# Towards 5G DenseNets: Architectural Advances For Effective Machine-Type Communications over Femtocells

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**Abstract**
Ubiquitous, reliable and low-latency machine-type communication (MTC) systems are considered to be one of the value-adds of emerging 5G cellular networks. To meet the technical and economical requirements for exponentially growing MTC traffic, we advocate for the use of small cells to handle the massive & dense MTC rollout. We introduce a novel 3GPP-compliant architecture which absorbs the MTC traffic via Home evolved NodeBs (HeNBs), allowing us to significantly reduce congestion and overloading of radio access and core networks. A major design challenge has been to deal with the interference to human-type traffic (HTC) and the large degree of freedom of the system due to the unplanned deployments of small cells and the enormous amount of MTC devices. Simulation results in terms of MTC access delay, energy consumption and delivery rate corroborate the superiority of the proposed working architecture.

**Keywords:** machine-to-machine, M2M, MTC, 5G, ultra dense networks, femtocells, HeNB, Wi-Fi

## 1. Introduction

The support of machine-type communication (MTC) via evolved Long Term Evolution-Advanced (LTE-A) [1] represents one of the growing main challenges for cellular network providers in order to fulfill the requirements of future fifth generation (5G) wireless networks [2]. MTC has promising economic and strategic value in the mobile market scenario since an exponential growth in the data traffic generated by heterogeneous devices (such as smart meters, signboards, cameras, remote sensors) is expected with consequent unprecedented opportunities and business models to telco operators in different fields (e.g., transport and logistics, smart power grids, e-health, home and/or remote surveillance) [3].

MTC represents a novel transmission paradigm where devices send their data to remote servers or to other machines (e.g., actuators) without human intervention. MTC has a set of unique and challenging characteristics [4] (such as group-based communications, low or no mobility, time-controlled, time-tolerant, secure connection) which require technically advanced solutions currently under investigation by academia, industry and standards bodies, such as the Third Generation Partnership Project (3GPP) [5], [6].

Due to the high (and unpredictable) number of MTC devices expected to simultaneously access the cellular network [7], **congestion and overloading of radio access and core networks**[1] are the

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[1] Congestion arises when a base station has not enough resources to support the traffic load generated by the enormous number of MTC devices within the cell, while the overloading is due to very large load at the network entities which have to manage data/control traffic from/to MTC devices. Such issues increase the time needed by MTC devices to access the network and transmit data.

prime issues to be solved in order to guarantee low-latency & low-energy MTC and to minimize the impact of MTC onto these network segments. Another important issue is related to the observation that many machines are geographically **located in a very confined and coverage-limited area** (e.g., sensors/actuators in a hospital or a refinery). As a consequence, the radio access network of Beyond LTE-A should be able to efficiently manage several hot-spots, many of which might be located in challenging position (e.g., indoors or at the cell-edge). Above mentioned issues are exacerbated by the strict requirements on the design of MTC terminals which should be low cost (i.e., low complexity and computational capabilities) and with **low energy consumption** in order to guarantee extended lifetimes. Furthermore, the M2M solution provider may not want to be **dependent on the coverage and rollout strategy of a given operator** and may thus want to provide coverage on its own. Finally, another design driver is that **MTC should not affect the performance of traditional human-type traffic (HTC)** in form of e.g. voice/data calls [4].

To the best of our knowledge, the architecture outlined in this work is the first of its kind which meets above design criteria by explicitly tying MTC and femtocells. In Section 2, we show the architectural enhancements able to adequately support the extremely dense MTC deployment scenarios through the exploitation of femtocells. The proposed system architecture guarantees low-latency MTC without meaningful additional costs compared to non-3GPP wireless networks and without affecting the performance of HTC traffic, as shown in Sections 3. The exceptional performance under ultra-dense MTC rollouts is demonstrated in Section 4. Finally, in Section 5, we summarize our findings and outline some future work.

## 2. Scalable Network Architecture for Ultra-Dense MTC

We consider a scenario where MTC is handled by a network operator which provides control (e.g., subscriber management) and data functionalities (e.g., traffic transport) via a 3GPP LTE-A system. According to ETSI [8], the MTC application is typically hosted by an Application Server (AS), which may be directly connected to the operator network or make use of a Services Capability Server (SCS) that offers additional control (such as device triggering) and data services for MTC. The SCS may be controlled by the MTC Service Provider or by the 3GPP network operator. Also, a hybrid solution is permitted, where the user plane communications with the MTC device is directly managed by the AS and the control plane connections handled by the SCS.

The high number of machines (mainly located in challenging position within the cell) which simultaneously access the network poses several issues for traditional macro-cellular systems which are not able to guarantee the requirements of ubiquitous connectivity and high capacity of MTC. An effective transport network able to support MTC has to efficiently manage the expected extremely dense scenarios and to improve both radio access and core networks by reducing traffic overload and interference with the HTC traffic, while guaranteeing low-latency interconnection with non-3GPP networks.

The proposed evolved 3GPP architecture tailored to efficiently supporting MTC is illustrated in Figure 1. In our architecture, LTE-capable MTC devices communicate directly with *Home-evolved NodeBs (HeNBs)*, which are low-cost femtocells (with economic efforts close to those of non-3GPP access points in terms of device cost, installation and manteinance) for local-area access with low-power transmission (less than 100mW) capability [9]. Non-3GPP devices access through *trusted* non-3GPP access points (APs) that are operator controlled, and are managed by the *HeNB-Gateway (HeNB-GW)* like legacy HeNBs. The *HeNB-GW* aggregates traffic from a large number of HeNBs and trusted non-3GPP APs into the existing core network. Motivations and advantages of the illustrated architectural choices are individually analyzed in the following.

## 2.1 MTC & HeNB Network Architecture

The exploitation of HeNBs for MTC, instead of Macro-eNodeBs (MeNBs), in the radio access network achieves the following goals:

- ***Stronger separation of MTC and HTC traffic.*** HeNBs may be installed by cellular customers in form of individuals and companies/industries, which aim at (mainly but not exclusively – see later section) interconnecting their own MTC devices in specific areas, such as in hospitals, offices, laboratories, plants, etc. Once plugged-in, HeNBs connect to the 3GPP core network via the digital subscriber line/fiber and represent the entry-point for LTE-A MTC devices. MeNBs are instead exploited by the operator for HTC services without being affected by MTC traffic load.
- ***Closed access.*** MTC could be advantageously handled via *closed access* HeNBs. According to this solution, the access to HeNB(s) is allowed only to those machines which belong to a given Closed Subscriber Group (CSG) [9]; for instance, a customer can admit only its own devices through its own HeNB. Closed access HeNBs offer the customer/operator *secure* access and the possibility to perform *load-balancing* through CSGs creation and management.
- ***Coverage extension.*** HeNBs are useful to provide local connectivity for MTC devices located in remote or challenging locations (e.g., rural areas, indoor-deployments, smart meters in the basements of the buildings) without requiring network re-planning.

The simultaneous exploitation of MeNBs and HeNBs requires effective solutions to reduce/avoid the inter-cell interference. Whilst co-channel deployments have been advocated (and well researched) in the past, an interesting study [2] has recently stated that *frequency-separated* deployments is the most promising solution addressed by telco operators. Licensed spectrum below 3 GHz has already been widely exploited for cellular services via MeNBs; however, additional higher frequency bands (such as 3.5 GHz and above) have recently become available. Such frequencies are challenging for macro-cell deployments due to propagation characteristics, while they are suitable for HeNBs communicating over relatively short range. This proposed frequency-separated deployment avoids inter-cell interference and relaxes the radio frequency (RF) requirements of MTC devices with a consequent reduction of equipment costs [2].

In the proposed network architecture, the *X2* interface handles the exchange of control traffic between MeNB and HeNBs for system parameters configuration/reconfiguration (e.g., frequency band selection). The *X2* interface can be further exploited as a low-latency interface to exchange data traffic for time-critical events (such as handovers) [10].

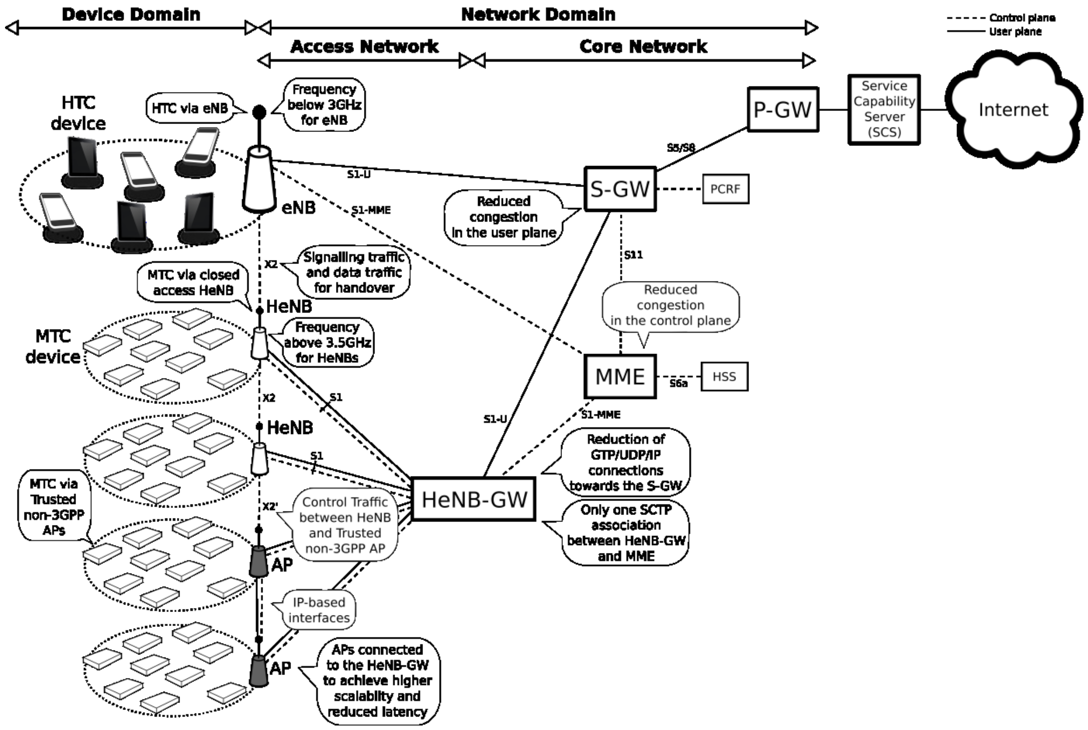

**Figure 1. Enhanced network architecture for ultra-dense MTC access to the 3GPP LTE-A core via HeNBs/HeNB-GWs and trusted non-3GPP APs.**

## 2.2 Reducing the Core Network Load

Femtocells are attached via digital subscriber lines/fiber to the 3GPP LTE-A core network (a.k.a. System Architecture Evolution, SAE), which is composed of two entities [11]: the Mobility Management Entity (MME) and the Serving Gateway (S-GW). The MME is a control plane unit which manages security functions (e.g., authentication and authorization), handovers and handles idle mode state and CSG subscription. The S-GW works in the user plane by routing and forwarding data packets to and from the MeNBs/HeNBs. In addition, it offers connectivity to external networks through the packet data network gateway (P-GW).

3GPPP proposed solutions for both direct and non-direct connection of HeNBs to core network entities. Although the former solution is attractive to reduce the number of network units needed for HeNB deployment, it suffers from several inefficiencies in terms of MME/S-GW overload when the number of HeNBs as well as the number of connections per HeNB are large. In the proposed architecture, the HeNB-GW – part of the backhaul and securely connected to the core – has the key role of being a concentrator of several HeNBs for both control and user planes. This has obvious advantages in terms of scalability and load reduction in the core network. The benefits offered by the mandatory use of a HeNB-GW can be summarized as follows:

- ***One Stream Control Transmission Protocol (SCTP) association between the HeNB-GW and MME.*** In LTE-A, a SCTP association is created between two entities exchanging control plane traffic. Through the use of the HeNB-GW, the presence of a large number of HeNBs does not imply congestion at the MME. Indeed, only the HeNB-GW transmits SCTP *heartbeat* messages to the MME instead of each single HeNB. Furthermore, the number of SCTP association establishments and releases due to HeNBs switching on/off is minimized.
- ***S-Gateway scalability.*** The number of GPRS Tunneling Protocol (GTP), UDP and IP connections between HeNB-GW and S-GW are drastically reduced compared to a direct HeNBs connection. In this way, the number of HeNBs may increase without an increase in

the number of UDP/IP Paths and GTP Echo messages managed by the S-GW.
- ***Paging optimization.*** Optimized paging mechanisms for downlink data transmission to the managed HeNBs can be implemented within the HeNB-GW to reduce latency.

According to the architectural solution proposed in Figure 1, two challenges need to be evalueated. The first one is due to the fact that the HeNB-GW has to switch from the HeNB-GW–S-GW tunnel to the HeNB-GW–HeNB tunnel (and vice versa). Consequently, the higher the traffic from the machines, the higher the load at the HeNB-GW in the user plance. Nevertheless, it is worth noting that the HeNB-GW is the only entity overloaded when the traffic from the machines increases and this influences only the performance of devices connected to the femtocells managed by the HeNB-GW. On the contrary, by using alternative solutions where the femtocells are directly connected to the S-GW, an increase in the MTC traffic involves overloading at the S-GW with influence to the traffic from/to all the nodes (i.e., a large set of macro-cells and femtocells) managed by the S-GW. The second issue is that the HeNB connects to a single HeNB-GW at one time and this reduces the redundancy and load sharing possibilities in comparison with other architectural variants. It is worth noting that we foresee the use of the X2 interface among different femtocells. Such interface can be further exploited as a low-latency interface to increase the redundancy as well as the sharing possibilities. As a consequence, it is clear that our proposals is more effective to reduce the overall system overload than other solutions.

### 2.3 Interconnection with Non-3GPP APs

An important issue to consider is the interconnection of machines belonging to non-3GPP networks, such as IEEE 802.11ah (Low Power Wi-Fi) which is gaining in popularity. In the proposed network architecture, we foresee *trusted* non-3GPP APs [12], which are typically operator-managed Wi-Fi APs that provide access functionalities, over-the-air encryption, secure authentication and billing functionalities.

The communication between Wi-Fi enabled devices and LTE-A MTC terminals can be achieved for instance through traditional Internet communication. In this case, the data sent by the Wi-Fi machine is conveyed to the LTE-A terminal via the P-GW and the S-GW. This solution may involve intolerable data transmission delay, especially if two MTC devices are geographically close (e.g., in the same room).

To cope with this issue, we propose the introduction of a short data path (while other functionalities such as access, authentication and billing are the same as in [12]) by connecting the *trusted* non-3GPP APs to the HeNB-GW. The APs exchange data through the non-3GPP interface with the served MTC devices, while they appear like HeNBs to the HeNB-GW, with the following advantages: *(i)* **reduced latency**, since data communication between non-3GPP and LTE-A devices can be handled through the HeNB-GW; *(ii)* **additional scalability**, since the increase in the number of non-3GPP APs does not overload the S-GW. In addition, the latency of some control procedures can be cut by reducing the amount of operations in the core network entities. Indeed, since APs and HeNBs share the same protocol stack, a novel logical IP-based control interface, the *X2'* in Figure 1, ought to be standardized to support system parameters configuration and for the handover of those devices equipped with both non-3GPP and LTE-A interfaces .

## 3. Analysis of MTC Radio Access and Data Transmission

With the aim to corroborate the expected MTC enhancements of the proposed architecture, a simulation campaign has been carried out through a 3GPP-calibrated system level simulator. The analysis focuses on the radio access network, which is the most solicited segment by the multitude of MTC devices.

The cell layout, radio channel model, and power transmission levels are set according to the 3GPP Macro-cell case #3 [13]. HTC and MTC devices are in the coverage area of one macro-cell site (hexagonal grid, 3 sectors per site, 2 GHz carrier frequency, 5 MHz channel bandwidth) while 18 neighboring cells are considered as interfering cells (the inter-site distance is set to 1732m). We considered 30 VoIP and 20 active best effort (BE) users which are uniformly distributed in the macro-cell, while 1000 MTC devices are clustered in a restricted area (with a radius equal to 50m) of the cell.

In order to effectively evaluate the benefits introduced by the use of HeNBs in the radio access network, we compare two scenarios. The first one (namely, Case A) is a macro area environment, where both HTC and MTC devices are attached to the MeNB. In the second scenario (namely, Case B), HTC users are attached to the MeNB while all MTC is handled via the HeNB. To further consider the impact of the position of MTC devices on HTC communications, we varied the mean distance of MTC terminals from the MeNB.

### 3.1 Random Access Procedure

The random access (RA) procedure [14] is performed by a device in several cases; e.g., upon initial network access, in idle mode, during handover, for connection re-establishment after a radio link failure. The contention-based access is managed via a four-message handshake between the device and the base station. A well designed network should be able to guarantee low-latency access to MTC devices. This aspect is especially crucial, considering that commonly MTC devices transmit only one data packet after succeeding with the RA procedure. As a consequence, reducing the RA latency allows to decrease the control overhead necessary for data transmission.

To analyze this aspect, we considered a period of 60s during which MTC devices and HTC users perform one RA procedure and we measured the delay spent for such procedure (the *access delay*). The arrival rates of HTC and MTC terminals are uniformly distributed within the considered period of 60s. The RA parameters are set according to [15].

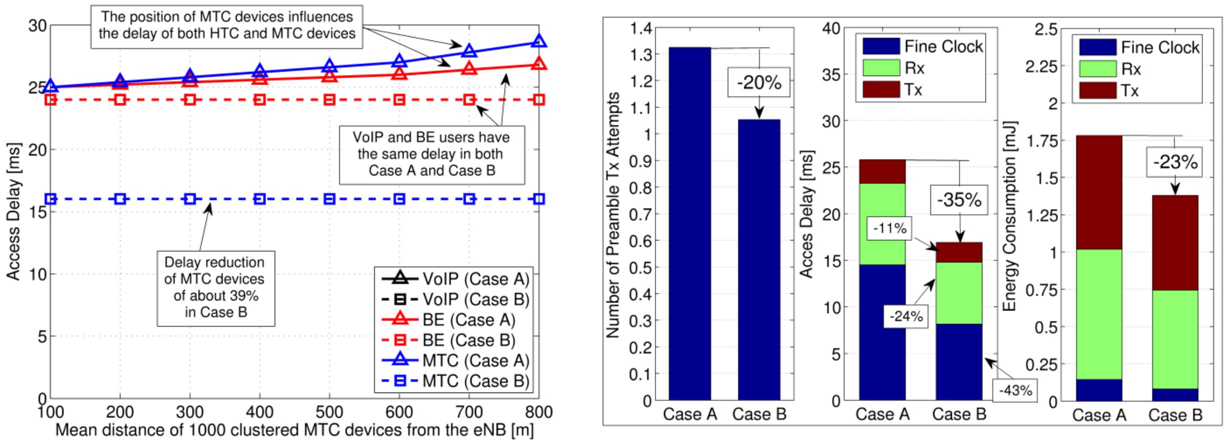

**Figure 2. Access Delay for HTC and MTC terminals versus distance of 1,000 MTC devices from the MeNB (left) and comparison between RA via MeNB and HeNB when devices are at 100m from the MeNB (right).**

The achieved results are shown in of Figure 2. Considering the Case A, when MTC devices are in challenging positions within the cell (i.e., larger distance from the MeNB), both MTC and HTC users experience higher RA delays. It emerges, instead, that the use of HeNB (i.e., Case B) for MTC traffic has the positive effect of reducing the access delay of both HTC and MTC terminals;

the main benefit is for MTC devices that achieve an access delay reduction of about 39% in the considered scenario while HTC users gain less than 3ms. It is worth noticing that the MTC access delay is insensitive to the position of MTC devices in the cell with respect to MeNB, since the HeNB is always located close to MTC devices.

The MTC behavior is further analyzed in the right-hand side of Figure 2 which confirms the enhancement introduced in the RA procedure by the use of HeNB. It is worth noticing that, in the Case B, the number of preamble transmissions (i.e., the first message of RA procedure) is reduced by a factor equal to 20% compared to the case when MTC terminals are attached to the MeNB (i.e., Case A). This is not due to a lower preamble collision rate (which is the same for both cases and depends on the number of machines which access in the same RA slot), but due to the better channel conditions experienced by MTC devices due to the shorter device/base station distance which increases the probability of successful preamble transmission. By reducing the number of RA procedures necessary to accomplish radio access, the MTC devices spend less time in *fine clock* (i.e., the waiting time for uplink transmission or downlink reception), *receiver* and *transmission* states. A further positive effect is the decrease of energy consumption in the MTC devices by 23%.

### 3.2 Data Transmission

Data transmission from HTC and MTC devices poses several issues since different requirements for HTC and MTC services need to be considered. VoIP communication can be considered as a *periodic* transmission (20 bytes every 20ms during on-periods) and is handled by the MeNB through semi-persistent scheduling. The BE traffic is instead scheduled according to the resources still available after the transmission of flows with higher priority. Finally, MTC devices usually transmit only one small message after the radio access procedure, thus asking for few system resources. The main concern related to MTC for the system is instead due to the massive number of instantaneous transmitting MTC devices. We considered a period of 60s during which MTC and HTC terminals perform data transmission. MTC devices are assumed to transmit one 200 bytes long message, while BE users are served by the MeNB through a maximum throughput scheduler. Finally, VoIP users are considered as “background” services since they are semi-persistently scheduled by the MeNB.

The transmission performance is shown in Figure 3. The mean throughput of BE users is shown on the left side plot. When MTC devices are served via the MeNB (i.e., Case A), the throughput of BE users decreases, the more so at higher distances. This is due to the fact that the higher the distance from the MeNB, the poorer the channel quality of MTC devices. As a consequence, they require a higher portion of system resources for data transmission and this causes a throughput reduction for BE users. When MTC devices are handled by the HeNB (i.e., Case B), the throughput of BE flows increases by about 4% until the case when MTC devices are at 400m from the MeNB, then it increases by a factor equal to 20% when the MTC devices are more distant from the MeNB.

The data delivery delay for MTC devices is shown in the right side plot. It clearly emerges that the performance deteriorates in Case A. On the contrary, through the HeNB, the delivery time is decreased by a factor of 14% until the distance of 400m, while the gain increases up to 30% when the distance becomes higher. The improvement is due to the fact that, being at a shorter distance from the HeNB w.r.t. the distance from the MeNB, MTC devices experience better channel qualities and consequently data transmission can be handled in a more efficient way by exploiting less robust transmission parameters (i.e., modulation and coding schemes).

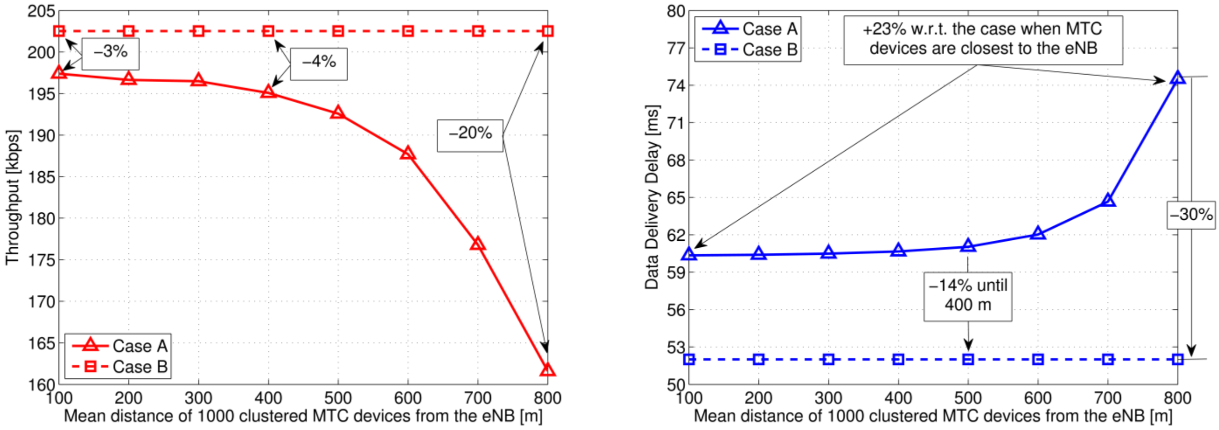

**Figure 3. Impact of MTC on throughput of BE users (left) & latency data transmission of MTC devices (right).**

# 4. Radio Access Congestion under Ultra-Dense MTC Deployment

The analyses presented so far demonstrated the suitability of supporting MTC via HeNBs in a scenario with a fixed number of MTC devices. Here, we are interested in showing the scalability of our solution with an increasing number of MTC devices. When a very large and not predictable number of machines will simultaneously attempt to access LTE-A networks, we expect that the use of HeNBs should reduce the radio access congestion. With this aim, we stressed the simulation scenario by (i) reducing the period for arrivals of both HTC and MTC terminals down to 20s, and (ii) by varying the number of MTC devices (from 1,000 to 30,000) located at the cell-edge (i.e., 800m from the MeNB). This scenario also resembles the case of MTC devices located in challenging locations with poor network coverage, like in indoor environments.

## 4.1 Impact on HTC Traffic

The radio access network becomes the bottleneck of LTE-A system when a very large number of MTC devices transmit in a short time interval. As highlighted in Figure 4, when HTC and MTC traffics are served via the MeNB only (i.e., Case A), the probability of successful data transmission is drastically reduced for both traffics with the increase in the number of MTC devices. Indeed, with numerous MTC devices simultaneously transmitting, the amount of resources available for HTC users becomes quickly scarce. As a consequence, they are not able to successfully complete their own data transmission. It is worth noticing that network congestion becomes evident already with 3,000 MTC devices; and above 5,000 MTC devices, the transmission of BE flows is denied in the cell.

When we consider the Case B, we obtain a totally different behavior. Indeed, the HeNB avoids MTC services to take resources from the HTC traffics, which are always successfully transmitted (i.e,. success probability equal to 1 for HTC and MTC traffic). In addition, also for the case with 30,000 MTC devices, the HeNB is able to handle the MTC traffic, confirming the effectiveness of the proposed solution in extremely dense network scenarios.

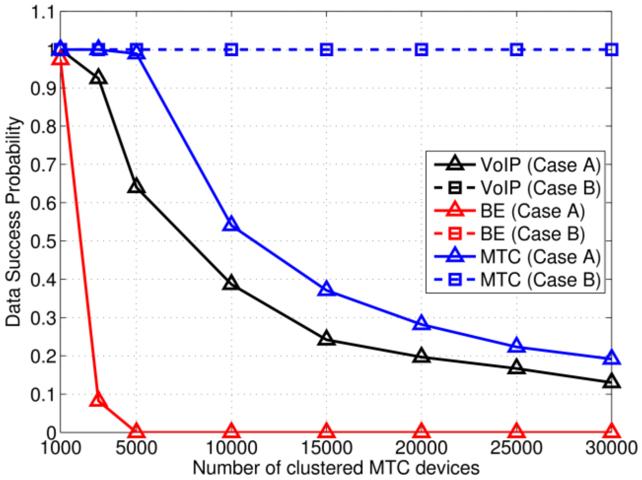

**Figure 4. Data Success Probability for HTC and MTC devices by varying the number of clustered MTC devices located at the cell-edge.**

### 4.2 Impact on MTC Traffic

In Figure 5, the MTC performance is shown to underline the meaningful improvements achieved by femtocells. In addition to above mentioned Case A and B, we further consider a scenario (namely, Case C) with mixed MTC and HTC traffic over femtocells. In detail, in Case C we assume that the HeNB is exploited to serve MTC devices, 5 VoIP and 5 BE users (the dependency of number of voice/data users in the HeNB has been omitted here for space reasons). We firstly consider the data delivery delay (left-hand side). When MTC devices are attached to the MeNB (i.e., Case A), the high network congestion causes a quick increase in the data latency. Indeed, with 3000 devices, the delivery delay is already higher than 2s and it is close to 14s for the case of 30,000 machines. On the contrary, in Cases B and C the data delivery delay is lower than 60ms until the case of 20,000 machines. We can observe that, when considering 30,000 devices, the presence of HTC traffic in the Case C introduces a MTC delay increase of about 200ms compared to Case B. Focusing on the performance of HTC users in Case C (results are not plotted due to the lack of space), both VoIP and BE terminals are always able to accomplish the data transmission with some performance degradation. In particular, VoIP users experience an increase in the percentage of packet losses up to 20% for the extremely scenario with 30,000 MTC devices, while BE users observe a throughput decrease from 670 kbps (scenario with 1,000 MTC devices) down to 560 kbps (scenario with 30,000 MTC devices).

We also considered a fundamental parameter for MTC, i.e., the energy consumption. We are assuming that the MTC devices transmit one packet per minute (which is rather a high-load case) and their battery capacity is equal to 1500mAh. By analyzing the *lifetime* of MTC devices in the right side plot of Figure 5, we observe that the increase in data delivery delay due to network congestion in Case A involves a drastic reduction in terms of battery lifetime (i.e., from 492 to 17 days when the number of MTC devices varies from 1,000 to 3,000). The exploitation of HeNB allows significantly longer battery life, i.e., 625 days in the case of 20,000 machines for both Cases B and C. When the number of MTC devices increases, and the data delivery time consequently becomes larger and the battery lifetime is reduced down to only tens of days.

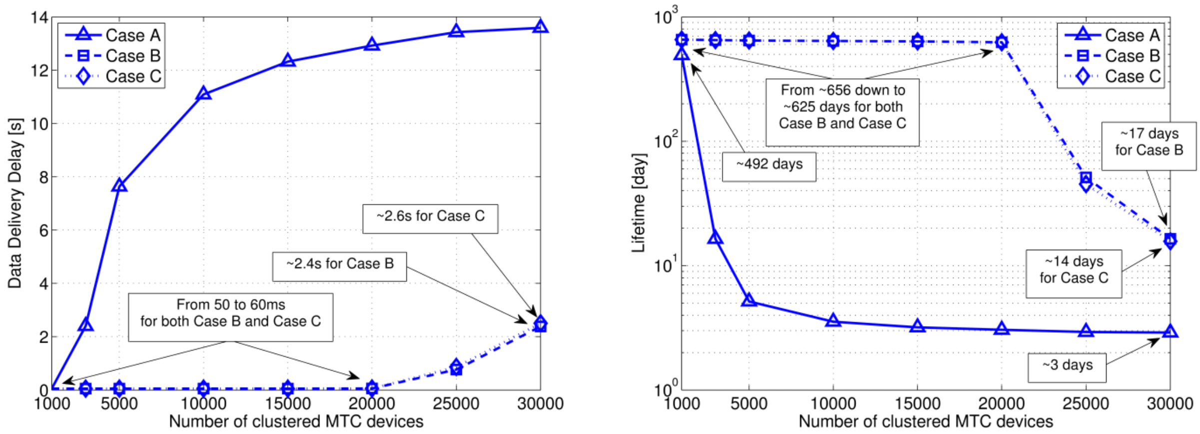

**Figure 5. Delivery Time (left) and Lifetime (right) of MTC devices.**

# 5. Concluding Remarks

## 5.1 Conclusions

We presented and quantified the performance of a novel network architecture able to efficiently handle ultra-dense MTC over LTE-A networks by exploiting closed access femtocells. Such an architecture allows meaningful advantages which are summarized in Table 1**Errore. L'origine riferimento non è stata trovata.**. Focusing on the coexistence of HTC and MTC traffic, the proposed solution allows for an effective separation of the traffic and, as a consequence, fulfills the requirements of MTC without affecting the performance experienced by HTC users. Concerning the enhancements on MTC devices, the exploitation of HeNBs is useful to offer several benefits such as **significantly reduced latency and energy consumption** in RA and data procedures, and higher capacity (i.e., number of supported machines).

Finally, it is worth noting that the proposed solution with frequency-separated deployment for MeNB and HeNBs guarantees a reduced complexity (and lower cost) for MTC devices. On the core/backhaul network side, the exploitation of HeNB-GW in the proposed architecture has the main benefits of reducing the congestion/overloading for both the MME and the S-GW in the core. In addition, the proposed network offers connectivity with reduced latency among LTE-A and non-3GPP MTC devices via trusted non-3GPP APs.

## 5.2 Open Challenges

Open challenges relevant to the capability of LTE-A to support the extremely dense scenarios expected for MTC remain:

- *Latency reduction.* According to the analyses shown above, the exploitation of HeNBs is a valid solution to reduce the latency for MTC devices. However, we should consider that the RA procedure involves a very large overhead for data transmission mainly due to two factors: *(i)* high latency required for RA before the effective data transmission; *(ii)* a large number of control bits transmitted before the transmission of typical small packets. To solve such issues, enhanced mechanism for RA and data transmission procedures are required to further reduce latency and energy consumption, and to the enhance the efficiency.
- *Energy-aware radio access.* The design of novel techniques to improve the energy efficiency and performance of RA procedure still continues to be considered an open challenge. In this direction, effective solutions are still needed to guarantee energy-aware RA, i.e., ad-hoc RA procedure where the residual energy-life of MTC devices is taken into

account to guarantee RA higher probability for those devices with limited battery charge.

- *Transmission of alarm messages.* A portion of MTC applications are based on the transmission of alarm messages which should be conveyed to remote servers or actuators with very strict time constraints. The transmission of alarm messages still represents an open issue since effective solutions are required to guarantee reduced (and deterministic) latency for alarm messages.

Overall, however, we addressed the arising problems of massively dense MTC deployments through the architectural changes proposed and quantified in this paper.

**Table 1. A summary of the main benefits of the proposed network architecture for MTC over HeNBs in LTE-A.**

| | |
|---|---|
| **Design Drivers** | • reduced complexity thanks to the frequency-separated scenario |
| **RA Procedure** | • higher success probability for the transmission of the first preamble<br>• reduced latency (i.e., switching time from idle to connected mode)<br>• reduced energy consumption |
| **Data Transmission** | • reduced latency<br>• reduced energy consumption<br>• higher capacity (i.e., number of supported MTC devices)<br>• no negative impact on HTC services |
| **Core Network** | • high scalability (increase in the number of HeNBs does not cause network overload)<br>• no overload at the MME thanks to the use of HeNB-GW<br>• no overload at the S-GW thanks to the use of HeNB-GW<br>• paging optimization at the HeNB-GW<br>• inter-connection with trusted non-3GPP APs |
| **M2M Uptake** | • decreased dependency on coverage provisioning in challenging environments<br>• whilst not losing ability to use operator's connectivity and service platforms<br>• significantly quicker time to market because of reduced telco engineering work<br>• significantly reduced risk due to availability of SLAs in licensed bands |

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## References

[1] 3GPP, TS 22.368, "Service requirements for Machine-Type Communications (MTC)," Rel. 12, Dec. 2013.

[2] D. Astely, E. Dahlman, G. Fodor, S. Parkvall, and J. Sachs, "LTE Release 12 and Beyond," *IEEE Communications Magazine*, vol. 51, no. 7, July 2013, pp. 154-160.

[3] V. Gonclves and P. Dobbelaere, "Business Scenarios for Machine-to-Machine Mobile Applications," *International Conference on Mobile Business and Ninth Global Mobility Roundtable (ICMB-GMR),* Jun. 2010, pp. 394-401.

[4] J. Alonso, and M. Dohler, "Machine-to-Machine Technologies & Markets - Shift of Industries," Tutorial, *IEEE WCNC*, 6 Apr. 2014, Istanbul, Turkey.

[5] K. Zheng, F. Hu, W. Wang, W. Xiang, and M. Dohler, "Radio Resource Allocation in LTE-Advanced Cellular Networks with M2M Communications," *IEEE Communications Magazine*, vol. 50, no. 7, Jul. 2012, pp. 184-192.

[6] 3GPP, TR 37.869, “Study on Enhancements to Machine-Type Communications (MTC) and other Mobile Data Applications; Radio Access Network (RAN) aspects,” Rel. 12, Sep. 2013.

[7] Ericsson, L. M. "More than 50 Billion Connected Devices." (2011).

[8] ETSI TS 123 682, “Architecture enhancements to facilitate communications with packet data networks and applications,” Sep. 2013.

[9] J. G. Andrews, H. Claussen, M. Dohler, S. Rangan, and M. C. Reed, “Femtocells: Past, Present, and Future,” *IEEE Journal On Selected Areas In Communications*, vol. 30, no. 3, Apr. 2012, pp. 497-508.

[10] I. Widjaja, and H. La Roche, “Sizing X2 Bandwidth for Inter-Connected eNBs,” *IEEE Vehicular Technology Conference Fall (VTC-Fall)*, Sep. 2009, pp. 1-5.

[11] 3GPP, TS 36.300, “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN)” Rel. 12, Dec. 2013.

[12] 3GPP, TS 23.402, “Architecture enhancements for non-3GPP accesses,” Rel. 12, Mar. 2014.

[13] 3GPP, TR 25.814, “Physical layer aspect for evolved universal terrestrial radio access (UTRA),” Rel. 7, Sep. 2006.

[14] A. Laya, L. Alonso, and J. Alonso-Zarate, “Is the Random Access Channel of LTE and LTE-A Suitable for M2M Communications? A Survey of Alternatives,” *IEEE Communications Surveys & Tutorials*, vol. 16, no. 1, Dec. 2013, pp. 4-16.

[15] 3GPP, TR 38.868, “RAN Improvements for Machine-type Communications,” Rel. 11, Oct. 2011.