Toward Ubiquitous Massive Accesses in 3GPP Machine-to-Machine Communications

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ABSTRACT

To enable full mechanical automation where each smart device can play multiple roles among sensor, decision maker, and action executor, it is essential to construct scrupulous connections among all devices. Machine-to-machine communications thus emerge to achieve ubiquitous communications among all devices. With the merit of providing higher-layer connections, scenarios of 3GPP have been regarded as the promising solution facilitating M2M communications, which is being standardized as an emphatic application to be supported by LTE-Advanced. However, distinct features in M2M communications create diverse challenges from those in human-to-human communications. To deeply understand M2M communications in 3GPP, in this article, we provide an overview of the network architecture and features of M2M communications in 3GPP, and identify potential issues on the *air interface*, including physical layer transmissions, the random access procedure, and radio resources allocation supporting the most critical QoS provisioning. An effective solution is further proposed to provide QoS guarantees to facilitate M2M applications with inviolable hard timing constraints.

INTRODUCTION

Wireless personal communications have been widely applied to exchange voice, audio, video, emails, photos, and more among individuals. Such demands of ubiquitous communications among humans thus drive the development of abundant advanced wireless technologies and systems such as the cognitive radio network (CRN) and Third Generation Partnership Project (3GPP) Long Term Evolution-Advanced (LTE-Advanced) [1]. In addition to human-to-human (H2H) communications, an emerging technology empowering full mechanical automation (e.g., the Internet of Things and the smart grid) that may change our living styles is vigorously being developed. Such communications among machine-type communications (MTC) devices are known as machine-to-machine (M2M) communications [2].

To enable full mechanical automation, three major classes of communications shall be involved.

- **Communications between the sensor and the decision maker**: Meters/sensors report the measured data to the decision maker.
- **Communications among multiple calculation agents within the decision maker**: The decision maker may comprise multiple calculation agents. Based on the measured data, the decision maker may perform the decision making calculations by leveraging calculation agents with cloud computing or distributed computing technologies [3], and each calculation agent keeps exchanging temporal calculation results with other calculation agents.
- **Communications between the decision maker and the action executor**: After accomplishing calculations, the decision maker announces the set of actions to corresponding action executors.

Therefore, the sensor network [4] can be viewed as a primitive form of M2M communications, where a certain number of sensors are responsible for measuring certain physical quantities and transmitting measured data to the decision maker. In the 1990s, the supervisory control and data acquisition (SCADA) system was a primitive realization of the sensor network, where the central decision maker actively polls field equipment regularly. In sensor network communications, only a firm connection between each sensor and the decision maker (by direct transmissions, or multihop relaying via other sensors in recent enhancements) is provided. However, the communication framework in the sensor network faces difficulties in satisfying the requirements of recent, more sophisticated scenarios such as the smart grid or intelligent transportation system (ITS), where each smart device can play more than one role of sensor, decision maker, and action executor. As a result, in M2M communications, the ultimate goal is to provide comprehensive connections among all smart devices.

In the literature, few realizations of M2M communications have been proposed, such as leveraging Bluetooth (IEEE 802.15.1), Zigbee (IEEE 802.15.4), or WiFi (IEEE 802.11b) technologies. However, there is still no consensus on the network architecture of a general scenario for M2M communications. Considering that the ultimate goal of M2M communications is to construct comprehensive connections among all devices, the network architecture of general M2M communications can generally be considered as the heterogeneous mobile ad hoc network (HetMANET). As a consequence, general M2M communications may face challenges that can be encountered in the HetMANET. Although a considerable amount of research has provided solutions for the HetMANET (connections, routing, congestion control, energy-efficient transmission, etc.), it is still not clear whether these sophisticated solutions can be applied to M2M communications due to the constraint on the hardware complexity of the MTC device. As a result, how to construct and manage connections logically and physically among a large number of MTC devices distributed over an extensive coverage area invokes technological challenges. Furthermore, to enable low-cost implementations, standardization of communications schemes is very much needed. These concerns consequently obstruct the development of general M2M communications. Scenarios defined by 3GPP thus emerge as the most promising solution to enable M2M communications [5, 6].

The 3GPP infrastructure provides (wired) connections among all stations. In LTE-Advanced, these stations can be evolved universal terrestrial radio access (E-UTRA) NodeBs (eNBs) in macrocells or picocells, relay nodes (RNs), and home eNBs (HeNBs) in femtocells [7], which provide ubiquitous wireless access in both outdoor and indoor environments. By attaching to these stations, higher-layer connections among all MTC devices can be provided. However, it does not imply a successful practice of M2M communications in 3GPP. Instead, a series of challenges comes. One major challenge lies in the *air interface*. In order to meet requirements defined by International Mobile Telecommunications Advanced (IMT-Advanced) as the fourth-generation (4G) wireless system, the air interface in 3GPP (especially LTE-Advanced) is designed to support a high peak data rate for H2H communications. However, in M2M communications, there can be trillions of MTC devices, each with only a small amount of data needing to be transmitted. Therefore, the air interface design for high-data-rate transmissions may not effectively support M2M communications. This concern has recently attracted serious attention in the standardization progress of LTE-Advanced, and the impacts of introducing M2M communications into LTE-Advanced are now under considerable study in 3GPP.

Considering that the air interface is key to realizing M2M communications in the first and last mile, 3GPP organized a work item to begin the standardization progress for the air interface of M2M communications [8]. The first task is to identify impacts on system performance of applying transmission schemes of LTE-Advanced to MTC devices. This article thus provides an overview of M2M communications supported by 3GPP LTE-Advanced, and identifies major issues with the air interface of LTE-Advanced to support M2M communications. Potential solutions and technology options are also proposed to enhance the capability of LTE-Advanced. We begin by providing an overview of the network architecture and major features of M2M communications supported by 3GPP in the next section. Then, issues of directly applying existing mechanisms (in both physical layer transmissions and the random access procedure) designed for H2H communications to M2M communications are discussed. Since the most critical requirement for M2M communications is guaranteed quality of service (QoS), issues of scheduling and radio resource allocation for LTE-Advanced stations for the support of QoS for MTC devices are also identified. We consequently propose grouping-based radio resource management to achieve the most critical QoS guarantees for MTC devices.

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Overview of M2M Communications Supported by 3GPP

The Network Architecture of M2M Communications in 3GPP

As defined by 3GPP [5], two communication scenarios of M2M communications are supported.

MTC Devices Communicating with One or More MTC Servers — In this scenario (as depicted in Fig. 1), an MTC user (e.g., a person, a power plant in the smart grid, or a control center in the ITS) can operate an enormous number of MTC devices through MTC server(s). The MTC server(s) is provided by an operator, who offers an application program interface (API) for MTC users to access the MTC server(s). The MTC server(s) and LTE-Advanced infrastructure can be under the same operator domain (i.e., operator domains A and B in Fig. 1 can be the same). Since LTE-Advanced is a *heterogeneous network* [1], in additional to conventional macrocells with eNBs, there are RNs, picocells with eNBs, and femtocells with HeNBs. There is an interface (the S1 interface) between the mobility management entity (MME)/serving gateway (S-GW)/packet data network gateway (P-GW) and eNBs. HeNBs and RNs can also communicate with the MME/SGW/ P-GW through the S1 interface. Therefore, by attaching to these LTE-Advanced stations, MTC devices are controlled by the MTC user via the MTC server(s). 3GPP also allows the scenario in which the MTC server is collocated with the MTC user outside the operator domain.

MTC Devices Communicating with Other MTC Devices without Intermediate MTC Server(s) — An alternative scenario is depicted

Since M2M communications can be as general as the HetMANET, providing scrupulous connections between any pair of MTC devices among MTC devices distributed all over the world emerges as the most challenging task.

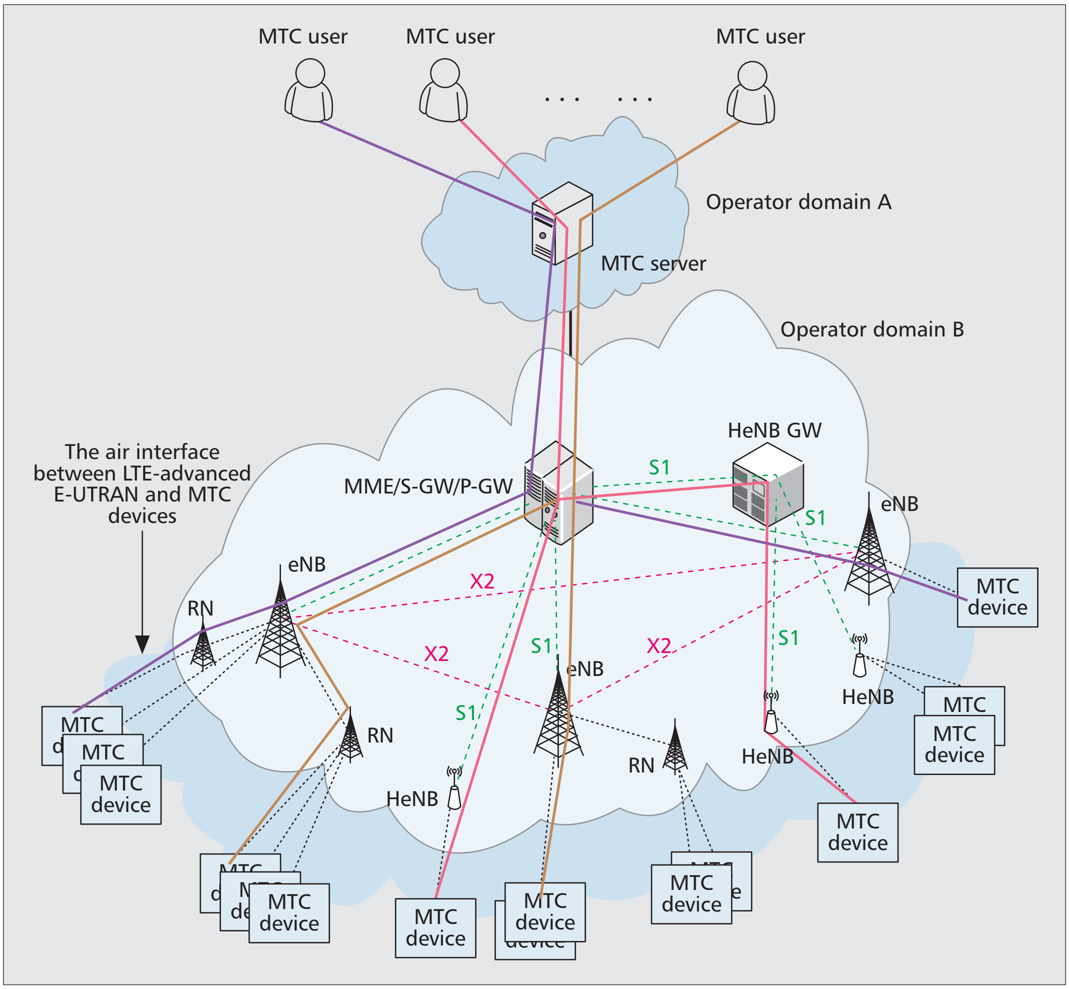

Figure 1. *The communication scenario with MTC devices communicating with the MTC server. Dotted lines denote physical connections; solid lines denote logical connections.*

in Fig. 2, where MTC devices can communicate with each other without MTC server(s). Communications among MTC devices can happen within the same operator domain or among different ones. In both cases, MTC devices shall attach to LTE-Advanced stations, and packets are forwarded by the LTE-Advanced infrastructure.

To enable communications between MTC devices and MTC server(s), the public land mobile network (PLMN) shall allow transactions between an MTC device and an MTC server, initiated by either the MTC device or MTC server. The PLMN shall also be able to authenticate and authorize an MTC device before the MTC device can communicate with the MTC server [5].

Features of M2M Communications in 3GPP

There can be all kinds of applications in M2M communications. For the facilitation of system optimizations, 3GPP defines 14 features in M2M communications [5] to characterize possible applications. Although there are common characteristics of communications between M2M and H2H such as *mobility*, *packet switched only*, and *secure connections*, these features also disclose that some characteristics of communications in M2M can be much different from those in H2H, such as *infrequent transmissions* (MTC devices may send or receive data at possibly a low duty cycle), *small data transmissions* (MTC devices may only send/receive a small amount of data), *time control* (MTC devices can send or receive data only during an access grant time interval, AGTI, and the network shall reject access requests, sending/receiving data and signaling of MTC devices within a forbidden time interval, FTI) and *group-based MTC* (for certain management or resource allocation purposes, the system shall provide a mechanism to associate one MTC device with one or more MTC groups; such a concept can also be found in [9, 10]). In the literature, few schemes for managing MTC devices with these features have been proposed such as leveraging user equipment (UE) to manage MTC devices in [10, 11]. However, these schemes are not compatible to LTE-Advanced and therefore they can not be smoothly applied to LTE-Advanced. As a result, schemes for managing MTC devices with these unique features are still under the development in 3GPP.

In light of the network architecture and features of M2M communications defined by 3GPP, it is known that the 3GPP network plays a decisive role in coordinating communications

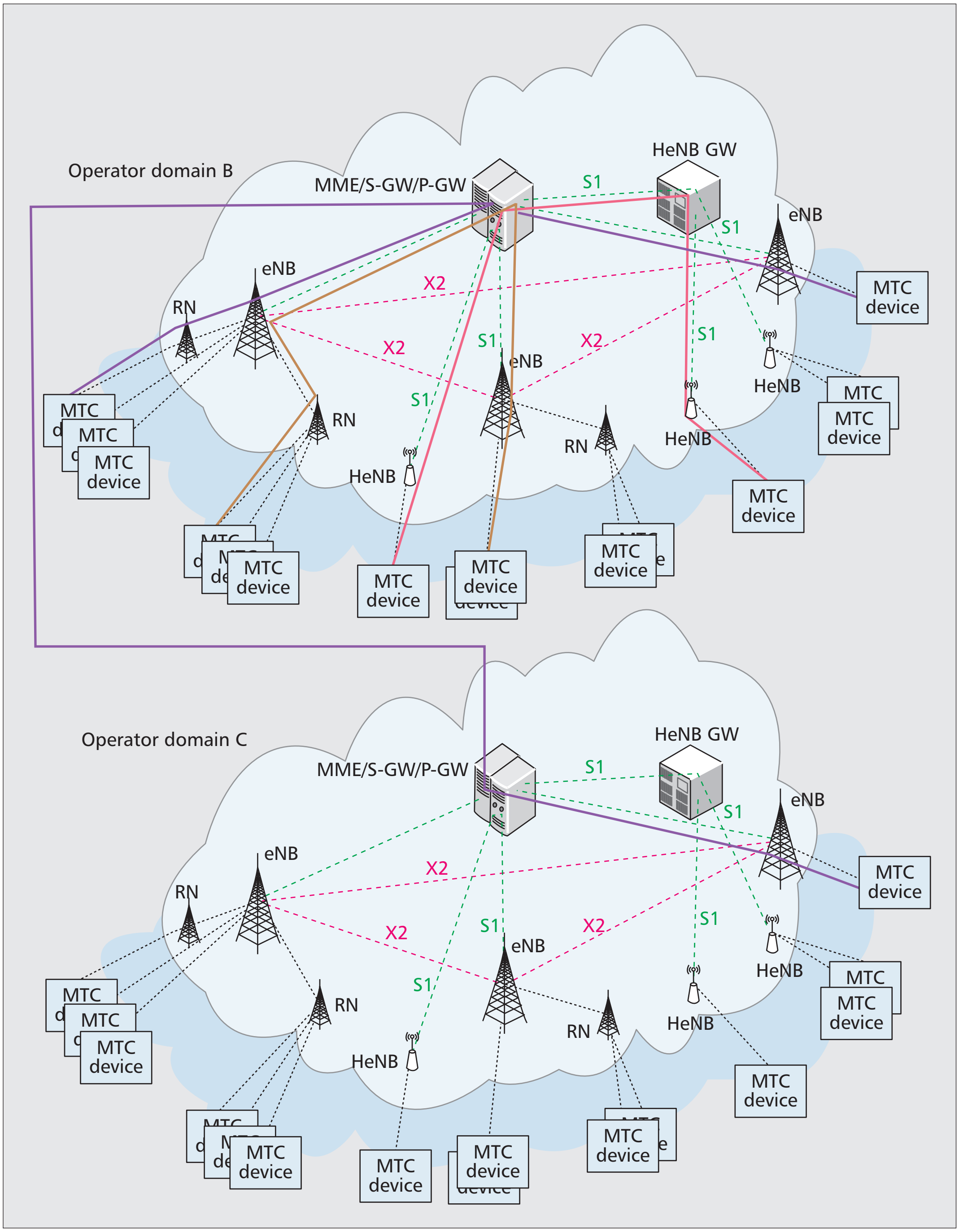

Figure 2. *The communication scenario of MTC devices communicating with each other without intermediate MTC server(s). Dotted lines denote physical connections; solid lines denote logical connections.*

We note that there may not be a globally feasible spectrum for general M2M communications in addition to the ISM band due to the crowded spectrum. As a result, a promising solution for the air interface of general M2M communications may lie in the cognitive radio technology [12] to reuse licensed spectrum.

among MTC devices, and between MTC devices and the MTC server. Such an architecture and features lead to a number of differences between the 3GPP M2M communications and the general M2M communications. Since M2M communications can be as general as the HetMANET, providing scrupulous connections between any pair of MTC devices among MTC devices distributed all over the world emerges as the most challenging task. As a result, a distinct feature in the general M2M communications is that failures (transmission errors, end-to-end connection loss, etc.) can be tolerable. However, failures shall be avoided in 3GPP since the system and network architecture designs in 3GPP particularly support robust connections and communications. In Table 1, comprehensive comparisons on system aspects and technical challenges are provided. We particularly note that there may not be a globally feasible spectrum for general M2M communications in addition to the industrial, scinetific, and medical (ISM) band due to crowded spectrum. As a result, in addition to utilizing the high frequency band (e.g., 60 GHz), a promising solution for the air interface of general M2M communications may lie in cognitive radio technology [12] to reuse licensed spectrum.

	3GPP M2M	General M2M
Number of MTC devices	Enormous	Enormous
Network architecture	Based on the 3GPP network	Generally considered as the HetMANET
Connections intermediate	Via the 3GPP network	Via all possible wired/wireless IP networks
Connections construction	Provided by the 3GPP network	Sophisticated mechanisms required and management
Direct communications among MTC devices	Not allowable in current stage (via LTE-Advanced stations as intermediate)	Allowable in short-distance communications
Failures tolerant	Not much acceptable	Acceptable
QoS provisioning	Available	Difficult
Air interface	Defined by 3GPP (e.g., LTE-Advanced)	May be based on existing communications standards (IEEE 802.15.1, IEEE 802.15.4, etc.) or other advanced technologies such as cognitive radio
Resource management	3GPP infrastructure controls the resource allocation	Sophisticated mechanisms required
Technology standardization	In progress	Unclear

Table 1. *Comparisons of 3GPP M2M communications and the general M2M communications.*

AIR INTERFACE CONSIDERATIONS

Identifying potential technical issues on the air interface has been considered as the first priority in the MTC work item in 3GPP (radio access network 2, RAN2, for radio layer 2 and 3). In this section, potential issues and design tradeoffs on the air interface requiring further investigations in 3GPP M2M communications are discussed.

PHYSICAL LAYER CONSIDERATIONS

Although the standardization progress of M2M communications in RAN1 (physical layer) has not been initiated yet, based on features of M2M communications, potential issues of applying existing physical layer mechanisms in LTE-Advanced to M2M communications can be identified in the following.

Are Sophisticated Link Adaptation Techniques Required? — To achieve the high peak data rate requirement for the 4G wireless system (1 Gb/s for static and 100 Mb/s for high speed mobility), sophisticated link adaptation techniques, such as single-user multiple-input multiple-output (SU-MIMO), multi-user MIMO (MU-MIMO), adaptive modulation, hybrid automatic repeat request (HARQ), beamforming and coordinated multiple-point (CoMP) transmission, are included as mandatory functions in 3GPP Release 11 and further versions. All these link adaptation techniques require sophisticated channel estimation schemes and estimation results report procedures. However, due to the *small data transmissions* feature, each transmission of an MTC device may only carry a small amount of data. Thus, a high peak data rate transmission scheme may not be necessary for MTC devices. Instead, reliable (low bit error rate, BER, and low latency) transmissions are critical. Link adaptation techniques in LTE-Advanced with sophisticated channel estimations and estimation results report procedures may induce a large overhead, which is inefficient and may induce considerable energy consumptions in MTC devices. As a result, a simple, fixed, and conservative (to achieve low BER and low latency instead of a high data rate) alternative shall be taken into the design considerations.

Are There Enough Resources in the Control Channel? — In LTE-Advanced, the physical downlink control channel (PDCCH) area is the first 1, 2, or 3 orthogonal frequency division multiplex (OFDM) symbols of a subframe, which comprises several control channel elements (CCEs) as the minimum unit carrying radio resources allocation and control information. Considering that the number of CCEs allocated for the PDCCH is 20 and the PDCCH format 1 is adopted (that is, control information for one MTC device is transmitted on an aggregation of two consecutive CCEs), only 10 MTC devices can be supported in a subframe. Such a design may not support a large number of MTC devices and UE units. As a result, whether additional resources shall be allocated for the PDCCH and whether the PDCCH shall be separated for MTC devices and UEs requires further investigations.

RANDOM ACCESS CHANNEL CONGESTIONS

In LTE-Advanced, random access is generally performed when the UE turns on, performs handoff from one eNB to another eNB, or loses the uplink timing synchronization. When the number of UE units is within an acceptable value, random access provides efficient request delivery. Unfortunately, the number of MTC devices can be far larger than the number of UE units. Investigations in 3GPP [13] indicate that both MTC devices and UE may suffer continuous collisions at the random access channel (RACH) when a large number of MTC devices is involved. This critical issue received considerable attention, and four possible solutions have been discussed in 3GPP [13].

Backoff-Based Scheme — In this scheme, the backoff time of UEs is set to a fixed small value (e.g., 20ms), while the backoff time of MTC devices is set to a large value (e.g., 960ms). It is expected that the extended backoff time can alleviate collisions and thus facilitating the collision resolution. However, although the backoff based scheme can provide performance improvements under a low congestion level in the RACH, it can not solve a high congestion level when the RACH is overload.

Access Class Barring (ACB) Based Scheme — The ACB-based scheme is originally designed for the access controls of UE. In the ACB, there are 16 access classes (ACs). AC 0–9 represents normal UE, AC 10 represents an emergency call, and AC 11–15 represents specific high-priority services. The ACB is achieved by broadcasting an access probability p and AC barring time by the eNB for UE corresponding to ACs 0–9. The UE also randomly draws a value q, $0 \le q \le 1$. If $q \le p$, the UE proceeds to the random access procedure. Otherwise, the UE is barred for an AC barring time duration. This scheme is also proposed for the random access control of MTC devices [14]. The ACB-based scheme can deal with high congestion levels in the RACH by setting an extremely small value of p. However, a small p leads to unacceptably large latency in delivering the request. In addition, if a congestion happens in a very short time, the ACB-based scheme may not adjust p in time due to a low response time.

Separating RACH Resources — In this scheme, preambles and time-frequency resources of the RACH for UEs and MTC devices are separated to prevent a large number of UEs and MTC devices from utilizing a common preamble at common time-frequency resources. The separating RACH resources scheme facilitates to reduce the impact on UEs. However, the performance improvement in extremely high congestion level of MTC devices is still limited.

Dynamic Allocation of RACH Resources — In this scheme, the eNB dynamically allocates additional resources for the RACH based on congestion levels and overall traffic load. Although the dynamic allocation of RACH resources can be effective in most cases, the performance improvement is limited by the availability of additional resources.

In the current stage, none of the above schemes alone can achieve acceptable performance in general cases. Thus, alleviating congestions in the RACH remains an open issue requiring further investigation.

ENERGY AND COMPLEXITY CONSIDERATIONS

The lack of an unfailing supply of energy is always a challenge limiting the performance of wireless communications devices, both UE and MTC devices. In H2H communications, the battery can easily be changed in the handset. However, it is not generally the case in M2M communications since MTC devices may be deployed to certain danger zones or places not easily reached. As a result, the battery in an MTC device shall be utilized for a very long time; thus, energy consumption in MTC devices is extremely low. Therefore, energy consumption and reliability are the most important constraints in M2M communications beyond the requirement for the high data rate in H2H communications, which may result in unique issues and designs in M2M communications.

In addition to energy consumption, complexity is another constraint in the design of M2M communications. Since a transceiver is an additional component of an MTC device rather than the major part, the transceiver and processor hardware for communications may only have limited capabilities. As a result, sophisticated transmission algorithms may not be feasible in M2M communications, and algorithms in M2M communications shall be simple and effective, which may not align with designs in H2H communications.

RADIO RESOURCE ALLOCATION WITH QOS GUARANTEES

For MTC devices, some applications (e.g., measured data reports from meters in the smart grid or navigation signal transmissions in the ITS) require strict timing constraints, and disasters occur if timing constraints are violated. Therefore, in M2M communications, providing *hard* QoS guarantees is the most important requirement. Although a lot of schemes and methods have been proposed for providing QoS guarantees in H2H communications, that research may nr difficult to directly apply to M2M communications. The reason is twofold.

Enormously Diverse QoS Requirements — In H2H communications, major applications requiring timing constraints are multimedia. For multimedia traffic, the packet arrival periods typically range from 10ms to 40ms. However, the packet arrival periods in M2M communications can range from 10ms to several minutes due to the infrequent transmission feature. Such enormously diverse QoS requirements perplexes the design of the radio resources allocation algorithms in M2M communications for providing a guaranteed jitter performance, as jitter (defined by the difference between the time of two successive packet departures and the time of two successive packet arrivals) fully captures the timing performance of periodic traffic.

Small Data and Massive Transmissions — Distinct from multimedia traffic, typically with bursty packet arrivals, each MTC device may only occupy a few orthogonal frequency-divi-

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How to effectively arrange such a massive amount of transmissions with enormously diverse QoS requirements turns out to be the most challenging task for the design of radio resources allocation algorithms for MTC devices.

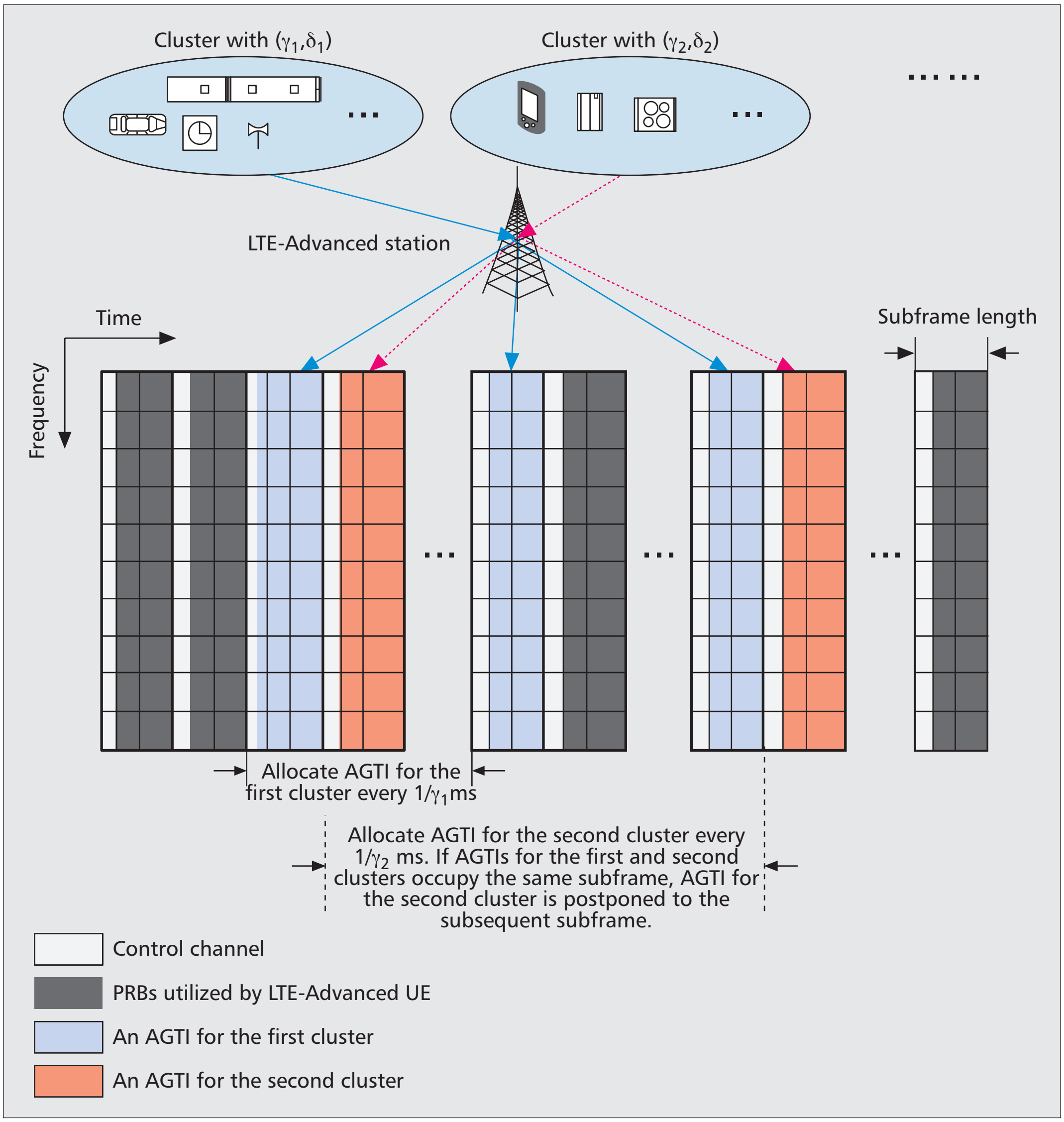

Figure 3. *The proposed grouping-based radio resource management.*

sion multiple access (OFDMA) physical resource blocks (PRBs) in each transmission due to the small data transmission feature. A PRB is the basic unit for radio resources allocation in LTE-Advanced. Furthermore, each LTE-Advanced station may support a large number of MTC devices. As a consequence, in each subframe time, the complexity of radio resources allocation for MTC devices can be higher than that in H2H communications, even although a sophisticated transmission scheme in the physical layer could be avoided in M2M communications.

Consequently, how to effectively arrange such a massive number of transmissions with enormously diverse QoS requirements turns out to be the most challenging task for the design of radio resource allocation algorithms for MTC devices. Furthermore, for LTE-Advanced stations, the computational complexity of radio resource allocation algorithms for UE has been a burden. Therefore, the radio resource management scheme for MTC devices has to be simple and effective.

GROUPING-BASED RADIO RESOURCE MANAGEMENT

In this subsection, we provide an effective solution for LTE-Advanced stations to manage radio resources for MTC devices requiring QoS guarantees. To support a large number of MTC devices with small data transmissions and enormously diverse QoS requirements, an effective scheme is to adopt the *group based MTC* feature. Specifically, MTC devices are grouped into M clusters (indexed by $i = 1, \ldots, M$) based on QoS characteristics and requirements (γ_i, δ_i), where γ_i is the packet arrival rate of the ith cluster (thus, $1/\gamma_i$ is the packet arrival period) and δ_i is the maximum tolerable jitter of the ith cluster. MTC devices in the same cluster are with an identical QoS characteristic and requirement. A cluster with a larger γ_i has a higher priority. By this grouping operation, the LTE-Advanced station can manage radio resources on a cluster basis instead of an individual MTC device basis, which alleviates the complexity.

Due to the *time controlled* feature, MTC devices can only communicate with the LTE-

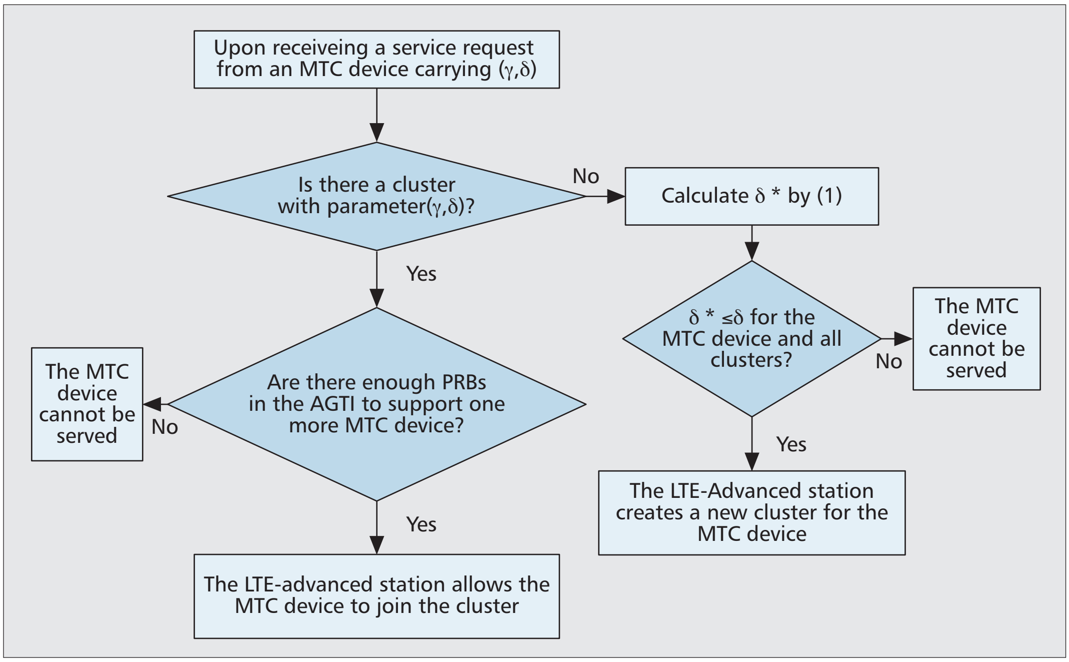

Figure 4. *The proposed call admission control procedure.*

In the proposed grouping-based radio resource management, sophisticated calculations can be avoided. Thus, the computational complexity can be considerably decreased to support an enormous number of MTC devices.

Advanced station within an AGTI. Therefore, the LTE-Advanced station allocates an AGTI (comprising L PRBs) every $1/\gamma_i$ ms for each cluster according to priority. If AGTIs for different clusters are arranged in the same subframe, the AGTI for the cluster with lower priority is postponed to the subsequent subframe. Such AGTI allocation is depicted in Fig. 3. Each AGTI has a fixed length, τ, for all clusters. Based on such a radio resource management, the sufficient condition for QoS guarantees can be provided as below. If $\delta_i^* + \tau < 1/\gamma_i$, the jitter of packets in the ith cluster is bounded above by

$$\delta_i^* = \tau + \sum_{k=1}^{i-1} \left\lceil \frac{\gamma_k}{\gamma_i} \right\rceil \cdot \text{for } i = 2,\ldots,M, \tag{1}$$

and $\delta_i^* = \tau$ for $i = 1$. If $\delta_i^* \leq \delta_i$ for all clusters, packets in all clusters can meet the jitter constraints. This bound can serve as a call admission control scheme to guarantee that QoS constraints of all packets of MTC devices admitted in the system can be satisfied. Thus, this criterion is effective to be adopted for deciding whether an MTC device can be served by the LTE-Advanced station when a service request carrying (γ, δ) is received by that station.

Figure 4 depicts the details of such a call admission control procedure. When an MTC device successfully attaches to the LTE-Advanced station and attempts to transmit data, the MTC device sends (γ, δ) via the RACH to the LTE-Advanced station to request radio resources. If there is a cluster of MTC devices with (γ, δ) that has been admitted, the LTE-Advanced station only checks whether there are enough PRBs in the AGTI allocated for the cluster to support the new MTC device. The MTC device can be served if there are sufficient PRBs in the AGTI for the cluster, and this MTC device is grouped into the cluster. If there is no cluster with (γ, δ), the LTE-Advanced station calculates the jitter bound according to Eq. 1. If $\delta^* \leq \delta$ is valid for the new MTC device and all existing clusters, the LTE-Advanced station creates a new cluster for the MTC device, and the MTC device can be served.

In the proposed grouping-based radio resources management, sophisticated calculations can be avoided. Thus, the computational complexity can be considerably decreased to support an enormous number of MTC devices.

Performance Evaluations

To evaluate the performance of the proposed solution, the system parameters of LTE-Advanced is adopted [15] to conduct the simulation. Consider that the system bandwidth is 20MHz and each AGTI is a subframe length (1ms) comprising 100 RBs to support 20 MTC devices in each cluster. Each MTC device occupies 5 PRBs to transmit a packet of size 1.28 kb. When 16-quadrature amplitude modulation (QAM) is adopted, each PRB can carry 336 bits. We consider 12 clusters and the simulation time is 100s. The packet arrival periods of clusters range from 10 ms to 1.67 min, which covers general applications in M2M communications. The simulation results are shown in Table 2. We can observe from Table 2 that the bound in Eq. 1 is very conservative and is effective to guarantee jitter performance lower than the required value. This result is not surprising. With the facilitation of grouping MTC devices with identical QoS characteristics and requirements into the same cluster, the worst case performance can be analyzed in Eq. 1. Therefore, the radio resource allocation scheme developed based on such a worst case analysis certainly achieves an effective QoS guarantees.

Cluster	Characteristics (γ_i, δ_i)[1]	Jitter bound in (1) (ms)	Max. jitter in simulation (ms)
1	(0.1,2)	1	0
2	(0.05,4)	3	0
3	(0.05,6)	4	0
4	(0.025,12)	9	0
5	(0.01,50)	24	1
6	(0.01,60)	25	1
7	(0.005,80)	50	0
8	(0.004,100)	67	6
9	(0.002,150)	129	2
10	(0.002,200)	130	2
11	(0.001,500)	259	0
12	(0.00001,30000)	25951	0

[1] Both $1/\gamma_i$ and δ_i are in the unit of ms.

Table 2. *Simulation results of the jitter performance of clusters with mtc devices under the proposed solution.*

Conclusion

In this article, we provide an overview of M2M communications in 3GPP, with a particular focus on the air interface, including the physical layer transmission schemes, random access procedure, and radio resource management for QoS guarantees, to fully comprehend practical issues of enabling M2M communications over LTE-Advanced. The provided elaborations show that the characteristics of M2M communications are very different from those of H2H communications. To orientate these unique features, grouping-based radio resource management is particularly proposed for QoS guarantees. It is just the beginning stage in the development of 3GPP M2M communications, and a number of issues still remain open for further investigation.

Acknowledgment

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Biographies

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