Impact of heavy traffic beyond communication range in multi-hops ad-hoc networks

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Abstract

For commercial availability reasons, most actual multi-hops ad-hoc simulations and test-beds are based on IEEE 802.11 standard [1] and its medium access method CSMA/CA. But this standard has not been designed for that kind of network and presents serious flaws in this context. In this paper, we shall try to highlight problems that can appear in the **non-direct** neighborhood of important data flows in ad-hoc networks. In some situations, the fairness of the medium access can indeed be very poor. Various techniques could be used to solve this problem. In this paper we present one solution, which only requires minor modifications to the standard.

Keywords: Ad-hoc networks, Radio interferences, Medium access, 802.11

Résumé

Pour des raisons de disponibilité commerciale, la plupart des simulations et des bancs d'essai de réseaux ad-hoc multi-sauts sont réalisés avec l'aide de la norme IEEE 802.11 et de sa méthode d'accès au médium CSMA/CA. Mais cette norme n'a pas été conçue à l'origine pour ce type de réseau, et présente dans ce contexte des problèmes sérieux. Dans ce rapport de rechercher, nous allons mettre en lumière certains des problèmes qui apparaissent au voisinage de flux importants dans les réseaux ad-hoc multi-sauts Dans certaines situations, l'équité de l'accès au médium peut en effet être très mauvaise. De nombreuse techniques peuvent être utilisées pour résoudre ces problèmes. Nous présenterons ici un solution qui à, entre autres avantages, de ne nécessiter que des mofifications mineures à la norme

Mots-clés: Réseaux ad-hoc multi-sauts, interférences radio, accès au médium, 802.11

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1 Introduction

Ad-hoc technologies (according to the definition given by the manet working group at IETF [2], namely mobiles associated in a network, without fixed facilities), are going to be more and more used on laptops and equivalents (ease of deployment and use, fault tolerance, and many more other advantages).

Most of the actual work on ad-hoc networks concerns routing algorithms. All these works generally assume that a fair medium access method is provided by the underlying layer. Most of the measurements and simulations in this field are based on 802.11 standard or its variants.

The radio medium has obviously some specificities. For example, it suffers from interferences and signal attenuation problems which are unknown in wired networks. To solve some of these problems, RTS/CTS mechanism has been proposed and included in 802.11. Moreover, a large number of alternative access methods have been proposed in the literature ([9], [4], [10]); but they do not address all the problems that appear when the mobiles causing the interferences are not in the communication range of each other.

Measurements and simulation of 802.11 networks using base stations usually give good results, mainly for two reasons: - Spatial re-use of the medium can be finely tuned (by assignating in a concerted manner different frequencies to base stations). This means that the fast attenuation of radio signals is taken into account, and that a same frequency can thus be used by more than one base station, provided that they are not too close to each other. - The base stations may be used to coordinate the mobiles which depend on them, thus providing a good fairness in the cell.

But if 802.11 technologies are used to build a multi-hops ad-hoc network (and base stations removed), this ability to planify and control transmissions in a centralized manner is lost, and problems appear.

In particular, to maintain the connectivity through the complete network, all the mobiles need to work on the same frequency (in traditional wireless cell based networks, only mobiles around a same base station have to work on the same frequency). These mobiles in the non-direct neighborhood increase the contention, because of the interferences they produce.

At the physical layer, to understand messages, a mobile needs to receive them with a power above a fixed level. A "communication region" can thus be considered around each mobile; anybody in this region being able to correctly send messages to it. A mobile located out of this region could nevertheless jam the reception, even if its signal is too low for direct communication. The 802.11 standard defines a carrier sense threshold (lower than the communication threshold) which determines a "jamming region" and is used to determine if the medium is free or not.

We shall begin in Section 2 by stating the limitation of the simulator we used. In Section 3, we shall present simulations results showing equity problems with the medium access method in ad-hoc networks context. We shall pay a particular attention to what happens when communication needs exceed what can be provided. In Section 4, a technique improving equity in a significative manner will be presented, which only require very small modifications to 802.11 MAC layer to be implemented. This article will be concluded in Section 5, by considering possible ameliorations of our technique and the relevance of the "injection" of neighborhood topology and traffic informations, still with the intention of improving the equity without sacrifying the performances.

2 Constraints and limitations of our simulations

The following simulations have been realized with Network Simulator 2 [7] and its wireless module (which originally was an extension proposed by the Monarch project [8]). We have used the default parameters for 802.11 under ns2. The simulated hardware was a 2MBit/s card, working at 914 MHz. One of the major flaws of ns concerning radio interferences, is that the simulator does not add the different noises existing at a given instant. Instead, it only compares those noise one by one with the communication and carrier sense thresholds. In real world, independently harmless noises can add up and jam our communications. This kind of case is unfortunately not simulated in a correct manner. Given the nature of the problem, we can consider that the results obtained are optimistic (the interferences problems should be even more important).

In some of our simulations, we have used constant bit rate UDP flows. In real world, this kind of flow will unlikely be used. But in simulations, they allow the highlighting of layers 1 and 2 problems which would otherwise have been hidden. Using TCP, a number of other parameters should have been taken into account (in particular, the TCP window size, and the presence of reception acknowledgments would have drastically influenced the results). Several works have been conducted on the impact of the medium access method on TCP flows ([11],[6]). But these papers focused on the interactions between mobiles able to communicate with each other. Our present work is deals with what happens when mobiles jam each other without being able to communicate.

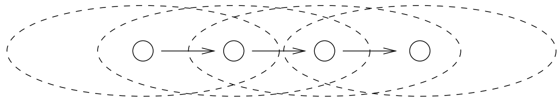

Figure 1: topology used in the “chain” experiment

3 Simulations

3.1 Experiment 1 : “chain” of static mobiles, of variable length

The first experiment implement a varying length chain of mobiles (Figure 1). Each mobile can communicate with its direct neighbors (the mobiles are placed all 200 meters, their communication range is about 250 meters and they do not move during all the simulated time). As we have used the defaults thresholds of 802.11 and the “two-ray ground” reflection model of ns2, the jamming region of a node is two time larger than the communication region (so about 500 meters). In this simulations, a node is therefore able to jam its one and two hops neighbors. We have put a 2 Mbit/s UDP Constant Bit Rate source (the theoretical maximum allowed by the medium) at one end of the chain, and a receiver for this flow at the other end. Figure 2 presents the simulation results for chain lengths contained between 2 and 8 mobiles. The routing protocol used was DSR [5].

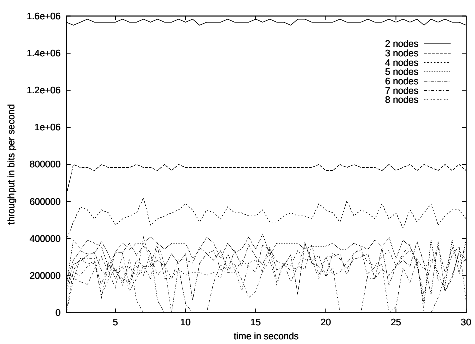

Figure 2: Throughput on the chain depending on the number of mobiles (DSR)

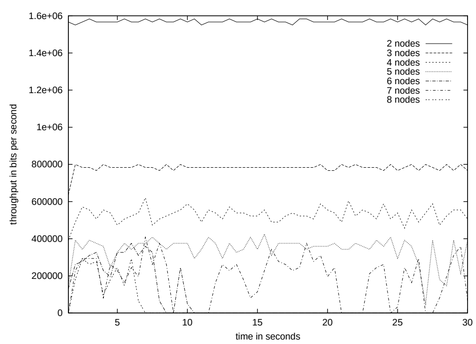

Figure 3: Throughput on the chain depending on the number of mobiles (AODV)

It clearly appears on Figure 2 that the bandwidth is shared between the mobiles, and that the throughput is subsequently reduced. One drawback of the intense contention at the medium access, is that the packets broadcasted by the routing protocol can be repeatedly blocked (no acknowledgment is indeed required for broadcasted packets). The transmitter will not known that these routing packets have been lost, and will not try to send them again (even if they are absolutely necessary for the routing).

As we used DSR in this simulation, as the “mobiles” did not moved and as the route as been established before the sending of the first data packet, the problem did not appeared (don’t forget that DSR doesn’t try to modify a route as long as it is up).

But when we use AODV [3], then we can see (Figure 3 that when the chain length is increased (thus increasing the contention), the “hello” packets broadcasted for the route maintenance are lost. If too many are lost, the routes expire (curve 5,6,7 and 8 on Figure 3). In general however, any routing protocol which broadcast signaling packets may experiment this kind of problem. In our simulation, if the mobiles had moved, the route would have had to be rebuilt. In the case of DSR, this rebuilding would have been done by a flooding of Route Request packets. This problem may appear as well during the setting up of a route, when there is already a great activity in the network.

3.2 Experiment 2 : the three moving pairs

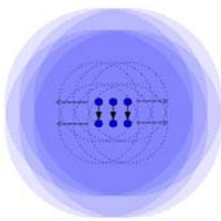

Figure 4: Initial positions of the pairs

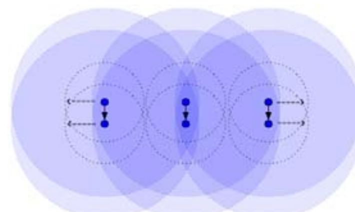

Figure 5: Interferences in the experiment

This experiment highlights medium access unfairness. We used the configuration presented on Figure 4: Three pairs of mobiles are initially very close. Each pair is composed of one transmitter and one receiver. The transmitter tries to send a 2 Mbit/s UDP Constant Bit Rate flow. The mobiles of a pair stay very close to each other all the time. During the simulation, the central pair will stay at its initial position, while the others will move away from it in opposite directions at a speed of 25 meters per second (Figure 5). The Figure 6 show the throughputs measured for the three flows, depending on time. The phenomenon can be explained as follows:

- from 0 to 5 seconds : the three pairs are in direct “contact” (in the same communication zone). Even when the network is saturated, as the throughputs requested are the same, the bandwidth is fairly shared (maximum physical throughput – around 1.6Mbit/s – divided by 3.

- from 5 to 11 seconds : the pairs can still jam each other, but direct communication are no possible anymore. Each time a mobile transmits a packet, the others know the channel is used, even if they may not understand what is said. For the same reasons of well-balanced requests, the medium access is quite fair.

- from 11 to 22 seconds : the central pair is in a different situation from the others. It is in the jamming region of the two others, while the laters are only jammed by the central pair. In this asymmetric context, the medium access mechanism presents flaws. As soon as the central pair loses the channel to a peripheral pair, it has no possibility to get the access back. What happens can be explained in this way : The central pair can only transmit when the others are silent. But as the others

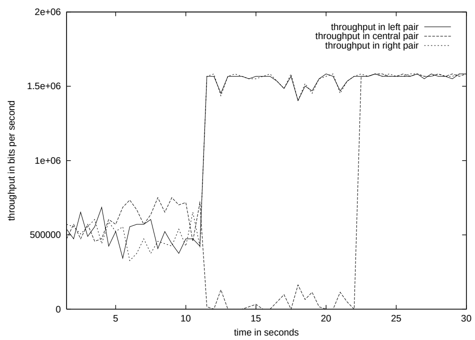

Figure 6: Throughput depending on time

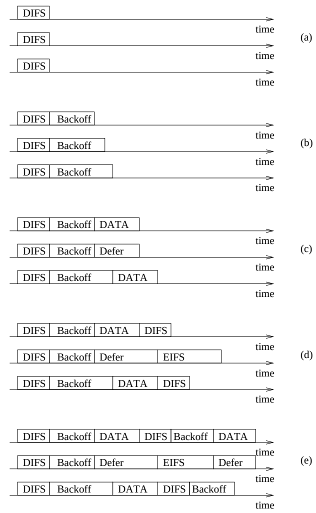

Figure 7: details of the medium access problem with EIFS

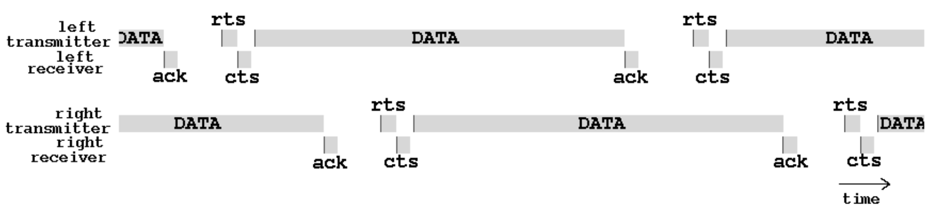

Figure 8: detail of the simulated transmissions during the 11 to 22 seconds period

pairs do not jam each other, there is no reason for them to be synchronized. Therefore, there is no reason for their backoff periods to coincide. Moreover, the longer the payload is, the smaller the chance of backoffs to occur at the same time (Figure 8). The phenomenon is amplified by another mechanism implemented in 802.11. The standard imposes that a mobile has to wait for an EIFS period when the channel becomes free again, after a message has not successfully been received.

The Figure 7 shows in a simplified way (for legibility reasons, the durations are not the real ones) what happens. Please note that even if unlike in this example, in reality all nodes begin at different times, the problem still appears after some time. First, the channel has to be free for a DIFS period before a node decides to transmit (Figure 7a). Then the nodes wait for a random backoff period (Figure 7b). As the transmitter of the first pair has finished its backoff and the channel is free, it begins transmitting, thus jamming the second pair (which enters a defer period until medium is free again). As the third pair has not been jammed, it has finished its backoff and has started to transmit too (Figure 7c). Because of the jamming coming from the third pair, the second has to defer for a longer time. And when the medium become free at last, it has to wait for a EIFS period (about 6 times longer than DIFS in our case). During this time, the two others have entered a new cycle (Figure 7d). And things start over ... (Figure 7e)

- beyond 22 seconds : the pairs are totally isolated and do not jam each other anymore. The observed throughput thus reaches the maximum value allowed by the medium.

3.3 Experiment 3 : the “static” chain and the roaming “troublemaker”

This experiment shows the impact of the phenomenon previously depicted in a more realistic situation. The topology of the experiment is shown on Figure 9. A UDP CBR flow goes through a “chain” of 6 mobiles (similar to those used in the first experiment, with a distance of 200 meters between each node). One pair of mobiles (between which another UDP CBR flow exists) is initially located far away from the chain (outside interference region of the nodes of the chain). The mobiles of the pair are always very close to each other (1 meter) during all the simulation. The “mobiles” of the chain never move. During the simulation, the pair moves and progressively goes to the other side, crossing the chain.

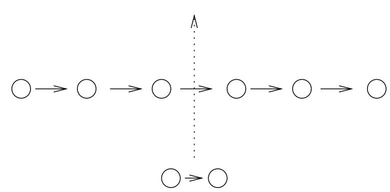

Figure 9: Topology used in the third experiment

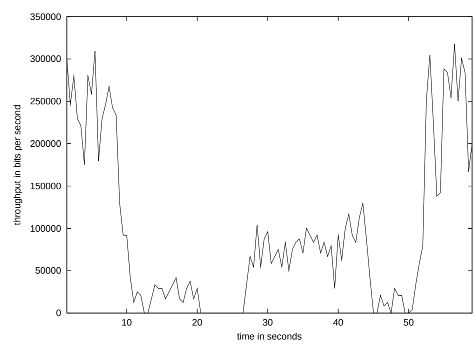

Figure 10: mean throughput on the chain

Measures have been taken for various requested throughput for each flow (2000, 1333, 1000, 800, 400 and 200 kbit/s). Except when only 200 kbit/s are requested for each flow, the network capacity is saturated and not enough bandwidth can be provided. For legibility reasons, Figure 10 only presents the mean of measured throughputs. The symmetry is easily seen, as are the two “holes” corresponding to the phenomenon previously described (between 10 and 30 seconds, and between 45 and 50 seconds). This clearly show that the chains flow is the most perturbated when the “troublemaker” flow is in its interference region.

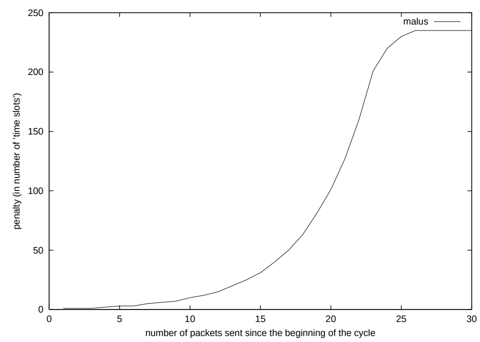

Figure 11: progression of the penalty depending on the number of packets already sent

4 A solution

The following solution has been elaborated in order to minimize the changes to the 802.11 MAC protocol, and if possible to remain compatible with mobiles running unmodified 802.11. We wanted a mechanism able to work even when communications between jamming/jammed mobiles are not possible at all. In this case, it may neither be possible to know which mobile is jamming us, nor if we are jamming someone else, techniques trying to compute exacts times to transmit for each node no longer work. The modifications we propose try to penalize mobiles which transmit too much, so that oppressed mobiles can still gain access to the medium.

The simplest way to impose such penalties is to act on the backoff period. So we have made the following changes to its computation:

At the beginning of each time period, all nodes are in the same situation. Next, each time a node gains access to the medium and sends a packet, a penalty is added to its backoff (thus the backoff for the next packet that will be sent by this mobile will be statistically greater). We furthermore precise that except for this penalty, the backoff is computed in the way indicated in 802.11 standard.

The penalty progression curve (Figure 11) is for now arbitrarily defined. It presents a lower "plateau" ("the first packets do not cost much"), then an abrupt ramp ("now it's time to let the others speak"), and finally a higher plateau (if we continue to increase penalty in an exponential manner, the throughput will be too reduced when a single flow is present in the network).At the beginning of each cycle, all the penalties are set to zero. In this mechanism, the parameters we can adjust are essentially the length of the cycle and the shape of the penalty progression curve.

Even if this method is simple, it gives quite valuable results. In simulations, it appeared that the probability for a mobile to be completely run over by its non-direct neighbors is much smaller than with standard 802.11. And routing protocols benefit a lot of this (in particular proactive protocols). As probability for their packets to be lost in serie is lowered, the probability of needlessly dropping routes is greatly reduced.

We used again the "chain and troublemaker" example (Figure 9), but with TCP, and with a requested throughput of 2 Mbit/s. With standard 802.11, we got disastrous results (Figure 12).

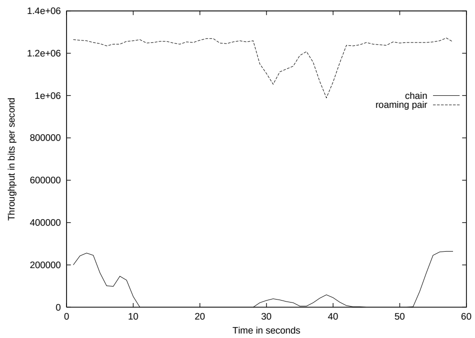

Figure 12: throughputs in the chain and troublemaker experiment (TCP, normal 802.11)

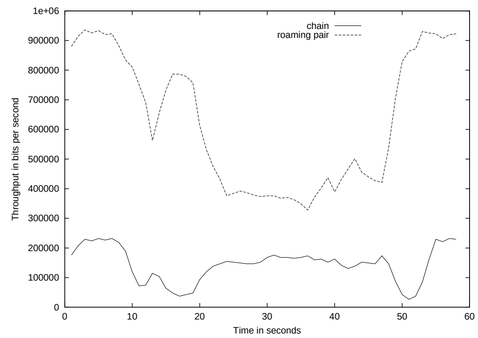

Figure 13: throughputs in the chain and troublemaker experiment (TCP, modified 802.11)

Keep in mind that the erratic behavior of the medium access mechanism for the chain prevents TCP acknowledgments to be sent in time, thus preventing ANY progress in the communication. The modified version looks quite better (Figure 13)

Of course, our method presents some drawbacks. We already talked about reduction of the maximum usable bandwidth for an unique node. As we statistically increment the backoff, the maximum number of packet per second is reduced. But this problem quickly becomes imperceptible when we increment the number of contending flows. The other important drawback is the bursty behavior of the communication, which can cause problems for some types of applications (multimedia in particular).

On the other hand, it has the advantage to remain compatible with mobiles using standard 802.11. Even if mobiles using the modified version are penalized (getting less bandwidth than others in case of contention), it will still works in an acceptable manner.

5 Conclusion

In this paper, using ns2 simulations, we have highlighted some flaws of 802.11 medium access method when used for ad-hoc networks. It appeared that as 802.11 has been primarily designed for base-stations based networks, it doesn't handle well the contention when direct communications are not possible. In particular, in case of heavy traffic between two nodes, other transmissions outside communication range but inside jamming region of the transmitter may be almost completely blocked. We have analyzed the problems and have proposed a simple, effective and compatible way to bypass them. However, our solution may be improved in various ways, in order to limit its drawbacks ("bursty" behavior, and in some case decrease of maximum bandwidth). One way would be to find better (dynamic ?) and more effective penalty progression shape. Another way would be to try to integrate to the penalty computation some information about the non-direct neighborhood. Those informations about activity in the vicinity could be, for example, obtained through packets exchanged by routing protocols (in particular by proactive routing protocols, but in general by all protocols making use of “hello” packets).

References

[1] *IEEE Std 802.11, "Wireless Lan Media access control (MAC) and physical layer (PHY) specifications"*. 1999.

[2] S. Corson and J. Macker. *RFC2501 Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations*. 1999.

[3] S. Das, C Perkins, and E. Royer. *Ad Hoc On Demand Distance Vector (AODV) Routing*. 2001.

[4] J. Garcia-Luna-Aceves and C. Fullmer. Floor acquisition multiple access (fama) in single-channel wireless networks. *Mobile Networks and Applications, vol. 4, pp157-174*, 1999.

[5] D. Johnson, D. Maltz, Y Hu, and J. Jetcheva. *The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks*. 2001.

[6] M. Correa K. Tang and M. Gerla. Effects of ad hoc mac layer medium access mechanisms under tcp. 2001.

[7] The VINT Project. Network simulator 2. "http://www.isi.edu/nsnam/ns/", 2001.

[8] The CMU Monarch projet. The cmu monarch project’s wireless and mobility extension to ns. http://www.monarch.cs.cmu.edu/.

[9] S. Shenker V. Bharghavan, A. Demers and L. Zhang. Macaw: A media access protocol for wireless lans". *ACM SIGCOMM*, 9 1994.

[10] Y. Wang and B. Bensaou. Achieving fairness in ieee 802.11 dfwmac with variable packet lengths. In *GLOBECOM 2001 proceedings*, November 2001.

[11] S. Xu and T. Saadawi. Does the ieee 802.11 mac protocol work well in multihop wireless ad hoc networks? *IEEE communications Magazine*, 2001.

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