Cell Sectoring

Introduction

We have seen that a larger reuse factor results in closer co-channel cells and hence a higher S/I. To maintain an acceptable S/I we may therefore be forced to use a relatively low reuse factor. One approach to overcoming this limitation is *cell sectoring* where directional antennas divide a hexagonal cell into somewhat pie-shaped pieces and each piece "sees" fewer interferers than the original omni-directional antenna did.

Directional Antennas

To implement cell sectoring we can no longer use omni-direction antennas. One way to implement a directional antenna is by the use of a wire antenna and reflector, as shown in Fig. 16.1.

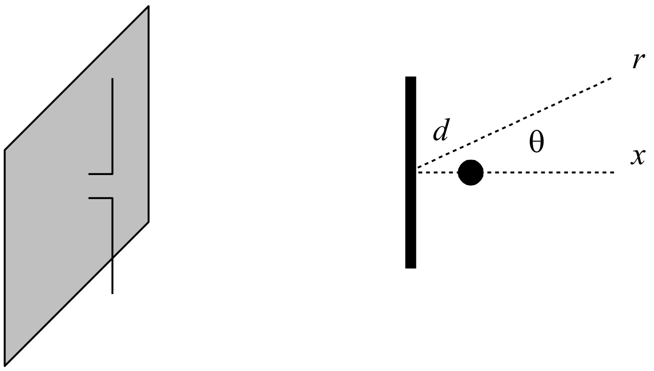

Figure 16.1: Dipole in front of a ground plane. Left: perspective view, right: top view.

If the dipole is a distance *d* in front of the plane then, ideally, there is no field behind the plane. In front of the plane the reflector acts as a mirror to produce a virtual or image dipole a distance *d* in back of the plane with a phase shift of 180 degrees due to the plane's reflection coefficient of -1. With a little trig you can show that the field for $|\theta| \le 90°$ is then essentially

$$
\begin{aligned}
E(\theta) &= E_0 \frac{r_0}{r} e^{-j\frac{2\pi}{\lambda}r} \left(e^{j\frac{2\pi}{\lambda}d\cos\theta} - e^{-j\frac{2\pi}{\lambda}d\cos\theta} \right) \\
&= 2jE_0 \frac{r_0}{r} e^{-j\frac{2\pi}{\lambda}r} \sin\left(\frac{2\pi}{\lambda} d\cos\theta \right)
\end{aligned}
\tag{16.1}
$$

Converting this to received power, with P_0 the received power at distance r_0 and $\theta = 0$, and for the special case $d = \lambda/4$, we have for $|\theta| \le 90°$

$$P(\theta) = P_0\left(\frac{r_0}{r}\right)^2 \sin^2\left(\frac{\pi}{2}\cos\theta\right) \tag{16.2}$$

while $P(\theta)=0$ for $|\theta|>90°$. Since $P(\pm 60°)=1/2$ the ½ power beam width is 120°. This beam pattern is illustrated in Fig. 16.2.

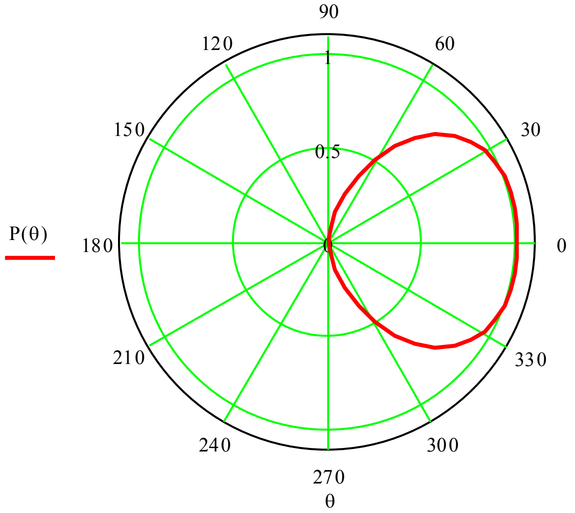

Figure 16.2: 120° beam pattern, i.e., relative power (at a given distance) vs. angle.

Although for simplicity in our discussion below we'll assume ideal, pie-shaped beam patterns, i.e., P is 1 inside the beam and 0 outside, it's important to keep in mind that real systems must use patterns such as that shown in Fig. 16.2

120-Degree Sectoring

If we use three 120-degree beam antennas we can divide a cell into three 120-degree sectors as shown in Fig. 16.3.

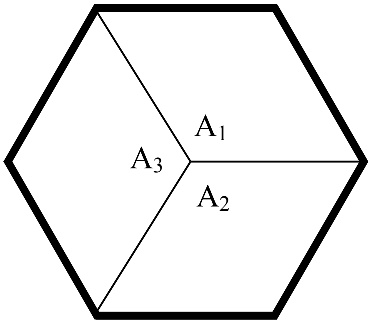

Figure 16.3: 120° sectoring. The original block of channels A must be divided into three blocks as shown.

We cannot use the same channels in the different sectors because at the sector boundaries the *S/I* would go to 0 dB. Instead, we need to split the original "A" block of channels into three sub blocks A_1, A_2, A_3. Now when we examine the first-tier inference situation we will find that two, instead of six, mobiles or base stations will interfere with any particular sector.

Consider the scenario in Fig. 16.4 that shows the first-tier interferers for an $N = 4$ reuse pattern with 120-degree sectoring. Here we focus on the uplink for the "A_2" block of Fig. 16.3. The mobiles transmit omni-directionally, but the base stations only see those mobiles that fall within their 120-degree sectors. The primary base station thus sees only two, instead of six, interferers in additional to the primary mobile.

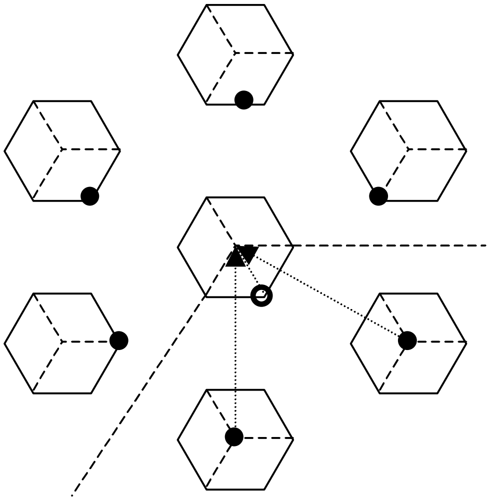

Figure 16.4: Worst case uplink S/I for N=4 and 120° sectoring. The primary mobile is the open circle, the potentially interfering mobiles are the filled circles. Only two of these mobiles will produce interference due to the directional antenna pattern of the primary base station. Sectoring effectively "hides" some of the potential interferers.

Now consider the downlink, as illustrated in Fig. 16.5. The mobile will receive interference only from those base stations in whose 120-degree sector it falls. There are only two, instead of six, such base stations, in addition to the primary base station.

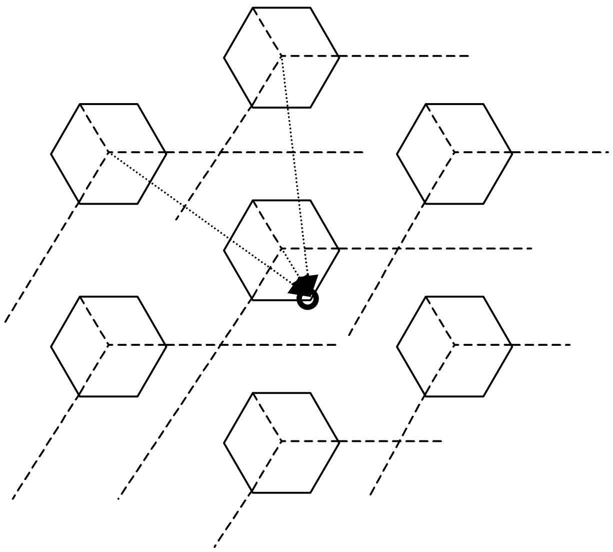

Figure 16.5: Worst case downlink S/I for N=4 and 120° sectoring. The directional antenna patterns of the base stations cause the transmission of four of the first-tier interferers (in a omni-direction system) to miss the mobile. Thus, again, sectoring effectively "hides" some of the potential interferers.

We see that using 120° sectors cuts the interference to about 1/3 of what it would be in an omni-directional system, hence raises the S/I by about a factor of 3, or 4.8dB. In fact, we do even a bit better than that because, for example in Fig. 16.4, the worst-case interferers cannot get as close to the base station or mobile as they can in the omni-directional case.

For example, assume $n = 4$. Then the N=4 cluster with 120° sectors will have a worst case S/I a factor of 3 larger than the "typical" omni case value of $\sqrt{3\cdot 4}^{4}/6 = 24$, hence 72 or 18.6dB. This is nearly the same as the "typical" N=7 case ($\sqrt{3\cdot 7}^{4}/6 = 73.5$ or 18.7dB). Yet our reuse factor jumps from 1/7 to 1/4, an increase of 75%. Apparently we can generate 75% more revenue while maintaining the same link quality. But there are costs.

One obvious cost is the increased complexity of the system. We essentially have to replace each omni base station with three co-located, sectored base stations. This requires more antenna, radio, and network equipment. Then we have to deal with handoffs within cells as mobiles move from one sector to another. This increases the computational burden on the network. However, as technology improves these issues become relatively less important.

A more fundamental "cost" is the decrease in trunking efficiency. If we start off with N channels per cell in an omni system, 120-degree sectoring leaves us with $N/3$ channels per sector. Each sector covers 1/3 the area of a cell, and the number of users per channel remains the same. However, we know that trunking efficiency decreases with decreasing number of channels available. So, the traffic that can be supported at a given PB within each sector will be less than 1/3 the traffic that could be supported in an omni cell. This means that the increase in system capacity due to sectoring will not be as large as the increase in reuse factor, assuming we maintain the same PB. Nonetheless, sectoring will increase the capacity of a cellular system, and second-generation systems generally employ sectoring.

Example 16.1

You have a total of 200 voice channels. Compare the number of Erlangs per cell supportable at *PB*=2% with *N*=7 omni and with *N*=4, 120° sectored systems.

The *N*=7 case has about 29 channels per cell. For *PB*=2% this will support 21 Erlangs. The *N*=4 case has 50 channels per cell, but only about 17 channels per sector. This will support 10.7 Erlangs per sector, hence about 32 per cell. This is a big improvement over 21 Erlangs – 52% – but not the 75% you'd expect without accounting for decreased trunking efficiency.

Other Types of Sectoring

120-degree sectoring is the most commonly used. However other types of sectoring are possible. For example, Fig. 16.6 shows 60-degree sectoring. Here each cell is divided into 6 sectors.

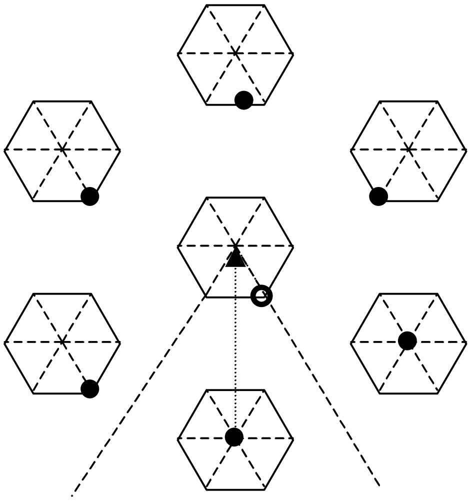

Figure 16.6:Uplink interference with 60-degree sectoring. Only one of the first-tier mobiles provides interference. S/I improves by about a factor of 6 over the omni case, but trunking efficiency decreases accordingly.

Only 1, instead of 6, of the first tier base stations or mobiles will provide interference. The *S/I* goes up by a factor of 6 relative to the omni case and by a factor of 2 relative to the 120-degree sectoring case. But, the system complexity increases and the trunking efficiency decreases accordingly.

Example 16.2

Your phone system needs an *S/I* of at least 14 dB. You want to offer a PB (GOS) of 2%. The offered traffic density is 2 Erlangs/km^2. You have a total of 200 channels available. Compare omni and 120-degree sectored systems assuming $n = 3.5$.

Since 14 dB is a factor of 25, for an omni system we need approximately $\left(\sqrt{3N}\right)^{3.5}/6 = 25$. This gives $N = 5.84$ so we would need an $N = 7$ reuse pattern. In example 16.1 we saw that this system will support about 21 Erlangs per cell. Therefore we need $2/21 = 0.095$ cells/km^2.

For a 120-degree sectored system, we need $\left(\sqrt{3N}\right)^{3.5}/2 = 25$. This gives $N = 3.12$ so we would need an $N = 4$ reuse pattern. (We might be able to get by with an $N = 3$ pattern, but let's be conservative.) In example 16.1 we saw that this system can support about 32 Erlangs per cell. Therefore we need $2/32 = 0.063$ cells/km^2. This will require only $63/95 = 66\%$ of the number of towers needed in the omni case.

References

1. Garg, V. K., and J. E. Wilkes, *Wireless and Personal Communications Systems,* Prentice Hall, 1996, ISBN 0-13-234626-5.
2. Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design,* Wiley, 1998, ISBN 0-471-02590-9.