A Guide to Cellular Boosters, v1.3

by Otto Pylot

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A cellular (signal) booster works by amplifying the cell phone signal being sent to, and from your phone to the macrocell (tower) closest to you. This is useful when the received signal in your home is weak, or of insufficient quality to maintain a reliable connection for making/receiving cellular calls. Call quality can also be affected (dropped calls, garbled voice, etc).

Basic Cellular Network Technology

Cellular technology has basically been released in generations (G).

2G:

second generation networks were released in the early 1990s and consisted of two technologies, CDMA and GSM. Verizon and Sprint chose to use CDMA while AT&T and T-Mobile chose to use GSM. 2G networks had very limited data capability. A faster version of 2G was also introduced called EDGE (Enhanced Data rates for GSM Evolution), sometimes called 2.75G.

3G:

third generation networks were released around 1998 and consisted of two technologies, CDMA2000/EVDO and UMTS/WCDMA/HSPA. Verizon/Sprint chose to use CDMA/EVDO and AT&T/T-Mobile chose to use UMTS/WCDMA/HSPA. Voice and data capability was better than 2G. EHSPA (Enhanced High Speed Packet Access) and HSPA+ were further refined and actually were more like 3.5G.

4G:

when fourth generation networks were rolled out the two "competing" technologies (GSM and CDMA) were merged into a single cellular network called LTE (Long Term Evolution). LTE is now the predominant cellular technology for data and voice.

5G:

The specifications are still being finalized so what 5G can, and can not do is unknown at this point in time. It appears that 5G will implement some type of millimeter wave (mmWave) technology, running at higher frequencies (probably around 35GHz) which should allow for much faster data rates.

VoLTE:

In the last three years (as of this writing), Voice over LTE (VoLTE) has been rolled out by all of the major carriers with a large majority of calls on AT&T, Verizon, and T-Mobile being carried over VoLTE. VoLTE allows phones to make calls entirely over the 4G LTE network without ever connecting to 2G/3G networks. Call quality and reliability is much better.

T-Mobile was the first to roll out VoLTE country wide.

Almost any device released since 2014 is capable of VoLTE if an LTE signal is available. However, the implementation of VoLTE on current phone models is up to the individual carrier. VoLTE also may have different names depending on how the carrier wants to market the technology (AT&T for example calls VoLTE, HD Voice). Sprint is expected to start rolling out VoLTE in Fall 2018, but AT&T, Verizon, and T-Mobile should be completely converted by now.

Current status of network technologies:

All four major carriers currently offer 4G LTE (and LTE-Advanced) networks. All carriers are doing limited trials of 5G, but you won’t start seeing 5G handsets until 2019, with broad availability in 2020.

AT&T shut down their 2G network on 2017 and is only running 3G and 4G LTE networks.

Verizon has plans on shutting down their 2G network sometime in 2019.

Sprint has not yet rolled out VoLTE and still relies on 1xRTT and 3G CDMA2000 for network calls.

T-Mobile still operates its 2G and 3G networks in addition to 4G LTE.

Cellular Frequency Bands

700 MHz band: LTE bands 12, 13, and 17 and are used by AT&T, Verizon, and T-Mobile for 4G LTE only.

850 MHz band: LTE band 5 used by AT&T and Verizon only, mostly for 2G and 3G until completely transitioned to LTE.

1900 MHz “PCS” band: LTE band 2 and is used by all four major carriers for a mix of 2G, 3G, and 4G LTE.
1700/2100 MHz “AWS” band: Band 4 and is used by T-Mobile, AT&T, and Verizon for 4G LTE only.

There are three more bands that are used a bit more selectively:

800 MHz extension: LTE band 4 used by Sprint only, which is a key spectrum although they only use thin channels.
2300 MHz or WCS: Band 30 used by AT&T in some areas for LTE.
2500 MHz: Used by Sprint for LTE. This will also become its core band for its 5G deployments.

Signal Strength

All phones have bars or dots to indicate signal strength. The more bars or dots you have, in theory, the better the signal. However, that’s only partially true. The bars or dots indicate two things:

Signal strength – a measure of the strength of the cellular signal reaching your phone, measured in dBm.

Signal quality – the ratio of actual source signal to noise and interference received by your phone, measured in dB.

NOTE: dBm is usually given as a negative (-) number so the closer that number is to zero, the stronger the signal. A -70 dBm is a strong signal whereas a -100 dBm is a weak signal.

With LTE networks, the signal strength and quality are given in terms of RSRP and SINR.
Reference Signal Received Power (RSRP) and Received Signal Strength Indicator (RSSI) are the two measurements of signal strength.

RSRP is the LTE measurement and is the more accurate of the two because it averages the "carrier" signal across the entire band. That means the RSRP signal strength is the same regardless of the size of the band, and it only measures the signal from one tower. RSRP signal strength is typically 20 dB to 30 dB lower than RSSI.

RSSI (Received Signal Strength Indicator) is an older measure of signal strength. It is a measure of the total signal strength which includes noise, interference, and the signal from multiple towers. When a booster is rated at 12 dBm downlink output power (DOP) that measurement is RSSI, not RSRP, because boosters can't "demodulate" the signal so measuring RSRP is not possible.

Signal to Interference Plus Noise Ratio (SINR) is the measure of an LTE signal's quality. A clear signal has an SINR of over 10 dB, while a low quality signal has an SINR of under 5 dB.

Reference Signal Received Quality (RSRQ) is another measurement that can be used as well and has a "quality range" from -3 dB to -19.5 dB.

Other network technologies use different methods to determine signal quality. HSPA+ and EVDO use Ec/Io, measured in -dB (closer to zero is better) and WiMAX (a competing 4G technology that isn't used in the U.S.) uses CINR (Carrier to Interference plus Noise Ratio), measured in dB (a higher positive number is better).

Causes of Weak and Noisy Signals

1. Distance from the cellular tower – weak downlink signal (tower to phone) and weak uplink signal (phone to tower).
2. Building materials/vehicle construction – drywall, wood, concrete, metal, and low-e glass can attenuate the signal.
3. Inter-cell interference or competing signals – if your phone is located between two or more towers, the other signal towers will interfere with the tower you are attempting to connect to, causing a lower signal quality. This is usually measured by SINR and RSRQ (Reference Signal Received Quality, measured in dB) and is the most common type of weak signal seen in urban and suburban areas.
4. Tower load.
5. Geography and nearby buildings.
6. Weather.

Measuring Signal Strength on Apple and Android Phones

Apple:

This used to be fairly simple prior to iOS 11. All one had to do was type *3001#12345#* on the phone's keypad and the Field Test Mode (FTM) would appear and you could see dBm RSRP signal measurements where the signal bars used to be. You could even toggle between RSRP dBm and bars or make the dBm measure "permanent" (which could easily be reversed back to the bars). This was not a hack but just a "hidden feature".

However, the displaying of -dBm has apparently become “lost” with iOS 11.x depending on the model of iPhone and chipsets involved. The FTM info is still available but you have to dig a bit for it now and look closely at the information given. There is a lot of information available, most of which makes no sense to the normal user but the basic info given above can still be found on newer iPhones.

Newer iPhones typically fall into two buckets: devices with Qualcomm Chipsets and devices with Intel Chipsets. The Qualcomm devices typically do not have accurate FTM information, while Intel models do. Verizon and Sprint phones typically use the Qualcomm chipset, so Verizon and Sprint users usually have a harder time accessing this information. AT&T and T-Mobile users usually have better luck.

On an iPhone SE (model A1662) with the Qualcomm chipset, the Field Test Mode will display:

SIM Info
Connected mode LTE Intra-frequency Measurement
Serving Cell Info
Reselection Candidate
Serving Cell Measurements
PDP Context Info
Neighbor measurements

Serving Cell Info will display Freq Band Indicator (for example “17”)

Serving Cell Measurements displays Measured RSSI, Average

RSRP, Average RSRQ, Measured RSRP, and Measured RSRQ. *Unfortunately, these numbers are often not accurate on these Qualcomm iPhones*.

Neighbor Measurements -> Neighbor Cells List displays the info for 0, 1, and 2 (possibly tower antennas)

NOTE: the iPhone SE FTM info was measured on two iPhone SE's, one was locked to AT&T and the other was unlocked. The info displayed was inconsistent in that sometimes the FTM displayed the -dBm info and sometimes not.

On an iPhone 7 (model A1778) with the Intel chipset, entering Field Test Mode will display Main Menu:

Device Info
LTE
UMTS
GSM

LTE -> Serving Cell Meas displays rsrq0 and 1, rsrp0 and 1, and sinr0 and 1 in negative numbers (dBm is not shown).

LTE -> LTE Neighbor Cell Meas displays nbr_rsrp, nbr_rsrq for LTE Neighbor 0 and 1, but the values are slightly different negative numbers. 0 and 1 may indicate individual tower antennas.

Both phones above are running iOS 11.2.6.

Android:

The recommended method for testing signal strength is to use the app LTE Discovery. This provides more signal information than Android's FTM. By long-pressing on the top left box in the "Signals" screen, you can enable display of SINR in addition to RSRP.

If you want to use Android's FTM just enter Settings -> About Phone and your signal strength in dBm will be displayed under Network or Status.

Some Android phones may be a bit different so you may need to enter Settings -> More Options -> About Phone -> Mobile Networks -> Signal Strength

How Does a Cellular Booster Work?

A signal booster works by amplifying the cellular signal sent to and from your cell phone. There are three basic components involved.

Donor Antenna:

The donor antenna is installed on the roof and sends/receives signals from the local tower. A directional antenna may be useful in some cases as it allows you to aim at a particular tower, which both increases the signal strength and decreases interference from neighboring towers.

Amplifier:

The amplifier is sometimes called a BDA (Bi-Directional Amplifier) and is what is used to boost the cellular signal to and from the tower. The BDA is connected to the donor antenna and indoor antennas via a coax cable. The two main specifications of the amplifier are *gain* and *downlink output power (DOP)*. Both are explained in a little more detail below.

Indoor Antenna(s):

The indoor antenna(s) distribute the signal to, and receive signal from, your cell phone. The two most common types of indoor antennas are panel and dome.

Amplifier Gain:

Gain is the measurement of how much the signal is amplified, which is measured in dB. The larger the value, the more the signal from the donor antenna is amplified.

Downlink Output Power:

Downlink output power (DOP) is the maximum signal that the amplifier can retransmit inside a building or vehicle. The maximum DOP sets the maximum coverage area of the system when the amplifier has enough signal.

If you have a **weak** outdoor signal (-80 dBm RSRP or less) then a typical broadband amplifier may be gain-constrained, meaning that even if you have the maximum gain of the amplifier, you are unlikely to reach its maximum DOP. To overcome that you would need an amplifier with highest gain possible. Some amplifiers, like the Cel-Fi Go X for example, have up to 100 dB gain, and thus aren't gain constrained until you're at around -110 dBm.

If you have a **strong** outdoor signal (-70 dBm RSRP or higher) the amplifier will be DOP-constrained. In that situation, you're unlikely to hit the maximum output power of the amplifier, so focusing on the DOP of the booster is important, otherwise your indoor coverage may be affected.

FCC Requirements

As with all things having to do with communications, the FCC has set regulations on the use of cellular boosters. In 2014, the FCC created two sets of regulations. One set of regulations is for “broadband” devices that amplify all cellular signals from all carriers, and the other set is for “carrier-specific” devices that only amplify the signal of one carrier at a time. The stationary, indoor, and mobile use regulations are given below.

“Broadband” booster regulations:

- The gain of a fixed, in-building amplifier can be no more than:
  - 63.5 dB for the 700 MHz band
  - 65 dB for the 850 MHz band
  - 72 dB for the 1900 MHz band
  - 71.3 dB for the 2100 MHz AWS band.
- The gain of mobile/in-vehicle boosters can be no more that 50 dB when used with an in-vehicle antenna or 23 dB when using a cradle-type booster.

The DOP of the entire amplifier system, including losses from the cable, can be no more than 17 dBm per frequency band.

“Carrier-specific” booster regulations:

- The gain of the amplifier can be no more than 100 dB on any band for stationary or indoor use and 65 dB for mobile or in-vehicle use.

> The DOP on the entire system, can be no more that 17 dBm total per frequency band, or 10 dBm per 5 MHz channel (LTE channels are at least 1.4 MHz wide, and more typically 5, 10, 15, or 20 MHz).

Being as the gain of boosters is limited by FCC regulations, the recommendation at this point in time is to use a carrier-specific booster where possible if you have a weak signal (less than -80 dBm RSRP) at the outdoor antenna.

Antennas – Outdoor and Indoor

Outdoor Antennas

Choosing the right Donor Antenna (outdoor) and being able to aim it correctly is key to improving the performance of a cellular booster system. Most donor antennas have some gain, measured in dBi, and this gain can add to the overall gain of the signal booster system. A high gain donor antenna can increase the donor signal, and thus the DOP. This is particularly useful if you have a weak outdoor signal, and will allow you increase the indoor coverage of your booster kit.

Two types of outdoor antennas are Omni-directional and Directional. Directional antennas allow you to focus signal reception and transmission in one direction. This helps to clarify the signal being received which ultimately improves the indoor coverage and the number of bars or dots you see on your phone.

Omni-directional:

"Omni" antennas work best if you have a strong and clear outdoor signal. They are easier to install and don't need to be aimed, but you need to have 3 or more bars/dots of signal where you plan on installing the antenna.

Directional:

These antennas require a bit more work to install and aim correctly but are recommended if you have a weaker signal or a strong signal with lots of noise (low SINR and RSRQ). The benefits of a directional antenna are threefold:

Gain –

The antenna can add up to an extra 12dB of extra signal if your outdoor signal is weak.

Noisy signal –

Usually this is due to the inter-cell interference mentioned earlier. Focusing on a tower with a directional antenna can improve indoor coverage.

Near-far effect –

This is caused by a saturation effect from a tower that is preventing a carrier's signal from being amplified. Using a directional antenna pointed at the weaker, distant tower, can help to balance the incoming signal for better reception.

Installing a directional antenna doesn't necessarily mean sacrificing signal from one carrier over another. This rarely happens because carriers typically share cell towers, so the best direction for one carrier is often the best for all carriers. Pointing at one tower will just optimize the signal from that tower and the other tower signals will be somewhat less in strength. So, one can still get great coverage from two different carriers with a directional antenna.

Aiming an outdoor tower requires two people. One person on the roof aiming the antenna and the other person indoors at the amplifier taking signal readings. Some booster manufacturers (such as Cel-Fi) have made this somewhat easier by providing you with RSRP (signal strength) and SINR (signal clarity) readings as part of their device.

Indoor Antennas

The general rule of thumb is the more indoor antennas you use, the better the coverage. However, this is not as simple as it sounds. Signal travels much better thru coaxial cable than it does thru air, wall, and doors. By using coax cable to distribute the signal one gets more consistent coverage.

Running multiple coax cables with multiple antennas installed is the biggest drawback for residential users. Nobody wants to have a lot of cable running thru their walls with antennas in every room. Fortunately, the basic rule is that one antenna for every 1,000 square feet should be adequate for most users. The caveat to that rule is the type of amplifier used, and whether the space covered is large and open or divided by walls. If the outdoor signal is weak, and you are using a weak amplifier, you should use more antennas. If the space is more open and there are fewer walls, then you can use fewer antennas.

The two main types of indoor antennas are dome and panel.

A dome antenna should be used when the area to be covered **is not** thin and narrow (like a hallway) and you can access the space behind the ceiling. Dome antennas have the cable connection on the back of the antenna so installing it on the ceiling (if one has access to the crawl space above or it is in an office with ceiling tiles) is the recommended method.

Dome antennas distribute the signal equally in all directions so they should be installed in a central location.

A panel antenna should be used when the area to be covered is long and thin and you are not able to access the space behind the ceiling. Panel antennas are usually installed on the walls because the cable connection comes out from the bottom of the antenna so you don't need to make a hole in the wall to connect the cable.

Panel antennas distribute the signal in a focused beam that typically has a relatively wide angle (around 45 degrees). This makes them ideal if you are trying to cover an area that is long and thin.

What Do I Do?

1. Determine your signal strength (RSRP) and signal quality (SINR) on your roof using Field Test Mode (on iPhones) or LTE Discovery (on Android phones).
2. Most carriers use a combination of bands. 700 MHz and 850 Mhz penetrate buildings more easily, so focus on amplifying them.
3. For weak outdoor signals
    a. Focus on amplifier gain
    b. Use a single carrier booster

   c. Use a directional antenna (yagi, panel, and log-periodic antennas are the main types)
4. For strong outdoor signals
   a. Focus on DOP
   b. Use a broadband booster
   c. Use an Omni-directional antenna
5. Indoor antennas (for buildings)
   a. If the outdoor signal is strong, one antenna per 1,000 square feet should be sufficient. Multiple floors should have their own antenna.
   b. Panel antennas are installed on walls. Dome antennas are installed on ceilings if you have access behind the antenna either thru a crawl space or ceiling tiles.

Femtocells/Picocells vs Cellular Boosters

There appears to still be some confusion between femtocells/picocells and cellular boosters, both of which can help with poor in-home cellular coverage, but by entirely different technologies.

Femtocell/Picocells:

These are actually mini-cellular towers that are placed in your home and use your internet connection to establish a connection to your carrier's mobility servers. They **do not** boost the existing, outdoor cellular signal. They broadcast either a 3G, 4G or 4G LTE signal within a limited range in your home so that your phone can connect to it for cellular calls. Each carrier's femtocell/picocell goes by different names and have different capabilities. There is no cost other than the initial purchase cost and your data plan usage is calculated the same as if you were connecting to a macrocell (tower). Some examples are below:

AT&T - MicroCell (sales discontinued as of Dec. 31, 2017. AT&T will continue to support the MicroCell for the time being).
Verizon – 4G LTE Network Extender
T-Mobile – 4G LTE CellSpot
Sprint – Airave and Magic Box

Cellular Boosters:

Some examples of cellular boosters are below. As with the microcells/picocells, each have their own capabilities and options and there is no cost to use them other than the initial purchase cost:

Wilson Pro	SureCall
weBoost	Cel-Fi

You can go to RepeaterStore's Definitive Guide to Cell Phone Signal Boosters as well for specific product recommendations.

Safety

There have been some concerns about using cellular boosters in a closed environment such as a home. They are actually quite safe and can be safer than a cell phone alone because the majority of the harmful cellular radiation comes from your cell phone being held so close to your head, and not from the cellular tower or cellular booster. The cellular output from your phone can be as much as 1,000 times less with the use of a booster because the phone doesn't need to use as much power to reach the tower(s).

Basic Troubleshooting

Poor indoor coverage, poor data performance, signal strength (even when close to the antenna), etc. can be caused by the following:

1. Near-far effect
   a. Broadband boosters amplify the whole frequency band, not just one block. So, if one carrier (e.g. Verizon or T-Mobile) has a strong signal on the same band that AT&T uses, that band will become "saturated" by the stronger signal, and not amplify AT&T very much. Even if there is decent donor signal (2 bars or more) and the amplifier is running in AGC (Automatic Gain Control) issues may still occur.
   b. The fix is to use a higher-gain, log periodic or yagi style antenna, or try the four sides of the building to see if you can use the building materials to block the stronger signal that's saturating the amplifier.
   c. Alternatively, you can switch to a carrier-specific booster like the Cel-Fi GO X. Carrier-specific boosters only amplify the specific block that a carrier is using, and thus avoid near-far problems.

2. Low SINR at the donor signal
   a. This results in low bars, poor data performance, and coverage area.
   b. The fix is to try different locations or a higher gain donor antenna.

3. Low power (RSRP/RSSI) problems
    a. Some users just have a hard time because the outside signal is so weak (less that -80 dBm RSRP) that an amplifier barely works.
    b. The fix is to use a Cel-Fi GO X (which has a 100 dB gain), a higher gain antenna, or to change antenna locations.

4. Isolation problems
    a. If the amplifier reduces its gain or shuts down altogether due to “oscillation” (a type of feedback), then you need to have more isolation in dB than you have gain between the outdoor and indoor antennas.

Terminology

1. Gain (dB) – The measure of amplification and is typically measured on a logarithmic scale. The higher the gain, the more the signal is amplified and is given as a positive number. 0 dB means no gain at all.
2. Antenna gain (dBi) – This is not a measure of amplification but the sending and receiving of a signal in a given direction. It is also given on a logarithmic scale. A 0 dBi signal doesn’t focus the signal at all.
3. Attenuation (dB) – Attenuation is the weakening of a signal over distance or as it passes thru building material. The dB readings are given as a negative (-) number and the further the number is from zero, the weaker the signal. -10 dB is 10 times weaker than 0 dB.

4. 3 dB – dB is a logarithmic number as mentioned above and a 3 dB attenuation is exactly half the power. Most splitters have around 3 dB attenuation so they split the power that comes thru a coax cable in half.
5. Signal strength (dBm) – RSRP (measured as the average carrier signal over the entire band regardless of the size of the band) and RSSI (measured as the total signal strength including noise, interference, and the signal from multiple towers). RSRP is the more accurate of the two.

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Additions/Changes

Version 1.3, June 2018
1. Added a comment about safety on page 19
2. Added a troubleshooting section starting on page 20
3. Added a cover page and table of contents

Version 1.2, April 2018
1. Clarified frequency band usage on page 4

Version 1.1, March 2018

1. Clarified page 17 about the AT&T MicroCell being discontinued

Version 1.0, March 2018

1. Initial release