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Ericsson Microwave Outlook

Maximizing capacity in spectrum-limited networks

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Maximizing capacity in spectrum-limited networks

Can higher frequency reuse provide a viable solution to meet increasing demand for more capacity in microwave networks with limited spectrum?

More aggressive frequency reuse is a way to achieve higher link capacity in networks without the need for more spectrum. However, are there other benefits of higher frequency reuse? What about interference between closely spaced links and how does it affect availability? To shed some light on these questions, this article describes and compares the concepts of frequency Reuse 1 and Reuse 2.

Frequency reuse

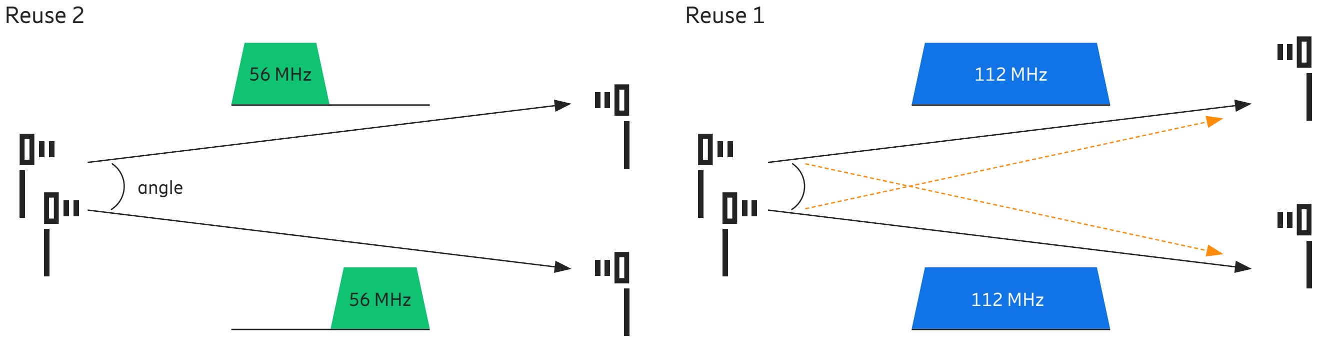
Today's networks most often employ traditional planning strategies where neighboring links are, together with high-performance antennas, allocated separate frequency channels to guarantee principally interference-free operation. As capacity demand increases in our networks, the need for wider channels also increases. However, spectrum is typically limited, and it is therefore challenging to achieve wider channels without reducing the number of separate channels. The fewer channels there are available in a network, the greater the risk of interference.

One extreme deployment scenario is a frequency Reuse 1 network. This denotes a network where each link is allocated the same frequency channel, and the total available bandwidth is, thus, used by all links. Another deployment scenario is a Reuse 2 network where the total bandwidth is split into two halves with each half comprising a separate frequency channel. In Reuse 2, neighboring links are allocated different frequency channels.

On one hand, the risk of interference between neighboring links is much higher in a Reuse 1 network when compared to a Reuse 2 network, but, on the other hand, the channel bandwidth allocated to each link is doubled. Therefore, the trade-off between interference and bandwidth becomes of high interest. Traditionally, backhaul links operate in the bandwidth-limited regime where the signal-to-interference-and-noise ratio (SINR) is very high. However, in the bandwidth-limited regime, the link capacity scales linearly with bandwidth and only logarithmically with SINR. Interference will reduce SINR, but the key point is that it is much more beneficial to take a slight penalty in SINR in order to be able to enjoy a wider bandwidth when the system is bandwidth-limited.

Loss in SINR translates directly to loss in availability, so a very relevant question is what availability we should expect in a Reuse 1 network where links may interfere with each other. To make things slightly more complicated (or, perhaps, more interesting), modern systems may also use traffic-aware output power control, which means that the output power of an interfering link depends on the instantaneous traffic passing through that link. Furthermore, when links increase their output powers to meet certain SINR or capacity demands, this may lead to links rushing their output powers when competing for capacity if not carefully controlled.

Figure 6: Higher frequency reuse with wider bandwidth



Using two different 56 MHz channels, in two neighboring hops with a small angle between them.

Using one and the same 112 MHz channel in neighboring hops, with a small angle between them. This provides twice the bandwidth with the downside of increased risk of interference.

Figure 6 illustrates a simple Reuse 2 versus a Reuse 1 system, consisting of two links where the total bandwidth in both systems is 112 MHz. In Reuse 2, the total bandwidth is split into two 56 MHz channels, and each link is allocated a separate 56 MHz channel which assumes interference-free operation between the links. While in the Reuse 1 system, both links use the same 112 MHz channel to enjoy the full bandwidth but with increased risk of interference between the links. The potential peak capacity of the Reuse 1 system is thus twice the peak capacity of the Reuse 2 system.

Achievable capacity

Figure 7 shows the achievable capacity rate regions for the simple two-link system illustrated in Figure 6. The simulation parameters can be seen in the box underneath the figure. The x-axis represents the capacity of one of the links in Figure 6 and the y-axis represents the capacity of the other link. Any rate combination point in the graph represents the capacity rates that the two links can achieve at the same time. The capacity is achieved by using the minimum output power, in other words traffic-aware output power, that fulfills the corresponding capacity with at least 99.995 percent availability.

The different rate regions are colored differently, with orange representing the unachievable rate region. "Unachievable" means that both links cannot achieve any of the rate combinations within that region at the same time. The dark blue region is the achievable rate region for a Reuse 1 system which has 36 dB of antenna discrimination or isolation between the two links. The antenna discrimination is dictated by the angular separation between the links and the antennas used. Finally, the light blue region is the achievable rate region for a Reuse 1 system with 28 dB of antenna discrimination, and the green region is the achievable rate region for a Reuse 2 system. By observing the rate regions in Figure 7, we can make some interesting observations:

- The peak capacity of the Reuse 1 system is twice the peak capacity of the Reuse 2 system.
- The capacity region of the Reuse 2 system is square since there is no interference between the links.
- When the antenna discrimination is not large enough, it is sometimes not possible to achieve peak capacity for both links at the same time in a Reuse 1 system, due to too much interference.
- The higher the antenna discrimination, the higher the rates that can be achieved simultaneously for both links in a Reuse 1 system.

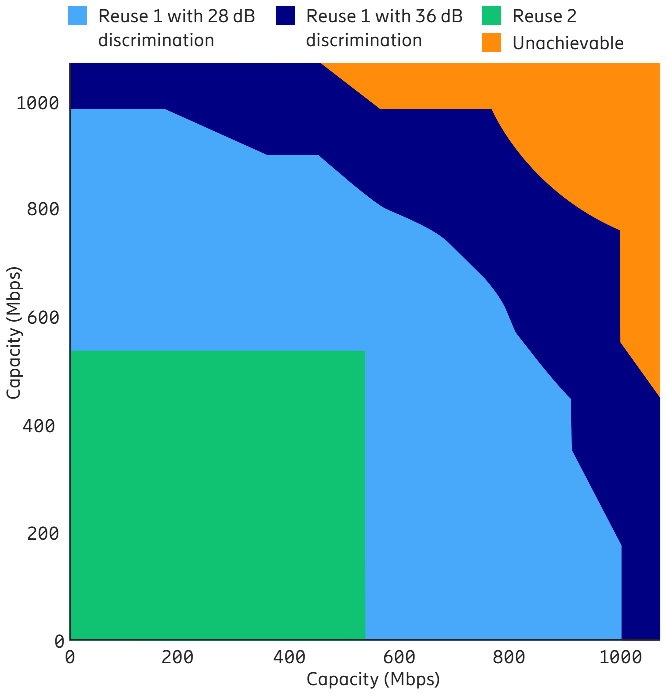
The peak capacity of the Reuse 1 system is twice the peak capacity of the Reuse 2 system.

2x

Antenna discrimination

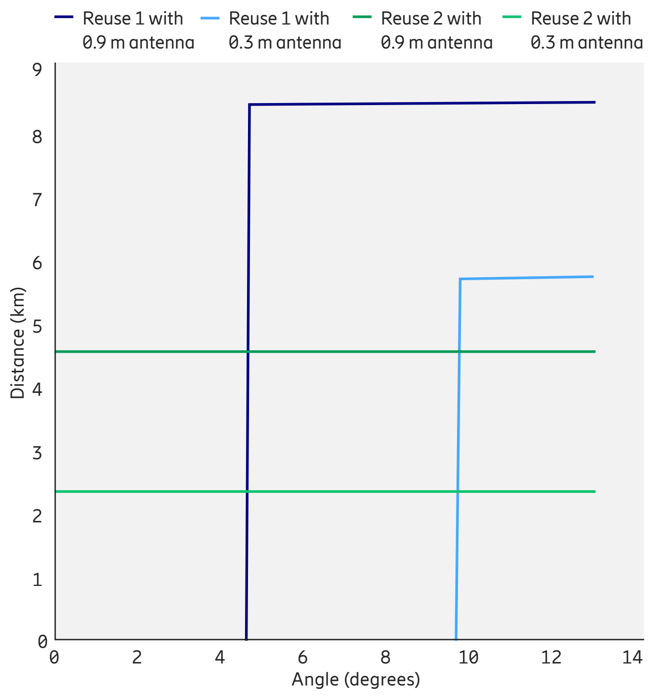
As mentioned above, antenna discrimination between neighboring links affects achievable rates because of its ability to suppress interference. Antenna discrimination can be improved by using larger antennas, by using larger separation angles between antennas, or a combination of both. Larger antennas provide more antenna discrimination thanks to narrower beamwidths. Figure 8 shows the possible

Figure 7: Capacity rates available with two close links



The figure shows which rate combinations are possible with at least 99.995% availability for two links, using either Reuse 1 or Reuse 2. As the antenna discrimination increases for Reuse 1, the available rate region increases. With increased antenna discrimination the two links cause less interference to each other.

Figure 8: Hop distances with different angles



The figure shows the possible hop distance for Reuse 1 and Reuse 2 with an availability of 99.995% at 550 Mbps. If the antenna discrimination reaches above 23.5 dB, the hop length almost doubles for Reuse 1 compared to Reuse 2.

Simulation parameters

Rain zone Gothenburg, Sweden 43 mm/h (99.995%)
Carrier: 15 GHz
Antenna: ETSI class 3, 0.9 m (Figures 7 and 8), 0.3 m (Figure 8).
Max power: 18 dBm
Min power: -10 dBm
Bandwidth: 112 MHz
Hop length: 4 km (only applies to Figure 7)

hop distances with an availability target of 99.995 percent at 550 Mbps. If the antenna discrimination reaches above 23.5 dB, the hop length approximately doubles for Reuse 1 compared to its Reuse 2 counterpart. The isolation value of 23.5 dB occurs approximately at 5 degrees of angular separation for 0.9 m antennas and 10 degrees for 0.3 m antennas, which in this case should be regarded as the minimum angular separations for conventional ETSI class 3 antennas.

Angular separation clearly plays a very important role in Reuse 1 systems. To further explore the importance of antenna discrimination, we have plotted capacity at two different availabilities against antenna discrimination in Figure 9, for a link with random interference from a neighboring link that transports random traffic. Additional simulation parameters are shown in the box underneath the figure. If the antenna discrimination, or similarly, the angular separation between antennas is too small, then there is not enough interference suppression for Reuse 1 to work properly. However, if the antenna discrimination is 23.5 dB or above, then the Reuse 1 system will outperform the Reuse 2 system. Maximum capacity for Reuse 1 is achieved at 41.5 dB of antenna discrimination, which in the simulated case corresponds to 4096 Quadrature Amplitude Modulation (QAM). Another peak rate would require another antenna discrimination. For the simulated case however, the corresponding angular separations are highlighted in the boxes to the right of the figure. Note that Reuse 1 can already outperform Reuse 2 at relatively small angular separations, and that its peak capacity is twice that of Reuse 2.

Conclusion

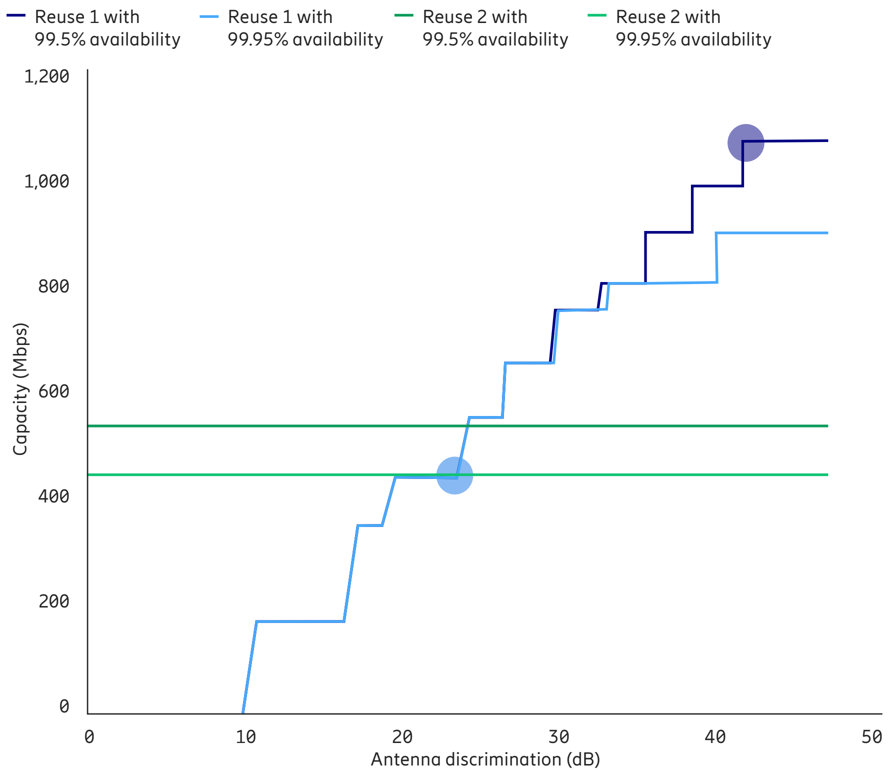
Reuse 1 offers several benefits over Reuse 2. Foremost, it offers wider channels and more efficient spectrum usage when the same frequency channel is used across the whole network. Wider channels translate to higher capacity for a given availability target or longer hop lengths for a given availability and capacity target.

It should be stressed that it is important to fulfill the minimum requirement on antenna discrimination, since this provides the required interference suppression which enables the use of Reuse 1. The good news is that the required antenna discrimination already occurs at relatively small angular separations, for example 5 to 10 degrees, for commercially used ETSI class 3 antennas. Of course, larger antenna discrimination results in larger benefits. Depending on antenna size, peak capacity is achieved at 30 to 50 degrees of antenna separation.

These examples are for 15 GHz links with 2x56 MHz (Reuse 2) or 1x112 MHz (Reuse 1), evaluated with respect to antenna discrimination which depends on frequency and antenna size. However, Reuse 1 is generic; it can be used in any frequency band, with any channel size in block-licensed spectrum. For example, 2x28 MHz may be interesting to replace with 1x56 MHz in some countries. In fact, it was recently announced that India will allocate two 250 MHz channels in E-band for 5G transport. Reuse 1 has big potential in E-band as very narrow beamwidths are typically used, limiting co-channel interference.

To conclude, Reuse 1 will play an important role in meeting increasing capacity demands in dense networks with limited spectrum where there is a considerable need for aggressive channel reuse.

Figure 9: The impact of antenna discrimination on available capacity



Maximum capacity for Reuse 1 is achieved at 41.5 dB and above

ETSI class 3 antenna	0.3 m	0.6 m	0.9 m
Angle between links	50°	48°	30°

Reuse 1 delivers higher capacity than Reuse 2 at 23.5 dB and above

ETSI class 3 antenna	0.3 m	0.6 m	0.9 m
Angle between links	10°	7°	5°

At only a 10° angle between 2 links, Reuse 1 delivers higher capacity than Reuse 2 with 0.3 m antennas.

Simulation parameters

Rain zone Gothenburg, Sweden 43 mm/h (99.995%)
Carrier: 15 GHz
Antenna: ETSI class 3, 0.9 m
Max power: 18 dBm
Min power: -10 dBm
Bandwidth: 112 MHz
Hop length: 9.5 km

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