THROUGHPUT ANALYSIS OF AN ALOHA-BASED MAC POLICY FOR AD HOC NETWORKS*

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Abstract Re-use of existing widely explored Medium Access Control (MAC) schemes, like the well-known Aloha scheme, is not applicable in ad hoc networks where the transmissions of the users can be normally sensed by only a fraction of the users present in the network. Therefore, *estimations of the network traffic load* are not possible anymore. Here, an *adaptive probabilistic policy* for medium access control in ad hoc networks, inspired by the Aloha paradigm, is proposed and analyzed. Simulation results show that this policy is capable of achieving higher *system throughput* when compared to other policies that have been proposed for ad hoc networks. It is also shown that *mobility* severely impacts the system throughput and therefore, an alternative approach is proposed that reduces the effects of mobility in the expense of the maximum achievable system throughput.

Keywords: Ad Hoc, Aloha, MAC

1. Introduction

The design of Medium Access Control (MAC) policies in ad hoc networks is challenging due to the idiosyncratic behavior of these networks. Several MAC policies have been proposed, [1], [2], [3], which are based on the CSMA/CA

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*This work has been supported in aprt by the E-NEXT research program that is partly funded by the European Commission.

mechanism, including in most of the cases the Ready-To-Send/Clear-To-Send handshake dialogue to avoid the *hidden/exposed terminal* problem. TDMA-based MAC protocols have also been proposed (e.g., [4]) and it has been shown that when an optimal solution is required, the derivation of the *scheduling* (*time slots* in which a node is allowed to transmit during a *frame*), is an NP-complete problem, similar to the n-coloring problem in graph theory, [5], [6]. Consequently, these approaches are *not suitable for ad-hoc networks* where, in general, nodes are moving and therefore, the scheduling needs to be recalculated for all nodes in the network.

TDMA-based MAC policies, which do not require recalculation of the scheduling of the nodes when the *topology of the network* is changing and the *frame size* is significantly smaller than the number of nodes in the network, have already been proposed, [7], [8], [9], [10]. The Deterministic Policy (referred to hereafter as D-Policy) has originally been proposed in [7]. Under this policy nodes are allowed to *transmit only at a (small) subset of the available time slots* carefully selected so that at least one of them be collision free. While the latter results in a guaranteed minimum throughput per node, restricting the transmission opportunities of a node to a (small) subset of the available slots, leads to a fairly low overall system throughput, [10].

Since most of the non-assigned - under the D-Policy - slots may be wasted if other nodes are temporarily idle or move away, it has been proposed in [10] that such slots be utilized *probabilistically*. This is the key idea behind the Probabilistic Policy (referred to hereafter as P-Policy) introduced in [10]. It turns out that the system throughput is (in general) significantly increased under the P-Policy. The higher system throughput under the P-Policy is achieved by *giving access to all nodes to all slots*, with probability 1 if the slot is assigned (under the D-Policy) to a node and with *access probability* p otherwise.

In this paper, an Aloha-based MAC policy is proposed and studied. This new policy assumes the deterministic framework provided by the D-Policy and *adapts* accordingly to the *network traffic load* conditions and the *topology density*. The proposed policy will be referred to, hereafter, as the Adaptive Policy, or A-Policy. The probabilistic transmission attempts introduced under the P-Policy are preserved, the key idea being, behind the A-Policy, transmission attempts with probability 1 after successful transmissions, provided that there are data available. As a result, the utilization of any unused time slots (under the D-Policy and the P-Policy) is further improved, as it is shown in this study.

2. The Adaptive Policy (A-Policy)

The key idea behind the A-Policy is to utilize further (compared to the P-Policy) the set of unused time slots and at the same time reduce as much as possible any interference caused to other time slots. Exchanging control messages among the nodes, is one possible way to proceed, but this process should be repeated every time the network topology changes and an extra overhead would be introduced.

The A-Policy: Each node u transmits in slot i during frame j, if $i \in \Omega_u$ and transmits with probability $p^j_{i,u\rightarrow v}$, if $i \notin \Omega_u$, provided it has data to transmit.

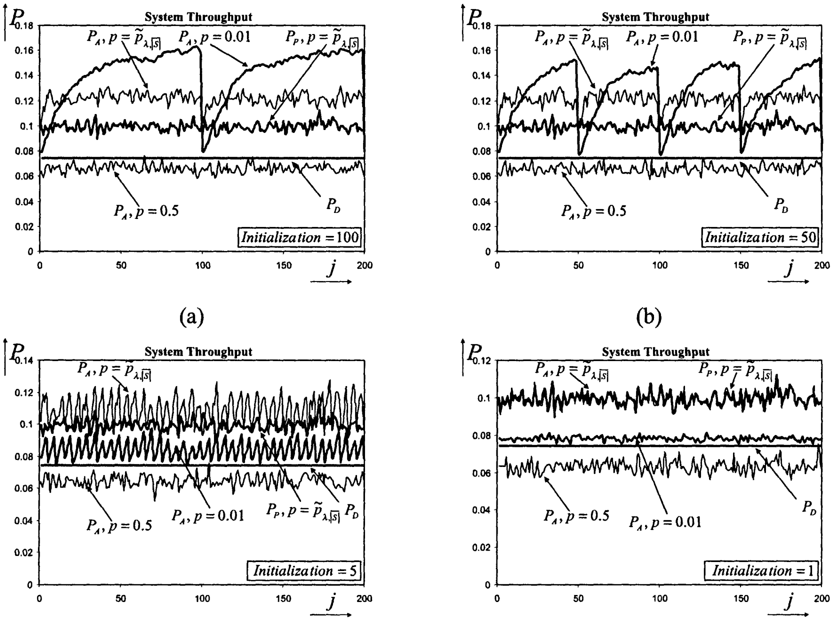
$p^j_{i,u\rightarrow v}$ may take two different values, p or 1, depending on the status of the most recent attempt of transmission $u \rightarrow v$ in time slot i. The initial value (for the case that no transmission $u \rightarrow v$ took place in the past) is set to p. The remaining of this section focuses on the derivation of an analytical expression regarding the *system throughput* under the A-Policy.

3. Simulation Results

In ad hoc networks, nodes are generally moving and it is interesting to examine the system throughput under the A-Policy under certain mobility conditions. Certainly, the D-Policy and the P-Policy are not affected by the movement of the nodes (except when the mobility of the nodes results in a denser topology, [10]) as the A-Policy does. It is already shown that a certain number of frames is required before the system throughput under the A-Policy (P_A) converges to a certain value. If nodes are moving, then the value of $p^j_{i,u\rightarrow v}$ will change (initialize and start converging again) by the time node v is not within the transmission range of node u. Obviously, the higher the mobility of the nodes, the more frequent the initializations and the smaller the system throughput under the A-Policy.

In order to demonstrate the aforementioned case using simulation results, nodes "initialize" the corresponding values of $p^j_{i,u\rightarrow v}$ after a number of frames equal to parameter *Initialization*. This is depicted in Figure 1. In Figure 1(a), where *Initialization* is set to 100 frames, it can be seen that P_A, for $p = \tilde{p}_{\lambda,\overline{|S|}}$ and $p = 0.01$, begins from 0.1 and 0.08 and converges towards, 0.12 and 0.16, respectively. At frame $j = 100$, both curves return to their initial values and converge again towards 0.12 and 0.16, respectively. Of course this is not the case for the other policies or for P_A for $p = 0.5$ (for the latter case the convergence period is rather small and equal to 2 frames).

In Figure 1(b), *Initialization* is set to 50 frames and it may be observed that P_A, for $p = 0.01$, is not able to reach 0.16 (the system throughput drops down before reaching the maximum achievable value). For smaller values of *Initialization* (5 and 1 in Figures 1(c) and 1(d), respectively), P_A, for $p = 0.5$, remains unaffected, while P_A, for $p = 0.01$, is severely affected. However, it is observed that P_A, for $p = \tilde{p}_{\lambda,\overline{|S|}}$, even though affected by the mobility of the nodes, is equal or slightly higher than P_P.



(a) (b)

(c) (d)

Figure 1. System throughput, P, simulation results for various values of $Initialization$, as j increases.

4. Conclusions

Here, a new MAC policy for ad hoc networks, the A-Policy, based on the Aloha paradigm, was proposed and analyzed. It is a simple policy that requires no knowledge of the topology to operate and it is shown that it achieves higher system throughput than other existing policies. The limitations of the A-Policy were also revealed in this work.

The A-Policy is suitable for ad hoc networks, since it is a simple policy to be implemented, it does not introduce any extra control overhead and the system throughput is largely increased compared to other policies (under certain conditions studied in this work). Even for the case of highly-mobile environments, an eloquent choice of the access probability p determines a certain lower bound for the system throughput, equal to the maximum system throughput under the P-Policy. However, the possible unfair treatment of some nodes in the network has to be taken into account with respect to the desired system throughput.

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