MACHINE-TYPE COMMUNICATIONS: CURRENT STATUS AND FUTURE PERSPECTIVES TOWARD 5G SYSTEMS

The authors provide a clear mapping between the main MTC service requirements and their associated challenges. Their goal is to develop a comprehensive understanding of these challenges and the potential solutions. This study presents, in part, a roadmap from the current cellular technologies toward fully MTC-capable 5G mobile systems.

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ABSTRACT

Machine-type communications (MTC) enables a broad range of applications from mission-critical services to massive deployment of autonomous devices. To spread these applications widely, cellular systems are considered as a potential candidate to provide connectivity for MTC devices. The ubiquitous deployment of these systems reduces network installation cost and provides mobility support. However, based on the service functions, there are key challenges that currently hinder the broad use of cellular systems for MTC. This article provides a clear mapping between the main MTC service requirements and their associated challenges. The goal is to develop a comprehensive understanding of these challenges and the potential solutions. This study presents, in part, a roadmap from the current cellular technologies toward fully MTC-capable 5G mobile systems.

INTRODUCTION

Machine-type communications (MTC) or machine-to-machine communications (M2M) refer to automated data communications among devices and the underlying data transport infrastructure. The data communications may occur between an MTC device and a server, or directly between two MTC devices [1]. MTC has great potential in a wide range of applications and services. The potential applications are widespread across different industries, including healthcare, logistics, manufacturing, process automation, energy, and utilities.

Communications among MTC devices can be handled through different network technologies. Point-to-point and multi-hop wireless networks, such as ad hoc networks, sensor, and mesh networks have been considered as a means to provide Internet access for devices, forming the so-called Internet of Things (IoT) [2]. For instance, IEEE 802.15.x with its different amendments has been developed to serve a variety of applications in personal area networks [3]. IEEE 802.11ah is another technology that supports low-power transmissions with extended coverage range in Wi-Fi networks [4]. However, these technologies suffer from some fundamental limitations that limit their wide implementation for MTC. The main drawback is the lack of efficient backhaul, which limits network scalability and coverage. Another issue is their operation over unlicensed frequency bands, making the communication links unreliable and susceptible to interference. Therefore, it is challenging to support applications requiring a high degree of reliability. Cellular systems, such as Long Term Evolution (LTE), are considered as alternative solutions for the wide provision of MTC applications. Their ubiquitous presence reduces network installation cost and provides widespread coverage and mobility support. In addition, since cellular systems are regulated and interference controlled, their communication links are more reliable.

Until recently, cellular systems have been mainly designed and optimized to serve traffic from human-to-human (H2H) communications, which are generally characterized by bursts of data during active periods with a higher demand on downlink. However, major MTC applications have different traffic characteristics: usually small and infrequent data generated from a mass of MTC devices imposing a higher traffic volume on uplink. Examples of these infrequent data transmissions, which are uplink-centric, include advanced metering infrastructure and vending machines. Furthermore, MTC devices are also different from H2H equipment: most MTC devices are inexpensive with limited computational or power resources. These distinct features have raised new technical challenges to enable the widespread deployment of cellular-based MTC [2, 5]. Therefore, these challenges must be effectively addressed for the future broadband wireless communications toward 5G systems in order to fully support MTC. In this vein, the Third Generation Partnership Project (3GPP) has also launched numerous activities to support MTC for future releases of LTE networks, referred to as LTE-Advanced (LTE-A). 3GPP has already specified the general requirements for MTC applications and identified issues and challenges related to them. Network and device modifications have been considered in upcoming releases of LTE standardization to facilitate and better support the integration of MTC [6].

Various methods, use cases, and requirements for 5G systems have been studied lately to support a diverse set of communications. Some of the visions and early results have been summarized in [7]. In this article our goal is to present a thorough overview of the current status of MTC in 4G systems, or more specifically in LTE and LTE-A systems (in the rest of this article, LTE and LTE-A are used interchangeably), and in particular to present perspectives toward 5G mobile systems.

The remainder of this article is organized as follows. We review different MTC service functions and address the main requirements that they impose on cellular systems. Then we

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describe the current and envisioned cellular-based MTC network architectures. We provide some potential solutions and enhancements for meeting the requirements. Finally, conclusions are drawn.

MTC SERVICE FUNCTIONS AND THEIR REQUIREMENTS

With MTC, a diverse range of new services and applications can be offered. The potential MTC applications have very different features and requirements that imply constraints on the network technology as well as on MTC devices. Table 1 provides some notable MTC service functions and application examples, including their imposed requirements on cellular systems to be served as radio access technologies.

Metering applications facilitate automatic collection of utility measurements. The gathered information can be utilized for online system optimization and billing purposes. In general, the metering devices generate infrequent and small amounts of data. In addition, the density of metering devices is usually high. These features require that the network technology be capable of handling small bursts of data from a large number of devices. The metering devices may be deployed in indoor environments; hence, they require enhanced coverage for their connectivity. Further examples of MTC services are control and monitoring systems, which enable remote system control or optimization. Reliable communications are required for most of these systems, while low-latency data transmissions are essential for many real-time control systems. Among others, tracking applications assist in managing fleets, locating assets, and preventing theft of equipment. Large-scale connectivity is necessary to support these applications. Furthermore, MTC devices used for these applications are generally equipped with batteries and are expected to operate for a long period of time without the need to replace the batteries; hence, very low power consumption is vital for their operations. For payment applications, security is the most important concern. Security and public safety services need reliable communications with low-latency in addition to a high level of data security to ensure flawless operations.

Service functions	Application examples	Main requirements
Metering	Electric power, gas, and water metering	Support of a massive number of MTC devices with small data bursts and high coverage
Control systems and monitoring	Industrial and home automation, and real-time control	High mobility and low-latency data transmissions
Tracking	Fleet management and asset tracking	High mobility and low power consumption
Payment	Point of sale and vending machines	High level of security
Security and public safety	Surveillance systems, home security, and access control	High reliability, high security, and low latency

Table 1. Examples of MTC applications and their requirements.

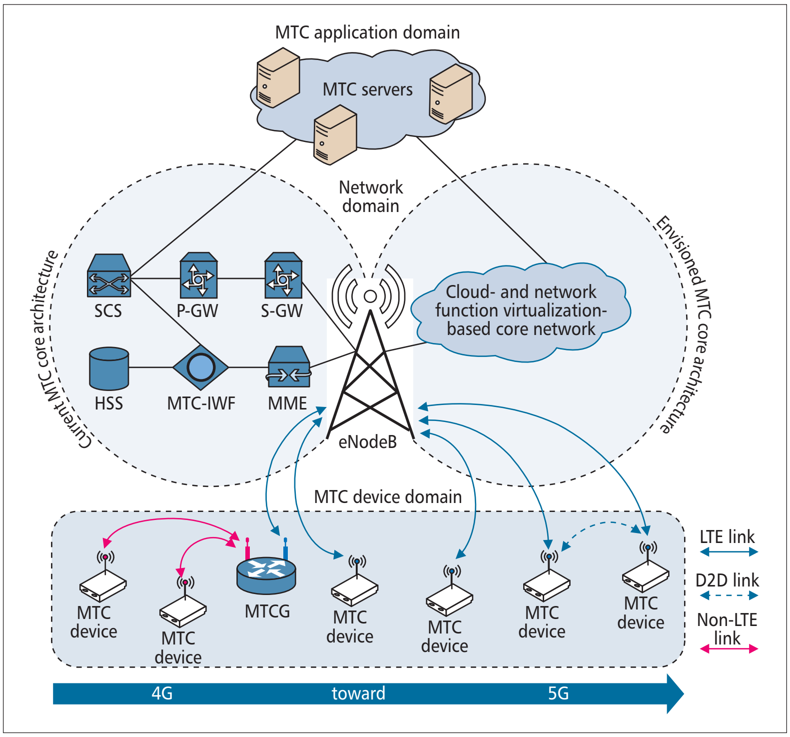

Figure 1. Current and envisioned cellular-based network architectures for supporting MTC services.

NETWORK ARCHITECTURES FOR MTC

3GPP has defined two kinds of communications for MTC applications: communications between an MTC device and a server, and communications between two MTC devices. The required connectivity for the MTC devices and the servers can be provided by cellular systems. Figure 1 shows a typical MTC architecture underlying the current design of LTE networks, along with proposed enhancements toward 5G mobile systems. This architecture consists of three parts: an MTC device domain, a network domain, and an MTC application domain. The MTC devices can be connected to base stations (e.g. eNodeBs) directly or through MTC gateways (MTCGs). The direct connection requires that the devices directly interact with the eNodeBs and are necessarily compatible with the cellular air infrastructure. The use of MTCGs enables the MTC devices to form capillary networks benefiting from other wired or wireless communication technologies. The MTCGs exchange data between the cellular and capillary networks [8].

The cellular network provides connectivity for MTC devices and MTC servers to exchange data. It comprises two subsystems: a radio access network (RAN) and a core network (CN). The RAN connects the MTC devices to the CN through air interfaces, while the CN manages the overall control of the MTC and the actual data delivery. In LTE systems, data transmissions are performed utilizing the radio resources in a dedicated or shared manner. The available

LTE networks support Internet Protocol version 6 (IPv6), which provides a large address space for devices connected to the network. However, handling a large number of MTC devices simultaneously, required for metering and monitoring applications, causes problems in connection establishment and radio resource allocation.

radio resources are divided into various uplink and downlink physical channels to segregate the different data types. The CN, known as evolved packet core (EPC) in the context of LTE, consists of a number of entities that are used for all types of communications, H2H as well as MTC. The packet data network gateway (PGW) and the serving gateway (SGW) are responsible for forwarding the user data traffic to and from the network via the so called bearers, i.e. channels created with the end users. The mobility management entity (MME) is responsible for all mobility related functions, paging, authentication, and bearer management in the network. The home subscriber server (HSS) functions as a main database containing subscription-related information. Two newly defined entities, service capability servers (SCSs) and the MTC-interworking function (MTC-IWF), are specified for MTC. The SCS entity is mainly designed to offer services for MTC applications hosted in external networks. The MTC-IWF hides the internal public land mobile network (PLMN) topology and relays or translates signaling protocols to invoke specific functionalities in PLMN. This entity is also responsible for relaying trigger requests from the SCS after checking authorization and reporting the acceptance or denial of these requests [5].

The current design of cellular networks can accommodate many MTC applications by meeting their requirements. However, some requirements, stated in Table 1, would need additional considerations before the actual deployment of their relevant applications. Some of these enhancements are illustrated in Figure 1 as part of the ongoing evolution toward 5G mobile systems. An important enhancement for MTC is the support of direct communications between nearby devices, which is known as device-to-device (D2D) communications [7]. Direct communication refers to a radio link establishment between devices without transiting through the network. This feature is already specified in LTE Release 12. Another MTC enabler is network function virtualization (NFV) which allows running network functions on virtual machines instead of utilizing sophisticated and expensive infrastructures. This approach provides virtual instances of the required hardware according to the demand [9]. In addition, the equipment and operation cost of eNodeBs can be further reduced by moving higher layer functionalities to a network cloud. These enhancements have been partially considered for network enhancements in future LTE releases, and for 5G systems. The next section discusses the main challenges associated with the deployment of MTC applications over an LTE network infrastructure and presents some possible remedies.

CURRENT MTC CHALLENGES AND PROPOSED SOLUTIONS

As mentioned earlier, the adoption of MTC devices into LTE systems has introduced new challenges. The main consideration in addressing the challenges is to simplify the complexity of the network to support MTC devices without jeopardizing the security or quality of services for both MTC devices and H2H users that share the same network infrastructure. This section describes the challenges listed in Table 1 and the corresponding solutions under discussion to:

- Support the deployment of a massive number of MTC devices.
- Accommodate small data bursts.
- Ensure a high level of security.
- Provide ultra-reliable communications with low-latency.
- Achieve low power consumption.
- Support low cost devices.
- Enhance coverage.

SUPPORT A MASSIVE NUMBER OF MTC DEVICES

LTE networks support Internet Protocol version 6 (IPv6), which provides a large address space for devices connected to the network. However, handling a large number of MTC devices simultaneously, required for metering and monitoring applications, causes problems in connection establishment and radio resource allocation.

In LTE, each eNodeB hosts radio resource control (RRC) to maintain the RRC state and perform radio resource allocation for all active users. A device can be either in RRC_IDLE or RRC_CONNECTED states. In the former state, the device is not connected to any eNodeB and is not granted radio resources for data transmissions. The power consumption of the device is low in this state as the radio transceiver is mostly off. However, the device must transit to the RRC_CONNECTED state to be able to communicate with an eNodeB. Transiting to this state is initiated by a random access procedure, sending a random preamble over a shared physical random access channel (PRACH) [10]. Performing the random access procedure simultaneously by a large number of MTC devices may congest and degrade the performance of the channel. The system overload is not only on the RAN and CN, but also on the interconnecting nodes such as gateways. This results in undesirable delays and waste of radio resources in the network, and lower performance for both MTC and H2H communications.

Solutions: In order to avoid congestion in PRACH, the offered traffic to the channel should be proportional to the allocated resources. Various schemes have been considered to improve the performance of the PRACH and resource allocation to handle a large number of devices [10]. These schemes adopt some of the following approaches.

- Defining new PRACH resources, particularly for MTC, to avoid congestion for H2H.
- Dynamic PRACH resource allocation to adjust available resources based on traffic conditions.
- Performing priority based channel access, granting access to a user with the highest priority among all users requesting access. The desired quality for H2H can be guaranteed by associating higher priorities to them compared to MTC devices [3].
- Access class barring, enabling eNodeB to control traffic on PRACH by setting a barring factor for non-time-critical MTC devices.

Depending on their class, MTC devices execute a different back-off timer before attempting to access PRACH.

- A pull-based scheme to page MTC devices that have permission to send their requests on PRACH.
- A group-based communication protocol for MTC application. For instance, instead of having individual bearers established for each MTC device, a single bearer can be created for a group of MTC devices that have certain characteristics in common or carry on the same MTC service. This group of MTC devices is identified by a unique identifier that can be known a priori to the network or is dynamically created by the network, similar in spirit to the work presented in [11]. A bearer, dedicated to a group of MTC devices, is created following the standard procedure when the first MTC device of the group connects to the network. For other MTC devices of the group, they simply are notified of the availability of the bearer immediately after it is created or when they attempt to establish one. The group bearer remains established as long as the actual data is being transferred between the MTC devices and the MTC servers, or following a particular policy that depends on the behavior of the MTC devices and the underlying MTC service. After a predetermined timeout, or if the actual delivery of data from the MTC group stops for a predetermined period of time, the group bearer may be released.
- To address the system overload, there are solutions based on separating the MTC and H2H traffic. One approach is to use NFV for MTC traffic, which enables allocating the required resources on virtual machines to run network functions [9].

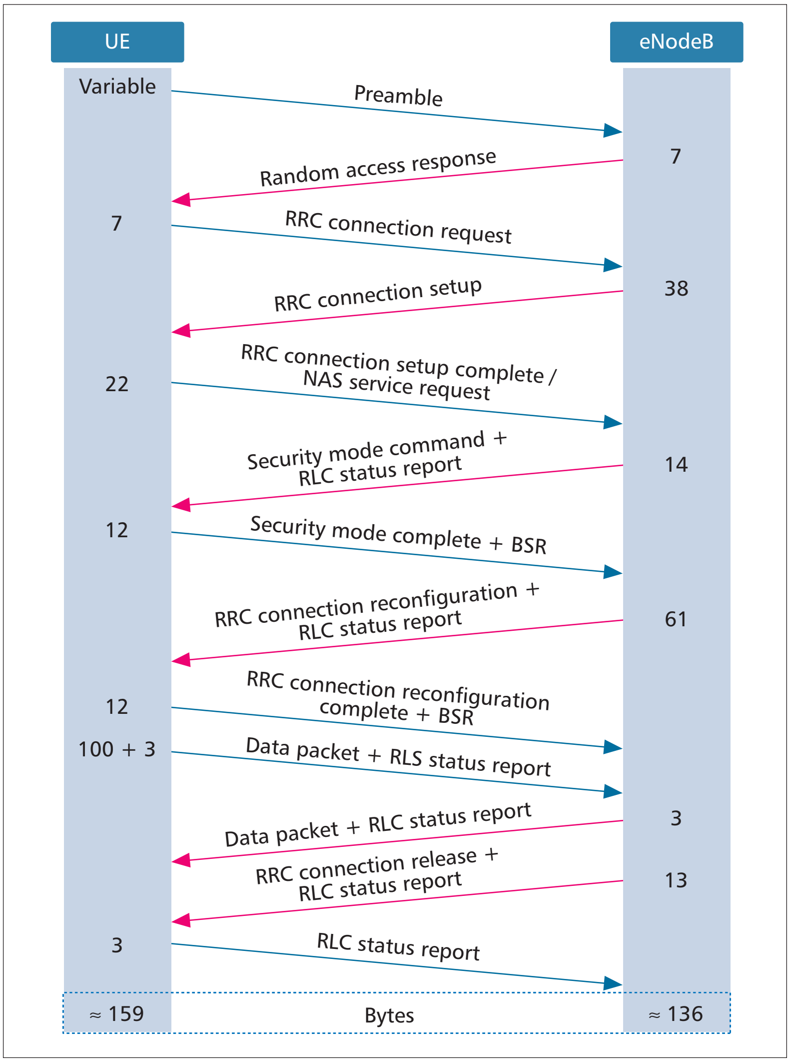

Figure 2. Network access procedure for data transmissions in LTE system.

Accommodate Small Bursts of Data

The current design of LTE systems requires that a user perform the connection establishment procedure before sending the information data. This approach adds signaling overhead to the information data. The efficiency of this scheme is low for handling small amounts of data, which is the case for some MTC applications, because that amount of signaling overhead is high compared to the amount of information data. As an example, Figure 2 illustrates the network access procedure and signaling messages for transmitting 100 bytes of data from a device to a serving eNodeB. The access procedure includes a random access procedure followed by RRC connection establishment and security procedures. When the RRC connection is established, the device transmits the information data and then releases the connection [12]. The signaling transmissions for this process take approximately 59 bytes of overhead on the uplink and 136 bytes on the downlink.

Solutions: Increasing the efficiency of data transmissions helps in reducing power consumption and latency. The following solutions are considered to achieve this goal.

- The network access procedure for transmission of small amount of data can be redesigned. For example, a portion of radio resources in the uplink can be dedicated to a group of MTC devices to transmit their data in a contention manner without establishing a link in advance [13].
- There are solutions based on modifications of the random access procedure to handle small data bursts from detached MTC devices. The small data bursts can be carried either by implementing predetermined preambles dedicated to this purpose, or by sending the data load in the initial uplink resource allocated for RRC connection requests. However, sending the data along with RRC connection requests has security implications.
- Data aggregation can improve the efficiency of data transmissions. Data or signaling message aggregation may occur at different locations in the network (e.g. MTC device, MTC gateway, eNodeB, or MME) [11, 14]. Intuitively, this incurs some additional delays and is only applicable to non delay-sensitive MTC applications.

Ensure High Level of Security

LTE systems provide security for communications by integrating various security algorithms, such as authentication, integrity, and encryption. In addition to security for communications, most of the envisioned MTC applications require security for data. This concern is mainly due to

Using asymmetric security schemes, the burden of required computations can be moved to the network domain or gateways, which usually have high computation power. This helps in performing the security computations faster, and reduces energy consumption in MTC devices.

the deployment of MTC devices in unprotected environments, which increases the risk of tampering or fraudulent modification. For instance, moving sensor nodes can disrupt the proper functionality of the MTC applications. In addition, low-cost MTC devices may not be able to perform existing security schemes since they have limited computation power.

Solutions: Some solutions for the security relevant challenges are as follows.

- A higher level of security for MTC devices is achievable by utilizing new security mechanisms. For example, the operation of MTC applications can be restricted only to authenticated devices. Also, embedding subscriber identity module (SIM) cards reduces the risk of fraud and SIM theft.
- Employing physical-layer security adopting radio-frequency (RF) fingerprinting. An MTC server should monitor the signal emission characteristics of devices and exploit this information to detect abnormal activities [15]. If the signal from an MTC device changes significantly, it can be deduced that the device has been tampered with or moved to another place. The MTC server then might deactivate the account for the MTC device. However, an RF fingerprinting scheme requires that signal measurements are delivered to the MTC server from the network. Furthermore, variations in the environment and device aging can affect the performance of the scheme.
- Using asymmetric security schemes, the burden of required computations can be moved to the network domain or gateways, which usually have high computation power. This helps in performing the security computations faster, and reduces energy consumption in MTC devices.

PROVIDE ULTRA-RELIABLE COMMUNICATIONS WITH LOW-LATENCY

Ultra-reliable communications are vital for safe operation of some MTC applications, such as control and monitoring systems, cloud-based systems, and vehicle-to-vehicle wireless coordination. Additionally, some of the mentioned applications also require data transmissions with low-latency. LTE systems currently do not support these features.

Solutions: The following solutions are considered to provide ultra-reliable communications with low-latency.

- In order to bypass the link establishment procedure and reduce its associated delay, semi-persistent scheduling can be utilized. This scheme can provide low-delay connection for real-time control applications by periodically providing dedicated radio resources for MTC devices. The semi-persistent scheduling can also eliminate scheduling delays in feedback control applications, as sensors and controllers usually produce data periodically.
- In some applications, reliable communications are required mainly for exchanging data between MTC devices that are located in close proximity. A network enhancement for such applications is to support D2D communications between nearby devices, which can significantly reduce transmission latency and improve link quality. D2D communications have been studied in LTE Release 12, referred to as proximity services (ProSe), which is one of the areas of 3GPP LTE enhancements to address public safety applications. ProSe allows the identification of mobile devices in physical proximity and enables optimized communications between them. It generally includes two main elements:
  - –Network assisted discovery of devices that wish to communicate and are located in close physical proximity.
  - –The establishment of direct communication between such devices with or without supervision from the network.
- Low-latency communications cannot use the classical coding methods that relay on long code words. Instead, they need techniques for handling short packets using new coding methods designed for finite block length. Thus, the coded symbols need to be transmitted within the given time budget using more bandwidth or spatial dimension of freedom.
- Massive multi-input multi-output (MIMO) antennas can provide reliable links by benefiting from spatial diversity and the mitigating effects of fast fading, beamforming, and zero forcing caused by multi-user interference.
- A new medium access control (MAC) scheme is needed for handling event-based ultra-reliable communications. Here, joint coding of the metadata (header) and information payload can help. The challenge is to dimension the random access resources in such a way that delay bounds can be met with high probability.
- The most challenging cases for ultra-reliable communications are safety critical systems, which need low latency and also require high availability of the infrastructure. In some cases, D2D communications and ad hoc networking could be utilized to provide additional links and maintain connectivity when the primary link fails.

ACHIEVE LOW POWER CONSUMPTION

Energy-efficiency is a decisive metric for choosing a radio technology, particularly for MTC applications whereby MTC devices have a limited energy budget. This is a common constraint for many sensing and monitoring applications whereby MTC devices are expected to operate in scattered areas without the possibility of regular battery replacement. Deploying such MTC devices in LTE networks requires that the network support low-power consumption mode.

Solutions: In order to accommodate low power consumption devices in LTE systems, different modifications have been proposed, including the following.

- Modifying signaling and MAC protocols, which can boost energy efficiency by reducing the time that a radio should be turned on. However, the modifications should not greatly affect network performance. For instance, disabling tracking area updates for static MTC devices is a way to reduce signaling transmissions.
- Aggregating the control information and sending them only when data transmission is scheduled.

- Allowing longer discontinuous reception (DRX) sleeping periods.
- Deploying MTC gateways and supporting multi-hop communications can reduce power consumption by allowing MTC machines to transmit with lower power.
- Defining a new communication state for MTC devices. Indeed, LTE has been designed with the assumption that user equipments (UEs) have to be always connected to the network. This "always on" concept gave rise to two main states for UEs: active and idle. During idle state, UEs still have to carry on some control procedures to keep their respective bearers and to update the network of their points of presence. In the case of MTC services whereby MTC devices are triggered only at specific points in time (e.g. the end of the month for utility meters), these MTC devices do not have to be always in idle mode. Rather, they should be "off" with the ability to switch to idle or active state very quickly when required. Such an "energy saving" state will exempt MTC devices from carrying on many standard procedures that would otherwise waste their energy budget.
- Supporting D2D communications between nearby MTC devices can reduce power consumption by allowing transmissions with lower power. However, distributed network management is the main concern for supporting D2D links.

Support Low Cost Devices

Typical LTE devices have been designed to provide broadband services and are therefore overdesigned for low-rate and delay-tolerant MTC services. For MTC uses, it is desired that LTE devices with bill of materials cost be comparable to that of Global System for Mobile Communications (GSM).

Solutions: In Release 12, 3GPP has introduced a new low-cost MTC UE category (called Category-0 UE) with the following reduced capabilities:

- Support of a single antenna instead of at least two receive antennas for other UEs. It is estimated that this could provide a cost reduction of approximately 24 to 29 percent of the bill of materials cost for the modem when compared to the baseline Category-1 UE [16]. However, a single-receive antenna will reduce downlink coverage and the capacity of the system due to the loss of receiver combining gain and lack of channel diversity.
- Reduced peak data rates of one Mbps in both downlink and uplink. The overall achievable cost saving using this technique is 10.5 to 21 percent of the modem electronic bill of materials, and has only a small impact on system efficiency due to small MTC data bursts.
- Use half-duplex operation for frequency division duplex (FDD). In this mode, a UE can only either transmit or receive data at one time (i.e. time-division multiplexing operation). This allows the duplexers to be removed, leading to an estimated cost saving of 7 to 10 percent in the modem. Half-duplex is already an optional feature in LTE, and it is well suited for MTC applications with low data rates.

As a result, Category-0 UE can achieve a cost saving of approximately 50 percent over the baseline LTE UE. In Release-13, further device cost reduction will be achieved by considering additional modifications, including:

- Reducing the RF bandwidth of the UE from 20 MHz to 1.4 MHz in both downlink and uplink. This reduces both cost and power consumption. However, the UE will still be able to operate in wideband systems by operating only in a portion of the system bandwidth.
- Reducing the maximum transmit power to allow for an integrated power amplifier implementation. However, this power reduction will reduce uplink coverage.

When considered together, Release 13 low-complexity UEs will be able to provide a cost saving of approximately 75 percent over the baseline LTE UE. In terms of deployment, LTE Release 12 and 13 networks will be able to support both legacy and low-cost devices simultaneously. The network will be informed about the capability of the devices earlier during the access procedure, so that they can be treated appropriately. However, it is important to note that low-cost MTC devices will not be able to access legacy (pre-Release 12) networks.

Furthermore, as noted earlier, low-cost MTC devices will have decreased performance due to reduced capabilities. For instance, in the downlink, it is estimated that the performance of low-cost MTC devices will be worse by up to 5 dB due to the single receive antenna deployment and lack of frequency diversity. In the uplink, coverage will be smaller for UEs with reduced maximum transmit power. To compensate for these losses, coverage enhancement features will be standardized.

Enhance Coverage

Coverage is an important issue for wide area MTC deployment where machines are installed in challenging locations (e.g. indoor environments, basements, or meter closet). In addition, as discussed earlier, low-cost MTC UE will decrease coverage due to reduced capabilities, such as single receive antenna and lower power. Thus, network access must be extended to ensure ubiquitous coverage throughout the service area. Coverage enhancement features for MTC will be specified in Release 13. The goal is to provide coverage improvement compared to Release 8. The amount of coverage enhancement in each cell is configurable and scalable. Thus, it would be up to the network to configure the level of coverage enhancement.

Coverage analysis via link budget calculation is performed to determine the normal LTE footprint as shown in Table 2. This footprint is determined by the channel with the worst coverage as determined by the maximum coupling loss (MCL). In Release-13, the target is to extend the coverage to 155.7 dB MCL. From Table 2 it can be observed that different amounts of coverage enhancement will be required for different channels.

Solutions: The potential coverage improvement techniques applicable to different physical channels are listed in Table 3 and correspond to the following.

Coverage enhancement features for MTC will be specified in Release 13. The goal is to provide coverage improvement compared to Release 8. The amount of coverage enhancement in each cell is configurable and scalable. Thus, it would be up to the network to configure the level of coverage enhancement.

LTE modes	Physical uplink control channel (PUCCH)	Physical random access channel (PRACH)	Physical uplink shared channel (PUSCH)	Physical downlink shared channel (PDSCH)	Physical broadcast channel (PBCH)	Synchronization channel (SCH)	Physical downlink control channel (PDCCH)
FDD 2Tx-2Rx	147.2 dB	141.7 dB	140.7 dB	146.1 dB	149.0 dB	149.3 dB	145.4 dB
TDD 8Tx-8Rx	149.4 dB	146.7 dB	147.4 dB	146.9 dB	149.0 dB	149.3 dB	148.1 dB

Table 2. Maximum coupling loss for LTE channels.

Coverage enhancement techniques	PUCCH	PRACH	PUSCH	PDSCH	PBCH	SCH	PDCCH
Repetition/subframe bundling	✓	✓	✓	✓	✓		✓
Frequency hopping	✓	✓	✓	✓			✓
PSD boosting				✓	✓	✓	✓
Receiver based techniques			✓	✓	✓		
Retransmission			✓	✓			
Relaxed requirement		✓				✓	
Increased RS density	✓		✓	✓	✓		✓

Table 3. Potential coverage enhancement techniques.

- Repetition or subframe bundling. Longer transmission time allows additional energy to be accumulated at the receiver, thus improving the strength of the desired signals.
- Frequency hopping across wideband systems to provide frequency diversity gain to narrowband UEs.
- Power spectral density (PSD) boosting and receive-based techniques such as multi-subframe channel estimation, multiple decoding attempts, and advanced receiver.
- Retransmission using hybrid automatic repeat request (HARQ).
- Relaxing the current specification requirements, such as reducing the missed probability of the random access transmissions.
- Increasing reference signal density to improve channel estimation performance.

To improve performance under coverage enhancement, several techniques may be jointly utilized. As an example, a smart meter installed in a basement may experience penetration loss of 10 dB to 15 dB. To ensure the coverage for the meter, at a maximum coupling loss of 155.7 dB, the downlink data channel can be transmitted employing 40 repetitions, frequency hopping, and 3 dB PSD boosting. This assures that the smart meter receives the data reliably.

CONCLUSION

In this article we have presented some of the most important requirements imposed by specific MTC applications. Such requirements cause technical challenges when incorporating MTC in cellular systems. Throughout the description of the challenges, we elaborated on the feasible solutions and their status in terms of maturity and integration to the technical specifications. Even though there has been extensive progress in terms of standardization regarding MTC, currently only some of these challenges have been partially addressed. Hence, further research and exploration are essential to move from current cellular systems toward fully MTC-enabled 5G networks.

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