

Improving Accuracy in Available Bandwidth Estimation for IEEE 802.11-based Ad Hoc Networks

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Abstract—In this article, we propose a method to enhance accuracy of the available bandwidth estimation in IEEE 802.11-based ad hoc networks. This method combines medium state monitoring, probability of collision estimation and backoff time evaluation, improving the method described in [6]. We evaluate our solution by simulation on different scenarios and compare it with different QoS routing protocols based on different available bandwidth estimation techniques.

I. INTRODUCTION

The quality of service issues in ad hoc networks are now extensively studied and more and more QoS protocols are proposed, based on the bandwidth parameter.

To design an efficient QoS routing, it is very important to get accurate information on the used and available bandwidth. In multihop wireless networks, this estimation is not so easy to compute as the perception of the medium use is different from one mobile to another. Therefore, to precisely determine the available bandwidth for its own, a node has to know the bandwidth available to the nodes with which it share the medium in order to not penalize them.

We define the *available bandwidth* between two neighbor nodes as the maximum throughput that can be transmitted between these two peers without disrupting any ongoing flow in the network. Different solutions have been previously proposed to address this problem. They can be classified into two main categories: the intrusive techniques that send probe packets for the estimation and the passive techniques that are based on a local computation of the available bandwidth and sometimes on a sparse exchange of this information.

Our solution is based on the IEEE 802.11 technology as it is widely used in wireless local networks

and multihop wireless networks. However, our method could also be applied on other technologies based on a CSMA/CA approach, simply by using different values for the parameters we use in our solution.

II. RELATED WORK

Available bandwidth estimation methods can be divided in two major approaches:

- We call *intrusive approaches* methods that are based on end-to-end probe packets to estimate the available bandwidth along a path.
- We call *passive approaches* methods that use local information on the used bandwidth (like for instance the channel usage computed by sensing the radio medium) and that may exchange this information via local broadcasts. Usually these local broadcasts are performed with the *Hello* messages that are used in many routing protocols. If these exchanges are not too frequent, we consider that the method is not intrusive.

Intrusive bandwidth estimation methods. Many intrusive bandwidth estimation methods have been proposed for wired networks. A detailed survey of the different methods is proposed in [3]. The Self-Loading Periodic Streams (SLoPS) method measures the end-to-end available bandwidth by sending packets of equal size and by measuring the one-way delays of these probing packets. The Trains of Packet Pairs (TOPP [2]) method is based on the same principle but uses a different rate increasing function: TOPP increases linearly the rate whereas SLoPS uses a binary search.

These methods are *intrusive* as they use end-to-end probe packets to evaluate the channel characteristics. When every node in an ad hoc network needs to

perform such an evaluation for several destinations, the number of probe packets introduced in the network can be important. Therefore, such methods have mainly two drawbacks: they consume much bandwidth and they have an impact on the on-going traffic they measure.

Passive bandwidth estimation methods. Chaudet and Guérin Lassous have proposed a bandwidth reservation protocol, called Bandwidth Reservation under InTerferences (BRuIT) [1]. BRuIT attempts to compute the channel usage in the carrier sensing area, which is approximated by the two-hop neighborhood. BRuIT periodically broadcasts a Hello message containing information on the sending node and its one-hop neighbors, bringing information to nodes in the two-hop neighborhood.

The main drawback of this method is that the two-hop neighborhood is only a subset of the effective carrier sensing area.

Like in BRuIT, Yaling and Kravets have proposed the Contention Aware Admission Control Protocol (CACAP)[7], which goal is also to determine the available bandwidth of the nodes in the carrier sensing area. To address this issue, the authors propose three different methods: to use, like in BRuIT, Hello messages to propagate this information over the two-hop neighborhood; to increase the transmission power of nodes so that every node in the carrier sensing area can be reached; or to reduce the sensitivity of the mobiles in order for each node to take into account the bandwidth used in its carrier sensing area

QoS-AODV [5] is a per node available bandwidth estimation. To estimate the available bandwidth, the authors propose a metric called Bandwidth Efficiency Ratio (BWER) that computes the ratio between the number of transmitted and received packets. To collect the neighbors' available bandwidth, Hello messages are periodically broadcasted in the one-hop vicinity. Then, the available bandwidth of a node is defined as the minimum of the bandwidths available to the one-hop neighbors and to the computing node.

In the protocol AAC [4], each node estimates its local used bandwidth by simply adding the size of sent and sensed packets over a fixed period of time. The packet size is computed from a measure of the medium occupancy time. Therefore, this method considers traffic sent in the carrier sensing area. The available link bandwidth is defined as the minimum available bandwidth of all nodes belonging to the carrier sensing areas of the sender and the receiver.

The passive methods presented above estimate the impact of the level of contention on the bandwidth available to each emitter. In other words, they only consider interaction between emitters and can therefore be qualified as node-based evaluations. However, collisions happen at receivers, for instance in the well-known hidden node scenario, and also have an impact on the available bandwidth. Therefore, the whole link, emitter's side as well as receiver's side, should be considered to enhance the evaluation accuracy.

III. ACCURATE AVAILABLE BANDWIDTH ESTIMATION

Based on the previous observations, we designed a per-link available bandwidth estimation method that combines three measurements: a time-based channel utilization monitoring to estimate the bandwidth usage in the carrier sensing area, a probabilistic estimation of the overlap of the silence periods experienced by the two peers on a link and an estimation of the collision probability on a link.

The two last estimates require nodes to exchange bandwidth-related information. This exchange does not necessarily require dedicated control packets. This information can easily be appended to neighborhood discovery messages used by many routing protocols. Therefore our approach can be qualified as passive.

A. Estimating a node's available bandwidth

In order to evaluate the bandwidth it may use, every node shall monitor the radio medium and measure the total amount of time during which the medium remains free. As this method is solely based on a signal level measurement, it allows taking into account emissions happening in the carrier sensing area without identifying interfering emitters. In order to enhance the accuracy, we only consider silence periods long enough, *i.e.* lasting long enough (more than the *DIFS* timing) to allow a frame emission.

B. Estimating overlap of silence periods

In [6], we proposed a method to derive the available bandwidth on a link from the available bandwidth computed by the two nodes of the link. This evaluation uses a probabilistic estimation of the overlap of the silence periods and only requires the exchange of bandwidth usage information between neighbor nodes. In [6], we conclude that this method improves the evaluation but is still inaccurate, particularly when collisions decrease the available bandwidth, for instance with hidden nodes configurations.

C. Collision probability estimation

To enhance this estimation, we evaluate the collision probability by monitoring *Hello* packets. These control messages are sent periodically. Therefore, if we consider a given measurement period, it is possible to deduce the *Hello* collision rate using the number of actually received packets and the expected number of such packets.

This estimation requires the *Hello* packets sending rate to be known by every node. This information can either be shared by all nodes, or included in *Hello* packets.

It should be noted that *Hello* packets are sent in local broadcast, unlike data packets. Therefore, the collision rate experienced by *Hello* packets only reflects the probability that a data packet emission attempt fails. However, as collision detection is not possible in wireless systems, retransmissions performed by the MAC layer consume bandwidth as if they were different frames. The collision probability evaluated on broadcasted frames may thus be used to evaluate the bandwidth consumed by collisions.

The main imprecision in this approach comes from the different frames sizes. *Hello* packets are expected to be rather small frames, unlike data packets. As the probability that a given frame collides with another is highly dependant on both frames' sizes, the performed measurement should be adapted. Actually, we deduce the collision probability on arbitrary frame size by using a Lagrange interpolating polynomial. This approach is static and performed offline. However, the simulations we performed show that this interpolation gives rather accurate results and allows an enhancement in the available bandwidth estimation method. Designing a dynamic mechanism may further enhance accuracy and is currently under investigation.

D. Taking into account the backoff

Each frame emission is accompanied by a certain medium access overhead. In particular, before sending most frames, the MAC protocol imposes a random waiting time (*backoff*) that is, on average equal to $(CW_{min} - 1)/2$. This *backoff* time may be somehow considered as wasted as no emission is performed meanwhile. Moreover, when an emitter experiences a collision, the IEEE 802.11 standard indicates that it should retry sending the frame after a *backoff* time drawn in a window twice larger than at the first attempt, and so on. As the medium gets loaded, this *backoff* is expected to have an increasing impact. It should therefore be considered in the available bandwidth estimation.

However, a backoff increase follows an unsuccessful transmission and it can be shown that the time spent in

backoff time when the contention window increases can be neglected compared to the time spent in collision.

Let us denote by $T_{backoff}$ the total time spent in backoff wait during the measurement period when the contention window is larger than CW_{min} , by $T_{collision}$ the total time wasted due to collision. $\alpha = \frac{T_{collision}}{T_{collision} + T_{backoff}}$ is the proportion of extra waiting time introduced by the backoff due to collisions.

To evaluate the value of α , we consider a scenario in which mobiles are randomly positioned on an area of $1000\text{ m} \times 1000\text{ m}$. We increase both the network load and the number of nodes and measure the value of α . Results presented on Figure 1 are the average of 30 simulations.

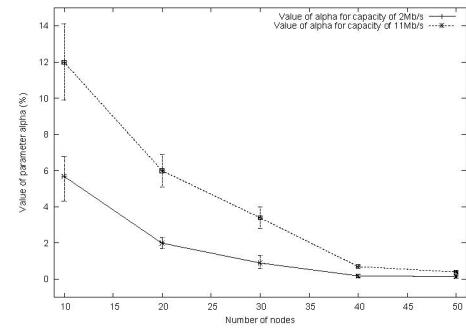


Fig. 1. Extra backoff waiting time

We can notice that, in the worst case, the extra time induced by the backoff hardly represents more than 6 % of the collision-related overhead for a 2 Mb/s link bandwidth and 12 % for a 11 Mb/s link bandwidth. Hence, the major part of this extra time is wasted by the colliding packets transmission. Moreover, when the network load increases, the value of α decreases until it becomes almost null. Therefore, it seems not necessary to take into account the exponential backoff time because the major part of wasted time is consumed by collisions. For higher throughputs (IEEE 802.11g for instance), however, as the time transmission is reduced, the part of waiting time due to the backoff becomes more and more important and may not be neglected anymore.

To conclude, our method gives the following formula for the link available bandwidth between two neighbor nodes s and r :

$$E_{final}(b_{(s,r)}) = (1 - K) \cdot (1 - p_m) \cdot E(b_{(s,r)}) \quad (1)$$

where $E(b_{(s,r)})$ is the expected available bandwidth on the link (s, r) computed with the method of [6], K is

the proportion of wasted time due to the backoff scheme and p_m the collision probability.

IV. SIMULATIONS

We have evaluated our estimation method and compared it to some passive approaches described in Section II. We used the NS-2 simulator (version 2.27), with the IEEE 802.11 implementation provided with the simulator. We compare the bandwidth estimated by our method, called ABE for *Available Bandwidth Estimation* in the following, with the estimation performed by BRuIT, QoS-AODV and AAC, that are available on the web

To compare the different solutions, we have generated random topologies with random flows (random source, random destination and random throughput). The results presented on Figure 2 were obtained on 20 nodes multi-hop networks with 7 random throughputs CBR flows.

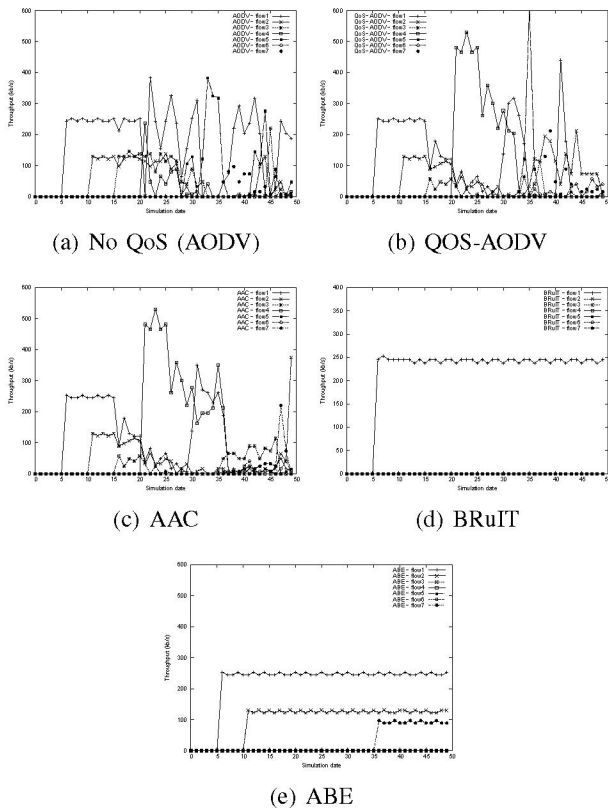


Fig. 2. Flows throughputs with different estimators

When no bandwidth estimation and therefore no admission control is performed, the network becomes

rapidly congested and routes are often broken, leading to a poor overall performance. AAC and QoS-AODV over-evaluate available bandwidth, therefore, as soon as QoS flows are accepted the throughputs of already existing flows begin to decrease. BRuIT underestimates the available bandwidth because it does not take into account the fact that some distant emissions can be performed in parallel ABE performs a more accurate estimation and more flows may be admitted than with BRuIT, meeting their bandwidth requirements and without provoking any degradation of close flows.

V. CONCLUSION

In this article, we have presented an improved method to compute the available bandwidth between two neighboring nodes. This estimation can be extended to a path in order to derive a QoS routing protocol.

The estimation leads to more accurate results than previous solutions by combining different parameters: the medium occupancy ratio, a probability of silence overlap, the collision probability evaluation and an average overhead estimation. Through simulations, we show that, even though the evaluation is still not perfect, it is more accurate than previous proposals.

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