RACH Overload Congestion Mechanism for M2M Communication in LTE-A: Issues and Approaches

A. H. El Fawal (1,2), A. Mansour (1), F. Le Roy (1), D. Le Jeune (1) and A. Hamié (2)
ahmad.el-fawal@ensta-bretagne.org; mansour@ieee.org;
frederic.le_roy@ensta-bretagne.fr; denis.le_jeune@ensta-bretagne.fr; ali.hamie@aul.edu.lb
(1) Lab-STICC, ENSTA Bretagne, 29806 Brest, France; (2) Lab-CRITC, AUL University, Beirut, Lebanon

***Abstract*—The next generation of mobile systems based on LTE-A (Long Term Evolution-Advanced) networks are expected to support the new promising technology M2M (Machine-to-Machine) communications while keeping an eye on its previous H2H (Human-to-Human) communications not to be affected especially when it comes to the expected exponential growth of the number of M2M in the coming years, in particular, with the advance of IoT (Internet of Things) deployment and the expected ubiquity of such objects in the near future.**

In this article, we review the M2M communication technology from the LTE-A perspective and we outline the random access challenges in high dense areas where the LTE-A network is striving to fulfill the massive number of M2M devices.

Moreover, we compare the most common mechanisms found in the literature that deal with the RACH (Random Access Channel) procedure issues and challenges by analyzing the existing solutions and approaches to avoid RACH overload congestion in the M2M communications.

To this end, we have developed different M2M scenarios using SimuLTE Modeler to investigate the impact of M2M communications on LTE-A networks in emergency events.

***Keywords*—** IoT, M2M, H2H, LTE-A, SimuLTE, RACH, overload congestion mechanism, LPWAN.

I. INTRODUCTION:

The dawn of M2M, or Machine-Type-Communication (MTC), is taking place inevitably in the coming years. During this new technological take-off, a new era of communication is going to rule the new opening business markets (e.g., smart cities, e-health care, logistics, surveillance and security systems, smart metering, in-car satellite navigation systems, etc.) [1]. In this coming era, M2M communications will be handled either by the current mobile infrastructure LTE-A networks [2] - in particular with the innovative 3GPP cellular IoT solutions (e.g., NB-IoT, LTE-M, etc.) [3] according to the 3rd Generation Partnership Project (3GPP) proposal - or by the non 3GPP Low Power Wide Area Network (LPWAN) solutions such as LoRa, SigFox, etc.

Unfortunately, the current LTE-A network was designed to fulfill the H2H needs (e.g., internet browsing, voice messages, video streaming, etc.) in which huge amount of data and files are downloaded. But on the flip side, the M2M communications, with their huge expected number, are mainly found to automate many types of services which require uploading only few bits of information (e.g., temperature, humidity, location, etc.) [1].

Moreover, It is highly recommended to develop an innovative M2M/LTE-A approach which supports the network infrastructure in order to accommodate the new M2M application requirements without any sacrifice in the QoS (Quality of Service) of the legacy H2H communications (or Human-Type-Communication (HTC)) [1].

Needless to say that LTE-A networks should serve the expected massive number of M2M devices contending to access a LTE-A network using the RACH (Random Access Channel) procedures [1].
This contention causes a remarkable performance degradation (e.g., huge delay, packet loss, etc.) especially when a large number of M2M devices try to access the network over the same channel (e.g., alarms triggered by unexpected events, failures of the power grid, earthquakes, flooding, etc.). Consequently, it will lead to a network overload problem [2].

This unavoidable challenge sheds the light on the implementation of RACH procedure in LTE-A networks as a key-point improvement which attracts the research community in order to propose solutions for this potential bottleneck in mobile networks [4]. Moreover, many questions arise trying to investigate the impact of M2M devices communication on LTE-A networks. The maximum number of M2M devices that could be handled by an eNodeB[1] is still a challenging point. This paper describes the existing approaches found in the literature which addresses the impact of M2M devices on LTE-A networks, then illustrates this impact in different scenarios by comparing the results in two different platforms using the SimuLTE Modeler during an emergency event.

II. LTE-A NETWORK ACCESS METHODS AND RESEARCH CHALLENGES:

In order to gain access to the network resources and according to European Telecommunications Standards Institute (ETSI), there are three different methods of access in LTE-A networks that can M2M devices choose from [4]:

1) *Direct Access:*
   In this access method, M2M and H2H devices can directly access the LTE-A network via eNodeBs. While this access method is the simplest one (no need for any intermediate device or complicated mechanism), it may lead to an eNodeB overload problem when a huge

[1] evolved Node B is the network access device in the LTE-A network which provides connectivity to a mobile phone.

amount of M2M devices are contending in a limited amount of access resources network [4]. Therefore, a new RACH overload control mechanism is required for the random access procedure in M2M communications to solve this problem [2].

2) *Gateway Access:*
A "M2M Gateway" is a dedicated device, added to the network infrastructure, used to provide a suitable path and to facilitate local control for M2M communication [2]. In dense areas, M2M gateways are used to manage the huge volume of M2M devices by relaying data between the eNodeB and its connected M2M devices [4]. However, providing access to them via gateways worth studying it, especially when researchers are interested in satisfying the QoS requirements for both M2M and H2H devices. Consequently, an efficient M2M Gateway selection mechanism is needed while addressing the RACH overload control [2].

3) *Coordinator Access:*
In this method, adjacent M2M devices can be grouped before transmission. This can reduce the redundant signaling and avoids congestions. One M2M device (a member group) can be chosen in order to play a role of a temporary M2M gateway which has to collect the data from all members in the same group and delivers it to the eNodeB [4]. In this method, although there is no need for an additional equipment to be added to the network infrastructure but a more complicated mechanism should be designed to select the group coordinator and to manage group members' requests. Moreover, the challenging task is to develop an adaptive algorithm for preamble allocation which improves the overall network performance (e.g., "Clustering Techniques" presented in [5]).

Regardless of the access method used to request an access to the network, consequently the device used to provide this access method (M2M device, M2M gateway or coordinator M2M device), any device will be able to transmit its data after establishing a Radio Resource Control (RRC) connection successfully with an eNodeB in LTE-A networks, which requires a prior allocation of periodic resources dedicated to its Random Access (RA) preamble[2].
Now, with a huge number of expected M2M devices, the eNodeB should serve loads of RRC connection requests simultaneously. As a result, and by reaching the cut-off point, a RACH procedure overload problem could lead to an unacceptable performance degradation in the LTE-A network. To address this problem we should have a clear description of the RACH procedure overload problem, as explained in the next section.

III. RACH PROCEDURE OVERLOAD PROBLEM DESCRIPTION:

The procedure is similar to any User Equipment (UE) access procedure. For this purpose, the term UE will be used to represent either M2M device/MTC "Machine-Type-Communication" or H2H device/HTC.
In the frequency domain, each Random Access (RA) slot[3] consists of six RBs (Resource Block) and has 1.08 MHz bandwidth (6 x 180 KHz). In the time domain, the basic duration is equal to 1 ms (as shown in Figure 1). Using one of the 64 RA preambles provided by the eNodeB an UE can submit his access request in one RA slot [1].
In one hand, M2M devices transmit only their data in small packet sizes in most cases, but on the other hand, a huge amount of M2M devices are expected to contend in a higher frequency than H2H devices in order to establish data connections, especially the signaling and traffic load spikes caused by a sudden surge of the number of M2M devices trying to access the same eNodeB simultaneously (e.g., a huge number of smart meters becoming active simultaneously after power outage), leading to a low random access success rate. In this sticky situation, a high network congestion in the RACH procedure occurs and many problems arise (e.g., extra energy consumption, packet loss, etc.) causing in the end a service interruption.
To reduce the load on the RACH procedure, we can increase the number of access opportunities scheduled per frame, but this determines a reduction of the amount of resources available for data transmission.

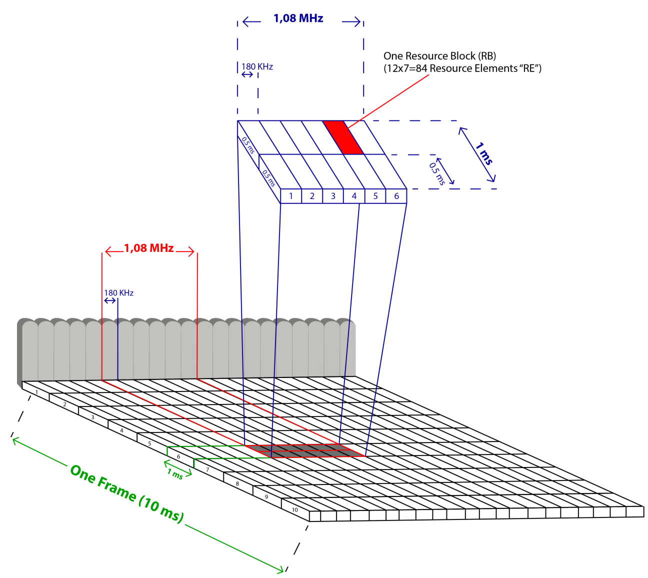

Figure 1. The RA slot in one LTE-A frame.

Summing up, the standard LTE-A procedure for managing channel access requests will not properly scale in the presence of massive access attempts by a large number of UEs. As a result, a sharp degradation of the quality offered to the conventional services arises because of long access delay and high access failure rate [1].
Addressing this issue requires having a close look at the access procedures and how the "Contention-based RA procedure" is affected by the M2M traffic, as explained in the next section.

[2]A Random Access (RA) preamble is an unique signature chosen by the UE from a list of 64 preamble signatures provided by the eNodeB in each LTE-A cell.

[3]RA slot is the allowable time slot for an UE to transmit its access request.

IV. RACH PROCEDURES:

To transmit packets an UE performs a random access during an allowable time-frequency slot, called RA slot. The RACH procedure should be initiated in two cases: a) The UE is in "idle mode"; therefore it does not have an uplink radio resources. b) The UE is in "connected mode": either the UE is moving from a previous coverage area to another one during a Handover process [6], or after a radio link failure which requires recovery. A contention-based or a contention-free RACH procedure starts relatively as soon as one of the two previous cases is detected. The contention-free RACH procedure (shown in Figure 2) is under the full control of the eNodeB in order to avoid delayed-constrained access requests with high success requirements, such as those related to Handover [1]. Obviously, no contention is required to be resolved in this procedure, hence, it is not affected by the M2M traffic; therefore, we will not focus on this case (For more details about the contention-free RACH procedure refer to [2]).

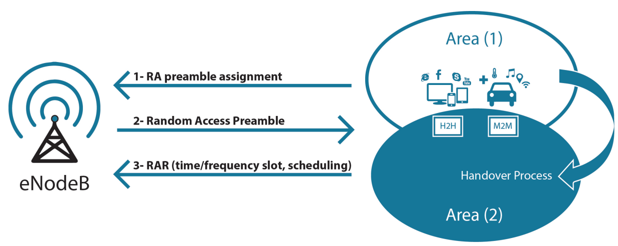

Figure 2. Contention-free RACH procedure.

On the flip side, the contention-based RACH procedure is much more susceptible to M2M traffic; as it is discussed in the next section.

V. CONTENTION-BASED RACH PROCEDURE:

In this procedure, an UE initiates a contention-based random access by choosing randomly any RA preambles (less than 64 preambles) initially provided by the eNodeB [1]. Unfortunately, because of the expected huge amount of UEs, it is more likely that more than one UE choose the same RA preamble, which requires a contention resolution procedure to solve this issue [2]. The contention-based RACH procedure (shown in Figure 3) consists of the following four steps:

1) *Random Access preamble assignment*: An UE chooses one RA preamble provided by the eNodeB and sends it during the RA slot. A collision may occur -it will be detected in step 3- when two or more UEs select the same RA preamble, that requires a contention resolution -in step 4-.
2) *Random Access Response (RAR)*: When the eNodeB receives a RA preamble, it replies with a RAR message containing the appropriate configurations (e.g., time/frequency slot, uplink scheduling, etc.) for further communication between the candidate UE and its eNodeB. When an UE receives these configurations, it synchronizes its uplink timing and proceeds to the next step.

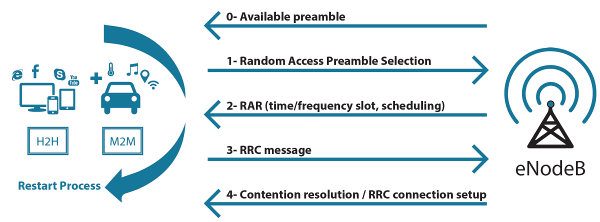

Figure 3. Contention-based RACH procedure.

3) *Connection request*: After receiving the RAR, the candidate UE transmits a request Radio Resource Control (RRC) message to the eNode in order to establish a connection.
4) *Contention resolution*: If the eNodeB can decode any request message from the previous step, it replies with an identifier. This identifier can be detected by an unique UE owner which acknowledges the message. Therefore, the connection is established and the UE gains access to the network and transmits its data successfully. The remaining colliding UEs try to access the network by triggering a new RACH procedure in a second attempt after waiting for a random back-off period [2].

Consequently, many challenges are expected to arise as result of the previous procedure. These challenges and their existing solutions in the literature are outlined below.

VI. RACH OVERLOAD CONTROL MECHANISMS:

In this section, the different mechanisms to control the RACH overload problem caused by M2M traffic in LTE-A networks are outlined as follows:

1) *Access Class Barring (ACB) scheme:* ACB can define 16 Access Classes (AC); AC"0" to AC"9" represents normal device, while AC"10" represents an emergency call, and AC"11" to AC"15" represents specific high-priority services [7]. Each class is assigned an Access Probability Factor (APF) and a Barring Timer (BT). The devices belonging to a certain AC are allowed to transmit their RA preambles in a RA slot only by drawing a random number lower than the APF. Otherwise, the access is barred and the devices have to wait for a random back off time which is determined according to the BT of that class, before attempting a new access [1].
2) *RACH resource separation scheme:* In this mechanism, two approaches are suggested in order to allocate RACH resources to M2M devices different than H2H devices. In the first approach, available RA preambles are split into two groups; The first group is dedicated for M2M devices and the second one is dedicated for H2H devices. While, in the second approach, although the available RA preambles are split into two groups, but the first group is dedicated to M2M devices and the second one is shared by H2H devices and M2M devices [1].
3) *Slotted access scheme:* In this mechanism, initially M2M devices are in "sleep mode". In specific radio frames and in specific RA-slots, M2M devices are allowed to send their RA preambles. The radio frames and the RA-slots

are calculated by M2M devices based on their identity and RA-cycle [8]. (A RA-cycle is an integer number multiple of a radio frame broadcast by the eNodeB [2]).

4) *Dynamic resource allocation between M2M and H2H devices:* In this mechanism, there is no dedicated resources neither for M2M devices nor for H2H devices. All resources are shared in a dynamic mechanism based on the network access requests. When excessive access attempts initiated by loads of M2M devices are detected by the network, it allocates additional RACH resources for M2M devices automatically [4].
5) *Pull-based scheme:* In this mechanism, M2M devices receive paging messages sent from the eNodeB, which triggers responses from M2M devices towards the eNodeB by initiating random access requests. This centralized mechanism helps the eNodeB in controlling the paged devices based on the network congestion level and the remaining available resources [9].
6) *M2M-specific back off scheme:* This mechanism implements different delays on the random access attempts based on the device type (M2M or H2H device). The back-off time assigned to M2M devices is 48 folds H2H devices (960 ms for M2M devices vs. 20 ms for H2H devices) [7].
7) *Grouping or Clustering scheme:* In this mechanism, UEs are grouped based on QoS applications or based on their geographical locations. A*"coordinator"* for each group is selected which plays the role of a relay agent for the whole group members with their associated eNodeB [2].

VII. Comparative Analysis of current RACH overload control mechanisms:

In this section, we analyze the proposed solutions -found in the literature- to alleviate the overload problem in M2M communications and list the gaps needed to be filled in the near future in order to fully support the M2M paradigm:

1) *Access Class Barring (ACB) scheme:* In [7], it is concluded that using the ACB mechanism the eNodeB can deal with the RACH overload by lowering the value of APF, but this could cause longer random access delays to some devices. While in [2], they shed the light on using EAB (Extended Access Barring) in which delay-tolerant devices are not allowed to perform a random access when a M2M device is labeled as "EAB device". Meanwhile in [1], they stress the fact that ACB can alleviate the M2M massive access issue by defining a dedicated class for M2M devices with higher AP and a lower barring timer. One main drawback appears when many M2M devices need to access the channel in a short time interval as result of a sudden event (e.g., earthquakes, flooding, etc.). This issue needs more studies on how to combine the ACB mechanism with other techniques.
2) *RACH resource separation scheme:* In [2][9], the authors used the same mechanism in which the total available number of RA preambles is split into two groups based on two different approaches:
a) Dedicated H2H and Dedicated M2M preambles.
b) Dedicated H2H and Shared H2H-M2M preambles.
The RACH congestion problem could be solved especially when an ACB mechanism previous to the selected approach is implemented first, then UEs can send their RA preambles (or by adopting a "Game Theory Scheme" presented in [10]). In this scheme the eNodeB selection method and the back-off procedure are neglected. Therefore, it is preferable to do extra efforts to delve more into finding a sub-solution to this issue and by mixing all together, we can tackle in the end an ideal solution (e.g., "Q-learning" solution presented in [11]). In [4], two ways of resource separation are proposed: a) Radio resource separation in the same frequency-band; one for H2H devices and the other one for M2M devices. b) Out-of-band dedicated frequency-band (e.g., below 1 MHz); this band is dedicated to the M2M devices only. Both suggested ways need additional research and design modifications. In [1], the authors proposed two different approaches to distinguish M2M resources from H2H resources by either splitting the RA preambles into two groups or by allocating different RA slots for each group. We can notice a drawback to this solution: when the number of reserved resources in each group of devices doesn't reflect the actual demand causing low performance. This scheme needs to be coupled with other mechanisms to switch dynamically between both groups in order to fulfill the requested needs (e.g., using "SOOC" Self-Optimizing Overload Control presented in [8]).
3) *Slotted access scheme:* In [1][2][7][9], the authors present the same previous mechanism without any additional explanation. Moreover, no proposed improvements are suggested, but one weakness point was mentioned in [2] "long access latency": in dense areas, where massive number of M2M devices are attempting to access the network simultaneously, the total number of unique access slots do not fulfill the excessive access needs causing a contention among M2M devices to seize shared access slots which leads inevitably to many collision incidents. We can resolve this issue by extending the RA cycle but this can cause a huge delay in RA requests and require searching for an appropriate solution especially with delay-constrained M2M applications (e.g., alarms).
4) *Dynamic resource allocation between M2M and H2H devices:* In [2][7][9], the authors outline the same mechanism, but they spot on two remaining challenges:
a) This technique is still limited by the available resources.
b) The adjustment decision is not clear enough: "when and how to make it".
5) *Pull-based scheme:* In [1][2][7][9], the same scheme was analyzed in each article, and the following issues arise:
a) The scheme cannot deal with unexpected surge of M2M access requests.
b) The scheme is suitable to manage channel access with

a regular pattern (a "QoS-based clustering" proposed in [12] can be useful in this case).

c) The eNodeB selection problem was not addressed (in [2], a reinforcement learning-based eNodeB selection was proposed, in which an eNodeB which maximizes its QoS performance of a M2M device, can be chosen in an overlapping area where multiple eNodeBs could be found).

6) *M2M back-off scheme:* In [1][2][7][9], this scheme improves the performance in low channel overload but cannot solve the congestion problem in high overload situations (when more devices perform the RA mechanism simultaneously).

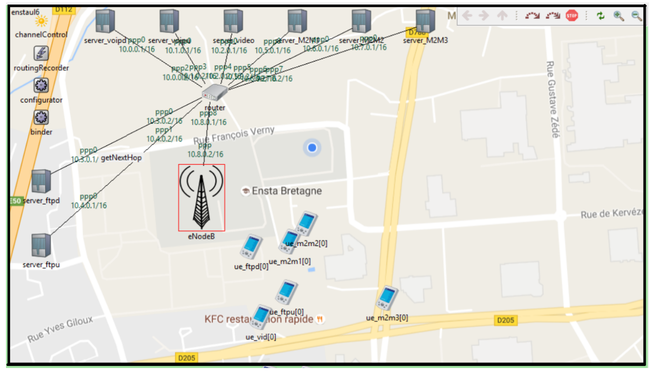

Figure 4. SimuLTE Scenario

VIII. LPWAN Solutions:

In the upcoming years, supporting a massive number of devices will be one of the key requirements for the new innovative IoT solutions called LPWAN Solutions [3] characterized by its low-rate and long-range transmission. Inevitably, major RACH challenges are expected in this new field which could pave the way for new research topics in the academia studies. In this section, we describe the new LPWAN solutions in a nutshell, but we will dedicate our coming paper to negotiate LPWAN challenges and to provide an appropriate solution for M2M congestion problem.

On one hand, non 3GPP LPWAN solutions (e.g., LoRa, SigFox, etc.) are expected to play a significant role in Smart Cities especially when it comes to the massive number of connected devices:

- SigFox: is able to connect around 1 million devices per BS [13].

- LoRa: is able to connect a large number of devices (e.g, 62K devices using a SX1301 gateway [14]).

On the other hand, the forthcoming 3GPP Cellular IoT solutions (e.g., NB-IoT, LTE-M, etc.) are striving to share the market with the legacy LTE-A network in order to reach the total potential volume of 20 billion of things by 2020 [15].

Reusing "3GPP Cellular IoT solutions" takes advantage on "non 3GPP LPWAN solutions" because it is possible to reuse the same hardware and share spectrum by making LTE-M and NB-IoT compatible with the legacy LTE-A without running into coexistence. Therefore, deploying LTE-M and NB-IoT is as simple as a software upgrade to enable a full IoT network with significantly better coverage than the LTE-A network [3].

Finally, the LPWAN solution battle has just started. In this battle, the "3GPP Cellular IoT solutions" are expected to attract a huge amount of connected devices from the "non 3GPP LPWAN solutions", if it can offer a better IoT platform that allows customers to scale and manage their business requirements more efficiently.

IX. Scenarios:

Our scenarios show an example of the M2M traffic load in an emergency event (e.g., earthquakes, fire, terrorist attacks, etc.). In such emergency events, besides of the regular H2H network traffic (VoIP, Video Streaming and file transfer), an additional M2M surge traffic attempts to access the network caused by the consequences of the emergency event.

The core of the scenario uses the SimuLTE Modeler to focus on the ability of an eNodeB to deal with a fixed number of H2H traffics (FTP-UL, FTP-DL, VoIP-UL, VoIP-DL, Video Streaming "10 each") with an increasing number of M2M requests attempting to access the LTE-A network simultaneously in 1 sec interval as shown in Figure 4.

The SimuLTE scenario settings are given in Table I.

Parameter	**Value**
Simulation Length	300 sec
Min./Max. (eNodeB-UE distance)	35 m / 300 m
Terminal velocity	120 Km/h
Mobility model	Linear Mobility
Transmission bandwidth	5 MHz (for DL and UL each)
No. of PRBs	25 (for DL and UL each)

TABLE I
Simulation Parameters

The different LTE-A traffic: VoIP, Video Streaming, file transfer and M2M are shown in Table II.

Model	**Parameter**	**Setting**
VoIP Model	Application Packet	40 Bytes
	Interval	20 ms
	Talkspurts and Silences	Default settings
Video Streaming Model	**Parameter**	**Setting**
	Video Size	10 MB
	Packet Length	1000 Bytes
	Frame Interval	75 ms
M2M Model	**Parameter**	**Setting**
	Packet Size	128 Bytes
	Interval	1 sec
FTP Model	**Parameter**	**Setting**
	File Size	20 MB

TABLE II
LTE-A traffic Models

The above scenario is simulated using the open-source network modeler SimuLTE 0.9.1 in an environment of OMNeT++ 4.6. with INET 2.3.0. in two different platforms:

1) *PC platform:* Intel(R) Core(TM) i7-6700 HQ processor at 2.60 GHz, with 12 GB of RAM, and Windows 10 operating system 64-bit.

2) *Cluster platform:* AMD Opteron(TM) processor (6274x58) at 2.2 GHz, with 24 GB of RAM, and Ubuntu 16.04 operating system 64-bit.

In all scenarios, the number of VoIP-UL, VoIP-DL, video streaming, FTP-UL and FTP-DL users is 10 each.

The number of M2M increases till the peak of M2M is reached as shown in the Table III.

M2M Traffic	16 B/1 sec	128 B/1 sec	6 KB/1 sec
Cluster Platform	above 1000	above 1000	above 1000
PC Platform	800	600	800

TABLE III
MAXIMUM NUMBER OF M2M DEVICES

Now, by exceeding the maximum number of M2M on the PC platform, an error appears: *"Error in module (TCP) server M2M.tcp Model error: Address already in use: there is already a connection listening on IP address: Port Number"*. Meanwhile, this error didn't appear while simulating using the same parameters on the cluster platform. This conclusion sheds the light on the importance of the robustness of the platform while simulating such scenarios in order to end up with concrete results. Furthermore, if we consider the results of [16] [17] shown that the performance of voice users remain unaffected by the additional users, while file upload and M2M traffic experience a significant delay around four times higher, and if we continue to [18][19][20] in which the authors spot on the maximum number of UEs that could overload an eNodeB especially when loads of M2M devices are contending to access the network in dense areas. The answers vary as follows: 250 UEs [18], 320 UEs [20] and 400 [19], which show a kind of contradiction in between the aforementioned results.

This contradiction needs additional analysis -which could be our next future work- according to the different components and various parameters among several scenarios and platforms.

X. CONCLUSION:

Certainly, IoT will take place in every part of our lives with loads of innovative applications. The M2M communications emerged with LTE-A networks are becoming the more candidate infrastructure to fulfill these needs. As result, a surge of M2M devices should be connected via LTE-A networks in order to fully automate our daily lives.

Our aim in this article is to shed the light on the coming overload congestion problem caused by the ubiquity of M2M communications which shall arise in the near future. Furthermore, a survey of the main solutions proposed in the literature to overcome this issue is presented. Additionally, an analysis has been conducted here as a result of RACH procedure limitations. Although, many proposed solutions appear to be optimized on (time, frequency) but for the moment the overload congestion problem is still a talking point with no clear solution.

To this end, different results are concluded according to two different platforms in an emergency event full of H2H and M2M devices, which require extra investigations using different parameters among several scenarios and platforms.

XI. ACKNOWLEDGMENTS

The authors would like to thank Dr. A. Virdis from Università di Pisa for his great help in SimuLTE scenario planning and Dr. M. Najem from ENSTA-Bretagne for his support in the implementation of different scenarios and Mr. M. Ammaduddin from University of Tabuk for his advising.

REFERENCES

[1] A. Biral, M. Centenaro, A. Zanella, L. Vangelista, and M. Zorzi, "The challenges of M2M massive access in wireless cellular networks," *Digital Communications and Networks*, vol. 1, no. 1, pp. 1–19, 2015.

[2] M. Hasan, E. Hossain, and D. Niyato, "Random access for machine-to-machine communication in LTE-advanced networks: issues and approaches," *IEEE Communications Magazine*, vol. 51, no. 6, pp. 86–93, 2013.

[3] NOKIA. Lte evolution for iot connectivity. (Accessed: 04-Dec-2016). [Online]. Available: http://resources.alcatel-lucent.com/asset/200178

[4] K. Zheng, S. Ou, J. Alonso-Zarate, M. Dohler, F. Liu, and H. Zhu, "Challenges of massive access in highly dense LTE-advanced networks with machine-to-machine communications," *IEEE Wireless Communications*, vol. 21, no. 3, pp. 12–18, 2014.

[5] C.-Y. Tu, C.-Y. Ho, and C.-Y. Huang, "Energy-efficient algorithms and evaluations for massive access management in cellular based machine to machine communications," in *Vehicular Technology Conference (VTC Fall)*. IEEE, San Francisco, USA, 2011, pp. 1–5.

[6] S. Sesia, I. Toufik, and M. Baker, *LTE-the UMTS long term evolution*. Wiley Online Library, 2015.

[7] F. Ghavimi and H.-H. Chen, "M2M communications in 3GPP LTE/LTE-A networks: architectures, service requirements, challenges, and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 2, pp. 525–549, 2015.

[8] A. Lo, Y. W. Law, M. Jacobsson, and M. Kucharzak, "Enhanced LTE-advanced random-access mechanism for massive machine-to-machine (M2M) communications," in *27th World Wireless Research Forum (WWRF) Meeting*. Dusseldorf, Germany, 2011, pp. 1–5.

[9] Y. Mehmood, C. Görg, M. Muehleisen, and A. Timm-Giel, "Mobile M2M communication architectures, upcoming challenges, applications, and future directions," *EURASIP Journal on Wireless Communications and Networking*, vol. 2015, no. 1, pp. 1–37, 2015.

[10] Y.-C. Pang, S.-L. Chao, G.-Y. Lin, and H.-Y. Wei, "Network access for M2M/H2H hybrid systems: a game theoretic approach," *IEEE Communications Letters*, vol. 18, no. 5, pp. 845–848, 2014.

[11] L. M. Bello, P. Mitchell, and D. Grace, "Application of Q-learning for RACH access to support M2M traffic over a cellular network," in *European Wireless 2014; 20th European Wireless Conference;*. Barcelona, Spain, 2014, pp. 1–6.

[12] S.-Y. Lien, K.-C. Chen, and Y. Lin, "Toward ubiquitous massive accesses in 3GPP machine-to-machine communications," *IEEE Communications Magazine*, vol. 49, no. 4, pp. 66–74, 2011.

[13] M. Centenaro, L. Vangelista, A. Zanella, and M. Zorzi, "Long-range communications in unlicensed bands: The rising stars in the iot and smart city scenarios," *arXiv preprint arXiv:1510.00620*, 2015.

[14] Semtech. Lora-faqs. (Accessed: 04-Dec-2016). [Online]. Available: http://www.semtech.com/wireless-rf/lora/LoRa-FAQs.pdf

[15] C. A. Garc, P. Merino *et al.*, "3gpp standards to deliver lte connectivity for iot," in *2016 IEEE First International Conference on Internet-of-Things Design and Implementation (IoTDI)*. IEEE, 2016, pp. 283–288.

[16] T. Pötsch, S. N. K. K. Marwat, Y. Zaki, and C. Gorg, "Influence of future M2M communication on the LTE system," in *Wireless and Mobile Networking Conference (WMNC), 2013 6th Joint IFIP*. IEEE, 2013, pp. 1–4.

[17] T. Pötsch, S. N. K. Marwat, Y. Zaki, and C. Görg, "Performance Evaluation of Machine-to-Machine Communication on Future Mobile Networks in Disaster Scenarios." Springer Berlin Heidelberg, 2013, pp. 270–273.

[18] P. Masek, J. Hosek, and M. Dubrava, "Influence of M2M communication on LTE networks," in *Sbornik prispevku studentske konference Zvule*, vol. 1, 2014, p. 2014.

[19] D. Kovac, P. Masek, and J. Hosek, "Simulation-Based Study on Capacity Performance of 4G Mobile Network for M2M Services," *"Technical Universities"*, 2014.

[20] Y.-C. Chang, "Study of Overload Control Problem for Intelligent LTE M2M Communication System," *Advances in Smart Systems Research*, vol. 3, no. 3, pp. 44–48, 2013.