Coexistence of M2M and H2H types of connections in LTE technology

Mattia Lecci, Umberto Michieli, Matteo Ciprian
Department of Information Engineering, University of Padova – Via Gradenigo, 6/b, 35131 Padova, Italy
Email: {mattia.lecci, umberto.michieli, matteo.ciprian}@studenti.dei.unipd.it

***Abstract*—Machine-Type Communication (MTC) is expected to exponentially grow in the next few years. Therefore understanding its traffic patterns is of fundamental importance in order to correctly exploit the current LTE network and define the future 5G network's requirements.**
In this paper we want to give a wide view over the possible coexistence and integration between MTCs and traditional Human-Type Communications (HTCs) in LTE. These two traffic behaviors are completely different and have already been modeled in literature, but so far there are just a few works about the joint analysis of the combination of these two types of traffic.
Thus, after having improved the existent ns3's (Network Simulator 3) LTE module by adding User Equipment's (UE) disconnections, some simulations of a typical smart-city scenario have been performed analyzing how the presence of Machine-Type Devices (MTDs) impacts on the performance of the whole network. The most significant results are then shown at the end of this paper.

I. Introduction

Over the last decades a great development in the production of well-known smart-devices has been done. These new devices such as sensors, bio-sensors, household alarms are designed to cooperate in order to offer new smart-services as health-monitoring, remote control and smart grids [1]. These devices need to intercommunicate in order to fulfill their tasks and, for this reason, an increasing interest in MTC has spread among the scientific community over the last few years. As these new kind of communications differ from the classical ones called Human to Human (H2H or HTC), a new paradigm has been developing in a field commonly referred as Internet of Things (IoT). Machine-to-Machine (M2M) services, a branch of IoT, aims to realize a complete automatic interconnection between MTDs without a minimal human intervention. Different from traditional H2H communcations, such as voice, web surfing and video streaming, M2M services have different requirements due to their peculiar features. In a M2M scenario there are usually a very large number of MTDs [2] concentrated in a specific area and each one express different types of traffic in relation to its task. In order to realize the aforementioned goal, several protocols have been proposed like ZigBee for small wireless sensor networks or EIB for home automation [3]. Although these efforts can be considered valid solutions, an important requirement for M2M communication consists in implementing the so-called "plug-&-play" principle according to which a device, placed in a specific location, should not need additional structures to be connected with the rest of the world. Considering this assumption, the exploiting of LTE cellular networks have been proposed as a possible solution. LTE is a mature technology which has been deployed in hundreds of networks around the world, with regional or national coverage. Although it was designed for H2H communications, in a future scenario it could be used to support a large number of MTDs. As drawback, the sharing of resources between HTC and MTC in LTE could deeply affect the performance of the entire network in term of packet delay and congestion probability. For these reasons a possible coexistence of H2H and M2M has to be evaluated through simulations of different smart-city environments, in order to estimate the potential impact of Machine Type Communication on its Human-to-Human counterpart.

It is well known that LTE is a very complex system to simulate, as a matter of fact it involves a multitude of interconnected layers for both communication and signaling as well as few different nodes inside its core network to provide connectivity among mobile users and the rest of the Internet.

In order to simulate such a complex system we used a well-known open source event-based simulator: Network Simulator 3. It currently implements different types of applications, channels, protocols and complex systems such as LTE (both the Evolved UMTS Terrestrial Radio Access Network, or EUTRAN, and the Evolved Packet Core, or EPC), Point-to-Point links, wireless channel implementations, UDP, TCP, IP, mobility, handover and much more.

The official implementation, however, presented two main problems: the RACH (Random Access CHannel) procedure and the RRC (Radio Resource Control) layer are far too idealized since the *Connection Release* and *Resume* mechanisms are not implemented. The first problem is well discussed in [4], which also proposed an integration to ns3's LTE module in order to model a more realistic procedure. On top of that, we also present a solution to the second problem, more deeply discussed in Section III-A.

These two key features are very important in order to perform a realistic simulation. Since we have considered a big number of devices, PRACH (Physical RACH) overloading may become a non-negligible phenomenon, especially if many devices transmit periodically and have to resynchronize with the cell every time. As already discussed, MTDs tend to transmit with very long periodicities (usually not less than 30 minutes), wasting useful resources thus impacting on the performance of HTC. Implementing the *Connection Release* mechanism gives the possibility to eNBs (Enhanced-NodeB, how LTE's base stations are called) to avoid dedicating resources on MTC for too much time as well as making the simulation more realistic.

The most innovative aspect of our study is the joint analysis of M2M and H2H traffic behavior. In fact a lot of researches have been done in order to characterize M2M traffic scenarios (for example [5], [6] and [7]), but only a few works developed a scenario in which the attention is focused on the coexistence between M2M and H2H communications (see [4] or [8]).

The results reported in this article show how an increasing number of devices, even with very low traffic, puts under strain the LTE system. Moreover, it is also possible to appreciate how a full H2H traffic and a mixture between H2H and M2M ones with similar loads behave in different ways. Unfortunately because of computational constraints we could not simulate a fully realistic and large scale scenario. This may have hid important trends that we were not able to fully capture.

The remainder of this paper is structured as follows: Section II provides an holistic view of LTE, H2H and M2M communications. Section III discusses the ns3's LTE module, that we improved and then used to perform some simulations, and the general scenario we considered. Section IV shows the main results of our simulations and Section V concludes the paper and underlines strengths and weaknesses of our analysis with a view to future work.

II. Related Work

A. LTE Overview

Long Term Evolution, better known as LTE, is a standard for high-speed wireless communication for mobile devices. Its primary goals were to achieve a much higher per-user bit rate together with lower latencies and a more efficient utilization of radio resources than the previous generation of cellular system.

In order to reach these objectives a lot of different improvements were designed over the "legacy" UTMS standard. For what concerns the physical layer, now OFDM and MIMO are at its very basis, moreover a fine slotting of both frequency and time are applied to the channel and precisely scheduled from the eNB to the UEs. While in UMTS the Radio Access Network (RAN) was divided into multiple entities, in LTE all its complexity has been moved to eNBs gaining a big improvement in latencies.

Also, for the first time in mobile systems, the whole network is IP-based and packet switched. This gives a great flexibility and responsiveness to the system.

Just for completeness a brief explanation of the three most important nodes of the EPC and their main functions follows:

- MME (Mobility Managements Entity):
  - Control node, user data do not flow through it
  - Manages roaming, selection of S-GW, P-GW, security negotiations
  - Setup and maintenance of bearers
  - Idle UE reachability (paging)
- S-GW (Serving Gateway):
  - All users' IP packets go through this node
  - Serves as local mobility anchor when UEs move across different eNBs
  - Retains information about UE bearers when user is in idle state
  - Buffers UE data during paging procedure (while MME re-establishes bearers)
- P-GW (Packet Data Network Gateway):
  - It is responsible for IP address allocation for the UE
  - Responsible for filtering down-link UE packets into appropriate bearers depending on their QoS requirements
  - It is the mobility anchor point for non-3GPP technologies (e.g. WiMAX/802.11)

One of the crucial points for our purpose regards the *Connection Release* mechanism. As thoroughly discussed in Section 5.3 of [9], this procedure can only be activated by an eNB. Its purpose is to avoid wasteful resource allocation to devices that do not transmit frequently. In order to do that, usually eNBs maintain a timer for each connected UE that is started the first time the UE connects to the specific eNB and it is reset every time a data packet is sent or received.

Once the timer expires the eNB asks to the MME the permission to release the UE context. In other words, the eNB would like to forget everything about that devices in order to release its resources. If the MME accepts the request, it stores the current UE context, advertises the appropriate S-GW to tear down all the related S1 Bearers (the ones towards the eNB) but not the S5/S8 Bearers (the ones towards the P-GW), then replies positively to the eNB. Once the response is received, the eNB sends to the UE a *RRCConnectionRelease* message, tears down its sides of the Radio Bearers (both data and signaling) and deletes the UE context.

On the other side, the UE has to accept the request without replying and to enter the *RRC_IDLE* mode.

The inverse operation is called *Connection Resume*. It can either start from the UE or from outside the LTE network (e.g. the Internet). In the latter case, a data packet arrives to the P-GW, which then sends it to the S-GW. Once there, the gateway realizes that it has no way to communicate the information to the destination since the E-RAB (EUTRAN Radio Access Bearer, i.e. the portion of the EPS Bearer composed of the S1 Bearer and the Radio Bearer) has been previously torn down. Therefore a message is sent to the MME, who promptly starts the paging mechanism. Another possibility is that the UE wakes up as it wants to send a data packet. In either case we are now in the exact same situation. Now the E-RAB has to be restored and this can be done following the usual *Connection Request/Setup* procedure right after a successful preamble transmission. More informations on this procedure and its implementation on ns3 can be found on [4].

B. Human-To-Human Traffic

HTC is a general term used to define communications among mobile or fixed terminals allowing interconnections between humans. In this big and heterogeneous set, a large variety of common devices can be included such as smartphones, laptops and modems which exploit the LTE network in order to provide many type of services. A first distinguish between *Human Type Communications* and its M2M counterpart concerns the kinds of data exchanged. As known, HTCs have to provide several class of services as: *Conversational Voice* (VoIP), *Conversational Video* (live streaming), *Real-Time Gaming*, *Non-Conversational Video* (buffered streaming), *IP Multimedia Sub-System*, *TCP based* (www, e-mail, chat, ftp, p2p,...). About this matter, LTE has introduced an innovative mechanism named *QCI*, "QoS Class Identifier". Thanks to this, each class is

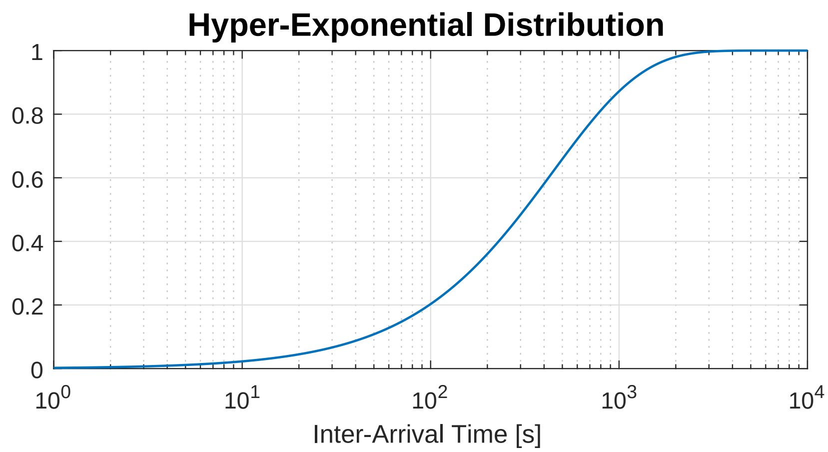

Figure 1: Hyper-exponential distribution with parameters corresponding to $RRC_{IT} = 10\ s$ from Table I.

characterized by a specific bearer associated to an appropriate *Quality of Service*, a set of parameters which indicate particular connection requirements such as packet's priority, latency, packet error rate, etc. [10]. In order to obtain precise statistics about the characterization of H2H traffic, in [11] a probe has been installed on a UMTS network to monitor the nature of packets exchanged by users using smartphones. The results show that more than an half of the packets (54,18%) were exchanged for web-application services, 10,11% for instant-messaging, 1,16% for video-streaming, 3,11% for p2p-stream and the remaining for other minor services.
Another important difference beetwen Human-Type Devices (HTDs) and MTDs concerns the mobility. HTDs are tipically more dynamic than the second ones, which show usually a more static behavior and often their position can be approximated as fixed. Although this is not directly correlated with traffic modeling, the mobility of each device can affect network performance in some particular scenarios. In the literature different models have been implemented: for example in [12] HTDs' movement follows a random-walk whereas in [13] they are assumed fixed.

As regards to temporal statistics used to model H2H traffic, different solutions have been proposed in the literature. In some previous papers it has been modeled as a Poisson process with a fixed parameter λ, but one of the most complete work is reported in [14], which investigates deeply on the RACH preambles separation between M2M and H2H. In this paper the statistics of HTDs' RACH requests were captured analyzing a large amount of data-traffic on a commercial eNB and detecting the transitions between idle and connected state realized by each user. After a deep data analysis, it was possible to evaluate the most suitable model to describe the HTDs access to the channel. According to this work, each HTD initiates a RACH procedure with inter-arrival times modeled as i.i.d hyper-exponential random variables. The pdf of this variable is obtained as a weighted-sum of the distributions of different exponential r.v.:

$$f(x) = \sum_{c=1}^{C} \alpha_c \lambda_c e^{-\lambda_c x} \tag{1}$$

where x is the value of inter-arrival time, C is the number of exponential random variable considered, λ_c is the parameter of each exponential random variable and α_c is the value of the weight coefficients (with the constraint of $\sum_{c=1}^{C} \alpha_c = 1$). A list of possible values for the characterizing parameters λ_c and α_c is reported in Table I. As shown, these values are strictly connected with different configurations of *RRC Inactivity Time* (RRC_{IT}). Further details will be given in Section III.

C. Machine-To-Machine Traffic

M2M communications are seen as a form of data communication among devices and/or from devices to a remote server, that do not necessarily require human interaction [2]. This type of communication enables the creation of the so-called IoT and it is increasingly gaining share of traffic: Cisco® predicts that by 2020, there will be 3.2 billion of M2M connections (i.e the 26% of the total number), with an annual growth of 38% from 2015 to 2020 [15].
According to the 3GPP standard [16] the number of MTDs per cell site sector is expected to grow up to approximately 50.000 units.
It is widely demonstrated in literature that the current 3G and 4G wireless networks, designed for the traditional HTCs discussed above, are unable to support such a huge number of MTDs. In fact, even if the traffic produced by a single MTD is supposed to be kept small (e.g. at most tens to hundreds of bytes per second), the aggregated traffic could jeopardize infrastructures, that were optimized for a continuous

RRC_{IT} [s]	α_c	λ_c
2	0.7782, 0.0955, 0.0102, 0.1160	0.0804, 0.0192, 0.0013, 0.0046
5	0.1935, 0.0149, 0.7916	0.0043, 0.0013, 0.0334
10	0.0291, 0.2269, 0.7441	0.0015, 0.0039, 0.0185

Table I: Characterizing parameters of hyper-exponential distribution for different RRC_{IT} values.

flow of information, as HTC [17]. Hence the MTC paradigm is determining the characteristics that 5G network should have [18]. Therefore it is of fundamental importance to understand all the M2M traffic flavors and features.

Possible MTDs' applications are related to intelligent transport, smart meters (such as automatic electricity, water and gas meters reading), automotive, smart agriculture, security, health monitoring, gaming and many others ([19], [20]). Since the set of M2M applications is so vast, it is impossible to reduce all these different devices in a single traffic pattern and in a single QoS requirement, nevertheless there are many recurrent features that can be found. For example, according to [2], [5] and [21], the MTC traffic should include at least some of the following peculiarities: short and small number of packets, low duty-cycle packets (i.e. long period between two data transmissions), uplink-dominant transmissions, real time and non-real time transmissions, periodic and event-driven transmissions, raw and aggregated packets (i.e. combining traffic of multiple sources into a single packet), unsynchronized and synchronized transmissions (i.e. simultaneous access attempts from many devices reacting to the same/similar events).

Furthermore, by analyzing the functionalities of the majority of typical applications, it is possible to classify three elementary traffic patterns for MTDs ([5], [22]):

- Event-Driven (ED): these MTDs send packets only when certain events happen. The event may be either caused by a measurement parameter passing a certain threshold or generated by the server to send commands to the device and control it remotely. ED is mainly a realtime traffic with a variable time pattern. Typical examples are alarms and health emergency notifications.
  ED MTDs have been studied in [23], where this traffic was simulated as an on-off traffic with constant and uniform packet sizes.
- Periodic Update (PU): these devices transmit status reports of updates to a central unit with a regular interval. PU is non-realtime and has a regular time pattern and a constant data size. A typical example of the PU message is smart meter reading (e.g. gas, electricity, water).
  The 3GPP standard [16] expects the total number of periodic MTDs to be split, in function of their periodicity, as follows:
  - 40% with period 1 day;
  - 40% with period 2 hours;
  - 15% with period 1 hour;
  - 5% with period 30 minutes.

  Periodic MTCs will demand for periodic network's accesses: this will definitely increase the access collision probability and the average access delay. This problem has been examined in [24], where they also proposed an efficient scheduling scheme in order to reduce the network access conflict with a consequent delay decrease.
- Payload Exchange (PE): this last type of data-traffic comprises all cases where larger amount of data is exchanged between the devices and a server. This traffic is more likely to be uplink-dominant, either real time or non-real time and without fixed pattern for packet sizes.

Owing to the variety of M2M traffic patterns, a large number of traffic simulations have already been done in many scenarios. Some of these studies have already been discussed above. Other studies on traffic modelization are given by [7], in which a new model for video traffic - based on lognormal distribution - is proposed and tested, by [14], where some good analysis were performed in many scenarios with HTDs and MTDs, but no joint analysis was given. Finally in [4] the worst case of M2M synchronized activation (e.g. after a power outage) has been deeply analyzed showing unacceptable channel access delays.

In order to implement some M2M traffic simulations it is necessary to better understand how that traffic can be modeled. In literature, so far, two families of models have been identified: some are based on source traffic (i.e. from the single application point of view), while others are based on aggregated traffic (i.e. considering the statistics of the traffic generated by a large set of users) [6].
Since we are interested in scenarios with a large number of MTDs, scalability is an important issue and a trade-off should be found between complexity and suitability of the model [22]. For this reason source traffic, even if more precise, might be a potential limitation for the number of MTDs to be simulated; hence aggregated traffic models are often preferred. A simple example of such a model is a Poisson process, but, due to synchronization in MTC traffic, the respective departure rate λ may be changing over time: $\lambda(t)$ (as proposed in [25]).

III. System Model

A. NS3 and LENA+: Overview and Improvements

Network Simulator 3 is a complex, flexible and complete open source simulator. For its completeness it is well recognized among the scientific community and it is used as an instrument to empirically prove a particular calculation or a new protocol proposal.

Indeed, its characteristics come at a price: it is very complex to operate with and to learn its (even basic) functioning. Its core is written in C++ and it comprises almost everything you need right away: nodes containing protocol stacks, interconnections with different types of channels and noise models, the full TCP/IP protocol stack including routing algorithms, tunable traffic models and much more. It also includes WiFi, WiMAX, LTE modules, as well as propagation and mobility models, just to name a few.

It is an event-based type of simulator, which means that time does not follow a continuous flow, but it just jumps from event to event. Each event can be scheduled both during the setup of the simulation and during runtime (usually as a consequence to another event or to a scheduled activity).

For example, in the setup portion of the code of a typical LTE simulation you would usually call an *attach* between one or more UEs and eNBs. This, among other operations, schedules the whole *Connection Request* mechanism which, in turn, schedules all the necessary subsequent signaling transmissions. The simulation is then ended when either there are no more events or when a manually set timer (which is actually just another scheduled event) expires.

For what concerns the LTE module, a huge amount of work has been done in order to properly model it. From a city-like

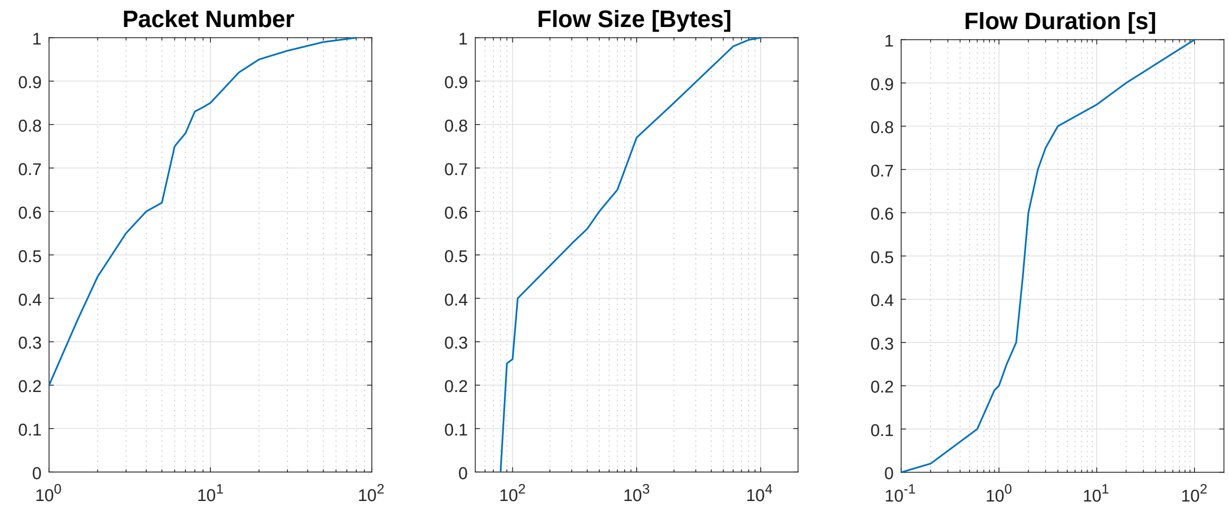

Figure 2: Empirical CDFs taken from [11]

scenario perspective everything has already been implemented (e.g. buildings, propagation models that consider indoor, outdoor and mixed transmissions, different types of eNB's antenna models, scheduling algorithms, PHY error models, MIMO models, power control, frequency reuse algorithms, handovers and much more).

The EPC comprises of two nodes: the MME and a S-GW/P-GW combo-node connected via a P2P link. Every external device that wants to communicate with a UE will be connected to the LTE network through the P-GW. Every eNB will be connected both to the MME and the S-GW, again with P2P links, using the appropriate interfaces.

The entire protocol stacks for both UEs and eNBs has been modeled, both for signaling and data transmissions. The radio bearer management has also been modeled although simplified by the union between of the serving and the PDN gateways.

Despite the apparent completeness of this system a few simplifications were made, in particular the RRC protocol and the connection request signaling were too ideal to properly simulate an MTC environment. Also, the model was thought as connection oriented, meaning that once a UE were properly connected to an eNB it could only remain connected or perform a connection reconfiguration (e.g. if a handover or a modification to the bearers were needed).

The first problem, as mentioned in Section I, has been solved through a patch to the LTE module called LENA+. A more proper explanation of the issue, the solution and the implementation is given in [4]. Basically this patch makes the connection request more realistic managing in a more proper way the preambles used for contacting an eNB for the first time, asking for synchronization. The possibility of a preamble collision has also been added and experimental results were presented.

In order to solve the second problem we created a fork to the GitHub repository of LENA+ and added a configurable timer (10 seconds by default) for each eNB that keeps track of every UE activity. Whenever a data packet is sent or received by the specific UE, the timer is reset. When the timer expires the appropriate bearers are canceled, the EPC stores the current UE context and a connection release message is sent to the UE. If the UE has to send a new packet while it is in *RRC_IDLE* state, the packet is stored in a queue, a connection request message is sent and whenever the connection is reestablished all the packets in the queue are sent.

Another very important addition for our simulation was the increase of the *Sounding Reference Signal* (SRS) Periodicity. The SRS is a signal that is periodically sent in broadcast from the eNB to the UEs, whose purpose is to let them take measurements of the current channel state and possibly reporting them back. The period is set as an integer number of milliseconds and only one UE per millisecond can report the measurement to the eNB. The highest periodicity allowed by ns3 is 320, limiting in this way the maximum number of devices that can be simultaneously connected to this same number. Since we wanted to simulate much more device-rich scenarios, this limit had to be overcome. Previous attempts were made in order to increase this limit, but none of them was complete. Now this feature is fully working and all the changes can be found at [26].

B. Simulation

As already stated, in these types of simulations a fundamental trade-off between complexity and accuracy occurs; the main issue, then, is to determine what to include and what we are willing to tolerate.

A fully complete model should take into account various sub-models in order to determine the behavior of MTDs and HTDs - mainly in terms of traffic, mobility and numerosity - and to fully characterize the presence of buildings and scatterers. However, since our aim was to simulate how the access to the network and the traffic generated by MTDs impacts the HTC in contemporary LTE networks in a SmartCity scenario, we were mainly interested at the steady-state traffic point of view and some simplifications have been done.

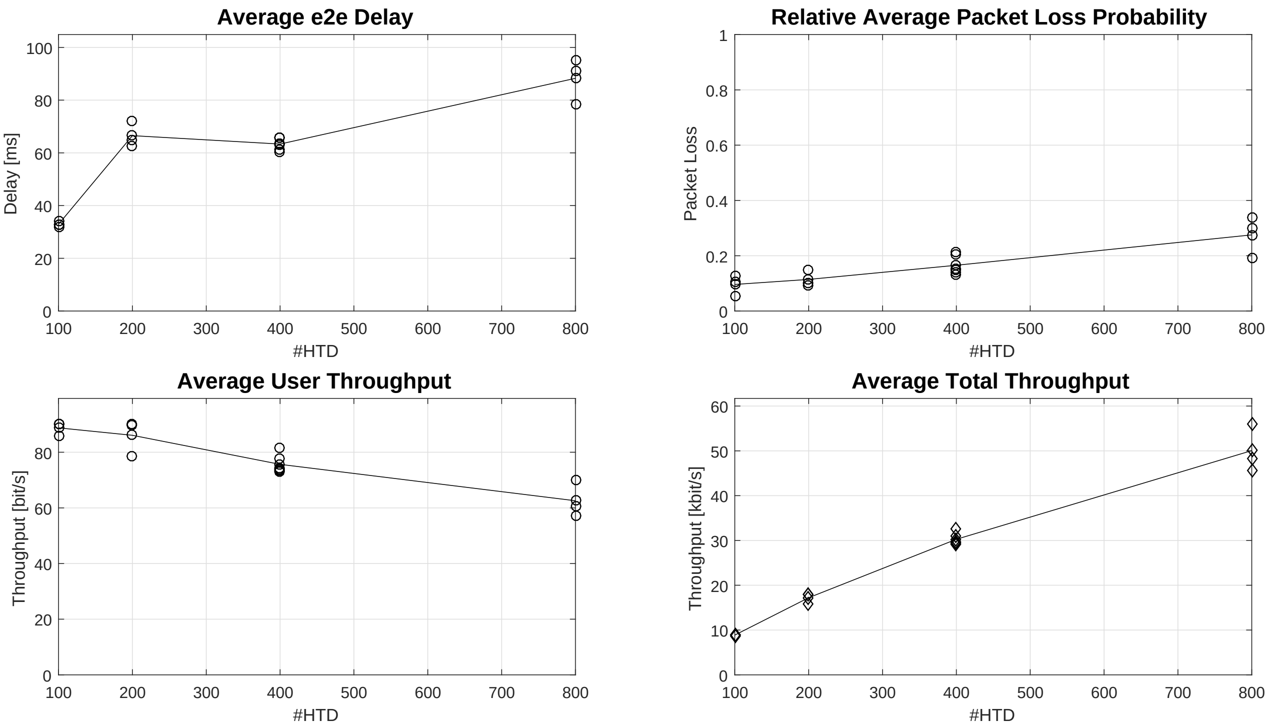

Figure 3: Results with varying number of HTDs.

Parameter	Value
Downlink carrier frequency	945 MHz
Uplink carrier frequency	900 MHz
RB bandwidth	180 kHz
Hexagonal sectors	1
eNBs for each sector	3 (co-located) in center
eNBs beamwidth (main lobe)	65 ° C
TX power used by eNBs	43 dBm
eNB noise figure	3 dB
MTD noise figure	5 dB
Shadowing	log-normal (σ = 8)
Box	150m x 150m
Simulation Time	1800 s

Table II: Simulation parameters.

First of all, the mobility models, that in general have to be implemented in different flavors for HTDs and MTDs, are not relevant for this study due to the reduced dimensions of the scenario. This assumption, that does not affect the traffic behavior, is a huge computational relief because the interest is focused on a device-dense scenario.

Secondly it can be noticed that the per-device traffic volume is much smaller for IoT devices than for smartphones and also MTDs have a much higher upload/download ratio. Therefore MTDs' downlink traffic can be safely neglected (except for acknowledgments for some MTDs). For this reason we considered only the uplink traffic also for HTDs.

The overall traffic model, used as the structure for all of our simulations, as already partially anticipated in Sections II-B and II-C, is here more thoroughly described.

H2H uplink traffic has been modeled as in [14]. According to this model each HTD tries to initiate a RACH procedure with hyper-exponential inter-arrival time described in Equation 1 and Table I. In our scenario RRC_{IT} was set for each user equal to $RRC_{IT} = 10\ s$, hence the traffic generated by all HTDs follows the same hyper-exponential distribution. Fig. 1 shows the CDF of said distribution.

Although [14] describes accurately the statistics of HTDs' RACH procedure, no indication was given about the amount of data exchanged during each transmission or, for example, the number of packets. For this reason we referred to [11] which reported some useful CDFs empirically obtained through a deep analysis of smartphones' traffic. The plots of these CDFs are reported in Fig. 2 and describe the distribution of the following parameters: *flow duration* (the duration of a single H2H transmission), *number of packets per flow*, and *flow size* (i.e. the amount of bytes generated by one HTD in a single flow). Despite the number of HTDs considered in [14] were equal to 1.000, we chose to decrease it in order to reduce the computational demand of the simulations (more on this later).

For what concerns M2M traffic we considered only periodic patterns and we made a lot of simulations even varying the transmission period of MTDs. As stated in [16], the application-layer payload size follows a Pareto distribution, with shape parameter $\alpha = 2.5$ and bounded between 20 and 200 bytes. Half of these MTDs receives ACKs in downlink with payload size assumed to be 0 bytes. The total packet size is then computed taking into account the overhead due to the CoAP (Constrained Application Protocol), DTLS (Datagram Transport Layer Security), UDP and IP headers, that, without IP header compression, have total size of 65 bytes. Furthermore, for all the patterns above, we properly randomized the start times in order to avoid simulation artifacts and to avoid as much as possible preamble collisions, which [4] shows to be very harmful to the incoming traffic and unrealistic in a steady-state scenario like the one we are interested in.

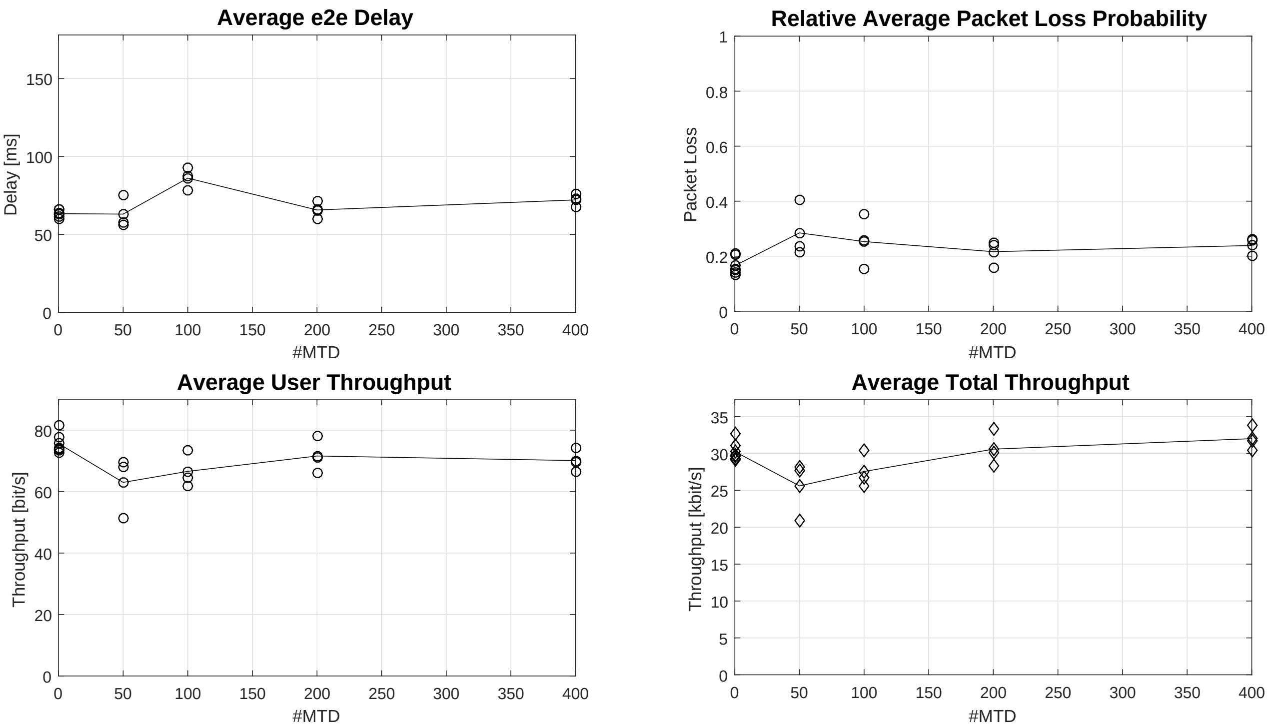

Figure 4: Results with varying number of MTDs.

For what concern the scenario, we consider a Smart City environment similar to the one proposed in [4]. HTDs have been placed randomly inside the whole box (both indoor and outdoor), whereas MTDs have only been deployed inside the households. As stated above the mobility has not a big impact on our simulation so both MTDs and HTDs are considered fixed. In Table II the most relevant setting parameters are summed-up.

In order to properly characterize the impact of M2M communication on the network performance we simulate different situations considering as significant statistics the *packet-loss*, the *average end-to-end delay*, the *total throughput* and the *user throughput*. In the first cases we analyzed only HTC with an increasing number of devices: 100, 200, 400, 800. As a second scenario we fixed the number of H2H to 400 and introduced a variable number of MTDs: 50, 100, 200, 400 with a fixed transmission period of $90\ s$. As a third and last scenario we fixed both the number of HTDs and MTDs varying only the transmission period of the latter ($8\ s$, $15\ s$, $30\ s$, $60\ s$, $90\ s$).

IV. Results

As a first set of simulations, we only deployed different amounts of HTDs in order to understand how they behave as the traffic increases and how much time do simulations with our scenario take. Relying on this results we decided how many devices we could simulate. As partly expected, the complexity and the duration of the simulations did not allow us to use more than 1.000 devices in total. Note that as a trade-off between time constraints and accuracy we decided to do three simulations for each configuration, but more simulations would be needed to achieve a higher confidence level.

In Fig. 3 the results of this first analysis are shown. The behaviors follow the expected trends: the more the number of transmitting devices arises, the more delays, packet loss and total throughput increase while the user throughput decreases. From the distribution of the different runs, the results look quite accurate even for such a little number of simulations.

Moving on, graphs in Fig. 4 show the same parameters as before, but fixing the number of HTDs at 400 units and varying only the number of MTDs as reported in the x-axis. The MTDs' period was chosen in order to mimic the full 50.000 MTDs with the periodicities discussed previously in Section II-C with only the few devices that we could actually simulate. After some simple calculations, we decided to use $90\ s$ as the transmission period for MTDs in order to match the average access rate of the worst case scenario proposed by the 3GPP [16] with only 400 MTDs as our worst case scenario. This time the results are much less impressive: HTDs' delay and packet loss do not really seem to be affected by the increasing number of MTDs, excluding peaks probably due to random fluctuations and a not high enough confidence interval. User throughput, instead, drops as soon as a few MTDs are added into the scenario, then stays almost constant as the number of MTDs increases, while the total throughput tends to slightly increase with the number of devices just as expected. Of course, the traffic offered by the MTDs is very low, so even with a lot of them (comparable to the number of the HTDs) the increase is almost negligible.

Furthermore, looking at the results from Fig. 3-4 it looks like a scenario with the same number of total devices is greatly differentiated by the type of offered traffic. In fact every statistic is more extreme when there is only H2H traffic while having an equal mixture of HTC and MTC seems to alleviate the pressure from the cellular system.

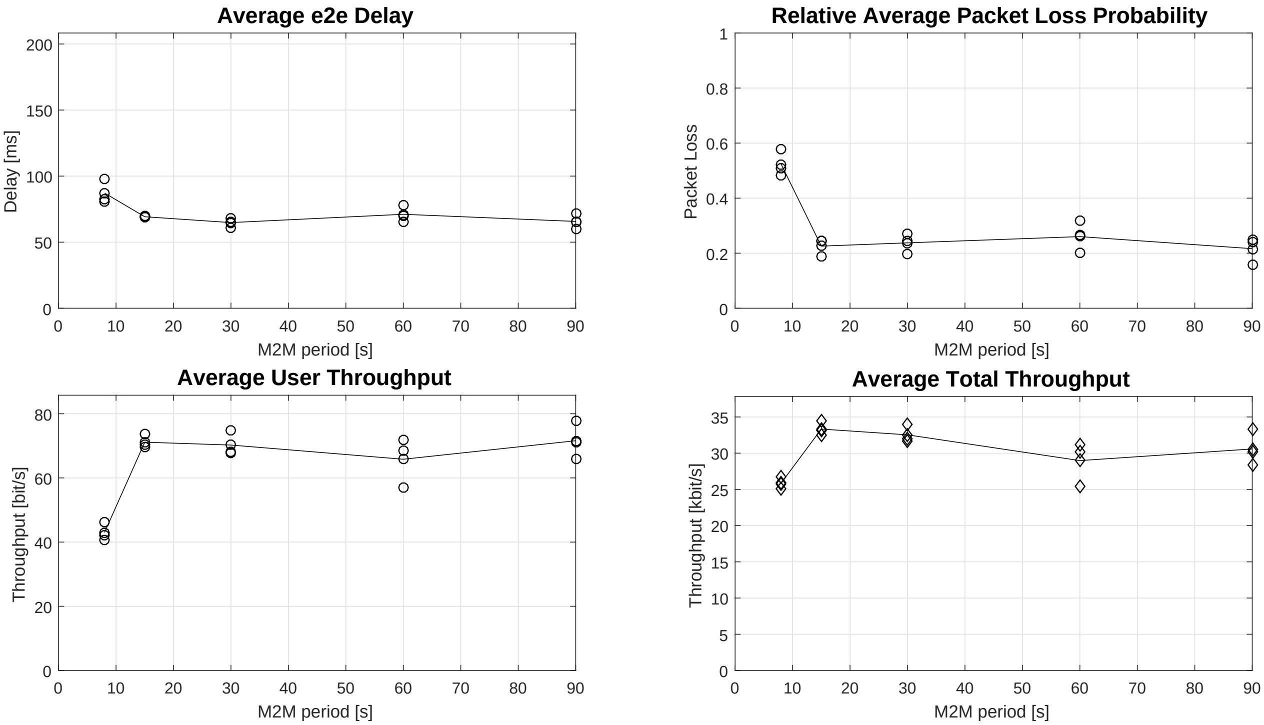

Figure 5: Results with varying MTDs' transmission period.

After these considerations we thought that the MTDs were not interfering with HTCs enough because of the huge scale down that we had to do for computational reasons. Following that logic we then decided to do more simulations with a fixed number of both HTDs (400) and MTDs (200), decreasing the transmission period of the latter.

From the results in Fig. 5 it is possible to notice that the transmission period plays an important role in many statistics: indeed the end-to-end delay is quite heavily worsened and also the packet loss gives extreme results with very low periods. Considering the fact that a period shorter than $10\ s$ does not allow the *Connection Release* mechanism to play any role, it is clear that resources permanently allocated to a large number of periodic devices and never reallocated tend to penalize H2H communications with much longer average inter-arrival times as previously observed.

Note that in all the cases above the user throughput is very low: this is due to the empirical distributions discussed in Section II-B and also due to the fact that only the uplink traffic is modeled for these type of devices. Overall we can see that these simulations did not show huge losses in performance for H2H communications, excluding very extreme cases. This may be caused by our scenario, which is too small and maybe inappropriate to highlight significant results. Another point to consider may be the very low total traffic, in particular for the HTDs: these devices tend to have much more downlink traffic rather than uplink and for this reason the results may seem inaccurate.

V. Conclusions

In this work, we have simulated a potential Smart City scenario analyzing the impact of Machine-Type Communications on its Human-Type Communications counterpart using Network Simulator 3. We used the LENA+ module improving it by implementing some new features such as *Connection Release* and *Connection Resume* mechanisms. We analyzed the usual network performances varying the number of HTDs and MTDs as well as the duration of the transmission period for this second class. According to the results, M2M communications seem not to have a great impact on H2H ones.

Possible enhancements concern the implementation of a more articolated and complete traffic-model in a bigger scenario. For instance, H2H downlink traffic has not been considered in this paper and therefore the overall traffic could have been underestimated. Secondly, a bigger environment should be implemented in order to obtain a more realistic situation following accurately the 3GPP standards ([2] and [16]): the expected number of MTDs should be at most around 50.000 units per hex sector and they should express a more heterogeneous traffic. For example machine devices should be split into groups with different transmission periods and also a Poisson component should be modeled.

During this work we have just partially implemented this advanced scenario but we did not succeed in simulating it because of its huge computational complexity.

Future efforts should aim at improving our work in these proposed directions.

References

[1] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A Survey," *Comput. Netw.*, vol. 54, pp. 2787–2805, Oct. 2010.

[2] "Service requirements for Machine-Type Communications (MTC), Technical Specification, TS 22.368 V11.5.0," *3GPP*, 2012.

[3] J. Zheng and M. J. Lee, "A comprehensive performance study of IEEE 802.15. 4," 2004.

[4] M. Polese, M. Centenaro, A. Zanella, and M. Zorzi, "M2M Massive Access in LTE: RACH Performance Evaluation in a Smart City Scenario," *Proceedings of the IEEE International Conference on Communications (ICC)*, vol. 357, pp. 4613–4618, 2016.
[5] N. Nikaein, M. Laner, K. Zhou, P. Svoboda, D. Drajic, M. Popovic, and S. Krco, "Simple traffic modeling framework for machine type communication," in *Wireless Communication Systems (ISWCS 2013), Proceedings of the Tenth International Symposium on*, VDE, 2013.
[6] M. Laner, P. Svoboda, N. Nikaein, and M. Rupp, "Traffic models for machine type communications," in *Wireless Communication Systems (ISWCS 2013), Proceedings of the Tenth International Symposium on*, VDE, 2013.
[7] R. Liu, D. Rao, Z. Huang, and D. Yang, "An emperical traffic model of M2M mobile streaming services," in *2012 Fourth International Conference on Multimedia Information Networking and Security*, pp. 400–404, IEEE, 2012.
[8] M. Centenaro and L. Vangelista, "A study on M2M traffic and its impact on cellular networks," in *2015 IEEE 2nd World Forum on Internet of Things (WF-IoT)*, pp. 154–159, Dec 2015.
[9] "3GPP TS 36.331 V13.3.0; LTE; Evolved Universal Terrestrial Radio Access (E-UTRAN); Radio Resource Control (RRC); Protocol specification," 2016-10.
[10] "3GPP TS 36.300 V8.3.0 ,3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 8)," 2007-2012.
[11] J. Yang, S. Zhang, X. Zhang, J. Liu, and G. Cheng, "Characterizing smartphone traffic with MapReduce," in *2013 16th International Symposium on Wireless Personal Multimedia Communications (WPMC)*, pp. 1–5, June 2013.
[12] L. Costantino, N. Buonaccorsi, C. Cicconetti, and R. Mambrini, "Performance analysis of an LTE gateway for the IoT," in *2012 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, pp. 1–6, June 2012.
[13] T. Kim, K. S. Ko, and D. K. Sung, "Prioritized Random Access for Accommodating M2M and H2H Communications in Cellular Networks," in *2015 IEEE Globecom Workshops (GC Wkshps)*, pp. 1–6, Dec 2015.
[14] G. Foddis, R. G. Garroppo, S. Giordano, G. Procissi, S. Roma, and S. Topazzi, "On RACH preambles separation between human and machine type communication," in *Communications (ICC), 2016 IEEE International Conference on*, pp. 1–6, IEEE, 2016.
[15] C. V. N. Index, "Cisco visual networking index: Global mobile data traffic forecast update, 2015-2020 white paper," *Available at: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html*, Feb. 2016.
[16] "Cellular System Support for Ultra Low Complexity and Low Throughput Internet of Things, Technical Report, TR 45.820 V1.3.1," *3GPP*, 2015.
[17] 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)*, pp. 1–4, IEEE, 2013.
[18] 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.
[19] P. Bellavista, G. Cardone, A. Corradi, and L. Foschini, "Convergence of MANET and WSN in IoT urban scenarios," *IEEE Sensors Journal*, vol. 13, no. 10, pp. 3558–3567, 2013.
[20] "Study on RAN Improvements for Machine-type Communications, Technical Specification, TS 37.868 V11.0.0," *3GPP*, 2011.
[21] M. Z. Shafiq, L. Ji, A. X. Liu, J. Pang, and J. Wang, "A first look at cellular machine-to-machine traffic: large scale measurement and characterization," *ACM SIGMETRICS Performance Evaluation Review*, vol. 40, no. 1, pp. 65–76, 2012.
[22] "First classification of IoT traffic models," *CTTC*, 2015.
[23] A. Paramonov and A. Koucheryavy, "M2M traffic models and flow types in case of mass event detection," in *International Conference on Next Generation Wired/Wireless Networking*, pp. 294–300, Springer, 2014.
[24] C. You and Y. Zhang, "A radio resource scheduling scheme for periodic M2M communications in cellular networks," in *Wireless Communications and Signal Processing (WCSP), 2014 Sixth International Conference on*, pp. 1–5, IEEE, 2014.
[25] R. C. D. Paiva, R. D. Vieira, and M. Saily, "Random access capacity evaluation with synchronized MTC users over wireless networks," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, pp. 1–5, IEEE, 2011.
[26] "`https://github.com/mattia-lecci/lena-plus`."