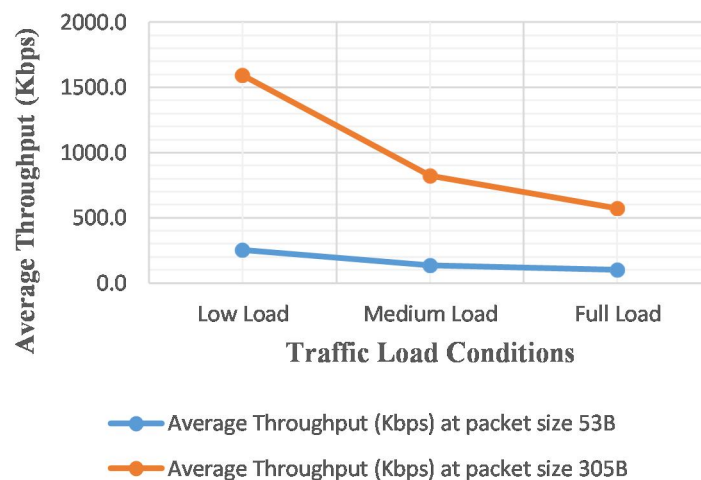


Figure 6. Comparison of the average throughput when packet size is 305 bytes and 53 bytes.

traffic load condition, in which case the available bandwidth is not fully utilized, rather than increase the codec rate, more time slots can be assigned to all users.

At medium load traffic condition and packet size 305 bytes, the mean throughputs obtained are tabulated in

Table 9. From Table 9 and Figure 8, there is a 0.9% gain in the average throughput in transmitting at a codec rate of 64Kbps compared to a codec rate of 32Kbps. Again, it can be observed that the throughput reduced by 0.1% when the codec rate is varied from 64Kbps to 128Kbps.

Table 8. Mean throughput at low traffic load for various codec rates and packet size 305 bytes.

Codec rates	Average throughput (Kbps)	% Gain
32Kbps	1344.9	
64Kbps	1447.2	7.1
128Kbps	1431.5	-1.1

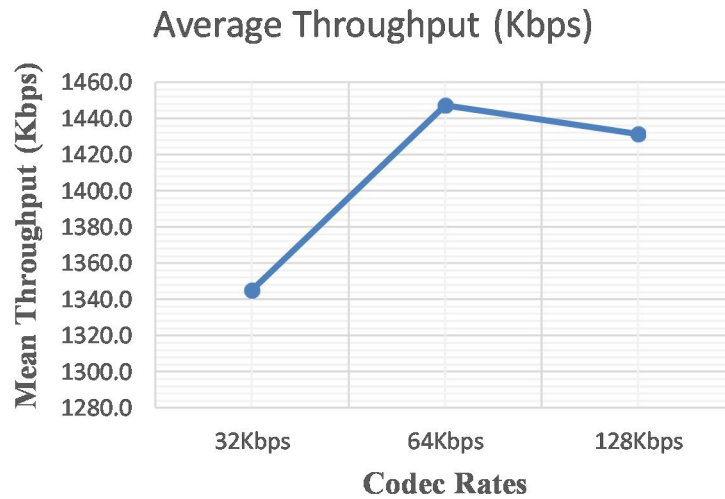


Figure 7. Impact of codec rate on average throughputs at low traffic load condition at packet size 305 bytes.

Table 9. Mean throughput at medium traffic load for various codec rates and packet size 305 bytes.

Codec rates	Average throughput (Kbps)	% Gain
32Kbps	820.3	
64Kbps	827.5	0.9
128Kbps	828.4	0.1

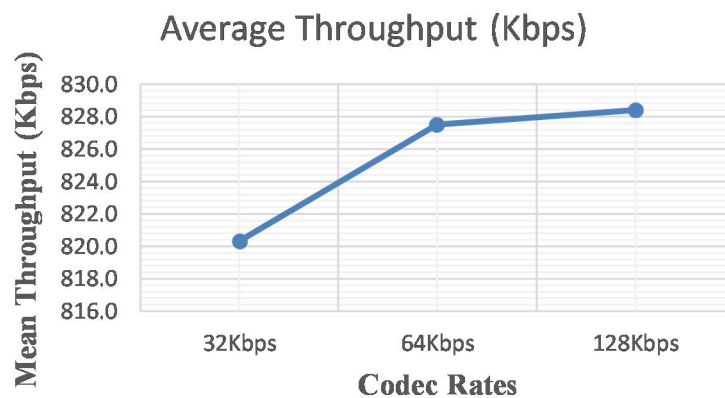


Figure 8. Impact of codec rate on average throughputs at medium traffic load condition at packet size 305 bytes.

Increasing the codec rate guarantees slightly better average throughput for the users but not significant performance.

At full load traffic condition and packet size 305 bytes, the results obtained are shown in Table 10 and Figure 9.

The impact of a codec rate of 128Kbps at full traffic load condition is seen as there is an 11% percentage gain in throughput over 64Kbps and 0.6% percentage gain in average throughput from 32Kbps to 64Kbps.

Therefore, in cases of a high volume of telemedicine traffic users, and the system is in full traffic load

condition, the packet size of 305 bytes and codec rate 128Kbps will be efficient for accelerated transmission.

The research has evaluated the impact of scheduling algorithms on the performance of telemedicine traffic transmission in cellular networks, with throughputs as the metric. The impact of the packet sizes and codec rates at various network conditions on the throughputs of telemedicine traffic has also been evaluated and quantified. The priority-based scheduling algorithm provides better performance to telemedicine traffic than the non-priority based scheduling algorithm.

Table 10. Mean throughput at full traffic load for various codec rates and packet size 305 bytes.

Codec rates	Average throughput (Kbps)	% Gain
32Kbps	564.8	
64Kbps	568.0	0.6
128Kbps	637.8	11.0

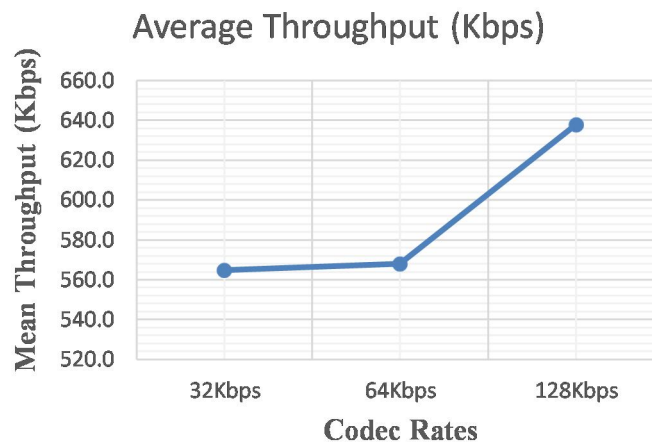


Figure 9. Impact of codec rate on average throughputs at full traffic load condition at packet size 305 bytes.

CONCLUSION

The research measured, compared and evaluated the average throughput of each traffic class with and without priority-based scheduling. The average throughputs at each traffic load conditions were evaluated with different packet sizes and codec rates. These were presented to observe the impact of scheduling algorithms on the performance of Telemedicine traffic transmissions in cellular networks at different network conditions. The priority-based scheduling algorithm provides better average throughput to telemedicine traffic than non-priority based scheduling. This was noticeable more at

low traffic conditions than at higher traffic volume conditions.

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