PERFORMANCE EVALUATION FOR IEEE802.11G HOT SPOT COVERAGE USING SECTORISED ANTENNAS

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Abstract - Wireless Local Area Networks (WLANs) have a tremendous success in todays short range communication. The user density is permanently increasing and the planning focus shifts from pure coverage issues towards capacity improvements. As IEEE802.11 was originally planned for ragged coverage, cell planning issues have been neglected. Especially for hot spots they now become important. In this paper, we show the supply of an exhibition hall with IEEE802.11 service using sectorised antennas. A capacity increase by a factor 2 compared to omnidirectional antennas shows that this proven technology also works in the decentralised area. Special problems of the IEEE802.11 system are investigated by a performance evalution using stochastical simulations.

Keywords - IEEE802.11, Hot Spot, Sectorization

I. INTRODUCTION

It is expected that future mobile telecommunication systems will provide wide area broadband radio coverage for hot spots like city centers, business centers and other areas with high user density. Even today we face broadband radio coverage by means of recent WLAN systems at many hot spots like airports or coffee shops. But recent WLAN systems, namely IEEE802.11b and IEEE802.11g operating at 2.4 GHz and IEEE802.11a operating at 5 GHz face enormous problems, when many Access Points (APs) are used to cover a small area like, e.g., an exhibition hall. In this paper we propose the broadband radio coverage of a hot spot by means of IEEE802.11g using sectorised antennas in order to reduce the intercell interference between the different APs. To show the gain of using sectorised antennas, which can be seen as the first step on the migration path towards advanced antenna technologies, like smart antennas, against recently available systems with omnidirectional antennas.

In Sec.II we introduce theoretical aspects of unragged WLAN coverage, their problems and the benefits of sectorization. Sec.III provides an overview of the simulation environment including the models for the traffic load and the channel, the chosen hot spot scenario, an exhibition hall and the used simulation parameters. Finally we show the achieved simulation results in Sec.IV before concluding the paper.

II. THEORY

The IEEE802.11 standardization did not aim at a cellular approach but a ragged coverage. This leads to the following problems when the density of APs and the user density is high:

1) The offered traffic is dependent on the number of active users per AP. A large coverage area per AP limits the carried traffic per user.
2) A listen before talk protocol (Carrier Sense Multiple Access (CSMA)) with equal access probabilities for all participants will limit those who have to transmit a lot. In centralised scenarios, this is especially the AP. This effect, limiting the downlink capacity, is known as unfairness issue [1]–[3]. It increases with the number of active users per AP.
3) There are only three non-overlapping OFDM channels available in the 2.4 GHz band. This leads to tight reuse patterns with neighbouring co channel APs. Considering this, a high AP density leads to another problem. The inter-AP-distance must be small enough to cover the scenario. This means that mobile stations located at the border of two co channel APs find a good situation in DL (only a little area is covered by both APs) while the UL traffic is limited as mobiles near the border block the air in both AP areas in an unpredictable manner.

These effects must be considered when planning the coverage of a scenario.

A well-known technique to increase capacity in the cellular world is sectorization. As the area covered per AP decreases, the number of users per AP is reduced. This will improve problems 1) and 2).

Nothing is known about the behaviour of problem 3) which we will investigate with a simulative approach within this paper. Two frequency assignments will be compared. Fig. 1 shows a scenario with different frequency channels for overlapping beams (except for the center beam of AP1 and AP4).

The aim of this scenario is to avoid capacity sharing between neighbouring co channel sectors. This cannot be reached completely as the number of available frequency channels is limited. Only comparably small areas exist where mobile stations are covered by more than one co channel beam. If such a mobile (e.g. Station (STA) A in 1) is actually

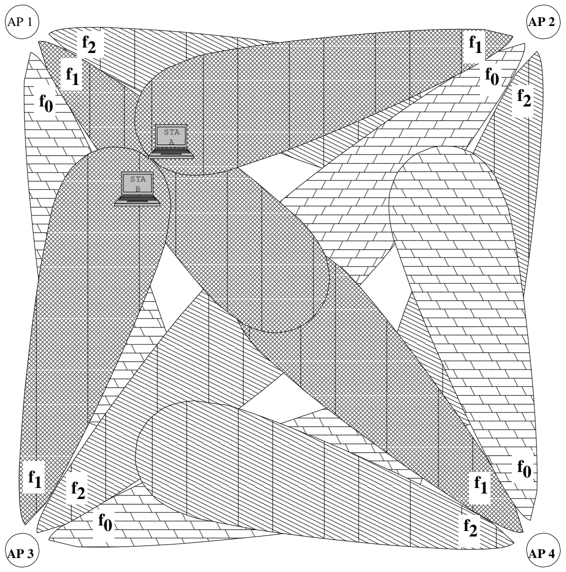

Fig. 1. Frequency assignment No. 1

sending, it consumes capacity at several APs. Problems 1) and 2) are addressed well by this setup while problem 3) is not.

Fig. 2 shows a scenario using equal frequency channels for overlapping beams.

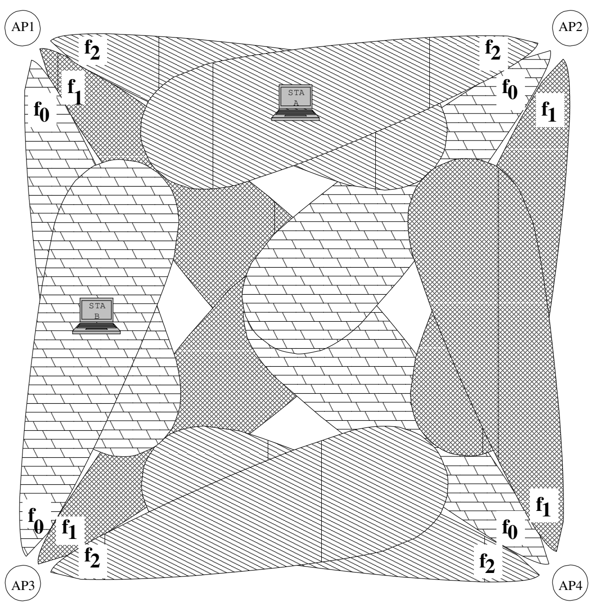

Fig. 2. Frequency assignment No. 2

This scenario aims at the reduction of the UL capacity sharing. Co channel cells either cover the same area or have a comparably large distance from each other so that the mobile station most probably does not consume capacity in more than one AP when sending.

The drawback is the capacity sharing between the two overlapping co channel beams. An increased throughput is expected for the uplink, especially in the center of the scenario while a deterioration should occur at the edges.

III. Simulation Environment

The simulations have been performed using the proven SPEET Generic Object Oriented Simulation Environment (SGOOSE) developed at the Chair of Communication Networks (ComNets) [4], [5]. The simulation environment provides load generators, channel models and the facility to connect different protocol emulators. It is based on stochastic, event-driven simulations. For the simulations described below, the IEEE802.11 protocol emulator SPEETCL-based Wireless Access Radio Protocol Emulator (SWARP) [6] has been connected.

A. Medium Access Control (MAC) Protocol Configuration

In the following the MAC protocol settings that have been used for all simulations are described.

All traffic is carried by the Distributed Coordination Function (DCF) with a minimum Contention Window (CW) size of $CWmin$ = 15 slots and a maximum CW size of $CWmax$ = 1023 slots. The fragmentation was disabled.

Ready to Send (RTS)/Clear To Send (CTS) have been disabled in order to increase throughput for small packets. The queue length for all queues was set to 50 entries.

To reduce the effect of problem 2), the APs are prioritised by starting the backoff countdown after Point (Coordiantion Functions) Interframe Space (PIFS) instead of Distributed (Coordination Function) Interframe Space (DIFS). As the countdown itself consumes most of the time, this has only a minor effect. However, it might be implemented in already existing environments.

B. PHY Protocol Configuration

For all simulations the Transmission (Tx) power of all STAs is set to 30 mW. For the simulations with the omnidirectional antenna the Tx power of the APs is set to 50 mW.

For APs using sectorised antennas, power is reduced by the gain of the main antenna lobe, here 16 dB in order to meet ETSI compliance rules, which allow a maximum power of 100 mW (20 dBm) for indoor scenarios.

The power was sufficient to supply the scenario. The reduction was not necessary in this case but must be considered when sending power is close to the limit.

The control blocks are transmitted at 6 Mbit/s using the lowest PHY mode BPSK $1/2$. For data blocks, Link Adaptation (LA) is applied. Starting at PHY mode QPSK $3/4$, the LA algorithm changes to a higher PHY mode if 25 consecutive packets have been received without errors. It reduces the PHY mode after 3 consecutive erronous packets.

The minimum Rx power level for synchronisation can be seen in Tab. 1 (values from the standard) [7], [8].

Table 1
Minimum Receive Power Level

PHY mode	min. Rx Power Level (dBm)
BPSK $1/2$	-82.0
BPSK $3/4$	-81.0
QPSK $1/2$	-79.0
QPSK $3/4$	-77.0
16QAM $1/2$	-74.0
16QAM $3/4$	-70.0
64QAM $2/3$	-66.0
64QAM $3/4$	-65.0

The encoding/decoding process is modeled by a table that maps Carrier to Interference Ratio (CIR) values to a mean Packet Error Rate (PER), Fig 3. The Packet Error Rate (PER) is used as an input to a uniform distribution, in order to determine whether the received packet is erroneous or not. Bit errors caused by delay spread will not be considered.

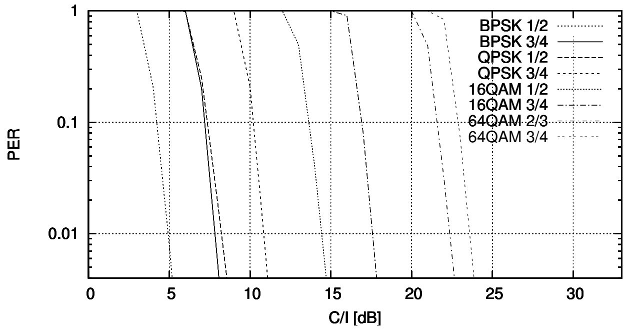

Fig. 3. PER over CIR, Packet length = 512 byte

C. Channel Model

For the path loss calculation, the COST multi-wall model [9] is used. The transmission attenuation for a light wall is 3.4 dB and for a heavy wall it is 6.9 dB at 2.4 GHz. As the users are not moving, the path loss is constant. All shadowing effects are contained in the path loss model.

For the fading model a user speed of 3 km/h is assumed. Fading is modeled by a correlated fading process for the carrier and each interfering signal. A sample pattern derived by measurements is used.

Co Channels are considered for the interference calculation. Further a background noise of -95 dBm is assumed. The interference calculation is performed once per 4 μs.

D. Scenario

Fig. 4 shows the investigated hot spot scenario, an exhibition hall with four exhibition centres, one in each corner. The exhibition centres are separated from the hall by walls. The walls separating the centre in the upper left corner have a heavy attenuation and are further called heavy walls according to COST multi-wall model (see Sec. III-C). The other three centres are separated by light walls referring to the COST multi-wall model. Fig. 4 shows further two heavy obstacles (concrete columns) in the middle of the hall.

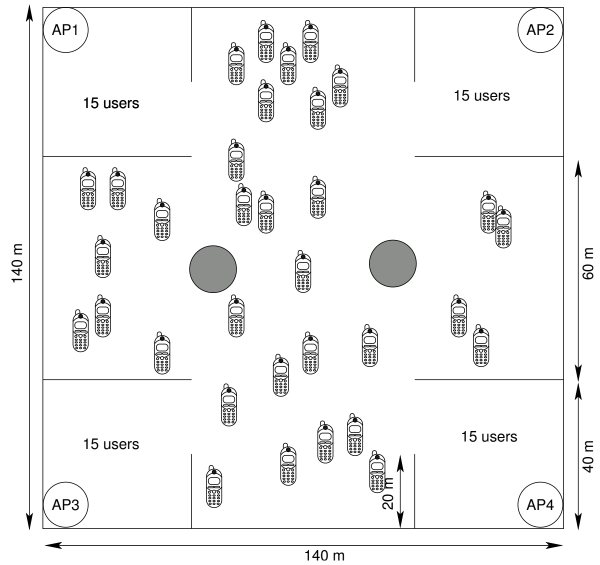

Fig. 4. Hot Spot Scenario: Exhibition hall with 4 rooms

The user density in the exhibition centres is assumed to be 9375 users/km^2 which results in 15 users per centre. In the inner area users are distributed uniformly with a lower density of 3700 users/km^2 (resulting in 48 users for the inner area). The users do not change their position during the simulation.

E. User Traffic

All users are active during the whole simulation. The users perform Constant Bitrate (CBR) traffic in order not to influence the simulation results by the traffic shape. Only the user locations and location distribution shall have an effect. In a first approach the system shall not be in state of saturation. For the different simulations, the offered traffic per AP respectively per sector shall be constant in a way that each sector has to carry 3 MBit/s. In a second simulation set the omni-directional APs are brought close to saturation, in order to show the achievements of the sectorised APs more impressively. Therefore the offered traffic is increased to 10.8 MBit/s per AP. The packet size delivered to the MAC layer is 512 Byte.

F. Antenna Models

Two different types of antennas have been used for the simulations. As reference the scenario was covered with the APs provided with an omni-directional antenna.

As second antenna a Printed Circuit Board (PCB) switched-beam antenna with 3 beams and 30 degree opening angle is used. The antenna model was based on a set of 2-dimensional patterns as shown in Fig. 5.

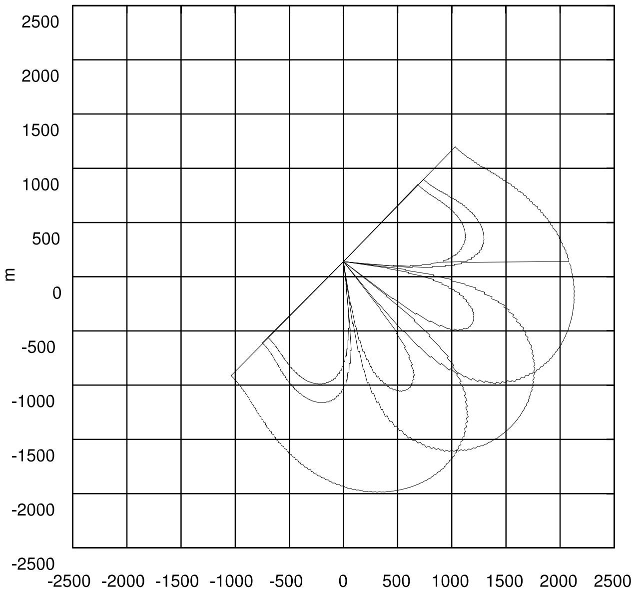

Fig. 5. Antenna Pattern of upper left AP, 1 dB = 50 m

The patterns show the far-field of one beam of the antenna for different azimuth values of the main lobe. Close-field effects in the antenna are not taken into account here. They shall be considered in later investigations. Adjacent channel influences are not modeled.

IV. Simulation Results

The simulations focus on the influence of interference effects, sectorization and performance of the standardised MAC, unless otherwise described.

A. Omni-directional Antennas

To allow comparisons to sectorised antennas, at first scenarios with omni-directional antennas are investigated.

1) 1 - 3 APs, No Interference: As a reference, AP1 is utilised alone. The users are distributed according Fig. 4. Transmission is done on frequency channel 1 (at 2412 MHz). The AP is able to cover the upper left quarter, all offered traffic can be carried (55 kbit/sec/user). No interference occurs except the background noise (-95 dBm). This results in a high mean CIR of 32 dB. The same scenario has been repeated with 2 APs (+ channel 7 at 2442 MHz) and 3 APs (+ channel 13 at 2472 MHz). The additional APs do not influence each other, the results remain the same.

2) Four APs with Interference: The aim of this scenario is to set up a reference for an interference scenario. In reality, more than 3 frequency channels are not available if adjacent channel interference shall be avoided, so channels have to be reused. As the number of active APs is 4, one frequency channel has to be reused (AP 1 and 4). While the results for AP 2 (channel 7) and 3 (channel 13) remain unchanged, for AP 1 and 4 (channel 1) the limitations by co channel interference are visible, Fig. 6, second and third row. As there is line of sight between these two APs, the carrier sensing can detect the packets of both and there are no packet collisions. The mean received signal power from other APs is -87 dBm (Uplink (UL)) / -90 dBm (DL) while the received signal power from the own AP is -66 dBm (UL) / -64 dBm (Downlink (DL)). The reason for the decreased DL Throughput (TP) is that AP 1 and 4 form a common basic service set (BSS) and therefore have to share the capacity.

For the 2 interfering APs, the CIR deteriorates to 20 dB (UL) and 26 dB (DL). This still allows high PHY modes.

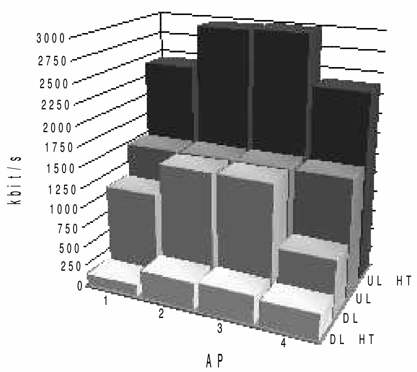

Fig. 6. TP for 4 APs with omni-directional antennas

3) One AP, no Interference, Increased Traffic: To provide a better comparison between the omni-directional and the sectorised scenarios, the traffic per user is increased to 200 kbit/s/user. All other parameters remain unchanged. This results in saturation for the omni-directional scenario. The throughput is very similar to that of the non-interfering AP of the scenario desribed below, Fig. 6, first and last row, APs 2 and 3. The offered traffic (10800 kbit/s/AP) cannot be carried completely. The carried traffic for the UL is 3000 kbit/s, for the DL it is 320 kbit/s. The increased offered traffic in the UL results in an increased carried traffic in the UL, but at the same the carried traffic in the DL is decreased. The overall carried TP is almost the same as in the lower traffic scenario (3320 kbit/s instead of 3000 kbit/s).

4) Four APs with increased Traffic: Again a scenario with omni-directional antennas is simulated with higher traffic (200 kbit/s/user). Fig 6 shows the TP for the different APs. AP 1 and 4 are the interfering ones. Although the offered traffic is increased from 3000 kbit/s/AP to 10800 kbit/s/AP, the carried traffic only increases from 10820 kbit/s to 11940 kbit/s. The mean CIR remains constant.

B. Sectorised Antennas

The next simulation set shows the advantages of sectorised antennas over omni-directional antennas.

For each AP three beams will point to the hall (see Fig. 1 and 4). The following frequency channels are used: $f_0 = 1, \quad f_1 = 7 \quad f_2 = 13$.

1) One AP: The traffic per user is increased by a factor of 3 compared to the first omni-directional scenario (165 kbit/s/user). The offered traffic can be carried completely, Fig. 7, first and second row. The results per beam are the same as the results per AP in the first scenario. For a true comparison, the traffic has to be increased for this scenario.

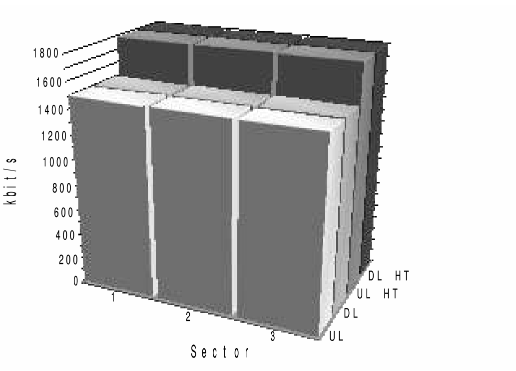

Fig. 7. TP for 1 AP with sectorised antennas

2) One AP with sectorised antenna in high load scenario: The results of the omni-directional scenario with increased traffic are now compared to a scenario with sectorised antennas and increased offered traffic (200 kbit/s/user). This is the same traffic as in the second omni-directional scenario. In contrast to the omni-directional scenario the offered traffic can be carried completely, Fig. 7, third and last row.. The usage of the sectorised antennas increases the TP by a factor of three. This is an evidence for the benefits of using sectorised antennas.

3) Two, three and four APs with sectorised antennas: In this scenario the offered traffic is 3 MBit/s per beam. The performance is now further influenced by the interference of other access points. As the interference power is reduced to -91 dBm(UL)/ -93 dBm (DL) for two APs, the mean TP increases compared to the omni-directional case, see Fig. 8 (2 and 4 APs). The situations with 3 APs is very similar to that with 2 APs and is therefore not shown. The overall TP is 16300 kbit/s (2 AP), 20300 kbit/s (3 AP) and 22900 kbit/s (4 AP). The mean CIR for the different scenarios is high, Tab. 2. This allows high PHY modes.

Table 2
Mean CIR

# APs	CIR (UL)	CIR (DL)
2	34.5	43.0
3	30.6	42.7
4	29.4	41.7

4) Four APs with high traffic load: The TP resulting from the scenario in Fig. 1 is shown in Fig. 9, second and last row. Due to the sectorization the carried traffic is more than twice as high as in the omni-directional scenario. The total TP increases from 11940 kbit/s to 25680 kbit/s.

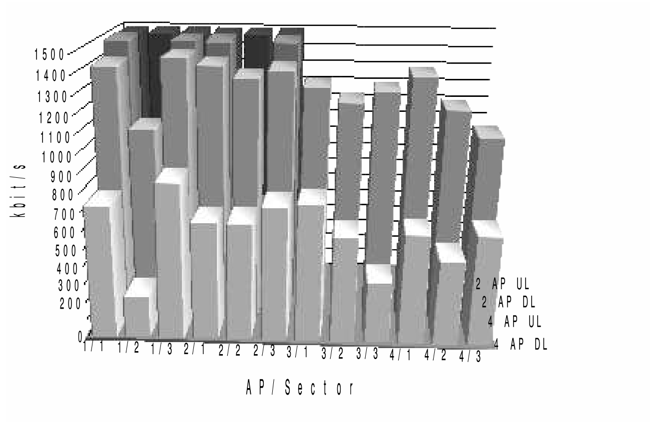

Fig. 8. TP for 2 APs with sectorised antennas

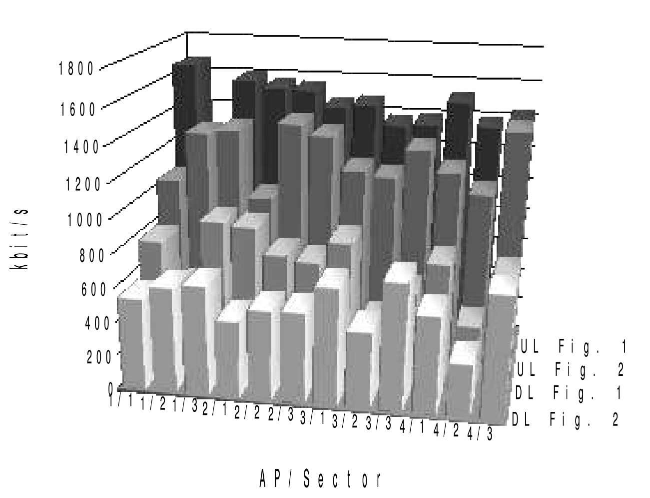

Fig. 9. TP for 4 AP with sectorised antenna and high traffic load

In contrast to the one AP case with sectorised antennas the offered traffic (10800 kbit/s/AP) cannot be carried completely because of the interfering APs. Nevertheless the benefits of using sectorised antennas can be seen regarding the increased TP. The mean CIR remains almost unchanged compared to the previous scenario. As expected, the UL performs much better than the DL.

5) New Frequency Plan for four APs scenario: The aim of the first frequency selection is to minimize the co channel interference of overlapping beams. It was observed that the packets of some STAs are received by more than one AP. Now the behaviour shall be investigated in a scenario conforming Fig. 2 with the following frequency assignment: $f_0 = 1 \quad f_1 = 7 \quad f_2 = 13$.

As seen in Fig. 9, first and third row, the TP in UL and DL is still different. The DL carries 32% of the total throughput in both cases. But the total throughput is further reduced to 21600 kbit/s. The mean CIR for the UL is 29.4 dB, for the DL it is 43.3 dB.

V. CONCLUSION

In this paper, a sectorised approach has been proposed for the supply of a hot spot with IEEE802.11 services. It has been shown that the total capacity is increased by a factor 2 compared to the omnidirectional approach. In order to optimize throuhgput, the frequency assignment should diversify the available channels so that areas covered by co channel APs are minimised. Further investigations should focus on the improvements of smart antennas against sectorised ones for the same scenarios.

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