Suggested solutions for the near-far effect in multimode WLANs

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Working Group	Short Range Radio Communication Systems
Objectives	(c) Contributing towards the already identified research areas. (d) Contributing towards the White Papers being developed within the Working Groups. (e) Sharing information about, or results from, complementary research projects or activities outside the forum.
Title	Suggested Solutions for the Near-Far Effect in Multimode WLANs.
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Subject areas	New MAC for high speed WLAN Multihop communication in WLAN Scheduling
Relevance	We present the near-far effect in multimode WLANs. This effect is illustrated in the case of IEEE 802.11b DCF in an indoor environment. The near-far effect causes unfairness and capacity degradation. We propose two solutions: a relay based solution and a solution based on packet sizes.

ABSTRACT

A recent paper [1] has highlighted the near-far effect in IEEE 802.11b [2-3]. It has been observed that when some mobile node use a lower bit rate than the others, the performance of all nodes is considerably degraded. For example, a node transmitting at 1 Mbps reduces the throughput of all other nodes transmitting at 11 Mbps to a low value below 1 Mbps. Thus, the near-far effect can cause unfairness and significantly reduce the capacity of a cell. This problem has been illustrated with IEEE 802.11b. However, any multimode WLAN systems based on DCF [2], i.e., 802.11a/b/g, is affected in the same manner. In this paper, we provide a detailed analysis of the problem through simulations in the case of IEEE 802.11b.

In order to mitigate the near-far effect, several solutions can be proposed: (a) adapt the packet size to the chosen physical (PHY) mode in case of uplink transmissions; (b) extend the infrastructure with a relay node; (c) adopt a centralized scheduling strategy; (d) adapt

the future IEEE 802.11e standard. Some of these might need the modification of the standard. This paper addresses the two first solutions.

INTRODUCTION

In a recent paper [1], the near-far problem in IEEE 802.11b has been identified. This problem actually occurs when a high bit rate user, i.e., located in the 11 Mbps, or the 5,5 Mbps zone of the cell, is interfered by a low bit rate user, i.e., located in the 1 Mbps zone, in the same cell. Indeed, the use of different physical modes for the transmissions is due to the link adaptation of the WLAN cards: when the channel conditions between a user and its access point (AP) are of bad quality, the modulation of the transmission is automatically adapted and the data rate is reduced for better robustness. Then in the considered scenario where 2 users are sharing the medium with different physical modes for transmissions, the user that can use the highest physical mode experiences a high degradation of its performances due to the low rate user. Besides, the cell aggregate throughput is also significantly affected. This problem is not specific to IEEE 802.11b: it can also be observed in IEEE 802.11a (physical modes from 6 to 54 Mbps) and is even higher with IEEE 802.11g equipments since they also have to share the medium with 802.11b equipments.

In this paper, the influence of a low bit rate user on the throughput of a high bit rate user is studied for various transmission scenarios (direction of transmission / transport protocols / applications).

Two scenarii are considered in section 2 with two transport protocols (UDP and TCP). Different solutions for mitigating this effect are also proposed: in section 3, a relay based solution is presented ; in section 4, the influence of the packet size is analyzed. All solutions are under the constraint of a distributed MAC protocol so that they are also useful for ad hoc networks.

The propagation model, as well as the link adaptation strategy, used along this paper are detailed in the following section.

1. MODELS

In this section, the indoor propagation model and the link adaptation strategy are presented.

Indoor propagation model : $Pr = Pt - L + Shadowing$, where Pr is the received power, Pt is the transmit power, L is the path loss and *Shadowing* is a zero mean log-normal random variable. $L = 32.4 + 20 \log(f) + 10n \log(d)$, where f is the frequency in GHz, n is the path loss exponent (4) and d is the distance in meters between sender and receiver. For IEEE 802.11b, we have the following values: $f = 2.4$ GHz and $Pt = 15$ dBm.

Link adaptation strategy : from the theoric values of the bit error rates (BER) of the DBPSK (1 Mbps), DQPSK (2 Mbps), and MBOK (5,5 and 11 Mbps) modulations [5], packet error rates (PER) are deduced as a function of the packet length. CCK is indeed a variation of the MBOK modulation [4] (Figure 1). From the PER curves, C/N thresholds are defined in order to meet the PER target of 0,1. The final decision for the PHY mode takes into account both the C/N thresholds and the sensitivity levels.

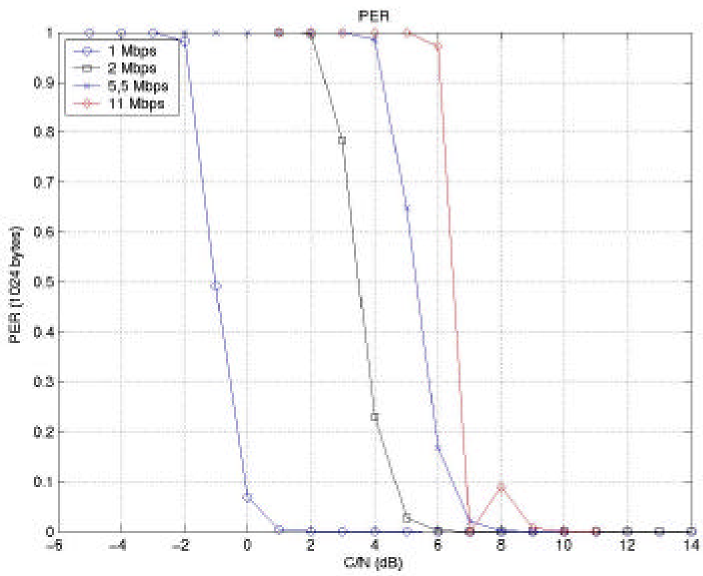

Figure 1 PER vs. C/N - AWGN channel and 1024 bytes packets.

2. THE NEAR-FAR EFFECT

In this section, the near-far effect is presented for different traffic types and transport protocols. For that purpose, a simple scenario is analyzed with two users in the cell. The *user 1* is assumed to be close to the AP, i.e., it can transmit and receive packets most of the time at 11 Mbps. After *T1* s of simulation and until *T2*, another user (*user 2*) is introduced that generates or receives the same type of traffic. Then, the influence of this new user on the performance experienced by user 1 is quantified.

- **CBR/UDP Downlink Traffic**

In this section, the AP is sending packets of 1024 bytes at a constant bit rate over UDP (CBR/UDP) to the two users. The input load is high, so that the AP has always something to send when the two users are active. The high data rate user, or *user 1*, is at 5 m from the AP, while the low data rate user, or *user 2*, is at *d* m from the AP with *d* = {35, 45 m} (Figure 2). *User 1* is clearly in the 11 Mbps area, 35 m is at the borderline between 5,5 Mbps and 2 Mbps, and 45 m is at the borderline between the 2 and the 1 Mbps areas.
User 2 starts receiving packets at *T1* = 5 s and stops at *T2* = 20 s. The simulation run lasts 50 s. On the curves, a persistence of the interfering traffic after *T2* is observed because some packets are remaining in the AP buffer after *T2*. In this section, the buffer of the AP is assumed to be infinite and use the simple policy first in first out (FIFO).
Simulation results (Figure 3) show a very fair behavior of the 802.11 MAC protocol, since both users get the same throughput irrespective of their distance from the AP (i.e. irrespective of the PHY mode they use for data transmissions). But, this fairness leads to a very bad situation for the high data rate user that experience a significant degradation of its throughput. When *user 2* is at 35 and 45 m (2 and 1 Mbps resp.), the high data rate user experiences a very severe degradation of its throughput (app. 57% and 86% respectively) and the aggregate throughput drops too.
Indeed, as explained in [1] and if the size of the packets are the same, a 1 Mbps user will occupy the channel 11 times more than a 11 Mbps user to transmit a packet. Thus, its data

rate is smaller, but its channel occupancy is higher. This phenomenon leads to an equal throughput for both users. Besides, since most of the time the channel is used by the 1 Mbps user, the aggregate throughput is also reduced.
In the downlink case, it is unefficient to change the packet size according to the PHY mode, e.g., long packets for *user 1* and short packets for *user 2*. Indeed, for same the UDP throughput for both users, there are much more small packets than long packets in the AP buffer and so on the channel. As a consequence, *user 2* still occupies the channel 11 times more than *user 1*.

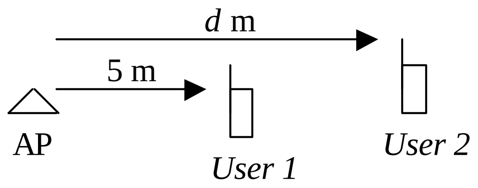

Figure 2 Scenario for the downlink near -far effect.

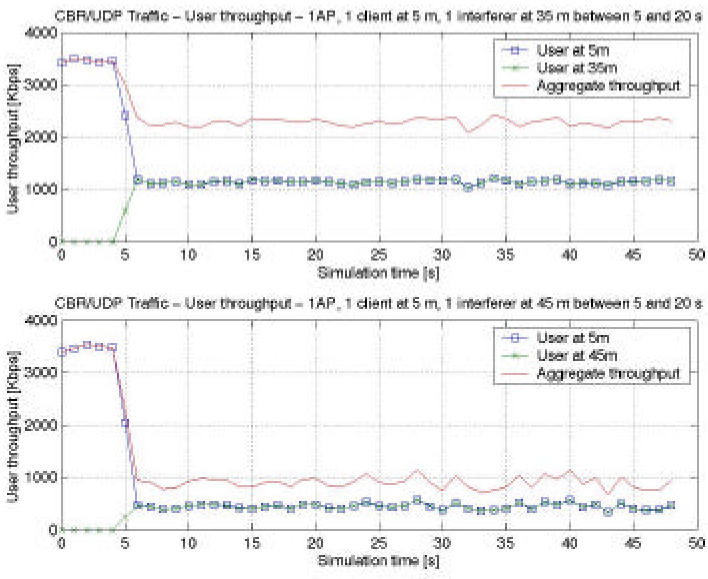

Figure 3 CBR/UDP downlink traffic - Users and aggregate throughputs.

- **FTP/TCP Downlink Traffic**

In this section, two downlink FTP/TCP transfers are considered. First of all, we show that the near-far problem is also observed with FTP/TCP. Simulations are done with an advertised window 64 segments of 1024 bytes and with two different distances for *user 2* (35 and 45 m, i.e., 2 and 1 Mbps).
In the four cases, we observe a degradation of the throughput for the high bit rate user and a decrease of the aggregate throughput. However, the degradation is less severe than with UDP since TCP adapts itself to the available bandwidth. Note that at 45 m (1 Mbps), the throughput of the low bit rate user is less stable because of the channel conditions. So, its congestion window may be reduced during the simulation. The PER also reduces the

backward traffic of ACK, thus reducing the TCP throughput. In this cases, the high bit rate user, that has less problem of congestion window, takes advantage from the situation to increase its instantaneous throughput.

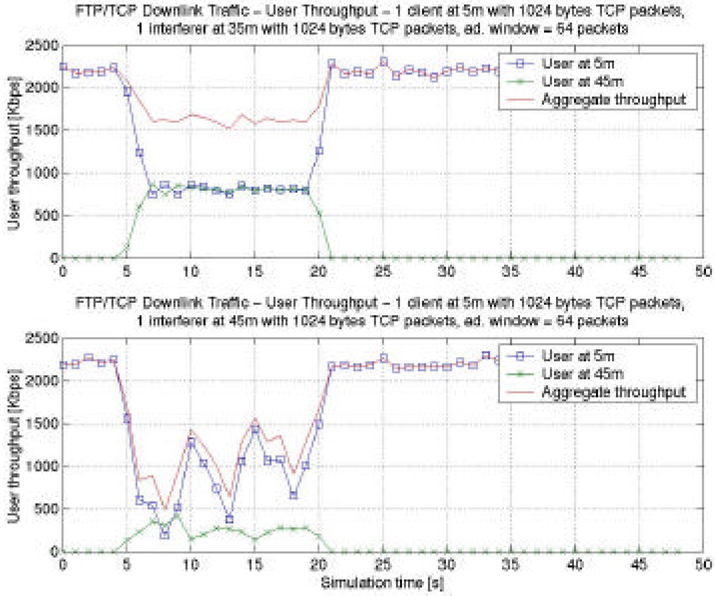

Figure 4 FTP/TCP downlink traffic - Users and aggregate throughputs.

3. RELAY BASED SOLUTION

In this section, the possibility to use a relay node in order to combat the near-far effect is investigated. In this scenario (Figure 5), a relay node is placed at a distance 30 m (5,5 Mbps) and then 20 m (11 Mbps) from the AP, i.e., successively in the 5,5 Mbps and in the 11 Mbps area. The high data rate user (*user 1*) is still located at 5 m (11 Mbps) from the AP, while *user 2* is at 35 m and then at 45 m from the AP, i.e., in the 2 Mbps and 1 Mbps areas.

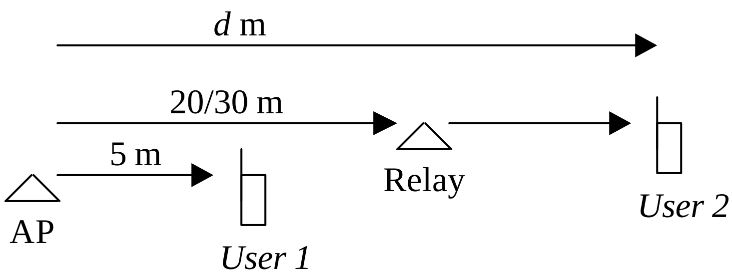

Figure 5 Scenario with the relay based solution.

A downlink UDP traffic is considered for both users. The previous section has shown that the presented situation is very bad for *user 1* and that the aggregate throughput doesn't exceed 2,2 Mbps in the first case (*user 2* at 35 m) and 1 Mbps in the second case (*user 2* at 45 m). The following curves show the user and aggregate throughputs in presence of a relay node. Note that the routing protocol forces packets with destination *user 2* to go through the relay node.

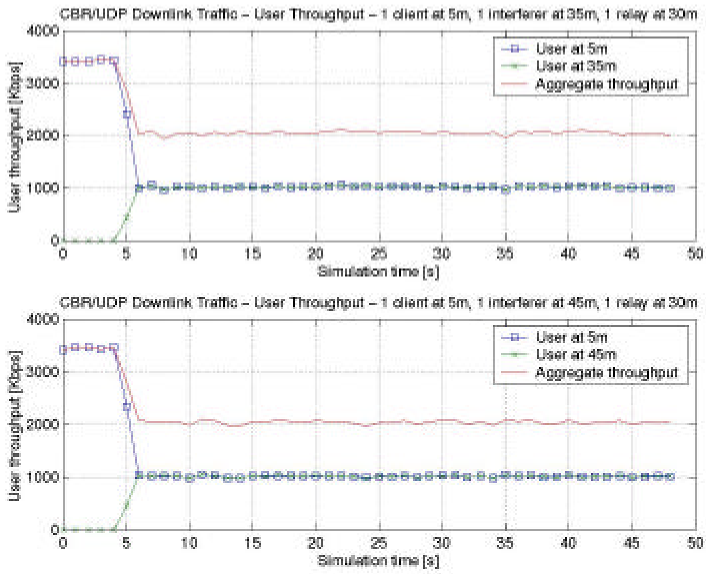

Figure 6 CBR/UDP downlink traffic - Relay based solution - Users and aggregate throughputs – Relay at 30 m.

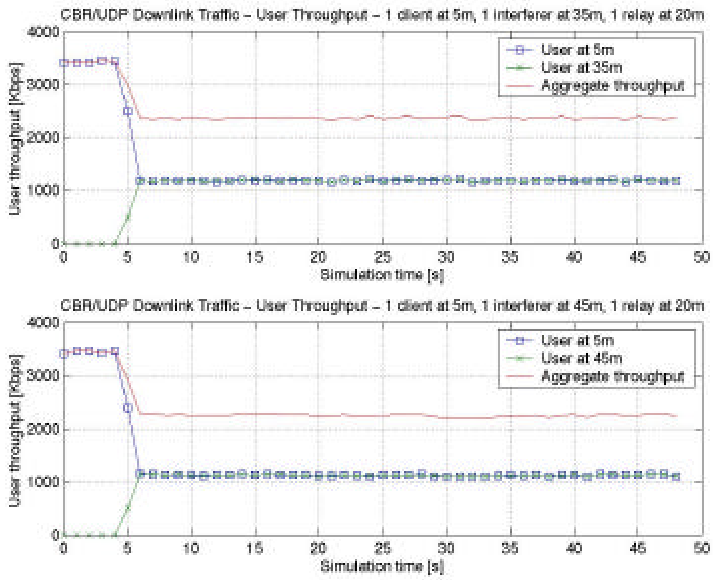

Figure 7 CBR/UDP downlink traffic - Relay based solution - Users and aggregate throughputs – Relay at 20 m.

These simulation results show that the near-far effect is partly reduced thanks to the relay node when *user 2* is at 45 m from the AP: the aggregate throughput equals or exceeds 2 Mbps in all cases. Indeed, the AP-*user 2* communication is, thanks to the relay, made of two high data rate links. The relay-*user 2* transmissions are often done at the 11 Mbps physical mode, and the AP-relay transmissions are performed with the 5,5 Mbps, or the 11 Mbps physical modes (according to the relay location). Packets at this high data rates, even if they have to be routed occupy much less the channel than in the previous section.

When *user 2* is placed at 35 m from the AP, there is no mitigation of the near-far problem. Indeed, in this case, *user 2* is at the limit between the 5,5 Mbps and the 2 Mbps areas. Hence, having two high data rate links is not so profitable compared to a single lower but still high data rate link but routing protocol may help in solving this issue.

Besides, this result has been shown with a downlink UDP traffic, but the arguments are still true with any traffic on the uplink or on the downlink. Hence, relaying can be seen as a solution to reduce to near-far effect, provided that the routing strategy is suitably chosen and the relay node is located in a high data rate zone.

4. PACKET SIZE BASED SOLUTION FOR THE UPLINK

On the uplink (Figure 8), the near-far problem is less pronounced, in particular if the two users have different packet sizes. There are two main reasons for that. The first one is that small and long packets have the same probability of accessing the channel and so theoretically alternate on the channel. This is much more favorable than in the downlink case. The second reason is the different packet error rates (PER) experienced by the two users. On the one hand, *user 1* has a low PER and thus can maintain a small average back-off window. On the other hand, *user 2* has a high PER. This is due to the fact that *user 1* is very close to the AP, while *user 2* is at the limit of of the 1Mbps (45 m) area. For each packet loss, the contention window is increased. As a consequence, the high bit rate user takes advantage of this situation to increase its throughput. This explains both the chaotic shape of the aggregate throughput and the advantage of the *user 1* performance.

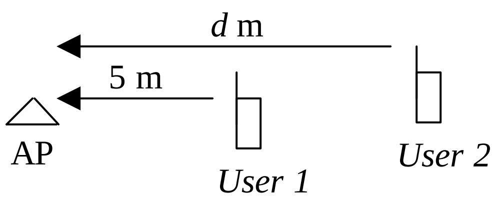

Figure 8 Scenario for the uplink near-far effect.

Figure 9 shows simulations, where a *user 1* sends 1500 bytes UDP packets on the uplink, *user 2* has the same traffic type (Figure 8). The different plots shows the influence of the varying packet sizes of *user 2*. It is clear that the users throughputs can be modulated using different packet sizes.

Hence, the near-far problem is less critical than in the downlink case. In particular, varying the packet size is an efficient solution to this problem.

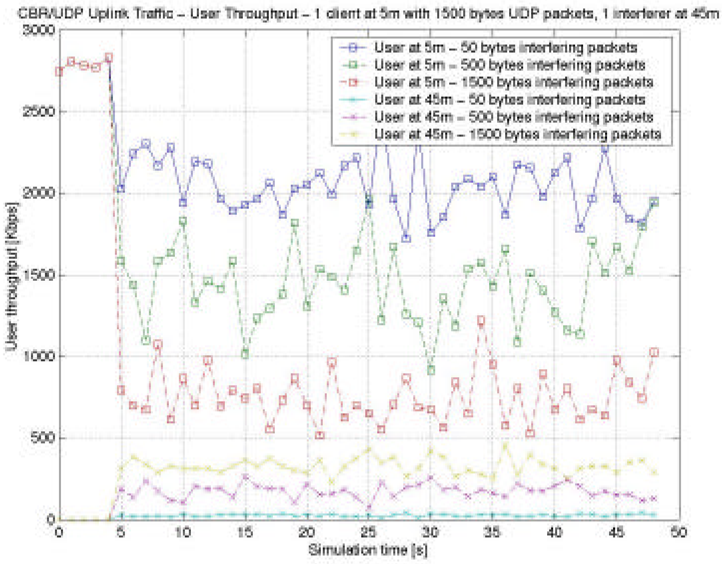

Figure 9 CBR/UDP uplink traffic - Users throughput - *User 1* with 1500 bytes packets, *user 2* with varying packet sizes.

5. CONCLUSION

In this paper, the near-far effect in multimode IEEE 802.11 DCF based system has been presented and analyzed in the special case of IEEE 802.11b. The effect occurs, when a high bit rate user and a low bit rate user communicating with the AP share the medium. Simulations show that this problem can result in unfairness and a significant degradation of the cell capacity. The near-far effect is particularly pronounced in the case of a UDP downlink traffic. This paper proposes two solutions to mitigate the problem: the use of a relay node in the 5,5 Mbps area and the variation of the packet size according to the PHY mode in the uplink case. In both cases, the modification of the DCF mode is not needed. However, an evolution of the standard is necessary in order to allow cross-layer interactions.

6. REFERENCES

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