# A Multidisciplinary Study of Competition in unlicensed networks

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***Abstract*- At the same time as 3G networks are deployed low-cost WLAN technology is used to create high data rate coverage in hotspots. Should this be viewed as a complement to 3G systems or is it a competitor? To understand, this technical properties of short range systems are mapped on the influence on the microeconomic firm behaviour. The influence on competition and the possibility to gain benefits from cheating are studied. The results indicate competition can be ensured.**

## I. Introduction

In Europe the telecom operators have paid large sums for the licenses for the third generation mobile networks [1]. Currently they are busy rolling out the infrastructure. At the same time WISPs (wireless internet service providers) are starting to create coverage in cafes, airports and similar places. The technology used is relatively inexpensive and the data rates provided are much higher than what is offered by the current version of 3G systems.

It seems like WISPs are able to successfully provide services in local hotspots. But how the WISP market will evolve is still an open question. Some of the questions that arise are if the current very local coverage will extend to cover cities and maybe whole regions? Another question is if and how the WISP offerings will influence the 3G market? These questions are broad and difficult to answer.

In this paper we add one piece to the puzzle. It is established that unlicensed bands can be used for communication, something that is shown by the success of IEEE 802.11b based equipment. However it is not sure that these bands can be used for providing services on a commercial basis. If services in unlicensed bands are to become successful operators have to be willing to enter the market. In addition more than one operator must be willing to enter to create competition. Here we focus on two problems. The first is to determine if competition can be established in these bands. The second problem is to determine if operators are willing to enter the market at all.

The behaviour of the "traditional" cellular operators in the market place is fairly well known, as well as the factors that underlie the behaviour of these firms. However little is known about how operators using unlicensed spectrum behaves. The approach in this paper is to start with the behaviour of systems in unlicensed bands measured in technical terms. The system behaviours we uncover are then used to investigate how operators in the marketplace behave. The systems studied in this paper do not adhere to a specific standard. Instead they can be viewed as generic design for data communication. The results should be general though.

The first issue we study is competition. The regulators are very interested in ensuring that there is competition even though this may lead to wasteful duplication of resources. The reason we want competition is that prices are lower on a market with competition [2] and that the pace of innovation is more rapid. To ensure competition it must be possible for an operator to enter the market where another operator already operates. The telecom sector has often been seen as one where natural monopolies occur. A natural monopoly is characterised by diminishing average costs. For a telecom operator building the network is the expensive part, which incurs high costs for the first customers. The following customers only add a little bit to the total cost. And the more customers the lower the average cost. This is very advantageous for the operator with the largest amount of customers. Thus it pays to be first in a market, the one entering second will have a much harder time.

Here we determine if the same reasoning holds for systems using the unlicensed bands. To determine this we study two operators that are present in the same geographical area. The number of access points the operators have in the area is different. This corresponds to one large established operator and one new entrant on the market. We can then calculate the average cost for each operator. If we assume that all users pay the same for the service they receive it is easy to realise that the operator with the lowest average costs will have the highest profits and thus will be able to expand the most. If the small operator has lower average costs than the large operator it means that the small operator will be able to expand the most. That situation is favourable to competition since that means that whenever a small operator enters the market he can grow, but when the operator become larger it becomes more difficult to expand.

One prerequisite for competition to occur is that operators are actually willing to use unlicensed bands. One important factor when deciding to enter a market is how large the risks are. The part of the risk evaluation we study here is how predictable the performance of the infrastructure is. This can be further divided into two issues. The first is how predictable the performance is when an operator follows the rules for using the spectrum.

The other issue is if an operator can benefit from not following the set rules or specifications, i.e. by cheating. It is interesting to know both how much the operator can gain and how that influences the other operators. Ideally it should not be possible to cheat, but if it is possible the gains should be low compared to the costs, and the influence on the others should be minimal. There are numerous ways that a system can be modified in order to gain advantages compared to other operators.

## II. Models and Assumptions

In this paper we concentrate our studies on systems that are employed in an outdoor environment. This assumption influences the choice of propagation models. The reason is that the outdoor environment is that there is where competition is likely to occur first. The propagation is modelled using the Okumura-Hata model [3]. Thus the propagation loss is modelled as $L=21+35\log(R)+X$ where R is the distance between the transmitter and receiver and X is a normal distributed variable with variance 8 dB.

It is of course possible to imagine scenarios where there are more than one WLAN network in an indoor setting, e.g. two companies have their own network on separate floors of a building. But in most cases the networks will be separated by geographical distance or by the concrete in the floor, this then incurs some extra pathloss between the networks. It is easy to realise that the worst case occurs when there is no isolation between the networks since they will interfere each other most in that case. Thus in the indoor setting the worst case where the networks are located in the same area is avoided. In addition operators are likely to sign agreements with owners of buildings to get the exclusive right to cover the indoor environment.

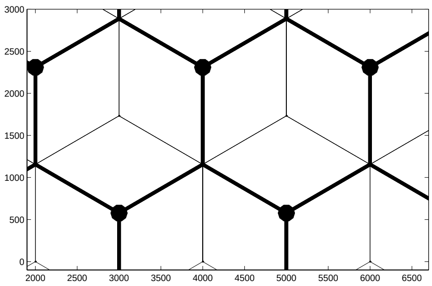

Figure 1. Cell layout for two overlaid operators with ratio 1:1. The thick black lines depict cell borders for operator 1 and the large black dots are access points belonging to operator 2.

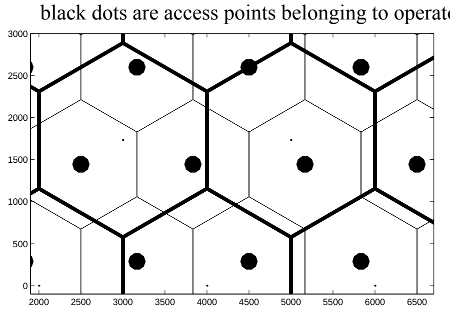

Figure 2. Cell layout for overlaid operators with ratio 1:2.25.

The two systems consist of hexagonal cells with the access points in the middle. I.e. we consider only omni-directional antennas. The two networks are shifted half a cell in relation to each other. Thus the interference problem is at its worst, since many users will be far from “their” accesspoint and close to an interfering access point. To be able to study operators of different sizes the operators also have different number of access points per area unit. In order to still be able to maintain the regular pattern we use the relationships, 1:1, 1:2.25, 1:3 and 1:4. These have the properties that only a few cells can be made to cover the same area, thus the computational complexity is reduced since only a few cells must be simulated. The access point locations are depicted in figure 1-4.

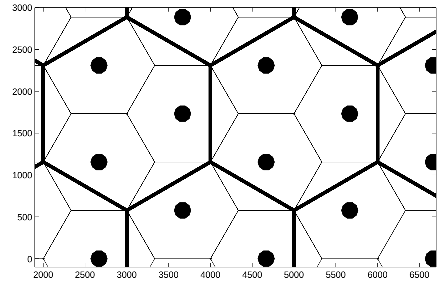

Figure 3. Cell layout for overlaid operators with ratio 1:3

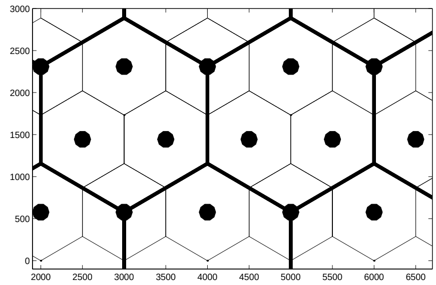

Figure 4. Cell layout for overlaid operators with ratio 1:4.

The users are located according to a 2D poisson process with on average 50 users per cell. This number is quite large to ensure that there are enough users to fill the available capacity of the cell. Users are stationary.

The behaviour of the systems is determined by means of computational experiments. The experiments are carried out in a cellular network using frequency hopping as multiple access scheme. DS-CDMA is not considered here. It has been shown that in this kind of environment the performance of that type of system suffers a lot when there are multiple operators operating in the same geographical area [4]. The reason is mainly the near-far problem. Dynamic channel allocation is also a technique used in unlicensed spectrum, e.g. by DECT systems. The behaviour is similar to frequency hopping since DCA also relies on orthogonal channels.

The frequency hopping system uses a random hopping sequence on 75 channels. The hopping sequences in one access point are orthogonal, i.e. there is no interference between users in the same cell. In addition adjacent channel interference is not considered. The data in one hop is considered to be successfully received if the (instantaneous) signal to interference ratio exceeds 11 dB. If the C/I is less than that transmission fails and the data is resent. The channel data rate is 10 Kbit per second.

The computational experiments focus on the downlink, i.e. the link from an access point to a user. This is the direction that is likely to be most utilised since users are more likely to consume information than generating it. The traffic model is one that models web traffic [5]. Each user carries out a number of sessions consisting of a number of packets of varying lengths. The session interarrival time is exponentially distributed. The number of packets in a session is geometrically distributed with mean 10 packets. The packet interarrival time is a truncated pareto distribution with $\alpha$ 1.2, the min is 0.84 s and the maximum is 333 seconds. The packet length is lognormal distributed with mean 5 Kbytes and variance 15 Kbytes. To achieve different traffic loads the session intensity is varied.

Since we are interested in the cost per user we add as many users as possible to the systems. Then the cost can be defined as the number of access points required per user. It would be possible to fit any number of users if there were no requirements on throughput and delay. Thus we set a limit on throughput (50% of maximum throughput) and require 95% of the users too be satisfied.

## III. Critical areas

In order to better understand the behaviour of frequency hopping systems in unlicensed bands and to explain the results in sections 4 and 5 we define the critical area for a communication link. The critical area is the area where one or several transmitters disrupt the communication on a communication link.

Assume that all transmitters use a fixed transmission power $P_{TX}$. Also assume that data is successfully received if the signal to noise ratio is larger than a specific threshold $\Gamma_T$. We assume that the system is interference limited, i.e. there is no thermal noise and finally we only consider distance dependent fading with parameter $\alpha$.

Let r be the distance from the transmitter to the receiver. Also let $r_i$ be the distance from interferer i to the receiver. For N interferers we can calculate the signal to interference ratio as:

$$\Gamma = \frac{P_{TX}\dfrac{C}{r^{\alpha}}}{P_{TX}\displaystyle\sum_{i=1}^{N}\frac{C}{r_i^{\alpha}}} = \frac{1}{r^{\alpha}\displaystyle\sum_{i=1}^{N}\frac{1}{r_i^{\alpha}}} > \Gamma_T$$

Where C is a implementation dependent constant to account for antenna gain etc. For successful transmission $\Gamma$ has to be larger than $\Gamma_T$. If N is 1 we can easily calculate the minimum radius an interferer can be located at without disturbing the communication. We denote this distance $R_1$.

$$r_1 > r \cdot \sqrt[\alpha]{\Gamma_T}\ ;\ R_1 = r \cdot \sqrt[\alpha]{\Gamma_T}$$

For the case when N is 2 the situation is more complicated. If one interferer is located at a distance slightly larger than $R_1$ the other can be located almost anywhere. However we make a bold simplification and assume that all interferers are located at the same distance from the receiver. Now we can compute $R_2$ since $r_1 = r_2$. In a similar manner we find for arbitrary N.

$$R_N = r \cdot \sqrt[\alpha]{N \cdot \Gamma_T}$$

As an example we $R_1$ to $R_4$ for a receiver located at the cell border (figure 5) and for a user located halfway to the cell border (figure 6), $\alpha$=3.5 and $\Gamma_T$=10 dB. The interpretation of the figure is that if there is at least one interferer in the centre area the communication fails. If there is at least 2 interferers in the first ring (and none in the centre) the communication also fails.

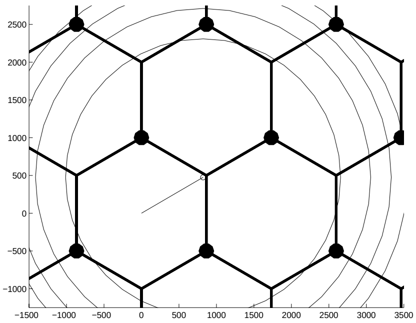

Figure 5. Critical area for a user located at the cell border.

There are some observations we can make from the figures. The most obvious is that for a long link the critical area increases dramatically compared to a short one (distance squared). Another observation is that the area in the centre is much larger than the other rings. At the traffic loads at which a system operates, i.e. when the quality levels are acceptable there are not many active interferers on each channel. Thus the probability that there is at least one interferer in the centre area is much higher than the probability that there are two in the first ring and so on. Thus in most cases a disruption in the communication is caused by an interferer in the centre area.

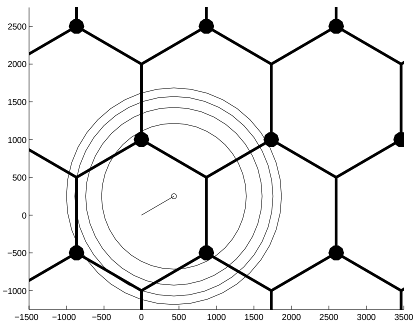

Figure 6. Critical area for a user located halfway between the access point and the cell border.

## IV. Competition

When we run the computational experiments we get the results in figure 7.

We can see that for the same access point density the operators share the total available capacity so that the total capacity is the same. However when operator 2 increases his access point density that is not the case. When most of the traffic belongs to operator 2 the traffic that can be supported per access point is the same, which is expected, since the system is interference limited and the increased access point density just corresponds to a scaling of the system.

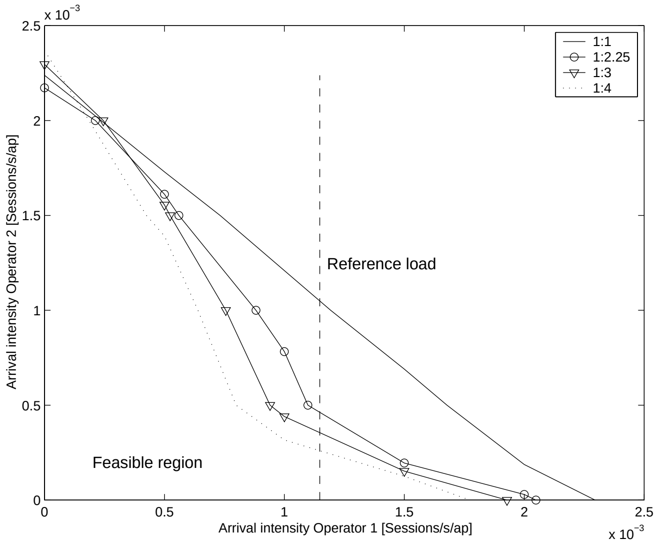


Figure 7. Feasible regions for different access point densities. In the feasible region 95% of all users are satisfied.

Since it is operator 2 that expands his network we let operator 1 keep the same amount of traffic. With traffic in both networks the amount of traffic that can be carried per accesspoint for operator 2 decreases. The explanation is the effect of the interference from users in network 2 on the users in network 1. For operator 1 the length of the communication links does not change which means that the size of the critical area does not change. Thus it is not possible for operator 2 to increase traffic since it really does not matter if it is one access point with high traffic in the critical are that creates interference or many access points with lower traffic in the same area.

We define the cost as the number of users, or rather the number of sessions, that can be supported divided by the number of access points the operator has. It may be a little different than the common view of infrastructure cost where the cost for the infrastructure has a very high fixed cost and very low per user cost. However here we assume that access points can be deployed to increase capacity where it is needed. In the long runt the capacity of the network is then proportional to the number of access points. In the cost definition there is an implicit assumption that the cost of the network is roughly proportional to the number of access points. This is a simplification but is fairly relevant if one considers that most of the network cost is related to cabling and so on.

It is easy to realise that our cost measure will change depending on how many users actually use the system. In addition the fraction of traffic each operator carries does influence the cost. Thus we select a reference case where both operators have the same access point density and the same traffic load. The load is such that we load the networks maximally.

When one of the operators (operator2) increases his access point density the results in figure 8 are obtained. We can see that the cost increases almost linearly with the access point density. The interpretation is that although there are more access points for the operator he cannot carry more traffic.

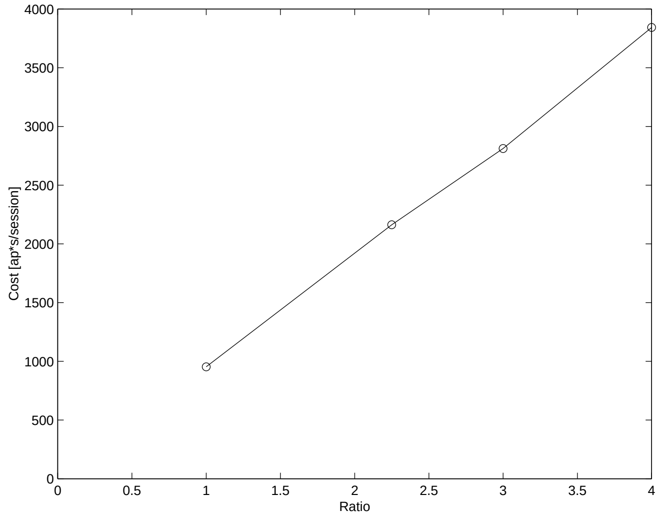


Figure 8. Figure – Average cost per user as a function of access point density differences.

The increasing average cost for an operator is promising since it indicates that new operators can establish themselves in the market. It seems like there will be competition.

## V. Will operators enter ?

One problem with shared spectrum is that the capacity of the infrastructure depends on the traffic load of the other operators. Thus it becomes more difficult to predict the performance. This is not a desired property.

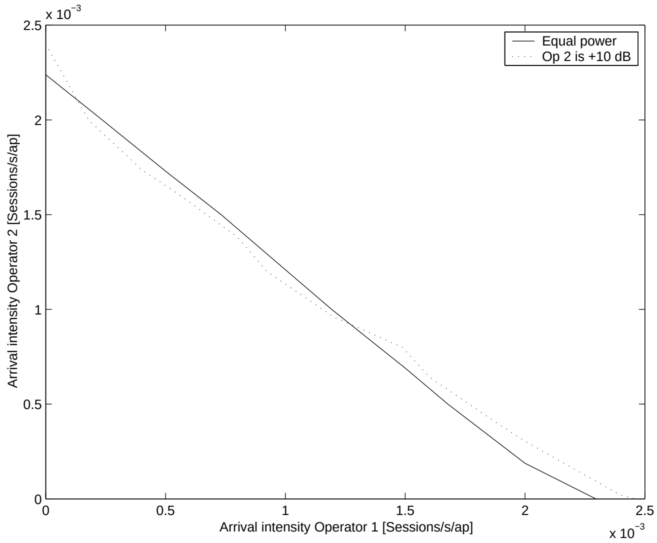


Figure 9. Figure – Feasible regions for two operators with the same transmission power and when one operator uses 10 dB higher output power.

Another thing that may make predicting the capacity is that one operator breaks the etiquette rules. This may be done to achieve higher performance or to sabotage for other operators. The problem here is to determine how easy it is to break the rules and what the effect will be. Here we look at two cases of rule breaking. The first case is when one operator tries to increase the output power. In this example we let one operator increase the output power with 10 dB. The results in figure 9 are then obtained.

We can see that there is not a lot to gain from breaking the rules by increasing output power. The reason is again the size of the critical area for a communication link. The size does not change a lot for only 10 dB increased output power. This is especially true for short communication links.

It is possible to imagine a set of etiquette rules that require operators to reduce load when the fraction of dissatisfied users become too high to keep the quality guarantees. In this scenario it is possible to gain benefits by breaking the rules. Consider the following example. In figure 10 the 5% outage line for operator 1 is plotted together with the 7% outage line for operator 2. Now assume that the rules state that the 5% outage line should be used for quality control purposes. Operator 2 breaks the rules by setting the target to 7% instead. What will happen in heavily loaded situations is that there will be too high outage for operator 1 who will remove users to keep the quality for the remaining ones. However this gives room for operator 2 to admit more users. This will again reduce the quality for operator 1 who needs to remove more users, etc. This illustrates a case where it beneficial to break the etiquette rules.

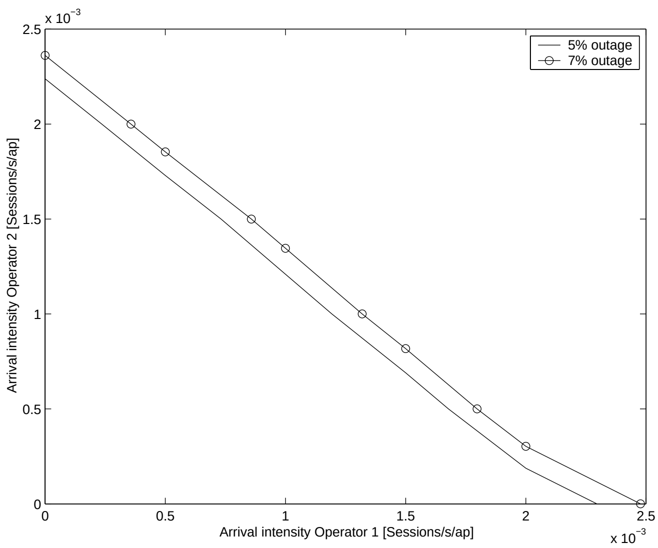


Figure 10. Feasible regions with 5% and 7% outage targets.

We have seen that breaking rules may benefit the cheater at the expense of the others. However it is not obvious which rules that are beneficial to break. Thus it is important to be careful when designing rules. This makes unlicensed bands more risky to use and also makes operators less willing to use them.

## VI. Concluding remarks

One of the obvious advantages with unlicensed operation is that for an operator that is alone in a specific area there is lot of frequency spectrum available. For example there are 83.5 MHz available in the 2.4GHz band for unlicensed use, but a typical 3G operator gets only 15+15 MHz. This fundamental difference potentially gives infrastructures in unlicensed spectrum more capacity for a given cost. However when there is more than a single operator in a specific area they have to share the available capacity. This increases the per user cost. It seems reasonable to think that operators will try to sign exclusive agreements with owners of sites, e.g. malls, airports, campuses and so on. This is in effect small local monopolies and regulators may step in to ensure interconnection rights.

One of the assumptions underlying this whole study is that quality of service is to be guaranteed for the users in the system and implicitly that it is important to the users. A part of that quality is full coverage for both operators. We have seen that the operators must cooperate to ensure this coverage guarantee. E.g. All operators must adhere to the quality of service guarantees since one operator can completely destroy the capacity for other operators by ignoring the quality of service requirements. We have also seen that breaking this agreement may be beneficial for the operator breaking the rules.

It may not be feasible to guarantee a specific quality of service, simply because it may be complex to get agreements, regulations and policing in place. If this requirement is removed the market situation and the operator behavior will be different. For example there will always be areas close to an access point where users can be serviced. Thus it makes sense to have a large number of access points since that will increase the area where users can communicate.

One important thing to point out is the interconnectedness of things. The operating conditions of the technical system, which are given by regulators, influence the behavior of the infrastructures. This in turn changes the market behavior of the operators. The important point here is that small changes in the operating condition can result in large differences in operator behavior. Thus it is important to make this kind of studies to see which effects have on the markets.

## VII. Conclusions

The increasing average cost when an operator increases the amount of access points is beneficial since this tends to equalize the operator size. Thus is seems like there will be competition. However the system capacity in unlicensed spectrum is not as predictable as in licensed spectrum. This makes operators less willing to use these bands. We have also seen that the rules governing the use of the spectrum are important and that careful design is needed.

## VIII. References


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