The Emerging Market Opportunity for Cat-M1 in a 3 MHz Channel for Utility Broadband Networks

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Overview

As utilities and smart grid vendors continue to address the challenges of grid modernization, 3GPP LTE low power wide-area (LPWA) technologies will play a key role. While NB-IoT and Cat-M1 (also referred to LTE-M or Cat-M) are both viable alternatives for today's utility networks, Cat-M1 is becoming increasingly important due to the ability to deliver faster data rates (as compared to NB-IoT) as well as the low latency required for smart meters, distributed automation, and other grid modernization applications. Cat-M1 is widely supported in the 5 MHz ecosystem today. Demand for Cat-M1 in-band on a 3 MHz LTE channel is accelerating driven by expanding utility applications. Interviews with Anterix Active Ecosystem members (including chipset, modem, and device vendors) and a private LTE market-sizing analysis by Harbor Research both identified a strong market opportunity for Cat-M1 in private LTE networks for utilities.

Low Power Wide-Area (LPWA) Technologies in Utility Broadband Networks

Utilities need to modernize the grid to enhance resiliency against climate change impacts, help meet decarbonization goals and to integrate distributed energy resources (DER). A standards-based, private LTE communication network can support a wide array of fixed grid endpoints and mobile devices. Networks enabling many of today's utility solutions (i.e., meters and SCADA systems) operate on unlicensed spectrum. The radios and devices are designed for low throughput with limited security features and require technology coordination to work within interference constraints. These challenges are typical of a connectivity solution designed to meet the needs of a specific grid application.

3GPP standards-based technologies like LTE operate global standard equipment primarily on licensed spectrum and historically support targeted high-quality mobile voice and data services. LTE industry standard LPWA technologies like Narrowband IoT (NB-IoT) and LTE for machine-type communication (LTE-M or Cat-M1) are focused on delivering coverage and reliability for low-throughput devices. These technologies are designed to utilize LTE capacity more efficiently and can support higher density of fixed grid endpoints when compared to LTE. LPWA technologies are optimal connectivity options for utilities looking to take advantage of the enhanced battery life of devices and to connect devices that have been otherwise hard to reach. A simplified version of 4G is used, which reduces hardware complexity and cost, lowering the costs of the device ecosystem. Both NB-IoT and Cat-M1 are future-proofed – ready to support the evolution to 5G – which means utilities can be confident that the technology will be in place for the entire lifetime of their investment. An overview of LTE technologies and use cases for utility networks is provided in Figure 1.

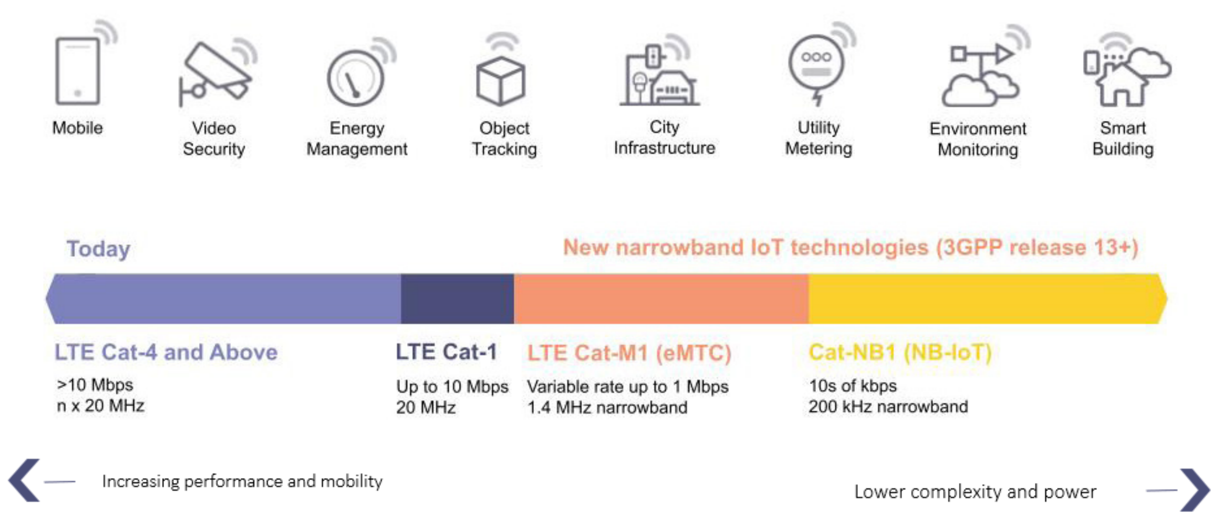

Figure 1: An overview of LTE technologies and use cases for utility networks

Market Adoption and Availability

Cat-M1 and NB-IoT are widely deployed in North and South America as well as Europe. NB-IoT is strong in Asia, especially in China. In a few years, both technologies should be available in all countries.

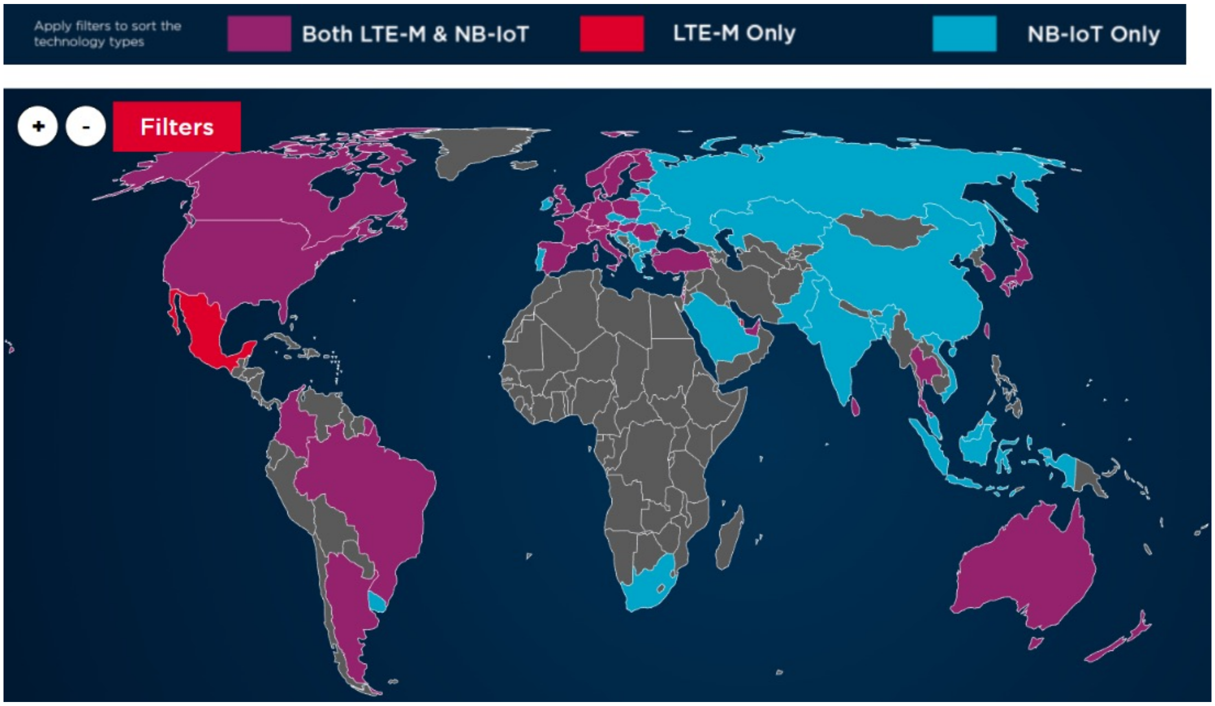

Figure 2: GSMA | Mobile IoT Deployment Map | Internet of Things

LPWA Capabilities and use cases

Each LPWA technology has characteristics that are well-suited to specific use cases, which is helpful to understand when forming a strategy to support utility broadband. Utilizing only 200 kHz of spectrum, NB-IoT is designed to efficiently address fixed devices that deliver small amounts of data at a low rate. NB-IoT is ideal for battery powered devices where small amounts of data on an infrequent sampling can extend battery life. As a narrowband technology, NB-IoT can provide long range coverage, strong signal penetration and greater cost efficiency compared to broadband. Use cases for NB-IoT include sensors, monitoring and diagnostics of transformers, and meter-reading associated with gas, water, and heat, particularly in residential applications. NB-IoT is not optimized for firmware downloads due to the limited bandwidth and impact on long-term battery life.

Cat-M1 provides increased data rates and low sub-second latency, supports both fixed and mobile communications (including voice), and enables more simultaneous connections or endpoints as compared to NB-IoT. Cat-M1 uses 1.4 MHz of spectrum when in use and can be deployed in-band within an LTE or 5G New Radio (NR) cell. Due to its higher bandwidth capabilities, Cat-M1 supports mobility and is better than NB-IoT at handling device and firmware updates and evolving use cases that require larger and more frequent data volume collection. Cat-M1 is an ideal choice when there is frequent interaction between the user equipment and the head-end system, including control applications and industrial scenarios. Though its ability to support higher throughput can impact device battery life, Cat-M1 typically supports meters which are connected to a constant power source. Also, as with other LTE technologies, Cat-M1 supports network resiliency.

If a serving cell site goes down, devices can connect to a neighboring site without having to re-attach to the network. Overall, Cat-M1 provides more adaptability to new use cases. The combination of higher throughput, quick responsiveness, and attractive cost per megabyte makes Cat-M1 an ideal choice for utilities to support today's real-time applications. Figure 3 below provides a summary of LTE LPWA technologies.

	Low Latency	Bandwidth	Voice Readiness	Spectral Efficiency	Number of Endpoints	Firmware Updates	Battery Life	Use Cases	Coverage Indoor
Cat-M1	☑☑☑	☑☑☑	☑☑☑	☑☑☑	☑☑☑	☑☑☑	☑☑☑	☑☑☑	☑☑☑
NB-IoT	☑☐☐	☑☐☐	☐☐☐	☑☑☐	☑☑☐	☑☐☐	☑☑☑	☑☐☐	☑☑☑

Figure 3: A summary of LTE LPWA technology strengths

Industry Support for Cat-M1 in a 3MHz Channel for Private LTE Use Cases

A significant majority of utility solution providers (e.g. providers of AMI, devices, modules and chipsets) from across the Anterix Active Ecosystem Program[1] confirmed a strong preference for Cat-M1 to support utility use cases. The members interviewed discussed the need for Cat-M1 to support AMI metering evolution, sensor aggregation in substations, monitoring, and diagnostics of transformers, as well as the benefits of embedding Cat-M1 capability in reclosers, line monitor sensors, and other utility equipment in support of distribution automation, transmission, and DER integration. Driven by utility requirements, Anterix Active Ecosystem members see an increasing demand to evolve from mesh AMI solutions to cellular to realize operations and maintenance benefits. Utilities are seeing the benefits of increased communication with

1. Anterix Active Ecosystem program research

meters to collect additional operational telemetry and gain increased real-time situational awareness – for example, detecting a fallen circuit (a fire threat) before the customer is aware –and many other use cases. Utilities are transitioning to utilize the meter as a sensor, increasing meter readings from hourly intervals to every few minutes to support billing, to manage distribution for power quality, and to provide new visibility and insights. Anterix Active Ecosystem members are even seeing RFPs requesting 1-minute interval readings to support bell weather meters. Real-time monitoring will provide insights to support capacity planning and resiliency, and it will help utilities deliver new and better services to customers. The real-time information collected also opens possibilities for new business models and opportunities for revenue generation.

The Ecosystem Supporting Cat-M1 in 3 MHz

The growth of Cat-M1 in 3 MHz private LTE is dependent on support across the ecosystem of devices, chipsets, and modules. A large ecosystem of Cat-M1 and LTE devices already exists for commercial networks using 5 MHz channels. As the industry moves to private LTE networks in the US 900 MHz band over the next few years, the device ecosystem for Cat-M1 in a 3 MHz channel is expected to accelerate rapidly. An increasing number of vendors are supporting Cat-M1 in a 3 MHz channel to support utility use cases including distribution automation, advance metering, pole sensors, and smart transformers, as well as DER use cases like smart inverters. The Anterix Active Ecosystem Program continues to foster the rapidly expanding set of vendors that support US 900 MHz private LTE.

Voices of the Ecosystem

“Cat-M1 volumes are growing in the US and we expect the same growth in 900 MHz for utilities.”

“Customers are selecting Cat-M1 consistently in the US.”

“Cat-M1 delivers the highest volume, revenue and profit to the business.”

“Cat-M1 will provide longevity in the market for 10-15 years or more.”

“Cat-M1 is a very good go-to communications technology for all types of meters in the field.”

“There is a large market opportunity for Cat-M1 for many years.”

“Use cases include sensor aggregation in substations, monitoring, and diagnostics of transformers.

Low-cost Cat-M1 modules and components are attractive.”

“We are now using the meter as a sensor, reading it every 5 minutes to support billing, distribution management for power quality, providing new insights.”

“Cat-M1 is required for most applications...and is even more of a requirement for smart meters due to bandwidth requirements.”

“Cat-M1 is ideal for multi-applications networks; primary applications are metering and distribution automation and monitoring.”

The Market Opportunity

In the Anterix research conducted with Anterix Active Ecosystem members[2], they predicted strong growth of Cat-M1 for utility use cases over the next decade driven by the need for more robust data across new and existing applications. Estimations by some members project a possible 20-30% growth rate, which reflects the strong utility requirements for Cat-M1 devices. Some meter vendors expect that approximately 20% of the market will be under the glass by 2025. With the signing of the Bipartisan Infrastructure Law (BIL), the market may accelerate dramatically beyond these projections.

Anterix also commissioned Harbor Research[3] to conduct a market opportunity study on private network and 900 MHz growth opportunities supporting grid modernization applications across the utility industry. The focus of the analysis is the electrical power utilities segment and critical infrastructure more broadly, including environmental and civil infrastructure, water utilities, urban systems, and public venues. According to the research, the private LTE total addressable market (TAM) for electric utilities is projected to reach 189 million endpoints by 2032, representing a compound annual growth rate (CAGR) of 28% from 2022-2032. The research data indicates that the Cat-M1 electric market opportunity in 3 MHz private LTE networks could reach 116 million endpoints by 2032, with potential to extend endpoints within utility service areas or expand into other verticals. As shown by the market projections, Cat-M1 is a strong driver for 900 MHz private LTE and the utility market.

2. “Anterix Active Ecosystem Research Study” (August 2022)
3. “Critical Infrastructure Private Networks Opportunity,” *Harbor Research* (May 2022)

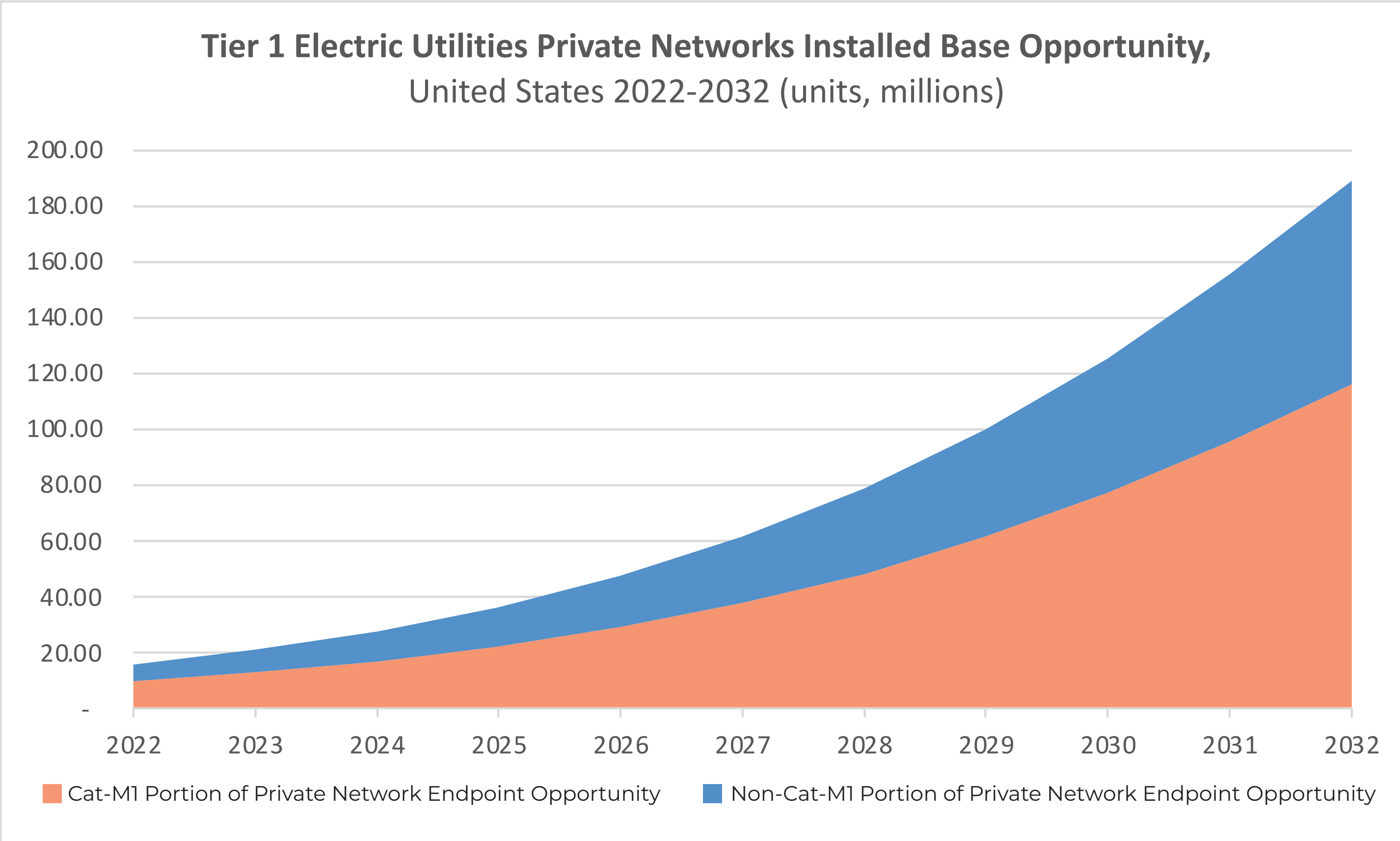

Figure 4: The market opportunity for Cat-M1[4]

Evaluating Cat-M1 for IoT Solutions

The relative advantage in deep coverage provided by Cat-M1 when compared to LTE and 5G is shown in Figure 5. While LTE and 5G New Radio (NR) provide higher data rates, NB-IoT provides the maximum coverage, but at a much lower data throughput. Cat-M1 provides the optimal trade-off between data rate performance and coverage to support utility applications.

4. "Critical Infrastructure Private Networks Opportunity," *Harbor Research* (May 2022)

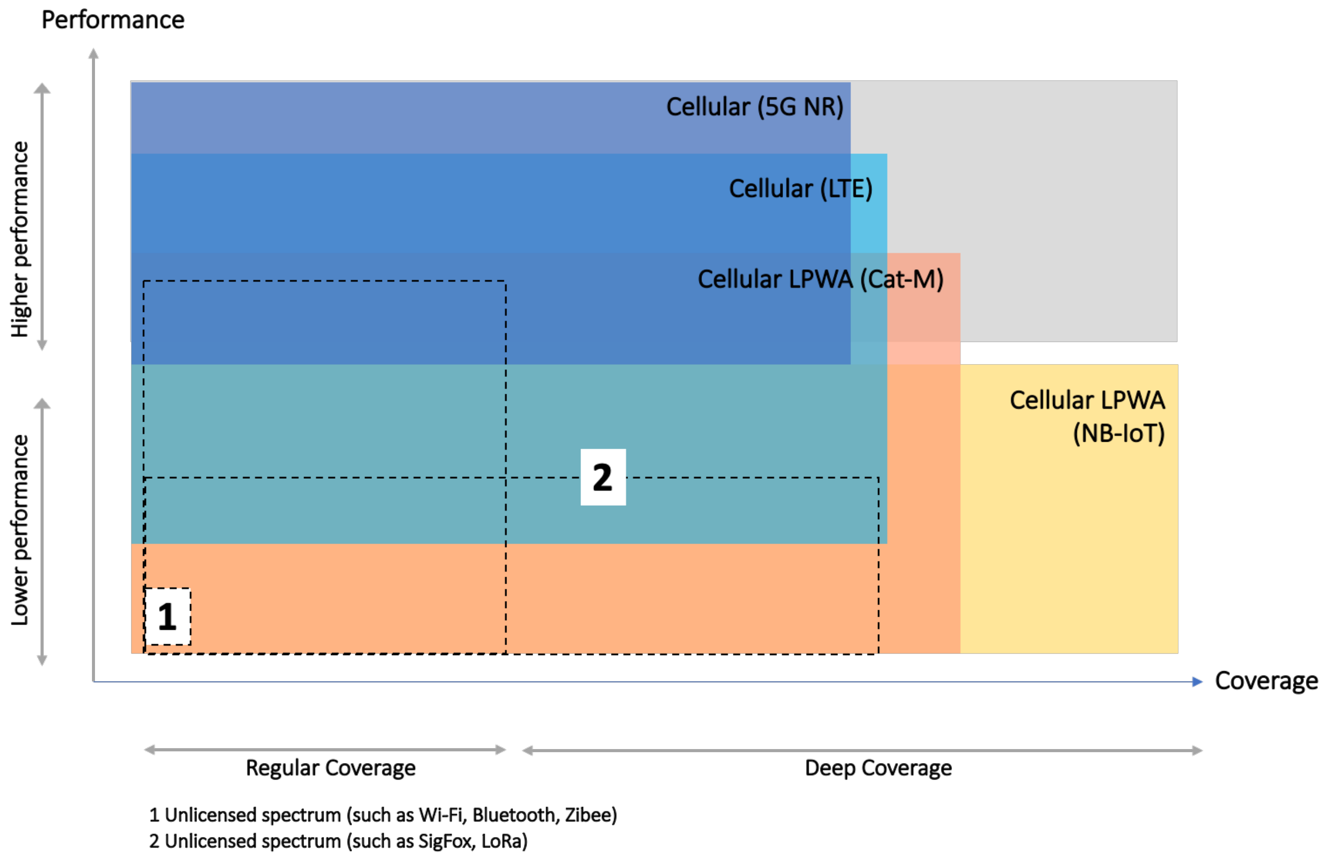

Figure 5: Cat-M1 capabilities compared to other communication technologies[5]

The comparison between NB-IoT, Cat-M1 and LTE technologies is provided in Figure 6:

- Spectrum: NB-IoT occupies the least spectrum (200 KHz), while LTE occupies the most (1.4 MHz, 3 MHz, 5 MHz, 10 MHz or 20 MHz). Cat-M1 occupies 1.4 MHz.
- Cell range: Cat-M1 delivers the optimal cell range at up to 100km (higher than NB-IoT) supporting the high signal penetration required for the remote and varied locations of utility endpoints.
- Uplink peak speeds: Cat-M1 supports higher uplink speeds (in comparison to NB-IoT) that are required for advanced metering and other utility use cases.
- Deployed in 1.4, 3, 5, 10 or 20 MHz channels depending on availability of LTE spectrum.
- Battery life is use case dependent. Cat-M1 supports more frequent use with higher throughput, which may reduce the battery life more quickly, however smart meters are typically powered devices.
- Latency: Cat-M1 has superior responsiveness (120ms) as compared to NB-IoT (800ms). LTE provides the best responsiveness (40-80ms) at the expense of coverage.
- Mobility: Cat-M1 allows devices to move while they are connected (unlike NB-IoT devices that need to re-connect)

5. “Whitepaper on cellular networks for Massive IoT,” *Ericsson*

	NB-IoT	Cat-M1	LTE[1]
Channel Size	200 kHz	1.4 MHz	3, 5, 10, 20 MHz
Latency	800 ms	120 ms	40-80 ms
Uplink Peak speeds	~151 kbps	~1,119 kbps	5 Mbps
Dnlink Peak speeds	~118 kbps	~500 kbps	10 Mbps
Cell Range	Up to 120 km	Up to 100 km	10-20 km
Deployment	In-band; Guard band; Standalone	In-band	Designated broadband segment
Battery Life[2]	Up to 10 years	Up to 10 years	Use case dependent
Usage	Fixed Only	Fixed and Mobile	Fixed and Mobile
Voice	Not supported	VoLTE	VoLTE
UE Energy Efficiency[3]	PSM, eDRX, RAI	PSM, eDRX, cDRX, RAI	PSM, eDRX

Figure 6: Comparison of technologies

1. *Deployed in 1.4, 3, 5, 10 or 20 MHz depending on availability of LTE spectrum.*
2. *Battery life is use case dependent. Cat-M1 supports more frequent use with higher throughput, which impacts the life of the battery but Cat-M1 is typically connected to a power source. The Primary use case is meters which are directly powered.*
3. *Power Saving Mode (PSM); Release Assistant Indication (RAI) was introduced in Release 13 to release the UE to Idle mode quickly to save power; eDRX – extended DRX for IoT; cDRX – connected mode DRX is introduced to improve UE battery power consumption by allowing the UE to periodically enter 'sleep' state.*

Performance and Deployment Considerations for Cat-M1 in 3 MHz Channel

3GPP LTE technology is designed to simultaneously carry Cat-M1, LTE, and NB-IoT traffic. An important consideration is the amount of spectrum available to carry all these types of traffic simultaneously. A 3 MHz channel can carry a maximum of two carriers of Cat-M1. Cat-M1 delivers lower throughput than LTE with average uplink device speeds between 200 kbps and 400 kbps (as compared to 1-3 Mbps on LTE 3 MHz). The corresponding speeds for traffic bursts could be up to 3 times these values.

NB-IoT offers multiple deployment options. It can be deployed in-band (within the full LTE allocation), in a guard band (the space reserved between bands to avoid interference) or standalone. NB-IoT can use a dedicated out-of-band channel (in a narrowband channel outside of the dedicated LTE band) however, additional spectrum would be required.

As utilities continue to deploy spectrum, network evolution can occur in stages. With initial access to 1.4 MHz of spectrum, utilities can deploy with a single carrier of 1.4 MHz of LTE.

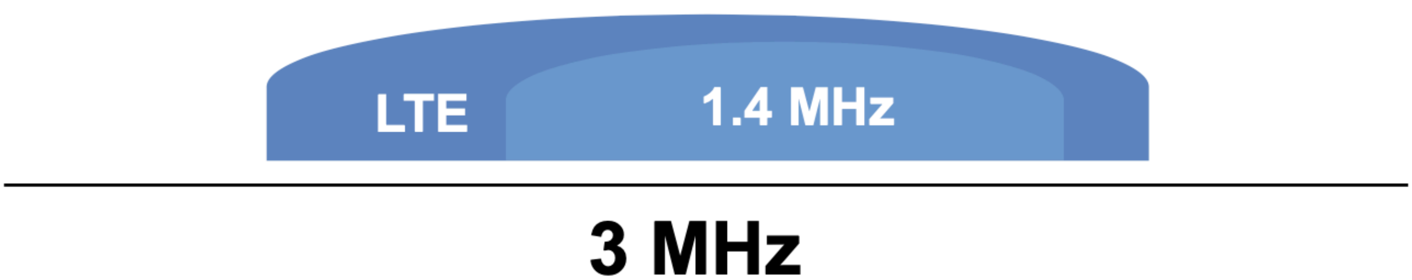

Figure 7: Initial 1.4MHz LTE deployment

In 3 MHz of spectrum, LTE can be deployed with either Cat-M1 or NB-IoT to support different use cases at a site but not in the same sector. This would allow for serving of multiple nearby devices with the LTE 1.4 MHz carrier, and the NB-IoT carrier becomes in-band to 3 MHz of LTE spectrum. This also adds capacity that allows for serving more nearby LTE devices. Additional NB-IoT carriers can be added for more narrowband capacity.

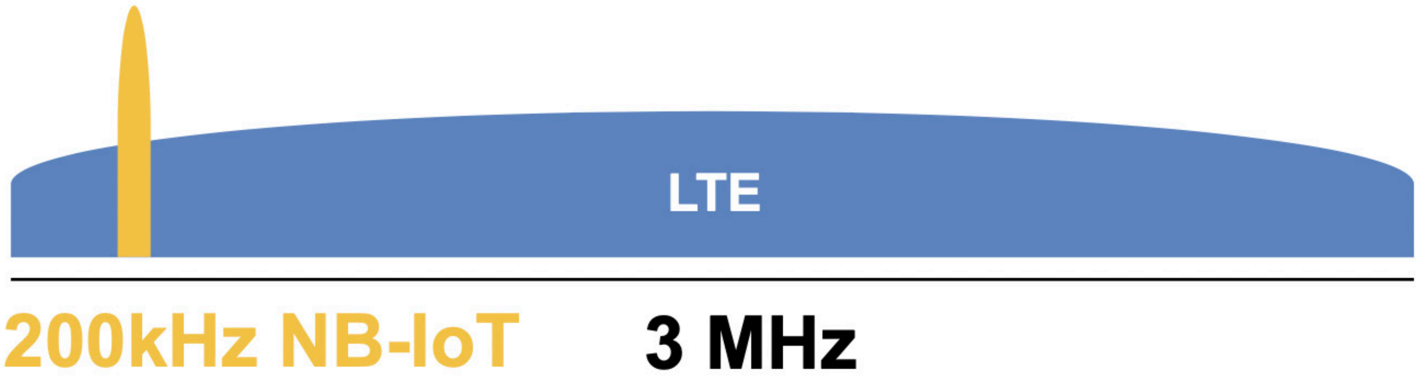

Figure 8: NB-IoT deployment in 3MHz spectrum

With the introduction of devices like smart meters that require both strong signal penetration and a robust uplink, it is time to introduce a flexible in-band 1.4 MHz LTE-M carrier to address Cat-M1 devices. With careful consideration of the capacity trade-offs, continuation of the in-band NB-IoT carrier is also an option as balancing all three – NB-IoT, Cat-M1 and LTE – with 3 MHz of spectrum resources is a challenge.

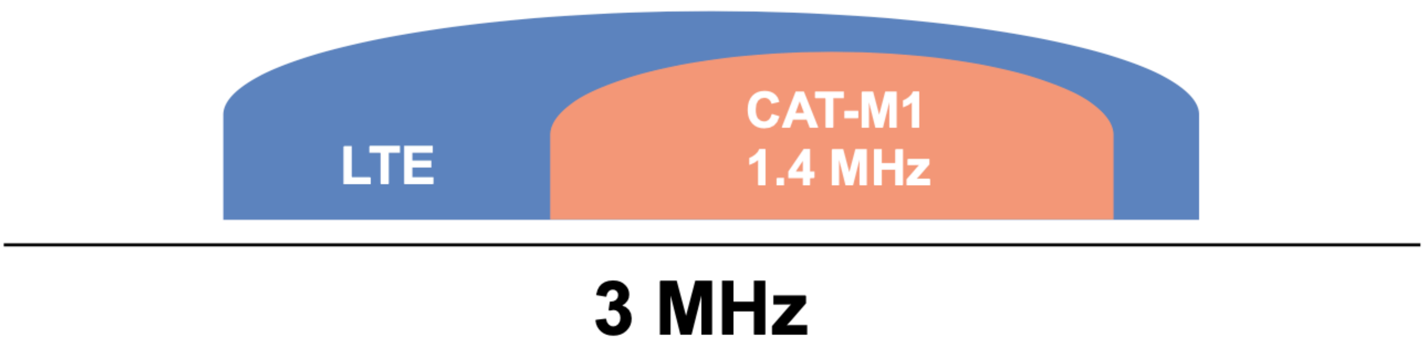

Figure 9: Cat-M1 deployment in 3MHz spectrum

The active and idle capacity usage of Cat-M1 is an important consideration for utilities that are considering the use of LTE and Cat-M1/NB-IoT on their private LTE networks. Cat-M1 occupies about half the available capacity on 3 MHz of spectrum in active traffic and approximately 20% of the capacity when idle. This restricts the simultaneous use of spectrum by LTE devices, limiting the number of devices that can communicate concurrently, as well as capacity and throughput on the LTE uplink and downlink. However, the Cat-M1 benefits of enhanced coverage, high signal penetration, and high device density outweigh the capacity occupied by Cat-M1. These factors, together with the high data rates as compared to NB-IoT, make Cat-M1 an ideal choice to meet utility needs for advanced metering and other emerging use cases. In addition, superior signal penetration by Cat-M1 allows access to low-speed devices more distant from the tower.

Planning for the traffic mix of Cat-M1 and LTE is critical to deliver a congestion free, reliable experience to smart grid devices. The capacity needed for LTE devices needs to be balanced with the capacity assigned to deep penetration devices reached by Cat-M1. RAN scheduling and Quality of Service (QoS) prioritization are two techniques used to address this balance.

RAN schedulers are built to dynamically share LTE spectrum between Cat-M1 and LTE simultaneously. Radio resources are assigned and re-assigned every millisecond based on traffic demand, maximizing spectral efficiency. When a Cat-M1 device is not demanding traffic resources, all of the available spectrum can be used for LTE traffic. Similarly, when a Cat-M1 or NB-IoT device comes online, the scheduler assigns spectrum resources instantaneously to that device. The spectrum resources get distributed between LTE technologies utilizing algorithms based on fairness, round robin, or other considerations.

Quality of Service (QoS) is an essential tool in the toolbox for companies focused on critical communications. Utilities deploying private LTE networks have the ability to prioritize the traffic of its most critical applications and provide the best path to establish a connection. LTE QoS and QoS class identifiers (QCI) enable that assignment. Hence, if a particular device on the private network required a connection, it could gain access regardless of the technology used. This is based on planning of priority across the variety of devices and use cases in the overall traffic mix.

Deployment Scenarios for Cat-M1

To set up deterministic connectivity for devices in a private LTE network, a coverage analysis is initially done, based on the local geography, to identify the grid of base stations. Based on further analysis of device distribution and required traffic capacity, densification of the initial grid occurs to add more sites. NB-IoT and Cat-M1 allow for larger coverage areas to cover devices with lower data rates, while LTE allows for higher data rates with lesser coverage areas.

The advantageous combination of deeper coverage and adequate speeds make Cat-M1 viable for smart meters and many other grid devices that utilities need to support. Coverage of wireless networks is highly dependent on the height and orientation of the base station and device antennas – higher antennas support increased coverage. A network designed for utility distribution grid automation usually considers devices at the height of the average utility pole.

The challenges and considerations in providing wireless connectivity for the smart grid as shown in Figure 10 can include:

- Devices at substations and rural meters are easily reached when the antennas are mounted at a greater height to allow for deeper coverage.
- Devices like voltage regulators, reclosers and capacitor banks are mounted above the ground, and can be reached from radio antennas mounted at a nominal height from the ground.
- Devices like residential, commercial meters or energy storage devices inside buildings are mounted close to the ground, and easily blocked by buildings, walls and foliage. These require radio solutions that are focused in their coverage.

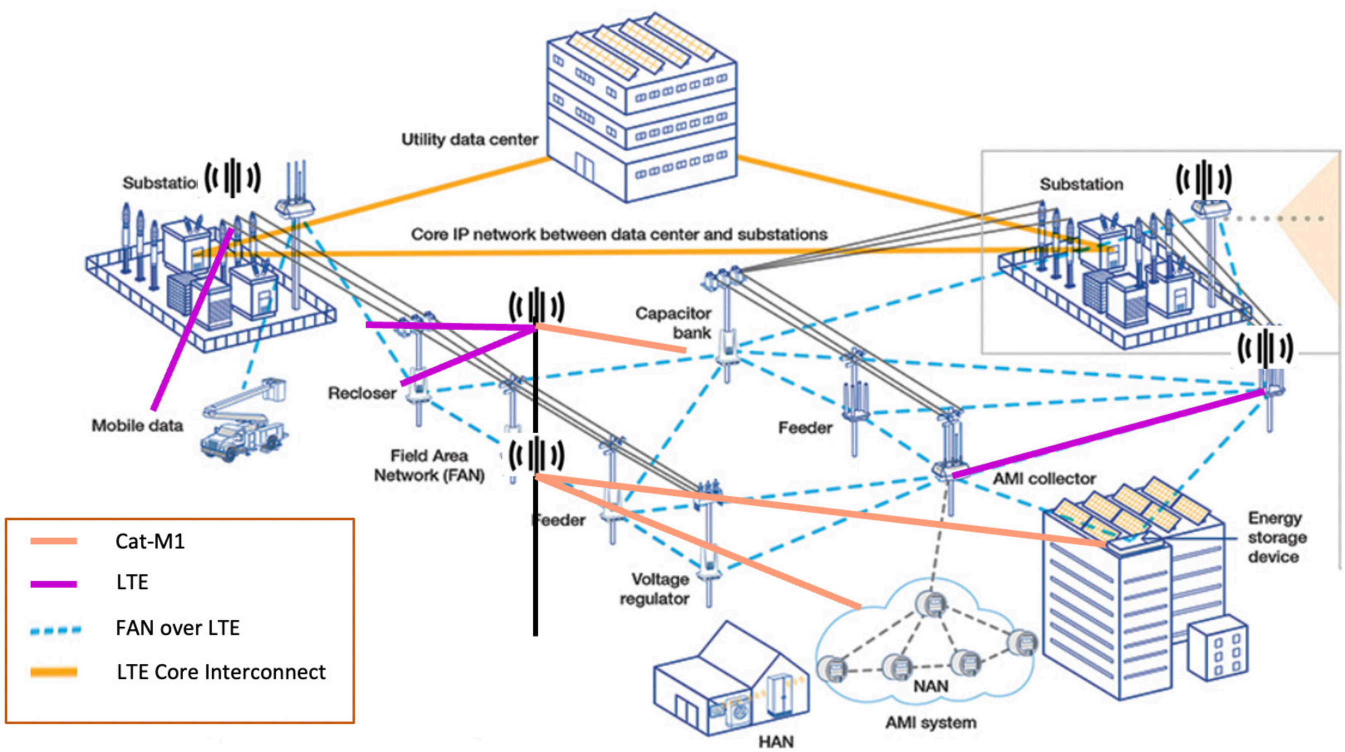

Figure 10: Illustration of network deployments considering Cat-M1 and LTE

Therefore, as wireless networks are enhanced to cover meters, they need to consider that the meters are much closer to the ground and could be located inside a building. This requires an estimated three times the number of wireless sectors to cover smart meters as compared to Distribution Automation (DA). The superior coverage characteristics of Cat-M1 allow for an optimized rollout.

LTE sites can be configured to support both LTE and Cat-M1 depending on the direction in which the traffic demand lies. Figure 10 also highlights some of the following use cases:

- The site at the center of Figure 10 has radios mounted at two different heights to address different use cases addressed in the description above.
- One of the sectors at the top of the site addresses LTE traffic for both the reclosers and pole-top transformers, while a different sector at the top provides Cat-M1 traffic to a capacitor bank that is a distance away from the site.
- The radios lower on the same site are positioned to provide focused deep penetration coverage to both the Cat-M1 smart meters in the community and the Cat-M1 energy storage device at the top of a nearby building.
- An alternate way to address smart meters that are not SIM-enabled is for the site near the substation on the right of the figure to address the pole-top AMI collector with LTE coverage, which then connects to the meters for periodic reporting over best-effort mesh network technology.

LTE 3 MHz-channel deployments are designed to cover at least 4,000 devices per radio site location. The number of Cat-M1 devices covered by a radio site are also dependent on the depth of Cat-M1 coverage, as speeds decrease with depth of coverage. Thus, speeds could be affected if a large number of the devices are deep inside a building.

As the smart grid is modernized, the approach is usually to deploy LTE on high structures to maximize coverage for distributed automation use cases that send low volumes of data to the network. As a next step, NB-IoT is deployed on the same base stations to allow for deeper coverage for the smart grid with similar data volumes. Finally, the smart home or smart industry is addressed with a technology like Cat-M1 that allows for larger volumes of data to be sent back to the network. During this stage, additional base stations are deployed as necessary to provide both focused coverage and adequate capacity for the continuation of existing DA traffic, while providing superior performance from Cat-M1.

Conclusions

The market opportunity for Cat-M1 supporting utility broadband use cases is growing, driven by Cat-M1's coverage and capacity benefits, new utility use cases, and a strong emerging ecosystem. Anterix Active Ecosystem members are developing a robust set of devices that support Cat-M1 to be deployed on a 3 MHz private LTE network, which is an indicator of the projected market growth. Cat-M1 is a strong option for utility broadband networks—delivering the bandwidth, coverage, low latency, and support for new use cases that utilities require. Use cases for Cat-M1 are rapidly expanding beyond distribution automation, to include advanced metering applications. The advantageous combination of deeper coverage and adequate speeds makes Cat-M1 an attractive choice to support smart meters and many other grid devices. The utility deployment scenarios reviewed in this paper provide a blueprint for how Cat-M1 can be deployed together with LTE and NB-IoT to support utility business goals including clean energy, DER integration, grid modernization, and new business models. Leveraging these insights and careful planning, utilities can successfully integrate these LPWA technologies to achieve the optimal network performance and coverage in support of their emerging grid applications.

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