IMPACT OF INTER-CELL INTERFERENCE IN A IEEE 802.11A NETWORK WITH OVERLAPPING CELLS

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Abstract - WLAN systems such as IEEE 802.11a bring end-user to the high-speed data rates within limited coverage areas. Deploying additional access points might extend the coverage as well as create inter-cell interference, thus reducing the network performance, as studied in this article through various scenarios of overlapping cells.

Keywords - 802.11a, inter-cell interference, AP placement.

I. INTRODUCTION

Wireless Local Access Networks (WLANs) are being more and more deployed in homes, public places and offices. They offer high data rates to end-users but are limited in coverage area, thus necessitating Access Point (AP) densification to provide all users with sufficient quality of service. Inter-system and intra-system interferences are significant issues in WLANs. The reasons are a small number of available channels for 802.11a [1],[2] systems, as well as insufficient isolation between them. Accordingly, there is the need for appropriate deployement strategies taking into account geographical and channel separation between overlapping cells.

A. Related Work

For a given area to cover, finding the optimum AP locations [3] is a complex task to achieve, depending on various objectives: cover the greater area with the smaller number of APs, or minimize capture effects to maximize fairness, or minimize inter-cell interference, or maximize overall network goodput. In each case, the final network configuration might be different. The AP placement optimisation algorithms developed are either complex solutions (optimum solutions) or simple ones (sub-optimum solutions obtained quickly and at a reasonable cost). The parameters usually considered by the planning algorithms are the propagation model and the geographical separation between APs. In fact, all the following parameters must be considered: channel separation, geographical distance between APs and the cells' topologies (users' distribution and AP relative position). The aim of this article is to show by means of simulations that the impact of inter-cell interference can be detrimental to network performance.

B. Organization

The rest of this paper is organized as follows. After introducing the context in section I, sections II and III will briefly present the 802.11a system. Section IV contains the simulation scenarios and assumptions. Then, section V presents the simulation results. Finally, we conclude the study and present the future work.

II. IEEE 802.11A MEDIUM ACCESS CONTROL (MAC) PROTOCOL UNDER DECENTRALIZED COORDINATION FUNCTION (DCF)

Using the 802.11 MAC protocol, a data transmission is a succession of three main phases:

- *Channel Access*: After a null Backoff Counter (BC),
- *Medium Reservation*: Request To Send (RTS) and Clear To Send (CTS) frames exchanges,
- *Data Transmission*: DATA and ACKnowledgement (ACK) frames exchanges.

All our simulations use the infrastructure mode (always an AP) and the compulsory DCF mode. Thus, there is no central point of coordination in the cell, instead the coordination is distributed over all the STAtions (STAs) causing collisions. A collision is said to occur when either two nodes that are not hidden transmit simultaneously, or when two hidden nodes transmit overlapping frames in time, resulting in none or only one packet being correctly decoded. The Carrier Sensing Multiple Access / Collision Avoidance (CSMA/CA) technique used by contending users is a random access method. Thus, there is no pre-established transmission schedule. Each STA delays its transmission start time by some random BC value (generated according to a uniform distribution) within a variable Contention Window (CW). A failure to transmit exponentially increases the CW size in order to reduce the probability that two users or more draw the same BC value, and simultaneously transmit. This minimizes collisions between multiple STAs by temporally spreading their transmission start times. The duration of these waiting periods is random and depends on the number of contending users, and the medium state around each STA.

Each STA must regularly listen to the medium to determine its state (idle, busy). Due to each STA having limited transmission range, the medium state perception is location-dependent leading to two important types of configurations with specific nodes:

- *Hidden Node*: A hidden node is within the range of the intended destination but out of range of the sender (increase in the number of collisions, significant performance degradation, unfairness in accessing the medium),
- *Capture Effect*: Capture is said to occur when a receiver can receive clearly one transmission out of two simultaneous transmissions, both within its receiving range (unfair sharing of bandwidth).

To reduce the performance degradation due to hidden terminals, a medium reservation technique based on a reserve (RTS frame) and confirm (CTS frame) mechanism between the source and the destination is proposed in DCF mode. Once the medium is successfully reserved for a STA, the data frame can be transmitted with a higher chance of success. Also, when a collision occurs between several RTS frames, far less bandwidth is wasted when compared with a larger data frame collision. Thus, using the RTS/CTS mechanism is recommended when many users are contending for the medium to transmit large data frames.

III. Network of cells

An 802.11a network can be composed of several cells, each one using the same frequency channel for both Uplink (UL) (from the Mobile Terminals (MTs) to the AP) and Downlink (DL) (from the AP to the MTs) transmissions. Intra-cell interference is the interference received from STAs from the same cell. As a cell uses a single frequency channel for both UL and DL, it corresponds to collisions and capture effects. Whereas inter-cell interference is the interference received from STAs from all the surrounding cells.

A lack of synchronisation between cells (each cell being independent) combined with an imperfect channel isolation can potentially lead to inter-cell interference in some cases, as studied in this article. Inter-cell interference can result in undecoded packets at the receiver due to the combination of the wanted signal with the interfering signals.

The radio frequency band used by 802.11a systems in Europe for indoor operations is from 5.15 GHz to 5.35 GHz. This band is divided in 8 channels of 20 MHz width (for an occupied bandwidth of 16.6 MHz). The channels' center frequencies are separated by 20 MHz, starting at 5180 MHz. According to the European regulations, the maximum allowed transmit output power in this band is 200 mW (23 dBm).

The Transmitter (Tx) mask represents the upper limits for the relative power allowed for a STA to transmit in each band of the radio spectrum. The Receiver (Rx) mask represents the protection from one channel with respect to other channels. The term dBr in Table 1 represents the value in dB relative to the maximum spectral density of the signal. In our simulations, both APs and MTs use the same Tx and Rx masks, presented in Table 1.

Due to imperfection of the Tx and Rx filters, each one being tuned on a different frequency channel, the Received

Table 1

(a) Tx spectrum mask

Frequency offset [MHz]	**Power value [dBr]**
≤ 9	0
11	-20
20	-28
≥ 30	-40

(b) Rx spectrum mask

Frequency offset [MHz]	**Power value [dBr]**
≤ 9	0
11	-27
≥ 30	-45

Signal Strength (RSS) at the Rx is the sum of:

- A signal falling in the receiver band and representing unwanted emissions. It is the RSS from the Tx attenuated by the Tx filter in the Rx band,
- A signal transmitted by the Tx in its own band, being received through the blocking of the Rx filter. It is the RSS from the Tx attenuated by the Rx filter in the Tx band.

The total attenuation (combining the effects of both the Tx and Rx filters) provided for each case of channel separation is presented in Table 2.

Table 2
Inter-channel attenuation

Case	**Channel offset**	**Attenuation [dB]**
Co-channel	0	0
Adjacent Channel (ACh)	1	24.7
Alternate Adjacent Channel (AACh) or more	≥ 2	40

All simultaneous interferers separately contribute (using attenuation from Table 2) to the total aggregation of interference received at the Rx. In an 802.11a system, only one user (or a few ones in case of collisions) is using the cell channel at a time, thus limiting the aggregation of interfererence. However, the impact of a single very close-by interferer can be very detrimental to the cell performance, as shown in this article.

IV. Simulation scenarios

A. Introduction

Any attempt to deploy a WLAN network in a given area has to answer the following questions: (1) how many APs to deploy? and (2) where to place each AP? The APs' final locations are obtained by optimizing many simultaneous parameters, resulting in a very complex problem. Also, the optimization can be solved at the user, the cell or the entire network level, depending on the approach. Examples of parameters to consider, given the users' number, bandwidth expectations and locations are target number of APs to deploy, coverage, goodput, inter-cell interference, network fairness (capture effects and distribution of collisions).

However, not all the above parameters can be simultaneously optimized, thus leading to different network configurations. Indeed, due to the shared nature of the medium, the higher the number of attached users, the lower the average offered goodput per user. Adding another AP can increase coverage and bring higher goodputs to all users by decreasing the number of users per AP. However, it potentially generates inter-cell interference, reducing the expected performance.

By means of simulations we investigated the impact of inter-cell interference by varying several parameters: number of cells, inter-AP distance, inter-cell frequency channel offset, cell topology.

B. Simulation model

Our simulations use a model close to the 802.11a [1],[2] standard, with various cells all in DCF mode. Users always use the RTS/CTS mechanism. During a simulation, the number of users is constant, they are static and the simulation time is long enough (200 s) to give every STA a chance to transmit a sufficient amount of data and reach a fixed transmit mode. The simulated scenarios take place in a 37.5 m x 75 m rectangular building. All 40 users are randomly distributed in this building, leading to approximately 20 users per half building part, as shown in Figure 1.

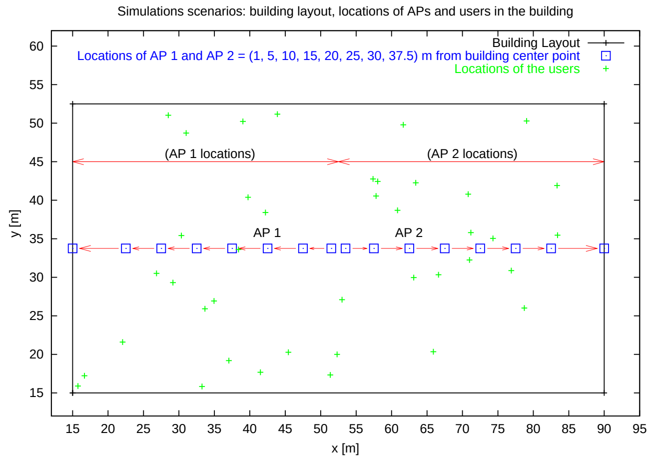

Fig. 1
Scenario map with 1 and 2 APs

The AP offset distance is defined as the distance between an AP and the building center point. Inter-AP distance is defined as the distance between 2 APs. If both APs have the same offset distance, the inter-AP distance it twice this distance. Various AP offset distances were simulated: 1, 5, 10, 15, 20, 25, 30, 37.5 m as shown in Figure 1. In the scenarios with only 1 AP (AP 1), the AP is only moving left, starting from 1 m offset until reaching the left-hand side building wall (37.5 m offset). When another AP is added (2 APs in total), AP 2 moves right. Thus, both APs (AP 1 and AP 2) are always equally separated from the building center point. APs' positions are fixed during a given simulation.

Only the UL is considered (transmission from an MT to the AP), thus the AP will not try to access the medium, it only acknowledges the MTs' operations. We use a saturated traffic model where all MTs constantly try to transmit fixed 2000 octets packets size.

The propagation model used is based on a power law [4], for class A scenarios referring to corporate indoor environments. No shadowing effect is included, in order to capture the impact of inter-cell interference on the MAC protocol performance. Due to cell size, the air propagation time ($\ll 1\ \mu$s) is neglected.

With the Link Adaptation (LA) algorithm implemented, a STA always transmits using the highest mode of operation determined by its distance to the AP. Thus, a cell is decomposed in "areas" of maximum modes around the AP. All control frames use Mode 1.

Table 3 presents the main numerical values used in our simulations.

Table 3
Simulation Parameters

Parameter Name	**Numerical value**
MT data payload	2000 octets
Cell radio channel	5180 MHz
AP and MT Tx power	23 dBm
AP and MT antenna gain	0 dBi
Short Retry Counter (SRC)	7
Long Retry Counter (LRC)	4

All other MAC protocol values are found in [1] and [2].

C. Metrics

To compare the results obtained from various scenarios, the following metrics have been studied:

- Number of users attached to a given AP position,
- Efficiency of the channel reservation and data transmission,
- Average goodput per user (cell and network levels),
- Aggregated goodput (cell and network levels).

The goodput is defined as the ratio of the delivered data payload to the total time necessary for transmission including all the protocol overheads (MAC/PHY overheads, backoff delay, inter-frame intervals, the control frames, the potential frame retransmission times and other users sharing the same channel). It is the effective performance offered on top of the MAC layer.

V. Simulation Results

A. Introduction

We first investigated the impact of a single AP placement (no inter-cell interference) on the coverage and the network performance. Then we studied the case with two APs. Adding another cell can increase the offered load as well as increase the level of inter-cell interference. In the case of overlapping cells, all the following inter-STA interference cases have to be considered: inter-AP, inter-MT and MT-AP.

B. Coverage

Our simulations showed that a single AP can cover a maximum of 95% of the entire building (38 users) when located near the building centre (1 m offset). Then, as the AP offset increases, the maximum number of users potentially attached to its cell almost linearly decreases until 47.5% (19 users) for 37.5 m of AP offset. For a user to be attached to a given cell, he chooses the AP signal received with the maximum RSS. As our propagation model is deterministic, it is always the geographically closest AP. Thus, each AP coverage area is determined by the inter-AP distance.

For two APs, cell 1 (left) and cell 2 (right) are approximately equally loaded (half the total number of users) whatever the AP offset. The result is a maximum network coverage of 100% (from 10 m to 30 m AP offset) and a minimum of 92.5% at 37.5 m AP offset. The cell load will impact the performance as presented in the following sections.

C. MAC protocol efficiency

Let us define S the ratio, for each user, between the number of expected successfully Rx ACK frames and the number of Tx RTS frames, expressed in %. S reflects the efficiency of both the channel reservation (exchange of RTS and CTS frames) and the data transmission (exchange of DATA and ACK frames) phases. Figure 2 shows the average cell S values without (1 AP) and with (2 APs) inter-cell interference.

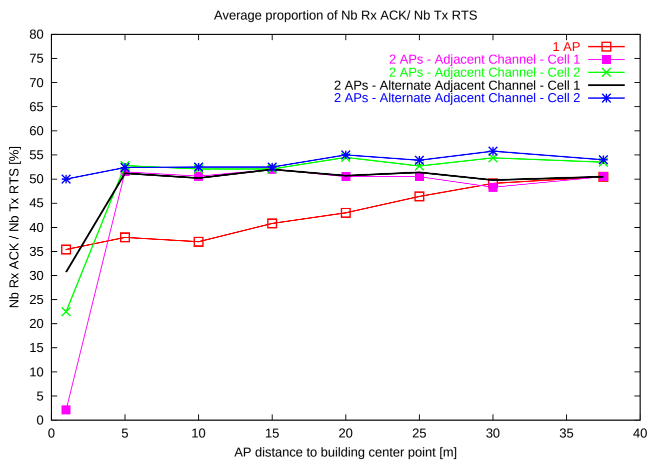

Fig. 2
Average proportion of Nb Rx ACK / Nb Tx RTS

Due to the known spatial unfairness of the MAC protocol, the average S values do not reflect the differences experienced at the user level. Some AP locations will favor some users compared to others. For a single AP, the greater the AP offset the smaller the number of attached users, and so does the number of collisions. The result is an increase of S going from 35% to 50%.

For two APs, the larger the AP offset, the smaller the overlap between both cells, and so does the inter-cell interference. For each cell and for a given AP offset (from 5 m to 37.5 m), increasing the inter-cell frequency offset (AACh rather than ACh) only sligthly improves average cell S value. These values are almost constant for various AP offsets (from 5 m to 37.5 m) for both cells 1 and 2, achieving respectively 50% and 55% of average cell S (cell 1 being slightly more loaded than cell 2).

However, for 1 m AP offset both cells are almost fully overlapping (2 m of inter-APs distance), thus maximizing the inter-cell interference. The result is a sharp reduction of S for any channel offset, achieving worse efficiency than with a single AP, even though the load per cell is only half of the single AP case. Cells 1 and 2 are equally loaded, however, cell 1 achieves 2% (ACh) and 30% (AACh) of average S, whereas, cell 2 achieves 22% (ACh) and 50% (AACh) of average S. The reason for such a difference is due to each users' distribution.

The channels are insufficiently isolated and overlapping cells are not synchronized. Accordingly, inter-cell interference can prevent the correct Rx of a frame UL and/or DL, for example a CTS frame, thus reducing the performance of a cell. The result can be a collision with a DATA frame, wasting a lot of time for the entire cell even though only a single user missed a single CTS frame. This problem is recurrent in some configurations. Another consequence of inter-cell interference is a wrong estimation of the medium state making a user freeze his BC decrement, thus increasing his waiting time.

For a high level of inter-cell interference (APs too close), the channel offset is not sufficient to cope for it, leading to worse efficiency than with a single AP. The decrease in the efficiency of the channel reservation and data transmission will be reflected in the goodput performance presented hereafter.

D. Average goodput per user

The higher the number of contending users in a 802.11a cell, the lower the average goodput per user. Accordingly, maximizing the AP coverage (high number of users attached) is opposed to maximizing performance at the user level (more users having higher transmit modes) as discussed in section V-B for a single AP.

To combine both, maximum coverage and maximum performance, another AP was added. However, inter-cell interference appeared. All average goodput values per user for 1 AP and 2 APs converge to the almost same value for the maximum inter-AP distance, all cells having almost the same number of users attached. Increasing the frequency separation between APs is always beneficial for the performance, unless APs are geographically too close (2 m inter-AP distance). In this last case, cells and network performance are worst than with a single AP. In the ”5 m AP offset and 2 APs” case, cells 1 and 2 have equal load. However,

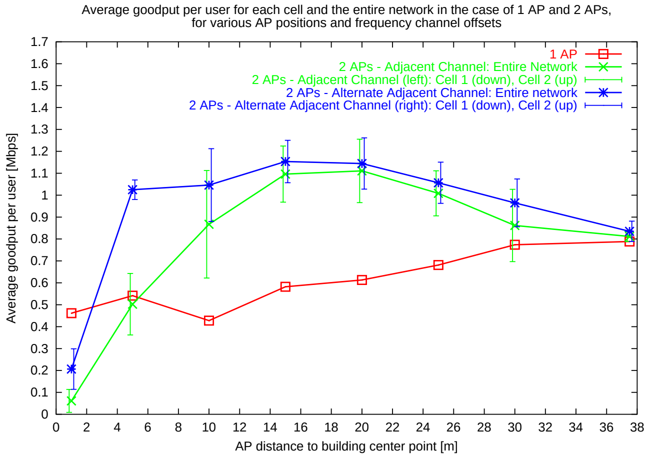

Fig. 3
Average goodput per user

in the ACh case cell 2 performance is twice the one of cell 1, whereas in the AACh case cell 2 performance is almost the same as cell 1. For a given load and a given inter-AP distance, a greater channel isolation leads to better performance for both cells. But for greater values of AP offsets cell 2 always achieves better goodput than cell 1 because of a lighter load and of each cell's distribution of users.

E. *Aggregated goodput*

Figure 4 shows the aggregated goodput values for a single AP and two APs (cell and network levels).

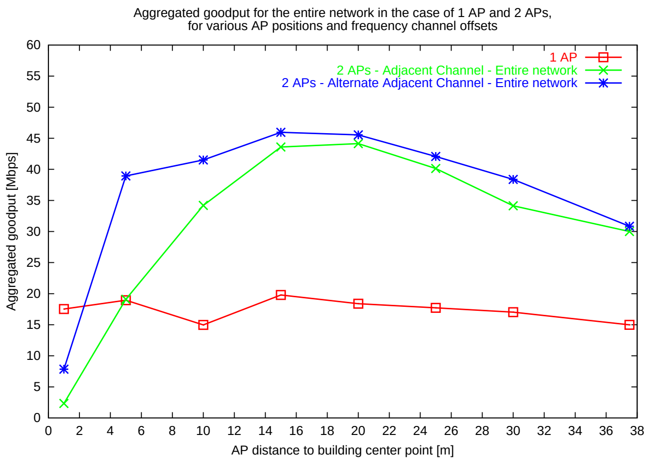

Fig. 4
Aggregated goodput

For a single AP, the aggregated goodput (total available bandwidth) is almost constant whatever the AP offset and cell load. However, if two APs are placed too close (AP offset of 1m), whatever their channel offset, the network aggregated goodput is lower than with only a single AP, for the same total number of attached users. Channel offset is unable to cope for inter-cell interference. Then, when each AP offset is 5 m, both cells support in total more users than a single AP and achieve the same aggregated goodput (ACh case), and twice of it (AACh case). The combination of both channel separation and AP geographical distance is necessary to effectively separate overlapping cells. In any case, the higher the channel separation, the higher the performance. Then, as the inter-AP distance increases, the aggregated goodput for two APs network is always at least twice the values for the single AP network.

VI. Conclusions and Future Work

Our simulation results highlight the importance of considering inter-AP geographical and channel separation when deploying overlapping cells, to effectively increase the goodput per area. Not taking it into account can become very detrimental to the entire network performance. Also, cell topology (users' distribution and AP relative positions) plays an important role in generating inter-cell interference. Load balancing algorithms could help improving performance, for example, triggering handover for users (costly in terms of generated interference) to another cell.

The impact of combining multiple services, as well as unhomogeneous load distributions on the inter-cell interference should be studied. Adding a power control algorithm and a more realistic channel model (shadowing effect) could bring as well additional interesting results.

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