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A MECHANISM TO ENSURE FAIRNESS IN WIRELESS MESH NETWORK

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ABSTRACT

The actual tendency of the computing networks requires supplying to the clients a permanent connection to the internet in a wireless manner. The wireless mesh network technology WMN came up to answer these priority needs, it also allows extending the network coverage with a less expensive infrastructure. The performance of all the network technologies are not perfect, it's the same case for the WMN. This network based on the IEEE 802.11s standard still in development to resolve problematics on several levels. Among these problems, we situate the unfairness problem concerning the bandwidth sharing between the flows flowing in the network. In this article, we will propose a protocol capable of guaranteeing a fair sharing of the bandwidth. This protocol, in a first place, is based on an exchange of information between the nodes, in order that these nodes agree to the benefit rate of each one of them, and in a second place, it works in collaboration with the "token bucket" mechanism.

Keywords: WMN, Bandwidth, Fairness, Token-Bucket.

1. INTRUDUCTION

The goal of creating a network with a wireless distribution system, that can guarantee an automatic management of paths and topology, that can also supply in an inherent way a strong fault tolerance and a high scalability, needs a extention extraction of the 802.11 standard, suitable to the WMN, which is actually the 802.11s standard.

In the operation scenario of hybrid WMN network shown in Figure 1, the Mesh access points MAP receives the packets flows from the client stations STA, then, they direct them to mesh points MP. These lasts play the role of a packet messenger, they route the flows to the mesh portal point MPP and then to the internet network.

The IEEE 802.11s standard allows to several nodes to connect to the same distribution system, which can increase the probability of having several packets flows at an instant t in the network. Moreover the MAC layer of a node within this network can receive on one hand, the packets flows coming from the other nodes, on another hand, the packets flows of applications at higher layers. The packets flows flowing in the network can have different rates, consequently, we will obtain a different bandwidth occupation for each packets flow.



Figure 1: Architecture of a wireless mesh network [1]

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The two previous findings, allow to declare a problematic concerning the bandwidth occupation by the different flows in the network. Since the packets rates of all the flows are not the same, we will have aggressive flows and non-aggressive flows. Thereby the aggressive flows have always the opportunity to occupy an important part of the bandwidth at the expense of the others.

The proposition in this article is a protocol as a solution to the unfairness problem. This protocol allows to limit the packets rates of the aggressive flows in order to not exceed a maximal value, and consequently, guarantee, to the non-aggressive flows, a part of the bandwidth available for transmitting data.

Our protocol is based on an exchange of control messages between the network nodes, these messages contain some information concerning the bandwidth desirable by each node. The aim of this exchange is to agree to the benefit rate of the network nodes at each period. Thereafter, the token bucket mechanism will use these rates to control the bandwidth occupation by the flows coming from each node.

To end the work [2], where we defined the idea of our protocol, we will project in this article our proposition to several simulation scenarios in order to show the added value in terms of fairness in different cases.

This article is organized as follows: in the part II, we will clear up, by a simulation, the unfairness problematic. Then, we will locate some previous works. In the part IV, we will define the elements and the operation of our mechanism. And to show the added value of our protocol, we will perform simulations on different topologies.

2. THE UNFAIRNESS PROBLEM

In the scenario where the nodes in a WMN network generate in the same time data flows, and when the network cannot guarantee a valid bandwidth to transmit each flow, we can mention the existence of the unfairness. Another way to define the unfairness is in the case when the network can't guarantee a fair sharing of bandwidth between the flows coming from each node.



Figure 2: Four nodes on a bus topology of a wireless mesh network

To clear up well this problem using our way, we will perform a simulation in NS2 (Network Simulation 2). We propose a bus topology of four nodes shown in Figure 2, the nodes connect with each other in a wireless way using the interfaces of 802.11 standard. We separate the nodes with a distance of 175 meters, and the transmission zone of each node is fixed to 250 meters.

The simulation will happen as follows:

- The nodes N₁, N₂, and N₃ send packets to the gateway N₀.
- We separate the beginning of each node packets sending with a duration τ.
- The size of a packet is 128 bytes with an under-departure between the packets of 0.003 ms.
- We use the HWMP protocol [3] to direct the packets to the gateway.
- The simulation duration is 300 seconds.
- At the end of the simulation, we will estimate the percentage of the received packets by the gateway for the different flows coming from different nodes as it's shown in Figure 3.
- We will try to present in Figure 4 the behavior of all the network flows throughput.



Figure 3: The percentage of the number of packets received by gateway from each node.

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Figure 4: The behavior of the bandwidth occupied by each node while the simulation

We note after the analysis of the Figure 3 that the gateway N_0 received a tiny quantity of packets coming from the far nodes. However, as long as the node is near the gateway, this last receive an important quantity of packets coming from this node. To understand and define the principal cause of this result, we will try to analyze the throughput obtained by each node during the simulation.

The Figure 4 showed that the flows ofnodes near the gateway are the aggressive type, we note that they obtain a high throughput compared to the other flows, consequently, they occupy a huge part of the bandwidth at the expanse of the other.

3. RELATED WORKS

Many researchers worked on the problems affecting the WMN technology in different levels. At the level of fairness, some mechanisms had been proposed as a solution, we will present and criticize one of them, which we'll be based on, to define our approach. Then we will place some works.

Within a node, the researchers of the work [13] tried to find the ideal combination of the queues, at the network's and mac layer, which can guarantee a fair sharing of the bandwidth. From some simulations on several scenarios, they agreed on a system among six. The presented schema at Figure 5 explains the mechanism with the result.

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



Figure 5: The queues system [13]

Even if the work [13] has some positive point, we will place two negative point that we will correct in our mechanism:

- The system provides a number of queues equal to the number of flows crossing the node. However in the case of a node crossed by endless flows, this principal will be a waste of memory.
- The service time of each flow is constant during the simulation time, it's like we considered that the rates of each flow are constant, but it's not the case in reality.

We will present in the following some previous works:

We start by the work [4], which was a solution to control fairly the flows in the network. The used mechanism was an inspiration from the works before it: [5] [6] [7], it's based on three necessary parts: the first one is to limit the activation time of each antenna link. The second one is that each node has a database on the periods when each link will be active. The last one uses also the mechanism RTS/CTS to send the data.

The article [8] is a proposition of a mechanism named Multicast Framework for Bandwidth Management in WMN (MFBW). This work is not concluded with a simulation to show his efficiency.

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This algorith	n includes	s the	advanta	ages of	two	We propose an algorithm named FGMA (fairness
mechanisms:	Shortest	Path	Tree	(SPT)	and	guarantee on medium access) so each flow in the

A study was made in the article [9] on the problems whereby the WMN technology cannot guarantee a fair sharing of the bandwidth. Then, they specify the proposed mechanisms in order to decrease the consequences of this problem.

Minimum Cost Tree (MCT).

The existing work in [10] allows measuring the available bandwidth considering the FIFO discipline and the CSMA/CA system. The measure is based on the packets dispersion.

The authors of [11] tried to solve the congestion problem by using the 802.11e protocol, they limited the resources reservation time for each node using the TXOP parameter (transmission opportunity). For this purpose, they allocate for a node a transmission time depending on two parameter: the TXOP and the number of clients stations related to this node.

The mechanism proposed in the article [12] has as goal to solve the congestion problem using a technique of dynamic routing. This mechanism is based on an algorithm allowing the detection, firstly, the loss channel due to the congestion at the level of a node queue. Then, if a sending node data cross this canal, so they have to change trajectory to another since the WMN technology stand the fault tolerance. With this algorithm they minimized the unfairness problem.

The work [14] was executed in order to reduce the collusion probability between the flows. The concept is based on a mechanism which allows to allocate to each node a different value from CW (contention window). If we have the same CWmin and CWmax in each node, so we will have a huge probability of collusion. That's why the mechanism chose to give the highest values of CWmin and CWmax to the nodes near the gateway and the smallest values to the far node from the gateway.

The geometric principle was present in the article [15], the authors were based on some mathematical calculations to find a geometric model that guarantees the fairness with an important number of nodes.

In the works [16][17][18][19], the authors worked on the analytic side to achieve the fairness goal, they were based on the Max-Min fairness principal.

4. OUR APPROACH

We propose an algorithm named FGMA (fairness guarantee on medium access) so each flow in the network obtain the available gateway at an instant t. for this purpose, the mechanism guarantees to the non-aggressive flows the desired rate, however, it limits the rates of the aggressive flows to a maximal value.

To calculate the benefit rate of a flow coming from a node, we will rely on the flows rates desired by the nodes around it and desired rate by this node itself. Then, in order that the node generate a flow with its benefit rate, it must use to token bucket mechanism.

4.1 Token Bucket Algorithm

Sometimes, a node in the network can generate a packet flow with a non-regular or high rate. In this case, we can use the token bucket mechanism to restore the rate of this flow in a constant value in a continuous way, the Figure 6 show this mechanism.



Figure 6: token bucket mechanism

The token bucket operation is as follows:

- Let's imagine that we have a leaky bucket at the bottom that contain some tokens and each token represents a bit.
- The size of the bucket represents the quantity of tokens that can be stored in it, measured by bytes.
- The bucket fills with tokens with a constant rate **R**_t.
- A packet transmission is accompanied with tokens reduction from the bucket. The number of the expelled tokens is equivalent to the packet size in bit.
- When a packet arrives and if there is not enough tokens in the bucket, it must wait in the queue until the bucket is filled again. If

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the queue is congested	, the packet is in	broadcast to the adjacent nodes with a single
excess.		hop.

Since the FGMA protocol works in collaboration with the token bucket mechanism, this last will be integrated in the link layer of all the network's nodes as it's shown in Figure 7. We will affect to each period ρ , the node $\mathbf{R}_{\mathbf{b}}$ benefit rate to the token $\mathbf{R}_{\mathbf{t}}$ arrival rate, in order to control the generated flow by each node with a suitable throughput.



Figure 7: The new architecture of node

4.2 The FGMA operation

The FGMA is an algorithm that runs in each period ρ . It allows to estimate the bandwidth part that can reserve a node in an instant t to transmit its data. This estimation is done thanks to the calculation of the flow rate benefited by the node, based on its desired rate and the adjacent nodes desired rate.



Figure 8: The exchange of FGMA RATE messages

The algorithm works as it follows:

All the nodes of the network will send a message named FGMA RATE as а

broadcast to	the adjacent	nodes with	a single
hop.			

- The **FGMA RATE** contains two necessary information: the mac address of the message generator node and the desired packet rate R_d.
- Each node will receive many FGMA 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. The exchange of FGMA_RATE messages is presented in Figure 8.
- At each storage of a new information in the rate table, the node will calculate its benefit rate $\mathbf{R}_{\mathbf{b}}$ from the network bandwidth.
- The node's benefit rate $\mathbf{R}_{\mathbf{b}}$ will be affected to the tokens rate **R**_t.

The sum up of the FGMA mechanism is showed as it follows:

Program: This mechanism allows each node to have an accurate throughput and to guarantee the network fairness Input: $\boldsymbol{R}_{d_i}:$ 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** • {0,1.2...,n}) \mathbf{R}_{a} : the overall rate of the network Output: R_{b_x} : the rate that will be benefited by a node **x** from the network bandwidth at time t Begin FGMA RATE When receive we а message, the node performs the following actions: Extract from the FGMA_RATE messages the sender's address @ and the rate it desired \mathbf{R}_{a} . Save the desired rate Rd and the sender address @ in the rates table. Calculate the rate that will be benefited $R_{_{\rm b}}$ by node **x** from the the network bandwidth. Affect the rate benefited R, to the rate of token R. at the token bucket mechanism

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End	$\mathbf{R}_{\mathbf{a}_{\mathbf{x}}}$: The quantum node x that dema	ntity of rate that we can add to the ands more than $\mathbf{R}_{\mathbf{e}}$.

The mathematical formula with which we calculate the benefit rate $\mathbf{R}_{\mathbf{b}}$ is a function of the recorded values in the rate table and also some variables linked to the performance of the network. Before presenting the formula, we will define the variables that contain:

- **R**_{dx}: The rate desired by a node **x** at an instant t.
- **R**_{bx}: The benefit rate of a node **x** at an instant **t**.
- **R**_{th} : The theoretical rate of the network.
- **R**_g : The global rate of the network.

 $\mathbf{R}_{\mathbf{g}} = \boldsymbol{\beta} \ast \mathbf{R}_{\mathbf{th}} \left(\boldsymbol{\beta} \sim = \mathbf{0}. \mathbf{7} \right)$

• **R**_e : The evenly shared rate.

$$R_e = \frac{R_g}{n}$$

n: the number of node in the network.

• **R**_r : The residual rate.

$$\mathbf{R}_{\mathbf{r}} = \sum_{i=1}^{p} \mathbf{R}_{\mathbf{e}} - \mathbf{R}_{\mathbf{d}_{i}}$$

The case when $R_e > R_{d_i}$

 \mathbf{p} :the number of nodes when $\mathbf{R_e} > \mathbf{R_{d_i}}$

• **R**_{min}: The minimum benefit rate of a node in the network.

The formula with which we calculate the flow rate benefited by the node $\mathbf{R}_{\mathbf{b}}$, it changes according to the following cases:

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

 $R_{b_x} = R_{min}$

If $R_{d_x} < R_e$

$$\mathbf{R}_{\mathbf{b}_{\mathbf{x}}} = \mathbf{R}_{\mathbf{d}_{\mathbf{x}}}$$

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

(1)

$$\mathbf{R}_{\mathbf{b}_{\mathbf{x}}} = \mathbf{R}_{\mathbf{e}} + \mathbf{R}_{\mathbf{a}_{\mathbf{x}}}$$

$$\mathbf{R}_{\mathbf{a}_{\mathbf{x}}} = \frac{\mathbf{R}_{\mathbf{r}} * \mathbf{P}_{\mathbf{x}}}{\mathbf{100}}$$

 $\mathbf{P}_{\mathbf{x}}$: The percentage of the residual rate that will be benefited by the node x.

(3)

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

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

From (2) and (3):

(4)

$$\mathbf{R}_{\mathbf{a}_{\mathbf{x}}} = \frac{\mathbf{R}_{\mathbf{r}} * \left(\mathbf{R}_{\mathbf{d}_{\mathbf{x}}} - \mathbf{R}_{\mathbf{e}}\right)}{\sum_{i=1}^{j} \left(\mathbf{R}_{\mathbf{d}_{i}} - \mathbf{R}_{\mathbf{e}}\right)}$$

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

From (1) and (4)

$$\mathbf{R}_{\mathbf{b}_{\mathbf{x}}} = \mathbf{R}_{\mathbf{e}} + \frac{\mathbf{R}_{\mathbf{r}} * (\mathbf{R}_{\mathbf{d}_{\mathbf{x}}} - \mathbf{R}_{\mathbf{e}})}{\sum_{i=1}^{k} (\mathbf{R}_{\mathbf{d}_{i}} - \mathbf{R}_{\mathbf{e}})}$$

5. THE SIMULATION WITH FGMA

5.1 Description

The importance to realize a simulation on a network with nodes, adopting the FGMA protocol, is to show that we will obtain an added value at the level of fairness, the simulation environment that we'll choose is the same as the previous, except in this step, we will perform simulations on several topologies and scenarios in order to define the behavior of our mechanism in different cases. During the simulation, we will extract the necessary results.

For each simulation scenario, we will present some statistics of the number of packets sent by each node to the intended destination. During the simulation time, we will try to extract the variation of the flows throughputs coming from the nodes that have sent packets though the network.



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- The Figure 9 presents the first simulation on a bus topology of six nodes. All the network nodes send packets to the gateway N_0 .
- The second scenario shown in Figure 10 will be on a grid topology of nine nodes (3x3), which try to send the packets to the gateway N₉₉.
- The third scenario of the simulation presented in Figure 11 is a random topology of nine nodes that are trying to send packets to the gateway N_0 .
- The fourth scenario is in the case when we have a common distribution system used in order that a set of nodes send packets to different destinations. In the presented network in Figure 12 we have:
 - ✓ N₀send packets to N₄
 - ✓ N₅send packets to N₉
 - \checkmark N₁₀ send packets to N₁₄
 - ✓ N₁₅ send packets to N₁₉
 - \checkmark N₂₀ send packets to N₂₄



Figure 9: Six nodes on a bus topology of a wireless mesh network



Figure 10: Grid topology of wireless mesh network

5.2.1 bus Topology



Figure 11: Random topology of wireless mesh network



5.2 Result

To Show that the FGMA mechanism guaranteed a fair sharing of the bandwidth, we will present to each simulation scenario the results with and without our agent.

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Figure 13: The percentage of the number of packets received by gateway from each node without FGMA



Figure 15: The percentage of the number of packets received by gateway from each node with FGMA





Figure 16: The behavior of the bandwidth occupied by each node while the simulation with FGMA



Figure 17: The percentage of the number of packets received by gateway from each node without FGMA



5.2.2 Grid topology

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Figure 19: The percentage of the number of packets received by gateway from each node with FGMA

5.2.3 Random topology



Figure 21: The percentage of the number of packets received by gateway from each node without FGMA



igure 20: The behavior of the bandwiath occupied by ea node while the simulation with FGMA





Figure 23: The percentage of the number of packets



Figure 24: The behavior of the bandwidth occupied by each

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received by gateway from each node with FGMA

node while the simulation with FGMA

5.2.4 Topologie des stations avec un système de distribution commun



Figure 25: The percentage of the number of packets received by gateway from each node without FGMA



Figure 27: The percentage of the number of packets received by gateway from each node with FGMA

X Graph Throughput Yx 103 N0.tr 100.000-N5.tr N10.tr 350.0000-N15.tr .N20.tr 300.0000-250.0000-200.0000-150.0000-100.0000-50.0000 Time 0.0000 100.0000 150,0000 200.0000 250.0000 50.0000 300.0000 Figure 26: The behavior of the bandwidth occupied by each node while the simulation without FGMA



Figure 28: The behavior of the bandwidth occupied by each node while the simulation with FGMA

5.3 Analyzes

The result that we have obtained has shown that our FGMA protocol took in consideration the fair sharing of the bandwidth in different simulation scenarios. The flows coming from packet generator nodes benefited from a regular rate at a continuous time, and the bandwidths parts occupied by each flow are almost equals. We can explain this positive result this way:

At each time a packet flow crosses a node in order to reach its destination, this flow acquires a delay due to a time dispersion practiced by the

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crossed node. It	's the case of the	nodes flows far	aggressive flows	benefit from an	important part of

crossed node. It's the case of the nodes flows far form the gateway, as the Figure 13, Figure 14, Figure 17, Figure 18, Figure 21 and Figure 22show, which obtain, therefore, flow rates less higher comparing to the adjacent nodes. The flows of these lasts have more chance to access to the medium, which explain the important quantity of these packets received by the gateway.

The descending packets flows of a node superior layers have always a high rate comparing to other flows coming from different nodes. For this purpose, they obtain a big opportunity to access to the queue at the expanse of the others, and consequently, the other flows packets is a time dispersion subject.

These two last findings allow sharing the flows in two categories: the aggressive flows with a high rate that obtain more chance of the medium access. Thereby, the non-aggressive flows that occupy a tiny part of the shared bandwidth.

The FGMA protocol came to limit the aggressive flows rates to not exceed a maximal rate. Consequently, these flows cannot occupy a bandwidth at the expanse of the non-aggressive flows. And also, the non-aggressive flows benefit from the bandwidth that they desire.

The conclusion is that our mechanism tried that the network's fairness is not unbalanced, which is shown at the Figure 15, Figure 16, Figure 19, Figure 20, Figure 23 and Figure 24.

For the simulation of stations with a common distribution system, we showed that the packets flows throughputs are not regular in the Figure 25 and Figure 26. We can explain this result by the competitiveness and collusion between packets in the common medium. The FGMA tried to reduce the collusion probability by guaranteeing a noninterrupted packet stream for each flow. The Figure 27 and Figure 28 show the new results.

6. CONCLUSION

This work was an opportunity to study the fairness performance of WMN network, based on the 802.11s standard. From this study, we extracted some information concerning the obstacles that prevent the fair sharing of the bandwidth between the packets flows. These information were the base by which we proposed a solution.

Through the first simulation, we showed that the 802.11s standard cannot guarantee the fairness in the WMN network. The results have shown that the

aggressive flows benefit from an important part of the bandwidth comparing to the others, also the different flows throughput are not regular at the continuous time.

The results have shown also, that the flows of the far nodes from the gateway are the subject of a severe competition from the flows of nodes near the gateway, in order to reach the medium access.

The solution, to trap each flow rates in the rate interval that deserve, allows to increase the opportunity of the medium access for the nonaggressive flows, and also to guarantee the valid bandwidth for them. This method was exploited in the FGMA protocol. After the second simulation on several scenario cases, we showed its added value: it allow converging each flow throughputs to a constant and common value to reach the fairness.

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