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GEBZE TECHNICAL UNIVERSITY
Computer Engineering Department

GRADUATION PROJECT I

DYNAMIC BANDWIDTH MANAGEMENT FOR SDN (SOFTWARE DEFINED NETWORKS)

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December, 2017
Gebze, KOCAELİ

Bu çalışma 04/01/2018 tarihinde aşağıdaki jüri tarafından Bilgisayar Mühendisliği Bölümü'nde Lisans Bitirme Projesi olarak kabul edilmiştir.

Bitirme Projesi Jürisi

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ÖNSÖZ

Bu kılavuzun ilk taslaklarının hazırlanmasında emeği geçenlere, kılavuzun son halini almasında yol gösterici olan Sayın Doç. Dr. Didem Gözüpek hocama ve bu çalışmayı destekleyen Gebze Teknik Üniversitesi'ne içten teşekkürlerimi sunarım.

Ayrıca eğitimim süresince bana her konuda tam destek veren aileme ve bana hayatlarıyla örnek olan tüm hocalarıma saygı ve sevgilerimi sunarım.

Aralık, 2017 **Mehmed MUSTAFA**

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ABSTRACT

This project proposes an improved dynamic bandwidth management mechanism for SDN, where user join and leave events occur frequently. The proposed method takes into account the following criterion: a user of a higher priority group is always allocated with more bandwidth than a user of a lower priority group and each user group will share the allocated bandwidth among the users of that group equally. The aim of this work is to reduce the control signaling for bandwidth management while fulfilling the mentioned criterion. In other words each user join or leave event will not trigger a bandwidth balancing operation, so the control signaling will be reduced. The simulation results show that the proposed method reduces the signaling overhead by nearly 90-95% compared with the method in which every user join or user leave event triggers a bandwidth balancing operation. The experimental results confirm that the dynamic bandwidth management method fulfills intra-group and inter-group bandwidth management behavior.

Keywords:

Software-Defined Networking,

Software-Defined Networks,

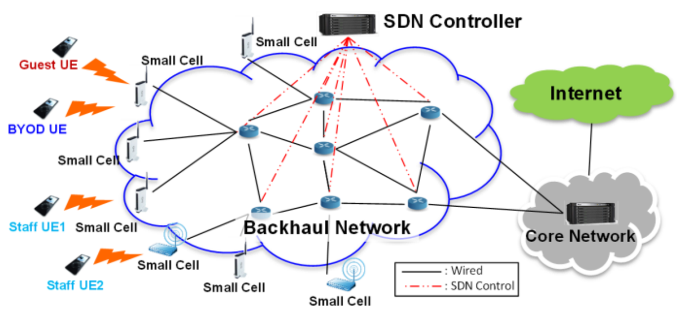
Dynamic Bandwidth Management

December, 2017 **Mehmed MUSTAFA**

1. INTRODUCTION

Bandwidth requirement in the next wireless communication generation (5G) is expected to increase dramatically up to tera scale [1]. The number of connected IoT devices is expected to surge to 125 billion by 2030 [2] which can cause bandwidth management to fail to fulfill the requirements of a such big network. Three new directions are tried to be followed: device-to-device direct communication [10], spectrum reframing [9] and ultra-dense network [8].

This project will implement an ultra-dense network which is consisted of 3 different type groups. The first group is the STAFF, the second group is the BYOD(Bring Your Own Device) [12] and the third group is GUEST. Different kind of people should be treated differently. The higher priority users, STAFF for example, must be provided with more bandwidth than GUEST.



Pic. 1. SDN Wireless Network [11]

In Pic. 1. an SDN-enabled network have main brain, the controller, which have access over the all network.

The aim of the project is to improve the proposed dynamic bandwidth management in an SDN network while trying to offer better quality of service (QoS) to higher priority users.

The remainder of this report is organized this way: In II. Background a little more information is given about SDN. In III. Method proposed method is analyzed and information about the algorithms designed by me is given in the III. A. In IV. section information about user interface, experiments and results are given. In V. section the project is concluded.

2. BACKGROUND

2.1 Software-Defined Networking

Software-Defined Networking is a field which is rapidly expanding. SDN is a fundamentally novel way to program the switches utilized in modern data networks. The SDN Architecture is directly programmable because it is decoupled from forwarding functions. Abstracting the control from the forwarding lets network administrators to meet changing needs by dynamically adjusting network traffic flow without having to touch individual switches. An administrator can change any network switch's rules when necessary. The network brain is centralized in software-based SDN controllers that maintain have a global view of the network. SDN controllers are based on protocols, such as OpenFlow and P4, that allow servers to tell switches to which port to send the incoming packets. SDN lets network managers configure, manage, secure, and optimize network resources very quickly via dynamic automated SDN programs which are independent on proprietary software. The SDN architecture is partitioned by ONF into three logical layers. The Application Layer which includes applications to help for better network management and optimization. The Control Layer consists of network services and at this layer the controllers operate. The communication between application and control layer is provided by APIs. The Infrastructure Layer which is formed by a number of SDN-programmable devices [6].

2.2 SDN-based similar bandwidth management method

The approach given by Huang and et. al., introduces two important principles by which the signaling cost of dynamic bandwidth management can be reduced to 60% as they claim [11]. In this project I am trying to improve the reducing of the signal overhead as much as possible. The main idea is to use the same two principles but change the algorithm to achieve better results and make the test in real-time environment.

3. METHOD

One of the biggest problems in bandwidth management is the bandwidth starvation. To be able to reduce the control signaling while preventing users from bandwidth starvation, the design idea is to give each user at least a minimum amount of guaranteed bandwidth according to the priority group of the user.

In order to design and implement rational and optimal algorithm to provide bandwidth management intelligence, the following steps are followed: problem definition (A), design overview of the mechanism (B), detailed view of the bandwidth management algorithms (C). The problem definition and mechanism are exactly the same as [11], but I have used a bit different approach on the algorithms (C) to get better results in reducing signal overhead.

3.1 Problem Definition

To reduce signal cost while satisfying the design idea three criteria should be formulated [11].

Criteria 1: $\forall i, 0 \leq i \leq m-1 \ni \frac{g_i}{n_i} \leq \frac{g_{i+1}}{n_{i+1}}$;

Criteria 2: $g \leq \frac{g_0}{n_0}$

Criteria 3: $\sum_{i=0}^{m-1} g_i \leq G$

G – total available bandwidth;

m – number of user groups. Number of user groups in this project is three;

g – minimal guaranteed bandwidth. Any user of any group should get at least **g** unit of bandwidth on average;

i – the index of the user group. **i** = 0 means the user group of the lowest priority and **i** = **m**-1 means the user group of the highest priority;

n – number of users in group **i;**

Criteria 1: A higher priority group receives a larger piece of bandwidth than a lower priority group;

Criteria 2: The users in the lowest priority group should be granted by at least **g** unit of bandwidth;

Criteria 3: The total guaranteed bandwidth would not exceed the total available bandwidth.

Every time a user join or user leave event occurs if these three criteria are satisfied then there is no need of bandwidth balancing operation. However, if one or more criteria are not fulfilled then bandwidth balancing operation is required to satisfy the three criteria again. In case of user join event if the bandwidth balancing operation is not able to suffice the three criteria, then user join is restricted.

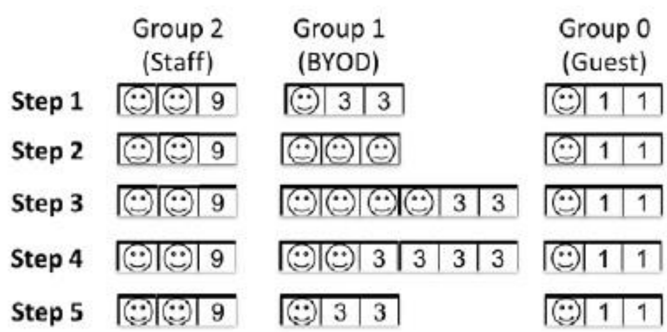
The goal of this project is to design a dynamic bandwidth management method which can fulfill the three criteria most of the time and reduce the signal overhead more than the bandwidth management proposed by Kuei-Li, Mu-Liang Wang and Chin-Tien Huang [11].

3.2 Design Overview of the mechanism

To minimize the control signaling, the batch grant and lazy-adjustment design principles [11] will be used.

Batch Grant Principle – Used whenever user join event occurs. The philosophy of this principle is to guarantee a piece more bandwidth than a minimal need. In this way, a user join event does not always trigger a bandwidth adjustment operation.

Lazy-Adjustment Principle – Used whenever user leave event occurs. The philosophy of this principle is to deallocate bandwidth only if one of the three criteria is broken. Therefore, a user leave does not always cause a bandwidth adjustment operation.



Pic. 2. Very basic example for better understanding the mechanism of bandwidth allocation with Batch Grant and Lazy-Adjustment Principles

These two principles are used to design the bandwidth management mechanism in the following way:

The default base of guaranteed bandwidth units is **b**, where **b** is an integer larger than 1. For example the value of **b** in Pic. 2 for Group 1 is 3. This means that each user in Group 1 will get at least 3 units of bandwidth. The **bi** means the **b** of group with index **i**. The value of **bi** for each group is calculated this way: **bi** = **b**^**i * g**.

The guaranteed bandwidth allocation unit of group **i** is denoted as **qi**, where the qi is calculated this way: **qi** = **b * bi**. The guaranteed bandwidth allocation shows how much bandwidth will be allocated for each group when needed. For example in Pic. 2 the value of **q1** and **q2** is 9 and 27. In other words, whenever Group 1 or Group 2 needs bandwidth allocation they will get extra 9 and 27 units of bandwidth, respectively.

The remainder bandwidth is denoted as **R**, which is the amount of the rest available unallocated bandwidth. For example in Pic. 2. if the total available bandwidth **G** is set to 100 units, then the remainder bandwidth **R** will be 61 units, since the allocated units for Group 2, Group 1 and Group 0 is 27, 9 and 3, respectively.

Pic. 2. shows a simple simulation which demonstrates the Batch Grant and Lazy Adjustment Principles. The number of user groups, **m**, is three and the base of guaranteed bandwidth units, **b**, is set to three. The simulation is as follows:

- Step 1: There are 2, 1 and 1 users in Group 2, Group 1 and Group 0, respectively.
- Step 2: Group 1 has two sequential user join events, but bandwidth adjustment operation is not needed since we already have allocated more bandwidth than needed. This is the Batch Grant Principle in action.

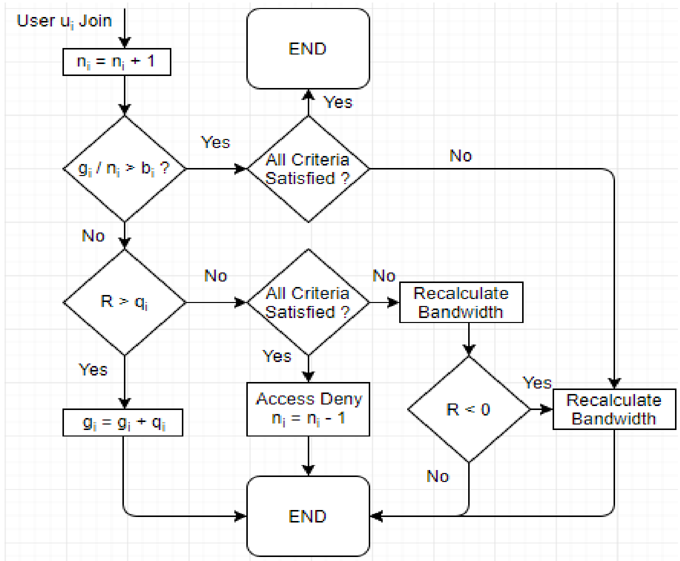
- Step 3: The fourth user joined to Group 1 and since there was no free allocated space bandwidth addition operation was triggered and Group 1 received 9 more units bandwidth, this is the value of **q1**.

- Step 4: Group 1 has two sequential user leave events, but bandwidth adjustment operation is not needed since all three criteria holds.

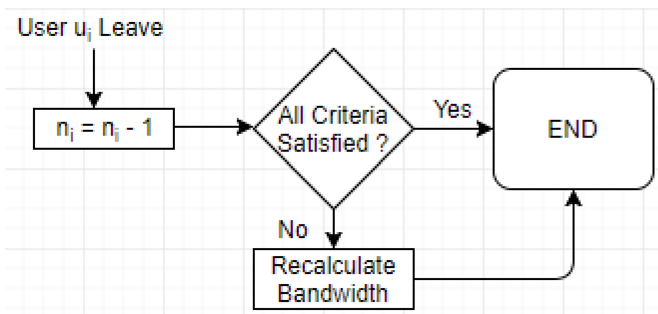
- Step 5: Group 1 has user leave event, which breaks Criteria 1 and thus bandwidth adjustment operation is needed. How is Criteria 1 broken ? Group 2 has 2 connected users and allocated 27 units of bandwidth. So average bandwidth per user is 13,5. Group 1 has 1 connected user and allocated 18 units of bandwidth. So average bandwidth per user is 18. This breaks the Criteria 1 and triggers bandwidth adjustment operation.

The network's total available bandwidth, **G**, is limited so at some point the amount of rest available bandwidth, **R**, could be insufficient in a bandwidth addition operation. If so the allocated bandwidth of each group is reallocated again according to the user number in the group. For example in Pic. 2. assume that the total available bandwidth, G, is 50 units and in Step 4 two sequential user join events occur in Group 2. The first user will join without problem because there is allocated bandwidth, but the second user will not be able to join since there are not allocated bandwidth left and the rest available bandwidth, R, will be 2 units (50 – 27 – 18 – 3 = 2) the. Since Group 1 has 2 connected users but have allocated 6 slots of bandwidth. 3 slots will be deallocated and allocated to Group 2 so the second joining user can join instead of being denied.

3.3 User Join and User Leave event algorithms



Pic. 3. User Join Bandwidth Allocation Procedure



Pic. 4. User Leave Bandwidth Allocation Procedure

Recalculate Bandwidth method:

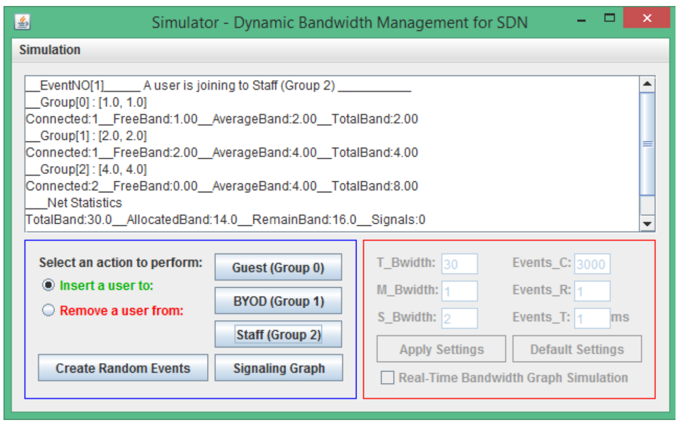
```
for(group : groups){
    bi = pow(b, i) * g;
    qi = b * bi
    if(group.userSize() < b)
        gi = b * bi
    else
        gi = group.userSize() * bi
}
```

4. EXPERIMENTS

4.1 Simulation Environment

The simulating environment and the implementation of the SDN environment was made in Java v6.0. XChart 3.5.0 library [3] was used to produce the simulating graphs. An inspiration for the design of the SDN environment was thanks too ONOS(Open Network Operating System) [4], Mininet [5] and ONF(Open Networking Foundation) [6].

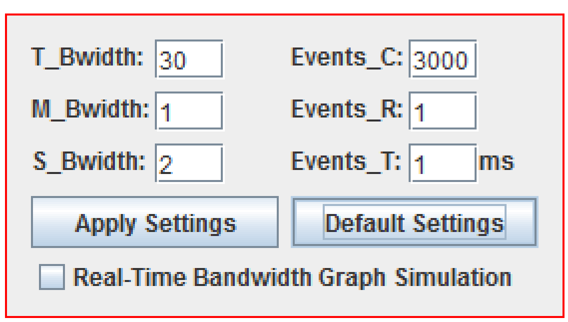
4.2 User Interface of the Simulator



Pic. 5. User interface of the simulator

The user interface of the simulation environment is very simple and easy for use. It consist from 3 panels (settings panel, user add or remove panel and scroll panel) and 3 start menu items (start, stop and exit). These panels will be explained in detail next.

- Simulation Settings Panel



Pic. 6. Simulation Settings Panel

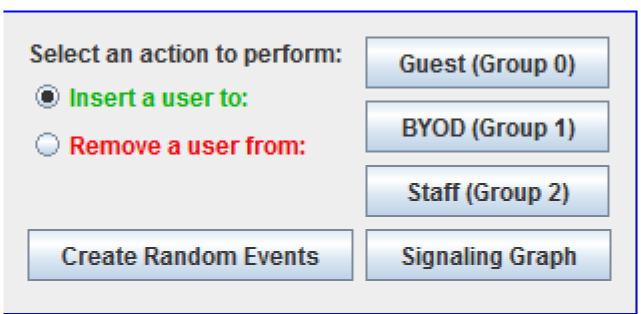
Label and Text Boxes Legend:

- T_Bwidth = Total Available Bandwidth, G;
- M_Bwidth = Minimal Guaranteed Bandwidth, g;
- S_Bwidth = Slots/Default Base of Guaranteed; Bandwidth, b;
- Events_C = Events Count. This number defines how many random user join/leave events will be produced when "Create Random Events" button in the User Add or Remove Panel is pressed;
- Events_R = Events Repeat. This is simple a multiplier to the Events Count. When you want to test 3000 events in 50 trials instead of pressing the "Create Random Events" 50 times with the help of the repeater only 1 press is enough.
- Events_T = Events Timer. This defines how often random event will occur. For example 1 ms means every 1 ms a random event will occur. So 3000 events will be completed in 3000 ms or in other words 3 seconds.

Buttons and Check Box Legend:

- Default Settings Button – when this button is pressed the ui automatically set all text boxes with default values.
- Apply Settings Button – saves the values in the text boxes to the simulation environment's memory. Make sure you not forget to press this button before starting the simulation or you might get wrong results!
- Real-Time Bandwidth Graph Simulation Check Box – when this check box is selected a new extra window with graphs will be opened. This graph window will draw the graphs of the average allocated bandwidth of each group in different colors.

- User Add or Remove Panel



Pic. 7. User Add or Remove Panel

Radio Buttons and Buttons Legend:

- Insert a user to – if this radio button is selected the group buttons will generate a user join event.
- Remove a user from – if this radio button is selected the group buttons will generate a user leave event.
- Guest (Group 0) Button – when pressed this button will generate user join or leave event into group 0 according to the selected radio button.
- BYOD (Group 1) Button – when pressed this button will generate user join or leave event into group 1 according to the selected radio button.
- Staff (Group 2) Button – when pressed this button will generate user join or leave event into group 2 according to the selected radio button.
- Signaling Graph Button – when pressed a new extra window with graph will be opened. This window will show how much the control signal is reduced according to the generated events.
- Create Random Events Button – when pressed random events will occur and these events will be displayed on the scroll panel. The count of the random events depends on Events_C and Events_R variables.

* Scroll Panel

```
__EventNO[1]_____ A user is joining to Staff (Group 2) __________
__Group[0] : [1.0, 1.0]
Connected:1__FreeBand:1.00__AverageBand:2.00__TotalBand:2.00
__Group[1] : [2.0, 2.0]
Connected:1__FreeBand:2.00__AverageBand:4.00__TotalBand:4.00
__Group[2] : [4.0, 4.0]
Connected:2__FreeBand:0.00__AverageBand:4.00__TotalBand:8.00
___Net Statistics
TotalBand:30.0__AllocatedBand:14.0__RemainBand:16.0__Signals:0
```

Pic. 8. Scroll panel with single event information

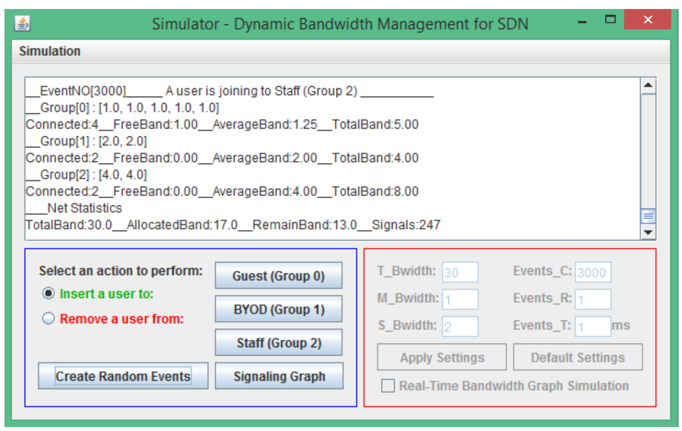
The scroll panel is used to track the events and networks statistics manually. Pic. 8. shows single event output. From this output we can observer the information of each event state. EventNo[1] shows that this output is the information about the first event. Next to the EventNo[1] we have information about the event whether the event was user join or leave and into which group. The next 6 lines show information about the all groups. The odd lines show how many bandwidth is allocated in each group. The even lines show statistics about each group, like how many connected users are in the group, the free bandwidth, the average bandwidth, the total bandwidth. The last line shows statistics about the whole network like what is the total available bandwidth, what is the allocated bandwidth by all user groups, the remaining bandwidth and how many control signals occured so far.

To run the simulation set your settings from the Simulation Settings Panel the Apply the settings. After that from the Simulation Menu select Start to start the simulation, Stop to stop the simulation and Exit to close the simulation program.

4.3 Simulation Examples

- Test cases for control signal reduction

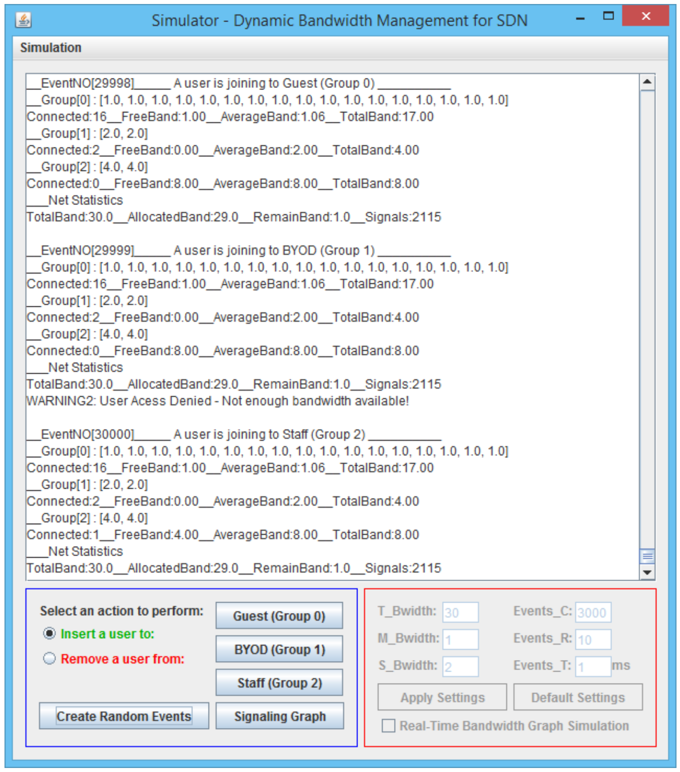
- Test 1 Inputs: T_Bwidth: 30, M_Bwidth: 1, S_Bwidth: 2, Events_C: 3000, Events_R: 1



Pic. 9. Test Case 1 – 3000 events, 247 control signals

The simulation result shows that from total 3000 events only 247 bandwidth allocations were made. Which is 92% reduction of the control signaling.

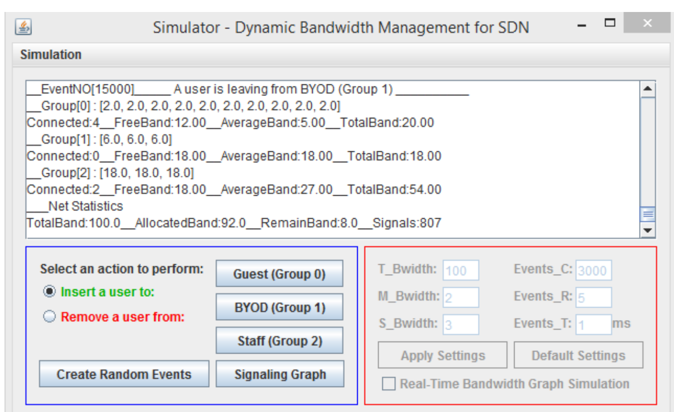
- Test 2 Inputs: T_Bwidth: 30, M_Bwidth: 1, S_Bwidth: 2, Events_C: 3000, Events_R: 10



Pic. 10. Test Case 2 – 30000 events, 2115 control signals

The simulation result shows that from total 30000 events only 2115 bandwidth allocations were made. Which is 93% reduction of the control signaling.

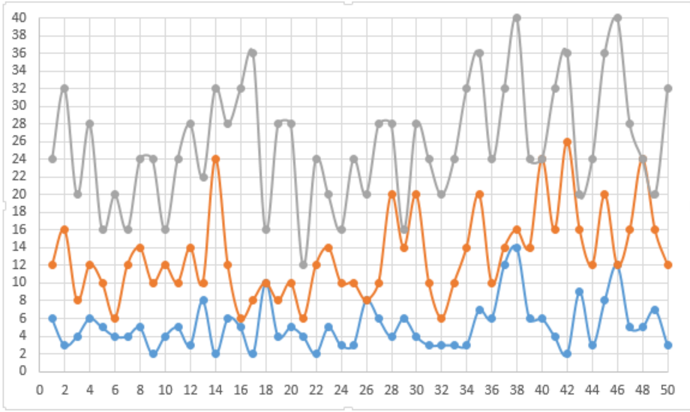
- Test 3 Inputs: T_Bwidth: 100, M_Bwidth: 2, S_Bwidth: 3, Events_C: 3000, Events_R: 5



Pic. 11. Test Case 3 – 15000 events, 807 control signals

The simulation result shows that from total 15000 events only 807 bandwidth allocations were made. Which is 95% reduction of the control signaling.

- Test case for average bandwidth allocation of each group – Inputs: T_Bwidth: 30, M_Bwidth 1, S_Bwidth: 2, Events_C: 3000, Events_R: 50



Pic. 12. Test Case for average bandwidth allocation of each group

Priority of the groups: Group 0 < Group 1 < Group 2

The graphs shows that a user from a higher priority group receives higher average bandwidth than a user from a lower priority group.

5. CONCLUSION

This project proposed a dynamic bandwidth management method for SDN. The simulation results show that it is possible to reduce the controlling signal for bandwidth management up to 95%. In other words the suggested method is reducing the control signaling by 19 times in comparison to the method which requires bandwidth management operation every time a user join or leave event occurs. This rate of signal reducing is improved by 35% in comparison to the algorithms proposed by Huand et. al. [11]

The experimental results verify the correctness of the algorithms with respect to the intra-group and inter-group bandwidth management behavior since no bandwidth starvation occurs and higher priority users always receive more average bandwidth than lower priority ones.

As a future work, we plan to experiment with the inputs of the simulation to obtain the best ratio among Total Available Bandwidth, Minimal Guaranteed Bandwidth and Default Base Guaranteed Bandwidth. With a good ratio we believe that the signaling overhead can be reduced by 98-99% and stabilized at that percentage.

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