Dynamic bandwidth management for multihop wireless ad hoc networks

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***Abstract*— In this paper, we propose a new cross-layer protocol named DRBT (Dynamic Regulation of Best Effort Traffic) which supports QoS guarantees and provides a distributed regulation mechanism for Best Effort traffic in wireless ad hoc networks. By adapting the rate of Best Effort traffic at the MAC Layer, DRBT increases the acceptance rate of QoS flows through the network. Our protocol also provides an accurate method to evaluate the available bandwidth in IEEE 802.11-based ad hoc networks which differentiates between QoS applications and those which are less exigent in term of bandwidth more commonly called Best Effort traffic. Through simulations, we compare the performance of our proposal scheme with AODV and ABE.**

I. INTRODUCTION

The expanded availability of small wireless devices has enabled the deployment of mobile ad hoc network. Ad hoc networks are autonomous, self-organized wireless and mobile networks. They do not require any fixed infrastructure and nodes themselves address topology changes due to mobility. This absence of centralized infrastructure makes the design of QoS protocols for these networks a challenging task. Moreover, only local information is available to any node, therefore QoS protocol must use distributed algorithms and not rely on global information.

QoS focuses on several metrics like for instance delay, bandwidth, loss probability, etc. Our proposed scheme focuses on the bandwidth parameter, which is a basic metric often used to perform admission control, flow management or congestion control in ad hoc networks. In this work, we distinguish two types of applications:

- The first one requires guarantees on their bandwidth like video transmissions for instance. They are called QoS traffic henceforth.
- The second one is more tolerant to changes on their bandwidth like file transfer for instance. They are called Best Effort traffic.

Most of the current works in this area supply guarantees for QoS flows, thanks to an evaluation of the available bandwidth. However, these evaluations of the available bandwidth do not provide any differentiation between QoS and Best Effort data packets. Therefore, it is sometimes possible to obtain situations where there is not enough available bandwidth for a new QoS traffic just because most of the bandwidth is occupied by Best Effort traffic. Such an approach limits the number of accepted QoS flows.

The main idea of our protocol (called DRBT for Dynamic Regulation of Best Effort Traffic) is to provide a crosslayer QoS mechanism, which can regulate the throughput of Best Effort traffic (when it is necessary), according to an evaluation of the available bandwidth. This evaluation mainly relies on the possibility for nodes to decode local information to differentiate between QoS and Best Effort traffic. DRBT decreases the throughput of Best Effort traffic in order to increase the number of accepted flows while guaranteeing a maximal use of radio links (i.e. allowing Best Effort flows to use the maximum of their throughput whenever it is possible).

The rest of the paper is organized as follows: Section II presents related work. Section III describes our distributed cross-layer protocol and finally, simulations results are presented in Section IV.

II. RELATED WORK

To offer bandwidth guarantees to QoS flows, mobiles need first to evaluate the amount of available bandwidth to ensure that the total resource requirements of admitted flows can be handled by the network. Different solutions have been proposed to evaluate the available bandwidth.

BRuIT [3] and CACP [4] attempt to provide a good estimation of the carrier sensing area in order to derive an accurate available bandwidth estimation. Indeed, with CSMA protocols (like in IEEE 802.11), two nodes within carrier sensing range share the medium and thus the bandwidth, even if they cannot directly communicate. Therefore, each node needs to know the channel occupancy in its carrier sensing area in order to derive an accurate available bandwidth estimation.

These two evaluations only compute the available bandwidth per node, whereas communications mostly take place between two nodes, i.e. on a link. If we consider an evaluation per link, we need to consider extra parameters. For a communication to take place between two mobiles, the medium has to be simulaneously available on both sender and receivers sides. Therefore, the overlapping of the silence periods of the sender and of the emitter has to be taken into account. Moreover, the possible collisions on the receiver side has an impact on the available bandwidth on the link. Therefore, the collisions

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have to be estimated. ABE [5] considers these two features in oder to provide an available bandwidth estimation per link in multihop configurations.

These different estimations are then used in a routing protocol in order to compute QoS routes: each route offers at least the requested bandwidth. These works mainly focus on the QoS traffic and do not optimize the cohabitation between QoS flows and Best Effort flows. For instance, BRuIT allocates a small fixed share of the bandwidth to Best Effort flows, which is not very efficient when there are no QoS flows in the network. The permanent channel sensing realized by CACP or ABE may limit the number of accepted QoS flows. Indeed, with sensing, Best Effort flows are considered in the computation of the used bandwidth, which can lead to situations where most of the bandwidth is used by Best Effort flows and new QoS flows consider that there is not enough bandwidth.

Protocols, like SWAN [1] and QPART [2], try to dynamically regulate QoS and Best Effort flows according to the environment. SWAN uses an admission control before accepting a QoS flow, but this admission control is based on a local bandwidth evaluation that is not accurate and that does not differentiate QoS flows from Best Effort flows. Thus, the regulation of Best Effort flows is triggered to not overload the existing flow but not with the goal to accept more QoS flows. QPART does not use any admission control protocol, but regulates the different flows according to a congestion threshold. The congestion threshold corresponds to a mean idle time between two occupancies of the medium. This congestion threshold is different according to the flow priority. However, we think that this congestion threshold is also dependent of the environment and should be different for flows of the same priority that do not impact or are not impacted by their surrounding flows in the same way. Moreover, the congestion threshold of QPART is based on a channel sensing that does not differentiate the different flows.

To sum up, none of the described protocols in this section takes advantage of the differentiation. In this work, we start with ABE that is, from our point of view, the most accurate protocol for the evaluation of available bandwidth on a link and we add a differentiation mechanism in order to provide a more efficient bandwidth management. For instance, lets consider the scenario depicted on Figure I. In this configuration, all the nodes are within communication range and the capacity (the maximum rate in the communication area) corresponds to 1600 kb/s. Two flows are transmitted: a QoS flow of 500 kb/s and a Best Effort of 1000 kb/s. A third flow attempts to transmit data on the medium. With ABE, the perceived available bandwidth is almost null. Therefore this new flow can not be accepted. But, if we provide an estimation that differentiates QoS flows from Best Effort flows and that takes into account only transmissions of the QoS flows in the evaluation, then we obtain a remaining bandwidth for the new flow almost equal to 1000 kb/s. Therefore, the third traffic can be transmitted without degrading the existing QoS flow providing that a mechanism reducing the throughput of the Best Effort flow is used. Thus, we can accept more QoS flows.

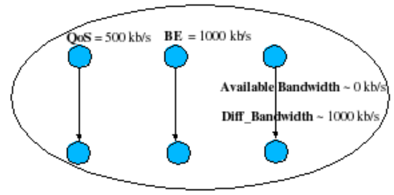


Fig. 1. Effect of differentiation

III. Dynamic protocol for the management of the available bandwidth

This section describes how we introduce the differentiation in the available bandwidth estimation and how we use this estimation for a regulation of Best Effort traffic.

A. *Estimating available bandwidth*

We start from ABE that provides an accurate available bandwidth estimation per link. First, in ABE, every node shall monitor the radio medium and measure the total amount of time during which it remains free. This method is based on a signal level measurement and thus takes into account emissions in the carrier sensing area. Then, ABE derives the available bandwidth per link by exchanging the bandwidth usage information between neighbor nodes and by computing a probabilistic estimation of the overlap of the silence periods. The exchange is done with the classical broadcasted *Hello* packets. Finally, ABE takes into account the impact of collisions in the evaluation by estimating the collision probability with a monitoring of the *Hello* packets. For more information on ABE, see [5] and [6].

1) Differentiation between QoS and Best effort traffic: As explained previously, a differentiation between QoS and Best Effort flows allows a better use of the available bandwidth for new QoS transmissions. This differentiation is done at the MAC layer and consists in measuring only medium occupancy of QoS data packets during the monitoring phase of ABE. Note that this differentiation is only possible if the node is able to decode data sensed over the medium. Packets sent in the carrier sensing area of this node will not be decoded because the signal perceived is below the transmission range threshold. Consequently, in DRBT the estimation of the available bandwidth is differentiated if the message sensed over the medium can be decoded. In other words, Best Effort traffic that can not be decoded are included in the used bandwidth during the monitoring.

2) Hidden station configuration: ABE takes into account the collision phenomenon in some configurations. However some cases are still missing. Let us consider the scenario depicted on Figure 2. In this configuration, as nodes 0 and 2 are totally independent, the emission of data packets from node 2 to node 3 involves collisions at the receiver node 1.

In ABE, a mechanism to predict collision probability at the receiver node 1, according to the throughput of node 2 is

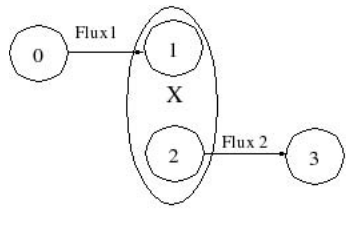


Fig. 2. Hidden nodes

already set up. With this mechanism, it is possible to deduce the real available bandwidth on the link $(0, 1)$.

Let us now consider the reverse problem. What is the available bandwidth on link $(2, 3)$ if there already exists a flow on the link $(0, 1)$? This estimation is crucial because, if a QoS flow is emitted on the link $(0, 1)$, we must know the maximum throughput of the Best Effort traffic to be emitted on the link $(2, 3)$ so that the throughput of the QoS flow on the link $(0, 1)$ will not be degraded.

For that, we denote by $d1$ the throughput on link $(0, 1)$. If we suppose that the throughput of link $(0, 1)$ is equal to the capacity (D_{max}) of the medium, the new question is: what is the collision probability p to apply on link $(0, 1)$ so that its throughput degrades up to the value $d1$? Thus, we compute the value of p with the following formula:

$$D_{max}(1-p) = d1 \Rightarrow p = 1 - \frac{d1}{D_{max}} \quad (1)$$

Off line, we derive by simulation the collision probability on node 1 by varying the load on link $(2, 3)$ and by emitting packets of fixed size at Dmax on link $(0, 1)$. These simulations, are carried out for different packet sizes. Thus, we obtain the collision probabilities for different packet sizes in function of the load on link $(2, 3)$ when node 0 emits at Dmax. Therefore, knowing $d1$, we can deduce p with Equation 1 and then derive the possible load on link $(2, 3)$ thanks to these off line results.

B. Regulation of Best Effort traffic

Providing throughput guarantees requires a mechanism to regulate dynamically the throughput of Best Effort traffic according to the available bandwidth estimation performed previously. In DRBT, the regulation scheme concerns only the Best Effort traffic. This regulation is done in two steps:

- Decreasing the throughput of Best Effort flows when a new QoS flow wishes to be transmitted and does not find enough available bandwidth because this one is partially consumed by Best Effort transmissions.
- Increasing the throughput of Best Effort flows when a QoS flow releases its bandwidth or moves to another transmission area.

1) Reduction of Best Effort traffic: In this section we explain how we decrease the throughput of Best Effort flows when necessary. To do this, DRBT does not introduce additional message overhead but uses the classical RREQ (Route Request) and RREP (Route Reply) packets found in many reactive routing protocols. Indeed, every time a new QoS flow wants to transmit data, it reserves the resources using these RREQ and RREP packets. The information stored on these packets with DRBT are:

- The throughput requested by the new QoS flow ($ThroughputQoS$).
- The number of Best Effort flows ($nbBE$) within the neighborhood of the QoS flow. Indeed, each Best Effort flow has a single identifier propagated on *Hello* messages. Therefore, each node can be able to know the number of Best Effort flows in its vicinity by analyzing these identifiers. This value is incremented at each node by the number of Best Effort flows that the node knows.
- The differentiated remaining bandwidth ($DiffBandwidth$). If the differentiated remaining bandwidth of the node that receives the RREQ is lower than the differentiated remaining bandwidth given in the RREQ, then the node modifies this field with its value. It allows us to know the available bandwidth computed along a path when considering only QoS transmissions (when possible).

The reliability of our resources reservation depends on the accuracy of the estimation of the available resources, but also on the routing process. We use an on-demand route discovery like in AODV. When a source node has data to send, it broadcasts a route request (RREQ) to its neighbors. The RREQ packet contains, in addition to the fields described previously, the address of the sender, the destination address and a sequence number. The sequence number is used in order to avoid cycles in the routing process, therefore a RREQ is just examined during its first passage. Each intermediate mobile that receives a RREQ performs an admission control by simply comparing whether the bandwidth requirement carried in the RREQ packet is lower than the differentiated available bandwidth of the link (previous sender, this node). If it is the case, the node adds its own address to the route and forwards the RREQ, otherwise it discards it. When the destination receives a RREQ, it also needs to do the checking procedure as described above. Finally the destination sends a unicast route reply (RREP) to the initiator of the request along the reverse path to ensure that mobiles along the reverse path are still reachable. The resources are thus reserved and the new QoS flow is sent.

Every time a Best Effort sender intercepts a RREQ or a RREP, it checks whether there is enough available bandwidth to carry the QoS flow without degrading its throughput. If it is not the case, it reduces its throughput by sending a packet called DRP for Dynamic Regulation Packet. This packet, sent from the IP layer towards the LL layer, contains the bandwidth information extracted from the RREQ or the RREP packets and the initial throughput of the Best Effort flow (T hroughputBE). The reception of this DRP packet at the Link layer activates the throughput reduction mechanism for Best Effort traffic. To set up the reduction scheme, two virtual queues are used at the LL level. The first queue conveys QoS data while the second one conveys Best Effort data packets. Therefore, we can control dynamically the size of each queue. To decrease in an optimal way the throughput of the Best Effort traffic, it is necessary to reduce the size of the Best Effort queue until a threshold. This threshold varies dynamically each time a new DRP packet is received. This threshold is computed according to the following formula:

$$Treshold_{dyn} = \frac{ThroughputBE}{AvailableBandwidth} \quad (2)$$

with :

$$AvailableBandwidth = \frac{DiffBandwidth - TroughputQoS}{nbBE} \quad (3)$$

Equation 3 computes the new available bandwidth allocated to the Best Effort flow if the new QoS flow is accepted. This equation is conservative, because it considers that all the Best Effort flows neighbors of the QoS flow on the path share the same radio medium, which is not necessarily the case and its considers the minimum differentiated bandwidth on the path. According to Equation 2, a threshold larger than one indicates that the throughput of Best Effort flow is higher than its allocated bandwidth and that a reduction is necessary.

Once the threshold is computed, the size of the Best Effort queue is fixed dynamically by computing the ratio between the number of Best Effort packets entering during a window of one second divided by this threshold. We choose a window of one second because in ABE, the available bandwidth of all links is updated every second.

2) Increase of Best Effort traffic: When a QoS flow stops transmitting or moves to another transmission area, all the Best Effort flows that have reduced their bandwidth should increase their throughput to its initial value in order to use the maximum of the available bandwidth when possible. To address this issue, we use the *Hello* messages. Indeed, each node carrying a QoS flow encapsulates, in its *Hello* messages, information about the identifier of this flow and the differentiated available bandwidth.

When a QoS flows stops transmitting or releases its bandwidth, it indicates this information in these *Hello* packets. The Best Effort emitter which is in the vicinity of this QoS flow will intercept these *Hello* messages indicating that a QoS transmission has stopped or that the available bandwidth has increased. Finally, the Best Effort flow can increase their throughput according to the updated available bandwidth. When a node moves, the nodes carrying a Best Effort flow do not received *Hello* messages anymore and can thus use their previous allocated bandwidth providing that they have stored it, according to this updated available bandwidth.

IV. SIMULATIONS

In this section, we evaluate the performances of DRBT and compare our protocol with AODV and ABE. We use network simulator (NS-2.27) for simulations, and the IEEE 802.11 implementation provided with the simulator as MAC Layer. For all scenarios, the physical rate is 2Mb/s, the packet size is 1000 bytes and the radio transmission range is 250m while the carrier sensing range is 550m.

A. A simple scenario

For this simulation, we consider a simple topology of four pairs of nodes as depicted on Figure 3. Four CBR connections, composed by two Best Effort traffic and two QoS transmissions, are established. The two Best Effort traffic begin at 1 s, while the QoS traffic of throughput respectively 1000 and 500 kb/s begin at 4 and 8 s. Simulations last twenty five seconds.

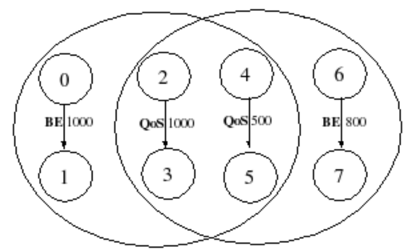


Fig. 3. Four pairs of nodes

When AODV is used, as shown on Figure 4(a), each connection tries to send its data packet when possible without any regulation mechanism and this situation leads to a congested network. The throughput of the two QoS flows are consequently degraded.

When ABE is performed (Figure 4(b)), the admission control step estimates that there is not enough available bandwidth to carry the two QoS flows with their bandwidth requirements. Hence, only Best Effort traffic are sent.

On Figure 4(c), when DRBT is used, a latency time is needed for the regulation mechanism to be enabled. Then, the two Best Effort traffic begin to decrease their throughput and the two QoS flows increase their throughput up to their bandwidth requirements.

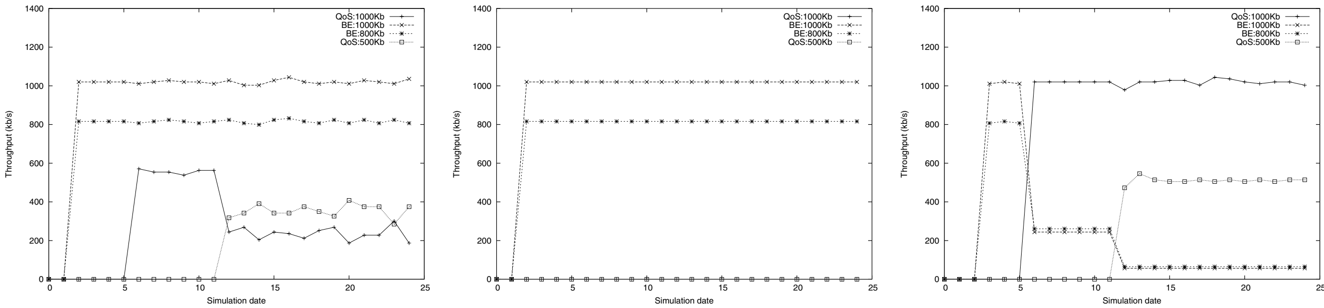
B. Random topology

To evaluate the accuracy of our protocol, we consider a topology of 10 randomly positioned nodes. Five CBR connections are established with random throughputs. The source and the destination are not in the same transmission range, therefore a routing process is necessary to reach the receiver. These CBR connections are composed by four best effort traffic and one QoS transmission of throughput 373 kb/s. Simulations last fifty seconds.

Figure 5(a) shows the throughput of all flows when AODV is used. As no QoS is maintained the network becomes congested and the throughput of the QoS flow is almost equal to zero since the beginning of its emission.

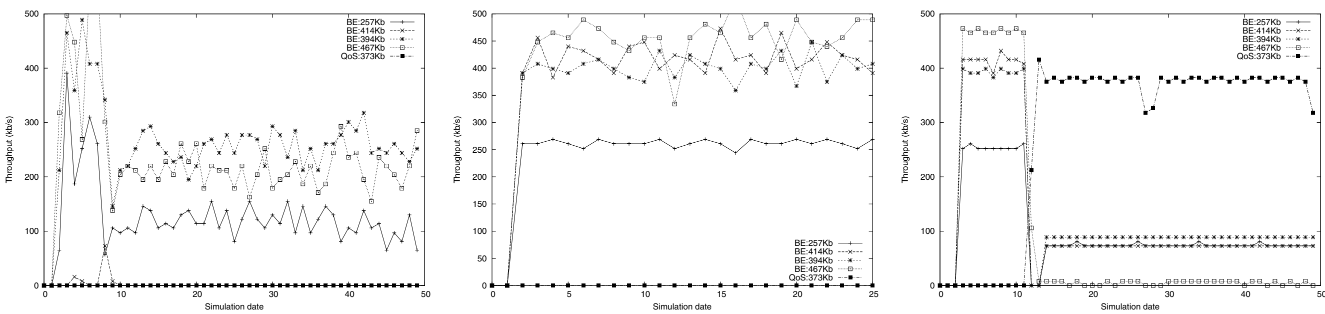
Figure 5(b) indicates the throughput of all flows when ABE is performed. As previously, the presence of the Best Effort traffic means that the amount of available bandwidth is insufficient to carry the QoS flow with its requirements. Therefore no QoS traffic is enable on the network.

Figure 5(c) depicts the throughput of all flows when DRBT is enabled. During the twelve first second, the QoS flow throughput is as previously almost equal to zero. This duration



(a) AODV (b) ABE (c) DRBT

Fig. 4. Flow throughputs with AODV, ABE and DRBT on a known topology



(a) AODV (b) ABE (c) DRBT

Fig. 5. Flow throughputs with AODV, ABE and DRBT on random topology

corresponds to the time required to activate the mechanism of throughput reduction for Best Effort traffic. Thereafter, the reduction scheme is on and consequently the QoS flow can increase its throughput to the value asked initially. This scenario demonstrates DRBTs ability to maintain the throughput of admitted quality of service flows when possible, by reducing effectively throughput of best effort transmissions.

To summarize, when DRBT is used the number of QoS flows admitted increases by reducing the throughput of contending Best Effort traffic.

V. Conclusions and future works

In this paper, we have presented DRBT (Dynamic Regulation of Best Effort Traffic), a new cross-layer protocol which guarantees bandwidth of QoS flows by adpating effectively and dynamically throughput of Best Effort transmissions when it is necessary. Our protocol relies on an estimation of the available bandwith differentiated according to the type of packets (QoS or best effort data packets). With these features, DRBT increases the acceptance rate of QoS flows. Furthermore, the effectiveness of our protocol is shown through simulations, wehere DRBT effectively manages bandwith of QoS transmissions by dynamically adapating rate of close Best Effort traffic.

In future works, we intend to improve some features and more particularly to deal with the problems induced by the carrier sensing mechanism. Another important point is to deal with mobility which prevents from guaranteeing resources due to the disappearance of link radio.

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