

POWER CONTROL IN SPONTANEOUSLY DEPLOYED WIRELESS LANs

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Abstract – Wireless LANs operate in the unlicensed frequency bands. Their deployment has seen a tremendous growth since their introduction. It is very common to see a wireless LAN in most homes around the world. These networks are deployed spontaneously leading to the possible coexistence of several networks in the shared frequency band. Their spontaneous deployment has made the networks to be collectively unmanaged and this has led to the existence of larger interference areas. Too much power is lost due to two reasons: interference and due to the reason that the default power settings of the access points lead them to operate beyond their required radio ranges. In this paper, we study this situation, assuming that access points want to cooperate in order to decrease their power usage while requiring that all network nodes are covered. We model the behavior of access points as an optimization problem in which each access point decides about its transmit power, or coverage area. We first identify a target function with possible constraints for two access points a certain distance apart. We then prove that an optimal point exists for the coverage area of each access point that minimizes the overall power transmission and also minimizes the interference area between the two access points. We finally show that, for an open area propagation, the total transmit power of all access points can be proportionally decreased by half.

Keywords – Wireless LAN, Power Control, Spontaneous Deployment, Voronoi diagram, Access Point

I. INTRODUCTION

Wireless LANs when deployed spontaneously are difficult to manage and due to this too much power is lost due to interference. An access point might transmit at the maximum authorized level and, due to the close proximity of another access point, might overwhelm a neighboring access point and vice versa. If both access points behave in this manner, too much power will be lost due to interference and this might affect performance of the networks.

In our paper, we assume that neighboring access points want to cooperate because of the benefits that can be achieved. Cooperation will create a win-win situation for the networks. We also assume that nodes can attach to an access-point (AP) with the strongest beacon signal irrespective of the access point it belongs to. From the interference point of view, this operating principle is much more efficient than the current practice, because it enables wireless nodes to find the “closest” access point in the area and hence both can significantly decrease their transmission power. We also assume that whatever radio range each access point uses, the

total area will be covered while the interference area is minimized. We model this contradictory idea with a Linear Programming (LP) optimization problem with the goal of minimizing interference and total transmit power while covering the entire area where wireless nodes are found.

We first consider a typical town house arrangement where two access points are operating with a certain distance between them. We assume that most of the wireless nodes are found between the two access-points. We model the situation as an LP problem based on power control of the APs. We then generalize our model for N Access points. Finally we show that through cooperation, transmit power decrement proportion to 50% can be achieved.

II. SYSTEM MODEL

We make the following assumptions with respect to the wireless LAN. We assume that two wireless APs communication network and we call the access points base stations b_1 and b_2 . We call the union of base stations B . We also assume that nodes equipped with wireless devices to access the network. The network resides in a given service area, where the base stations provide wireless access for the nodes. We first restrict ourselves to two base stations in order to provide an insight in the basic principles of cooperation in a multi base station context. We then analyze the situation for N base stations by following a step by step inclusion procedure of the base stations.

According to the physical model of signal propagation [5], the transmit power of a base station $b_i \in B$ can be received by a user device u if its signal-to-interference-noise ratio (SINR) exceeds a reception threshold β :

$$\frac{P_i g_{iu}}{N_{0+} \sum_{j \in B, j \neq i} P_j g_{ju}} \geq \beta \quad (2.1)$$

Where P_i is the transmission power of BS b_i , g_{iu} is the channel gain between the BS b_i and the user device u and N_0 is the Gaussian thermal noise. We assume the channel gain depends only on the distance of the transmitter and the receiver and we normalize the effect of the antenna characteristics, thus we have $g_{iu} = d_{iu}^{-\alpha}$ between the BS b_i and user device u , where $2 \leq \alpha \leq 5$ is the path loss exponent that characterizes the radio signal propagation properties of the environment. Equation (2.1) captures how the reception power

depends on the most important factors, namely on the transmission power and the distance between transmitter and receiver. Note that we considered the local average of the received signal but in reality, on a small time scale, the transmit power signals have a time-varying property due to fading.

We assume that (2.1) holds for every point in the service area for at least one base station and that the user device u attaches to the base station b_i with the best SINR. Thus, we can write that:

$$\frac{P_i d_{iu}^{-\alpha}}{N_{0+} \sum_{j \in B, j \neq i} P_j d_{ju}^{-\alpha}} \geq \frac{P_l d_{lu}^{-\alpha}}{N_{0+} \sum_{m \in B, l \neq m} P_m d_{mu}^{-\alpha}} \quad (2.2)$$

For any other base station b_l

We abstract away the end users and assume that their expected position is uniformly distributed over the service area. Note that this also means a balanced load on the base stations (i.e., no users have to switch base stations due to the lack of available bandwidth).

Let us assume that the transmit signals propagate in an almost open area, meaning $\alpha = 2$. Then (2.2) defines a multiplicatively Weighted power diagram (MW power diagram) [4], which determines the set of points in the service area (potential places of user devices) that are attached to a given base station. In the MW power diagram, a point belongs to a base station if it is "closer" to it than to any other base station, where the distance is defined as follows:

Definition 1: the multiplicatively weighted power distance between the points u and b_i is defined as:

$$pow_m(u, b_i; w_i) = \frac{d_{iu}^2}{w_i} \quad (2.3)$$

Where d_{iu} is the Euclidian distance between the points u and b_i and w_i is a weight assigned to point i .

We can define the Voronoi region $V(b_i)$ around a base station $b_i \in B$ as the set of points u that are "closer" to point b_i than to any other point b_j (i.e., $b_i \neq b_j$). Hence, we can write $V(b_i)$ as:

$$V(b_i) = \{u | pow_m(u, b_i; w_i) \leq pow_m(u, b_j; w_j) \text{ for } i \neq j\} \quad (2.4)$$

We can write the Voronoi diagram $V(B)$ of all base stations B as:

$$V(B) = \cup V(b_i) \quad (2.5)$$

Due to the complex shape of the Voronoi diagram with multiplicatively weighted distances, it is difficult to derive

analytical solutions for the power control problem. Hence, we apply a radio range model that is widely used in the literature.

Let us derive from (2.1) the radio range of the transmit signal of the BS b_i as the Euclidian distance within which the users are able to attach to this base station if there is no interference from other devices:

$$r_i = \sqrt{\frac{P_i}{\beta N_0}} \quad (2.6)$$

According to the radio range model, we can define the Additively Weighted Voronoi power diagram (AW power diagram) [4]. In the AW power diagram, the distance is defined as follows:

Definition 2: The additively weighted power distance between the points u and b_i is defined as:

$$pow_a(u, b_i; w_i) = d_{iu}^2 - w_i \quad (2.7)$$

Where d_{iu} is the Euclidian distance between the points u and b_i and w_i is a weight assigned to point i .

In this paper, we substitute $w_i = r_i^2$ and hence we obtain a Voronoi diagram in the Laguerre geometry [4]. This model corresponds to a Voronoi diagram, where the distance is defined as a tangential Euclidean distance to circles centered at the base stations' locations and radii corresponding to their radio ranges.

In this paper we analyze the power control problem in a spontaneously deployed wireless networks. Each wireless network is represented by a set of nodes equipped with wireless network adapters communicating via a wireless access point, from here on referred to as base stations. Each base station serves a given service area and all the base stations serve an extended service area that includes all the base stations and wireless nodes.

In the analyses of the power control problem the following assumptions are used in order to simplify our model.

- No place should remain uncovered in the service area. That is, all wireless nodes are found in between the base stations and within the coverage areas of the base stations.
- Each base station can estimate or measure their coverage including the action of the other base station.
- There exists a limitation on the maximum transmission power of any base station which is defined by the standards of the wireless LAN technology. This applies also for the minimum transmission power.
- Base stations with higher and lower radio ranges exist in the network. These are differentiated based on the topology of the network and particularly based on the distance and angle (direction) between the base stations.

The selection of these base stations could also be decided based on whoever has the furthest associated node initially.

- The base stations and the user devices have Omni-directional antennae.

III. POWER CONTROL IN SPONTANEOUSLY DEPLOYED WIRELESS LANs

A. Two Base stations case

Consider two base stations b_1 and b_2 deployed spontaneously as shown in figure 1. Figure 1b is obtained by rotating figure 1a by an angle α_{12} . Figure 1b corresponds to a spontaneously deployed two base station wireless network.

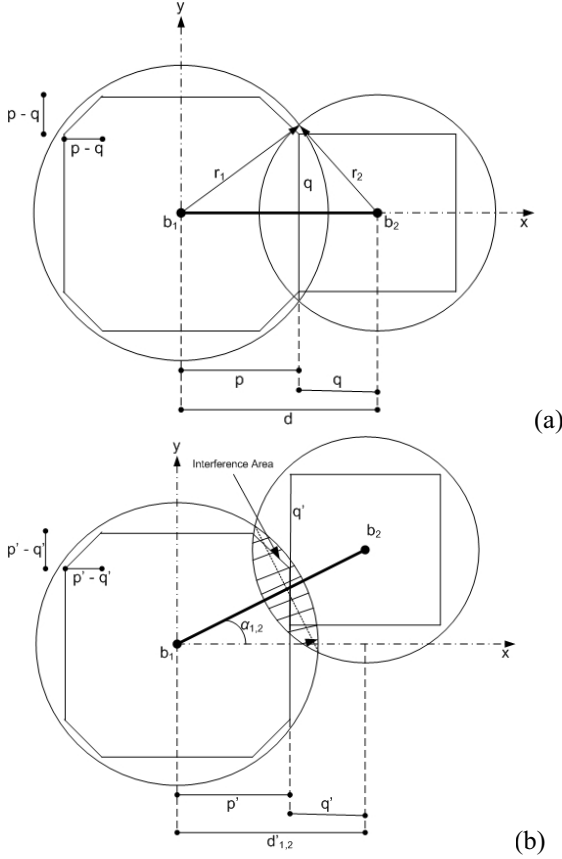


Figure 1 – a) – Coverage areas of the two base stations b) – Two Base Stations deployed spontaneously

Let $\alpha_{12} = \text{Min} \left[\alpha_{12}, \frac{\pi}{2} - \alpha_{12} \right]$, hence $\alpha_{12} \in (0, \frac{\pi}{4})$. We will assume that α_{12} is uniformly distributed in the range $(0, \frac{\pi}{4})$. The parameters p and q are defined as [3].

$$p = \frac{d_{12}}{2} + \frac{(r_1^2 - r_2^2)}{2d_{12}} \quad (3.1)$$

$$q = \frac{d_{12}}{2} - \frac{(r_1^2 - r_2^2)}{2d_{12}} \quad (3.2)$$

Where in figure 1b, we define that

$$p' = p \cos(\alpha_{12}) - q \sin(\alpha_{12}) \quad (3.3)$$

$$q' = q \cos(\alpha_{12}) + p \sin(\alpha_{12}) \quad (3.4)$$

$$d'_{12} = d_{12} \cos(\alpha_{12}) \quad (3.5)$$

Hence, the coverage areas of the base stations is given by

$$\begin{aligned} A_1 &= 2(p' + d')^2 - 4q'^2 \\ &= 2d_{12}^2 \cos^2 \alpha_{12} - 4q^2 (\cos^2 \alpha_{12} + \sin^2 \alpha_{12})^2 \end{aligned} \quad (3.6)$$

$$A_2 = 4q'^2 = 4q^2 (\cos^2 \alpha_{12} + \sin^2 \alpha_{12})^2 \quad (3.7)$$

We defined the coverage areas of the BSs as in equations (3.6) and (3.7) so that the necessary parameters that show the BS's spontaneous deployment can be considered in the analysis of the power control problem. These parameters are the angle and distance between the base stations.

For base station 1, b_1 , to use a higher radio range than b_2 , we require that the following conditions be met.

$$\begin{aligned} p' &\geq q', \quad p' \geq \frac{d_{12} \cos(\alpha_{12})}{2}, \quad q' \leq \frac{d_{12} \cos(\alpha_{12})}{2}, \quad A_1 \\ &\geq 4q'^2, \quad A_1 \leq 4p'^2 \end{aligned} \quad (3.8)$$

All of the requirements in equation (3.8) yield the inequality

$$r_1^2 - r_2^2 \geq d_{12}^2 \frac{\tan(\alpha_{12})}{1 + \tan(\alpha_{12})} \quad (3.9)$$

And the requirement that $A_2 \geq 0$ yields the inequality

$$r_1^2 - r_2^2 \leq d_{12}^2 \quad (3.10)$$

To get other constraints to our power control problem, consider the interference area in figure 1b (The shaded area in figure 1b). Let us define the coverage circles of BSs b_1 and b_2 , respectively as follows:

$$\begin{aligned} x^2 + y^2 &= r_1^2 \\ (x - d_{12} \cos(\alpha_{12}))^2 + (y - d_{12} \sin(\alpha_{12}))^2 &= r_2^2 \end{aligned} \quad (3.11)$$

The coordinate points at which the two circles intersect are given by: (Depending on which base station uses the higher radio range.)

$$(p \cos \alpha_{12} - \sin \alpha_{12} \sqrt{r_1^2 - p^2}, p \sin \alpha_{12} + \cos \alpha_{12} \sqrt{r_1^2 - p^2}) \quad (3.12a)$$

OR

$$(p \cos \alpha_{12} - \sin \alpha_{12} \sqrt{r_2^2 - q^2}, p \sin \alpha_{12} + \cos \alpha_{12} \sqrt{r_2^2 - q^2}) \quad (3.12b)$$

And

$$\left(p \cos \alpha_{12} + \sin \alpha_{12} \sqrt{r_1^2 - p^2}, p \sin \alpha_{12} - \cos \alpha_{12} \sqrt{r_1^2 - p^2} \right) \quad (3.13a)$$

OR

$$\left(p \cos \alpha_{12} + \sin \alpha_{12} \sqrt{r_2^2 - q^2}, p \sin \alpha_{12} - \cos \alpha_{12} \sqrt{r_2^2 - q^2} \right) \quad (3.13b)$$

The size of the interference area is determined by the lengths given by the following equations (The lengths of the lines, in the interference area, that are parallel and perpendicular to the line of sight of the two base stations.)

$$2\sqrt{r_1^2 - p^2} \quad \text{or} \quad 2\sqrt{r_2^2 - q^2} \quad (3.14)$$

Equation (3.14) gives the length of the line segment that is perpendicular to the line segment $\overline{b_1 b_2}$.

And

$$r_1 + r_2 - d_{12} \quad (3.15)$$

Equation (3.15) gives the length of the line segment that lies on the line segment $\overline{b_1 b_2}$.

Since the interference area should be greater than zero and the maximum value of q is p , we require that

$$2\sqrt{r_1^2 - p^2} \geq 2q \quad \text{or} \quad 2\sqrt{r_2^2 - q^2} \geq 2p \quad (3.16)$$

From which we get the inequality

$$r_1 + r_2 \geq \sqrt{2}d_{12} \quad (3.17)$$

We require that $r_1 + r_2 - d_{12} \leq d_{12}$. This requirement puts an upper bound to the size of the interference area. If this requirement is not met, we could argue that one of the BSs serve the entire service area while the other BS sleeps and the BSs do this alternatively. From this requirement we get the inequality,

$$r_1 + r_2 \leq 2d_{12} \quad (3.18)$$

From equations (3.9) and (3.17), we get the inequality

$$r_1 - r_2 \geq \frac{d_{12}^2 X_{12}}{[r_1 + r_2]_{\min}} = \frac{d_{12} X_{12}}{\sqrt{2}} \quad (3.19)$$

Where

$$X_{ij} = \frac{\tan \alpha_{ij}}{1 + \tan \alpha_{ij}} \quad (3.20)$$

From equations (3.10) and (3.18), we get the inequality

$$r_1 - r_2 \leq \frac{d_{12}^2}{[r_1 + r_2]_{\max}} = \frac{d_{12}}{2} \quad (3.21)$$

Transmit power is proportional to r^2 [1]. With equations (3.17), (3.18), (3.19) and (3.21) as constraints, we can formulate the power control problem as an LP optimization problem as

Minimize $r_1^2 + r_2^2$ with constraints

$$r_1 - r_2 \geq \frac{d_{12} X_{12}}{\sqrt{2}}, \quad r_1 - r_2 \leq \frac{d_{12}}{2}, \quad r_1 + r_2 \geq \sqrt{2}d_{12}, \quad r_1 + r_2 \leq 2d_{12}$$

The values of r_1 and r_2 that provide the minimum $r_1^2 + r_2^2$ are

$$r_1 = \frac{d_{12}}{2\sqrt{2}}[2 + X_{12}] \quad (3.22)$$

$$r_2 = \frac{d_{12}}{2\sqrt{2}}[2 - X_{12}] \quad (3.23)$$

B. N Base Stations Case

Consider N base stations in an extended service area of a wireless network. If each BS negotiates with every other BS at once, the problem of solving for the optimum value of r_i , where $1 \leq i \leq N$, that minimizes $\sum_i r_i^2$ would be NP-Hard [1] [6]. Instead let us follow the following procedure to arrive at the radio ranges of the BSs that minimizes the target function.

1. If a BS b_{i+1} exists in the Voronoi region of BS b_i , then BSs b_i and b_{i+1} will negotiate for their radio ranges as in the two BS case according to section 3.1a.
2. Then BS b_{i-1} , that negotiated with BS b_i for its radio range previously will re-negotiate with BS b_i for its new radio range. But now BS b_i will specify its new radio range as a constraint as $r_i \geq [r_i]_{\text{new}}$, where $[r_i]_{\text{new}}$ is the radio range obtained when negotiating with BS b_{i+1} .
3. All the other base station for b_1 to b_{i-2} will calculate their radio ranges accordingly as in step 2.
4. If BS b_i was operating at a lower radio range when negotiating with BS b_{i-1} , then BS b_{i+1} will negotiate with BS b_i assuming that it will operate at a higher radio range than BS b_i and vice versa.

We will derive the optimum radio ranges of the N base stations following the simple procedure just outlined. Our procedure lets odd numbered base stations to operate at a higher radio range while the even numbered base stations will operate at a lower radio range.

Consider N BSs deployed in an extended service area of a wireless network. An example of the spontaneous deployment of three BSs is shown in figure 2.

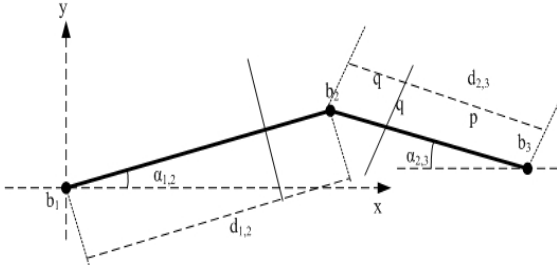


Figure 2 – Three BSs Deployed Spontaneously

When the N^{th} base station joins the network, it will negotiate for its radio range with base station $N-1$ as in the two base stations case. Its radio range will be given by

$$r_N = \frac{d_{N-1,N}}{2\sqrt{2}} [2 + (-1)^{N+1} X_{N-1,N}] \quad (3.24)$$

And base station $N-1$ will operate at a radio range given by

$$r_{N-1} = \frac{d_{N-1,N}}{2\sqrt{2}} [2 + (-1)^N X_{N-1,N}] \quad (3.25)$$

The other base stations in the network will calculate their radio range values based on base station's $N-1$ radio range recursively as

$$r_k = \sqrt{2}d_{k,k+1} - r_{k+1} \quad (3.26a) \quad \text{OR} \quad r_k = \frac{(-1)^{k+1}d_{k,k+1}X_{k,k+1}}{\sqrt{2}} + r_{k+1} \quad (3.26b)$$

Recursively solving the above equations will provide the radio ranges of the $N-2$ base stations as

For $1 \leq k \leq N-2$

$$r_k = (-1)^k r_{N-1} + \sqrt{2} \sum_{i=k}^{N-2} (-1)^{i+k} d_{i,i+1} \quad (3.27a)$$

$$r_k = r_{N-1} + \frac{1}{\sqrt{2}} \sum_{i=k}^{N-2} (-1)^{i+1} d_{i,i+1} X_{i,i+1} \quad (3.27b)$$

IV. CONCLUSION

Wireless devices in a wireless LAN are equipped with omni-directional antennas. Due to this detection of angles by base stations could be difficult. However, base stations can detect the distance of their neighboring base station from measurements and estimations of transmit and receive powers, path loss exponent, background noise and interfering signals. In order to see the power saving that we can achieve by adapting to our power control techniques, let us replace the parameters $X_{i,j}$ and $d_{i,j}$ with their average values.

We assume that $\alpha_{i,j}$ is uniformly distributed in the range $[0, \pi/4]$. Then

$$\bar{X} = \int_0^{\pi/4} X(\alpha_{i,j}) f(\alpha_{i,j}) d\alpha_{i,j} \cong 0.28$$

Where $X(\alpha_{i,j})$ is given by equation (3.20) and $f(\alpha_{i,j}) = \frac{\pi}{4}$ in the range $[0, \pi/4]$.

Let the average value of $d_{i,j}$ be d . Then the higher and lower radio ranges of the base stations will be

$$r_{\text{higher}} = 0.806d \text{ and } r_{\text{lower}} = 0.608d$$

If base stations operate at the higher radio range half of the time and at the lower radio range the other half alternatively, then the total average power consumed by the base stations is proportional to

$$P_{\text{Total}} \sim N \left[\frac{1}{2} (0.806d)^2 + \frac{1}{2} (0.608d)^2 \right] = \frac{N}{2} d^2$$

If we assume that the base stations were operating at a radio range of d initially, as is required for the base stations to know each other's existence, then by adapting to our power control technique, we can achieve a power saving that is proportional to 50%.

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