CELLULAR STATE OF THE UNION

Considerations for 2G, 3G, 4G LTE Wireless Design

Cellular is increasingly the technology of choice for projects in the Machine-to-Machine (M2M) and Internet of Things (IoT) sectors. Cellular is evolving rapidly and we are in the midst of another evolutionary step as carriers roll out 4G LTE networks. With so many changes happening and so many choices to consider, from 2G to 3G to 4G LTE and everything between, selecting the right technology for your product can be difficult. This paper provides an update on the current state of the cellular industry and explores the many design considerations when determining which cellular technology is best for your specific application.

Why Cellular for M2M/IoT?

Cellular technology is being adopted widely for use in M2M and IoT applications for six main reasons. Let's dive into each of the reasons in more detail.

1 Ubiquitous Coverage

Cellular networks are deployed worldwide in nearly 200 countries and cellular coverage is ubiquitous in all but the most remote regions.

A recent International Telecommunication Union (ITU) report estimates that the total number of global, mobile-cellular subscriptions is approximately 6.8 billion—nearly the same as the estimated world population.

Cellular devices can be deployed anywhere within network coverage. This enables mobile applications like fleet-monitoring and asset-tracking solutions, where devices must maintain connectivity across large geographical areas. Additionally, there is a growing population of picocell deployments that further extend cellular coverage and improve in-building coverage for shopping centers, large corporate buildings, subway stations, and other environments.

2 Easy Deployment

Cellular devices can be pre-provisioned by system integrators or by the factory before shipment, enabling devices to connect to the network right out of the box with zero setup or configuration required by the end user. This has the added benefit of simplifying product designs that do not require additional user-interface features.

Cellular devices are not dependent upon IT infrastructure (e.g., Wi-Fi access points, corporate Ethernet, etc.). Deploying other wireless technologies in environments like hospitals can be problematic because hospital IT departments do not want third-party devices on their network. When devices depend on a local wireless infrastructure, they are susceptible to local outages, changing security settings, equipment upgrades, and interoperability issues.

IT departments can remotely monitor, manage and control cellular devices just like other IT assets today.

3 Lower Support Costs

With cellular, the network infrastructure is owned, operated and maintained by the carriers – not the customer or product vendor. This eliminates upfront infrastructure costs and reduces support costs. Since cellular connectivity does not depend on customer-managed infrastructure, vendors do not need to provide as much support for basic wireless connectivity issues (e.g., “My device won’t connect to the access point.” or “The security settings are not working.”). Instead of deploying your own infrastructure, leverage one of the world’s largest communication infrastructures—the cellular network.

4 Improved Reliability

Reliability is critical for M2M applications, especially those involving security and real-time monitoring and alerts. With cellular, you leverage a robust wireless network used by nearly one-third of the world’s population every day. Cellular network outages, though rare, can be noticed and acted upon immediately. By contrast, a device connected to a consumer-grade Wi-Fi access point maintained by a store clerk in a small gas station is a far less reliable option. When the wireless connection fails, it could go unnoticed for extended periods of time and require manual intervention.

5 Lower Hardware Costs

Cellular module costs have fallen significantly in recent years. High-volume pricing for data-only modules is approaching sub-$10 for 2G GSM, sub-$20 for CDMA 1xRTT and sub-$30 for 3G UMTS. These price points are enabling a whole new class of devices and applications.

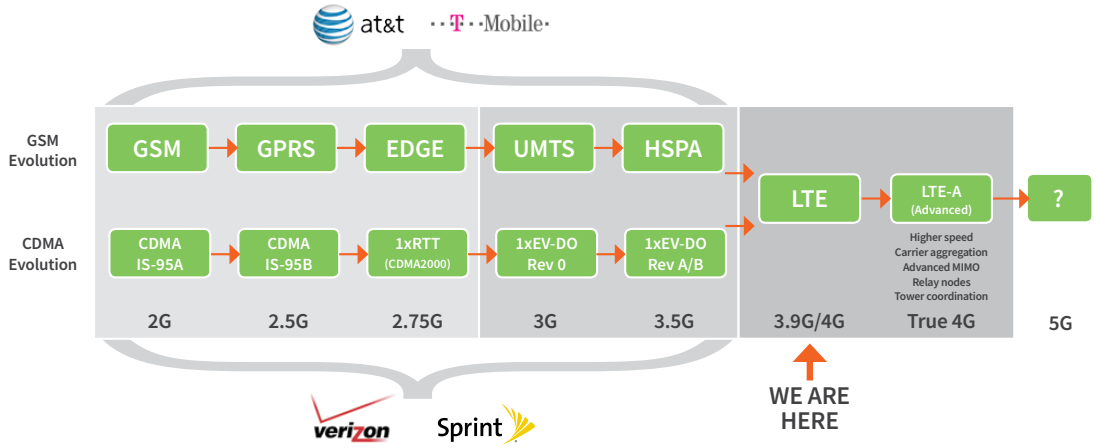
6 Lower Data Costs

Data costs have also fallen significantly. For connected machines that only need to report small amounts of data, connectivity costs can be less than $1/month. Vending machines that report daily inventory clearly do not need the same costly data plan as a consumer phone or tablet streaming HD video.

Cellular Technology Evolution

Cellular technology has come a long way since the first analog systems launched in the early 1980s. Digital cellular networks based on GSM and CDMA standards were launched in the 1990s and the technologies have undergone several major evolutionary steps, resulting in the stream of acronyms we have today: GSM, GPRS, EDGE, 1xRTT, UMTS, HSPA, EV-DO, LTE, LTE-A (and that's a simplified list!). We are now in early stages of the fourth-generation of cellular technologies: LTE and LTE-Advanced (LTE-A). While many carriers have been marketing 4G speeds for the last several years, real 4G deployment is just getting started and will offer significantly better performance than what users experience today.

Wireless Spectrum



To better understand current changes in the cellular space, let's look at the primary resource used by all cellular technologies—wireless spectrum, the set of radio frequencies that can be used to propagate wireless signals. Only a limited amount of spectrum is available in the world and it is treated by many governments as a limited resource, like land. Governments sell/license spectrum to cellular carriers and the amount of spectrum required to transmit cellular data is proportional to the amount of data being sent and the number of users (capacity).

In many ways, wireless spectrum is analogous to exclusive beachfront property. There is a limited supply, so resort owners (cellular carriers) seek to claim as much beach property (spectrum) as possible so they can build resorts (networks) and "rent them out" to their customers (subscribers) to maximize revenue. Since space (spectrum) is limited, resorts (carriers) must carefully manage how they use it. Building a new network is akin to constructing a new resort. The larger the resort, the more property required, and the more customers who can be served. When a resort's property is already built out and it must upgrade and build newer resorts to accommodate even more people, what are their options? They can either purchase more property to build on or tear down the old resort to make room for the new one.

To build out 4G LTE networks, which require significant spectrum, carriers are aggressively pursuing new spectrum and some are starting to decommission their legacy networks.

For instance, AT&T recently made a $1.9 billion purchase of 700 MHz B Block spectrum from Verizon. And Verizon sold 700 MHz A Block spectrum in exchange for $2.365 billion and some of T-Mobile's AWS/PCS spectrum. AT&T is also in the process of decommissioning its 2G GSM network to free up spectrum for its LTE build out. Its recent announcement of plans to shut down its 2G GSM network, sent shock waves across the M2M industry where the majority of devices in the field are still based on low-cost 2G technology. The implication for M2M device vendors is that they must redesign products to support alternate technologies like CDMA, 3G UMTS, or 4G LTE.

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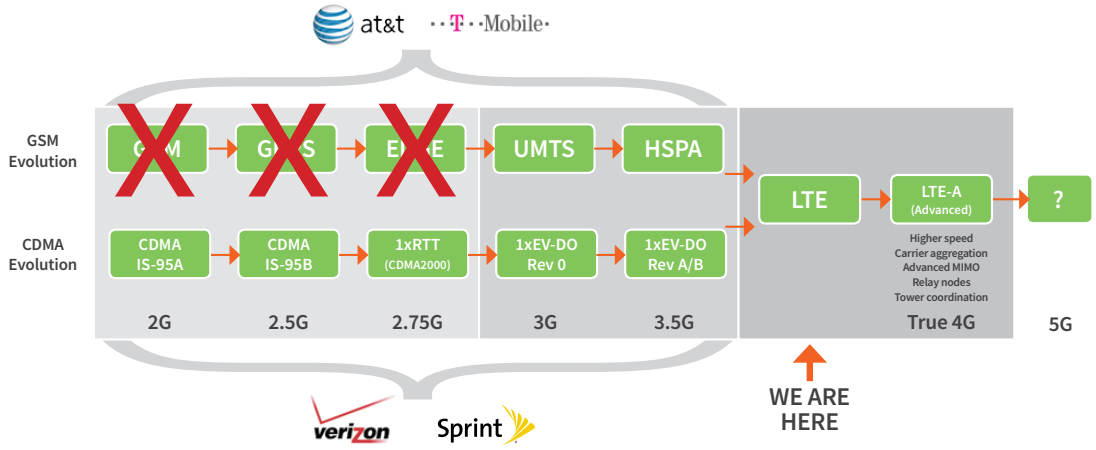


This series of events begs several questions: What does the future hold for the North American 3G UMTS and CDMA 1xRTT/EV-DO networks? How will this impact global deployment? What cellular technology should be selected for new devices? Should all new designs be based on 4G LTE? The answers are not trivial and many factors must be considered when making cellular technology decisions:

- Speed/Latency
- Module Cost
- Antenna(s)
- Target Market
- Data Cost
- Product Lifecycle
- Certifications
- Network Coverage
- Network Longevity

Cellular Technology Considerations

Target Market (Network Coverage)

North American Market Considerations

North America has both GSM and CDMA network operators. The major carriers in Canada and Mexico primarily use GSM/UMTS and are in the process of shutting down their CDMA networks. In the U.S., the best network coverage is still found with 2G GSM and CDMA 1xRTT, although this is changing as carriers migrate to 4G LTE. AT&T and T-Mobile's 2G GSM footprints are already shrinking as they shut down their 2G towers to support migrations to LTE (see below).

The four major U.S. carriers (Verizon, AT&T, Sprint, and T-Mobile) are all aggressively building out their new 4G LTE networks and LTE coverage is improving significantly. Verizon took the lead and claims its LTE footprint now matches its EV-DO footprint, covering 95 percent of the U.S. population (not geographical area). Refer to Verizon's latest LTE coverage: http://www.verizonwireless.com/b2c/CoverageLocatorController

Other carriers (AT&T, T-Mobile, and Sprint) are behind, although they all have plans to significantly build out their networks. Today, their LTE deployments are largely concentrated in key urban markets with the highest populations. When evaluating LTE strategies for your product, there are a few options to consider:

- **LTE with fallback:** Several LTE modules on the market also contain fallback support for 2G or 3G technologies. Fallback to 3G UMTS/HSPA or CDMA 1xRTT/EV-DO is an interesting option in North America. On Verizon, fallback to EV-DO is less useful since its LTE footprint already matches the EV-DO footprint. Modules with fallback are expensive but offer tremendous flexibility and the best overall coverage since they can leverage both legacy and new networks. Fallback is a good option for products with long lifecycles that must operate in both urban and rural areas. This option also enables global deployment in regions where LTE is not available or where LTE coverage is poor.

- **Future support for LTE:** Leading industrial module vendors like Gemalto M2M, Sierra Wireless, Telit and u-blox offer module families that support all technologies (2G/3G/4G/LTE) in a common form factor. This means you can start with a 2G or 3G module today and move to a 4G LTE module in the future, with significantly less design effort than starting from scratch. This is a good option for products with shorter lifecycles that must operate in both urban and rural areas and that do not immediately require LTE speeds.

- **LTE-only:** Several LTE-only modules have been introduced recently, offering a cost advantage over LTE modules with fallback support. While LTE-only may be acceptable for some applications, it is important to evaluate LTE coverage with your selected carrier to determine if LTE-only is sufficient for your application.

Global Market Considerations

Global cellular networks are primarily based on 2G/3G GSM, with a few exceptions. GSM (2G) remains the most widely deployed network technology and has the most subscribers. Worldwide, 2G/3G GSM will likely be around for a long time and should still be considered for global product deployments.

Global LTE is more complicated. LTE is still predominantly found in developed nations only and coverage is limited to major urban areas. LTE is fragmented and operates on many different frequency bands worldwide. Band requirements vary from carrier to carrier and country to country. While global 2G/3G/CDMA used only five frequency bands, LTE operates on 44 bands. Adding complexity, LTE comes in two flavors with different underlying technologies: Time-Division Duplex (TDD) and Frequency-Division Duplex (FDD). The implication is that a single product SKU cannot be used for global deployment at this time. Multiple product variants are required to support carrier- and country-specific cellular module and antenna configurations. A case in point: Apple sells six models of the iPhone 5s to support all LTE band combinations needed for global deployment.

Apple iPhone 6 Model Summary

Model A1549 (GSM)* / Model A1522 (GSM)*: UMTS/HSPA+/DC-HSDPA (850, 900, 1700/2100, 1900, 2100 MHz) GSM/EDGE (850, 900, 1800, 1900 MHz) LTE (Bands 1, 2, 3, 4, 5, 7, 8, 13, 17, 18, 19, 20, 25, 26, 28, 29)	North America (AT&T), Central/South America
Model A1549 (CDMA)* / Model A1522 (CDMA)*: CDMA EV-DO Rev. A and Rev. B (800, 1700/2100, 1900, 2100 MHz) UMTS/HSPA+/DC-HSDPA (850, 900, 1700/2100, 1900, 2100 MHz) GSM/EDGE (850, 900, 1800, 1900 MHz) LTE (Bands 1, 2, 3, 4, 5, 7, 8, 13, 17, 18, 19, 20, 25, 26, 28, 29)	USA (Verizon) USA (Verizon)
Model A1586* / Model A1524*: CDMA EV-DO Rev. A and Rev. B (800, 1700/2100, 1900, 2100 MHz) UMTS/HSPA+/DC-HSDPA (850, 900, 1700/2100, 1900, 2100 MHz) TD-SCDMA 1900 (F), 2000 (A) GSM/EDGE (850, 900, 1800, 1900 MHz) FDD-LTE (Bands 1, 2, 3, 4, 5, 7, 8, 13, 17, 18, 19, 20, 25, 26, 28, 29) TD-LTE (Bands 38, 39, 40, 41)	Model A1586* - USA (Sprint), China, Latin America, Europe Model A1524* - USA (Sprint)

Source: Apple, https://www.apple.com/iphone-6/specs/

Product Lifecycle / Network Longevity

In light of current and future network infrastructure changes driven by 4G LTE migration, you must carefully consider your product's lifecycle and network longevity when making design decisions.

- **2G GSM:** The North American 2G GSM network is being shut down; AT&T formally announced it will phase out its 2G GSM network by 2017. AT&T no longer activates 2G-only devices on its network and has already started refarming its 2G spectrum in key markets to support the build-out of its LTE network. T-Mobile recently made a similar announcement and is kicking off a major program to upgrade its 2G network to 4G LTE by 2015. In global markets, 2G remains a dominant technology, although more mature networks in Europe and Asia-Pacific have already started to repurpose their 2G spectrum for 3G/4G technologies.
- **3G UMTS:** No official carrier statements have been made on the longevity of 3G UMTS/HSPA. In North America, 3G usage will likely taper significantly after LTE networks are fully deployed and the technology is expected to be supported until at least 2020. Globally, 3G has a significant presence and will likely be around much longer outside of North America.
- **CDMA (1xRTT):** Verizon is committed to supporting its CDMA 1xRTT network until at least 2019. CDMA 1xRTT remains a viable technology for new designs with shorter lifecycles. In fact, many customers affected by AT&T's 2G network shutdown have already moved to, or are considering, CDMA 1xRTT as a low-cost alternative to 3G UMTS.

All mid- to long-term product roadmaps should seriously consider a strategy based on LTE or LTE with fallback support for 2G/3G.

- **CDMA (EV-DO):** No official statements have been made on the longevity of CDMA EV-DO. EV-DO is expected to be supported for the near future, although there is significant pressure from carriers like Verizon and Sprint to move customers to their new 4G LTE networks. This pressure will increase further as LTE networks mature and reach the same coverage as EV-DO.
- **4G LTE:** This is the future. LTE networks are appearing and rapidly expanding, and it's too early to discuss longevity concerns. All mid- to long-term product roadmaps should seriously consider a strategy based on LTE or LTE with fallback support for 2G/3G.

Speed and Latency

One main driver for cellular evolution is the desire for higher speeds and reduced latency. With each step forward, data rates increase by several orders of magnitude, and latency, a measure of communication delay, improves similarly.

2G speeds are acceptable for many M2M applications where only small amounts of data are being communicated. A cellular tank-level sensor that only reports a small amount of data (e.g., fuel levels) once per day, does not require leading-edge technology.

3G speeds enable more media-rich applications like video streaming and large image-file transfers.

4G LTE improvements enable new classes of applications like real-time gaming, live videoconferencing and voice-over-IP. It's worth noting that careful attention must be placed on antenna design to achieve true 4G/LTE speeds. This topic is covered in more detail below.

Technology	Data Rate (peak)	Data Rate (typ)	Latency	Applications:
2G	Kbps	100-400 Kbps	300-1000 ms	→ Email, text, basic web browsing
3G	Mbps	0.5-5 Mbps	100-300 ms	→ Video streaming, rich browsing
LTE	Gbps	1-50 Mbps	<100 ms	→ Real-time gaming, video chat, VOIP

Source: O'Reilly - High Performance Browser Networking. Ch 7

Module Cost

There are still significant cost deltas between 2G, 3G, and 4G LTE modules. While LTE modules are cost-prohibitive for many applications today, their costs are expected to drop significantly as LTE deployments increase. Many factors affect pricing: vendor, purchasing volumes, form-factor, feature support (e.g., voice, GPS, speed, band support, and embedded processing), and intellectual property rights (IPR) coverage. Ballpark, high-volume pricing is included for reference. For formal pricing, it is best to work directly with the module vendors.

Data Cost

Cellular data costs have fallen significantly across all of the different carriers. Data costs have more to do with the amount of data being sent, the number of total connections, features/services used (SMS, public/private IP) and the selected carrier, as opposed to the technology selected (2G/3G/4G LTE). Connecting devices and machines to a cellular network can cost as little as $1/device/month for applications using very low amounts of data. When engaging on a new cellular design or considering cellular technology for your application, it is critical to engage with the cellular carriers early to discuss data plan options and costs.

Technology	Approximate Module Cost
2G (GSM)	$10-15
2G (CDMA)	$20-30
3G	$30-50
LTE Only (no fallback)	$25-50
LTE + Fallback (2G/3G I CDMA)	$50-100

Antenna(s)

Antennas are a critical, and frequently overlooked, element of cellular designs. Several factors must be considered for cellular antennas including band support, size, diversity/ MIMO, and performance.

Band Support

For most 2G/3G designs targeting a single market like North America or Europe, a single two- or three-band antenna is sufficient.

For global 2G/3G coverage, a more complex penta-band antenna is necessary to cover all bands.

As discussed earlier, global LTE bands are fragmented and many operate on frequencies other than 2G/3G. The target market and selected carrier will dictate the LTE bands that must be supported as well as the minimum antenna performance required.

Size

Antenna performance is directly related to the size of the antenna and also to the frequency of operation. Lower frequencies have longer wavelengths and require larger antenna dimensions. This has several implications for cellular and specifically some LTE bands that operate on lower frequencies than 2G/3G (e.g., LTE Band 13 - 700 MHz).

Diversity / MIMO

Several techniques like antenna diversity and MIMO (multiple-input-multiple-output) have been introduced to further improve cellular data rates and wireless performance.

- Diversity uses two antennas to mitigate the effects of multipath on received signals and to improve link reliability.
- MIMO is an extension of diversity where both the device and base station use multiple antennas for both receive and transmit functions. This not only improves link reliability, but also significantly improves data throughput. MIMO is a key feature of 4G LTE and is a certification requirement for many major U.S. operators. MIMO is also mandatory to achieve maximum LTE speeds.

These techniques must be carefully considered since they have implications on product size, form factor, and performance.

Performance

To ensure good cellular network and device performance, many cellular carriers include over-the-air (OTA) performance testing as part of the certification requirements. To pass, designs must have a good antenna that is designed and integrated properly.

Certifications

Cellular certification requirements and costs vary by market, carrier, and technology. They change frequently and certifications for module integrations are expensive, often ranging from $15,000 to $50,000 or more. It is critical to design with certifications in mind from the beginning to avoid costly time-to-market delays and budget overruns due to significant recertification costs. It's also important to note that carrier certifications often focus on both hardware and software aspects of your product. Before you start, contact the wireless design experts at Digi to explore all design considerations and testing prior to certification.

Technology	Approximate Certification Cost
2G	$15,000-$25,000
3G	$25,000-$35,000
LTE Only	$35,000
LTE with Fallback	$50,000 +

Technology Summary

Many factors must be considered when selecting the right cellular technology for your device. These factors will continue to evolve. Making the right decision is critical. A poor technology choice can be expensive and create significant repercussions including time-to-market delays, poor coverage, unnecessary BOM and certification costs, or even forced end-of-life and redesign of your product.

Technology	Markets	Coverage*	Network Longevity	Module Cost	Speed & Latency
CDMA 1xRTT	USA, Japan, Korea	●	●	●	●
CDMA EV-DO	USA, Japan, Korea	●	●	●	●
2G (GSM/GPRS)	Global	●	● USA ● Global	●	●
3G (UMTS/HSPA)	Global	●	● USA ● Global	●	●
LTE Only (No Fallback)	Global	● USA ● Global	●	●	●
LTE + Fallback (3G or CDMA)	Global	●	●	●	●

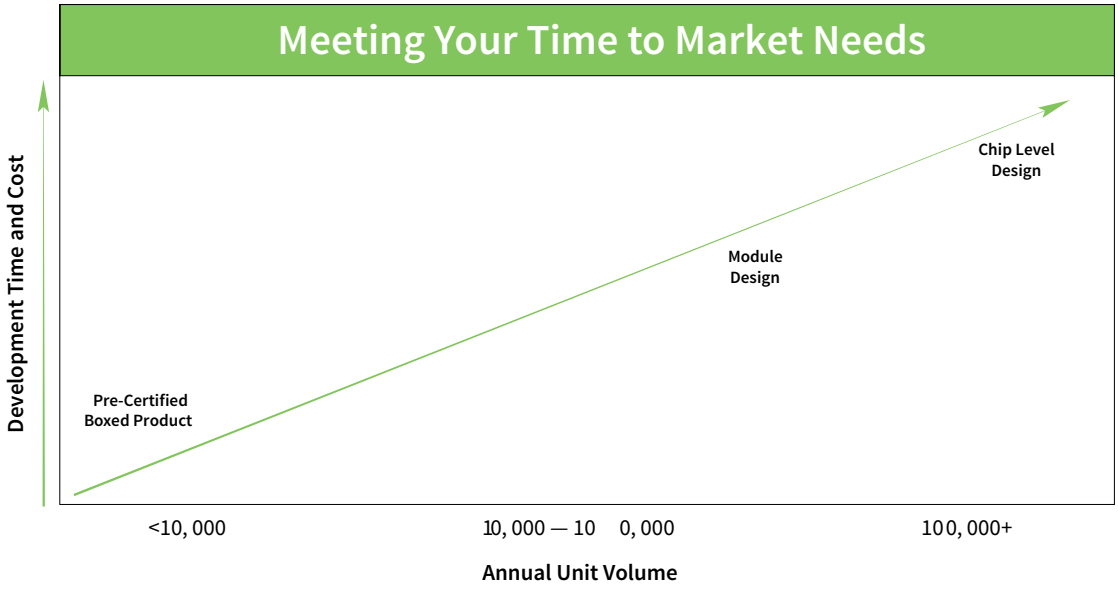
* Coverage varies by carrier and region. ● Good ● Fair ● Poor

Take Advantage of Extensive Cellular Expertise

For more than 30 years, Digi has provided companies with a broad range of reliable, innovative, long-life products – from embedded modules and single-board computers to routers and gateways, and more. Digi's complete family of cellular products and technologies can accelerate your market success.

When only custom cellular technologies will suffice, look to Digi's team of experienced engineers for your wireless design needs. Digi has a successful track record of custom design for a wide range of companies – from idea concept through product launch. We help ensure your product has the right design to pass the required compliance tests and get to market faster – with all necessary certifications and compliance tests, so you avoid costly delays and dead ends.

Digi has designed, developed and brought hundreds of cellular-enabled solutions to the market on 2G/3G/4G LTE networks. Our engineering teams have deep experience in cellular hardware, firmware, antennas, and certifications. We partner with all of the leading module vendors, certification labs, and cellular network operators and continue to make significant investments in the latest cellular test equipment to keep up with the evolving technology and customer demand.



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Key Takeaways:

- Cellular is an ideal choice thanks to its ubiquitous coverage, easy deployment, reliability, and lower hardware and data costs.
- Carriers are securing sufficient spectrum for 4G LTE networks with acquisition, sun setting earlier-generation technologies, and other reallocation strategies.
- All mid- to long-term product roadmaps should seriously consider a strategy based on LTE or LTE with fallback support for 2G/3G.
- Other key design considerations: network speed/latency, data costs, component costs, antenna design, and certifications.

Contact a Digi expert and get started today

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