Performance Analysis of 802.11e Networks with Hidden Nodes in a Star Topology

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***Abstract*— The paper presents a preliminary study of a revised analysis of IEEE 802.11e performance. One of many possible topologies is analyzed in order to emphasize the severe problem of the incapability to prioritize traffic in networks with hidden nodes. The article also provides some innovative conclusions.**

***Index Terms*— 802.11e, hidden nodes, QoS, RTS/CTS**

I. Introduction

WIRELESS ad-hoc networks are currently one of the most evolving and popular technologies. Their easy configuration and fast deployment makes them ideal, not only for the average customer and ISPs, but also for emergency situations. Ad-hoc networks, themselves, are not able to satisfy the QoS requirements of different services, such as real-time video streaming or VoIP. Therefore, in 2005, the IEEE 802.11e standard [1] was developed in order to face this serious problem. For ad-hoc networks, it provides QoS guarantees through EDCA (Enhanced Distributed Channel Access). Unfortunately the 802.11 protocols are not resistant to the hidden node (HN) problem. As a remedy, several different solutions have been proposed (cf., [4]), however, the RTS/CTS mechanism is most commonly chosen to combat the hidden node problem.

This paper presents a thorough analysis of a four-node 802.11b star topology network with the 802.11e extension. It highlights the problem of the incapability to prioritize traffic in networks with HNs. The main stress is put on the throughput levels of high priority traffic (voice and video) and unfairness in granting medium access. The validation of the given conclusions is done by eliminating HNs. Additionally, the usefulness of the RTS/CTS mechanism is addressed.

The rest of the paper is organized as follows. Section II gives a brief description of the analyzed testbed and discusses the obtained results. The article concludes with Section III.

II. Simulation Study

The simulation study was performed with the use of an improved version of the TKN EDCA extension [3] to the ns2 simulator. The modifications mostly affect the RTS/CTS mechanism. Important parameters are given in Tables 1 and 2.

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TABLE 1
EDCA Parameter Set

Priority	AC	$CW_{min}[AC]$	$CW_{max}[AC]$	$AIFSN[AC]$
P0	Vo	7	15	2
P1	Vi	15	31	2
P2	BE	31	1023	3
P3	BK	31	1023	7

TABLE 2
Simulation Parameters

SIFS	10 µs	DIFS	50 µs
PIFS	30 µs	Slot Time	20 µs
Tx Range	250 m	Tx Power	0.282 W
Frame Size	1000 B	Traffic Type	CBR/UDP
Carrier Sensing (CS) Range		263 m (network w/ hidden nodes) 550 m (network w/o hidden nodes)	
Node Distance		200 m	
Wireless Standard		IEEE 802.11b with 802.11e	

The analyzed scenario (Fig. 1) consisted of four nodes (N) sending traffic with priorities (P), with varying sending rates (form 10 kb/s to 7 Mb/s). For the clarity of presentation, only rates up to 4.8 Mb/s per node are presented. Three nodes were hidden.

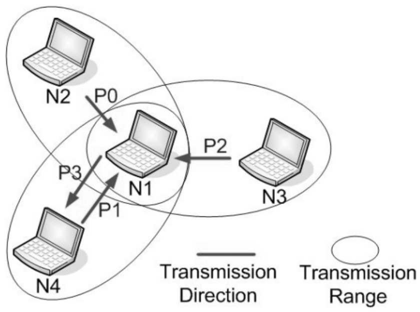

Fig. 1 Star topology network

Two main tests were conducted. The aim of the first one was to check the impact of the HNs on the 802.11e performance. The results are shown in Figures 2a-5a. The second experiment was performed with the CS range increased so as to make HNs not hidden any more (see Table 2). The obtained results are presented in Figures 2b-5b, where the error of each simulation point for a 95% confidence interval does not exceed 2%.

With enabled RTS/CTS (Fig. 2a) the order of the achieved throughput levels for HNs is in line with 802.11e guidelines. However, from all nodes, the highest throughput is achieved by the unhidden N1 which is sending the lowest priority traffic (P3). This odd performance can be explained by the total frame loss. Due to the fact that nodes experience no DATA collisions, only the retransmissions (Fig. 4a) and ifq drops[1] (Fig. 5a) are meaningful. Retransmissions are caused by both RTS collisions (not included in Fig. 5a) and EDCA parameters (Table 1). Thus, the lowest number of retransmissions is experienced by N1 which competes most seldom for the medium and hears every transmission. N3 has more retransmissions than N2 because N2 has a smaller CW and, as a result, a better chance of an undistorted RTS/CTS exchange.

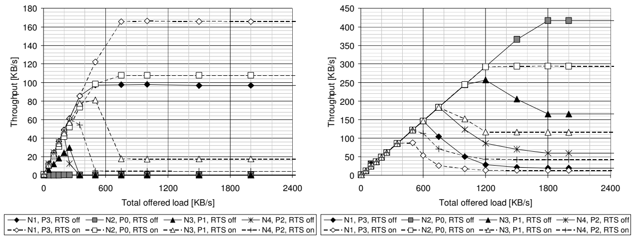

Fig. 2 Throughput. Network (a) w/ hidden nodes (b) w/o hidden nodes

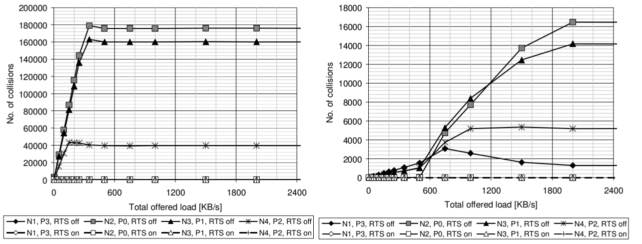

Fig. 3 Collisions. Network (a) w/ hidden nodes (b) w/o hidden nodes

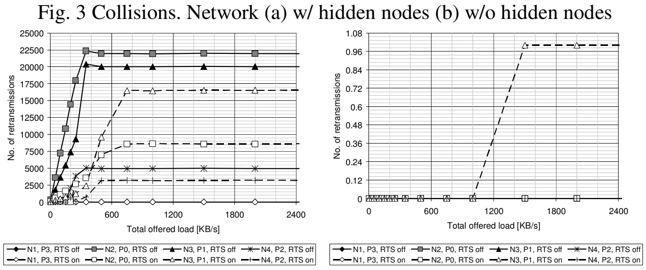

Fig. 4 Retransmissions. Network (a) w/ hidden nodes (b) w/o hidden nodes

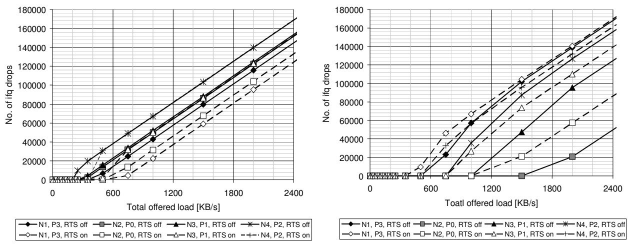

Fig. 5 Ifq drops. Network (a) w/ hidden nodes (b) w/o hidden nodes

The number of ifq drops for the HNs is related to their EDCA parameters, number of retransmissions, and their sending rate. I.e., a large CW, high number of retransmissions and a high rate cause frequent ifq droppings. For N1 the absence of retransmissions takes advantage over EDCA parameters and leads to the smallest number of ifq drops.

With disabled RTS/CTS the situation is even worse. It is only the N1 which has a meaningful non-zero throughput (Fig. 2a). From all HNs, N4 has the lowest number of retransmissions and DATA collisions. N2 and N3 have an unacceptably high number of collisions and retransmissions which results in an undesirably low throughput. This performance is an obvious result of the observation from the previous example. The only difference is that in this case, instead of RTS collisions, DATA collisions are observed. The maximum overall throughput, in comparison to the case with RTS/CTS enabled, is more than two times lower.

In the second experiment (with no HNs) the medium access is fair. Ifq drops have the most important impact on the total number of frames lost (Fig. 5b). In general, their number is incomparably higher than the number of collisions (around ten times lower than in Fig. 3a) or MAC retransmissions (practically equal to zero – Fig. 4b). Consequently, it is the 802.11e mechanism which plays the most important role in the process of traffic prioritization. As a result, the order of the throughput levels (Fig. 2b) is in line with the 802.11e guidelines. Enabling RTS/CTS causes a decrease in the general throughput value (mostly due to the increase in the signaling overhead and low sending rate of RTS/CTS frames which is 2 Mb/s) which results in worse overall network performance. It seems reasonable to disable the RTS/CTS exchange if the problem of HNs does not exist. However, the maximum overall throughput, both with enabled and disabled RTS/CTS, is higher than in the corresponding cases with HNs.

III. Conclusions

In this paper, we describe a preliminary study of a revised analysis of the performance of the 802.11e MAC QoS enhancements. The thorough study of the four-node star scenario reveals the problem of the incapability to provide services with desired QoS in a network with HNs. The experimental results, obtained for the network where the problem of HNs was eliminated, firmly validate this view.

The most innovative conclusions presented in this article are the following: (1) the unhidden node, despite its lowest access category, is always favored over HNs in the access prioritization procedure, (2) the RTS/CTS mechanism improves the throughput values achieved by the HNs, however, it does not completely eliminate the unfairness in granting medium access, (3) in the network with high HN ratio – the better the traffic class the more DATA collisions occur (due to the small CW sizes for Vi and Vo).

Future research will be focused on the analysis of different scenarios with a varied order of traffic priorities. Cases with a smaller and a higher number of HNs will be studied and compared. It is also expected that the proposed study will lead to the formulation of more general conclusions, on the basis of which, a good way of eliminating the degrading impact of hidden nodes will be found.

IV. References

[1] IEEE 802.11e: Medium Access Control (MAC) Quality of Service Enhancements, New York, IEEE Inc., November 2005

[2] IEEE 802.11b: Higher-speed PHY extension in the 2.4 GHz band, 1999

[3] TKN EDCA 802.11e: http://www.tkn.tu-berlin.de/research/802.11e_ns2

[4] H. Zhai, J. Wang, X. Chen, Y. Fang, Medium Access Control in Mobile Ad Hoc Networks: Challenges and Solutions, Wireless Communications and Mobile Computing, vol. 6, pp. 151-170, March 2006

[1] Frames dropped due to the overflow of the interface queues between the Link and the MAC Layers.