Journal of Network and Innovative Computing
ISSN 2160-2174 Volume 4 (2016) pp. 246-255

Medium Access Fairness and Services Differentiation in Wireless Mesh Network

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Abstract: **The recent computing networks have an important role in the data transfer in real time, such as IP voice data and multimedia streaming. The Applications that generate these traffic types have some performance requirements; they don't accept any delay in the delivery of their packages to their destinations, so they don't have any information distortion.**

The guarantee of special treatments to different packet classes requires the use of the differentiation services architecture. It is a method that allows on one hand, providing different quality services to the different types of packet, according to the treatment priority, on the other hand, reducing the loss rate of demanding packets.

In this article, we will present a mechanism with which we can, firstly, guarantee a fair sharing of the bandwidth to different flow classes, secondly, provide to each of them a special service quality.

Keywords: WMN, Diff-Serv, fairness, QoS, rate, token bucket.

I. Introduction

The wireless mesh network WMN based on the standard 802.11s, is an extension of the technology 802.11. The goal was to create a wireless distribution system, an automatic management of paths and topology, while providing, in an inherent way, a high fault tolerance and a big scalability. The use of a wireless mesh topology also allows to a network more of flexibility, and reduces the disadvantage.

In a WMN "Figure.1", all the STA stations are traffic producers. The MAP mesh access points recover these traffics and transfer them to the wireless distribution system where there is only the mesh points MP. The latters route the traffics to the gateway MPP and then to another type of network.

The goal of the QoS is to make a network infrastructure that is capable to stand the communication services having some specific qualitative requirements. These requirements come from some distributed applications that are not satisfied an, more with the BE service "best effort".

The Architecture for the differentiation services (Diff-Serv) is an idea that allows aggregating the applicative flows, also named micro-flows, depending on their QoS constraints. The most flowing micro-flows in the network, ordered by priority, are: audio, video, data, and the background. Each type has a special QoS treatment.

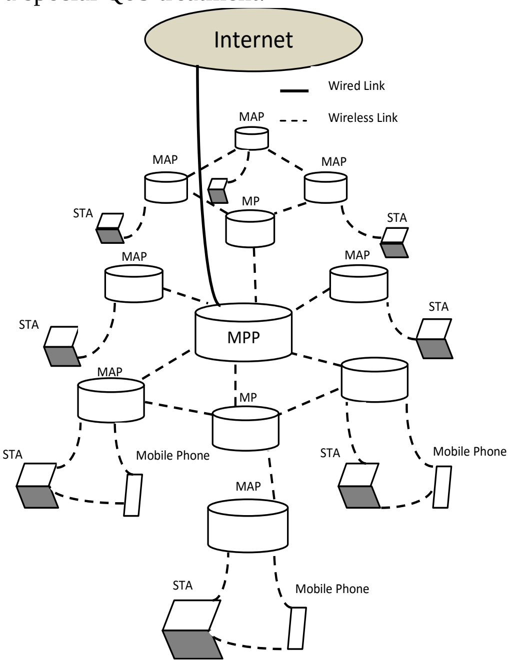

Figure 1. Architecture of Wireless Mesh Network [17]

The node in the wireless mesh network plays in the same time the role of a traffic generator and a medium of packet flows coming from the other nodes. Consequently, a node's link layer receives, on one hand, the generated packets by the superior layers, and on the other hand, an enormous amount of packets from the flows of different nodes. The packet flows of the superior layers are considered as an aggressive flow, because their packets' rate is higher than the other flows.

The wireless mesh network doesn't contain a differentiation service architecture, consequently, the different type of packets are treated the same way. Having a high priority, packet flows don't benefit from a specific quality service. In parallel, the flows of data and background packets, which have a lesser priority, can benefit from time to time, from a better QoS at the expense of the others.

These last findings, allow us to bring out some problematics linked, firstly, to the resources' occupation from different packet flows, and secondly, to the differentiation service of each type of micro-flow.

In this work we will clear up, by a simulation, the problematic concerning the fairness of the bandwidth occupation by different type of micro-flows, and provide them with different quality services. Then, based on the work [1], we will propose a protocol algorithm which allows a fair sharing of the bandwidth for the different types of flows, and to guarantee them different service qualities. This protocol is based on an exchange of control messages between the nodes, in order to agree on the QoS parameters, from which each flow type will benefit. The setting of these parameters will be performed with the help of the token bucket mechanism.

II. The Problem of Fairness and Differentiation of Service

A. Simulation parameters

To properly define the problematics concerning the differentiation service and the fairness, we chose the NS2 software (Network Simulation 2) v2.34 to achieve a simulation on a wireless mesh network, and the operating system linux as a simulation environment.

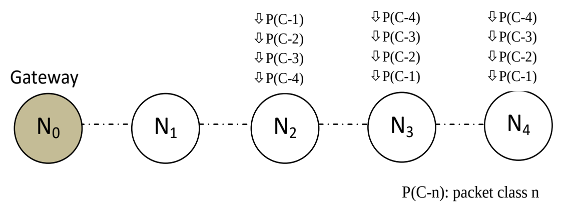

Figure 2. Bus topology of five nodes

The simulated network WMN is a bus topology of five nodes “Figure.2” which are adopted from the routing protocol HWMP (hybrid wireless mesh protocol) [2]. This protocol is developed in order to simulate the networks based on the 802.11 standard.

The distance between each node is 175 meters, which guarantees that the nodes cannot reach the further nodes without passing through the neighboring nodes of one hop. The channels are configured to have a data rate of 11Mbps and a base rate of 2Mbps, also the transmission zone is fixed in 250m.

We chose according to [3], the CBR traffic via UDP. These traffics have four classes depending on the treatment priority. The size of each packet is 128 bytes with an inter-departure of 0.003 ms.

As a simulation scenario, the nodes **N_2**, **N_3** and **N_4** will generate some packets at the instant t0 in order to send them to the gateway **N_0**. The packets are from different classes (1, 2, 3 and 4) according to the treatment priority. The node **N_2** starts sending packets of low priority class, and then packets of high priority class (from class 4 to class 1). However, the nodes **N_3** and **N_4** start sending packets in ascending order of class “Figure.2”.

The notation **P(C-k)** in the “Figure.2” represents a **k** class packet.

At the end of the simulation which lasted 300s, we will count the number of packets by class, and we will present the throughputs’ behavior during the time for the different types of flows coming from different nodes.

The summery of the simulation parameters is presented in the table I:

Variable	**Valeur**
Topology	bus
Number of nods	5
Routing Protocol	HWMP
Transmission range	250 m
Distance between Nods	175 m
Simulation duration	300 s
RANN interval	3s
Trafic type	CBR (over UDP) Class (1,2,3 and 4)
Packet size	128 (bytes)
inter-departure between packets	0.003(ms)

Table 1. The summary of the simulation parametres

B. Results of simulation and analysis

The analysis of the «Figure.3» allows us to extract some findings:

- Even if the nodes **N_3** and **N_4** have sent packets the same way (class 1, class 2, class 3 and then class 4), the gateway didn’t receive the same packet number of the same class from these nodes.
- We note also that the further the node is from the gateway, the lesser quantity of packets it receives from this node.
- The WMN doesn’t adopt a system of differentiation service, which shows the result concerning the node **N_2**. This node didn’t benefit from a system that allows sending packets by class priority. We remind that the node **N_2** started sending packets by this way (class 4, class 3, class 2 and class 1).

To understand the fundamental cause of this figure result “Figure.3”, we must analyze the behavior of each class throughput of a micro-flow coming from different nodes “Figure.4”.

The notation **N(n,k)** in the “Figure.4”, presents the k class flow generated by the node number **n**.

- For the flows coming from the node **N_2**, we consider that micro-flows of class4 are aggressive. During the simulation time, this flow benefited from a high rate comparing to the others, which explains the important quantity of these packets received by the gateway.

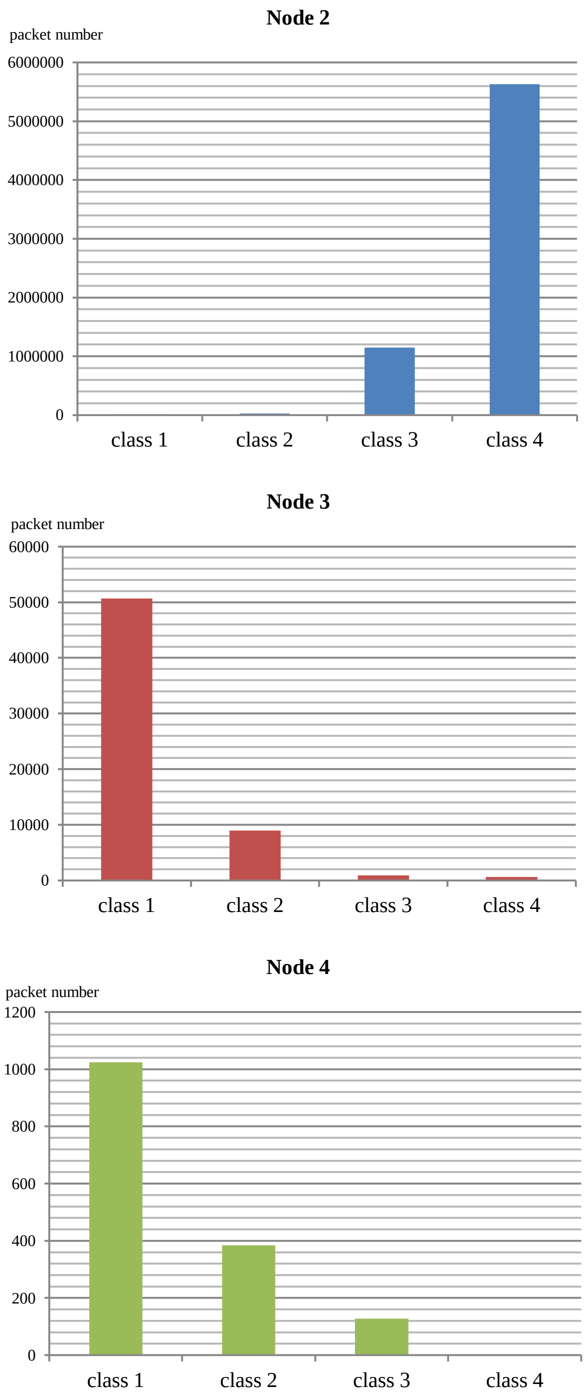

Figure 3. Number of different packet class received by the gateway

- The rates of each micro-flow of the node N_2 were regular, however the nodes N_3 and N_4 micro-flows' rates are only separate pulses. The further the node is from the gateway, the bigger the time is between pulses.
- The average of the rates of micro-flows coming from the nodes near the gateway is higher in comparison to the further nodes' micro-flows. In another words, the bandwidth sharing is not fair.

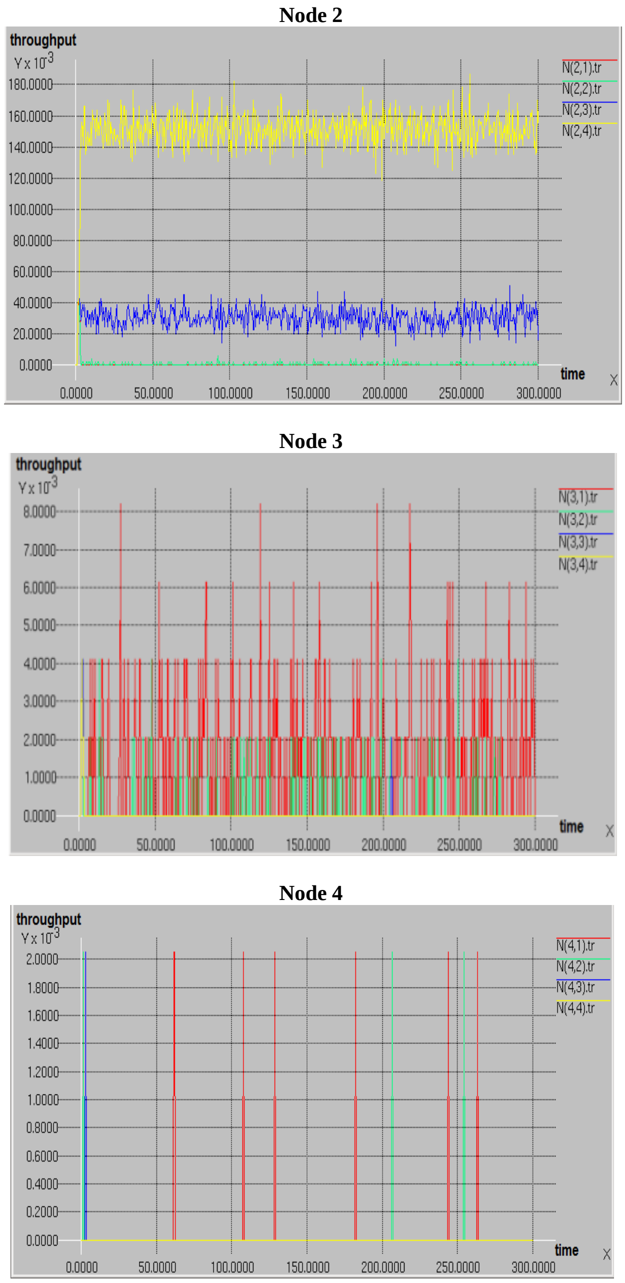

Figure 4. The throughputs behavior of each micro-flow

III. Related Works

Before locating some previous works, we will analyze and criticize the work [1] with which we extracted our protocol.

Within a node, the researchers of the work [1] tried to find the ideal combination of queues, at the level of the mac and network layers, which can guarantee a fair sharing of the bandwidth. From some simulations on several scenarios, they agreed on a system from six. The schema presented in "Figure.5" explains the mechanism with the result.

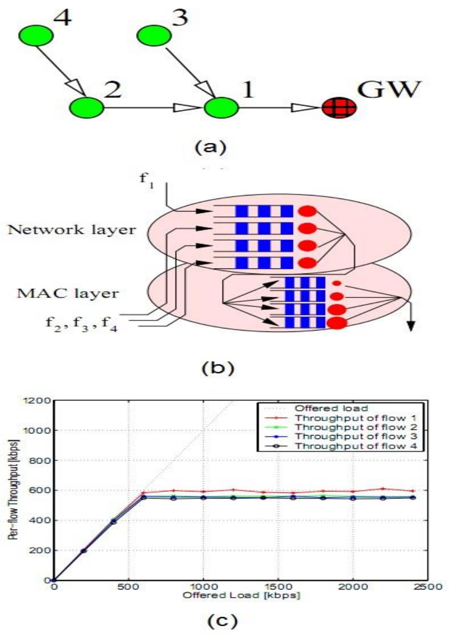

Figure 5. The queues system [1]

We note that the system has shown a positive effect on the fairness, it provides a queue to each flow entering the node, either at the level of the mac layer or network layer. The service time, which the system provided to the flows coming from the far nodes, is shorter than the others, because these flows acquire some delays while crossing a node.

Even if the work [1] has positive points, we will situate two negative points that we will correct in our mechanism:

- The system provides a number of queues equal to the number of flows that cross the node. But in case the node is crossed by an infinity of flows, this principle will be a waste of memory.
- The service time benefited by each flow is constant during the simulation time, whatever the arrival rate of flows to the nodes.
- In the simulation we considered that the rates of each flow are constant, but it's not the case in reality.

Several works were done in order to solve, in a separated way, the problem concerning the differentiation service, thereby the fair sharing of the bandwidth. Between these works we specify some ones:

The work [4] has mentioned the differentiation service problem in the networks based on the standard 802.11. Afterwards, they suggested a mechanism in order to provide the best QoS to the audio flow. The fundamental goal was to reduce the congestion at the level of a node from a packet's distribution before they access the link layer.

In order for the link layer to stand applications in real time, the researchers of [5] developed a routing protocol named Q-CBRP that works in collaboration with the mac layer so as to route the multimedia traffics. The network nodes in this case, adopt the IEEE 802.11e standard.

Also within the 802.11e standard environment, the work [6] developed a system that allows to estimate the valid bandwidth to transfer multimedia packets. The estimation is done through the channel interference measure.

The researchers of [7] introduced a mechanism combining the differentiation service and the aggregation of packets within the WMN network. The mechanism is implemented as an extension of the "MIT Roofnet" platform. The implementation doesn't require any modification in the mac layer, it can be deployed and exploited easily.

In order to develop the QoS in the WMN, the algorithm BEPTC [8] allows to estimate the available bandwidth through the flowing flows and using the maximum of cliques in the graphs theory.

The article [9] suggested a mechanism that allows, on one hand, the collusion reduction and the network global throughput increase, on the other hand, allows the addition of a CoS class service layer. The simulation on NS-2 has shown the efficiency of this mechanism.

The CPCRA MAC mechanism [10] is implemented in order to differentiate the services for different traffic priority, it's based on the assignmentof each packet class to different radio channels instead of putting the set in a single channel. This mechanism allows minimizing the disturbance between the packets' flows, as well as guaranteeing a better QoS for high priority traffics.

The work performed in [11] suggested an algorithm established in each node in the network, to guarantee a maximum access of the different packet flows to the queue. The execution of the algorithm depends on the recorded information in each node, these pieces of information concern the fair sharing of the queue for the flows that are crossing it. These pieces of information are stored in a table and vary dynamically according to the packets inter-arrival change.

The researchers of the work [12] considered that it exists two types of packets: the aggressive and the non-aggressive. With this principle, they innovated a mechanism based on a variable named "drop probability" that allows the node to decide either reject or accept the aggressive flows packets. During each rejection of non-aggressive flows packets, the "drop probability" variable value increases. This increase triggers a signal that prevents the access of aggressive packets to the medium. Once the loss rate of packets of the non-aggressive flows decreases, the "drop probability" decrements.

The work team in [13] considered that the wireless mesh network contains several gateways that their role is to transmit the data to internet. In this sense, this work team divided the gateways to two types: the first type manipulates the strong rate data, and the second one manipulates the weak rate data. The goal is to separate the aggressive flows from the others.

The works of the article [14] are about the development of a routing protocol that allows to change the packets flow path in case of a link congestion in a wireless mesh network. During each congestion of a node queue, the latter sends messages to the adjacent nodes so that they change their packets flows paths if they use the congested node as a medium.

The authors of [15] tried to solve the congestion problem by using the 802.11e protocol, they limited time of resources reservation of each node using the TXOP parameter (transmission opportunity). For this purpose, they allocated a transmission time to each node proportional to TXOP and that depends on the number of the clients stations linked to this node.

In the work [16], the mechanism allows giving the lowest values of CWmin and CWmax to the adjacent nodes to the gateway and the highest values to the far nodes from the gateway. The aim is to minimize the collusion probability between the nodes flows and to allow the fairness at the level of the resources allocation.

IV. Fairness and Differentiation of Service (FaDoS)

The FaDoS is an algorithm that we integrated in wireless mesh network nodes that, firstly, guarantees to the flows coming from different nodes a fair access to the medium, secondly, provides a differentiation service to each type of flows according to its treatment requirements. This algorithm is based on an exchange of information concerning the flow rate condition in the network. Moreover, it works in collaboration with the token bucket mechanism.

A. *The token bucket*

The token bucket algorithm allows controlling the number of packets generated at each second by a computer network node. It's used in particular to make a flow throughput regular (shaping) or to limit a throughput (policing) "Figure.6".

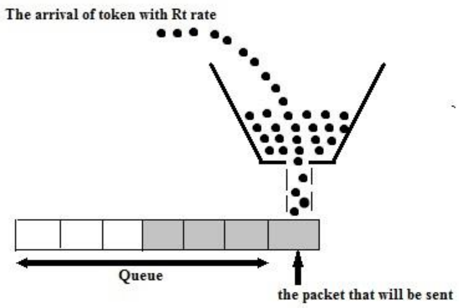

Figure 6. Token bucket mechanism

Here is a brief explanation concerning the token bucket mechanism.

- Let's take the example of a leaky bucket at the bottom that contains tokens, each token represents a bit.
- The size of the bucket, by bytes, represents the quantity of tokens that can be stored in it.
- The bucket is filled of tokens with a constant rate $\mathbf{R_t}$.
- A packet transmission is accompanied by a decrease of tokens from the bucket. The number of the expelled tokens is equivalent to the packet size in bits.
- When a packet arrives, if there are not enough tokens in the bucket, it must wait in the queue until the bucket is filled. If the queue is congested, the packet is in excess.

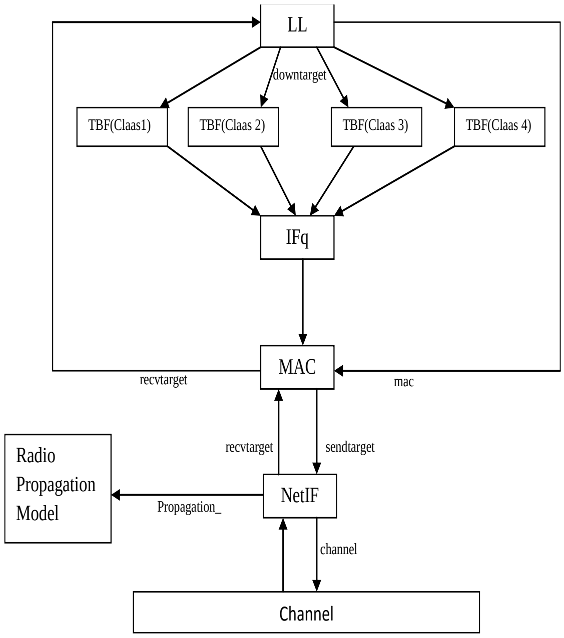

Figure 7. The node architecture

In our work, we integrate four token buckets in each node of the network in order to treat the four classes of micro-flow outgoing the medium "Figure. 7". The goal is to provide different quality services in a manner to vary dynamically the tokens rates $\mathbf{R_{t_j}}$ **(j ϵ {1, 2, 3, 4})**.

B. *The FaDoS mechanism*

Within a node of the network, the algorithm is executed periodically to define, on one hand, the need of the bandwidth by each flow outgoing from the other nodes, on the other hand, the treatment requirements of each micro-flow of different classes crossing this node. Then, the algorithm will calculate the benefit rates of each outgoing micro-flow from this node.

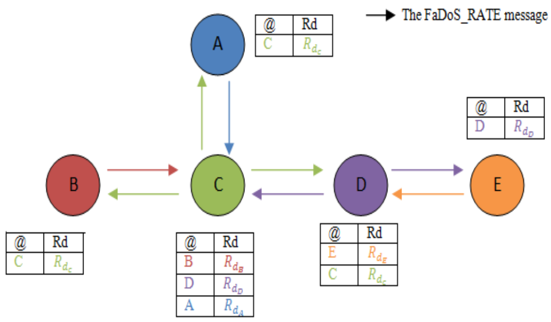

Figure 8. The exchange of FaDoS_RATE messages

- The **FaDoS_RATE** contains two necessary information: the MAC address of the message generator node and the desired packet rate $\mathbf{R_d}$ by this node.
- Each node will receive many **FaDoS_RATE** messages, and during each reception, the node will store this

message content in a table named "**rate table**" made of two columns: MAC address and desired rate Rd "Figure.8".

- At each storage of a new information in the rate table, the node will calculate each class of micro-flow rate that it will benefit $\mathbf{R_{b_j}}$ $\mathbf{(j \in \{1, 2, 3, 4\})}$ from the network bandwidth.
- We affect the benefit rates $\mathbf{R_{b_j}}$ which the algorithm calculated to the token buckets rates $\mathbf{R_{t_j}}$.

The sum up of the FaDoS mechanism is presented in the "Figure.9".

Program: This mechanism allows each node to have an accurate throughput and to guarantee the network fairness

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Input:

- $\mathbf{R_{d_i}}$: all desired rate by the adjacent nodes in a single hop at time **t**, and that are saved in the node **x** table of rates **(i ϵ {0,1.2…,n})**
- $\mathbf{R_g}$: the overall rate of the network

Output:

- $\mathbf{R_{b_{(x,j)}}}$: The rate that will be benefited by the micro-flow **j** of the node x from the network bandwidth at time **t(j ϵ {1, 2, 3, 4}).**

Begin

When we receive a **FaDoS_RATE** message, the node performs the following actions:

- Extract from the **FaDoS_RATE** messages the sender's address **@** and the rate it desired $\mathbf{R_d}$.
- Save the desired rate $\mathbf{R_d}$ and the sender address **@** in the rates table.
- Calculate the rate $\mathbf{R_{b_{(x,j)}}}$ that will be benefited by the micro-flow **j** of the node **x** from the network bandwidth.
- Affect the rates benefited $\mathbf{R_{b_{(x,j)}}}$ to the rate of token $\mathbf{R_{t_{(x,j)}}}$ at the token bucket mechanism.

End

Figure 9. The FaDoS algorithm mechanism

In order to calculate the benefit rates of each flow class coming from a node **x**, we rely on the recording of the table of rates desired by the other nodes, and the following variables:

- $\mathbf{R_{d_x}}$: The rate desired by the node **x** at an instant **t**.
- $\mathbf{R_{b_x}}$: The benefit rate of the flow outgoing from the node **x** at an instant **t**.
- $\mathbf{R_{b_{(x,j)}}}$: The benefit rate of the **j** class flow coming from the node x at an instant **t**.
- $\mathbf{R_{th}}$: The theoretical rate of the network.
- $\mathbf{R_g}$: The global rate of the network.

$$\mathbf{R_g = \beta * R_{th}} \quad \mathbf{(\beta\sim=0.7)}$$

- $\mathbf{R_e}$: The rate shared evenly.

$$\mathbf{R_e = R_g/n}$$

  - ✓ **n:** The number of nodes in the network.
- $\mathbf{R_r}$: The residual rate.

$$\mathbf{R_r = \sum_{i=1}^{p} R_e - R_{d_i}}$$

  - ✓ Case when $\mathbf{R_e > R_{d_i}}$
  - ✓ **p** : the number of node, with $\mathbf{R_e > R_{d_i}}$
- $\mathbf{R_{min}}$: The minimum rate benefited by a node in the network.

If we consider that the node x in the network generates a single macro-flow (that contains the four types of micro-flows), we will first calculate the benefit rate R_{b_x} of this macro-flow at the time t according to the following cases:

If $\mathbf{R_{d_x} < R_{min}}$

$$\mathbf{R_{b_x} = R_{min}}$$

If $\mathbf{R_{d_x} < R_e}$

$$\mathbf{R_{b_x} = R_{d_x}}$$

If $\mathbf{R_{d_x} > R_e}$ we will perform the following calculation:

(1)

$$\mathbf{R_{b_x} = R_e + R_{a_x}}$$

- ✓ $\mathbf{R_{a_x}}$: The quantity of rate that we can add to the node **x** that demands more than $\mathbf{R_e}$.

(2)

$$\mathbf{R_{a_x} = \frac{R_r * P_x}{100}}$$

- ✓ $\mathbf{P_x}$: The percentage of the residual rate that will be benefited by the node **x**.

(3)

$$\mathbf{P_x = \frac{(R_{d_x} - R_e) * 100}{\sum_{i=1}^{k} R_{d_i} - R_e}}$$

The formula below is applied when $\mathbf{R_{d_i} > R_e}$ (**k :** the number of nodes with $\mathbf{R_{d_i} > R_e}$).

From (2) and (3):

(4)

$$\mathbf{R_{a_x} = \frac{R_r * (R_{d_x} - R_e)}{\sum_{i=1}^{j} (R_{d_i} - R_e)}}$$

The final formula that allows us to calculate the benefit rate of a node x in the case of $\mathbf{R_{d_x} > R_e}$ is as follows:

From (1) and (4)

$$\mathbf{R_{b_x} = R_e + \frac{R_r * (R_{d_x} - R_e)}{\sum_{i=1}^{k} (R_{d_i} - R_e)}}$$

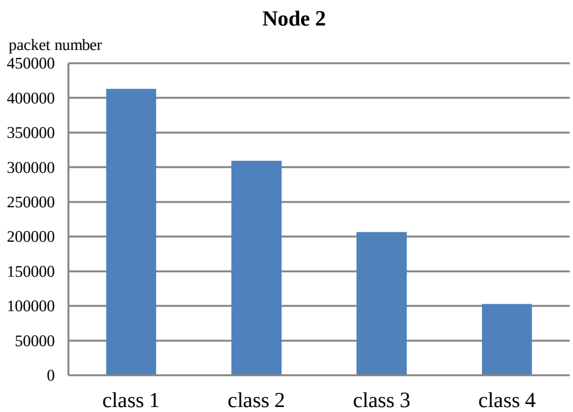
The table II, summarize the formulas to calculate the benefit rates for each class of the flow generated by the node **x** according to the possible cases.

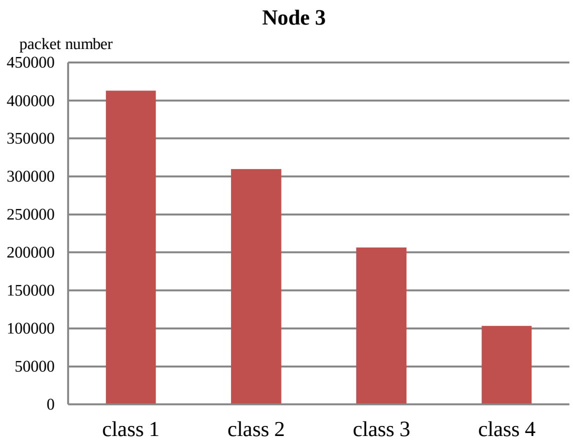
if	$R_{d_x} < R_{min}$	$R_{min} < R_{d_x} < R_e$	$R_{d_x} > R_e$
Class 1	$R_{b_{(x,1)}} = R_{min} * 0.4$	$R_{b_{(x,1)}} = R_{d_x} * 0.4$	$R_{b_{(x,1)}} = 0.4 * \left(R_e + \frac{R_r * (R_{d_x} - R_e)}{\sum_{i=1}^{j}(R_{d_i} - R_e)}\right)$ Case when $(R_{d_i} > R_e)$
Class 2	$R_{b_{(x,2)}} = R_{min} * 0.3$	$R_{b_{(x,2)}} = R_{d_x} * 0.3$	$R_{b_{(x,2)}} = 0.3 * \left(R_e + \frac{R_r * (R_{d_x} - R_e)}{\sum_{i=1}^{j}(R_{d_i} - R_e)}\right)$ Case when $(R_{d_i} > R_e)$
Class 3	$R_{b_{(x,3)}} = R_{min} * 0.2$	$R_{b_{(x,3)}} = R_{d_x} * 0.2$	$R_{b_{(x,3)}} = 0.2 * \left(R_e + \frac{R_r * (R_{d_x} - R_e)}{\sum_{i=1}^{j}(R_{d_i} - R_e)}\right)$ Case when $(R_{d_i} > R_e)$
Class 4	$R_{b_{(x,4)}} = R_{min} * 0.1$	$R_{b_{(x,4)}} = R_{d_x} * 0.1$	$R_{b_{(x,4)}} = 0.1 * \left(R_e + \frac{R_r * (R_{d_x} - R_e)}{\sum_{i=1}^{j}(R_{d_i} - R_e)}\right)$ Case when $(R_{d_i} > R_e)$

Table 2. The formulas of benefit rates

C. The simulation with FaDoS

To show the efficiency of the FaDoS algorithm at the fairness and the differentiation services level, we effectuate, in the same environment, and on the same topology of a WMN network "Figure.2", a simulation adopting the nodes by our mechanism.





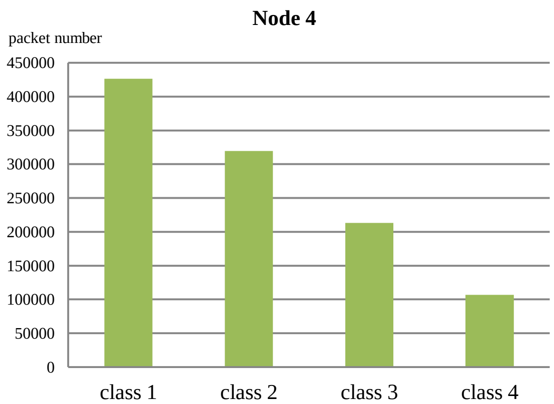
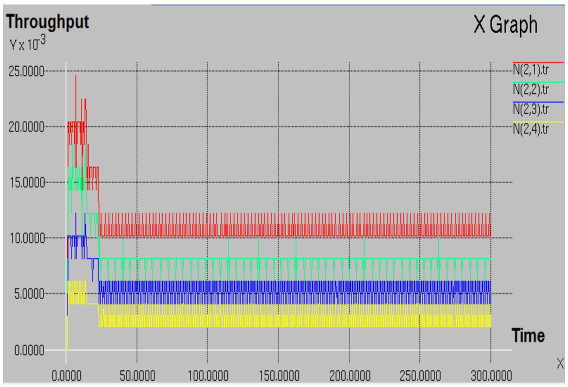


Figure 10. The number of different packet class received by the gateway, in the case of a network with FaDoS

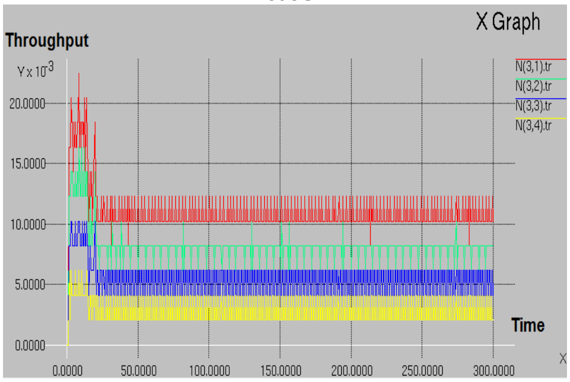
The simulation scenario is the same as the previous, the node N_2 starts sending respectively the packets of the class 4, class 3, class 2 and the class 1, however the nodes N_3 and N_4 start sending packets in an ascendant order of class.

The "Figure.10" and "Figure.11" represent respectively the new results of the packets number received by the gateway of different flow classes from different nodes, and the behavior of each type of flow throughputs.

Node 2



Node 3



Node 4

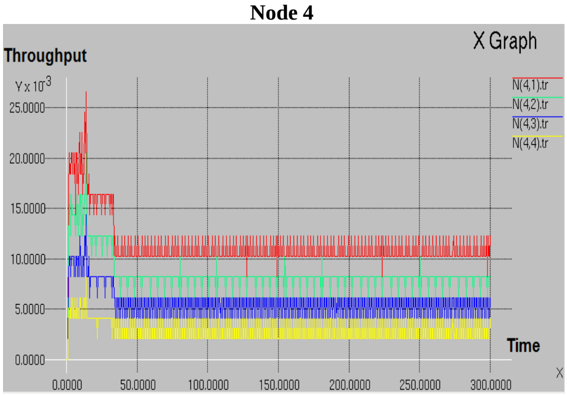


Figure 11. The throughputs behavior of each micro-flow, in the case of a network with FaDoS

The analysis of "Figure.10" and "Figure.11" allows us to deduce the following notes:

- The FaDoS produced a positive effect at the differentiation service level. The node N_2, which has started sending the packet classes in this way: class 4, class 3, class 2 and class 1, benefited from different services for each flow class, we note that the packet flow of class 1 took the highest throughput in spite of being the last flow sent by the node N_2.
- With the help of the FaDoS mechanism, the sharing of the network bandwidth between the nodes became fair. The result of the "Figure.11" showed that the benefited throughput by each flow class coming from different nodes is equal.

The positive result produced by the FaDoS protocol, is explicable in a way that the flows rates of each generated class by different nodes became limited, the goal is to not promote the flows having a low priority over the flows having a high priority, and also the flows of the nodes close to the gateway over the flows of nodes far from the gateway.

V. Conclusion

This work is an opportunity to achieve performance simulations on the WMN environment, and retrieve some results that we were based on to clarify some conclusions that concern either the problematic of unfairness or differentiation services. These conclusions were the starting point to propose our mechanism as a solution.

The first simulation allowed us to see how the WMN has reacted to the different flow classes. The simulation results showed that the WMN does not make a difference between packet classes at the treatment level, in other words, it does not accept a system to differentiate the quality of services. Thus, the fair sharing of the bandwidth between flows coming from the different nodes is missing in this type of network.

To solve the two previous problematic, we started from the point where we must periodically adjust the treatment rate of each class of the flow coming from each network node. The FaDoS protocol which is in a partnership with the token bucket mechanism that we have inserted in the MAC layer, has allowed us to achieve our goal.

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