The performance of adaptive frequency allocation in an environment of non-cooperative interference.

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Abstract - **WLAN technology is likely to be a part of future wireless broadband communication systems. As the wireless unlicensed radio traffic increases, the need for good solutions to co-existence problems caused by interference becomes apparent.**

In this paper the performance of a hypothetic WLAN operating at 17 GHz, using decentralized dynamic channel allocation, is assessed in regard to its susceptibility to external interference. Three different interference cases are studied. The first case is narrowband static interference. The second case is wideband interference, similar to the interference caused by a spread spectrum system. The third case is agile interference caused by a frequency hopping system. In all cases the WLAN and the interferers are located in the same geographical location.

The results suggest that the chosen channel allocation algorithm, Adaptive Frequency Allocation, provides excellent channel plans within seconds from start-up as long as the interference is static. It is however not, as it is defined here, able to perform well when the interfering devices use frequency hopping technology.

I. INTRODUCTION

During the last few years we have seen an increased usage of unlicensed spectrum. The most significant contribution is perhaps made from wireless LAN technologies such as the IEEE 802.11, but there has also been an increase in the unlicensed spectrum load due to other types of devices, such as for example Bluetooth enabled apparatus.

Part of the increase popularity of unlicensed bands is that the entry barriers are quite low. There is no need to obtain a license to operate a network and thus a quite cumbersome process can be avoided. Also since the rules that devices must comply to we are rather simple there is a lot of room for technical development.

This increased use of the unlicensed bands also creates problems where devices interfere with each other in an uncontrolled way. In the licensed parts of the radio spectrum the interference problem is remedied either by planning in advance or by using, possibly decentralized, algorithms that ensure that devices do not cause harmful interference to each other. In unlicensed spectrum however there is no central authority that can control all the devices in a network. Thus, devices operating in unlicensed spectrum must be able to cope with this interference that cannot be controlled [1].

There are a number of strategies to manage this type of situation. One possible strategy is to use diversity techniques, I.e. spreading the information using different frequencies, spreading codes, transmission times or spatial techniques even if some of the information is lost redundancy ensures that the message eventually gets through. These methods are blind in the sense that they do not try to assess the interference situation before transmitting. Another possible strategy for coping with interference is to try to use the parts of the spectrum where the interference is low or nonexistent. Dynamic channel allocation is an example of a radio resource allocation method where this strategy is used. The idea here is that the available spectrum is divided into a number of separate channels. Each mobile terminal measures the interference on each channel and whenever he has something to transmit he chooses a suitable channel for transmission.

The decisions can be made in both centralized and decentralized ways. A centralized algorithm always has better or at least as good decision criteria as a decentralized algorithm. However when most of the interference to the system is caused by sources that cannot be controlled the advantages of a centralized approach diminishes since the most important interference is local in nature anyway.

When designing a dynamic channel algorithm a number of decisions have to be made. There must be a way of determining which channel to use and also how to measure the interference levels. A number of algorithms have been proposed, for example first available channel FA or least interfered LIC[2] or a number of other variations.[3]

The performance of these algorithms has been studied, but the context has been to find algorithms that maximize the capacity in a systems. The implicit assumption has been that all devices use the same algorithm and that the only interference in the system (besides thermal noise) is caused by the other mobile terminals in the system. Little is known about how these algorithms perform when they encounter interference from a different system. In this paper we determine how a specific dynamic channel allocation algorithm performs in the presence of non-cooperative interference.

The algorithm we have used in our numerical experiments is named automatic frequency allocation (AFA) and was introduced by Huschke and Zimmerman [4]. AFA is intended for solving the problem of allocating channels to different access points in Hiperlan/2.

The interference problem can of course be lessened by introducing better algorithms and smarter radio resource management. However, another obvious solution is to increase the amount of available spectrum. Currently the band at 2.4 GHz is very popular and equipment for 5 GHz is already on the market, and we will probably see an increased use of the 5 GHz band shortly. Moving up in frequency, the next available band is around 17 GHz. This has motivated us to determine if dynamic channel allocationin general and AFA in particular is suitable for radio resource management in this frequency range.

II. Problem definition

In this paper we determine how well a network using AFA performs when faced with non-cooperative interference, i.e. interference that cannot be controlled by the network. There are of course many kinds of interference that the network can be exposed to. Here we have chosen three interference scenarios that can be seen as typical representatives of an interference class. In addition, these cases resemble the kind of interference created by some popular systems used today on the unlicensed bands.

The first is one where the interference is static and where the carrier bandwidth is the same as for the hypothetical WLAN. The interferers will randomly pick one channel and continue using that regardless of what happens around it. This case mimics the situation where two systems of the same type are used in the same area. It should however be noted that the interference in this case do not switch channels which the system under study do.

In the second case the interferer occupies half the available spectrum (four channels), although the total interference power is kept at the same level as in the first case. Thus, the per channel interference power is only one fourth of the first case. This case represents the case where the interference is generated by a CDMA system, e.g. IEEE 802.11b based systems.

In the third interference scenario the interferer bandwidth is the same as for the hypothetical WLAN, but the interference is changing frequency rapidly and randomly. This is similar to the interference caused by frequency hopping systems, e.g. Bluetooth.

We also determine the network performance in the case when there is no external interference. This case is used for reference purposes. But it is also used to evaluate how well the AFA algorithm works when used in the 17 GHz band.

The network is determined in terms of SINR distribution and reselection probabilities. The SINR distribution gives a hint of achievable data rates for the individual mobile terminal as well as the total system throughput. Of course this also depends on scheduling policies, modulation schemes et cetera. Still, the SINR distribution gives a good overall impression. Moreover, it is easy to obtain in this type of numerical experiments. We also estimate the reselection probability of the system, i.e. how likely an access point is to change frequency. This gives an indication of the stability of the channel plan as well as the signaling requirements.

III. Topology and System Parameters

The environment used in this paper (see figure 1), is a statistical model of an office environment. 32 access points and 21 interfering stations are spread over a 96 by 48 meter rectangle. There are 230 mobile terminals randomly located over the area, they remain stationary for the duration of the numerical experiments.

The system has 8 channels, each 25 MHz wide. At the beginning of the numerical experiments the access points pick a random channel. Likewise, the interferers are assigned random channel/channels, as it applies.

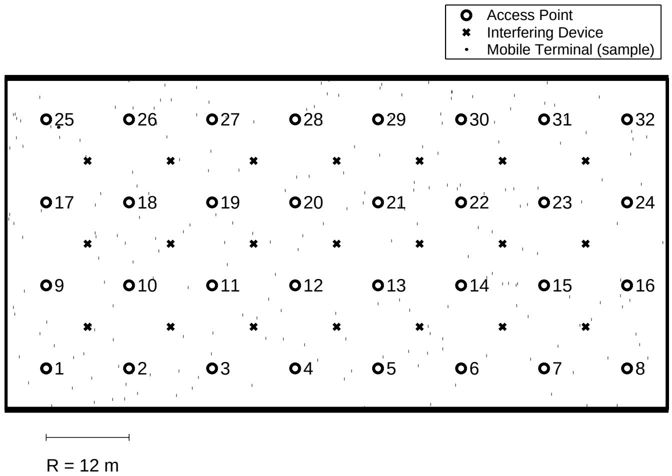

Figure 1. Topology of the simulated office environment. 32 access points and 21 interfering devices are spread over an 48 x 96 meter rectangular area.

The traffic model used here is of a fully loaded network. I.e., each access point is either transmitting or listening to a transmission from a mobile terminal. The direction of data is assumed to be either downlink or uplink with a 0.8/0.2 probability. All devices use omnidirectional antennas.

The mobile terminals use power control to ensure a received power level of -63 dBm. The access points also use power control to ensure that the receiver with the worst propagation conditions receive -63 dBm. The noise floor is set at -93 dBm., i.e. the system is essentially interference limited.

IV. 17 GHz propagation model

The propagation model used here is derived in the Ph.D. thesis of M. Unbehaun [5]. In this work he has made parameter estimations for an extension of the Keenan-Motley [6] propagation model found in the paper by Törnevik et al [7]. The data used for parameter estimation was obtained using a ray-tracing tool and using environmental data from our offices.

In essence the Keenan-Motley model uses a distance dependent path loss together with a fixed attenuation for every floor (wall) traversed. In the thesis of Unbehaun the walls are statistically accounted for. He determines the average number of wall traversals for a receiver at a specific distance together with the average wall attenuation. In addition a remaining factor is obtained to further account for the other statistical variations.

The resulting propagation model we used is as follows. The received power can be expressed as:

$$P_{rx} = P_{tx} - 20\log_{10}\left(\frac{4\pi r}{\lambda}\right) - \alpha W r - X_f \qquad (1)$$

Where Pts is the transmitted power, r is the distance between transmitter and receiver, \lamda is the wavelength (0.018 m), \alpha is the expected number of walls per meter (0.231 walls/m), W is the average wall attenuation (5.2 dB/wall) and Xf is a lognormal random variable with mean 0 and variance 23.6 dB. The numbers are from the thesis of Unbehaun [5].

V. AUTOMATIC FREQUENCY ALLOCATION

AFA assesses the long-term quality, i.e. the expected interference, of each carrier frequency (channel) and picks the best. It does so in a very simple way; in fact it is little more than a recursive filter.

The frame structure includes fields for broadcast control, UL and DL transmission. The broadcast channel (BCH) contains control information from the AP to the MTs and is sent in every frame.

All the WLAN devices (APs and MTs) are able to perform measurements on the Radio Signal Strength (RSS) of each channel. The lesser the RSS is, the greater the quality of the channel. They are also able to lock on to, and distinguish, BCH transmissions from APs. The RSS of the most powerful transmitter on the BCH channel "f" at time instant t is called $RSS_{BCH,t}(f)$.

This latter feature of determining $RSS_{BCH,t}(f)$ has the effect that this AP is not forgotten when making channel selections, regardless of the direction of traffic at the moment, or if there is no active link. APs will transmit on the BCH even if there are no MTs assigned at that moment. In the simulations, the frames are aligned, i.e. all APs transmit on the BCH simultaneously.

Both MTs and APs will make error free measurements on each channel ($RSS_t(f)$ and $RSS_{BCH,t}(f)$) every second. For reasons of simulation convenience, the APs (and their assigned MTs) never measure simultaneously. Instead they will measure and make channel allocation decisions in sequence, the order of which (for fairness) is randomized every second. Thus, the intermediate time (Δt) between channel allocation decisions at an AP is not constant, but ranges between 32^{-1} second and $63 * 32^{-1}$ seconds. Summarizing, the following measurements are made, at both APs and MTs:

- $RSS_t(f)$, the total RSS emanating from data transmissions on channel f at time instant t.
- $RSS_{BCH,t}(f)$, the RSS of the strongest BCH transmitter on channel f at time instant t.

The instant quality on the UL is calculated for every frequency (channel) as:

$$R_t(f)_{UL} = \max(RSS_t(f), RSS_{BCH,t}(f)) \qquad (2)$$

The DL quality is assessed the same way, but as a mean of the MT measurements. Due to the assumption of full load in the simulations, $RSS_{BCH,t}(f)$ will not often be higher than $RSS_t(f)$.

Instant total link quality is defined as where UL and DL denotes uplink and downlink:

$$q_t(f) = -(R_t(f)_{UL} + R_t(f)_{DL})/2 \qquad (3)$$

To form the long-term quality measure, $Q_t(f)$, the instant quality $q_t(f)$ is passed through a recursive filter such that:

$$Q_t(f) = 0.1 * q_t(f) + 0.9 * Q_{t-\Delta t}(f) \qquad (4)$$

The current frequency f_0 is kept if $Q_t(f) < Q_t(f_0) + 1$ dB for all f.

VI. RESULTS

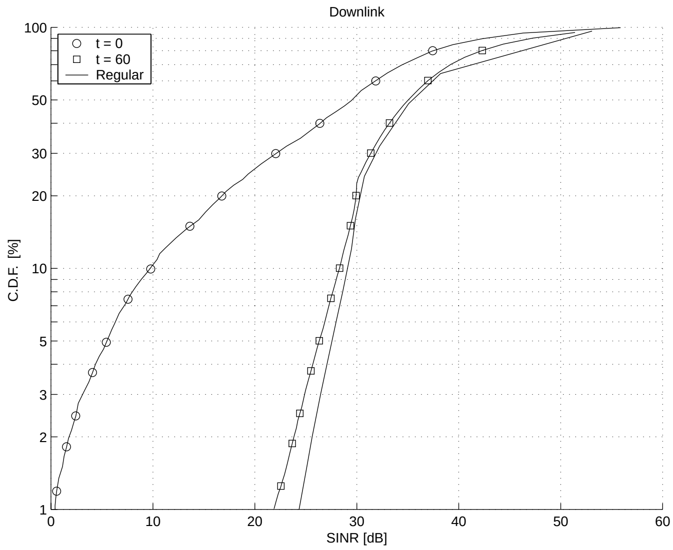

Figure 2. SINR distribution in the downlink at system start and at 60 seconds compared with a regular channel plan. The AFA algorithm is able to find a channel plan that generates similar results to a regular channel plan.

The AFA algorithm is first studied for the case of no interference. In figure 2 we plot the SINR distribution for the system in its initial state and when the algorithm has been run for 60 sec. This is compared to a regular channel plan. We can see that the algorithm is able to provide a channel plan which resembles a regular channel plan after 60 seconds both in the way channels are used and the SINR distribution that the system is able to obtain. In some cases the algorithm is even able to achieve a SINR distribution which is "better" than the regular channel plan. Since the propagation conditions are quite uneven, and since the mobile terminals are randomly located, it is not certain that the cell shape is square and thus it is not always best to use a regular channel plan to maximize the distance to interferers. Figure 3 is an example of a typical channel plan created by the algorithm.

We also estimate the reselection probability for the system. In figure 4 we can see that after a few seconds there are few reselections. Thus we can assume that the channel plan is quite stable after just a few seconds.

○ 7	○ 1	○ 5	○ 7	○ 4	○ 6	○ 8	○ 1
○ 8	○ 3	○ 4	○ 6	○ 1	○ 3	○ 5	○ 4
○ 5	○ 2	○ 7	○ 8	○ 2	○ 8	○ 7	○ 2
○ 6	○ 3	○ 1	○ 5	○ 3	○ 4	○ 6	○ 1

Figure 3. One example of a typical channel plan obtained after the AFA algorithm has run 60 seconds in the no interference case. The numbers refer to channel number.

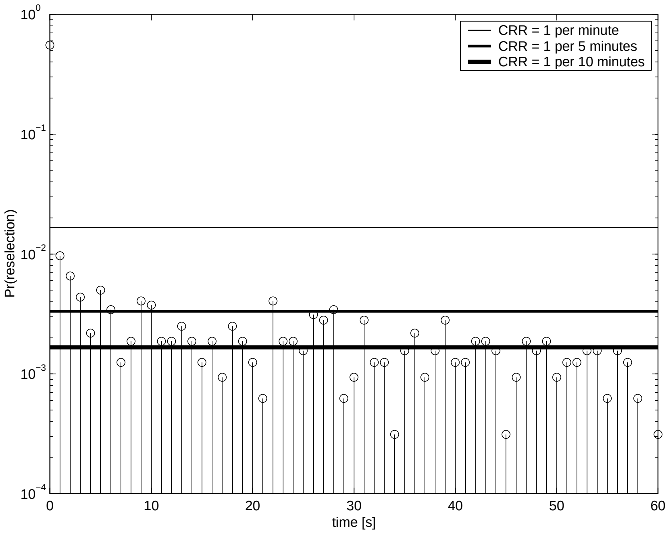

Figure 4. Estimated probability of a channel reselection (CRP) vs. time in the no interference case Examples of corresponding channel reselection rates (CRR) included for reference.

Actually the results are quite similar to those obtained when using the algorithm in the 5 GHz band [4]. Thus it seems like the algorithm is a suitable candidate for resource allocation in the 17 GHz band.

When the system is subjected to non-cooperative interference the performance degrades. In figure 5 we compare the performance of the system when exposed to different kinds of interference. We can see that the broadband interference has the worst impact. The reason is that the reduction in interference caused by spreading the interference power is not enough to compensate for the fact that there are many more channels that are interfered with. Thus it becomes very difficult to find a suitable channel for communication.

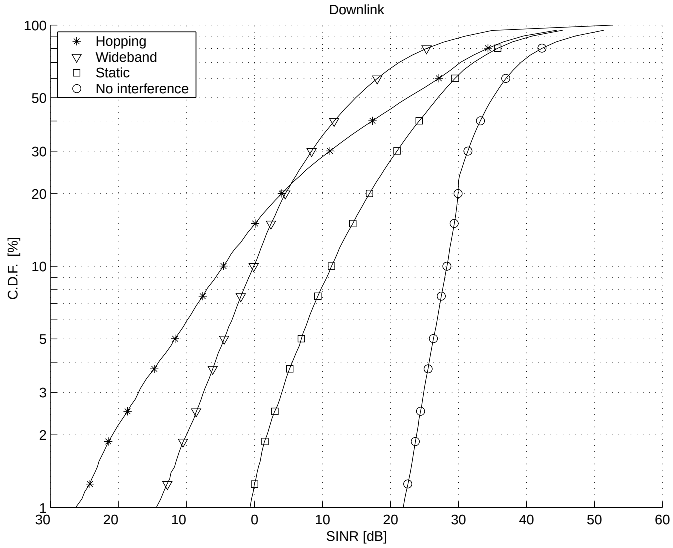

Figure 5. SINR distribution in the downlink after 60 seconds for systems with no external interference and systems subjected to interference from a frequency hopping, wideband and static interferers.

The hopping interference also causes a large performance loss. Since the measurements and channel quality estimation is comparatively slow compared to the speed of the interference hopping it causes the AFA algorithm to consider a number of channels bad. For an access point in he middle of the office most of the channels will be considered interfered with. Thus there are few, if any, channels left to communicate on. The slow reaction of the algorithm in this case is also illustrated in figure 6. Here we see that for all interference cases the channel plan stabilizes after a few seconds. The algorithm is not able to avoid this agile interference and settles on one channel which may be interfered a lot.

In the static interference case there is a lot of degradation, but the AFA algorithm is able to avoid some of the interference. It seems like our system has the best chance of coexisting with a system of the same kind.

The SINR results in the higher percentiles are mainly from devices relatively close to their access point, thereby less vulnerable to interference. Consequently the plotted lines tend to converge there.

Another interesting comparison is made in figure 6, where the estimated reselection probabilities for the different scenarios are seen in the same scatter-plot.

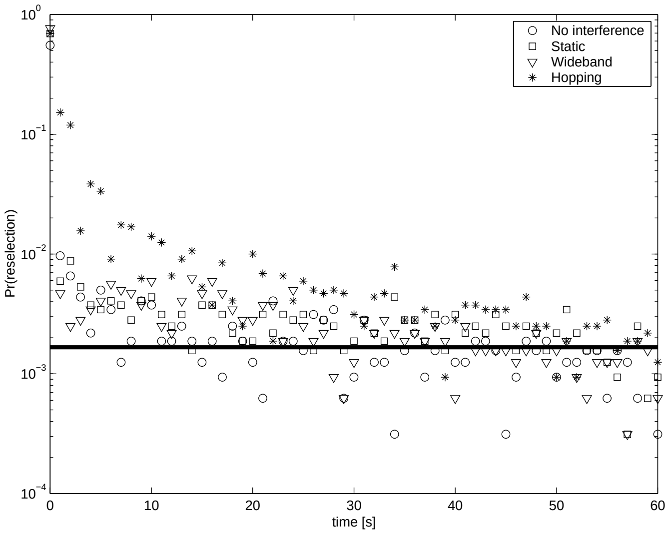

Figure 6. Estimated reselection probabilities for systems subjected to no interference as well as hopping, wideband and static interference. In all cases the channel plan stabilises after a few seconds.

It is clearly seen that the channel plan stabilizes quickly, and similarly, for all scenarios. At 60 seconds the estimated reassignment rate is on average 1 per 10 minutes or less. The scenario with hopping interference makes the system take a little longer to settle, it is however (perhaps surprisingly) stable within the simulated 60 seconds.

VII. Conclusions

As expected the AFA algorithm works well even in 17 GHz spectrum even if the different propagation conditions may lead us to think different.

The AFA works well when there is static non-cooperative interference. But the impact from the interference is sometimes quite severe, so there is really nothing that can be done to give the network good performance.

We have also demonstrated that the impact of non-coordinated interference can be quite severe. Especially the slow reaction times of the system is problematic when there is quickly changing interference.

VIII. References

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