

# The Relationship of INTERFERENCE AND CAPACITY IN LTE



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When people ask me about how inter-cell interference and capacity interact in LTE networks, I like to start from the basics. Let's talk about how LTE uses subcarriers and combines them to form the overall transmission carrier, which is what you probably know as the "LTE channel".

## The Building Blocks: Subcarriers and OFDM

The transmission carrier is formed using a method called Orthogonal Frequency Division Multiplexing (OFDM), which divides the available spectrum into multiple narrow subcarriers spaced 15 kHz apart (in the specific case of LTE).

Let's talk a bit about multiplexing to understand how these subcarriers came to be. Multiplexing is a technique that allows a medium to carry different streams of information at the same time. Multiplexing can be done in frequency (FDM- Frequency Division Multiplex), time (TDM- Time Domain Multiplex), or code (CDM-Code Division Multiplex) domains.

Let's focus on FDM for our purposes. You can think of traditional FDM as multiple radio stations broadcasting on different frequencies. Each user gets their own frequency channel, but these channels can't be too close together because even with sophisticated filters to shape the signals, we need to leave substantial gaps between channels to prevent them from bleeding into each

other. In some FDM systems, the interference needs to be kept extremely low – sometimes up to 30 dB below the main signal – just to make sure the information can be recovered reliably. This means that we end up needing spacing between channels that is about 2-3 times wider than the actual signal itself.

This is where OFDM comes in, instead of keeping signals completely separate, OFDM arranges subcarriers so that they overlap in a very special way – each subcarrier's peak lines up perfectly with the zero points of all other subcarriers as shown in Figure 1. We call this arrangement "orthogonal" because the subcarriers do not interfere with each other despite the overlap. While this OFDM concept has been around since 1957, we couldn't actually implement it until the late 1990s because of limitations in computer processing capabilities.

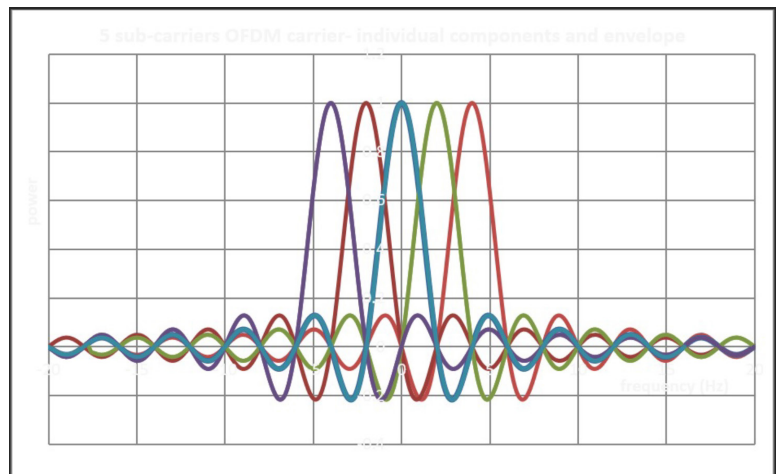


Figure 1 Example of orthogonal carriers

In this multiplexing technique, individual carriers are called sub-carriers and the combination of all sub-carriers is called an OFDM carrier. For data transmission to happen in OFDM, a data bit stream is mapped into symbols, which are represented by power levels, I and Q, according to the constellation (modulation scheme) that is being used. I and Q values then modulate the sub-carriers.

Figure 2 shows a representation of the waveform of the LTE carrier (in orange) formed by adding five subcarrier components. The LTE carrier is what is transmitted over the air, not the individual subcarriers and this is the key to understanding why no frequency planning is done in LTE. We will delve more into this later in this article.

The technique used to modulate the subcarriers is OFDM and LTE uses the multi-user version of it for transmission - OFDMA (Orthogonal Frequency Division Multiple Access) – which allows multiple users to share the subcarriers dynamically in both time and frequency domains. In the specific case of LTE, another level of complexity is added by creating groups of twelve consecutive subcarriers called Resource Blocks (RB) and then assigning these to users. For the specific purpose of this article, I chose to put the concept of resource blocks aside as it will add another level of complication that is not required for grasping the concept I'm aiming to explain, instead we will keep dealing directly with the subcarriers.

Now that we understand how the LTE carrier is divided into subcarriers, let's talk a little bit about how these subcarriers may be used. Some of them may not be used at all, and we refer to these as null subcarriers; they might function just as a reference to locate the middle of the LTE carrier, or as an inner guard band at both ends of the LTE carrier. Another type is the pilot subcarriers, which are specifically designated subcarriers that carry known reference signals. Finally, you have subcarriers used for

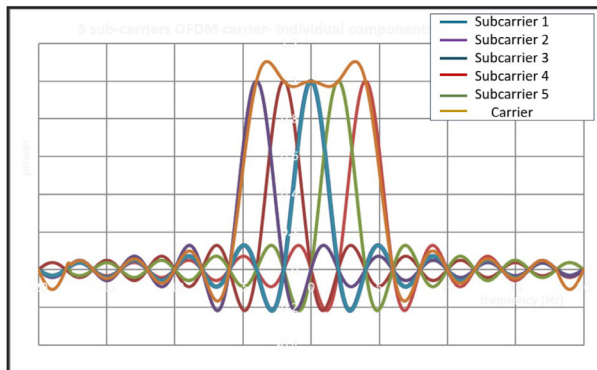


Figure 2 Example of OFDM Carrier obtained from combining orthogonal subcarriers

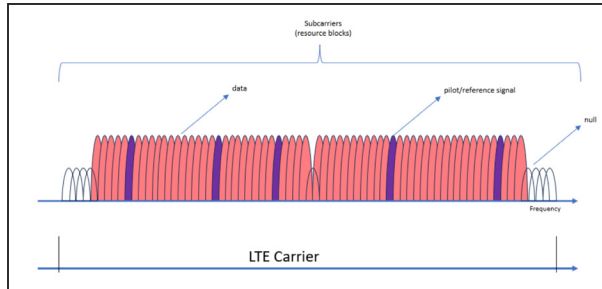


Figure 3 Example of an LTE carrier with different types of subcarriers

data transmission. We will focus now on this last type, the subcarriers that are effectively being used for data transmission. In Figure 3 you have a simple representation of an LTE carrier composed of subcarriers used for different functions.

### The Concept of "Reuse 1"

If you have been working with wireless networks for a while, you know that inter-cell interference is something you want to avoid, and the way to do this is usually by optimizing your frequency plan, not always a fun task. So, when you hear that LTE networks use reuse 1 and no frequency planning is needed, you naturally breathe a sigh of relief. But there's a caveat. The issue here is that this reuse 1 is applicable to the LTE carrier, that is, you have a wide LTE channel (e.g. 3 MHz, 5MHz, 10 MHz) and you use that same channel for all sites and sectors of your network.

But how about the subcarriers? Do you need a frequency plan for those? The short answer is no. However, you cannot use the same subcarrier at the same time, at the same place in two different sites, that would be a co-channel assignment as in any other technology and you would have a lot of inter-cell interference. The trick here is to pay attention to a couple of the terms I just used: "at the same time" and "at the same place". Basically, you can use the same subcarriers everywhere, as long as you are in a location where you cannot "see" that another site is also using that subcarrier, or you are transmitting at a different time than the other site.

Figure 4 illustrates an example of perfect subcarrier allocation between three sites. A user located where the service area of the three sites overlap would see the subcarriers allocated by all three sites. Notice that in this example the subcarriers used by each site are different thus the user in the overlap sees a full LTE carrier and no conflicts in allocation (no inter-cell interference).

Now imagine that one of these sites has a sudden increase in traffic demand and now needs to use double

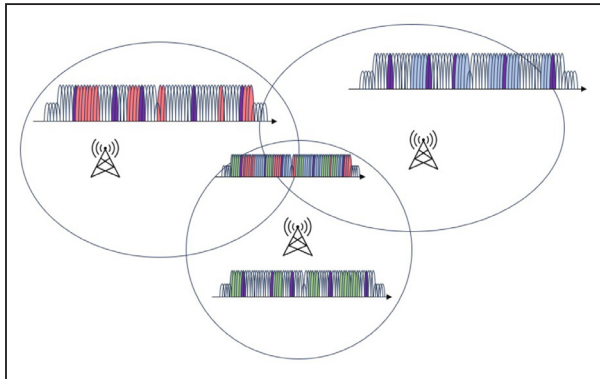


Figure 4 Example of the perfect scenario for subcarrier allocation in different sites

the number of subcarriers. What would happen to a user or device located in the overlap region? There would be conflicts in subcarrier allocation (inter-cell interference) which could cause higher error rates, lower signal to noise ratio, drop in modulation scheme, lower throughput, and repeat requests. All of these consequences impact cell capacity because now you need more time to transmit the same thing you were trying to transmit initially. And here lies the issue, if you need more time for transmitting the data, you will need more subcarriers, which will cause more inter-cell interference, which will cause more capacity issues, which will cause more inter-cell interference... you get my point.

So now we know that you do not create a frequency plan for LTE but you need to plan subcarrier allocation. How exactly do you do that? Well, you don't really do much by yourself, most of this job is done by the Scheduler, which is a critical component in the eNodeB (LTE base station) that manages radio resources. If you go research why the scheduler is important you will find lots of reasons including things such as: maximize system throughput, reduce latency, optimize spectrum efficiency, maintain service quality, optimize power usage, maximize network capacity amongst others. The vast majority of these reasons are a direct consequence of one thing, the scheduler tries to reduce conflicts in subcarrier allocation, thus reducing inter-cell interference.

### Inter-Cell Interference Coordination (ICIC)

Which brings us to ICIC, or Inter-Cell Interference Coordination. ICIC in LTE networks is a technique used to manage interference between neighboring cells, particularly at the cell edges. As we have just discussed, when multiple cells in an LTE network operate simultaneously, users at cell edges often experience interference from neighboring cells using the same subcarriers. ICIC helps minimize this interference through coordinated resource allocation.

ICIC can be implemented in different ways: in the frequency domain, in which different cells use different parts of the frequency spectrum for their edge users; in power domain, with cells coordinating their transmission power levels; and in time domain with cells coordinating when they transmit using specific resources.

ICIC works dynamically, with cells constantly communicating and adjusting their resource allocation based on network conditions and user demands. The LTE standard (3GPP specifications) does not specify specific techniques for ICIC, it only provides mechanisms and interfaces that can be used to implement interference coordination; vendors are free to choose the techniques and methodologies they will employ.

The LTE Scheduler and ICIC work together to optimize network performance, with ICIC focusing on managing interference between cells while the scheduler handles resource allocation within each cell. In a nutshell, the ICIC algorithm provides interference information to the scheduler which then makes allocation decisions considering ICIC restrictions.

If all is done automatically, what part is under your control? The traffic demand. You cannot control the resources that are being allocated but you can control how much demand you are placing on the eNodeBs (sites).

Think about it this way, if you put so many users or devices in a cell that all the subcarriers are always used, there is no ICIC and scheduler in the world that will be able to avoid conflicts from happening. You need to leave "room", i.e. empty subcarriers, for the ICIC and scheduler to do their magic.

For most LTE networks, the recommended maximum usage is around 80 to 85% of available resource blocks, keeping 15 to 20% of resources as "headroom". This will allow ICIC to more efficiently handle sudden traffic spikes and accommodate high-priority traffic.

For mission-critical LTE networks, however, a maximum of 60 to 70% of available resource blocks should be allocated leaving 30 to 40% of resources as headroom for ICIC. This extra headroom is needed to accommodate things such as ultra-low latency demands, high reliability requirements, guaranteed resource availability, and immediate access needs for emergency traffic.

In summary, for an LTE network to work well, you need to consider how much you can load each site to reduce the possibility of inter-cell interference. To determine this, you need to understand the throughput demand of your users and try to maximize their transmission efficiency (modulation scheme) as much as possible. More to come on this topic on future issues of The UTC Journal. ■