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Grey Wolf Optimization for Resource Allocation in RAN Slicing for Heterogeneous Requirements

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Abstract: Dealing with the rapid growth of the devices in 5G scenario is where the 5G NR helps to cope up with the heterogeneous requirements. Network slicing technique is the solution to work with the different use cases with various Quality of Service (QoS) requirements like Ultra Reliable Low Latency Communication (uRLLC), Enhanced Mobile Broadband (eMBB) and Massive Machine Type Communication (mMTC) devices. In network slicing latency plays a vital role in fulfilling the expectations at required rate. Thus, we have considered the latency parameter in the designing of the slice. In this paper, we have developed a Linear Programming Model (LP) to allocate the required resources to the various applications under uRLLC, eMBB and mMTC. In all these use cases latency plays a very vital role, hence in this regard we have created latency sensitive slices for all three use cases. Further we have extended the work with Grey Wolf Optimization (GWO) for allocation of resources to the slices. In this paper, we have investigated the model by (i) varying number of applications (ii) number of resources keeping the resource blocks constant. Numerical results shows the average percentage (%) satisfaction of resource allocation for 5,7,9 and 11 applications. With LP model we could gain average 79.05% satisfaction of allocation of resources. In the extended work with GWO the average satisfaction percentage increased to 96.42%. The comparative results of both the models show that GWO could gain 25.39% of increase in the average satisfaction for allotment of resources than the LP model.

Keywords: *5G RAN Slicing, Resource Allocation, Heterogeneous Requirements, Linear Programming Model, Grey Wolf Optimization.*

1. Introduction

With the development in wireless communication, users desire to have undistributed mobile connection for multimedia content. On the other hand we are talking about the connectivity required in the IoT devices. According to the global statistics almost 30 billion devices are expected to be using the wireless communication by 2025. Figure 1 shows the percentage increase in the number of devices in all the use cases till 2025.Due to the covid pandemic the usage of multimedia has tremendously increased. The OTT (over the top) platforms requires high speed internet for undisturbed services. 3GPP has divided the services according to the parameters requirement as Ultra Reliable Low Latency Communication (uRLLC), Enhanced Mobile Broadband (eMBB) and Massive Machine Type Communication (mMTC). Table 1 gives a brief description of the parameters and their applications to these use cases. However the present mobile networks works on point to point architecture and with the current capacity of 4G cannot cope up with the growing traffic of the devices. Therefore, in 5G all these hard coded structures in 4G are moved towards the virtualization (ie) Virtual Network Function (VNF) and Software Defined Networks (SDN) [1]. This virtualization brings improvement in network, visibility in performance and management control; reduce cost, network automation, traffic programmability etc. As referenced above, in 5G there are three categories uRLLC, eMBB and mMTC with different parameter requirements to serve different verticals.

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Table 1: 5G Requirements and Applications

Use Cases	Parameter Requirements	Verticals
eMBB	Mobility, Spectrum Efficiency, Peak Data Rate, Connection Density	Video Broadcast, Virtual Workspace, Augmented Reality, Smart Home
uRLLC	Latency, Mobility	Smart Cities, Infrastructure, Asset Management

mMTC	Connection Density, Energy Efficiency	Remote Training, Industry Automation, Drones, Robots, Digital Health

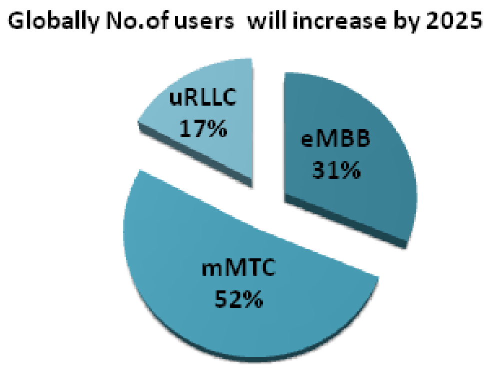


Fig 1: Global users till 2025

Therefore network slicing is a technique in 5G where the network is formed virtually on a single infrastructure. This virtual network forms different slices (ie) sub-networks to serve various applications according to the parameters requirement. Network Slicing can be divided into two levels as shown in figure 2 at the RAN level and at the core level. The creation of slice and optimization at both the levels is known as end-to-end slicing. This customization ability in the network allows the customers to use these networks resources dynamically (ie) on temporary needs or on varying scale according to the traffic.

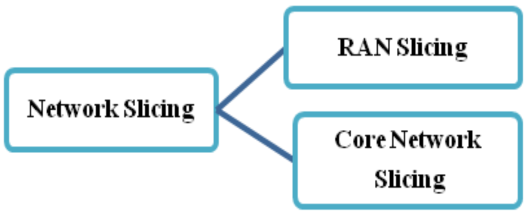


Fig 2. Different Layers of slicing

Most of the work in network slicing till date has focused more on core network. However to make it work from end –to-end we also need to focus on RAN slicing which will improve the end-to-end performance figure 3 gives a brief idea about the elements which are included in the 5G NR with all the flexibility in the network with SDN and VNF at the RAN level.

2. RAN Slicing in 5G

The flexibility in new 5G radio facilitates the deployment of RAN slicing. 5G NR defines different slot duration, to support simultaneous applications with different requirements whereas in 4G the slot duration as 1ms. RAN slicing shares computing, storage and various resources at RAN but configures their radio resources differently according to the requirement. Below is the Table 2 which shows the flexibility in sub carrier spacing in 5G NR. These sub-carrier spacing variations introduce variations in slot length and thus vary no. of slots in 1 frame. 5G NR divides the channel into frame size of 10ms and sub frame size of 1ms. Each sub-frame has no. of slots. This no. of slots varies depending upon the sub-carrier spacing. Slots include 14 OFDM symbol. Each PRB (Physical Resource Block) contains 12 subcarriers. For each numerology (μ), sub carrier spacing (Δf) as shown in equation 1 is given by,

$\Delta f = 2\mu * 15kHz$ --------------- (1)

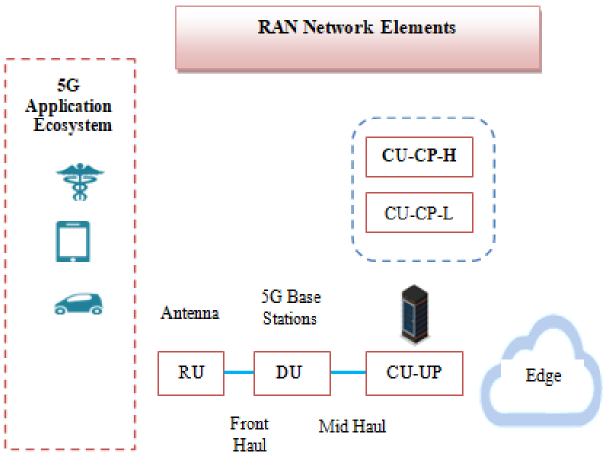


Fig 3: Network Architecture

Table 2: Flexibility in Subcarrier Spacing

Numerology (μ)	**Sub-carrier Spacing (kHz)**	**Symbol Length (μsec)**	**Slot length (msec)**	**No. of Slots in 1 sub-frame**	**Frame Length (msec)**
0	15	71	1	1	10
1	30	35	0.5	2	10
2	60	17	0.25	4	10
3	120	8.8	0.125	8	10
4	240	4.4	0.0625	16	10

According to 3GPP there are 3 use cases in uRLLC, eMBB and mMTC in 5G which differ in their requirements. In figure 4, slice 1 supports low latency applications with shorter time duration. Slice 2 supports large no. of devices. Slice 3 supports large bandwidth demands of the application. RAN slicing decides how to allocate these radio resources. Design of the slice, creation of the slice, allocation of resources dynamically, which guarantees to serve the application according to the QoS requirement is known as lifecycle of RAN slicing.

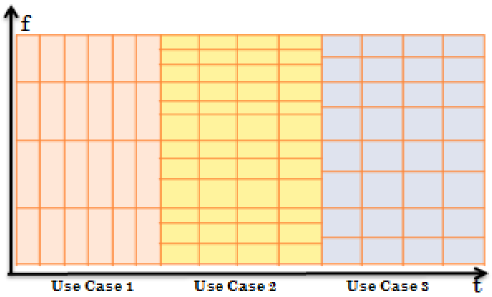


Fig 4. Slice variation for different use cases

3. Related Work

In recent years, there are many surveys which highlight the work in RAN slicing in detail, with various architectures and different models which deal with specific applications like vehicular network, information centric networks. However above research did not consider the allocation and co-ordination of slice for the backhaul, BS bandwidth and caching [2]. In this the authors have developed algorithm to jointly have slice allocation and co-ordination to improve the resource allocation strategy as well as to reduce the latency in the backhaul. To extend the work done, further the authors in [3] have also concentrated on user admissibility and slice association for adequate resource allocation. In the above papers they have only considered number of radio resources available to design a slice so as to complete the QoS requirements of the application. Since, RAN slicing flexibility in 5GNR plays a vital role. In [4] eMBB and uRLLC applications are considered where the authors have worked on sub 6GHz bandwidth, but these slices cannot move in between slices. Even though the eMBB and uRLLC slices satisfies the QoS of the applications but did not consider the slice admissibility at all. The RAN slicing framework works with a hierarchical structure (ie) network –level slicing, gNodeB slicing and packet level slicing. In [5] the authors have proposed to work on packet scheduling level where the resources are allocated from the pool of resources. Further they have also proposed this framework to be self-sustained.

All these above papers do not refer to latency requirement while creation of slices. Consideration of latency at the creation of the slice plays a major role in the applications such as below table 3 gives the details of the work for the resource type used and also the scenario considered for the slicing technique. In the next section, the size and shape of the slices are calculated for different traffic classes. The latency parameter is more focused and is considered while the creation of the slice for each service request. For experiment purpose as shown in figure 5 the traffic classes are divided into three categories:

1. Non-Deterministic Traffic
2. Deterministic Periodic Traffic
3. Deterministic Aperiodic Traffic

The below figure gives the overlook of the same:

The next section provides the proposed model for all the three types of traffic classes. In the proposed model the consideration of the latency parameter varies with respect to the achievable QoS depending upon the type of service.

4. Proposed Model

Figure 6 illustrates the complete model for the proposed system. In the system we have considered all three traffic types, for which the slices are created and designed as per the parameter requirements. Then these slices are allotted the resources so as to fulfil the upcoming requirements.

In this section, we have considered three phases; initialization, creation and allocation for each type of traffic.

i) In phase 1; initialization we have considered the load calculation for every type of traffic, total number of resources available and also fixed the allocation window.
ii) In phase 2; design and create slice in this all the calculations related to the resource block requirement which varies according to the application, depending on which the size of the slice is calculated.
iii) In phase 3; the resources are allocated to application depending upon the calculation done in phase2.

The major contribution to the proposed work is as follows:

(i) Design of linear model for all the different traffic variations for resource allocation.
(ii) Implementation of Grey Wolf Optimization (GWO) algorithm in the model to improve the resource allocation and thus resulting in improvement of the resource utilization.

Grey Wolf Optimization (GWO) has been used by many authors for 5G technology related to antenna design [6], routing and clustering [7]. But GWO has been rarely explored for the 5G in Slicing technique. This in this paper GWO has been utilized as the optimization algorithm. GWO is meta–heuristic nature inspired algorithm which works with the nature of wolves [8]. The general nature of the wolf is the leader hunts for the prey and other wolves helps the leader in the hunt. In this algorithm there are four search agents in the search space. Alpha (α) works as the leader and thus is the best search agent. In the algorithm, Beta (β) is the second agent, Delta (δ) as the third and Omega (ω) as the fourth search agent. For each iteration we get values for all the search agent values, but the proposed work we have considered alpha as the prime search agent as alpha. Equation a ,b and c are the basic equations of GWO.

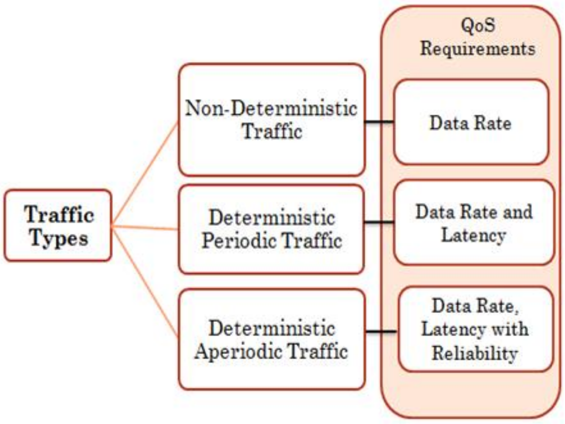


Fig 5: Types of Traffic Classes

The gaps identified from the related work are as follows:

- Latency parameter for every type of traffic should be considered while design of the slice.
- Hybrid meta-heuristic optimization algorithm must be utilized for optimum resources allocation.

Table 3: Literature Survey

Paper No.	Contribution	Resource Type	Scenario	Key Description
[6]	Throughput of network slices	PRB (Physical Resource Block), BBU (Baseband Unit) capacity, Transmission Power	C-RAN	Admission control, user association, virtual BBU capacity, PRB/transmission power allocation
[7]	Packet delay, remaining resource	Computing, Bandwidth Resource	RAN + CN	Resource allocation formulation by VNE/complex network theory to obtain network topologies
[8]	Revenue of infrastructure providers	Network Slice	RAN	Optimal decisions on accepting/rejecting network slice request through Q-Learning
[9]	Data rate of all users	PRB	RAN	Fisher market and a fair utility function: dynamic network slicing than that of static network slicing

[10]	Cost of creating VNFs	VNF (Virtual Network function)	CN	Optimal number of VMs(Virtual Machines) for each VNF/VNFs on different cloud networks to minimize the creation cost of VNFs
[11]	Improvement in Slice Isolation and data rate	PRB	RAN	Packet scheduling functions and Admission control Functions for eMBB and mMTC
[12]	Data Rate and Isolation	Bandwidth Resource	RAN	Functional characterization of the RAN slice by parametrizing the features, policies and resources in different protocol layers of the radio interface
[13]	Blocking probability, Degradation probability, throughput	PRB	RAN	Markov approach is used for slice aware admission control policies
[14]	Date Rate and Reliability	PRB	RAN	Risk Sensitive partition problem for eMBB and uRLLC

$\vec{V\alpha} = |\vec{C12} \cdot \vec{W\alpha} - \vec{W}|$

$\vec{V\beta} = |\vec{C22} \cdot \vec{W\beta} - \vec{W}|$

$\vec{V\delta} = |\vec{C32} \cdot \vec{W\delta} - \vec{W}|$ -------- (a)

$\vec{W1} = \vec{W\alpha} - \vec{C11} \cdot (\vec{V\alpha})$

$\vec{W2} = \vec{W\beta} - \vec{C21} \cdot (\vec{V\beta})$

$\vec{W2} = \vec{W\beta} - \vec{C31} \cdot (\vec{V\delta})$ -------- (b)

$\vec{W}(t+1) = \frac{\vec{W1}+\vec{W2}+\vec{W3}}{3}$ -------- (2)

- **Phase 1: Initialization**
  - No. of Applications
  - No. of Resource Blocks
  - Allocation Window
  -

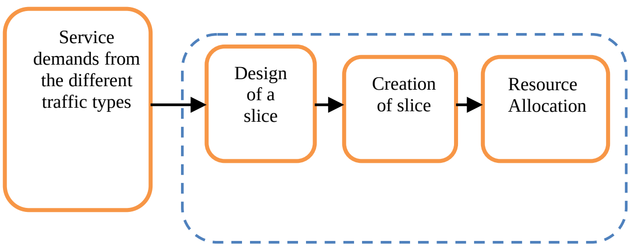


Fig 6: Design of RAN Slices

- **Phase 2: Design and Create the Slice**
  - Calculate effective Transmission Rate
  - Calculate no. of RB's required
  - Calculate the Size of the Slice

- **Phase 3: Allocation of Resources**

According to the requirement the RB's are allocated to the application.

A] Non-Deterministic Traffic:-

The slice s_i, is formed to complete the specific requirements by the non –deterministic traffic for the group of M nodes. Since non-deterministic traffic demands the data rate (R_i) equation no.1 defines the throughput requirement of each node for the assigned RB. For experimentation the Modulation Coding Scheme is selected on the basis of TBS and SINR. Figure 7 shows the allocation window, where we have considered random allocation of resources for non – deterministic type of traffic. For all types of traffic to represent the concept diagrammatically we have considered the allocation window to be 10.

(i) Calculation for the size of the Slice

Throughput that node u will experience per assigned RB

$$T_r = \frac{TBS(SINRu)}{Aw}(1 - BLER) \quad \text{---- (3)}$$

where, TBS=Transport Block Size

BLER= Block Error Rate

SINR= Signal to Interference plus Noise Ratio

Ei= Latency Deadline

(ii) Allocation of Resources is expressed as:

$$A_i(K_i) = 1 \quad ; K_i >= S_i \text{ size} \quad \text{----- (4)}$$

$$= 0 \quad ; K_i < S_i \text{ size}$$

where,

K_i = no.of resources required are allocated in the allocation

$$\sum_{t=1}^{Aw}(Li, t) = Si\ size$$

----- (5)

where,

Li is the amount of RB allocated to slice s_i in slot t.

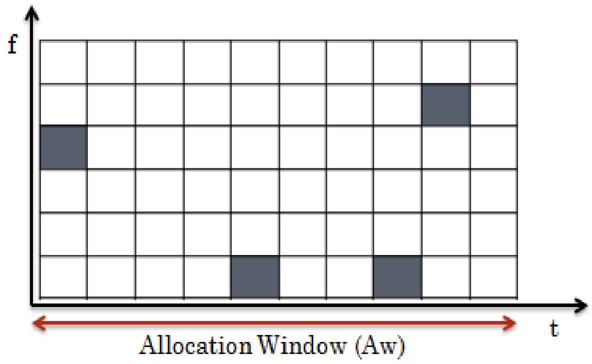


Fig 7. Allocation Window for Non-Deterministic Traffic

B] Deterministic Periodic Traffic:-

For deterministic traffic the slice s_i is such that the data rate as well as the latency is considered while creation of the slices. Figure 8 shows the allocation window, in which the resources should be available after a constant period of time slot for satisfying the resources requirement of the upcoming application. In this fig there are 4 blocks of resources available for each time slot between t_0 to t_0+E_i.

(i) Calculation for the size of the Slice

Throughput that node u will experience per assigned RB

$$T_r = \frac{TBS(SINRu)}{Ei}(1 - BLER) \qquad ---- (6)$$

where,

TBS =Transport Block Size

BLER = Block Error Rate

SINR = Signal to Interference plus Noise Ratio

Ei = Latency Deadline

The number of RB's required by node u to achieve the required Rate

$$Ru = \frac{Ri}{Tr} \qquad ----- (7)$$

Size of the slice to serve M nodes

$$Si\ size = \sum_{u=1}^{M} R_u$$

---- (8)

For allocation of resources, according to the equation the slots of resources available to the slice are considering the latency. The size of the slice is decided such that the resources are kept reversed each time from t_0 to t_0+E_i.

(i) Allocation of Resources

$A_i(K_i) = 1 \quad ; K_i >= S_i$ size ----- (9)

$= 0 \quad ; K_i < S_i$ size

where,

K_i = no.of resources required are allocated in the allocation

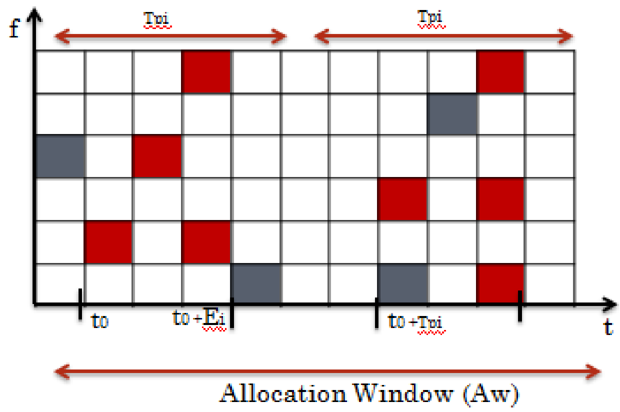
$$\sum_{t=tz}^{tz+Ei-1}(Li, t) = Si\ size$$

------ (10)

where,

Li is the amount of RB allocated to slice s_i in slot t

t_z is the time at which the packets are generated.



C] Deterministic Aperiodic Traffic

In 5G NR standard defines that the particular node in 5G can share their resources. Now this technique can be used for deterministic aperiodic traffic. Using this technique brings the condition of packet collisions as they will select the resources randomly. Figure 9 shows that the random resources are available for l to l+Ei, where in the resources are allocated to the slice in that particular slot. Thus while creation of slice the probability of collision with the packet reliability is considered:

(i) Calculation for the size of the Slice

Probability of Packet Generation

P = 1- exp (Tslot *λ) ----- (11)

where,

λ = average no.of packets generated per second

T_{slot} = Time interval (1ms)

Throughput that node u will experience per assigned RB

$T_r = \frac{TBS(SINRu)}{Ei}(1 - BLER)$ --- (12)

where,

TBS=Transport Block Size

BLER= Block Error Rate

SINR= Signal to interference plus Noise Ratio

E_i = Latency Deadline

The number of RB's required by node u to achieve the required rate

$$Ru = \frac{Ri}{Tr}$$ ----- (13)

Average RB per node

$$R_u = \frac{1}{M}\sum_{u=1}^{M} R_u$$ ---- (14)

Packet Collision

$P_c = 1 - [(k-R_u*P) /k]^{M-1}$ ---- (15)

Packet Reliability

$P_{rel} = 1 - Pc$ ----- (16)

Minimum number of RB's required to satisfy P_{rel}

k = (Ru*P) / (1-Prel^ (1/M-1))) ---- (17)

Size of the slice to serve M nodes

$$Si\ size = \sum_{u=1}^{M}(R_u)$$ ----- (18)

Size of the slice with minimum window A_w

min (k, Si size)

(i) Allocation of Resources

$A_i(K_i) = 1$; $K_i >= S_i$ size ------- (19)

$=0$; $K_i < S_i$ size

where, K_i = no.of resources required are allocated in the allocation

$$\sum_{t=l}^{l+Ei-1}(Li, t) = Si\ size$$ ------ (20)

where,

Li is the amount of RB allocated to slice s_i in slot t

t_z is the time at which the packets are generated.

l = time at which a packet is generated.

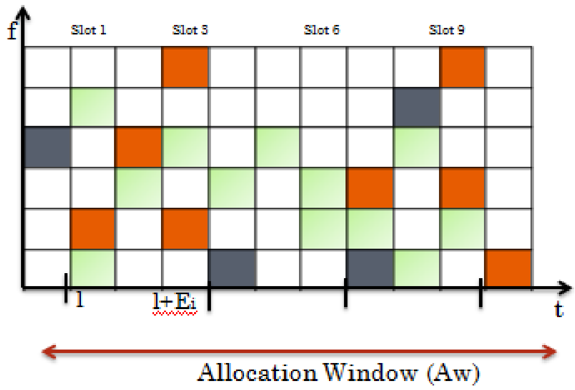


Fig 9: Allocation Window for Deterministic Aperiodic Traffic

As shown in the figure 10, the heterogeneous traffic has resource requirements depending on the application. The resources are been allotted to all the applications with different criteria as mentioned in the proposed work. These allotments of the resources are further optimized by the GWO algorithm so as t achieve the maximum allocation of resources. For experimentation we have considered the allocation window as 10, the packet size to be 30 and the no.of wolfs considered are 3. The iteration we have worked for the linear and the GWO model is 100. As specified earlier we have considered the alpha as the best allocation variable for the GWO model.

5. Results

In this section, from equations 5, 10 and 20 for Non-Deterministic Traffic (ND), Deterministic Periodic Traffic (DP), Deterministic Aperiodic Traffic (DAP) respectively; the resources were allocated and investigated the results for various applications. In this we have considered all the three type of traffic keeping the number of resources as 100. The below table 4 shows that for a particular traffic, the latency, payload, transmission period and the number of nodes considered for that scenario. The system designed was tested with varying number of applications for different types of resources. Table 5 to table 8 shows the % satisfaction of the resources to different types of traffic. This experimentation was carried for 5, 7, 9 and 11 applications and the related results are shown in the tables respectively. According to the results obtained the % satisfaction goes on decreasing with the increasing number of applications.

Table 4: Applications

Type of Traffic	Latency	Payload	Rate	Average Nodes	Transmission Period
Non-Deterministic	-	-	1Mbps 2Mbps 2Mbps	78 27 42	2ms 1ms 5ms
Deterministic Periodic	2ms 1ms 5ms	20Kbytes 2kBytes 42Kbytes	-	15 20 40	-
Deterministic Aperiodic	2ms 1ms 5ms	40Kbytes 20kBytes 32Kbytes	-	14 7 12	-

Table 5: Average % of RB's received by the Slices for 5 applications

Type of Traffic	No. of applications	Required RB's	% satisfaction with LP Model	% satisfaction with GWO Model
Non-Deterministic	2	16	100	100
Deterministic Periodic	2	113	100	100
Deterministic Aperiodic	1	25	100	100

Figure 11 shows the graph of the result for 5 applications as shown in table 5, we considered different number of applications in various traffic types. The slices were created and the resources were allotted to the slices according to the requirements of the applications. The table shows the percentage satisfaction for the LP and GWO models. The allocation window is considered as 10 for the simulation purpose. The different colors resemble a particular slice for particular type of traffic. On similar grounds the experimentation was carried out with variations in the number of applications.

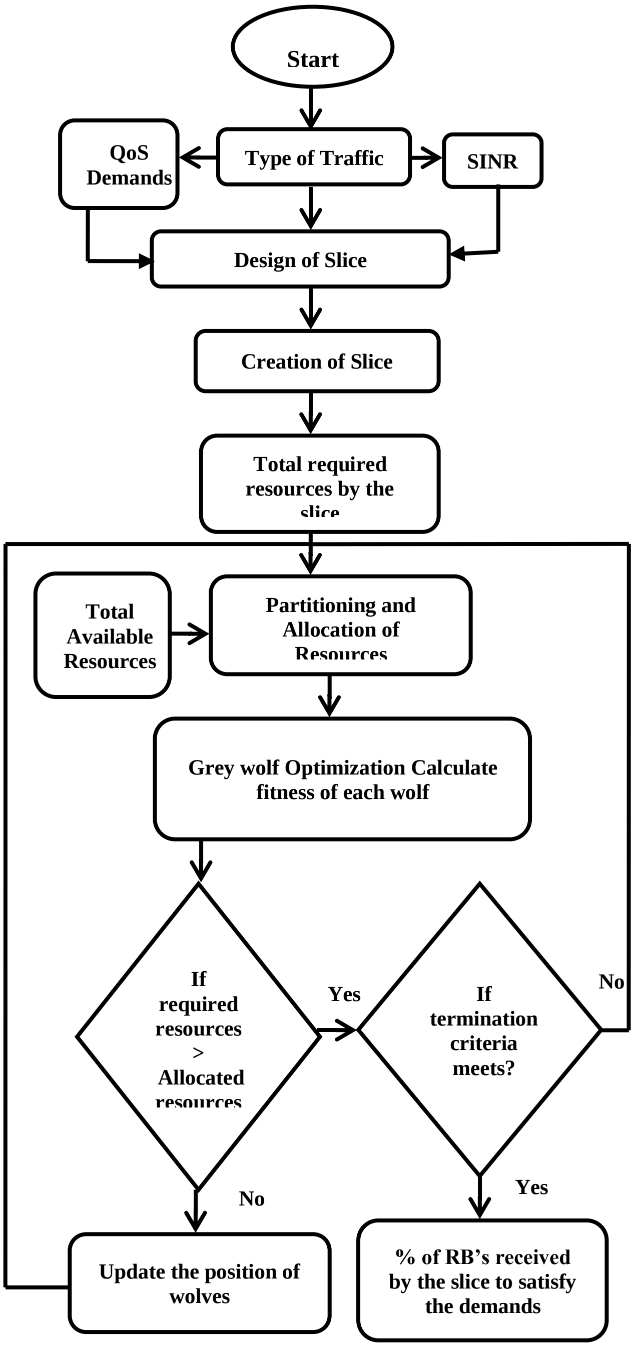


Fig 10: Flow chart of the model with GWO

Table 6 shows the number of applications considered for total 7 applications and figure 12 shows the allotted resources and slices created after the simulation. In the below table it is observed the resources the number of resources allotted to the deterministic traffic is 72 % as the allocation window considered is 100 and our model tries and fits the resources at its best and hence we could achieve better results for the GWO model for deterministic periodic and deterministic aperiodic model

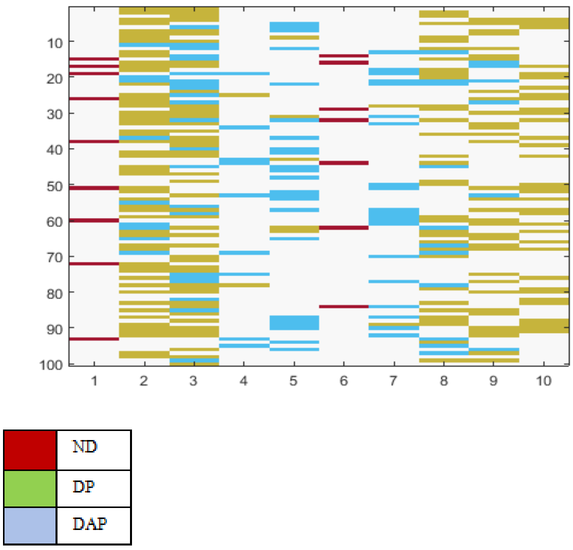


Fig 11. Resources allocated to 5 applications of ND, DP, DAP

Table 6: Average % of RB's received by the Slices for 7 applications

Type of Traffic	No. of applications	Required RB's	% satisfaction with LP Model	% satisfaction with GWO Model
Non-Deterministic	3	32	100	100
Deterministic Periodic	3	155	72.11	100
Deterministic Aperiodic	1	25	59.85	100

Table 7: Average % of RB's received by the Slices for 9 applications

Type of Traffic	No. of applications	Required RB's	% satisfaction with LP Model	% satisfaction with GWO Model
Non-Deterministic	3	32	100	100
Deterministic Periodic	2	110	58.58	94.21
Deterministic Aperiodic	4	80	50.55	88.30

Table 7 shows the number of applications considered for total 9 applications and figure 13 shows the allotted resources and slices created after the simulation. In this the level of satisfaction as decreased more when compared to table 6 as here the number of applications have increased and thus the average % of resources allocated reduced. But here we are still able to manage allocation more than 90% for non deterministic and deterministic models.

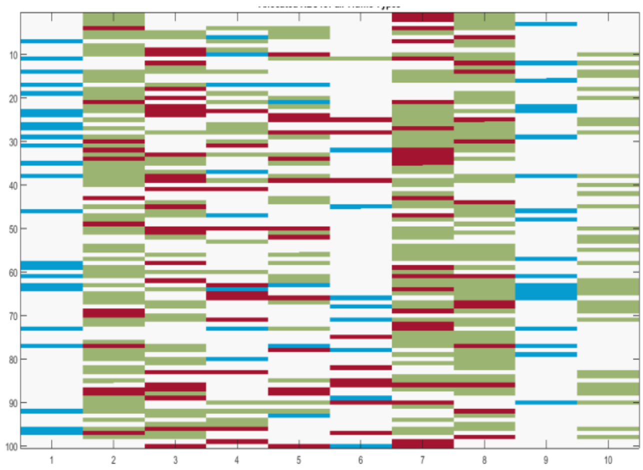


Fig 12. Resources allocated to 7 applications of ND, DP, DAP

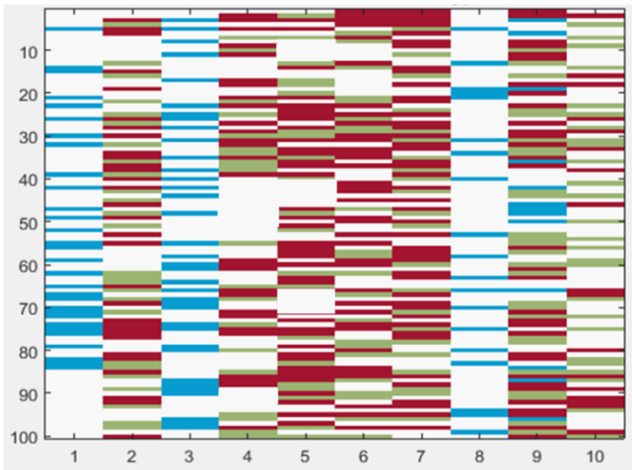


Fig 13. Resources allocated to 9 applications of ND, DP, DAP

Table 8: Average % of RB's received by the Slices for 11 applications

Type of Traffic	No. of applications	Required RB's	% satisfaction with LP Model	% satisfaction with GWO Model
Non-Deterministic	4	59	100	100
Deterministic Periodic	4	223	44.91	89.82
Deterministic Aperiodic	3	70	36.90	84.87

Table 8 shows the number of applications considered for total 11 applications and figure 14 shows the allotted resources and slices created after the simulation. We also simulated the model for 11 applications in which the % allocation has reduced to 60%. With this we could infer that the designed model with the consideration of allocation window to be 10 cannot be used for more than 11 applications as the percentage satisfaction will reduce further.

Figure 15 describes the overall graph of the number of resources versus the applications considered for the experimentation. The graph shows the number of resources required in the slice been designed to satisfy the resources required. From the graph, the number of resources allotted to each type of slices goes on reducing as the applications goes on increasing. For this experimentation we could only comply till 11 no. of applications with considering 100 resources as the total available resources.

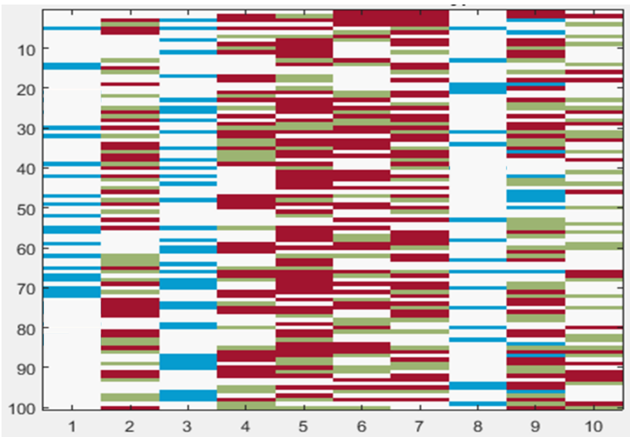


Fig 14. Resources allocated to 11 applications of ND, DP, DAP

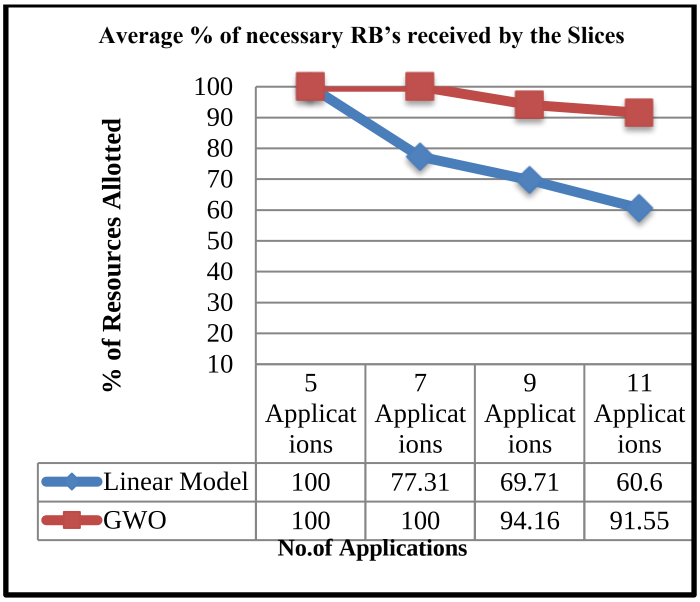


Fig 15. Comparison of LP and GWO model for average percentage satisfaction of resources

In the figure 16 the number of resources was varied for different number of applications for both the models. In this experimentation we reduced the number of resources required with GWO to a larger extent as compared with the LP model and also verified the satisfactory resource allocation for each type of traffic classes. From the graph, the minimum number of resources required increases according to the increase in number of applications.

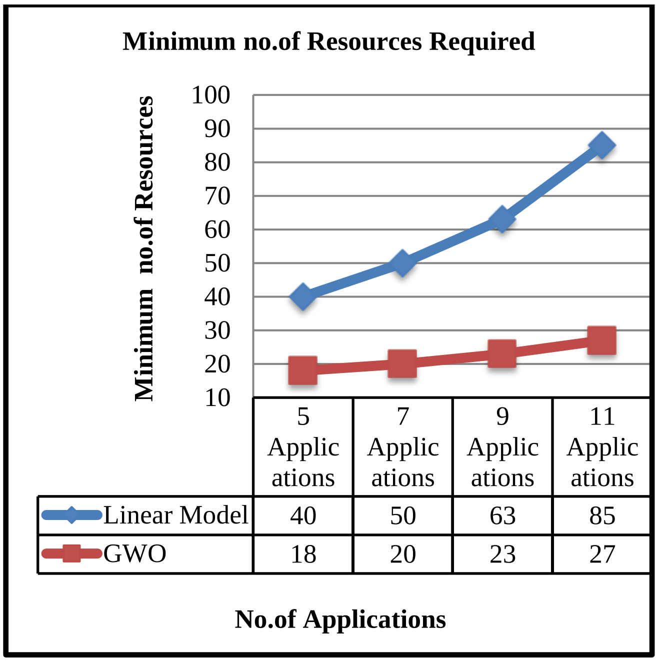


Fig 16. Comparison of LP and GWO model for minimum number of resources requirement

6. Conclusion

In this we have considered the RAN slicing technique for heterogeneous requirements of applications for Non-Deterministic, Deterministic Periodic and Deterministic

Aperiodic applications. Firstly, we have investigated the results by variation in number of applications while keeping the number of resources same and found the percentage satisfaction of resource allocation for 5, 7, 9 and 11 applications for LP and GWO Model. With LP model we could gain average 79.05% satisfaction of allocation of resources. In the extended work with GWO the average satisfaction percentage increased to 96.42%. With GWO model we could gain 25.39% of increase in average satisfaction as compared to LP model. From the experimentation we could conclude that the designed module with initial consideration on number of resources could be applied to not more than 11 applications. This work could also be further checked in the real time scenario which is out of scope in this research. Secondly, we kept the applications same and on experimentation basis reduced the number of resources to examine the minimum number of resources by each type of application scenario. Through this experimentation we inspected the model to work with the least number of resources and still allocating the resources according to the demand of the applications, whereas compromising on the percentage satisfaction.

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