The Basics of LTE

A closer look at the foundations of this ubiquitous wireless broadband communication standard.

iBwave

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LTE is a 4G standard developed in 2009 and deployed in 2010. It was considered as 3G standard by 3GPP back in 1998 but was dropped in favor of wideband CDMA because LTE requires large amount of baseband processing, which was not commercially viable in 1998.

Even though LTE is evolution path for 3GPP (UMTS) only, most narrowband CDMA (3GPP2) operators announced that they will adopt LTE as evolution path to 4G, making LTE as the de facto 4G worldwide standard. LTE is an all-IP network. Circuit switch voice is not supported in LTE. LTE relies on VoIP to support voice application.

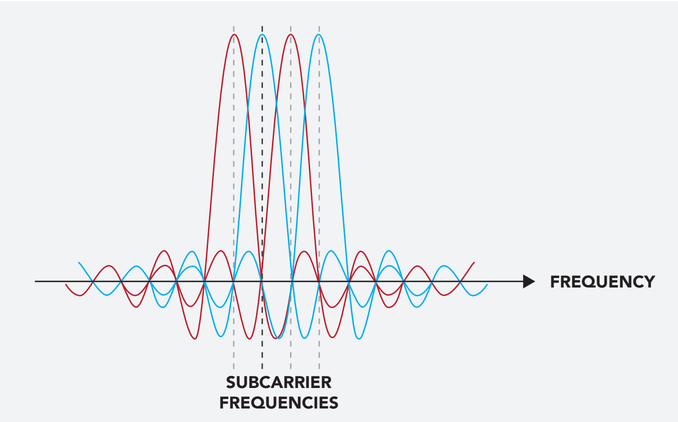
Most prominent LTE features are OFDMA (Orthogonal Frequency Domain Multiple Access), adaptive modulation, frequency channel adaptation, inter-cell interference mitigation and MIMO antennas.

LTE OFDMA Basics

Here we will cover basics of OFDMA principles, without going into too much detail. In OFDMA, usable bandwidth is divided into a large number of subcarriers. Information is split into subsets called Symbols. Each symbol is assigned to a unique subcarrier, so there can be as many symbols as available subcarriers. Symbols are transmitted simultaneously over subcarriers.

At the user end, low data rate symbols are received and parsed together to recreate the original high data rate information. It should be noted that the number of assigned subcarriers per user is not necessarily constant in time, it may vary within each Symbol. This means that data throughput rate for each user may change within duration of a Symbol. This gives added flexibility to LTE to transmit bursty data, but also to combat frequency selective fading (more on this later).

Subcarriers and their spacing is chosen so that their frequencies are mathematically orthogonal. Omitting the mathematical derivation, we will just mention that the spacing between carriers, Δf, must be $\Delta f = 1/Tu$, where



OFDM Signal and Subcarrier Principle in the Frequency Domain

Tu is Symbol duration. Typically, in LTE Δf =7.5 kHz or 15 kHz. The beauty of orthogonality in frequency domain is that it simplifies the design of both transmitter and receiver. Due to frequency orthogonality, a separate filter for each subcarrier is not required. However, should frequency offset occur between transmitter and receiver, the orthogonality between subcarriers ceases to exist, and inter-carrier interference (ICI) occurs. The situation worsens if ICI is combined with multipath, which then occurs at various frequency offsets.

LTE Adaptive Modulation

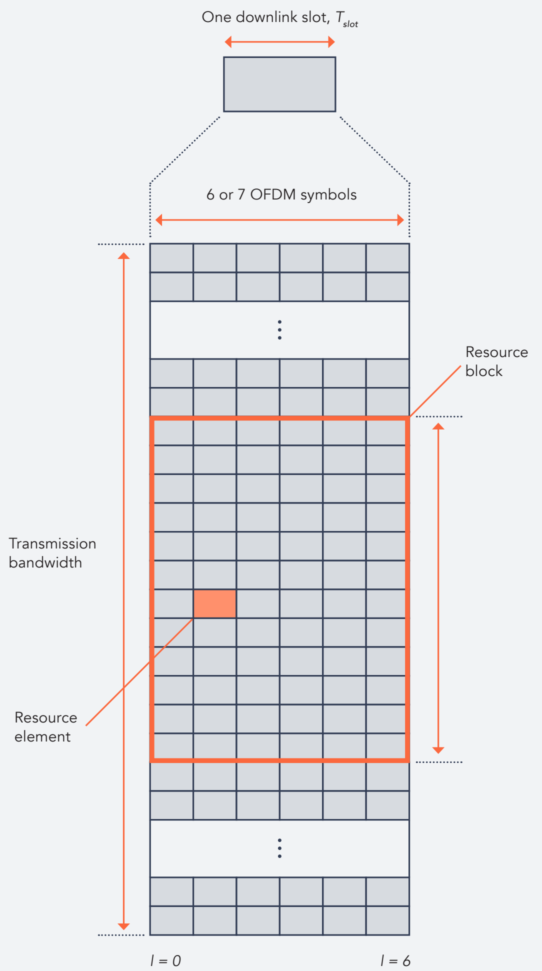
Adaptive modulation is a technique where modulation scheme is decided based on RF channel condition, namely fading and interference. If the channel experiences very little fading and/or interference, higher order modulations may be used to modulate the Symbol. Higher order modulation is Quadrature Amplitude Modulation (QAM), and LTE has in its disposal 16-QAM and 64-QAM. Those types of modulation produce high bits/sec/Hz ratio, which allows for high data throughput rate. If the channel has a lot of fading and/or interference, QPSK modulation may be used. Bits/sec/Hz ratio for various modulation schemes is shown in the table to the left.

It should be noted that LTE's resilience toward interference is what allows the use of QAM modulations. Those high order modulations are one of the main reasons why LTE data throughput rate is so much higher than any other technology. In the table below, we show an overview of modulation schemes used in various 3G and 3.5G technologies. Clearly, LTE is the superior one because it deploys two higher order modulation schemes (16-QAM and 64-QAM), whereas EvDo and HSPA only deploy one (16-QAM).

Modulation	bits/sec/Hz
QPSK	2
8-PSK	3
16-QAM	4
64-QAM	6

	QPSK	8-PSK	16-QAM	64-QUA
EvDo	✓	✓	✓	✗
W-CDMA	✓	✗	✗	✗
HSPA	✓	✗	✓	✗
LTE	✓	✗	✓	✓

Resource Grid of OFDM Signal in LTE



- 6 or 7 OFDM symbols in 1 slot
- Subcarrier spacing = 15 kHz
- Block of 12 SCs in 1 slot = 1 RB
  - 0.5 ms x 180 kHz
  - Smallest unit of allocation

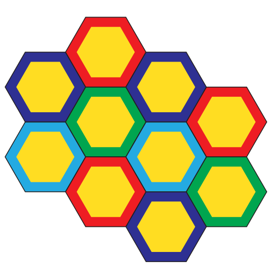
LTE Frequency Channel Adaptation

Frequency channel adaptation is a scheme in which a part of frequency spectrum affected by frequency selective fading is assigned to low data rate users. High data rate users are moved to the portion of the spectrum not affected by fading. Measurements across the whole bandwidth are constantly performed to estimate fading depth, and whether it is narrowband or affects the whole LTE band.

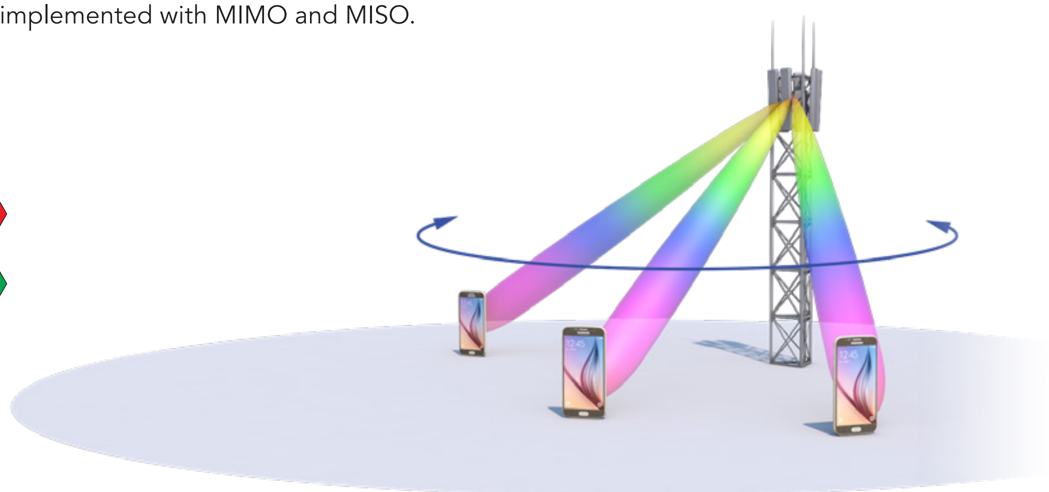
LTE Inter Cell Interference Mitigation

There are three cell interference mitigation techniques used in LTE: interference coordination, interference randomization and interference cancellation.

1. **Interference coordination** is a scheme where the spectrum is divided into sub-bands. One sub-band is assigned for the core of each eNodeB, and other sub-bands are assigned at cell edge of each cell. In a way, cell edge frequency band distribution is similar to frequency planning in TDMA systems. In this example, frequency reuse factor is N=7, because the sub-band assigned to the edge of a cell can only be reused after 6 neighboring cells use a different channel band at their cell edge. In the picture below, we see that the frequency sub-band in light blue color was not reused in any of the 6 neighboring cells. Obviously, if interference coordination is applied, frequency reuse F is greater than 1.
2. **Interference randomization** can be applied using one of the three schemes: Cell specific Interleaving Division Multiple Access (IDMA), frequency hopping and cell scrambling. Cell specific IDMA modulates the signal using interleaving patterns that depend on cell ID. Frequency hopping is a well-known interference randomization scheme, explained in GSM technology. Finally, cell scrambling is left as an option in LTE, and was fully explained in example of using short PN codes on downlink in CDMA.
3. **Interference cancellation** is spatial suppressing of the signal using beam forming. An array of antennas “steers” the signal toward the user by shaping the composite antenna pattern in a way to minimize interference that is coming from a certain direction. For this scheme to be even possible, multiple transmit antennas are needed; therefore, it can be only implemented with MIMO and MISO.



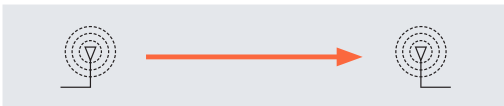
N = 7



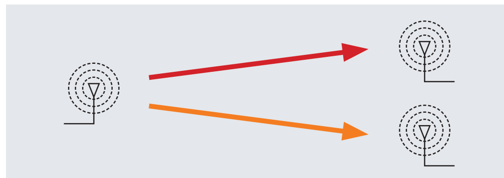
Interference mitigation with interference cancellation

LTE MIMO

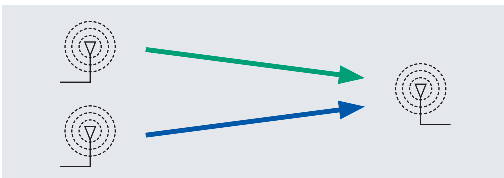
"Smart Antenna" technology is a technology where multiple transmit or receive antennas (or both) work in unison to create transmit (or receive) antenna patterns that maximizes carrier signal, and vastly reduces or even eliminates interference. Smart antennas were first commercially deployed in the US by US WEST New Vector in the early 90s in AMPS network, then further developed for other technologies by Arraycom, a startup company from California. However, up until LTE Smart Antennas were never a part of an official standard and therefore never deployed in large numbers in the US.



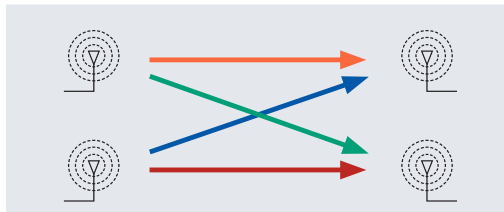
Single Input Single Output (SISO)



Single Input Multiple Output (SIMO)



Multiple Input Single Output (MISO)



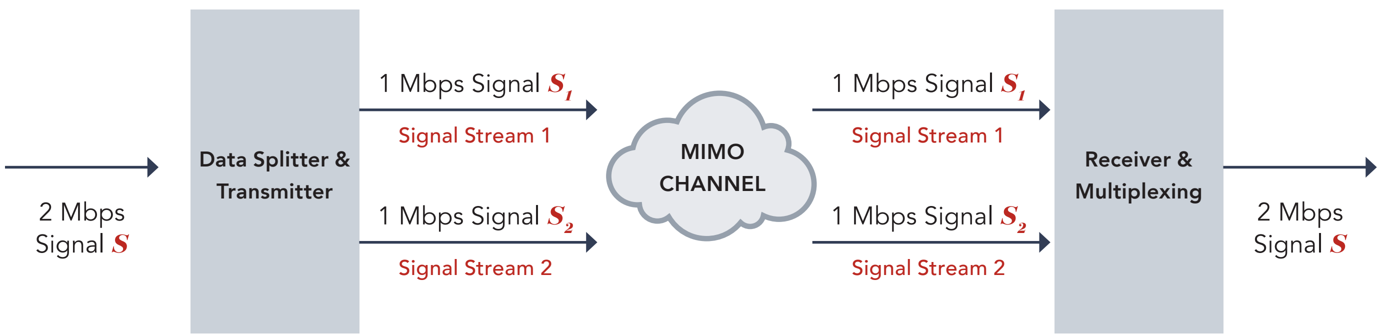
Multiple Input Multiple Output (MIMO)

"Smart Antennas" come in 3 flavors: MIMO, MISO and SIMO. We are going to focus on the most beneficial, MIMO. MIMO can either apply Space-Time coding to increase range, or Spatial Multiplexing to increase throughput. Which MIMO flavor is deployed depends entirely on LTE deployment scenario? If it is "greenfield" deployment, an operator may want to maximize eNodeB's range. If it is underlying of an existing 3G system, an operator may want to reuse 3G cell site footprint and use MIMO to increase throughput. The third option is to automate the process to apply space-time coding when the general condition is poor and spatial multiplexing when the general condition is good.

In general, MIMO works the best in scattering-rich environment, where signals from multiple sources bounce several times before they reach receiving antennas. In other words, multipath is beneficial to MIMO.

MIMO has 3 possible configurations. The first is single user MIMO, which is most common type of use. Data stream is split into two halves, and each half is transmitted on a different transmit antenna. The transmit antennas have different transmit power and phase. At the user, signals are received by two antennas, and multiplexed back together.

Principle of MIMO Spatial Multiplexing



Primary purpose of this scheme is to increase the data rate; since only half of the original data is transmitted, the data throughput after de-multiplexing at the end can be twice as fast as what it would be without deploying Su-MIMO. This configuration can be used on both links.

The second configuration is Multiple User MIMO. Unlike Su-MIMO, this is applied only at uplink. This configuration is also known as "diversity gain" in 2G and 3G networks.

The third configuration is Cooperative MIMO. It requires cooperation with multiple eNodeB's. Each eNodeB close to the user transmits different data streams to the user. This configuration is beneficial at cell edge because it improves SINR and data rate in that location. However, it may only be used on downlink.

LTE In-Building Considerations

While LTE requirements are similar to what we have seen for various 2G and 3G technologies. There are two notable exceptions.

First, there are three KPIs that are LTE specific: RSRP, RSRQ and PDSCH SINR. RSRP is similar to UMTS Pilot CPICH. RSRQ is similar to UMTS Ec/Nt. PDSCH SINR is signal to noise ratio referenced to the shared data channel.

Second exception is MIMO. While macro network MIMO deployment benefits are well documented, questions still remain whether in-building scattering environment is rich enough to warrant additional expense to deploy MIMO. Care should be taken to evaluate each venue and make a decision whether to deploy MIMO at each remote unit, or at selected remotes only.

KPIs AND TARGET DESIGN VALUES

We are now going to talk about key performance indicators for CDMA, GSM, UMTS, HSPA and LTE technologies, and discuss target design values for indoor networks.

Technology KPI Summary

Here are the critical KPIs for various technologies.

CDMA	Pilot Strength	Pilot Ec/Io	Mobile Tx	FER	RSSI	PN
GSM	RxLev	RxQual	Mobile Tx	C/I	Cell ID	
UMTS	CPICH RSCP	CPICH Ec/No	Mobile Tx	FER	RSSI	Scrambling Code
HSPA	SINR	Max. Data Throughput				
LTE	RSRP	RSRQ	PDSCH SNIR	Max. Data Throughput		

For CDMA, Key performance indicators are pilot strength, Pilot signal quality or Ec over Io, Mobile transmit power, frame erasure rate or FER, received signal strength indicator or RSSI and pseudo-noise or PN code. For GSM key performance indicators are received signal level or RxLev, signal quality or RxQual, mobile transmit power, carrier to interference ratio or C to I and sector identification or cell ID. UMTS technology is similar to CDMA. UMTS pilot is called 'CPICH', so instead of pilot strength or pilot Ec/Io we have CPICH RSCP and CPICH Ec/No. For HSPA, key parameters are signal to interference + noise ratio, or SINR, and Max. data throughput rate. For LTE, we have reference signal receive power or RSRP, reference signal receive quality or RSRQ, physical downlink shared channel and signal to interference + noise ratio or PDSCH SNIR and maximum data throughput.

Macro KPI Values

CDMA and UMTS

Now we focus on typical macro Key Performance Indicator values for CDMA and UMTS. Pilot strength for CDMA or CPICH RSCP range is between -55 and -110 dBm. CDMA Pilot signal quality, or Ec over Io range is from -14 to -3 dB. For UMTS Pilot signal quality, Ec over No the range is from -16 to -3 dB. Mobile transmit power range is from -50 to +20 dBm. Frame erasure rate is from 0% and higher. Received signal strength indicator range is from -50 to -105 dBm. CDMA Pseudo Noise or PN code or UMTS scrambling code values are integer numbers ranging from 1 to 512. Turning our attention to target design values for indoor DAS, we have to point out that the exact target value for Pilot signal, be that CDMA pilot strength or UMTS CPICH RSCP depends on whether we design against a fixed value or against the background macro signal. Designing against the fixed value is usually done if the residual macro signal is very low. A signal level of -85 dBm is then used as the target pilot value. If the residual macro signal inside a building is high, then the target pilot value is 5-7 dB greater than the residual macro signal. As for CDMA Pilot signal quality, Ec/Io or UMTS Ec/No, they should be greater than -5 dB at 50% cell loading. Mobile transmit power should be less than 0 dB, and PN code or scrambling code should be consistent throughout the building.

GSM

Typical GSM macro key performance indicators are as follows. Received signal level, or RxLev, is from -55 to -110 dBm. Receive signal quality is from 0 to 7, and it can be measured either as RxQual full or sub. Mobile transmit power range is from -50 to +20 dBm. Carrier to Interference ratio range is from -20 to +30 dB. Cell ID is a number unique to cell sector. The target design values for indoor DAS are as follows: target signal level is either -85 dBm, if we residual macro signal is very low, or 5-7 dB higher than the residual macro signal if the residual macro signal is high. Target Carrier to interference ratio is 9 dB for co-channel C to I, and 5 dB for adjacent channel C to I. Target Mobile transmit power is less than 0 dBm.

HSPA

For HSPA, typical macro values for signal to interference and noise ratio are from -10 to +25 dB. Maximum physical layer data throughput rate is up to 21 Mbps. When designing for indoor DAS network, signal to interference and noise ratio should be greater than 10 dB. As a side note it should be mentioned that SINR can define the max. data throughput rate. However, values for SINR and related data throughput are very much BTS vendor specific. Always check with the vendor!!!

Also, it should be mentioned that for indoor DAS there are probably location specific data throughput requirements. Hot spot areas usually require high data throughput rates, whereas in storage areas or other areas, high data throughput might not be needed!

LTE

For LTE, typical macro Key Performance Indicator values are as follows. Reference signal receive power or RSRP has a range from -65 to -120 dBm. Reference signal receive quality or RSRQ has a range from -3 to -20 dB. Physical downlink shared channel range signal to interference + noise ratio range is from -10 to +25 dB. Maximum physical layer data throughput rate is up to 150 Mbps, with 2x2 MIMO in 20 MHz channel.

Target design values for indoor DAS are as follows. RSRP should be greater than -100 dBm for 5 MHz channel if residual macro signal is very low. It should be 5-7 dB higher if the residual macro signal is high. RSRQ should be greater than 5 dB for 50% cell loading, and PDSCH SINR should be greater than 10 dB. Also in LTE, the data throughput is very much dependent on vendor specific parameters and also other things like MIMO. Same as in HSPA, for indoor DAS there are probably location specific data throughput requirements. Same rules apply.

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