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eMTC Report

Technical Specification and Declared Patent Analysis for eMTC in 3GPP Standardisation

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Purpose of the Report

As the eMTC market evolves it is essential that patent owners and licensees have a clear understanding of the competitive landscape. This report provides information in the form of raw data, and also analysis and commentary on that data. The information contained within this report enables patent holders to better negotiate license terms, and also to avoid eventual license enforcement. Implementers can also benefit by checking their assertive patents.

There are three specific types of information provided within this report: specification numbers for eMTC (see page 18), identification of relevant sections and releases (see page 18) and, an understanding of top contributors in the market (see pages 22–26).

By focusing on technology-centric analysis, stakeholders are empowered with the knowledge they need to make informed decisions about technology investments and patent strategies.

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1. Introduction

1.1 What is eMTC?

eMTC (enhanced Machine Type Communication) is a low-power wide-area (LPWA) technology designed to support machine to machine (M2M) and Internet of Things (IoT) applications within the cellular network infrastructure. In particular, it is a sub-type of LTE-M (Long-Term Evolution for Machines) network and is called LTE-M1 or LTE Cat-M1. It is common for the terms eMTC and LTE-M to be used interchangeably.

1.2 How does eMTC work?

eMTC utilises the existing cellular network infrastructure and implements specific enhancements to support IoT and M2M applications. eMTC operates in the following manner:

- **Device registration:** eMTC-enabled devices, such as IoT sensors or M2M modules, register with a cellular base station to establish a connection. This registration process allows the device to be recognised within the network.
- **Network synchronisation:** Once registered, the device synchronises with the cellular network to ensure that it operates on the correct frequency and time slots for communication.
- **Narrowband transmission:** After synchronisation, the device is ready for transmission. eMTC uses narrowband techniques, such as Narrowband IoT (NB-IoT), to transmit data over a narrow frequency band. This narrowband design optimises spectrum usage which in turn allows for a large number of devices to be connected within a single cell.
- **Power optimisation:** To transmit data over long distances, power saving is important. eMTC devices are designed for low-power operation to conserve energy and to extend battery life. They can operate in power-saving modes in which they periodically wake up, transmit or receive data, and then enter sleep mode to conserve power.
- **Quality of Service (QoS):** To cater to diverse IoT applications, eMTC supports different levels of Quality of Service. It provides mechanisms to prioritise and manage data traffic based on specific requirements to ensure that critical data is delivered reliably and in a timely manner.
- **Extended coverage:** To communicate over long distances and penetrate through obstacles like buildings or walls, eMTC offers enhanced coverage capabilities. This extended coverage ensures reliable connectivity even in challenging environments.
- **Integration with cellular networks:** eMTC seamlessly integrates with existing cellular networks, leveraging the infrastructure and coverage of LTE networks. It can coexist with other cellular technologies, allowing for a smooth transition and compatibility with the existing network ecosystem.

eMTC provides a reliable, low power, and cost effective solution for connecting IoT and M2M devices within the cellular network infrastructure. Its narrowband transmission, power saving features, quality of service support, and extended coverage make it well suited for a wide range of IoT applications across industries.

1.3 Standards

The development of eMTC involves several standard developing organisations that work collaboratively to define the specifications and guidelines for its implementation. The key organisations involved in shaping eMTC standards are 3GPP, and GSMA. These organisations engage in ongoing research, discussions, and standardisation efforts to refine and evolve the specifications for eMTC. Through their collective expertise and collaboration, they contribute to the development of robust and globally accepted standards that drive the widespread adoption of eMTC and enable seamless connectivity and communication among diverse M2M devices and systems.

1.3.1 3GPP

The 3rd Generation Partnership Project or 3GPP is a conglomerate of seven “organisational partners” – ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC – functioning for the demarcation of telecommunication standards by releasing technical reports and specifications. 3GPP is responsible for developing the standards for mobile communication systems, including eMTC. 3GPP defines the technical specifications, protocols, and requirements that ensure interoperability and compatibility across different network operators and vendors.

1.3.2 GSMA

GSMA is an industry association that represents the interests of mobile network operators worldwide. It provides a platform for collaboration and knowledge sharing among industry stakeholders, including operators, vendors, and other organisations involved in eMTC deployment. GSMA works towards ensuring interoperability, promoting best practices, and facilitating the adoption of eMTC technologies.

1.4 Evolution of eMTC

eMTC has evolved through different releases of the 3GPP standards to address the specific needs of IoT and M2M communications. Each release has introduced new features, optimisations, and enhancements, making eMTC more efficient, reliable, and suitable for a wide range of IoT applications. The ongoing development and refinement of eMTC standards ensure that it remains at the forefront of enabling seamless connectivity and communication for the ever-expanding world of IoT.

Overview of the evolution of eMTC through 3GPP releases:

Release 13

Release 13 introduced the initial specifications for eMTC, also known as LTE Cat-M1 (Long-Term Evolution for Machines). It focused on providing enhancements to the LTE network to support IoT and M2M communications. Release 13 brought improvements in terms of reduced power consumption, extended coverage, and increased device density.

Release 14

Release 14 introduced LTE Cat-M2, an upgrade to LTE Cat-M1. It further enhanced eMTC by introducing features like enhanced coverage, reduced complexity, and improved support for IoT device requirements. It included optimisations for low-cost, low-power devices, making eMTC more suitable for a wide range of IoT applications. Release 14 also introduced the concept of positioning enhancements for improved location accuracy.

Release 15

Release 15 marked a significant milestone for eMTC with the introduction of Narrowband IoT (NB-IoT). NB-IoT is a narrowband radio technology specifically designed for IoT applications, offering improved coverage, lower device complexity, and extended battery life. Release 15 expanded the capabilities of eMTC by providing a standardised NB-IoT solution that can operate in various frequency bands.

Release 16

Release 16 further enhanced eMTC by introducing features like advanced positioning techniques, higher data rates, and improved support for massive IoT deployments. Release 16 also introduced multi-connectivity, enabling devices to connect to multiple networks simultaneously for enhanced reliability and coverage.

Release 17

Release 17 seeks to enhance the performance of the 5G system, serve new use cases and verticals, and offer ubiquitous connectivity in various deployment settings and scenarios. Public safety, non-terrestrial networks (NTN), non-public networks (NPN), improved positioning, improved multicast/broadcast, improved URLLC/mMTC/IAB, and improved sidelink are some of the features and advancements for MTC. [1]

Release 18

This release is scheduled for the second half of 2023. It is advertised as the first 5G Advanced release and represents a significant advancement of the 5G system. By using machine-learning-based approaches at various layers of the network, it adds additional intelligence to wireless networks. Extended reality (XR) and artificial intelligence (AI) are two examples of new use cases that it supports. AI/MLenabled network slicing, URLLC/mMTC/IAB/sidelink/NTN/NPN/positioning/multicast/broadcast, and AI/ML-enabled network optimisation are some of the proposed features and improvements for MTC.

Table 1 Features and enhancements in MTC within each release

3GPP Release	Enhancements
Rel-13 (2016)	Bandwidth limited operations (1.4 MHz), coverage enhancement (CE Mode A/B), half-duplex support, in-band operation mode, RRC connection suspend/resume, data transmission via the control plane, extended DRX, mobility support
Rel-14 (2017)	Positioning enhancements (E-CID requirements and OTDOA support), multicast support using SC-PTM, larger channel PDSCH/PUSCH bandwidth (up to 5 & 20 MHz), higher data rates, VoLTE enhancements, HARQ-ACK bundling, support of inter-frequency measurements
Rel-15 (2018)	Wake-up signal, early data transmission, resynchronisation signal, 64-QAM support in the downlink, relaxed UE monitoring, flexible starting PRB, support higher UE velocity, lower UE power class, improved load control of idle UEs, eDRX enhancements. [2]
Rel-16 (2020)	Grant-free uplink transmission, scheduling of multiple transport blocks using one grant, group wake-up signal, connection to 5G core, NR coexistence enhancement, stand-alone eMTC carrier, control channel performance enhancement

1.5 Categories

1.5.1 Cat M1

eMTC UE category was introduced in 3GPP Release 13 specification as LTE Cat M1. LTE Cat M1 is sometimes used synonymously with eMTC. It trades in high data rate delivered by LTE for better power efficiency and longer signal range and is therefore considered an IoT cellular technology. [3]

1.5.2 Cat M2

LTE Cat M2 is the second category of Long Term Evolution Machine Type Communication (LTE-M) standard introduced in 3GPP Release 14. It is a direct upgrade to LTE Cat M1 that offers more than three times the bandwidth, several times the download and upload speed of Cat M1, lower power consumption, enhanced coverage, and longer battery life. In particular, LTE Cat M2 supports a peak uplink data rate of around 7 Mbps and a peak downlink data rate of around 4 Mbps compared to 1Mbp in LTE Cat M1. LTE Cat M2 also has a bandwidth of 5 MHz compared to 1.4 MHz for Cat M1. Like LTE Cat M1, LTE Cat M2 also operates in both Half-Duplex and Full-Duplex modes. Thus, LTE Cat M2 offers the same advantages as Cat M1, but with faster speeds. These fast data speeds make it suitable for applications that require real-time data transfer. In addition, LTE Cat M2 operates using existing LTE networks, within the same LTE band used for cellular applications similar to LTE Cat M1. [4] [5]

Table 2 Difference between LTE CAT M1 and LTE CAT M2

	eMTC	
	LTE Cat M1	**LTE Cat M2**
3GPP Release	Release 13	Release 14
Downlink Peak Rate	1 Mbit/s	approx. 4 Mbit/s
Uplink Peak Rate	1 Mbit/s	approx. 7 Mbit/s
Latency	10–15 ms	10–15 ms
Number of Antennas	1	1
Duplex Mode	Full or Half Duplex	Full or Half Duplex
Device Receive Bandwidth	1.4 MHz	5 MHz
Receiver Chains	1 (SISO)	1 (SISO)
Device Transmit Power	20 / 23 dBm	20 / 23 dBm

1.5.3 5G eMTC

5G eMTC refers to the implementation of eMTC technology within the context of the 5G wireless communication standard. [6] 5G eMTC builds upon the foundation of eMTC in LTE and introduces enhancements to further optimise IoT connectivity in a 5G ecosystem. It leverages the advanced features of 5G, such as higher data rates, lower latency, increased capacity, and improved reliability, to deliver improved performance and capabilities for IoT applications. Some key features of 5G eMTC include:

1. **Ultra-Reliable Low-Latency Communication (URLLC):** 5G introduces URLLC, which provides ultra-low latency and high reliability for critical IoT applications that require real-time communication and rapid response times.
2. **Massive IoT connectivity:** 5G eMTC is designed to support massive connectivity, enabling a large number of IoT devices to be connected simultaneously. It allows for efficient management and communication with a vast array of IoT devices within the network.
3. **Network slicing:** 5G networks can be divided into network slices, which are virtual networks tailored to specific requirements. This allows dedicated slices for eMTC, ensuring optimised connectivity and resources for IoT devices.

1.6 Technologies related to eMTC

1.6.1 Machine to Machine (M2M) communication

Machine to Machine (M2M) communication refers to the exchange of data and information between devices or machines without human intervention. It enables devices to communicate, interact, and collaborate with each other, typically through a network connection. M2M communication involves devices equipped with sensors, actuators, and other components that facilitate the collection, transmission, and analysis of data. The primary goal of M2M communication is to enable machines or devices to communicate and collaborate to perform tasks, make decisions, and exchange information autonomously. This communication can occur within a local network or over a wide area network (WAN) such as the Internet or cellular networks. eMTC is designed to enable efficient M2M communication over cellular networks.

1.6.2 Internet of Things (IoT)

The Internet of Things embodies a network of things connected to each other over the Internet or a network for the exchange of data and information. eMTC is specifically designed to cater to the communication needs of IoT devices to provide a reliable, efficient, and standardised connectivity solution for a wide range of IoT applications. By utilising eMTC, IoT devices can establish seamless communication with each other and with cloud-based services, enabling data exchange, remote control, and real-time monitoring. In addition, Both IoT and eMTC revolve around the concept of massive connectivity. IoT envisions a network of billions of interconnected devices, and eMTC is designed to handle such scale.

1.6.3 Machine Type Communications (MTC)

Machine Type Communications (MTC) are a specialised category of wireless communication that is designed to facilitate seamless connectivity between a large number of IoT devices. MTC enables efficient communication and data exchange among machines, devices, and systems, without the need for human intervention. It plays a pivotal role in enabling the growth and development of various industries by providing reliable, low power, and cost effective connectivity solutions for a wide range of IoT applications. MTC is a broad concept encompassing various technologies for M2M communication, while eMTC is a specific implementation of MTC using the LTE standard. eMTC builds upon the foundation of MTC and introduces enhancements and optimisations tailored to IoT device communication, offering improved performance, power efficiency, and scalability.

1.6.4 LTE-M

LTE-M, also known as LTE Cat M or Long-Term Evolution for Machines, is based on the LTE standard, which is a widely deployed cellular technology used for high-speed mobile communications. eMTC is a sub-type of LTE-M network and both are closely related as they refer to the same technology designed to enable IoT and M2M communications. LTE-M is often used as another term for eMTC, particularly in the context of cellular networks to refer to the same set of standards and technologies specified by 3GPP. These standards define the technical specifications, protocols, and requirements for eMTC/LTE-M networks, ensuring interoperability and compatibility across different network operators and vendors. Also, GSMA (Global System for Mobile Communications) has selected "LTE-M" as the preferred term when publicly referring to Cat M1 networks. However, it is important to mention the difference between eMTC and LTE-M as an eMTC Cat M1 network is limited to 1.08 MHz channel width, and thus has a maximum data rate of 1 Mbps, whereas an LTE-M device may have a data rate up to 10 Mbps by using any existing LTE channel width.

1.6.5 BL/CE

Bandwidth Reduced Low Complexity and Coverage Enhancement or BL/CE is a term used to describe a set of techniques or approaches that aim to improve the performance and efficiency of wireless communication systems, particularly in terms of bandwidth utilisation, complexity, and coverage capabilities. It refers to methods and strategies that optimise the use of available bandwidth while minimising the complexity of signal processing algorithms and enhancing the coverage range of wireless networks. eMTC incorporates BL/CE for bandwidth reduction, complexity reduction, and coverage enhancement which makes BL/CE integral to eMTC. Thus, eMTC is sometimes referred to as BL/CE.

1.7 eMTC Band Support

Cat M1 utilises 1.4 MHz bandwidth, leveraging existing LTE numerology, and can be deployed to operate within a regular LTE carrier (up to 20 MHz). Cat M1 devices will leverage legacy LTE synchronisation signals (e.g., PSS8, SSS9) while introducing new control and data channels that are more efficient for low bandwidth operations. LTE network supporting Cat M1 can utilise multiple narrowband regions with frequency retuning to enable scalable resource allocation, and frequency hopping for diversity across the entire LTE band.

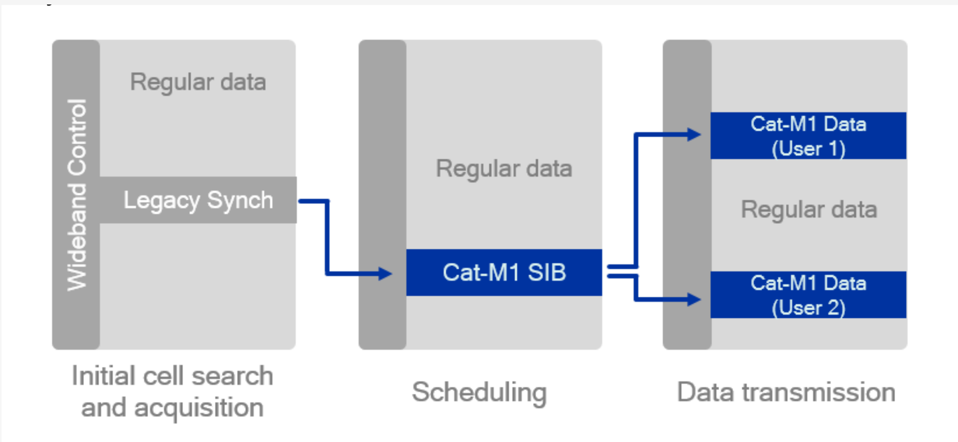

Figure 1 Cat-M1 (eMTC) operating across entire regular LTE band

CAT M is a subset of LTE and so, theoretically, CAT M devices can support any LTE band. However, CAT M devices are typically designed to operate in the frequency bands defined in section 5.5E in 3GPP TS 36.101 (v17.5.0). UE categories M1 and M2 are designed to operate in the E-UTRA operating bands 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 14, 18, 19, 20, 21, 24, 25, 26, 27, 28, 31, 66, 71, 72, 73, 74, 85, 87 and 88 in both half-duplex FDD mode and full-duplex FDD mode, and in bands 39, 40, 41, 42 and 43 in TDD mode. [7]

The full list of operating bands is defined in the table below.

Table 3 List of operating bands

Frequency Bands	Uplink (UL) operating band BS receive UE transmit	Downlink (DL) operating band BS transmit UE receive	Duplex Mode
	$F_{UL\_low} – F_{UL\_high}$	$F_{DL\_low} – F_{DL\_high}$	
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz	FDD
5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
11	1427.9 MHz – 1447.9 MHz	1475.9 MHz – 1495.9 MHz	FDD
12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
13	777 MHz – 787 MHz	746 MHz – 756 MHz	FDD
14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
19	830 MHz – 845 MHz	875 MHz – 890 MHz	FDD
20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
21	1447.9 MHz – 1462.9 MHz	1495.9 MHz – 1510.9 MHz	FDD
24[1]	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
26	814 MHz – 849 MHz	859 MHz – 894 MHz	FDD
27	807 MHz – 824 MHz	852 MHz – 869 MHz	FDD
28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
31	452.5 MHz – 457.5 MHz	462.5 MHz – 467.5 MHz	FDD
39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
41	2496 MHz 2690 MHz	2496 MHz 2690 MHz	TDD
42	3400 MHz – 3600 MHz	3400 MHz – 3600 MHz	TDD
43	3600 MHz – 3800 MHz	3600 MHz – 3800 MHz	TDD
66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
72	451 MHz – 456 MHz	461 MHz – 466 MHz	FDD
73	450 MHz – 455 MHz	460 MHz – 465 MHz	FDD
74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
85	698 MHz – 716 MHz	728 MHz – 746 MHz	FDD
87	410 MHz – 415 MHz	420 MHz – 425 MHz	FDD
88	412 MHz – 417 MHz	422 MHz – 427 MHz	FDD

[1] DL operation in this band is restricted to 1526 – 1536 MHz and UL operation is restricted to 1627.5 – 1637.5 MHz and 1646.5 – 1656.5 MHz.

1.8 Comparison of eMTC and NB-IoT

3GPP has specified two low-power, wide-area (LPWA) technologies for supporting the Internet of Things – eMTC and Narrowband IoT (NB-IoT).

1.8.1 Similarities

Both technologies can satisfy the following requirements –

1. Ultra-low complexity and low-cost IoT devices.
2. Minimum data rate of 160 bps at the application layer at the Maximum Coupling Loss (MCL) of 164 dB.
3. Battery life in extreme coverage beyond 10 years. Battery life is evaluated at 164 dB MCL with mobile originated data transfer consisting of 200 and 50 bytes of uplink and downlink data per day, respectively, and a battery capacity of 5 Wh.
4. Latency of 10 seconds or less on the uplink to deliver a 20-byte application layer packet measured at 164 dB MCL.

1.8.2 Differences

eMTC is intended for mid range IoT applications and can support voice and video services, while NB-IoT can provide very deep coverage and support ultra low cost devices.

Figure 2 summarises the high-level complexity differences of 3GPP Release 13 Cat M1 and Cat NB1.

	LTE Cat-1 (Rel-8)	eMTC Cat-M1 (Rel-13)	NB-IoT Cat-NB1 (Rel-13)
Peak data rate	Up to 10 Mbps	Up to 1 Mbps	<100 kbps
Bandwidth	Up to 20 MHz	1.4 MHz	200 kHz
Rx antenna	Dual Rx	Single Rx	Single Rx
Duplex mode	Full duplex FDD/TDD	Full or Half duplex FDD/TDD	Half duplex FDD
Mobility	Full mobility	Limited-to-full mobility	Cell reselection only
Voice	VoLTE	VoLTE	No voice support
Transmit power	23 dBm	23, 20 dBm	23, 20 dBm

Figure 2 Differences of 3GPP Release 13 Cat-M1 and Cat-NB1

Peak data rate: Both Cat M1 and Cat NB1 devices will have reduced peak data rates compared to regular LTE devices (e.g., Cat 1). Cat M1 has limited throughput of up to 1 MBps in both downlink and uplink directions, while Cat NB1 further reduces peak data rate down to tens of kbps. The reduced peak data rates allow for both processing and memory savings in the device hardware.

Bandwidth: LTE supports scalable carrier bandwidths from 1.4 MHz to 20 MHz, utilising 6 to 100 resource blocks. For LTE Cat M1, the device bandwidth is limited to 1.4 MHz only (1.08 MHz plus guard-band for 6 RBs in-band), to support the lower data rate. On the other hand, Cat NB1 further reduces device bandwidth to 200 kHz (180 kHz plus guard-band for a single RB). The bandwidth reduction for Cat M1 requires a new control channel (i.e., M-PDCCH10) to replace the legacy control channels (i.e., PCFICH, PHICH, PDCCH11), which can no longer fit within the narrower bandwidth. While for Cat NB1, a new set of NB-IoT synch, control, and data channels are introduced to accommodate the narrower bandwidth.

Rx antenna: Multiple antennas for MIMO (multiple-input, multiple-output) and receive diversity were introduced in LTE to improve spectral efficiency. For LTE IoT applications, there is little need to push for higher data rates, but it is important to reduce complexity. For both Cat M1 and Cat NB1, the receive RF is reduced to a single antenna, which simplifies the RF frontend. Though there is some RF degradation due to the lack of receive diversity, the lost signal sensitivity can be compensated by other advanced coverage enhancing techniques.

Duplex modes: Due to the less frequent and latency-tolerant nature of IoT data transmissions, LTE IoT devices can reduce complexity by only supporting half-duplex communications, where only the transmit or receive path is active at a given time. Cat M1 devices can support half-duplex FDD (Frequency Division Duplex) in addition to TDD (Time Division Duplex), while 3GPP Release 13 Cat NB1 devices only support half-duplex FDD. This allows the device to implement a simpler RF switch instead of a full duplexer that is more complex and costly.

Mobility: Only Cat M1 devices support limited-to-full mobility, which is a differentiating feature and is critical for many IoT applications such as asset tracking, where devices can frequently move between different cells. On the other hand, Cat NB1 devices support cell reselection only, which is optimised for static or nomadic IoT use cases. Voice: Another key Cat M1 feature is its ability to support VoLTE, which is needed for IoT applications such as wearables. Cat NB1 does not support voice due to its simplified hardware and limited bandwidth.

Transmit power: For both new LTE IoT UE categories, the maximum uplink transmission power is reduced from 23 dBm (200mW) in LTE, to 20 dBm (100mW) allowing the power amplifier (PA) to be integrated for lower device cost.

1.9 Co-existence of eMTC with NB-IoT

Introduced in 3GPP Release 13 as Cat M1 and Cat NB1, eMTC and NB-IoT are considered to be complementary narrowband LTE IoT technologies to support a wide range of low power IoT use cases. LTE IoT Cat M1, defined by eMTC, provides the broadest range of IoT capabilities, delivering data rates of up to 1 Mbps, while using only 1.4 MHz device bandwidth (1.08 MHz in-band transmissions of 6 resource blocks) in existing LTE FDD/TDD spectrum. It is designed to fully coexist with regular LTE traffic (Cat 1 and above). Cat M1 can also support voice (VoLTE) and full-to-limited mobility.

In enhanced coverage mode, it can deliver 15 dB of increased link budget, allowing LTE signals to penetrate more walls and floors to reach devices deployed deep indoors or in remote locations. LTE IoT Cat NB1, defined by NB-IoT, further reduces device complexity and extends coverage to address the needs of low-end IoT use cases. Cat NB1 leverages narrowband operations, using 200 kHz device bandwidth (180 kHz in-band transmissions of 1 resource block) in LTE FDD, to deliver throughputs of tens of kbps. NB-IoT supports more flexible deployment options: LTE in-band, LTE guard-band, and standalone. To further enhance coverage, it trades off spectral efficiency (e.g., data rate), and capabilities (e.g., no mobility or voice support) to achieve >5 dB of extra gain over Cat M1.

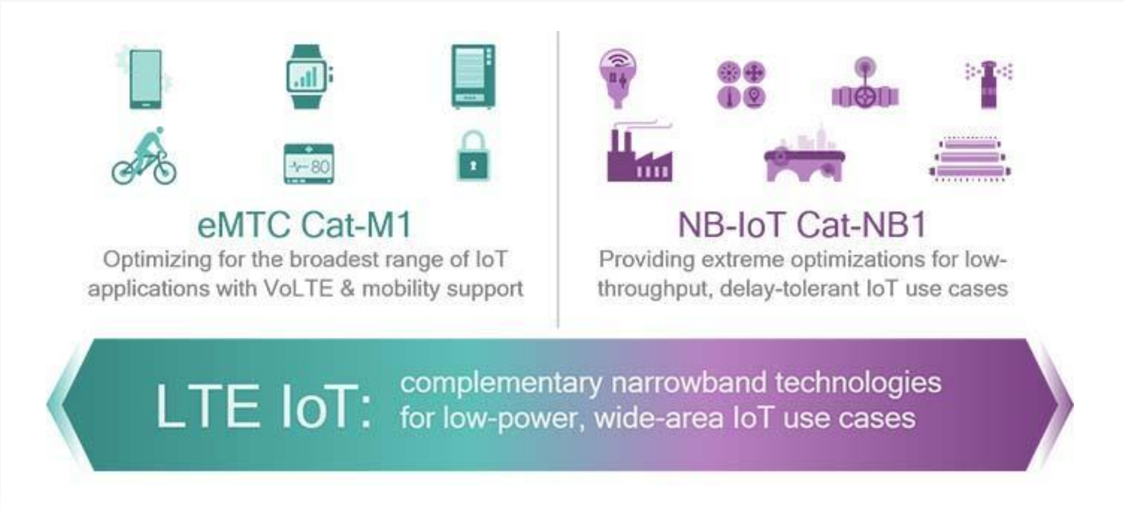

Figure 3 Complementary narrowband technologies for the massive IoT

Both Cat M1 and Cat NB1 can be deployed in existing LTE Advanced infrastructure and spectrum, efficiently coexisting with today's mobile broadband services. [7]

2. eMTC Architecture

eMTC is an IoT technology evolved on basis of the 3GPP protocols. It is mainly used for scenarios that feature medium and low rates, deep coverage, low power consumption, and massive connections.

In the context of eMTC based network architecture, eMTC technology serves as a vital navigational tool, enhancing various aspects of communication for IoT and M2M devices. [8]

The eMTC based network architecture works as:

Resource Allocation: efficiently distribute PRBs (physical resources blocks), ensuring resource equity.

Scheduling: coordinate resource usage, enhancing fairness and efficiency.

Power Control: conserve energy for low-power IoT devices.

Error Handling: Swift error correction and retransmission are enabled.

PRB Management: oversee PRB allocation among various UEs.

Resource Optimisation: adaptive to network conditions, optimising resource use.

Synchronisation: ensure well-timed and coordinated communication.

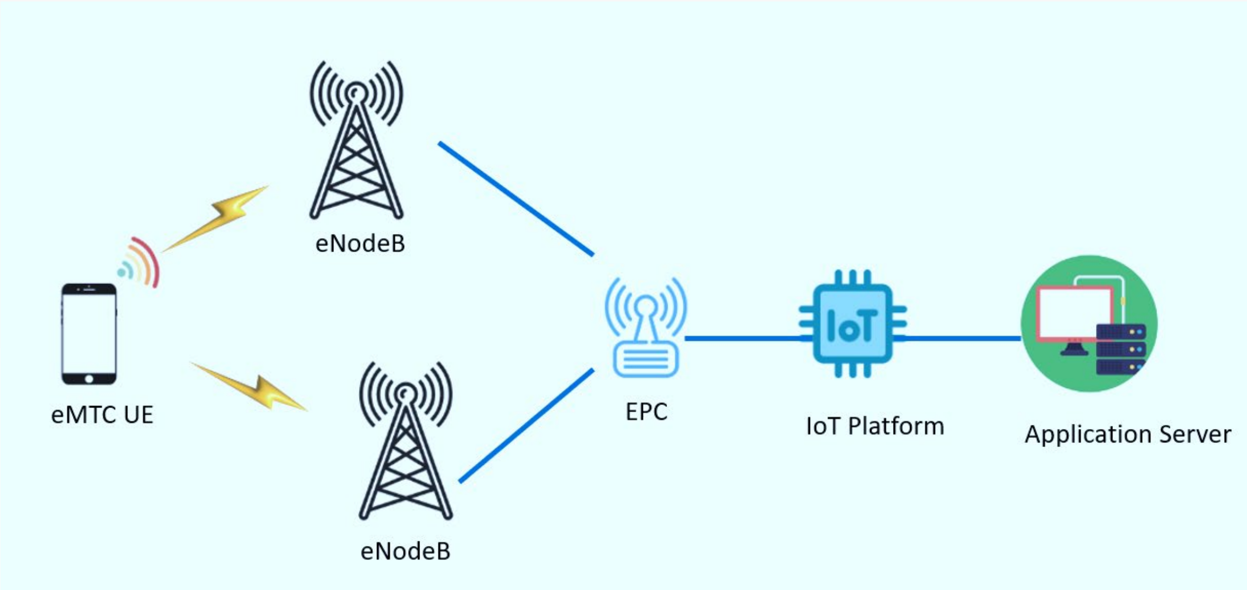

Figure 4 End-To-End network architecture of eMTC

3. Technical Specification Analysis

To understand the key patent contributions to eMTC technology, we have systematically followed some key steps including:

- Analysis of eMTC technology
- Extracting related technical specifications (TS) relevant to eMTC, including TS 21.111, TS 21.917, TS 22.011, and others using the official 3GPP website.

A comprehensive search for technical specification documents related to eMTC (enhanced Machine Type Communication) and its technical specifications involves the deployment of various keywords. These keywords encompass a broad spectrum of terms, including “machine type communication,” “machine-type-communication,” “mtc,” “m2m communication,” “machine-to-machine communication,” “machine to machine communication,” “Long-Term Evolution Machine Type Communication” (LTE-MTC), “LTE-M,” “enhanced machine type communication” (eMTC), among others. These keywords are critical in guiding the search for relevant documents, which may include technical specifications (TS documents), LTE standards, IoT communication protocols, and M2M communication guidelines.

The 3GPP technical specifications related to eMTC are TS 21.111, TS 21.917, TS 22.011, TS 22.101, TS 22.104, TS 22.119, TS 22.278, TS 22.289, TS 22.368, TS 23.002, TS 23.003, TS 23.008, TS 23.012, TS 23.060, TS 23.203, TS 23.221, TS 23.236, TS 23.271, TS 23.401, TS 23.402, TS 23.501, TS 23.502, TS 23.682, TS 24.301, TS 24.368, TS 29.061, TS 29.122, TS 29.171, TS 29.212, TS 29.244, TS 29.272, TS 29.274, TS 29.336, TS 29.337, TS 29.338, TS 29.368, TS 29.413, TS 29.502, TS 29.503, TS 29.505, TS 29.518, TS 29.522, TS 29.563, TS 29.571, TS 31.102, TS 32.251, TS 32.255, TS 32.274, TS 32.299, TS 33.128, TS 33.163, TS 33.187, TS 36.133, TS 36.141, TS 36.201, TS 36.211, TS 36.212, TS 36.213, TS 36.300, TS 36.304, TS 36.307, TS 36.321, TS 36.331, TS 36.413, TS 36.508, TS 36.521-3, TS 36.523-1, TS 36.523-3, TS 37.571-5, TS 37.823, TS 38.413, TS 38.423.

Note: A Technical Specification (TS) is a document that outlines the technical details and requirements for a particular aspect of a mobile communication standard. See Appendix for the full list of eMTC related technical specifications along with the Title, Relevant Sections, Associated Release, and cellular generation related information.

Table 4 Technical Specifications, Title, Relevant Section, and Release Associated with eMTC

Specification No.	Title	Associated Release	Relevant Section
TS21.111	USIM and IC card requirements	R14-17	S9
TS21.917	Release 17 Description; Summary of Rel-17 Work Items	R17	S7
TS22.011	Service accessibility	R13-19	S3
TS22.101	Service aspects; Service principles	R13-18	S29
TS22.104	Service requirements for cyber-physical control applications in vertical domains	R18-19	SA.4
TS22.119	Maritime communication services over 3GPP system	R16-17	S4
TS22.278	Service requirements for the Evolved Packet System (EPS)	R16-18	S7.B
TS22.289	Mobile communication system for railways	R16-17	S4
TS22.368	Service requirements for Machine-Type Communications (MTC); Stage 1	R10-17	S4,5,7
TS23.002	Network architecture	R11-17	S4
TS23.003	Numbering, addressing and identification	R11-17	S9
TS23.008	Organisation of subscriber data	R16-17	S2
TS23.012	Location management procedures	R10-17	S3
TS23.060	General Packet Radio Service (GPRS); Service description; Stage 2	R10-17	S5
TS23.203	Policy and charging control architecture	R17	S6
TS23.221	Architectural requirements	R11-17	S5
TS23.236	Intra-domain connection of Radio Access Network (RAN) nodes to multiple Core Network (CN) nodes	R10-17	S4
TS23.271	Functional stage 2 description of Location Services (LCS)	R17	S6
TS23.401	General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access	R10-18	S4
TS23.402	Architecture enhancements for non-3GPP accesses	R10-18	S5
TS23.501	System architecture for the 5G System (5GS)	R16-18	S5
TS23.502	Procedures for the 5G System (5GS)	R16-18	S4
TS23.682	Architecture enhancements to facilitate communications with packet data networks and applications	R11-18	S4,5
TS24.301	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3	R17-18	S10
TS24.368	Non-Access Stratum (NAS) configuration Management Object (MO)	R15-18	S5
TS29.061	Interworking between the Public Land Mobile Network (PLMN) supporting packet based services and Packet Data Networks (PDN)	R11-18	S11
TS29.122	T8 reference point for Northbound APIs	R15-18	S4,5
TS29.171	Location Services (LCS); LCS Application Protocol (LCS-AP) between the Mobile Management Entity (MME) and Evolved Serving Mobile Location Centre (E-SMLC); SLs interface	R15-17	S7
TS29.212	Policy and Charging Control (PCC); Reference points	R15-17	S5
TS29.244	Interface between the Control Plane and the User Plane nodes	R17-18	S5

TS29.272	Evolved Packet System (EPS); Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol	R15-18	S7
TS29.274	3GPP Evolved Packet System (EPS); Evolved General Packet Radio Service (GPRS) Tunnelling Protocol for Control plane (GTPv2-C); Stage 3	R15-18	S7
TS29.336	Home Subscriber Server (HSS) diameter interfaces for interworking with packet data networks and applications	R11-18	S5
TS29.337	Diameter-based T4 Interface for communications with packet data networks and applications	R11-17	S5
TS29.338	Diameter based protocols to support Short Message Service (SMS) capable Mobile Management Entities (MMEs)	R14-18	S4
TS29.368	Tsp interface protocol between the MTC Interworking Function (MTC-IWF) and Service Capability Server (SCS)	R11-17	S4,5
TS29.413	Application of the NG Application Protocol (NGAP) to non-3GPP access	R16-17	S5
TS29.502	5G System; Session Management Services; Stage 3	R16-18	S6
TS29.503	5G System; Unified Data Management Services; Stage 3	R16-18	S5
TS29.505	5G System; Usage of the Unified Data Repository services for Subscription Data; Stage 3	R17-18	S5
TS29.518	5G System; Access and Mobility Management Services; Stage 3	R16-18	S6
TS29.522	5G System; Network Exposure Function Northbound APIs; Stage 3	R16-18	S4
TS29.563	5G System; Home Subscriber Server (HSS) services for interworking with Unified Data Management (UDM); Stage 3	R17-18	S5
TS29.571	5G System; Common Data Types for Service Based Interfaces; Stage 3	R16-18	S5
TS31.102	Characteristics of the Universal Subscriber Identity Module (USIM) application	R15-18	S4
TS32.251	Telecommunication management; Charging management; Packet Switched (PS) domain charging	R13-17	S6
TS32.255	Telecommunication management; Charging management; 5G data connectivity domain charging; Stage 2	R17	S5
TS32.274	Telecommunication management; Charging management; Short Message Service (SMS) charging	R12-17	S5
TS32.299	Telecommunication management; Charging management; Diameter charging applications	R10-17	S4
TS33.128	Security; Protocol and procedures for Lawful Interception (LI); Stage 3	R18-19	S7
TS33.163	Battery Efficient Security for very low throughput Machine Type Communication (MTC) devices (BEST)	R15-17	S4
TS33.187	Security aspects of Machine-Type Communications (MTC) and other mobile data applications communications enhancements	R12-17	S4
TS36.133	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management	R13-18	S4,8
TS36.141	Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) conformance testing	R13-18	S4, Annex G

TS36.201	Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description	R13-17	S4
TS36.211	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation	R13-17	S5,6
TS36.212	Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding	R13-17	S5,6
TS36.213	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures	R13-17	S7
TS36.300	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2	R1317	S5
TS36.304	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode	R1317	S6,7
TS36.307	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements on User Equipments (UEs) supporting a release-independent frequency band	R17-18	Annex F
TS36.321	Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification	R15-17	S5
TS36.331	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification	R15-17	S5
TS36.413	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)	R15-17	S9
TS36.508	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Packet Core (EPC); Common test environments for User Equipment (UE) conformance testing	R16-17	S4,5,7
TS36.521-3	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) conformance specification; Radio transmission and reception; Part 3: Radio Resource Management (RRM) conformance testing	R16-18	S9
TS36.523-1	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Packet Core (EPC); User Equipment (UE) conformance specification; Part 1: Protocol conformance specification	R17-18	S6
TS36.523-3	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Packet Core (EPC); User Equipment (UE) conformance specification; Part 3: Test suites	R16-17	S7
TS37.571-5	User Equipment (UE) conformance specification for UE positioning; Part 5: Test scenarios and assistance data	R16-17	S7
TS37.823	Coexistence between LTE-MTC and NR	R16	S6,7,9,11
TS38.413	NG-RAN; NG Application Protocol (NGAP)	R16-17	S9
TS38.423	NG-RAN; Xn Application Protocol (XnAP)	R17	S9

Patent Contribution Analysis

Declared Patent Contribution Analysis with respect to technical specifications (TS) documents related to eMTC includes assessing the patents that have been officially declared in relation to extracted TS documents (i.e., mentioned above). This process involves identifying and understanding the patent landscape associated with eMTC.

By using the official 3GPP website to access relevant technical specifications associated with eMTC, the patent families declared in connection with LTE or 5G standards against this specification are gathered.

Extracting Relevant Technical Specifications:

- Identified technical specifications that had patent declarations made against them.
- Recognised that these specifications might encompass areas other than eMTC, containing specific sections related to eMTC.

Filtering for eMTC Focus:

- Acknowledged that patent declarations might pertain to technologies beyond eMTC.
- Applied targeted search strings related to eMTC technology, to patent metadata (Title, Abstract, Full Claims, and Description) to isolate eMTC related patents.

Compilation of Relevant Technical Specifications:

- Compiled a list of technical specifications deemed relevant to eMTC, along with their Titles, Relevant Sections, and Associated Release numbers.

Assignee Analysis for Contributions:

- Analysed the resultant patent declarations to determine the number of unique assignees contributing to each eMTC-relevant technical specification in relation to LTE or 5G.
- Calculated the count of unique assignees based on patent family declarations against each specification.

By systematically following these steps, insights were gained into the patent landscape related to eMTC technology. Significant patent contributions were identified from patent families associated with LTE and 5G standards.

Note: Note that out of the patent family declarations mentioned above, some are only related to 4G, some are only related to 5G and some are related to both 4G and 5G.

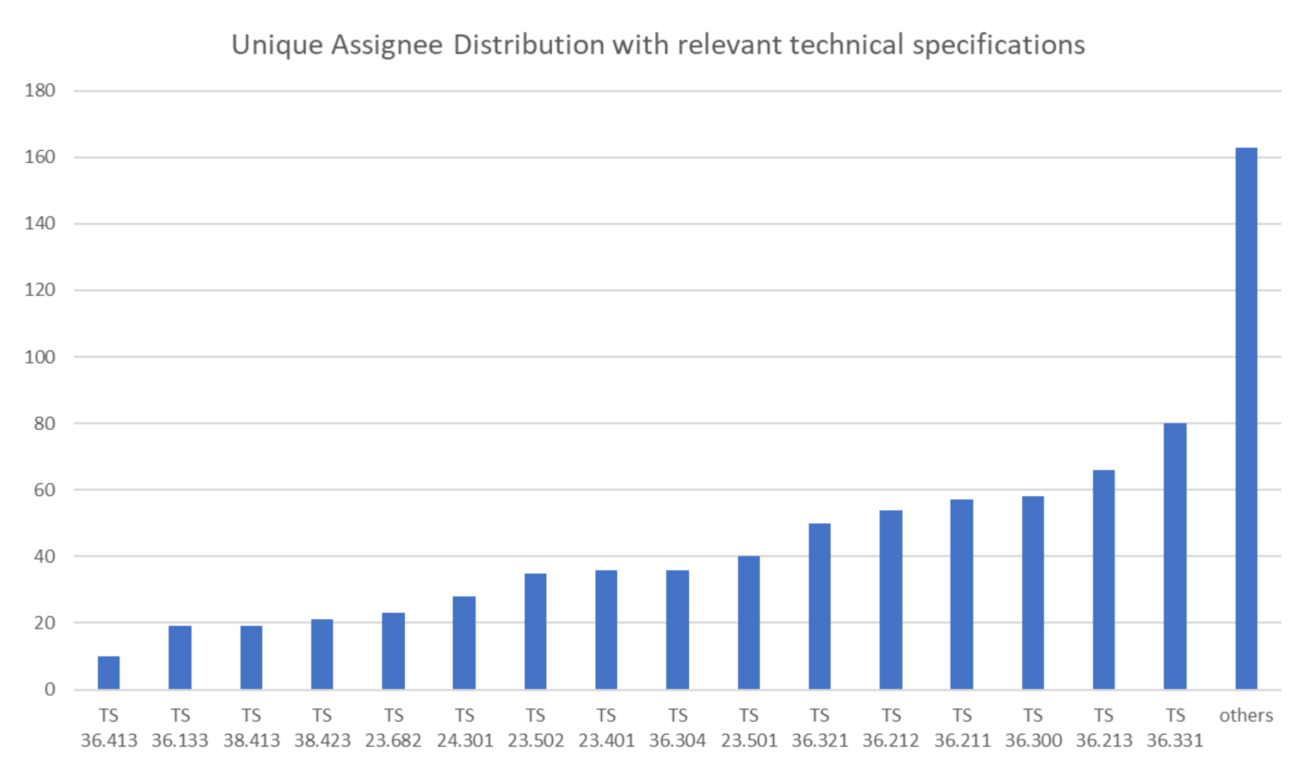

Figure 5 Unique Assignee Distribution in eMTC relevant technical specifications

In Figure 5, we observe the distribution of unique assignees across a range of technical specifications (TS) relevant to eMTC within the LTE and 5G domains. This analysis sheds light on the collaborative landscape within the eMTC technology sphere, demonstrating a multitude of organisations actively contributing to the development of these crucial standards. TS 36.331 is the most sought-after specification, with contributions from 80 unique assignees, indicating its central role in the eMTC ecosystem. TS 36.213 follows closely behind, with 66 unique assignees.

The diverse array of assignees underscores the collective dedication of various stakeholders and entities to advancing eMTC technology, aiming to unlock its potential for a wide range of applications across industries.

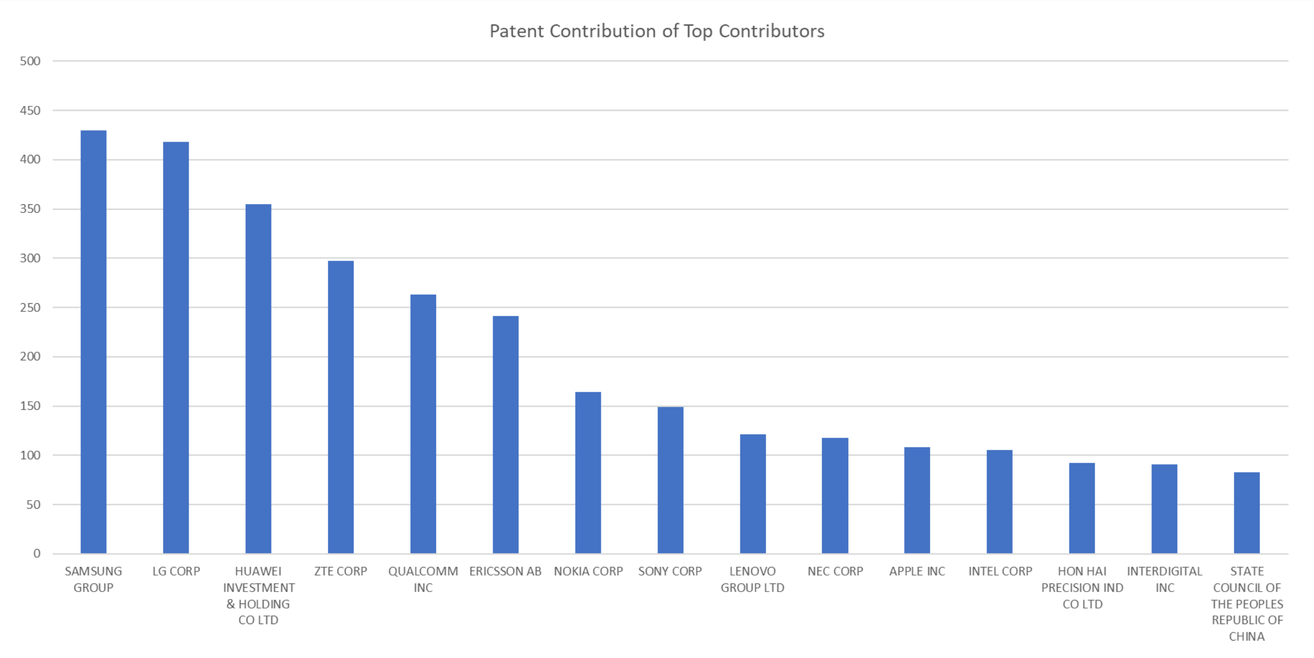

Figure 6 Patent Contribution of Top Contributors in eMTC

Figure 6 shows the significant patent contributions from the top 10 contributors in the field of technical specifications (TS) relevant to eMTC. These contributors are prominent players in the telecommunications and technology industry, showcasing their dedication to advancing this specific technology. The top ten companies are Samsung, LG, Huawei, ZTE, Qualcomm, Ericsson, Nokia, Sony, Lenovo, and NEC. Their substantial patent filings emphasise their commitment to innovation and development in the eMTC sector. Apple is also just outside the top ten contributors.

To compute the percentage of patent contributions to eMTC, the number of patent contributions made to eMTC by each contributor were calculated out of the total number of contributions made to eMTC.

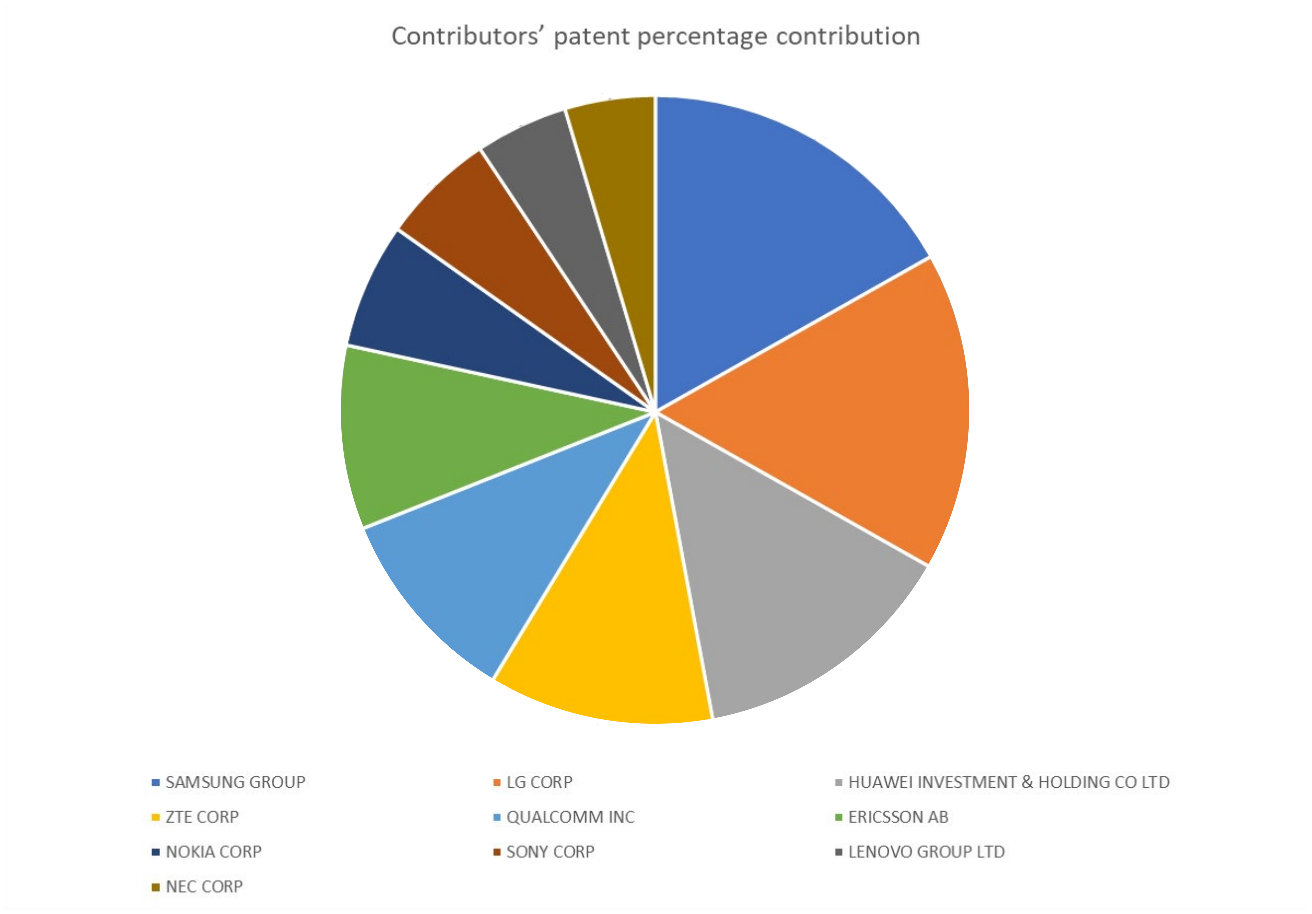

Figure 7 Patent distribution in eMTC relevant technical specifications

Figure 7 shows the distribution of patent contributions to eMTC technology presented as percentages. Samsung and LG are the leaders with 17% and 16% respectively. Huawei and ZTE follow closely behind.

Collectively, these contributions emphasise the collaborative effort of these major organisations in shaping the future of eMTC technology.

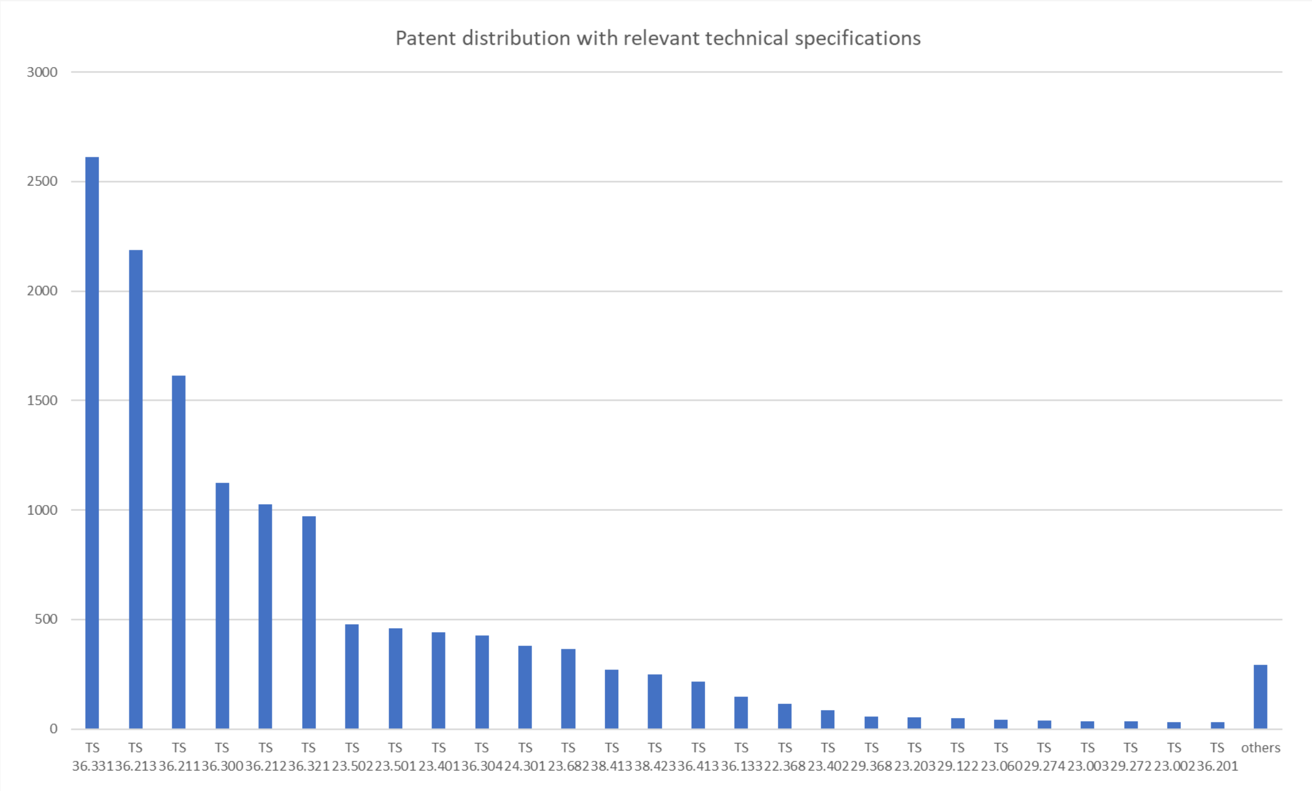

Figure 8 Patent distribution in eMTC relevant technical specifications

Figure 8 provides a comprehensive view of the number of patent families declared in eMTC relevant technical specifications (TS), offering valuable insights into the patent landscape surrounding this technology. At the forefront is TS 36.331 with a substantial 2,612 patent families, indicating its significant role and the extensive intellectual property interest in this particular specification. TS 36.213 is next with 2,187 patent families, and then TS 36.211 with 1,615 patent families.

The graph demonstrates the robust innovation efforts in these particular technical specifications. Overall, the distribution of patent families across these specifications highlights the active pursuit of intellectual property protection, demonstrating the competitive and dynamic nature of the eMTC technology sector.

4. Appendix

Table indicating Technical Specifications, Title, Release Associated with eMTC, Relevant Section, and cellular generation related information

Specification No.	Title	Associated Release	Relevant Section	Related to			
				2G	3G	4G	5G
TS21.111	USIM and IC card requirements	R14-17	S9	No	Yes	Yes	Yes
TS21.917	Release 17 Description; Summary of Rel-17 Work Items	R17	S7	Yes	Yes	Yes	Yes
TS22.011	Service accessibility	R13-19	S3	Yes	Yes	Yes	No
TS22.101	Service aspects; Service principles	R13-18	S29	No	Yes	Yes	Yes
TS22.104	Service requirements for cyber-physical control applications in vertical domains	R18-19	SA.4	No	No	No	Yes
TS22.119	Maritime communication services over 3GPP system	R16-17	S4	No	No	Yes	Yes
TS22.278	Service requirements for the Evolved Packet System (EPS)	R16-18	S7.B	No	No	Yes	No
TS22.289	Mobile communication system for railways	R16-17	S4	No	No	Yes	Yes
TS22.368	Service requirements for Machine-Type Communications (MTC); Stage 1	R10-17	S4,5,7	Yes	Yes	Yes	No
TS23.002	Network architecture	R11-17	S4	Yes	Yes	Yes	No
TS23.003	Numbering, addressing and identification	R11-17	S9	Yes	Yes	Yes	Yes
TS23.008	Organisation of subscriber data	R16-17	S2	Yes	Yes	Yes	Yes
TS23.012	Location management procedures	R10-17	S3	Yes	Yes	Yes	No
TS23.060	General Packet Radio Service (GPRS); Service description; Stage 2	R10-17	S5	Yes	Yes	No	No
TS23.203	Policy and charging control architecture	R17	S6	Yes	Yes	Yes	No
TS23.221	Architectural requirements	R11-17	S5	Yes	Yes	Yes	No
TS23.236	Intra-domain connection of Radio Access Network (RAN) nodes to multiple Core Network (CN) nodes	R10-17	S4	Yes	Yes	Yes	No
TS23.271	Functional stage 2 description of Location Services (LCS)	R17	S6	Yes	Yes	Yes	No
TS23.401	General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access	R10-18	S4	No	No	Yes	No
TS23.402	Architecture enhancements for non-3GPP accesses	R10-18	S5	No	Yes	Yes	No
TS23.501	System architecture for the 5G System (5GS)	R16-18	S5	No	No	No	Yes
TS23.502	Procedures for the 5G System (5GS)	R16-18	S4	No	No	No	Yes
TS23.682	Architecture enhancements to facilitate communications with packet data networks and applications	R11-18	S4,5	Yes	Yes	Yes	No

TS24.301	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3	R17-18	S10	No	Yes	Yes	Yes
TS24.368	Non-Access Stratum (NAS) configuration Management Object (MO)	R15-18	S5	No	Yes	Yes	Yes
TS29.061	Interworking between the Public Land Mobile Network (PLMN) supporting packet based services and Packet Data Networks (PDN)	R11-18	S11	Yes	Yes	Yes	Yes
TS29.122	T8 reference point for Northbound APIs	R15-18	S4,5	No	Yes	Yes	Yes
TS29.171	Location Services (LCS); LCS Application Protocol (LCS-AP) between the Mobile Management Entity (MME) and Evolved Serving Mobile Location Centre (E-SMLC); SLs interface	R15-17	S7	Yes	Yes	Yes	No
TS29.212	Policy and Charging Control (PCC); Reference points	R15-17	S5	No	Yes	Yes	Yes
TS29.244	Interface between the Control Plane and the User Plane nodes	R17-18	S5	No	No	Yes	Yes
TS29.272	Evolved Packet System (EPS); Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol	R15-18	S7	No	Yes	Yes	Yes
TS29.274	3GPP Evolved Packet System (EPS); Evolved General Packet Radio Service (GPRS) Tunnelling Protocol for Control plane (GTPv2-C); Stage 3	R15-18	S7	No	Yes	Yes	Yes
TS29.336	Home Subscriber Server (HSS) diameter interfaces for interworking with packet data networks and applications	R11-18	S5	No	Yes	Yes	No
TS29.337	Diameter-based T4 Interface for communications with packet data networks and applications	R11-17	S5	No	Yes	Yes	No
TS29.338	Diameter based protocols to support Short Message Service (SMS) capable Mobile Management Entities (MMEs)	R14-18	S4	No	Yes	Yes	Yes
TS29.368	Tsp interface protocol between the MTC Interworking Function (MTC-IWF) and Service Capability Server (SCS)	R11-17	S4,5	No	Yes	Yes	No
TS29.413	Application of the NG Application Protocol (NGAP) to non-3GPP access	R16-17	S5	No	No	No	Yes
TS29.502	5G System; Session Management Services; Stage 3	R16-18	S6	No	No	No	Yes
TS29.503	5G System; Unified Data Management Services; Stage 3	R16-18	S5	No	No	No	Yes
TS29.505	5G System; Usage of the Unified Data Repository services for Subscription Data; Stage 3	R17-18	S5	No	No	No	Yes
TS29.518	5G System; Access and Mobility Management Services; Stage 3	R16-18	S6	No	No	No	Yes

TS29.522	5G System; Network Exposure Function Northbound APIs; Stage 3	R16-18	S4	No	No	No	Yes
TS29.563	5G System; Home Subscriber Server (HSS) services for interworking with Unified Data Management (UDM); Stage 3	R17-18	S5	No	No	No	Yes
TS29.571	5G System; Common Data Types for Service Based Interfaces; Stage 3	R16-18	S5	No	No	No	Yes
TS31.102	Characteristics of the Universal Subscriber Identity Module (USIM) application	R15-18	S4	No	Yes	Yes	Yes
TS32.251	Telecommunication management; Charging management; Packet Switched (PS) domain charging	R13-17	S6	Yes	Yes	Yes	No
TS32.255	Telecommunication management; Charging management; 5G data connectivity domain charging; Stage 2	R17	S5	No	No	No	Yes
TS32.274	Telecommunication management; Charging management; Short Message Service (SMS) charging	R12-17	S5	Yes	Yes	Yes	Yes
TS32.299	Telecommunication management; Charging management; Diameter charging applications	R10-17	S4	Yes	Yes	Yes	Yes
TS33.128	Security; Protocol and procedures for Lawful Interception (LI); Stage 3	R18-19	S7	Yes	Yes	Yes	Yes
TS33.163	Battery Efficient Security for very low throughput Machine Type Communication (MTC) devices (BEST)	R15-17	S4	No	No	Yes	Yes
TS33.187	Security aspects of Machine-Type Communications (MTC) and other mobile data applications communications enhancements	R12-17	S4	Yes	Yes	Yes	No
TS36.133	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management	R13-18	S4,8	No	No	Yes	No
TS36.141	Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) conformance testing	R13-18	S4, Annex G	No	No	Yes	No
TS36.201	Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description	R13-17	S4	No	No	Yes	No
TS36.211	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation	R13-17	S5,6	No	No	Yes	No
TS36.212	Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding	R13-17	S5,6	No	No	Yes	No
TS36.213	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures	R13-17	S7	No	No	Yes	No
TS36.300	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2	R1317	S5	No	No	Yes	No

TS36.304	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode	R1317	S6,7	No	No	Yes	No
TS36.307	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements on User Equipments (UEs) supporting a release-independent frequency band	R17-18	Annex F	No	No	Yes	No
TS36.321	Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification	R15-17	S5	No	No	Yes	No
TS36.331	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification	R15-17	S5	No	No	Yes	No
TS36.413	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)	R15-17	S9	No	No	Yes	No
TS36.508	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Packet Core (EPC); Common test environments for User Equipment (UE) conformance testing	R16-17	S4,5,7	No	No	Yes	No
TS36.521-3	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) conformance specification; Radio transmission and reception; Part 3: Radio Resource Management (RRM) conformance testing	R16-18	S9	No	No	Yes	No
TS36.523-1	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Packet Core (EPC); User Equipment (UE) conformance specification; Part 1: Protocol conformance specification	R17-18	S6	No	No	Yes	No
TS36.523-3	Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Packet Core (EPC); User Equipment (UE) conformance specification; Part 3: Test suites	R16-17	S7	No	No	Yes	No
TS37.571-5	User Equipment (UE) conformance specification for UE positioning; Part 5: Test scenarios and assistance data	R16-17	S7	No	Yes	Yes	Yes
TS37.823	Coexistence between LTE-MTC and NR	R16	S6,7,9,11	No	No	Yes	Yes
TS38.413	NG-RAN; NG Application Protocol (NGAP)	R16-17	S9	No	No	No	Yes
TS38.423	NG-RAN; Xn Application Protocol (XnAP)	R17	S9	No	No	No	Yes

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