This article originally appeared in TidBITS on 2008-10-06 at 10:55 a.m.
The permanent URL for this article is: http://db.tidbits.com/article/9796
Include images: Off

Peering Inside a Mobile Phone Network

by Rich Mogull

Have you ever wondered why your mobile phone can alert you to new voicemail without having ever rung? Or why a text message can get through when a call can't? Maybe you've traveled across continents and been amazed at how calls still manage to follow you? Or perhaps you've noticed that sometimes your battery only seems to last a fraction of its normal life? And why can the iPhone 3G figure out your location in 3 seconds when it takes takes your car GPS 3 minutes?

Although we normally take the ubiquitous mobile phone for granted; assuming it should work anywhere at any time, there's quite a bit of complex technology involved in sending a call to a device in your pocket. While we've all screamed in frustration over dropped calls and other annoyances, the truth is these are impressive devices, packed with amazing technology, that still hold a few tricks up their sleeves. And after you learn a little more about the inside of the system, maybe, just maybe, you'll be a little less irritated the next time you battle to make a simple call.

How Your Calls Follow You -- One of the most fascinating aspects of mobile phones is how calls manage to find us in the first place. If you think about it, you are basically wandering the planet with a tiny radio in your pocket, but by calling a single number anyone can track you down in seconds. Although there are a few different types of mobile phone networks, they all follow the same basic, yet elegant, architecture. For this article I'll be using terms for the GSM (Global System for Mobile communications) network; the one used by AT&T and other international iPhone providers. I've also simplified things a bit, and Wikipedia [1] is a great source if you'd like to dig in deeper.

It all starts with the phone in your pocket. Every phone in the world has a unique identifier called an IMSI - your International Mobile Subscriber Identity. In most phones, this is encoded on a small smart card (yes, the same technology used by some banks and ID cards) called a SIM - Subscriber Identity Module. When you turn your phone on it tries to find the nearest base station, which is a collection of switching equipment tied to that (likely ugly) cellular antenna on the side of the highway. Your phone connects to the nearest base station, based on signal strength, and that's where the interesting stuff starts to happen.

The IMSI truly is a unique number tied to you and your mobile phone provider, and is the key to the entire system. The base station is a relatively dumb system that just passes on your information to the main brains of the system - the Mobile Switching Center

(MSC). The MSC can be located pretty much anywhere, which is why in the very early days of cell phones 911 calls might have been routed to a confused emergency dispatcher in a different city or state (don't worry, that's all fixed now). While each system is a little different, a large cell phone provider will generally have a bunch of MSCs to support different phone numbers for different local areas.

At its simplest, the MSC is just two big databases and a connection to the regular phone system. One database, called your Home Location Registry (HLR) is the master database for your account, with your IMSI, phone number, and current location. The second database is called the Visitor Location Registry (VLR) and it keeps track of people that have wandered into that area (a VLR serves only a single base station). Here's how it works - your phone registers your unique IMSI with the nearest base station, and that base station tells its VLR that you are connected. The VLR then contacts your HLR and, using your IMSI, registers your location.

When someone calls you, the call is routed from the regular phone system through your MSC all the way out to the highway you're driving on, since the system always knows where you are. If you happen to be on a GSM system like AT&T (and unlike Verizon), your call can even follow you to any other GSM system in the world, as long as it has some sort of agreement with your primary phone provider. I used to have to rent a local phone when I traveled someplace like Australia (since U.S. phone companies don't play nice with others), but in recent years my biggest worry is someone from home accidentally waking me up at 3 AM local time.

How Calls Work in Cars and Planes -- This may seem pretty straightforward, but it becomes more complex since we mobile phone users have a bad habit of moving around - sometimes at high speed - while we're on the phone. To handle this, the base stations and MSC work together to hand off your call as you move from tower to tower. This is a bit easier today since we've switched off the old analog system (where your phone needed a dedicated channel to talk) to the new digital systems (where many phones share a channel, just like a computer network). All your conversations are digitally encoded and the phone system routes them around as needed.

Not that it's perfect - especially if you drive the main highway between my home in Phoenix and my wife's office. Some of these hand-offs don't always work as planned, especially if there are dead zones between towers. But it does explain those times when your call becomes garbled or you lose half the conversation, then everything magically returns to normal (by magically, I mean rarely). As we move around with our phones, they're constantly negotiating with base stations, who are constantly negotiating with each other and one or more MSCs.

Now imagine you're 30,000 feet in the air traveling at 500 miles per hour. Although our mobile phones don't have a lot of power, from up in the sky it's not unlikely a single phone could hit dozens of towers with nearly equal power signals. That's the main reason you're not supposed to use your phones in the air; Wikipedia explains [2] in more detail. Planes are extremely well shielded from interference and won't crash, but all the base station switching and phone tracking confuses the heck out of the mobile phone network. The systems some airlines outside the United States are putting into planes set up a tiny cell network on the plane itself so your phone locks in to the plane's system, and then it handles talking to the ground.

As a side note, the real reason airlines make you turn all your electronics off during takeoff and landing is so you aren't distracted and can hear and follow directions if something goes wrong.

Why Text Messages Work When Your Phone Won't Ring -- All of that crazy call setup happens in the background without you ever noticing because, as anyone who watches spy movies will tell you, your phone is always talking to the network. It does this using channels dedicated to signaling and messaging that are separate from the channels we use to talk. That's how your phone is initially registered, or how calls are handed off (or dropped) as you move from one base station to another.

Early on when they invented GSM, someone decided it would be useful to dedicate a small part of this signaling to sending messages to your phone. They added a feature to send 160-character messages over the signaling channel. The initial idea was to use it to alert you to new voicemail messages, but then someone thought it might be nice to also send some short text messages, and thus the Short Messaging Service (SMS) was born.

That's why you sometimes get voice mail notifications without hearing your phone ring. If the local voice channels are all filled, the call can't get through and callers are forced to leave a message, but since the notification uses that signaling channel, it still reaches you right away. A nice side benefit is that SMS messages will often go through even when regular calls won't. When I'm wearing my part-time hat as a disaster worker, I often find myself using SMS when I can't make regular calls. If you are at that big concert, game, or Steve Jobs keynote you might try SMS instead of battling your neighbors for scarce voice channels.

The Multimedia Messaging Service (MMS) that Apple mysteriously won't support on the iPhone also uses SMS. In this case, the short message contains a special link that tells your phone where to find a photo or video someone shared with you.

The downside of SMS is that there's no guarantee your message will go through, and the system can't alert either you or the recipient if it was dropped somewhere along the line.

Why Your Battery Sometimes Dies Faster -- As you now realize, there's a ton of signaling and messaging going on in the background as you walk down the street with that amazing battery-powered radio in your pocket. Modern mobile phones are incredibly power efficient and use this signaling to "tune" themselves to their local environment. When they have a good signal, they use less power, but the further you move away from the base station the more power they need to maintain these signaling channels. If you are in a really busy area your phone might also be battling for space on the network, which increases how many signals are sent and thus how much power it uses.

So you might notice two effects - in some places your battery may seem to last forever, whereas in other places it drains quickly, no matter how little you use it. If you are deep inside in a big building your phone might need to use a lot more power to communicate with the nearest base station, taxing your battery. Another area might require less power under normal circumstances, but if it's saturated with a lot of phones you'll be signaling more, or talking to a base station that's further away, and your phone will die sooner. That's why my iPhone battery doesn't last nearly as long at Macworld Expo as it does during other conferences in Moscone Center - the density of iPhone (and thus AT&T) users is significantly higher.

Why the iPhone GPS is Faster than Your Car GPS -- By this point, you probably already know the answer to that question. While phones are constantly tracking their location so calls can reach you, when you turn a GPS on it needs to figure out where you are nearly from scratch. Your GPS looks for special signals from satellites, and then compares the strength of those signals to triangulate your position. When you pull a GPS out of the box for the first time, it has no idea where you are on the face of the planet, and has to spend a few minutes looking around for those signals to narrow your location. Every time you turn it on in roughly the same location after that, it will be faster to acquire the satellites, but it still has to lock on to the necessary satellite signals before it can determine your location.

Your iPhone cheats. In order to support 911 emergency services, all mobile phone systems now try to track your physical location down to about a minimum of 150 meters (it's a bit different outside the United States). Thus your phone has a good rough idea where you are before the GPS even starts. If you are near a Wi-Fi network, the Skyhook Wireless-enabled location feature of the iPhone may then narrow your location down even more. This means your iPhone GPS *already* has a good idea of where to look for those satellites, while the unit in your car needs to start scanning from scratch (or based on remembering where you are when you last turned it off).

The Future Is Now -- We take them for granted, but mobile phones, and the networks that back them, are fascinating pieces of technology that provide capabilities that seemed like science fiction only a few short decades ago (consider Dick Tracy's wristwatch radio [3], Maxwell Smart's shoe phone [4], and James Bond's car phone [5] in the 1963 "From Russia with Love"). Now maybe the next time you're ready to slam that frustrating marvel against the floor because you can't make a call, you'll hesitate briefly and send your mother a text message instead.

[1]: http://en.wikipedia.org/wiki/GSM
[2]: http://en.wikipedia.org/wiki/Mobile_phones_on_aircraft
[3]: http://en.wikipedia.org/wiki/Dick_Tracy#Evolution_of_the_strip
[4]: http://en.wikipedia.org/wiki/Get_Smart#Gadgets
[5]: http://en.wikipedia.org/wiki/List_of_James_Bond_gadgets#From_Russia_With_Love

---