Water Meters and the Internet of Things (IoT)

Cellular Communications Overview

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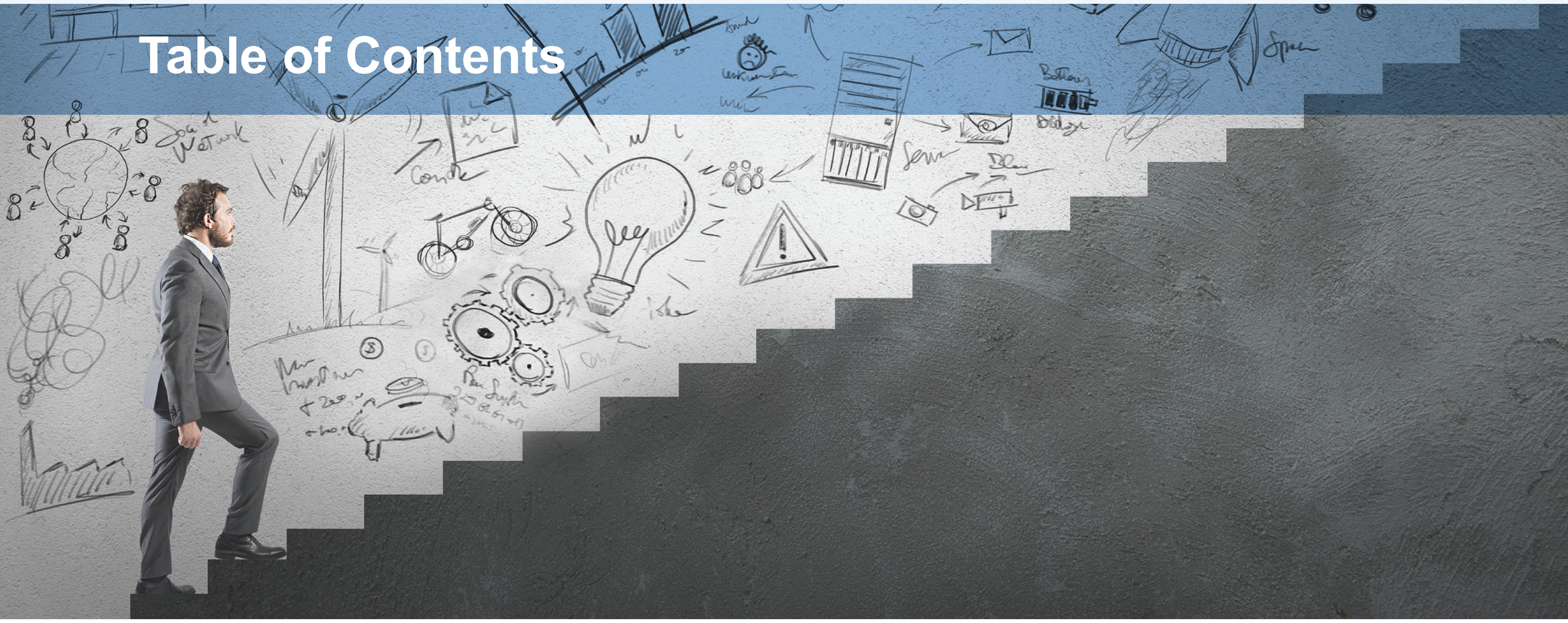

INTERNET OF THINGS — PROMISES AND OPPORTUNITIES

The Internet of Things (IoT) is a global industry movement that brings together people, process, data, and things to make networked connections more relevant and valuable than ever before. By 2020, it is estimated that over 50 billion new things/devices will be connected to the Internet (Valerio, 2014). The IoT is promising unprecedented value in terms of improved quality of life on the consumer side and significant operational efficiencies on the industrial side. Consumers have already seen major growth in new devices for home security, energy and utilities management, personal health, and wearable technology. Connected cars and self-driving cars are another major area of innovation that's going to transform our lives.

On the industrial side, the Industrial Internet is taking shape with focus moving from simple connectivity and monitoring applications to Big Data analytics and the integration of machine data with information technology applications to achieve complete business transformations.

The concept of machine-to-machine (M2M) communications has a rich history in the industrial world, and many technologies and standards exist that provide the foundations for a high degree of functionality across a broad range of industries. IoT combines the Cloud and Big Data analytics on top of the M2M foundation to derive new value for enterprises and consumers going forward.

OUTLOOK FOR M2M DEVICES IN THE IOT ERA

Traditionally, M2M devices played an important role in providing visibility and remote monitoring of devices deployed in the field. In the IoT era, these M2M devices are going to play an even more strategic role in terms of the generation and transportation of critical data that will be used to drive Big Data analytics and decision making to improve network reliability, address demand issues, and take action on outages in real-time.

In the utility industry, the smart grid and connected water meters have been transforming utility operations to achieve higher efficiency and reliable performance. Utilities and solution providers have been investing heavily in developing and adopting IoT/M2M technologies to collect data from various points in the network that can be used to analyze and make decisions to achieve operational efficiencies.

When we look at connectivity options for devices in the IoT/M2M space, while there are several options, cellular connectivity is one of the dominant choices. Initially, cellular networks were primarily used for voice communications. Over time, the growth of smart phones and the evolution of technology has enabled the cellular network to provide robust data transmission services along with voice services. In industries like connected cars, utilities, fleet management, and remote patient monitoring in healthcare, cellular connectivity plays a crucial role in providing a reliable and cost-effective solution for data communication with devices deployed in cars, trucks, and in-home patient monitoring devices.

Cellular connectivity provides several advantages that cannot be ignored by customers considering IoT/M2M solutions. Some of the key advantages of cellular solutions are:

- No in-house network infrastructure: It isn't necessary to build your own system. A simple data connection to the operator's cellular network is all you need.
- Standards-driven: Cellular technology is driven by major standards bodies like 3GPP that ensures interoperability between solutions from various operators and solution providers.
- Cost-effective: Cost of cellular data connectivity for IoT/M2M applications have dropped significantly and also flexible options like pooling and usage-based models provide transparency and help manage costs even more.
- Ubiquitous coverage: With the widespread adoption of mobile phones and solutions by consumers and businesses, the coverage from cellular networks is very strong, even in remote areas.
- Fast recovery: In the event of a natural disaster, cellular networks are often the preferred option by first responders because of their high up-time. If a cellular network is down for one operator, solutions that can automatically switch to another operator's network that is up and running, are critical.

However, many first responders also use private radio networks which tend to have interoperability issues. In the future, first responders have the deployment of FirstNet to look forward to. FirstNet (First Responder Network Authority) is a private network that will build, deploy, and operate the nationwide public safety broadband network which solves the interoperability issue for those entities using LTE as a transport.

...cellular connectivity plays a crucial role in providing a reliable and cost-effective solution for data communication with devices deployed in cars, trucks and patient monitoring devices placed in homes.

CELLULAR TECHNOLOGIES IN THE US

In the United States, there are two families of technologies used for cellular services: Global System for Mobile Communication (GSM) and ANSI-2000 CDMA (or CDMA).

These two technology families replaced the Advanced Mobile Phone System (AMPS), an analog cellular service deployed in the US in the early 1980s. AMPS used wireless spectrum very inefficiently, and the large growth in users required a transition to digital protocols that allowed a larger number of simultaneous users in the same spectrum.

CELLULAR GENERATIONS

Historically, the operators deploying digital cellular services took different technology paths, in multiple steps called "Generations." Thus, AMPS became known as the First Generation (or 1G) cellular technology, and the first GSM and CDMA cellular services (with wireless IP data) were the Second Generation (or 2G) technologies. In this document, operators who deployed GSM are called GSM operators, and operators who deployed CDMA are called CDMA operators.

These 2G cellular technologies also included wireless IP data services for accessing the Internet — for 2G GSM, this was the General Packet Radio Service (GPRS) and for 2G CDMA, this was the 1 Times Radio Transmission Technology (1XRTT).

The 2G technologies were followed by more spectrum-efficient Third Generation (3G) technology deployments, as the requirement to support an ever-increasing number of users continued unabated. The deployment of 3G also provided faster wireless IP data services in both technology families.

However, in the GSM family, 3G services were commercially deployed later than in the CDMA family, since it required a major change in the underlying data encoding protocol — 2G GSM used Time Domain Multiple Access (TDMA) and 3G GSM used Wide-band CDMA (W-CDMA) — and necessitated the development of new cellular standards.

Recently, the operators began deploying a Fourth Generation (4G) cellular technology called Long Term Evolution (LTE) while development of new technologies continues for the foreseeable future.

CDMA FAMILY

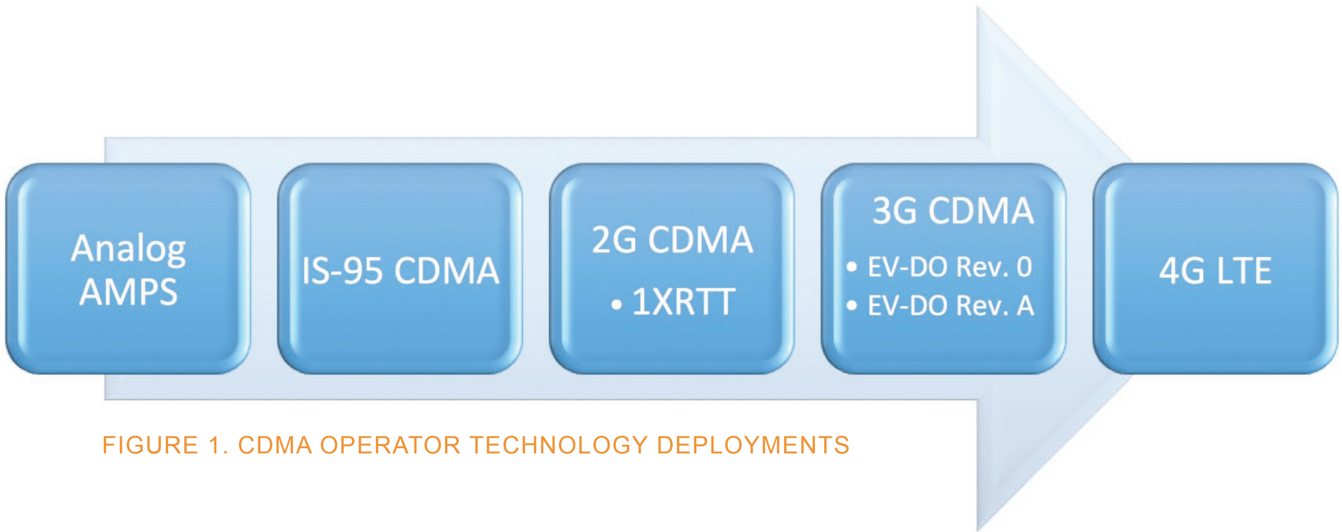

FIGURE 1. CDMA OPERATOR TECHNOLOGY DEPLOYMENTS

As shown in Figure 1. CDMA Operator Technology Deployments, the CDMA operators moved from AMPS to a digital cellular system using CDMA data encoding as defined by the TIA/IS-95 CDMA standards.

This digital cellular deployment eventually also supported a 2G data transport protocol called 1XRTT, per the ANSI-2000 CDMA standard, that allowed the transmission of Internet Protocol (IP) data on cellular networks. With later enhancements in the encoding protocols, the CDMA operators deployed faster wireless IP data capabilities over time:

- EV-DO Rev. 0, followed by
- EV-DO Rev. A, for faster performance

These 3G EV-DO data services on CDMA are widely used today for cellular IP data services and provide a stable and robust system for many WAN data communications requirements.

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[1] The specific details of how digital data is modulated in the TDMA, CDMA, and OFDMA encoding protocols are beyond the scope of this whitepaper – for more information, please refer to a book listed in *Appendix C. Reference Texts on Cellular Technologies.*

In North America, the CDMA operators have fully deployed 3G EV-DO (including Rev. A) in their entire coverage footprint — matching the coverage of their 2G 1XRTT footprint.

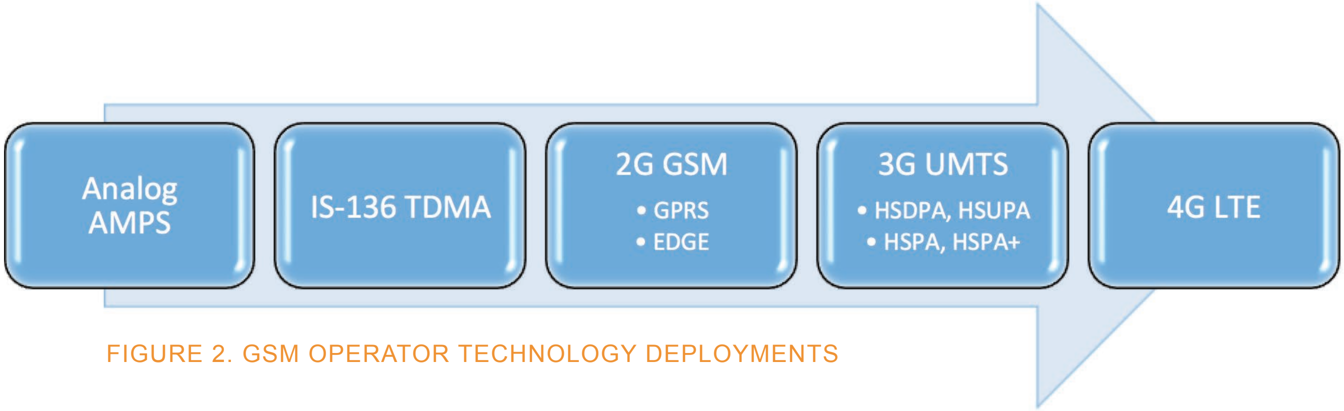

FIGURE 2. GSM OPERATOR TECHNOLOGY DEPLOYMENTS

As shown in Figure 2. GSM Operator Technology Deployments, the GSM operators moved from AMPS to a digital cellular system using the IS-136 TDMA standard. However, in other parts of the world, notably Europe, cellular operators had deployed another digital cellular system called GSM, which was incompatible with IS-136 TDMA, although it also used a TDMA encoding protocol.

Later, the American operators transitioned their digital services from IS-136 TDMA to GSM, to take advantage of the economies of scale afforded by the large number of GSM deployments around the world, but this required a fairly significant capital investment. In 2G GSM, the wireless IP data services are called GPRS and EDGE.

2G GSM was followed by a 3G GSM technology called Universal Mobile Telephone System (UMTS). In this technology, UMTS abandoned TDMA in favor of W-CDMA because of the higher spectrum efficiency of CDMA encoding compared to TDMA encoding.

4G LTE

The new technology in active deployment by all operators in the US and globally is Long Term Evolution or LTE. This technology uses new encoding protocols, such as Orthogonal Frequency Domain Multiple Access (OFDMA). This encoding technology provides excellent spectrum efficiency for wireless data and the standard for LTE allows the ability to use variable bandwidth cellular spectrum.

However, this flexibility also allows for deployment in a large number of possible frequency bands. As a result, operators have deployed the LTE service in different bands. For example, in the US, Verizon initially deployed LTE on Band 13 in 700MHz Upper C; AT&T began with Band 13 in 700 MHz Lower A/B; Sprint on Band 25 in 1900MHz Block G; and T-Mobile on Band 4 in 1700/2100MHz.

Cellular handsets for these operators did not (and still mostly do not) support all the necessary bands in the same model to allow that device to be used on all operators with LTE. For example, even though a particular model may be available for more than one operator to market, the specific version of that handset may not be able to use LTE in other operators.

Although LTE data performance is substantially higher than 2G or 3G cellular, there are also some limitations. In general, LTE cellular devices use more power than older 2G and 3G devices — hence, battery-powered applications are often difficult to support easily.zzz

Since LTE is a wireless IP data technology, voice services (using a new capability called Voice over LTE or VoLTE) have not yet been commercially deployed. Today, all operators providing LTE wireless data services continue to offer 2G and 3G cellular to allow their customers to make and receive voice phone calls.

Furthermore, LTE coverage today is not as good as the coverage of 2G and 3G technologies (which have matured over many years) although this will improve in time, as LTE towers are deployed. IoT/M2M applications being deployed today cannot expect LTE to be available at all locations.

Thus, LTE cellular units must “fall back” to older 2G and 3G services when they are not in LTE coverage. The devices must support encoding protocols such as TDMA (for 2G GSM), W-CDMA (for 3G GSM), and CDMA (for 2G and 3G CDMA).

This increases the complexity and cost of the chipsets within the devices — today, 4G LTE devices are substantially more expensive than 2G and 3G devices, but the costs are projected to drop over the next 2 to 3 years due to wider adoption.

When LTE coverage improves and VoLTE is deployed into production, LTE-only devices will come down in cost once the cellular chipsets drop support for non-OFDMA encoding protocols, and new cellular devices are designed and deployed.

IMPACT OF IOT ON COMMUNICATIONS TECHNOLOGY

SMARTPHONE AND CONSUMER MOBILE DATA VS. IOT DEVICE DATA

There is a fundamental difference between consumer smart phone data and data from IoT/M2M devices. Consumer smart phones consume a lot of data and are driven by bandwidth-hungry applications like YouTube, broadband TV, streaming music, and games. These applications require high bandwidth, and the new LTE networks are being built to support these bandwidth needs of 50Mbps and above.

On the other hand, IoT/M2M devices do not consume data. Also, the data these devices generate does not require high-bandwidth connections. In fact, 1Mbps is plenty bandwidth for most IoT/M2M applications. In a typical smart metering application, a smart meter generates only 2KB of data per day.

Given these fundamental differences, it is important that a utility provider factors in all the parameters when making a decision on the connectivity technology. Module costs, complexity, maturity of technology, longevity, and standardization roadmap must be considered as part of the decision-making process. Let’s explore some of these key factors.

IOT/M2M APPLICATIONS ON LTE TODAY

For the vast majority of IoT/M2M applications, LTE is not a requirement. Most applications send a limited amount of IP data every month, and the speed and performance of LTE are simply not needed and the incremental cost is not justified. Indeed, for many applications, 2G (both GSM GPRS and CDMA 1XRTT) technologies are completely sufficient for normal use.

In some IoT/M2M applications, 3G GSM and 3G CDMA can provide additional throughput for higher performance data requirements. This comes with a cost — higher priced radios since the 3G technologies require more complex chipsets.

LTE MTC SPECIFICATIONS FOR IOT

The 3GPP as part of the LTE standardization process has outlined a standard called Machine Type Communications (MTC), specifically to address the needs of IoT applications. Some of the key focus areas of the MTC specification are low bandwidth, low complexity, long battery life, and low cost of the solution. The MTC specification is in the process of being developed as part of LTE release 12 and 13. The first version of this specification was expected to be finalized in the April 2015 timeframe as part of release 12. Once the specification is finalized, products from vendors supporting the standard become available in the market anywhere from 18 to 24 months afterward. The MTC solutions are most ideal for water meter applications as they support long battery life, low complexity, and cost.

2G GSM SUNSET ANNOUNCED

Because of the ever-increasing demand for wireless data for smart phones and tablets, operators are transitioning their use from the less spectrum-efficient technologies if they do not have enough wireless spectrum to support their customers. Thus, AT&T announced that its 2G GSM (for GPRS and EDGE data services) will be shut down on January 1, 2017. The spectrum will then be used for 4G services.

Although T-Mobile has not announced a 2G GSM shut down date, it is expected that T-Mobile will also do a similar 2G GSM shutdown within a few years as well.

2G CDMA CONTINUES

The operators who deployed 2G CDMA are not under the same pressure to migrate services to 4G since they have enjoyed better data throughput performance for longer than the GSM operators. Thus, Verizon is likely to continue providing 2G CDMA services through the end of this decade. Currently, since VoLTE is not yet commercially deployed, the 2G CDMA technologies are needed to support voice services.

SPRINT 2G CDMA LONGEVITY

Sprint, which is in an excellent spectrum ownership position among the major operators, is expected to continue its 2G CDMA services beyond the end of the decade — particularly due to the fact that it has fewer customers than Verizon and less congestion on its network. Furthermore, some of its spectrum in the converted Nextel band (specifically Band 26) allows Sprint to continue to support 1XRTT services for longer than other operators.

ROAMING

When a cellular device is operating in a market where that device's operator does not provide native local service, the device must "roam" onto another operator network, where a business agreement for "roaming service" has been arranged.

If a roaming agreement does not exist, the cellular device cannot operate at that location — voice and data services are not available to it.

LTE ROAMING

In the US LTE deployments, the major operators have not yet made roaming agreements for LTE data services. Thus, a Verizon LTE device does not roam on an AT&T LTE network, even if the device is capable of using the correct AT&T LTE bands.

More importantly, an LTE-only radio with single-operator band support would be forever limited to operating on that one operator. If it were not in the native coverage of that operator, or where that operator had not yet deployed LTE service, it simply would not receive service even if another operator had deployed LTE at that location.

Furthermore, such single-operator devices can never be moved to another operator since the band support would not be available — this can be an untenable business risk.

2G AND 3G TECHNOLOGY FALL BACK

When not in LTE coverage, since some LTE devices fall back to 2G/3G CDMA technology families, and other LTE devices fall back to 2G/3G GSM families, roaming onto another operator may not be possible. Although cellular devices that fall back to both technology families do exist, these are quite expensive and not usable for IoT/M2M applications in most cases.

Cellular technology is gaining traction for several reasons including minimal infrastructure requirements, cost and ubiquity of coverage and global availability.

Today, 2G CDMA provides better coverage and service robustness for IoT/M2M applications since these devices can roam onto any operator who provides 2G and 3G CDMA services, once a roaming agreement is in place. Of course, 2G GSM can provide similar robustness, but due to the AT&T 2G GSM sunset, the technology longevity is simply too short for IoT/M2M applications.

Often, a device may be installed at a fixed location in a market where multiple operators provide data services. In these locations, the performance of the device can be optimized for better overall service if it is capable of roaming on any of the multiple operators. This is possible with 2G and 3G CDMA devices in the US, when roaming agreements exist.

SUMMARY

While IoT/M2M ushers in a new era of connected devices and applications to go with that, it's important to recognize that IoT/M2M use cases are fundamentally different from consumer smart phone applications. IoT/M2M requirements are unique, and several factors need to be considered in terms of providing the most robust connectivity solution that's also cost effective and satisfies the longevity requirements of utilities.

Cellular technology is gaining traction for several reasons including minimal infrastructure requirements, cost and ubiquity of coverage and global availability. Based on the customer need, the right technology solution can be deployed for the customer.

Badger Meter and Aeris understand the needs of utility customers very well. Badger Meter has also invested in solutions that support multiple cellular technologies and can communicate with multiple operator networks across the globe. Its managed solution assures the utility that buying decisions made today will be fully supported, and any migrations in the future will be handled seamlessly without service disruptions.

APPENDIX A. IP DATA THROUGHPUT

The various IP data protocols available in cellular technologies provide different data rates because of differing encoding protocols, channel bandwidths and the spectrum efficiency of the protocol.

This appendix provides the theoretical and typical data rates of the cellular IP data transports protocols in 2G and 3G technologies. For simplicity, data rates for only a few technology configurations are shown in Table 1. 3GPP Family Data Rates — the actual theoretical rates depend on the specific modulation, whether MIMO antennas are used, etc.

Since wireless channels are a shared resource at the cellular tower, the typical data rates are lower than theoretical data rates. Many variables affect the data rate: the number of devices accessing the IP network at the tower, time of day, how many sessions are active, etc.

3GPP FAMILY

TABLE 1. 3GPP FAMILY DATA RATES

Technology	Encoding		Downlink (kbits/sec)	Uplink (kbits/sec)
2G GPRS	TDMA	Theoretical	115	20 – 40
		Typical	5 – 20	5 – 10
2G EDGE	TDMA	Theoretical (4-8 slot)	236 – 473	64
		Typical	60 – 100	30
3G UMTS	W-CDMA	Theoretical	384	64
		Typical	200 (estimated)	30 (est.)
3G HSDPA	W-CDMA	Theoretical	14400	384
		Typical	600 – 1100	200 (est.)
3G HSUPA	W-CDMA	Theoretical	384	5760
		Typical	200 (est.)	500 – 1000
3G HSPA / HSPA+	W-CDMA	Theoretical	21000 – 42000	5760 – 11500
		Typical	1500 – 4000 (est.)	500 – 1500 (est.)

Table 1. 3GPP Family Data Rates does not show some of the recent specified improvements in HSPA and HSPA+ operation and performance. For example, using Dual-Operator HSPA where a mobile device can connect to two cell towers at the same time — theoretically doubling the data rates or MIMO antennas with multiple data streams.

3GPP2 FAMILY

TABLE 2. 3GPP2 FAMILY DATA RATES

Technology	Encoding		Downlink (kbits/sec)	Uplink (kbits/sec)
2G 1XRTT	CDMA	Theoretical	153	153
		Typical	60 – 100	60 – 100
3G EV-DO Rel. 0	CDMA	Theoretical (4-8 slot)	2400	153
		Typical	600 – 900	60 – 100
3G EV-DO Rev. A	CDMA	Theoretical	3100	1800
		Typical	600 – 1400	400 – 600

As can be seen in the tables, the 3G speeds in the GSM family (HSPA, etc.) are faster than the 3G speeds in the CDMA family (EV-DO, etc.). This is not surprising since HSPA uses channel widths of 5MHz, which are wider than EV-DO channel widths of 1.25MHz and can provide better throughput for similar encoding protocols.

And, just like cellular operation, the actual sequences in the call flows — whether authentication, authorization, or data related — between GSM and CDMA devices and the respective networks, are quite different, and beyond the scope of this document.

APPENDIX B. TEXTS ON CELLULAR TECHNOLOGIES

"3G, 4G, and Beyond: Bringing Networks, Devices and the Web Together," Martin Sauter. © 2013 John Wiley and Sons Ltd.

"GSM Networks: Protocols, Terminology, and Implementation," Gunnar Heine. © 1999 Artech House, Inc.

"CDMA Systems Engineering Handbook," Jhong Sam Lee, Leonard E. Miller. © 1998 J. S. Lee Associates, Ltd.

APPENDIX C. ACRONYMS AND GLOSSARY

1xRTT	Single Operator Radio Transmission Technology (used in ANSI-2000 CDMA)
1xEV-DO	Enhanced Voice-Data Only (also Enhanced Voice-Data Optimized)
2G	Second Generation Cellular
3G	Third Generation Cellular
3GPP	3rd Generation Partnership Project (GSM family of technologies)
3GPP2	3rd Generation Partnership Project 2 (CDMA family of technologies)
4G	Fourth Generation Cellular
AAA	Authentication, Authorization, and Accounting (see also RADIUS)
AMPS	Advanced Mobile Phone System, an Analog cellular mobile system using FDMA
ANSI-41	American National Standards Institute Standard 41, for control signal messaging on SS7
ANSI-95	American National Standards Institute Standard 41, for CDMA cellular
ANSI-136	American National Standards Institute Standard 41, for TDMA cellular
ANSI-2000	American National Standards Institute Standard 41, for CDMA2000 cellular
BS	Base Station
BSC	Base Station Controller
CDMA	Code Division Multiple Access
EDGE	Enhanced Data Rates for GSM Evolution
ESN	Electronic Serial Number (in CDMA); replaced by the MEID
EV-DO	Enhanced Voice-Data Only (also Enhanced Voice-Data Optimized)
FDMA	Frequency Division Multiple Access
GGSN	Gateway GPRS Support Node (see also SGSN)
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GSM MAP	GSM Mobile Application Part, for control signal messaging on SS7
HLR	Home Location Register
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSPA+	Enhanced or Evolved High-Speed Packet Access
HSUPA	High-Speed Uplink Packet Access
ICCID	Integrated Circuit Chip Identifier
IMEI	International Mobile Equipment Identifier (used in GSM)
IMSI	International Mobile Subscriber Identifier (used in GSM and CDMA)

ITU	International Telecommunications Union
IS-95	Interim Standard 95 (standard for CDMA Cellular)
IS-136	Interim Standard 136 (standard for TDMA Cellular)
LAN	Local Area Network
LTE	Long Term Evolution
MAP	See GSM MAP
MDN	Mobile Directory Number (used in CDMA — conceptually similar to the MSISDN in GSM)
MEID	Mobile Equipment Identifier (used in CDMA)
MIMO	Multiple Input, Multiple Output (in the context of antennas)
MS	Mobile Station (cellular radio handset or cellular M2M device)
MSC	Mobile Switching Center
MSISDN	Mobile Station ISDN (used in GSM)
RADIUS	Remote Authentication Dial-In User Service
SDO	Standards Development Organization
SGSN	Serving GPRS Support Node (see also GGSN)
SMC	Short Message Center
SMS	Short Message Service
SMSC	Short Message Service Center
SS7	Signaling System 7
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunications System
VLR	Visited Location Register
WAN	Wide Area Network

ABOUT AERIS

Aeris is a pioneer and leader in the market of the Internet of Things – as an operator of end-to-end IoT and M2M services and as a technology provider enabling other operators to build profitable IoT businesses. Among our customers are the most demanding users of IoT services today, including Hyundai, Acura, Rand McNally, Leica, and Sprint. Through our technology platform and dedicated IoT and M2M services, we strive to fundamentally improve their businesses – by dramatically reducing costs, improving operational efficiency, reducing time-to-market, and enabling new revenue streams.

Our global headquarters is in Silicon Valley (Santa Clara, California). Our European headquarters is near London, UK. Visit www.aeris.com or follow us on Twitter @AerisM2M to learn how we can inspire you to create new business models and to participate in the revolution of the Internet of Things.

ABOUT BADGER METER

Badger Meter is an innovator in flow measurement and control products, serving water utilities, municipalities, and commercial and industrial customers worldwide. The company's products measure water, oil, chemicals, and other fluids, and are known for accuracy, long-lasting durability and for providing valuable and timely measurement data. For more information, visit www.badgermeter.com.

Get in touch

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