

Machine Type Communications in 3GPP Networks: Potential, Challenges, and Solutions

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ABSTRACT

With a wide range of potential applications, Machine Type Communication (MTC) or Machine to Machine (M2M) communication is gaining a tremendous interest among mobile network operators, equipment vendors, MTC specialist companies, and research bodies. To facilitate convergence among these different stakeholders, different standardization groups started working on MTC. This article introduces briefly some of the relevant activities, with a focus on those related to the 3rd Generation Partnership Project (3GPP). The article focuses on two important aspects of MTC devices, currently discussed in 3GPP as part of its Release 10. They are subscription control and network congestion/overload control. For the latter, a new solution based on bulk signaling handling is proposed.

INTRODUCTION

Machine Type Communications — MTC (or Machine to Machine (M2M) communications) are about enabling direct communications among electronic devices, dubbed MTC devices, and/or enabling communications from MTC devices to a central MTC server or a set of MTC servers. Communications can use both wireless and fixed networks. MTC will enable an endless number of applications in a wide plethora of domains, impacting different environments and markets. It will connect a potential number of MTC devices to the Internet and other networks, forming the so-called Internet of Things (or Internet of Objects).

Several forecasts state a significant market growth over the next few years for both the MTC device and the MTC connectivity segments. The growth is expected at a compound annual growth rate (CAGR) exceeding 25 percent [1–3]. According to these forecasts, billions of machines or industrial devices will be potentially able to benefit from MTC.

While some existing MTC deployments use short-range radio technologies, MTC solutions based on mobile access technologies are easier to install and are of vital importance to support

a wide range of MTC devices, including those with mobility features. Mobile access based MTC solutions are also more adequate for supporting MTC services that require immediate and reliable delivery of data to distant MTC servers. Exhibiting different behavior than ordinary mobile network terminals, MTC devices need to be treated differently to enable mobile operators to accommodate a potential number of them. There is thus a need for the optimization of networking solutions, specifically tailored for MTC in mobile networks. To avoid fragmentation among the devised solutions, and therefore to prevent divergence among the different stakeholders of the MTC market, there is a need to join efforts to design a standard end-to-end MTC architecture. In the remainder of this section we briefly identify the different MTC-related activities initiated in this vein.

Very recently, 3GPP, the Alliance for Telecommunications Industry Solutions (ATIS), the China Communications Standards Association (CCSA), the Open Mobile Alliance (OMA), IEEE and the European Telecommunications Standards Institute (ETSI) have launched standardization activities on MTC. 3GPP and IEEE address cellular MTC, particularly how wireless cellular networks can support MTC. ETSI, in contrast, addresses the MTC service architecture, its components, and the interactions between its three domains, i.e. application, network and devices domains.

Regarding 3GPP, the first study on MTC was presented in [5], with no subsequent normative specifications. In Release 10, the 3GPP System Architecture working group 2 (SA2) is defining 3GPP network system improvements to support MTC in UMTS (Universal Mobile Telecommunications System) and LTE (Long Term Evolution) core networks. The focus is mainly on system optimizations that prevent MTC signaling congestion and network overload, two important challenges for the support of mass-market MTC services. For Release 10 and beyond, there are plans to study the impacts of the standardized system network improvements on the architecture.

In this article, we cover some of the standardization activities of 3GPP, focusing especially on

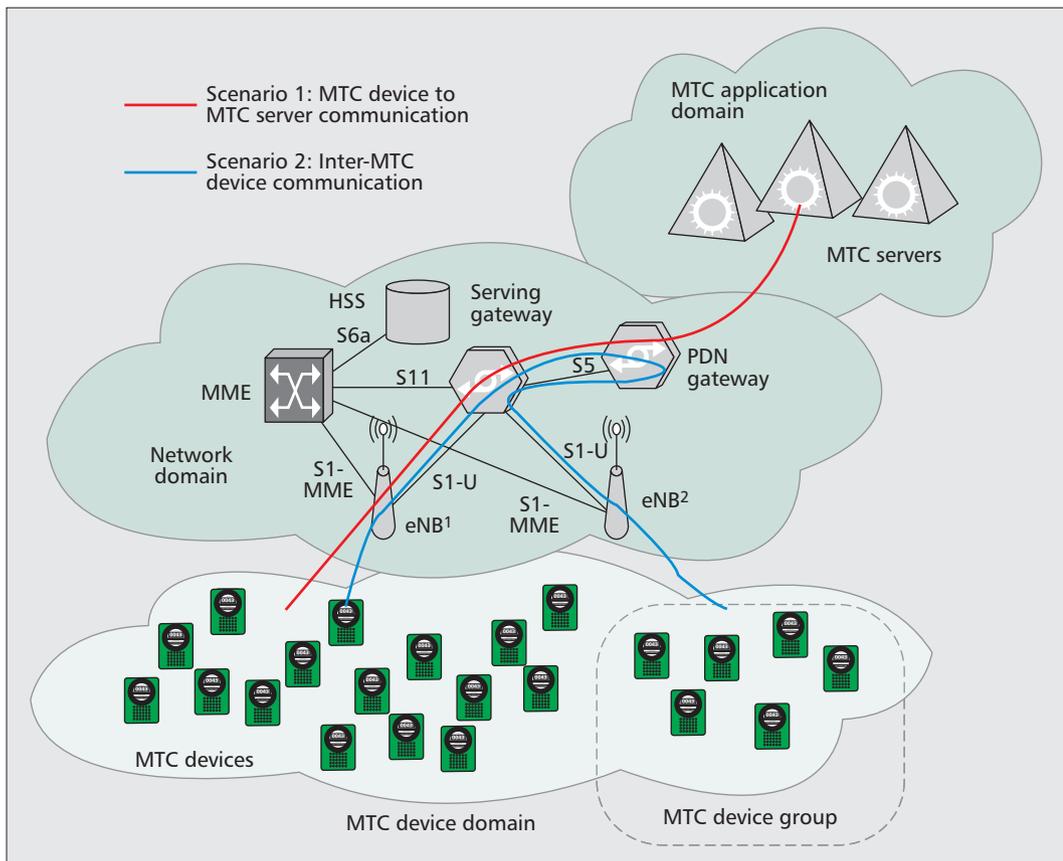


Figure 1. Typical MTC architecture and scenarios.

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those related to MTC device subscription control and network congestion/overload control. We will present current solutions exposed at the 3GPP SA2 WG and introduce a novel solution to tackle network congestion. The proposed solution suggests handling signaling messages common to a group of MTC devices in bulk.

The remainder of this article is organized as follows. We present the main components and domains of a typical MTC architecture. We discuss the subscription control feature of MTC devices. We give a summary of the solutions, agreed within 3GPP SA2, for congestion control and network overload avoidance. We also introduce a new solution based on handling signaling messages in bulk. Finally, we conclude our article.

MTC ARCHITECTURE

Figure 1 depicts a typical MTC network architecture. It consists of three main domains, namely the MTC device domain, the communication network domain, and the MTC application domain. In the network domain, most important nodes of a 3GPP Evolved Packet System (EPS) network are shown. Depending on the use case, the MTC devices transmit or receive a determined amount of data at a determined frequency, e.g. a smart meter sending measurement results every day at 23:00h. MTC devices can be either fixed installed (e.g. implemented in a factory's machine, gas meters, etc.) or mobile (e.g. fleet management devices in trucks). The hetero-

geneity of the features of MTC devices (i.e., in terms of mobility, amount of transmitted data, security, etc.) enables mobile operators to make different optimizations for grouping MTC devices, charging MTC applications, and controlling network resources used by the MTC devices. The communication network domain can be a wired or a wireless network. In this article, our focus is on the case when the communication network is a 3GPP mobile network. Table 1 provides a brief description of the most important EPS nodes, shown in Fig. 1, including the corresponding UTRAN nodes, namely SGSN and GGSN. The MTC application domain consists of MTC servers, under the control of the mobile network operator or a third party.

As depicted in Fig. 1, two communication scenarios can be envisioned. Indeed, one scenario adopts the client/server model and considers communication between the MTC devices and one or more MTC servers, in the MTC application domain. This scenario represents the most envisaged one and is adopted by many MTC applications, such as indoor health monitoring at home, water, gas, or power metering. Other types of MTC applications may require an alternative model of communication such as the peer-to-peer (p2p) model, whereby MTC devices are communicating directly among themselves. These applications form the basis of the second scenario. Inter-MTC device communications can be either via the mobile network or in an ad-hoc mode.

MTC SUBSCRIPTION CONTROL

As described earlier, MTC devices are able to communicate through a PLMN (Public Land Mobile Network) with MTC server(s) and/or other MTC device(s). At the writing of this article, only the MTC device — MTC server communication — is described in the 3GPP specifications.

A MTC device can support different MTC features, which are network functions to opti-

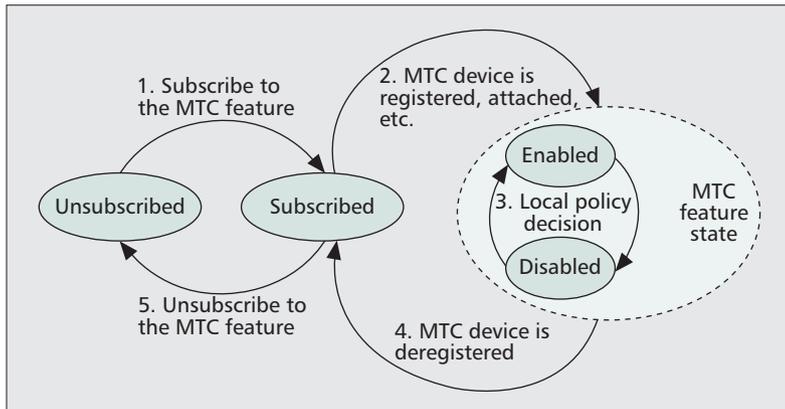


Figure 2. MTC feature cycle.

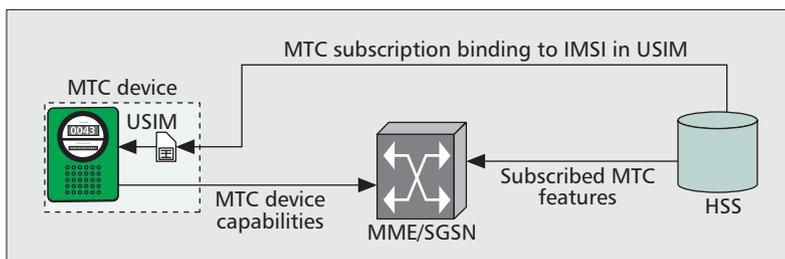


Figure 3. Main EPS network entities for subscription control.

Node	Description
eNB	Evolved Node B, the LTE's base station.
MME	Mobility Management Entity, a control plane entity for all mobility related functions, paging, authentication, bearer management in the EPS.
HSS	Home Subscriber Server, main database containing subscription-related information.
Serving Gateway	Local mobility anchor for intra-3GPP handoffs.
PDN Gateway	Packet Data Network Gateway, interfaces with the Packet Data Network (e.g., Internet).
SGSN	Serving GPRS Support Node, performs security functions, access control and location tracking. It plays the roles of MME and SGW in EPS.
GGSN	Gateway GPRS Support Node, interfaces with PDN, similar to the PDN Gateway, for UTRAN.

Table 1. EPS's most important nodes.

mize the network for use by MTC applications. These MTC features are subscribed and controlled by the MTC subscription in the HSS. One subscription can be shared among several MTC devices, includes the security credentials used to authenticate the devices. MTC devices sharing the same MTC subscription can use all subscribed MTC features belonging to the said subscription. The MTC features are activated at the time of the MTC device's subscription to the network and whenever it is supported by the network. During the course of the subscription, MTC subscribers have the flexibility to activate unsubscribed MTC features or deactivate subscribed MTC features based on the operator policies. There are already a set of MTC features considered in 3GPP [8]. Some of these features are listed in Table 2.

A use case, explaining how features could be subscribed for specific MTC devices, could be "pressure-sensing MTC devices" on a train bridge: each time a train runs over the bridge, the MTC pressure devices do their measurements and provide the result to the corresponding MTC application server which will alert when the bridge needs to be repaired. These devices are mounted on the bridge so they would subscribe to the "low mobility" feature to prevent unnecessary tracking area updates (TAUs), used by the device to notify the network about its current location within the network. The devices can also subscribe to the "small data transmission" feature, "PS only" feature, and the "mobile originated only" feature, since the devices initiate the transmissions. In case the bridge is rarely traversed by trains, then the "infrequent transmission" feature would also be applicable.

Since MTC features may be incompatible among each other, the network operator can restrict the subscription when incompatibility with already subscribed features is foreseen. Similarly, the network operator may also forbid attachment to the network when a mandatory feature is not or cannot be enabled. Figure 2 illustrates the MTC Feature cycle and describes in steps the first solution for the subscription control issue that is agreed in 3GPP:

1) Based on a pre-configuration in the operator system (e.g. HSS), MTC features are initially unsubscribed. A subscriber (i.e. the MTC service provider or a user) subscribes to a MTC feature via an operator web interface. This MTC feature is then marked as subscribed in the MTC subscription profile. The operator system (e.g. HSS) can always accept or reject the subscription request.

2) When a MTC device attaches and registers to the network, the subscribed features are downloaded from HSS to MME in the EPS [6, 7] or to the visitor location register (VLR) of SGSN in UMTS. The downloaded subscription features define the subscription profile. Unsubscribed features are simply not downloaded.

3) A MTC feature can be in either "enabled" or "disabled" state. Initially, all subscribed features are considered as "enabled". However, based on a local policy, SGSN/MME can disable all or part of subscribed features depending on the serving network capability and/or MTC device capability.

4) When a MTC device deregisters from the network, the MTC features are still subscribed. This is also regardless of whether all subscribed features are disabled or not in SGSN/MME.

5) All subscribed features can be unsubscribed by means of an operator interface regardless of whether they are enabled or disabled in the MME/SGSN.

Figure 3 shows the three main entities in the network that are involved in the MTC subscription control.

The MTC subscription identifies subscribed MTC features in the HSS. The binding between subscription and device is done with the IMSI (international mobile subscriber identity) of the USIM (universal subscriber identity module) in the MTC device for security and proper authentication with the network.

The support of MTC features may be different in a MTC device itself and in the network. Additionally, there may be more subscribed features in the MTC subscription than supported in a MTC device and/or the network. For this reason, a MTC device should either indicate its supported MTC features (i.e. its MTC capabilities) to the MME/SGSN, or the MME/SGSN has to query a special database and check based on the international mobile station equipment identity (IMEI) whether the MTC device supports a set of subscribed features. The MME/SGSN retrieves the set of subscribed features when it downloads the MTC subscription profile from the HSS.

In case a MTC device does not support one or more subscribed MTC features, the MME/SGSN may reject the attach request; otherwise, the MTC device may fail to operate properly. The MME/SGSN may then include information regarding the unsupported MTC feature in the rejection cause. Intuitively, the MME/SGSN needs to verify whether the subscribed MTC features are supported in the network or not. In addition to the rejection of an attach request from a MTC device, the MME/SGSN may also disable MTC features that are not supported in the network and/or the MTC device.

CONGESTION AND OVERLOAD CONTROL IN MTC

Congestion that may occur due to simultaneous signaling messages from MTC devices can be significant as they may lead to peak load situations and may have a tremendous impact on the operations of a mobile network, mainly on the performance of vital nodes with scarce resources such as domain control plane nodes (e.g. SGSN in UMTS, MME in the EPS [6, 7]), gateways (e.g. GGSN in UMTS, PDN GWs in EPS), and radio access network (RAN) (e.g. eNB, base stations and radio network controller (RNC) in UMTS). This explains the focus of 3GPP on finding efficient mechanisms to handle congestion at mainly the control plane of EPS that may happen due to nearly simultaneous signaling messages issued by a significant number of mobile devices. Thanks to the wide bandwidth of LTE and other emerging radio technologies

MTC Feature	Feature description
Low mobility	Rarely moving or only moving within a certain area
Time controlled	MTC data delivery only during predefined time intervals
Time tolerant	Data transfer can be delayed
Packet Switched (PS) only	MTC device supports only PS services
Small data transmissions	Only small amounts of data are exchanged
Mobile originated only	MTC devices utilizing only mobile originated communications
MTC monitoring	Monitoring events related to particular MTC devices
Priority alarm	Priority alarm generation upon the occurrence of a particular event
Secure connection	Secure connection between MTC devices and MTC servers required
Location specific trigger	Triggers MTC devices in a particular area
Network provided destination for uplink data	Uplink data to be delivered to a network provided destination IP address
Infrequent transmission	Long period between two data transmissions
Group based MTC features	Functions for associating a MTC device to multiple MTC groups

Table 2. MTC features in 3GPP.

(e.g., LTE-advanced), congestion due to user data packets is, for the time being, of less importance.

In the context of MTC, signaling congestion may happen due to a malfunction in the MTC server or application (e.g. synchronized recurrences of a particular MTC application) and/or due to massive attempts from a potential number of MTC devices to attach/connect to the network all at once [8]. A straightforward solution to signaling congestion can be in the form of designing MTC applications that are friendly to mobile network operators. However, mobile operators cannot risk the operations of their networks and the quality of the provided services by leaving the whole signaling congestion problem to MTC application developers.

STATE OF THE ART SOLUTIONS

Existing mechanisms for MTC devices signaling congestion avoidance and overload control can be classified into two categories, namely soft mechanisms and rigid ones [9]. In the former, the mobile network operator takes “soft” measures to minimize the frequency of attempts (of MTC devices) to carry out a particular procedure without having to throttle them. In case of the latter, the mobile network operator takes rigid measures disallowing the concerned MTC

devices from connecting to the network and/or executing the intended procedure.

Solution examples that fall in the former category are:

- Reducing signaling due to TAUs from MTC devices with low mobility feature by increasing the TAU period timer (e.g. from the default value 56 min to longer periods) or completely disabling it for static MTC devices.
- Triggering MTC devices, following a pull model, to attach/connect to the network only based on explicit indications from the MTC server.

The vast majority of signaling congestion avoidance and overload control adopt a rigid strategy, implementing one or a set of the following approaches:

- First, MTC devices are grouped based on different metrics/features (e.g. low priority access, low mobility, online/offline small data transmission, etc.)
- Forbidden/grant times are allocated for each MTC device based on its subscription in HSS.

MTC devices with time controlled MTC feature connect to the network only at certain time periods, predefined by the network operator, named “grant time intervals”. The network also

defines “forbidden time intervals” during which a MTC device is not allowed to connect to the network, be it the home network or a visited network. Intuitively, a grant time interval does not overlap with a forbidden time interval.

- Over the grant time, assigned to a MTC device, the communication window is further limited.

In some scenarios and depending on the target application, MTC devices do not need to connect to the network during the total duration of the grant time interval; a short communication window, worth a few minutes, is rather sufficient for accomplishing the objectives of the underlying application. Communication windows can be expressed in the format of a start and stop time, an offset from the beginning of the grant time interval and a duration, etc.

- The access time of MTC devices is also randomized over the communication window/grant time.

In case of multiple MTC devices attempting to connect to the network during a specific and short communication window/grant time, to avoid signaling congestion and to cope with possible network overload during communication windows, the communication windows of the different MTC devices can be distributed over the grant time interval, via for example, randomization of the start times of the individual communication windows. This operation assists in reducing peaks in signaling and data traffic from MTCs.

Another approach for tackling signaling congestion is by rejecting connection/attach requests, from MTC devices, by specific network nodes. This operation should take place targeting only MTC traffic, particularly those of MTC applications that are causing congestion, and shall have no impact on non-MTC traffic. Rejection of connection/attach requests shall be done while ensuring a rejected MTC device does not immediately reinitiate the same request (e.g. only after a predetermined back off time) and the rejected MTC devices do not attempt connecting to the network all at the same time, but rather at randomized times. In other words, the network indicates to the concerned MTC devices a back off time and ensures an even distribution of future incoming attach requests. Such randomization of MTC accesses can be triggered at the MTC device or by the network including the MTC server. When it is triggered by the network, the operation of a MTC device starts after receiving paging from the network or application level data from the server. In case of the former, the operation of the MTC device can start immediately after being paged or by adding some delay since being paged. The rejection can be done based on specific MTC group identifiers and/or by looking at MTC traffic for a dedicated APN (Access Point Network).

Network attachment requests can be rejected either at (or nearby) RAN (e.g., eNB, RNC) or by SGSN/MME. In case the MTC access is controlled by RAN, whenever the network is about to become congested by MTC applications, i.e. following a congestion status feedback from PDN GWs/Serving Gateways or GGSN, MME/SGSN sends a notification message to

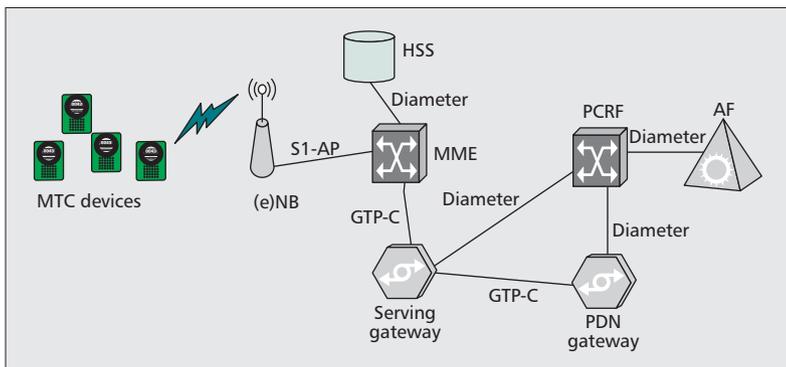


Figure 4. Protocols whereby bulk handling of signaling messages is possible.

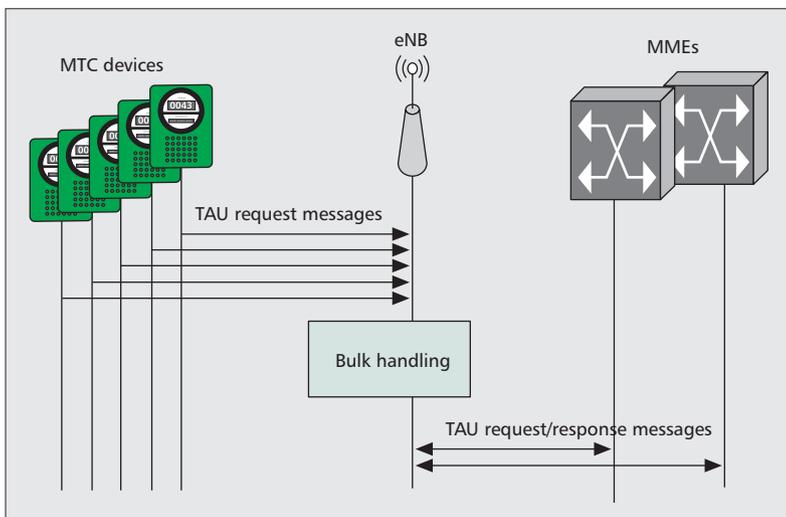


Figure 5. NAS signaling messages can be aggregated for bulk handling in the NW (e.g., eNB).

RAN nodes triggering MTC access control indicating MTC barring information (e.g. barring factor, MTC group to block, barring time, etc.) In case the MTC access is controlled by SGSN/MME, HSS may provision MME/SGSNs with information on grant time and forbidden time intervals in the MTC subscription. Based on this feedback and also on local operator policies, SGSN/MME then determines authorized times for each MTC device and communicates them to the respective MTC devices via the MTC server or by NAS (Non-Access-Stratum) signaling directly from MME/SGSN [10]. In case of congestion occurrence during the authorized times, SGSN/MME may reject connections from concerned MTC devices and provide them with back off times for later accesses, or simply send them a congestion notification message triggering them to reduce their data transmission rate. It should be noted that the latter incurs major impact on the MME/SGSN implementation. Intuitively, SGSN/MME-based access control works under the assumption that there are still some signaling resources available to receive and reject attach/connect requests. The RAN-based access control is more efficient as it bars the specific congesting MTC group/APN from attempting access and thus prevents MTC devices from congesting the NAS signaling further.

In summary, one of the advantages of the RAN-based solution consists in the fact that there is no waste in signaling from MTC devices that need to be blocked in the first place. It also assists in controlling overload of both RAN nodes and core network nodes. These benefits come at the price of additional implementations in terms of broadcasting barring information to RAN nodes from the network.

BULK MTC SIGNALING HANDLING

One aspect which is missing so far in MTC signaling congestion control consists in the lack of a mechanism that handles a bulk of similar signaling messages from MTCs in a single shot (i.e. bulk MTC signaling handling). In the following, we show the potential of handling signaling messages common to a group of MTC devices in bulk, as a complementary or alternative approach to the above mentioned solutions. Indeed, overload/congestion can be also mitigated by handling signaling messages, common to a number of MTC devices, by means of bulk processing. This signaling bulk can be handled by different protocols (e.g. S1 Application Part — S1-AP —, Diameter, and GPRS Tunneling Protocol for the Control Plane — GTP-C — as shown in Fig. 4).

Figure 5 depicts an example whereby NAS signaling messages from different MTC devices can be aggregated for bulk handling in the network. Effectively, in case a large number of MTC devices are simultaneously triggered to send a NAS signaling message (e.g. TAU request, massive attach/connect), eNBs can hold back the NAS signaling messages (e.g. TAU requests) for a pre-defined timeout or until a number of NAS signaling messages arrive (or a combination of the two) to proceed with a bulk of NAS signaling messages toward the MMEs. This intuitively assumes that the envisioned NAS

Type	Nr	Comment
Average Nr of MTC devices per MME	100 K	Distributed over a number of eNBs
Average duration of periodic TAU timer	56 Min	Default value [10]
Message Aggregation Period	10 s	Depends on the tolerance level of the procedure to delays

Table 3. Assumptions for a medium sized EPS network.

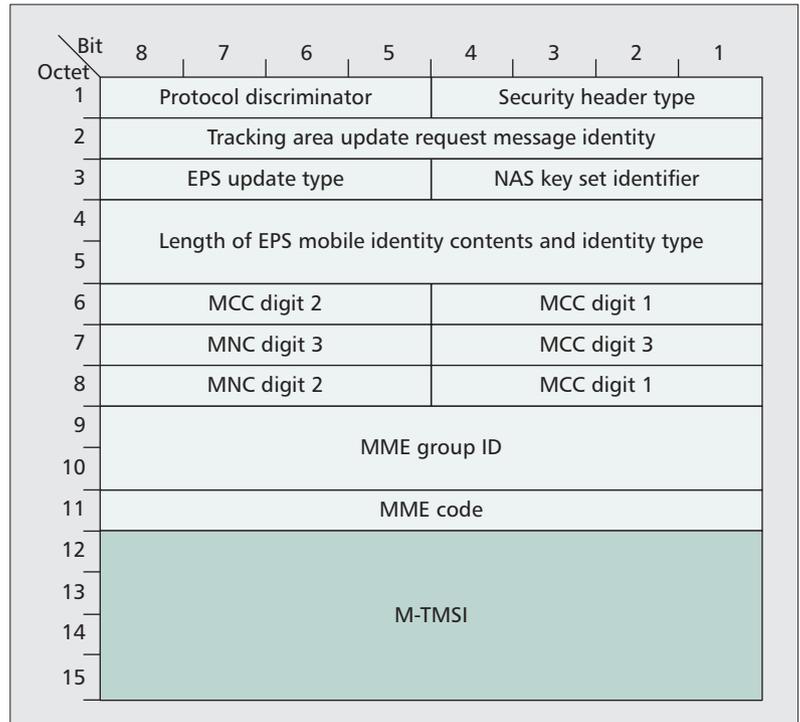


Figure 6. Tracking area update message with mandatory header fields.

signaling messages must be moderately delay tolerant. This can be achieved with proper time setting in NAS and/or core internal signaling (i.e. timers in MTC devices or MME for the admissible response time).

Using the possible aggregation of TAU messages, being issued from a large number of MTC devices, at eNBs as shown in Fig. 5 and considering a medium sized EPS network with the features indicated in Table 3, we demonstrate the potential of bulk MTC signaling in comparison to the state of the art.

TAU messages consist of mandatory fields, worth 15 octets, as shown in Fig. 6, and a set of optional fields. Since we concentrate only on MTC devices that are associated with the same MME, the only parameter that is device specific is the M-TMSI (MME Temporary Mobile Subscriber Identity), which identifies a device at one MME. The other fields, consisting 11 octets out of a total of 15 octets, are common to all MTC devices associated with the MME.

Based on the assumption that there will be an average of around 30 TAU requests per second at the MME only from the MTC devices, along

The gain in terms of shortening the overall procedure processing time/load depends on the underlying equipments. Unfortunately, vendors do not publicize relevant specifications and the gain cannot be quantified.

with the setting of the message aggregation period to 10s, it is possible to bulk 300 TAUs in a single message of 1211 Bytes, while with individual messages 4500 Bytes are needed. Further aggregation toward the HSS could be made at the MME. Indeed, NAS signaling messages, specifically Location Update Requests toward the HSS, can also be handled in bulk at the MME; this means that the message contents can be compacted considerably. Moreover, the effort of parsing the parameters of many messages is also reduced to a minimum, which shall reduce by a large factor the overall time spent for the procedure. Accordingly, signaling efficiency can be improved even if all IEs for the many original signaling messages would differ, just by avoiding the processing of multiple messages (e.g. every message must be acknowledged, i.e. protocol state needs to be kept for some time) and by much more efficient parsing. The gain in terms of shortening the overall procedure processing time/load depends on the underlying equipment. Unfortunately, vendors do not publicize relevant specifications and the gain cannot be quantified.

To conclude, handling signaling messages, common to a group of MTC devices, in a bulk could be an alternative or orthogonal approach for controlling congestion and overload in the network. It can be used as a complementary mechanism to randomization or as an alternative to it. Effectively, the network can trigger groups of MTC devices in a random fashion, but the signaling load caused by a single group of MTC devices, which is triggered at the same time, is minimized by means of bulk processing.

CONCLUSIONS

In this article we presented an overview of the potential and challenges of machine type communications. The focus of the article was mainly on issues related to the support of MTC in 3GPP mobile networks. We addressed issues relevant to subscription control and network congestion/ overload control. The latter may happen as a consequence of simultaneous signaling messages or misalignment of the MTC devices. An overview of the existing mechanisms for traffic overload and signaling congestion control is presented. A complementary solution is also presented. It suggests handling a bulk of similar signaling messages from MTCs in a single shot.

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BIOGRAPHIES

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