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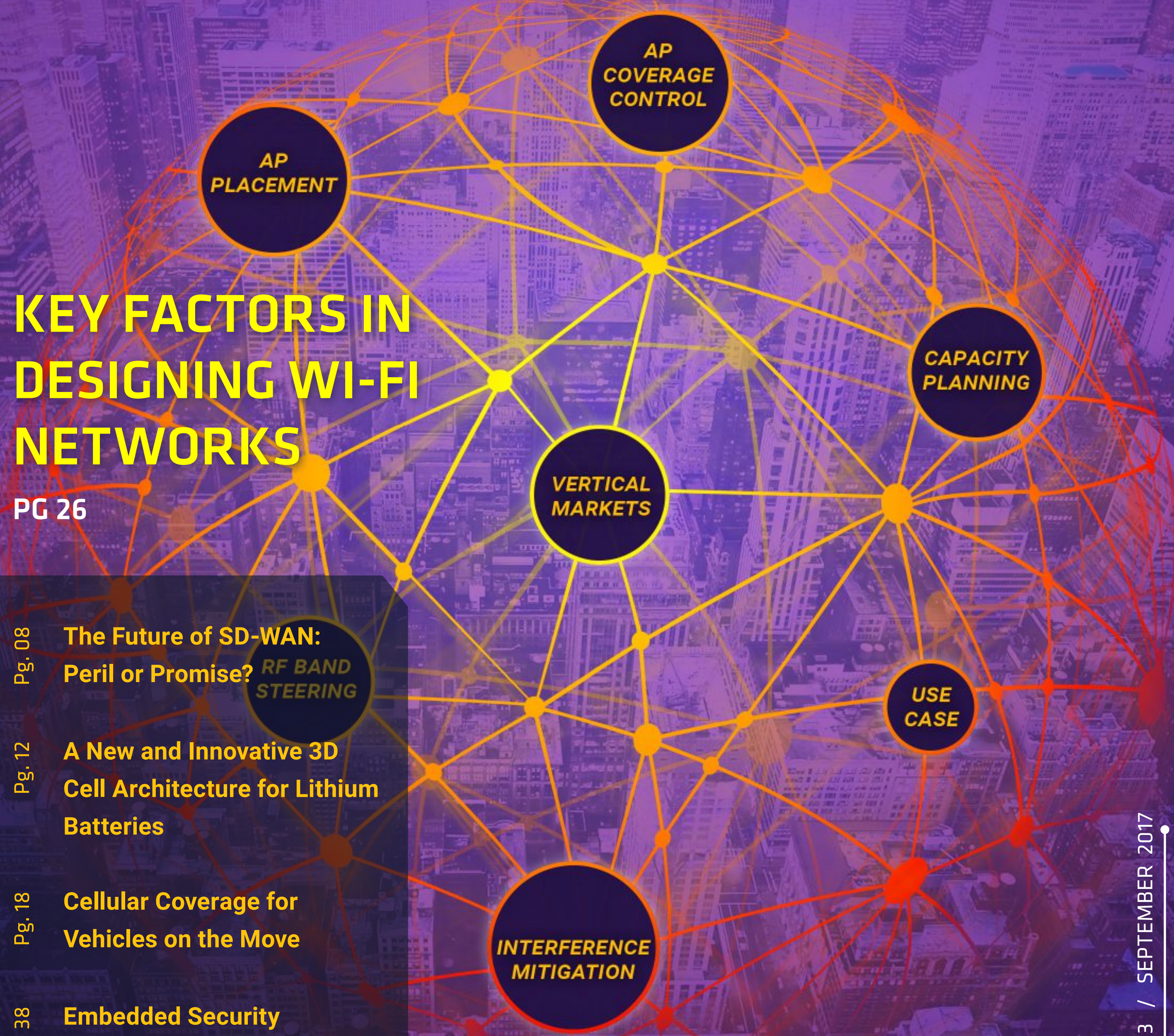

KEY FACTORS IN DESIGNING WI-FI NETWORKS

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Cellular Coverage for Vehicles on the Move

The Case for Cellular Coverage in Vehicles

BY JOE SCHMELZER

More than 380 million connected cars will be on the road by 2021, according to a report published last year by Business Insider. Another study published by the University of Texas reports that 98 percent of vehicle fleets in the US will have connectivity by 2030. Right now, the **US Department of Transportation ▸** is proposing a rule that would mandate vehicle-to-vehicle (V2V) communication in light vehicles, allowing cars to 'talk' to each other to avoid accidents.

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In addition to embedded cellular services, the OEM and aftermarket product and service companies are counting on "brought-in" cellular service — service that is not hardwired to the vehicle. In terms of market adoption, it is not clear exactly what the split will be between embedded wireless connectivity and brought-in connectivity, via smartphone or other similar devices. This author believes they will co-exist. Some systems in the vehicle will utilize the embedded (in vehicle) infrastructure. Others, systems will be brought to the vehicle ("tethered mode"). These will be the mobile apps that continue to evolve and provide services to the vehicle, or to the vehicle's occupants, via smartphones, for example.

In light of these staggering market projections, it is not surprising that multiple technologies exist today and are evolving to support this connectivity. Cellular, in particular, plays a key role in this evolution. However, it can be confusing as to where exactly it fits into the technology mix when it comes to connecting vehicles, and people or things in them, on the move. This article provides an overview of the relationship between cellular services and vehicle connectivity, offers a deeper dive into the underlying technology, and includes practical tips on cellular technology solutions today.

Cellular Coverage Today: What You Need to Know

Primer On "Gs" 2 Through 4

Understanding just a little bit about the generational cellular technologies — referred to, commonly, as 2G, 3G, 4G, and soon 5G — is useful when one is considering the overall strategy, requirements, and right-sized solution for addressing coverage challenges (note, 1 G cellular technology was analog, and is no longer relevant — it was retroactively named).

2G cellular technology is about 25 years old, and exists today primarily in two flavors: GSM and IS-95. 2G is used primarily for voice in the fringes of networks, rural areas, and in very low average revenue per user or unit (ARPU), low cost regions. Some networks continue to employ 2G in data communications where large amounts of data transmissions are unnecessary. Everyone receives ROI benefits from extending the lifespan of the 2G ecosystem.

3G cellular technology made web browsing over a mobile device possible. 3G has also been deployed in primarily two flavors: Universal Mobile Telecommunications System (UMTS) and CDMA2000. UMTS received broad global adoption. Whereas the adoption of CDMA 2000 was a bit spottier, primarily in parts of the Western hemisphere, and South Korea. 3G and UMTS, in particular, is still widely used for "fallback" outside of metro areas where 4G has been deployed.

4G cellular technology initially had two implementations: LTE and WiMax. WiMax never received substantial market adoption and has subsequently been scrapped, almost universally. Networks that deployed WiMax have mostly repurposed the equipment and spectrum to LTE. LTE stands for "Long Term

Evolution" and is being deployed globally. In some of the more advanced networks, where higher ARPUs are supported, LTE coverage is already ubiquitous. Most of the industry is expecting 4G LTE to be a 20+ year technology. Although other technologies will come about, for standard wireless voice and data communications, particularly as a network coverage layer, 4G LTE should have a long lifespan. Solutions that are standardized around LTE should enjoy long ROI recovery periods.

Spectrum and Band Classes

The International Telecommunications Union (ITU) coordinates the use of the radio spectrum, globally, to facilitate interoperability between device manufacturers and network operators. Individual countries have varying allocations for how they utilize their radio spectrum. Cellular services around the world, typically, operate somewhere between 450 MHz and 2700 MHz. As cellular technology expands, spectrum allocations also expand — above 3 GHz.

To simplify the variety of technical specifications that are required to describe spectrum allocations, a shorthand naming convention has been adopted by the industry. This is commonly referred to as "Band Class." A spectrum implementation will be referred to by the band class, like Band Class 5 which is loosely based around 850 MHz. The supporting details of the band class can be easily cross-referenced for technical detail. The salient point being, when planning for a specific coverage requirement, be sure to understand the band class(es) supported by each of the network components, as they need to be interoperable.

Future Coverage

The next generation (unsurprisingly) is named 5G. Commercial (non-trial) 5G deployment is projected to commence in the 2019 time frame and really start to gain traction in 2020. There is not agreement on exactly how 5G will be implemented in the long-term. However, it is safe to assume that initial deployments of 5G will be for the "last 100 feet" service; delivering wireless communications via some sort of fixed-wireless terminal.

4G LTE will remain the coverage layer for cellular for the foreseeable future. Since the details on 5G are still speculative, this piece will not delve any further into 5G coverage. However, we anticipate that, over the next 12 months or so, 5G standards and commercial plans will further crystallize. At that time it will be useful to look further into 5G in a practical application context.

Narrowband IoT and LTE Cat M1

The Internet of Things (IoT) is, of course, extremely topical. Underneath, 4G LTE standards have emerged some sub-classes designed specifically to support IoT use cases. While there are other technologies vying for adoption in the wireless IoT domain, LTE has a strong advantage of being, primarily, a software overlay on existing cellular networks. This has enabled major cellular service providers to add IoT capabilities to their service offerings without a lot of heavy lifting, or new CAPEX investments.

Coverage Challenges in Vehicles: Tech Awareness

Where the Network Ends

Performance of a given cellular device can vary greatly based on a number of factors, including:

- The built-in antennas on the device.
- Proximity to the macro tower providing service.
- Cloud cover and weather.
- Loading on the network, i.e. how many devices are attached to the network are being served.
- Local topography.
- Physical obstructions, buildings, large objects.
- A vehicle's construction, including the disposition of the vehicle, open/closed windows, etc.

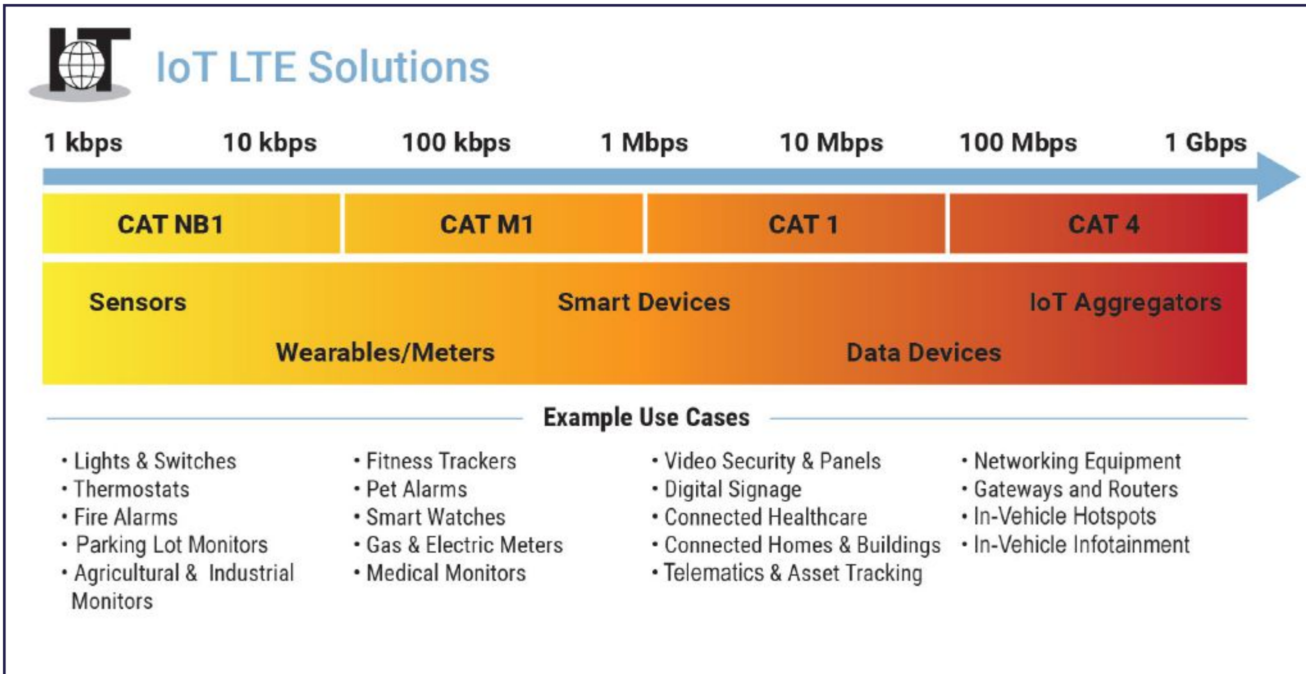

Figure 1. IoT solutions and platforms.

Frequency and Link Budgets

The ability of a given technology to provide good coverage is influenced, largely, by a couple of factors, including frequency. Lower frequencies have better penetrating power. Cellular coverage solutions that utilize 600–700 MHz frequency cellular bands will outperform similar solutions using higher frequencies, like 2100–2700 MHz.

A second critical factor is known as "link budget," which is an important measure for power calculation. It calculates the power received at the receiver (device) and accounts for gains and losses along the way. A link budget, essentially, indicates how bad the signal can be from the tower to the device (and vice versa) for the system to still operate (communicate). A cellular IoT (LTE Cat-M1 or NB-IOT) link budget (~ -164 dB) is about 20 dB better than standard 3G and 4G technologies (~ -144 dB). This improved link budget provides coverage to an area approximately seven times larger (in an open environment). This 20 dB improvement will also result in better in-building penetration. These are important factors when considering coverage solutions.

Standards bodies worked to ensure a better link budget for cellular IoT for a very good reason. 3G and 4G operators continue to struggle to provide good coverage and to expand coverage from external macro networks. Therefore, improving the link budget, improves their bottom line.

Attenuation

Attenuation is the drop in the signal power when transmitting from one point to another. Above and beyond attenuation is due to the free space loss created by the distance from the vehicle to the tower. An additional challenge, for cellular coverage inside a vehicle, is attenuation of the signal through the vehicle's exterior surface, and through interior surfaces/compartments. For example, there will be greater attenuation when a cellular router is mounted inside a trunk compartment than when it is mounted in the cabin. For budgetary purposes, 5 dB of attenuation can be anticipated from a vehicle's exterior to interior. Because of attenuation, cellular service exterior to the vehicle may be fine when referenced on a coverage map or tested, but poor or non-existent inside the vehicle.

Coverage Holes

A coverage hole is a region where the received signal level of the serving cell, and any other neighbor cell, is below the levels required to maintain the service at a minimum level of quality and robust radio performance. In particular, coverage holes are caused by the attenuation of physical obstacles (such as new buildings, and hills), unsuitable antenna parameters, a hardware fault, or inadequate RF planning. Coverage holes can be found nearly everywhere, even in locations where coverage is generally good, like urban or suburban centers.

Type of Coverage Needed

According to **Juniper Research's M2M report ▸** last year, car Infotainment and telematics services will account for 98 percent of M2M data traffic by 2021. Services to the connected car are particularly vulnerable to cellular coverage issues.

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Keep in mind, some wireless services, like Voice over LTE (VoLTE), require a good signal to provide an exceptional user experience. *OpenSignal* ran an extensive survey of the four main U.S. network operators and found that none of them have greater than 87 percent cellular coverage. Layer in the issues with attenuation and the challenge of providing good user experiences, while mobile, starts to take on more gravity.

General Coverage Issues

Mission-Critical vs. Best Effort

In a mission-critical scenario, where there is little or no tolerance for connectivity failure (border patrol vehicles or emergency first responders, for example) it is advisable to deploy a system with fallback capability. This capability is also referred to as "failover." This might entail multiple modems/devices connected to different carriers. Or it could mean support for multiple technologies in a single device. An example might be a system biased to connect on 4G LTE, but with fallback capability to 3G.

Low Data Rate vs. High-Speed Data

The variety of cellular wireless network technologies provides a spectrum of capabilities, ranging from high-speed and low latency, to low-speed (low data rate) with more latency (see Figure 1). This chart offers one view of the kind of connectivity required for a variety of use cases. As shown, vehicle connectivity requires 1 Mbps CAT 1 for telematics devices, up to 100 Mbps CAT 4 for in-vehicle hotspots and infotainment.

Wireless Devices and Mobility

It is worth mentioning that not all wireless technologies are designed to support mobility. Cellular technologies like LTE are designed to function at speeds as high as 500 km/h, while some technologies, like Wi-Fi is not designed for mobile use.

Coverage for Things

Providing cellular coverage for things presents a host of unique challenges.

Mobile vs. Immobile

If a given device is immobile, (cellular-enabled, but fixed in position), then coverage can be determined and solved at the location. Here, a static solution can be employed without too much additional concern for variations in coverage. System reliability and fallback may still be a consideration as cellular networks can (and do) experience outages, albeit infrequent.

The type of coverage solutions available will be, partially, determined by the type of 'thing' being covered. If the thing is stationary, it may be possible to attach and extend an antenna on the exterior of the space or vehicle. However, if the thing being covered is mobile, or nomadic, it may not be possible to extend an antenna through the exterior surface of the enclosure as the antenna could disconnect or even break.

Embedded (OEM) Cellular Systems

Embedded cellular systems are typically isolated and inaccessible by the consumer once a vehicle has shipped from the factory. These embedded systems use internal antennas, which are often routed and mounted at the rear of the vehicle's roof, in mirrors, even bumpers.

It is common for embedded radio systems to compete for antenna space as there is some requirement for physical separation, and accessible space at the exterior of a vehicle is precious. Modern vehicles often feature one or more embedded wireless modems, which are used by the vendor for functions like predictive maintenance, and by third parties, such as OnStar, for vehicle tracking, remote unlock, and other similar services.

Transient Devices

Transient devices are devices that will come and go from the coverage area. For example, while on a road trip or service call, a commercial vehicle's driver may stop to use a laptop. In addition to laptops, there are several other types of devices that fall into this category. Here are a few:

- » Mobile hotspots and USB modems.
- » Mobile routers.
- » Wearables and other IoT devices.

Under normal conditions, transient devices are not able to benefit from an externally mounted antenna. In fact, most devices in this category do not have a usable external antenna connector for improving cellular service. Some devices do have external antenna connectors, but they are typically designed for test and approval, rather than everyday use. These types of antenna connectors, for example, "u.FL", are rated for 50 cycles and would not last long if used regularly. A cellular booster is a good solution for improving coverage to these kinds of devices.

Coverage for People

Smart phones are the obvious mainstay in this category and, of course, are used for much more than simple voice communications. There are 'religious debates' in automotive and related industries about where consumers and businesses are headed in terms of service in, and to vehicles.

Services via smartphone apps that use location-based data are usually free to download. Most believe the ability to monetize such services through built-in options and monthly service fees will have less consumer appeal going forward. "Brought in" services, mostly for free (such as the WAZE app, which allows users, on the go, to note various roadside objects, events, hazards, etc.), should become de rigueur.

OEMs have traditionally focused on how to monetize these services. This contrasts sharply with Internet companies that burn cash to obtain mass customer adoption. In addition, updates to services (apps) are practically continuous, and customers update their smartphones every one to two years. Again, this contrasts with OEMs, whose development cycles are typically five to seven years.

What Options Are Available?

External Antennas

As mentioned, some devices can be outfitted with an external antenna. This is more common with embedded, fixed devices, like routers and modems. An externally mounted antenna will provide improved reception to the individually connected device, but will not benefit any other devices. In an implementation where only one device requires cellular service, an external antenna is viable. However, in scenarios where multiple devices require service, connecting external antennas to each of them can be costly and a practical challenge.

SIMs: Multi-Operator/Multi-SIM Solutions

The cellular account's credentials, supporting security and authentication parameters are stored on a subscriber identity module (SIM) card. SIM cards are typically supplied to the customer by the network service provider. The subscriber inserts the SIM card into the target device to enable connectivity. When in place, roaming agreements — where a SIM is allowed to connect to other networks via contract between network providers — are one way to improve coverage.

However, roaming is costly. Most network operators are not supplying roaming agreements to customers as a standard way to move between networks, but rather as a fallback solution to accommodate "what if" scenarios when a given user equipment (UE) has temporarily left the primary network. Users who frequently roam between networks benefit from solutions that do not require roaming in the traditional sense; example, as in Europe, where networks often follow country borders.

One option for working around extra roaming charges is to employ **multiple SIM cards ▸** in a single device. Software on the device can be configured to use the appropriate SIM for the network coverage detected. Employing a system that takes advantage of multiple SIMs, or multiple virtual SIMs, can greatly improve coverage (and lower the overall cost of coverage) for mobile or nomadic devices. The downside of supporting multiple SIMs is an increase in both hardware costs and overall system complexity. Products that support multiple SIMs are typically in

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the premium categories, so it can be a challenge to find low-cost multiple SIM solutions that are targeted for broad deployment.

However, in a situation where the device is, simply, physically hard to reach with cellular services, as with a device buried inside a vehicle, multiple SIM solutions will not offer much help.

The **embedded Universal Integrated Circuit Card (eUICC) technology ▸** is a new standard for the SIM card, also called eSIM. Rather than having credentials stored on a user-removable SIM card, credentials are stored on a chip that is soldered to the device's PCB at time of manufacture. Credentials can be uploaded to the eSIM after the card has been delivered to market. The advantage here is that operator provisioning can essentially be changed on the fly, without having to access, physically, the device. This technology is particularly useful for wireless solutions that are built-in to the device, as with automobiles. The automotive industry seems to have endorsed the eSIM technology for OEM solutions, proposed by the GSMA, and it should become standard practice over the next five to seven years as new connected car designs hit the market. Services, like the eSIM service from Sierra Wireless, are emerging that take advantage of the eUICC technology and provide entirely new value propositions to the global mobile device marketplace.

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Signal Boosters (and Repeaters)

Cellular repeaters and signal boosters have been employed in the mobile cellular context for many years throughout the world. There is a wide spectrum of regional adoption of repeaters, due to a variety of reasons, like regulatory controls, consumer and market expectations, and more.

Cradle-Based Repeaters

A cradle-based repeater, typically, will have some sort of cradle that functions to mount and secure a mobile handset. The amplifier will routinely be mounted out of the way — under a seat, or in the trunk. It will be connected to an external antenna that will, permanently or temporarily, be, mounted to the vehicle exterior. The cradle itself contains passively coupled antennas that pick up the radiated signal transmitted from the handset, boosts it, and sends it to the network via the external antenna (and vice versa.) These products can be used to boost a single mobile handset.

There are, however, a couple of downsides to the cradle-style architecture. First, it only benefits one handset at a time, so is best used in a vehicle with an individual user. Second, it only really works with a phone. Connected devices like a laptop, tablet, or hotspot are unlikely to get any benefit from a cradle repeater.

Smart Signal Boosters

Smart signal boosters (SSBs)can capture the exterior cellular signal, 'clean' the signal by eliminating noise, and then boost the signal into the interior of the vehicle. They have been endorsed by the FCC as "a cost-effective means of improving our nation's wireless infrastructure." One of the key benefits of the SSB architecture is that all devices within range (approximately 20 m²) will benefit. There are no requirements for each device to be connected to an antenna, or otherwise modified. A SSB simply brings the external signal in, and boosts it.

Some signal boosters are limited in the technologies they support. For example, some may only support 3G cellular service. The key is to ensure the right booster is matched to the intended application and network.

Gain

Gain is one of the most important differentiators when considering SSBs and repeaters. The gain of an amplifier is the ratio of the power of the outputted signal to the input signal. Amplifiers take a signal, add energy to it, and the output is always greater than the input. When talking about boosters (or amplifiers), gain will be listed in the specification, and it will be reported in decibels (dB). All else being equal, an amplifier with a higher gain will be more powerful than an amplifier with a lower gain. A good way to assess various boosters is "cost per decibel of gain." Take the purchase price for the unit and divide it by the amount of gain indicated. Lower numbers are better.

MIMO

As mentioned above, there are a variety of use cases for mobile wireless technology in vehicles. In applications where high-speed data is beneficial, for example mobile video, using system products that support multiple-in multiple-out (MIMO) is key. MIMO is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time. 4G LTE supports MIMO and can provide data rates at 100 Mbps, and beyond.

A signal booster can reduce data rates for devices if it does not support MIMO and intelligent boosting. In general, this degrades performance. This could result in, for example, slow video downloads, buffering, service inconsistency, etc.

For a vehicle on the move, the devices inside will go in and out of MIMO-capable service availability. A standard single-input, single-output (SISO) booster positioned in the vehicle, with these mobile devices, overpowers the external MIMO signal (based on the proximity to the devices) and, essentially, defeats it. The result is that devices will remain at SISO data rates that could have benefited from higher-speed MIMO connections.

In contrast, a SSB has the intelligence to sense the external network and ratchet its power up and down accordingly. In areas where the MIMO signal is good, a smart signal booster will shut down or reduce its power to allow the devices to connect to the external MIMO signal source to benefit from high data rates. As the MIMO signal fades and signal quality deteriorates, the booster ratchets power back up and continues to provide optimal signal in sub-optimal conditions.

A Note about Regulatory Compliance

There can be wide variation in the sorts of technologies and specific power values allowed across different regions. In the United States, there are effectively three classes of boosters regulated by the FCC:

» Part 90 (Industrial). These boosters are more complicated to install, require individual approval from network operators, and are installed in a stationary context. They are not relevant to the mobile use case.

» Part 20 (Consumer Wideband). Part 20 Wideband repeaters have lower gain values, typically in the 50-60 dB (max) range, and are very common for low-end consumer applications.

» Part 20 (Consumer Provider-specific). Part 20 provider-specific smart signal boosters are professional grade systems that support up to 100 dB of gain and offer the best performance.

Network operators across the European Union (EU) also use signal boosters and repeaters. In the EU, Radio Equipment Directive (RED) compliance is required, and compliance can be identified with the CE mark on the product. Beyond the CE mark (or as a replacement to it) required by all EU countries, some regions have their own compliance models, and corresponding test suites and certification marks. For example, the Australian Communications and Media Authority (ACMA) in Australia requires the Regulatory Compliance Mark (RCM). The best thing to do is check either with the regulatory bodies themselves in the region, or with trusted local suppliers.

Illegal, low-quality repeaters and signal boosters can be found in every region. To ensure a good experience, and to stay within compliance, it is strongly recommended to check products for proper certification marks. If a product is marked as certified, there should be a corresponding Declaration of Conformance available for public view, usually via the web site. It is recommended to check these documents, or risk potential fines for suppliers or end users.

In summary, connected cars, services delivered in the mobile context in and around vehicles, are going to become an everyday part of the mobile experience. The key is to consider the variety of technologies that can be used to ensure these services remain connected, and that the wheels keep on turning.

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