Congestion-driven Topology Control in Wireless Ad Hoc Networks

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Abstract— **The increasing popularity of wireless local area networks proves current trends in telecommunication industry with notably a growing need for flexibility and ubiquitous wireless connectivity. The introduction of quality of service (QoS) in these networks is even more complex since their topology and their resources evolve dynamically. With this fast evolution, performances and connectivity of wireless networks radio decreases. In this paper, we propose an approach to control the topology of wireless networks based on continuous QoS metrics performances measurements in 802.11 networks. This consists in ensuring the highest connectivity possible by dynamically selecting a set of dedicated mobile routers to ultimately increase the performance of infrastructure-less wireless ad hoc networks. In order to confine the network overload probability, our scheme features a forced handover technique along with a connection admission control (CAC). Finally, we introduce a QoS scheme to manage heterogeneous traffic requirements by allowing for different traffic priorities.**

Index Terms—**802.11, connection control, delay and bandwidth metrics, forced handover, mobile routers, topology control, QoS.**

I. Introduction

In Ad Hoc Networks, where nodes are deployed without any preconfigured infrastructure and communicate via multi-hop wireless links, the network topology is autonomously formed based on the nodes' locations, interference levels, and communication ranges. The network topology has a huge impact on the network performance. In fact, using a dense topology it may induce high interference, which, in turn reduces the effective network capacity due to limited spatial reuse. This often causes unnecessarily high energy consumption. In contrast, using a sparse topology is vulnerable to network partitioning due to node or link failures. The principal goals of Topology control (TC) for Ad Hoc networks is to maintain a planed topology by controlling which links should be included in the network to achieve a set of network-wide or session-specific objectives such as reducing interference or probability of detection, reducing energy consumption, increasing the effective network capacity and reducing end-to-end delay. The primary and intuitive goal of performing topology control is mainly to adjust the transmission power levels among network nodes.

In hierarchical topology control, where a subset of network nodes is selected to serve as network backbone over which essential network control functions are supported (e.g. [18]). This approach of topology control is often called clustering, and consists of selecting a set of cluster-heads in a way that every node is associated with a cluster-head, and cluster-heads are connected with one another directly or by means of gateways, so that the union of gateways and cluster-heads constitute a connected backbone. Once elected, the cluster-heads and gateways help to reduce the complexity of maintaining topology information, and can simplify such essential functions as routing, bandwidth allocation, channel access, power control or virtual-circuit support. For clustering to be effective, the links and nodes that are part of the backbone (i.e., cluster-heads, gateways, and the links that connect them) must be close to minimum and must also be connected. Ideally, topology control based on clustering would select a minimum and sufficient number of links to serve as the communication backbone of the network like in [12], while reducing network maintenance and control overhead. In graph theory, the minimum dominating set problem and the relevant minimum connected dominating set (MCDS) problem best describe the clustering approach to topology control.

However, it has a negative impact on the cluster-heads, because these later would have a significantly increased energy consumption compared to traditional nodes. The solution is to consider the load balancing in the election's algorithm [11]. The goal of this approach is to reduce the additional overload of network, the maintaining complexity and to simplify the essentials functions (routing, power control, security …).

Energy consumption in wireless networks is based on the adjustment of the transmission power of active nodes. These techniques of control can be centralized or distributed. In the centralized algorithm [9], a centralized entity calculates the transmission power by using the position of the nodes in the network in order to carry out a topology with strong connectivity. In the distributed algorithm [10], mobile nodes adjust their respective transmission power according to a local information which allow them to maintain a finite number of neighbors.

Power control mechanisms adjust the power on a per-node basis, so that one-hop neighbor connectivity is balanced and overall network connectivity is ensured[13][14][15][16]. Ramanathan et al [16] proposed to incrementally adjust nodes' power levels so as to keep network connectivity within a certain threshold. However, except for early work of Takagi and Kleinrock [14], topologies derived from power-control schemes often result in unidirectional links that create harmful interference due to the different transmission ranges among one-hop neighbors [17]. The dependencies on volatile information in mobile networks, such as node locations [13], signal strength or angular positions [15] also contribute to the instability of topology control algorithms based on power control. Furthermore, some distributed implementations of these algorithms can hardly improve the throughput of mobile networks [16].

In this paper we study a connectivity problem and we propose to control the topology of ad hoc network using a set of dedicated mobile routers. This topology control is based on forced handover method and quality of service measurements. A connection admission control is included to support the forced handover procedure. The main results are a new topology control witch maintains a connectivity and less congested cell. Our study following some steps: first we propose a method of topology control. Then, we implement a connection admission control to manage different traffic categories proposed in QoS scheme.

The article is organized as follows. In section II, we give an overview of existing topology control approaches which is based on dedicated mobile routers, a QoS schemes in Mobile Ad Hoc Network. Section III, we detailed our approach and the QoS scheme applied on it. Section IV, we evaluate the performance by simulations. Finally, in section V, we conclude this article with some discussions and future works.

II. RELATED WORK

A. Topology Control

Meraihi et al [4], detailed a novel approach to control a Mobile Ad Hoc Network using mobile robots routers. The idea is to provide the connectivity and interconnection between fixed infrastructure and Ad Hoc network with mobile robots which ensure a seamless communication service with a better network coverage. To ensure connectivity, we need to know the position of nodes to move mobile router in order to maximize the number of the nodes covered; the deployment of mobile routers must guarantee a connected network.

This approach increases, in significant way, the performances and the connectivity of Ad Hoc networks. But in other hand, it does not support the links' quality, load balancing and the interferences caused by other nodes. Moreover, this control is based in a centralized approach, which requires having powerful machine in term of computation and energy level.

B. Quality of Service in wireless mobile networks

For WLANs, IEEE 802.11 is designed for best effort services. The 802.11 standard specifies two medium access control (MAC) mechanisms: the mandatory distributed coordination function (DCF) and the optional point coordination function (PCF) [8].

The 802.11 legacy MAC does not support the concept of differentiated transmission routines for frames with different priorities. Basically, the DCF is designed to provide a distributed channel access with equal probabilities to all stations contending for the channel access. However, equal access probabilities are not desirable among stations with different priority frames. The emerging EDCF is designed to provide differentiated, distributed channel accesses for frames with 8 different priorities (from 0 to 7) by enhancing the DCF. As distinct from the legacy DCF, the EDCF is not a separate coordinate function. It is rather a part of a single coordinate function, called the Hybrid Coordinate Function (HCF) of the 802.11e MAC. The HCF combines the aspects of both DCF and PCF. All the detailed aspects of the HCF are beyond the scope of this paper.

C. QoS Measurement

On the multi-hops networks we measure the performance of the link for each connection <source, destination>[2]. A performance metric measurement was defined like this:

$$P(src, dst) = (1-u) * Throughput(src, dst) \quad (1)$$

where u is the L2 queue utilization.

In order to calculate the permissible throughput we first need to estimate the link throughput (see formula (1)). Each node passively estimates its throughput to each neighbor. The throughput seen by a single S-bits packet can be calculated as follow

$$Throughput_{packet} = \frac{S}{T_{ACK\ reception} - T_{transmission}}$$

where, $T_{ACK\ reception}$ *= timestamp of ACK reception*

and, $T_{transition}$ *= timestamp of packet transition*

The transmission time considers queuing time, 802.11 related overhead and actual bit transmission time. In order to understand what we are measuring with the above equation, let us express it in 802.11 terms:

$$Throughput_{packet} = \frac{S}{t_q + (t_s + t_{CA} + t_{overhead}) * R + \sum_{r=1}^{R} TB_r} \quad (2)$$

where tq is the L2 queuing time, ts the transmission time of the S bits, tCA the collision avoidance phase time, toverhead the control overhead time (e.g. RTS/CTS, ACK, Header, 4 propagation delay), R the necessary retransmissions and TBr the back-off time for retransmission r.
In the rest of the paper we will use the formula (2) to measure the link state.

D. Forced handover

In 802.16 wireless networks [5] the centralized entity collects information relating to the potential handoff and transfer them to the mobile, this later collects adapted information, and makes a decision to engage or no in a handoff procedure. Authors in [6] propose a method for a forced handoff, assisted by measures in a 4G networks. After the user authentication , the local server sends to that user a list of close cells (nodes in range of each other), including the physical parameters, the cell's identifiers, etc. These measurements are sent periodically, so that the user tests the quality of signal starting from this information and carries out a handoff governed by the local server.

In the next sections, we will discuss our topology control, the connection admission control and the QoS scheme applied. After, we compare our model with a standard 802.11

with two scenarios. Finally, discuss the idea and future works.

III. TOPOLOGY CONTROL CONGESTION ORIENTED AND QUALITY OF SERVICE

In this section, we propose a model to control the topology of ad hoc networks using a dedicated wireless routers [1], these routers have a high processing capacity, a powerful battery lifetime and can use different standards. In a mobile router, we add a new interface to manage two kinds of network's topologies. The first one is an Ad Hoc network which connects the mobile routers with each other; the second one is a centralized network used to connect mobile nodes with their mobile router1. We suppose that each mobile router has in its range at least one mobile router. With this method, we can perform a forced handover of a mobile node; the mobile may thereafter change a channel from its point of attachment go to another mobile router which uses another channel. By adding a new interface, we allow mobile nodes to connect to the routers in a centralized way. Thus, we release the routing function from a mobile which will have a profit in energy and capacity. The deployment of a set of these routers will be done so that all the mobile nodes will be covered. The only assumption we make is that the topology can not contain two identical channels used by close links, which may cause interferences. Thus, to the mobile station is allowed to perform a forced handoff at any position.

This approach is based on the measures introduced earlier; we summarize the various steps in these following points:

- Deployment of the mobile routers is done according to the first approach (collecting information, calculating new positions and deployment of routers);
- Carry out a frequencies' management policy [3] for the attribution of the channels;
- Execute a Connection Admission Control to accept or negotiate or refuse the bandwidth requirements of nodes.
- Make periodic measurements to avoid capacity collapse;
- If these measurements are greater than a certain threshold, then nothing to do and return to the measurement step;
- If not (measurements are lower than a threshold), determine the mobile routers near to the congested one;
- Be aware about the link-state of neighbor routers, to know if they would eventually accept mobile nodes;
- If yes, select the connected mobile nodes close to the neighbor mobile routers by sending them a forced handover order;
- If not, change the position of routers to cover all mobile nodes and have a less congested mobile routers. If this solution is not possible, bring back a new router.

Fig. 1 represents an explanatory diagram of the topology control's model.

In the next point, we discuss the connection admission control to manage the different connections.

A. Connection Admission Control (CAC)

Before performing measurements to manage the topology, a CAC algorithm is "a-priory" applied to accept, negotiate, send a forced handoff or refuse a connection. To better understand this process, we define two algorithms; the first one is executed in mobile nodes while the second is running in routers.

1) Definition of Algorithm I

This algorithm is executed in mobile node, before it starts connection with local mobile router; it sends a request throughput. After receiving an answer from this last, it chooses one of the following options: connect or change it throughput or choose another mobile router or cancel connection.

```
Begin
  Ask for (ThrAsk, MRloc);
  Rsp = Receive response;

  If(Accepted) // connection accepted
    Connection (MRloc, ThrAsk);
   Else
    {
      If(Negociation)//negociate bandwidth
       {
        If(Thrprop ≈ α.ThrAsk)// verify with the proposed
          Connection(MRloc, ThrNew);
        Else
          Send (No, MRloc);
       }
         If(Refused) //refuse the connection
       While(MRList is not Empty)
          Aswr = Algo_Connection(ThrAsk, MRCurr);
       If(MRList is empty)
          Inform user (cannot connect);
    }
End
```

Where

α: a factor used to determine a threshold of throughput

Thr_{Ask}: throughput asked by mobile node;

Thr_{Prop}: throughput proposed by mobile router;

Thr_{New}: new throughput negotiated with mobile router

MR_{loc}: local mobile router ;

MR_{Curr}: current mobile router.

2) Definition of Algorithm II

This algorithm is executed in mobile router, when it receives a requested throughput from mobile node. It consists in comparing with the available bandwidth and decide if mobile can or not be connected with this mobile router.

```
Begin
  Msg = ask received;

  If((ThrAvlb – ThrAsk) ≥ β.ThrAvlb)
   {
     Send(ok);
     ThrAvlb = ThrAvlb – ThrAsk;
   }
   Else
    {
     ThrNecs = ThrAvlb – β.ThrAvlb;
     Send(Negotiation, ThrNecs);
    }
    If(MsgRecv = ok)
     {
       Accept;
       Send(ok);
       ThrAvlb = ThrAvlb   - ThrNecs;
     }
     Else // see all mobile routers
       {
    Seek the neighbour mobile routers not congested
    Send link state;
       }
End
```

Where

β: a factor who defines a bandwidth threshold

[1] Mobile nodes that are under mobile routers' coverage.

`Thr_Avlb`: the available throughput of the radio link
`Thr_Necs`: the remaining throughput

B. Topology control

In this section, we introduce algorithms that control the topology of network, to provide high connectivity and prevent congestion in a cell by sending a handoff order to mobile nodes.

1) Definition of Algorithm I

This algorithm is executed in a mobile router. Each one checks periodically its radio link used to communicate with all mobile routers that are in its range, using the rule (2) defined in section II, if the result of this test is below a certain threshold; the mobile router requests the link state of its one-hop-away neighbors. Each of its neighbors reply with a percentage of their link load, after that, it searches for the last clients connected.

Then, for each successfully probed node, we must take only the nodes that have only one connection, the mobile router checks for the requested bandwidth, removes then from the efficient bandwidth and verify the link state, if it is always congested, it carries out the same test with another node until the end of the list. If it is always congested, it rejects future connections and sends an alarm message to the neighbor node to tell them that it is congested; else, it sends a forced handover order to the entire nodes that passed the test successfully.

```
Begin
     If (link congested)
Link_states    Ask about link state of close routers;
       Node_list    last_nodes_connected ();
         While (Node_list is not Empty)
          {
            If (Node has one connection)
             { Thr_avlb    Thr_avlb + Node_list->Thr;
               Node_list_HO     Node_list_HO  +  Node_list  -
                 >Node;
                  If (Mobile Router not congested) Break;
             }
          }
     If (mobile router is not congested)
        Send (forced_HO_order, Node_list_HO);
      Else
        {
         If (Node_list_HO is not empty)
            Send (forced_HO_order, Node_list_HO);
          Else
           {  Reject future connections;
              Send    (I'm    congested,    Neighbor_Mobile
              Routers);
           }
        }
End
```

Where

`Link_state`: the link state of the closed mobile routers;
`AdHoc_Channel`: the channel which all mobile routers communicate;
`Node_list`: is the list of last connected nodes, it got many fields (connection "active connections number", Bandwidth requested, Address …);
`Thr_avlb`: total throughput available in the radio link;
`Last_nodes_connected()`: function that tells us the last nodes who join the mobile router;
`Node_list_HO`: is the list of the nodes causes the handover;
`Forced_HO_order`: the message type that order the nodes_list_HO to make a handover;
`Neighbor_mobile_routers`: is the list of the mobile routers that are in one hop of the congested router.

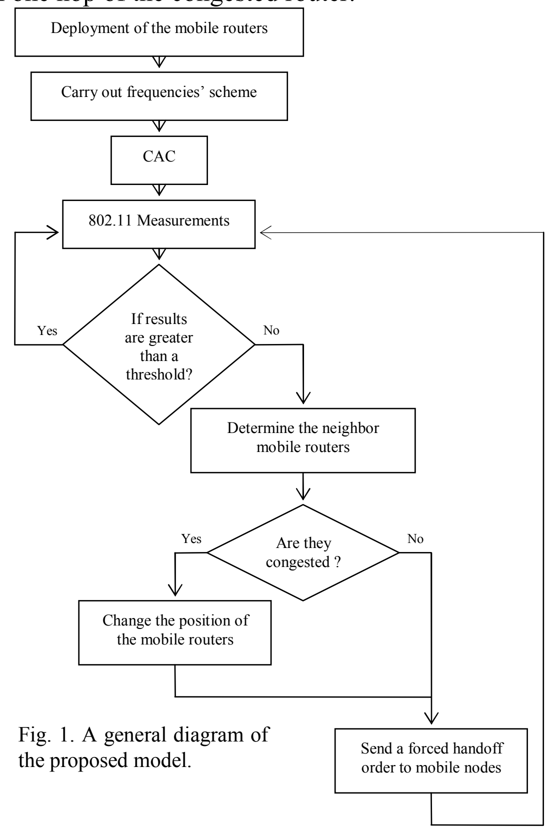

Fig. 1. A general diagram of the proposed model.

2) Definition of Algorithm II

The next algorithm is used in mobile node. It consists in scanning a channel using the list of a neighbor mobile routers. Each mobile node while it receives a forced handoff order, scans all the channels around which are in neighbor mobile routers list. Then, for each channel, checks if it is reachable; if so, the node sends its resources request to the reachable mobile router. At this point if the mobile router accepts, it performs reservation; otherwise it tells the user that the connection has failed and sends an alarm message to its mobile router.

```
Begin
  // this function is started when the message type
  //          "forced_HO_order" is received
  Scan = 0;
  While (Neighbor_mobile_routers not empty && Scan == 0)
   {
     Channel   =   Scan_channel(Neighbor_mobile_routers
                    Router  channel)
       If (Channel is reachable)
         {
              Send      (resources_reservation,
           Neighbor_mobile_router  router);
            If (ask accepted)  Break;
            Else   Scan = 1;
         }
         Else
          Scan = 1;
   }
     If (Scan == 1 OR Neighbor_mobile_routers is empty)
        User (Ask Rejected);
End
```

Where

`Scan`: is a variable that tell us about the ability of a node to search another channel;

`Scan_channel`: is a function to scan the radio link and return the number of a channel used.

`Resources_reservation`: type of message sends to MR to reserve resources.

In the next session we will discuss about specifics related to QoS scheme applied in this topology control to manage different traffics.

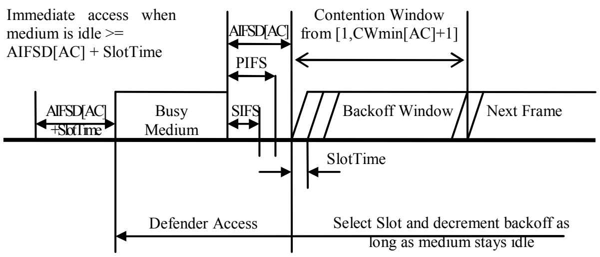

Fig. 2. IEEE 802.11e EDCF channel access

C. QoS scheme

As we can see in [7], the 802.11e is an appropriate standard that supports QoS provisioning at MAC layer. As seen in section II, the 802.11e allows differentiation between different traffic according to their priorities.

As we see in fig. 2, an Access Category (AC) uses Arbitration Inter Frame Space Duration (AIFSD[AC]), Contention Window (CWmin[AC]) and CWmax[AC] instead of Distribution Coordination Function IFS (DIFS), CWmin and CWmax of the DCF, respectively, for the contention process to transmit a frame belonging to access category AC. AIFSD is determined by

$$AIFSD[AC] = SIFS + AIFS[AC].SlotTime,$$

where AIFS[AC] is an integer greater than zero. Moreover, the Backoff counter is selected from [1, 1+CW[AC]], instead of [0, CW] as in DCF.

To perform our topology control, we consider only four ACs as shown in fig. 3. Each AC has it own Backoff counter, AIFS[AC], and *x*IFS[AC]. Our contribution is to use these MAC parameters and adapt them to our model. We differentiate two categories of traffic, real-time and non real-time; each one is divided into two types, handoff and new connection. Each traffic is associated with an AC and all its MAC parameters are multiplied by a specific factor (Table I).

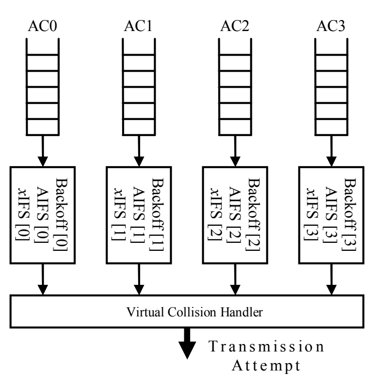

Fig. 3. Four access categories (ACs) for EDCF.

TABLE I.
TRAFFIC CATEGORIES AND THEIR PRIORITIES AND FACTORS

Traffic category	Priority	Factor
Handoff real-time	0	¼
New real-time	1	½
Handoff non real-time	2	¾
New non real-time	3	1

IV. SIMULATION AND RESULTS

Two scenarios have been used to evaluate the performance of our approach. The first is to evaluate the topology control; the second is to evaluate the QoS scheme which is applied in this topology management. These simulations were implemented using NS-2 simulator [19].

A. Scenario 1

This scenario reveals the reaction of wireless routers in face of a congested cell after performing 802.11 measurements. We can see the profit in bandwidth and in end-to-end delay. The simulation topology of this scenario is simple. It consists of 41 nodes where 1 node is the gateway and 4 are mobile router (MR) nodes. Fig. 4 shows an overview of our topology scenario. The radio access is network is defined with one gateway and modified mobile nodes[2]. The normal transmission range is 300 m and 180 m for MR and mobile node (MN), respectively. We used a standard 802.11 MAC & PHY layer.

To evaluate performances, we use two kinds of traffics, real time and data traffics. The data traffic has best effort characteristics, with packet size of 1024 bytes, while real time traffic has stringent requirements in throughput, delay, and jitter, used packet size 512 and 1024 bytes. We start the simulation with 10 nodes per MR in a 1000*1000m2 area. And we move 9 nodes from MR1 to MR2, each mobile node is handling two traffic types at the same time. We start with a minimum of traffics per node; and then we increase the offered load of each node at t=75s and t=150s. The duration of the simulation is 250 sec. the source traffic is especially nodes from MR2 and the destination are randomly chosen.

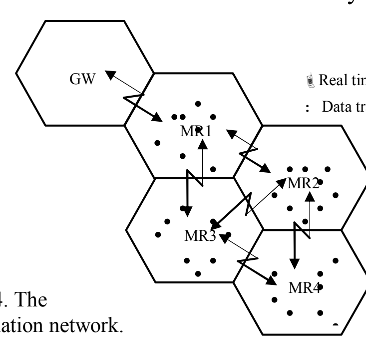

Fig. 4. The simulation network.

Fig. 5 gives the end-to-end delay in MR2 cells'. End to end delay represents the delay from MNi to MR1. We can see (at t=75s) that when we increase the traffics by moving nodes from MR1 to MR2 there is an significant increase in delays amplitude and oscillations. At t=150s, we can clearly see that

[2] An interface is added to a simple mobile node, the first one for the ad hoc radio network and the second one for the centralized cell.

as we start new traffics, the end-to-end delay in a cell is much more important with a classical topology compared to our scheme. With this topology control, we fixed the delay threshold to 1 sec, so when the MR carry out the 802.11 measurement, it detects that the results is greater than this threshold, which cause the MR to execute the Algorithm 1 (seen Section III). As a result, the last connected node will be disconnected from the MR2 cell and connected to MR1 or MR3.

As in the fig. 6, the global throughput in MR2 cell's decreases significantly. We fixed here the throughput threshold at 400 kb/s. There is a noticeable throughput stability when the algorithm is executed and some MNs are disconnected from the MR2 cell's.

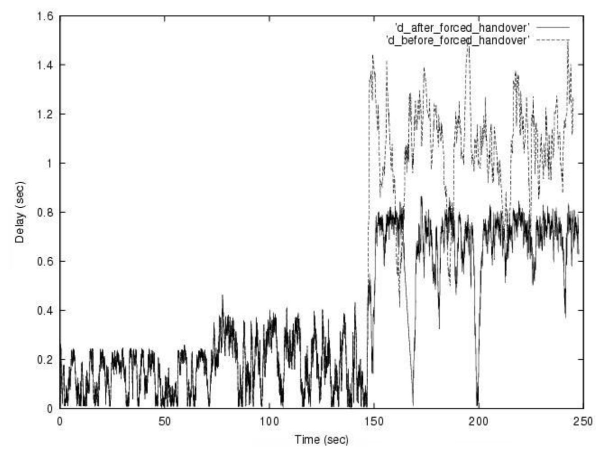

Fig. 5. End-to-end delay in MR2 cell's.

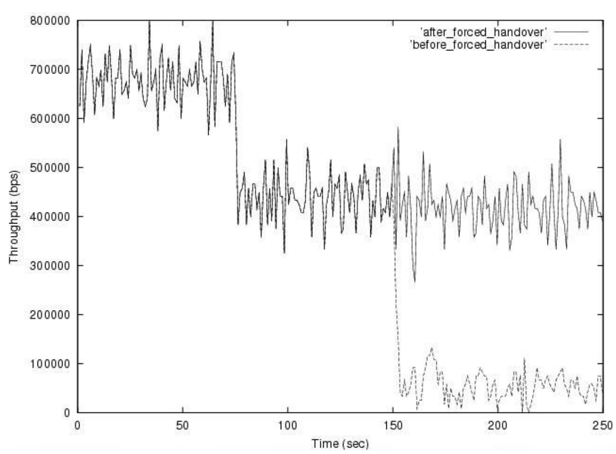

Fig. 6. Global throughput in MR2 cell's.

B. Scenario 2

The second shows the QoS scheme applied in our topology control with using differentiated traffics. We use two existing kind of traffic, real-time traffic (rt-traffic) and non real-time traffic (nrt-traffic). nrt-traffic is best effort, when rt-traffic, delay and jitter constraints must be satisfied. Here, the topology is simple, we use 5 nodes in 650*650m2 are. Where one node is a MR and the other are MNs. For well understand of results, we apply only one access category per node. Each MN is a source and a destination, and each one is transmitting with a different priority. Node1 is given a higher priority than Node2, which is given also a higher priority than Node3. Node3, in its turn, is given a higher priority than Node4. For this scenario we used a modified 802.11e standard. We give priorities to traffics; these priorities are shown in Table II, here the higher priority. The simulation time lasted for 120 sec.

TABLE II.
TRAFFICS USED IN SCENARIO AND THEIR PRIORITIES

Nodes	Priorities	Traffics
MN1	0	Handoff real time
MN2	1	New real time
MN3	2	Handoff data
MN4	3	New data

To evaluate the performance of the QoS, we compared the results with classical 802.11 standards. Fig. 7 and fig. 8 show the performance of our proposed QoS scheme. Fig. 7, Node1 starts transmitting at time T = 0.5 sec while Node2 starts transmitting at time T = 5.0 sec. During the period [0.5 sec, 20 sec] Node1 and Node2 are the only transmitting nodes using the entire available bandwidth. This justifies the constant and linear delay during the specified interval of time. At time T = 20 sec and T = 30 sec, Node 3 and Node 4 start transmitting respectively hence sharing channel resources with Node 1 and Node 2. This explains the increasing of delay. But if compared with the 802.11 standard we obtain a profit of 13% in an average delay. A similar dramatic behavior is also reflected in Fig. 8, which shows a high packet drop rate whenever the number of nodes sharing resources increases. In this case, we obtain a profit of 140% in average packet dropped.

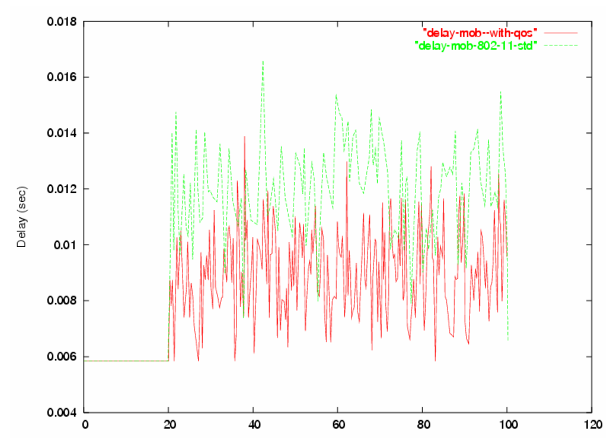

Fig. 7. Average packet end to end delay.

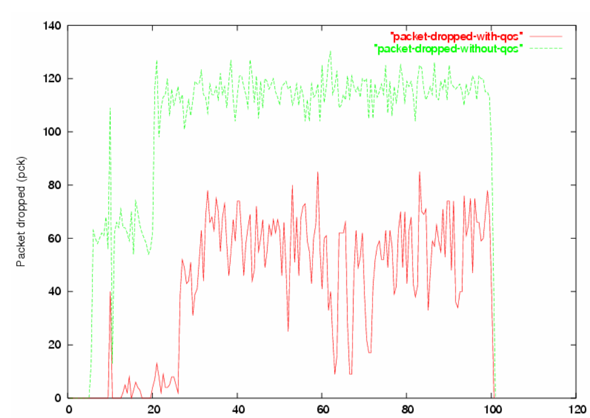

Fig. 8. Average packet dropped.

In Fig. 9 and Fig. 10, show a comparison of the throughput of all nodes using 802.11 and our proposition. In Fig9, we can clearly see that in higher priority traffic, when Node3 and Node 4 start transmitting, the throughput heavily decreases; this explains that there is no differentiation in traffics and all have the same priority. But, in Fig. 10, we can see that the traffic of Node1 and Node 2 which have a great priority to access to radio medium, are not disturbed after that Node 3 and Node 4 start transmitting and sharing channel resources.

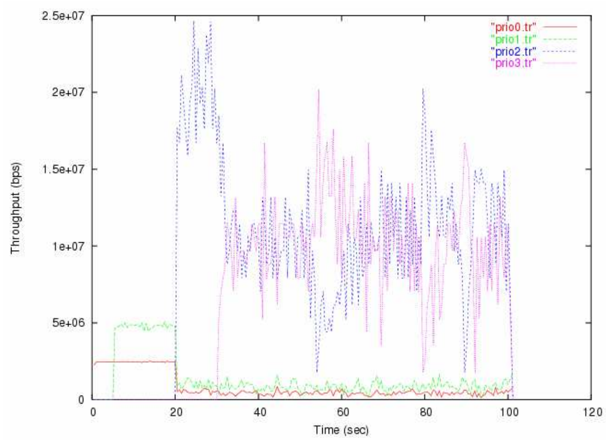

Fig. 9. Throughput of all nodes using 802.11.

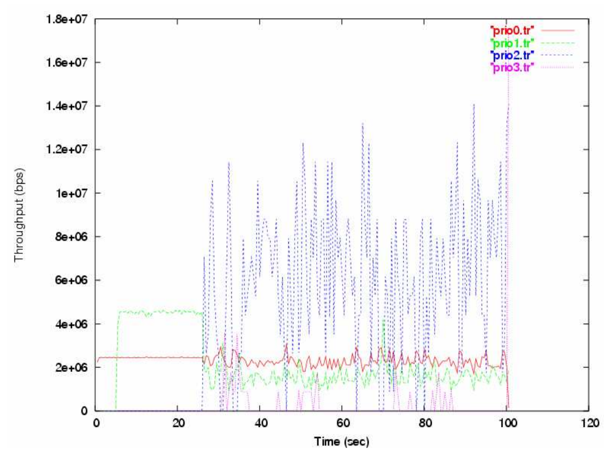

Fig. 10. Throughput of all nodes using differentiation of traffics.

V. CONCLUSION

In this paper, we present a new topology control based on dedicated mobile routers. Our goal is to ensure connectivity, while keeping a low congestion level on radio link. To control the topology, we use a dedicated connection admission control (CAC), based on network performances measurement; forced handover is introduce here to prevent congestion. Finally a QoS scheme was deployed to manage heterogeneous traffics by allowing different traffic priorities. The main features of our topology control are flexibility, less energy consumption in mobile nodes, good performances and less congested cell.

A key contribution to this work would consist in integrating a new metric in the network performances measurement (energy, link state, type of nodes … etc.), to study the deployment - which can be distributed and optimized - of other mobile routers. We also aim to ingrate this topology control to different networks, like sensor and 802.16 networks.

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