Machine-Type Communications as Part of LTE-Advanced Technology in Beyond-4G Networks

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Abstract—**Machine-Type Communications is an important part of the infrastructure of LTE. This technology connects with all the other new technologies in mobile communications. In this paper, we describe Machine-Type Communications and its relation with other technologies, e.g. heterogeneous networks and device-to-device communications. We will show a simple model of Machine Type Communications in the LTE-A network (random access procedure) and discuss M2M technology. First we describe the concept of heterogeneous networks and device-to-device communications. After that we consider the Machine-Type Communications and power consumption problem.**

Keywords—heterogeneous networks, device-to-device communications, machine type communications.

I. Introduction

It is a common fact that inclusive of radio and television, the history of public wireless networks started only several decades ago. However, over these years, wireless communication grows into a number of dedicated standards characterized by their purpose, principle and design. The scale of these networks could also vary over a wide range: starting from smaller Wireless Personal Area Networks (WPAN), which scale is usually 1-2 meters, and up to Wireless Wide Area Networks (WWAN) huge deployments spanning several kilometers in length. The total number of users, or, better to say, devices, involved as part of these networks nowadays is probably equal or even larger than the number of users or devices in wired networks. Already today, each of us has on average 3 wireless devices, e.g. laptop, cell phone and tablet. Each of them usually contains several wireless transmitters/receivers by different technology. For example, in a typical smart-phone, 4 communication technologies are usually presented: cellular transceivers of 2nd and 3rd generation, Wi-Fi and Bluetooth. Furthermore, due to the growing number of applications, as well as the traffic demand and user population, the number of devices grows dramatically, which could lead to several problems caused by limited wireless spectrum. The most noticeable is absence of an underlying cross-standard integration and, as an outcome, inefficient spectrum usage. Due to aforementioned trends and problems, the implementation of Machine Type Communication (MTC) concept, which main idea is to connect thousands of devices into one large network, becomes a very challenging task. In this text, we briefly summarize possible ways in which the MTC concept could develop [23].

First, to understand why todays market is so interested in this new development, let us briefly review what MTC is. The idea behind this concept is not new and, in fact, is the evolution of the smart-house/city/factory and sensor network concepts. The overall purpose is to create a new class of wireless applications, where the user-side device will be some sort of automatically-controlled unattended machine. The devices could be different, from smart fridge, which will transmit information about the quality of food inside at the central device, which could be e.g. smart-phone in a smart-house grid and to a sensor measuring pressure or temperature and sending this data to a central decision-making controller unit on the automated factory. From this description, we could derive the main attributes of any MTC network: machine-based devices as network units, centralized data collection (it does not exclude the connections between peer ordinary units), and high number of devices in the network. These main properties will lead to several implementation tasks.

The first task which the developers of MTC networks should solve is a choice of communication technology. Clearly, creation of a new standard will be the most beneficial from the point of view of system signaling, coverage and capacity optimization [24]. However, this will increase cross-standard operation, and will make efficient spectrum usage even more problematic. Furthermore, the procedure of a new standard development is a very sophisticated process, which could probably take years, before first commercial prototypes will be presented. Alternatively, there is an idea to implement MTC basing on the current standards, or several standards, which will somehow be integrated, or at least will communicate with each other through a gateway unit [25]. For this purpose, several wireless standards are now under consideration. Most probably, these would be commonly-used technologies with a flexible signaling and good opportunities for integration, as well as possibility to combine conventional high-traffic (demanding) human users with thousands of devices with a very low channel usage. For instance, 3GPP Long Term Evolution (LTE) WWAN cellular standard is one of the best candidates here from the point of view of its capacity and coverage. As the main benefits, (i) a combination of flexible spectrum usage due to Orthogonal Frequency Division Multiple Access (OFDMA) [7] on a physical layer and (ii) continuous support and development of the standard could be named. However, several drawbacks, such as complex signaling, not designed for several thousands of devices, are as well presented in LTE networks [11]. From this viewpoint, shorter-range technologies for MTC, e.g. smart-house WLANs, IEEE 802.11 Wi-Fi, could be a good alternative. High capacity, simplicity and robustness

ISSN 2305-7254

on small-size networks make Wi-Fi an ideal candidate. Moreover, one of the benefits of LTE and Wi-Fi as MTC candidate technologies is their possible future integration, across a so-called Heterogeneous Network (HetNet) deployment, which will merge several networks of different scale levels, as well as different tiers of one technology, e.g. Macro, Pico and Femto base stations of LTE. On the other side, Deviceto-Device (D2D) principle, which allows users to connect directly via e.g. Wi-Fi Direct instead of using the LTE Base Station is now under implementation and could also affect the MTC development through advanced network coverage planning and flexible data transfer.

Finally, we emphasize that the choice of MTC technology is just a top of the iceberg. The device transceiver implementation, which needs to take into account battery power consumption and price (probably the device should work for a long time without battery change and be very cheap), network-planning capacity and coverage issues, signaling modifications and other minor and major details will be, or better to say are challenging, but exciting problems for engineers and researchers are spreading around the MTC world.

In this paper, in section 2, we consider new concept of the cellular networks - heterogeneous networks. Further we describe device-to-device communication, which developing in present time. Thereafter we consider one of the models of MTC, which shows an example of the system and present a number of challenges that must be addressed in a real system. In section 6 we focus on the future work to be done.

II. Heterogeneous networks

Mobile communications are developing rapidly and so, the number of users of cellular networks is increasing. Wi-Fi networks are also serving an increased amount with of users. Also there is a great interest to mobile users in the fourth generation of cellular communication - LTE. This is due to low cost of service of mobile telecommunication and free Internet access with using WLAN ad-hoc.

However, to improve capacity of a network, in traditional cellular concept, you should increase the number of base stations deployed. This will worsen the interference situation, which means that the average cell radius should be decreased. Notwithstanding, this algorithm could lead to the situation where the size of signaling of mobile users will dramatically increase due to grow of cell edge reconnections because of tiny base station coverage. Existing solutions do not always work in such conditions. At the same time, progress in mobile communication networks has created many other alternatives that operate concurrently, e.g. HetNets and D2D. Combining WLAN with cellular networks can provide a significant increase in the total capacity of the network, this is at the core of the concept of HetNets [8].

In HetNet, the concept of a base station extends from the conventional cellular network and includes picocell, femtocell, access points. Usually the range of a picocell is 200 meters or less, and a femtocell is in the order of 10 meters. They have great potential for co-development with cellular networks. In this network, all these elements are part of a heterogeneous network that can communicate with each other. This feature allows optimizing the network in terms of effective use of resources [6].

The structure of HetNet's cell is showed in Figure 1. The cell is served by a base station LTE network (macroBS), which has a certain number of access points of WLAN that are now part of the overall network. If necessary, users can use a resource of the cellular network or Wi-Fi. Moreover, switching from one technology to another is automatic. For example, if we have a group of static clients that are in the same place for a long time and use a packet data connection, then it would be advisable to offload their traffic to Wi-Fi. At the same time, mobile users are rapidly crossing the border cells, it would be better to use the resources of the macroBS for them.

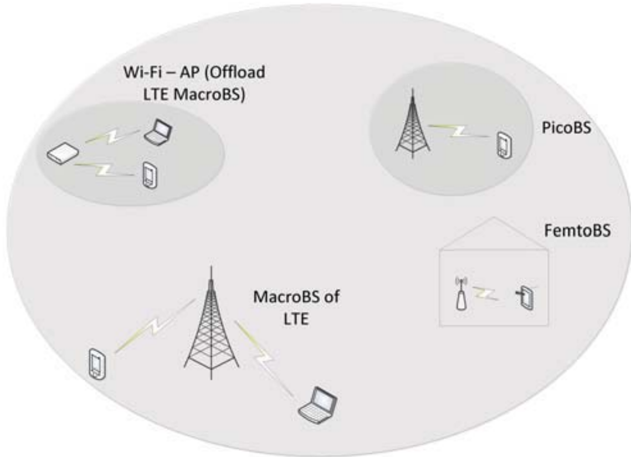

Fig. 1. Structure of heterogeneous network.

The concept of heterogeneous networks is in the development stage now and has several problems. The radio planning contains a number of open issues, e.g. uncertainty of position of the access point. The scheduler can only assume its existence and make some adjustments. Also, the operator cannot control all the elements of the network, i.e. there is a question about the degree of control over the supplementary parts of the network.

Another problem is the management of the system. We have two paradigms: user-centric and networks-centric. When we are using a user-centric approach, the users decide to change technology(LTE/Wi-Fi). In the case of network-centric approach we measure the capacity of our system and reach a decision. It is possible to take into consideration the user's measurements. The best management option is an open issue.

Despite the above problems, the concept is being actively developed and is promising for mobile communications. Along with such an important association of networks built on top of an existing network is the D2D communication that is being developed in parallel with HetNets. It is of particular interest in the combination of these two concepts. D2D is described below.

III. D2D communications

D2D communication is the communication between several devices without using access points or base stations.

One of the key aspects of the D2D technology is the use of unlicensed spectrum bands, e.g. Bluetooth and Wi-Fi Direct. These technologies are using short-range communications and do not have the special infrastructure. Although the technology does not need the infrastructure, this network can be useful for synchronization and security procedures in the future.

Wi-Fi and Bluetooth is installed in more mobile devices, because it is selected as the foundation of D2D communication. For example, if a user wants to share any content with their nearby friends he can send the content directly without the use of network resources. It is not necessary to use the resources of a cellular network. Using D2D communication offloads network resources. This feature of mobile devices can be an important part of combining D2D and HetNet.

Since there can be a lot of D2D links that are using the unlicensed band, this free resources of the operator. More details about D2D in [4] and [5].

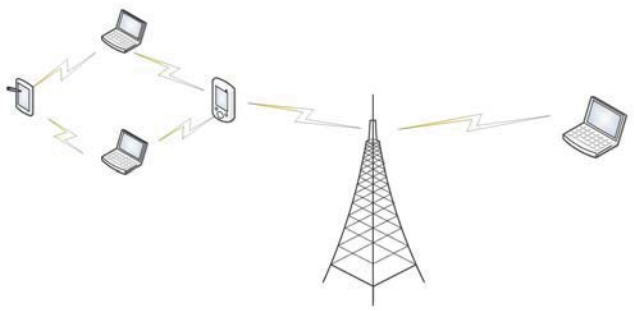

Fig. 2. Scheme of D2D communication.

Combining D2D communication and HetNet is a future work in mobile telecommunication.

Also one of the extensions over a cellular network is machine-to-machine communication, which will be part of the overall network like D2D links and HetNet.

Aggregation of MTC and D2D is important, because this allows sensors to communicate with network core and with each other.

IV. Machine-Type Communication

Smart home technology, sensor networks in factories, e-health, safety and protection, education is an incomplete list of areas in which machine-to-machine communications could be used [21]. Machine-Type Communication is a rapidly growing trend of mobile communications with a lot of applications [13], [14]. According to some estimates, in the future we will have around 300 billion MTC devices [26]. Thus, 3rd Generation Partnership Project (3GPP) standardizes the work principle of MTC applications in 3GPP networks.

MTC is the communication between different devices (usually sensors) and the core network [22]. MTC is used in security systems, navigation, communication between different objects, as a rule, self-contained, health systems, etc.

Based on the operating conditions, these devices must meet certain requirements:

- *Very low energy consumption for data transmits* [16];

Devices can have three states: idle, transmit and receive. A sensor transmits once in a period of time in the common mode. Frequency of transmission is selected on the basis of the conditions of work and the environment (1 min., 5 min., 1 h. etc.). For example, a video camera can transmit once in 5 min. Typically, the data size doesn't exceed several bytes. It can be information about pressure, temperature etc. Energy per device should be minimal, because data transmits frequently and in small portions. On the other hand, a big waste of energy leads to a short-lived operation of each device. In terms of battery life it becomes an important factor in their design. For example, if sensors will work in extreme conditions for a long time, the high cost of energy can interfere with the collection of information.

- *Devices should have low complexity;*

The number of MTC devices can vary from tens to tens of thousands. According to methodology [**?**] used by 3GPP [18], the number of MTC devices in a single cell may grow up to 30 000. Since price depends on the complexity of the device, high hardware complexity is quite expensive. It is not profitable for the enterprise to install several thousand units with the high cost per unit. Take for example the technology of Zig-Bee. They have popularity in the industry due to the simplicity of the hardware and cheapness. Regardless of the physical layer of the sensor (Zig-Bee, Wi-Fi, LTE, RFID etc.) it must be inexpensive.

- *Long battery life;*

The battery of the sensor should have the sufficient energy capacity which will run for a long time. This factor is a particularly important role in extreme conditions, where access is limited to the sensor and the ability to recharge is minimal. Fortunately, the progress in the development of batteries allows to create a device that can operate autonomously for a long time. When we are using an MTC-device in extreme conditions, operation time is an important factor.

- *Very large number of devices per cell.*

For aforementioned reasons, the number of MTC devices per cell can increase to tens of thousands. This situation raises a number of problems.

MTC devices use the LTE channel. Conventional CSMA/CA-based short range technologies have certain limitations when handling MTC traffic [17]. Therefore in majority of scenarios MTC devices are assumed to use LTE channel. Although they transmit and receive small amount of data, the growth of number of MTC devices causes the growth of the network load. A network can include 10000 sensors and even more. In this case a set of optimization tasks has to be solved, starting from the overload control [19], [20], [9] and fair resources sharing withing all the nodes, and up to coexistence with conventional Human-to-Human data flow. More detailed about physical layer of Machine-Type Communications in LTE can be found in subsection A.

As an example of such a network, consider the following model. We consider a cell of 3GPP LTE-A network with a large number of connected MTC devices (several thousands). Some devices transmit emergency information (A-devices);

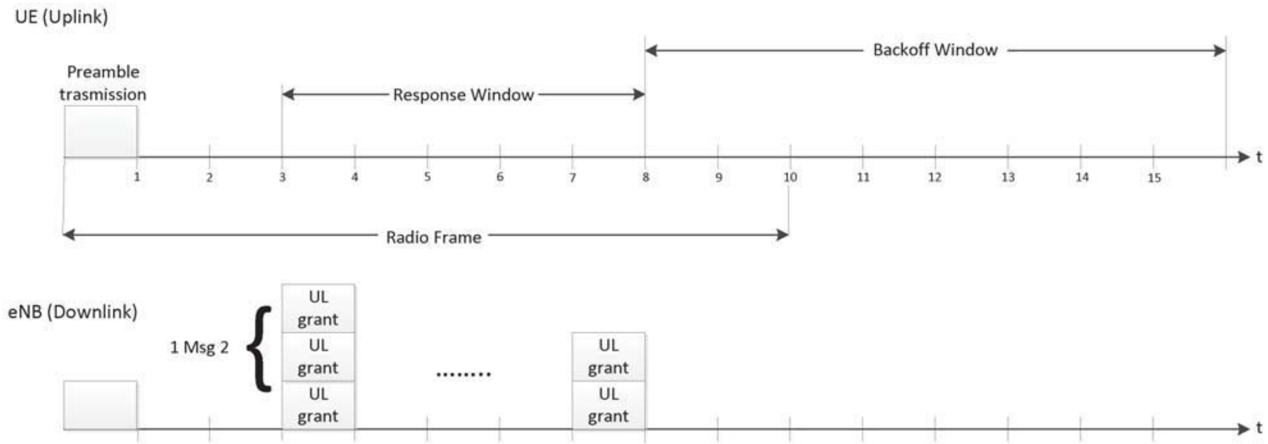

Fig. 3. Random access procedure.

other devices transmit service information (B-devices). The B-devices transmit information with certain intensity and a uniform distribution. The A-devices start to operate in extreme conditions and their distribution has the nature of the beta distribution [10].

A. RA procedure.

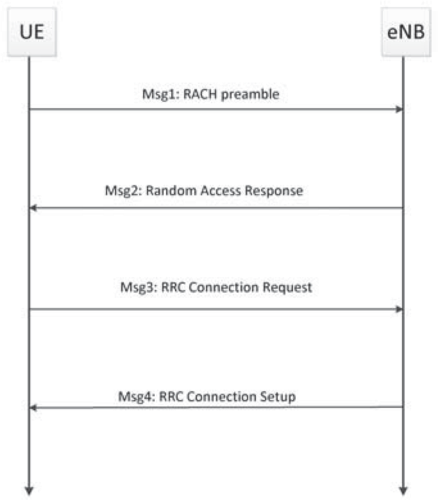

Fig. 4. RA procedure signaling.

First, a User Equipment (UE) sends a random access preamble (Msg1) to the base station via the Physical Random Access Channel (PRACH) by choosing it randomly out of the maximum of 64 preamble sequences. The preamble sequence consists of a cyclic prefix, a sequence and a guard time. It occupies 839 subcarriers in the frequency domain and 1, 2 or 3 subframes in the time domain. A collision can occur at the base station when two or more UEs choose identical preamble and send them at the same time.

If a preamble has been received correctly, the base station (eNB) sends the UL grant with using PDCCH channel within

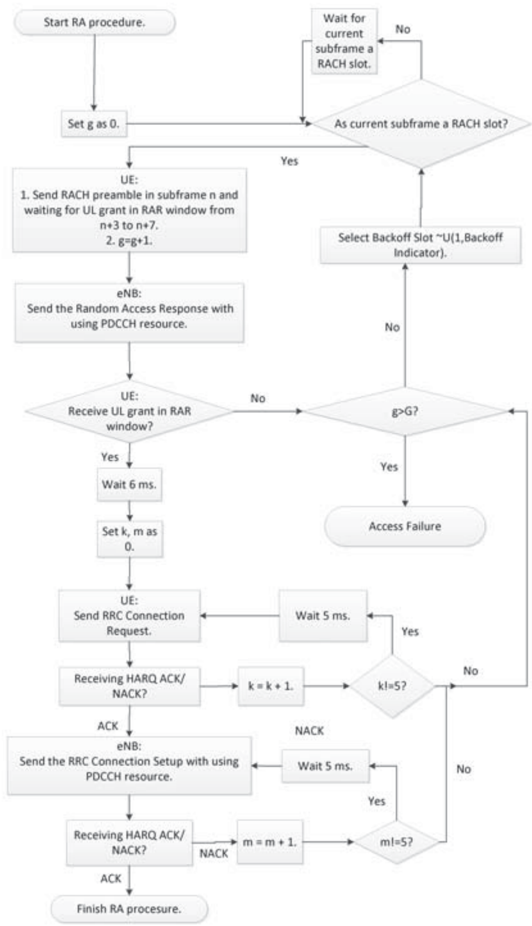

Fig. 5. Algorithm of RA procedure.

the response window. 1 UL grant includes 3 random access responses (RAR). 1 UL grant occupies 4 Control Channel Elements. After processing time of Msg2 UE sends Msg3 via the Physical Uplink Shared Channel (PUSCH) using the resources granted by Msg2. After receiving Msg3 eNB sends Msg4 with using PDCCH channel. 1 Msg4 occupies 4 CCE.

The PDCCH channel has 16 Control Channel Elements (CCEs). Every message is using 4 CCEs or 144 resource blocks. The base station can send one Msg2 and three Msg4 in the current subframe of four Msg4 if no Msg2. The serving of an Msg 2 has priority over the serving of an Msg 4.

More detailed algorithm can be found in [2].

V. Power consumption analysis

Power consumption is an important question in the network planning. This parameter depends on many factors. Among which an important role is played time of back off. Backoff is a special subheader of MAC layer that carries the parameter indicating the time delay between a sending PRACH preamble and the next PRACH preamble. Value of backoff in the table I.

TABLE I. Backoff Indicator

Index	Backoff value (ms)
0	0
1	10
2	20
3	30
4	40
5	60
6	80
7	120
8	160
9	240
10	320
11	480
12	960
13	Reserved
14	Reserved
15	Reserved

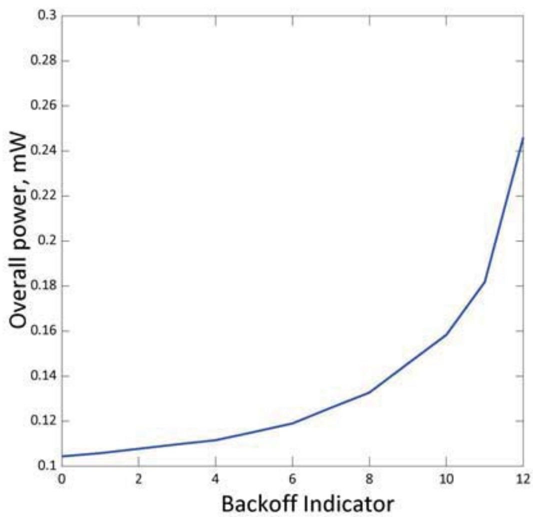

Fig. 6. Dependence of the overall power on the value of backoff indicator.

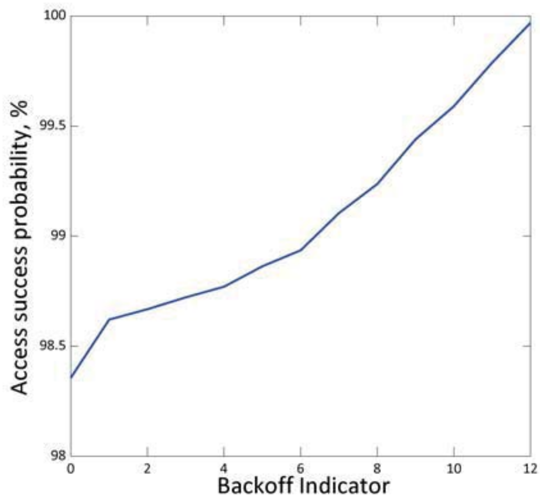

Fig. 7. Dependence of the access success probability on the value of backoff indicator.

Optimal selection of the back off value is an important factor for power consumption. We consider a population of some low priority MTC devices (B-devices) which coexist with some high priority MTC devices (A-devices) and all camp in the RRC_Connected state of 3GPP LTE-A system. We account for the following factors that jointly impact the system performance:

- Fixed number of low priority MTC devices: 60 000;

- Fixed number of high priority MTC devices: 10 000;

- Range of back off indicator: varies from 0 to 12;

- The remaining parameters are set according to 3GPP methodology.

Below we demonstrate our results of modeling.

Generally, all the figures demonstrates growth our metrics. We observe an increased access success probability, when we increase the back off indicator. As we see, the growth in power consumption is associated with increment waiting time.

VI. Conclusions

In this paper we described the application of the M2M technology and demonstrated a simple model of random access procedure. Analytic description of this procedure described in [1] and comparison data access schemes in [3]. In future works it would be interesting to examine the effect of overload control mechanism [15] on system performance compared to the system without it. Also we would like to consider various optimization techniques that improve the performance of the existing system. We also described the D2D technology and heterogeneous networks and the problems that are associated with them.

References

[1] M. Gerasimenko, V. Petrov, O. Galinina, S. Andreev, and Y. Koucheryavy, "Impact of MTC on Energy and Delay Performance of Random-Access Channel in LTE-Advanced", *In Transactions on Emerging Telecommunications Technologies - ETT*, 2013.

[2] Chen M.-Y., Lin G.-Y., Wei H.-Y., Hsu A., “Overload Control for Machine-Type-Communications in LTE-Advanced System”, *IEEE Communications Magazine*, 2012.

[3] S. Andreev, A. Larmo, M. Gerasimenko, V. Petrov, O. Galinina, T. Tirronen, J. Torsner, and Y. Koucheryavy, “Efficient Small Data Access for Machine-Type Communications in LTE”, *In the Proc. of the IEEE International Conference on Communications (ICC)*, 2013.

[4] A. Pyattaev, K. Johnsson, S. Andreev, and Y. Koucheryavy, “Proximity-Based Data Offloading via Network Assisted Device-to-Device Communications”, *In the Proc. of the IEEE VTC-Spring*, 2013.

[5] A. Pyattaev, K. Johnsson, S. Andreev, and Y. Koucheryavy, “3GPP LTE Traffic Offloading onto WiFi Direct”, *In the Proc. of the IEEE WCNC 2013 - Workshop on Mobile Internet: Traffic Modeling, Subscriber Perception Analysis and Traffic-aware Network Design*, 2013.

[6] M. Gerasimenko, N. Himayat, S.-p. Yeh, S. Talwar, S. Andreev, and Y. Koucheryavy, “Characterizing Performance of Load-Aware Network Selection in Multi-Radio (WiFi/LTE) Heterogeneous Networks”, *In the Proc. of the Globecom 2013 - Workshop on Broadband Wireless Access*, 2013.

[7] Sergey Andreev, Pavel Gonchukov, Nageen Himayat, Yevgeni Koucheryavy, and Andrey Turlikov, “Energy efficient communications for future broadband cellular networks”, *In Computer Communications Journal - COMCOM*, Vol. 35. No. 14. Pp. 1662 - 1671, 2012.

[8] N. Himayat, S.-p. Yeh, A. Panah, S. Talwar, M. Gerasimenko, S. Andreev, and Y. Koucheryavy, “Multi-Radio Heterogeneous Networks: Architectures and Performance”, *In the Proc. of the IEEE International Conference on Computing, Networking and Communications (ICNC), Invited Position Paper*, 2014.

[9] O. Galinina, A. Turlikov, S. Andreev, and Y. Koucheryavy, “Stabilizing Multi-Channel Slotted Aloha for Machine-Type Communications”, *In the Proc. of the IEEE International Symposium on Information Theory - ISIT’13*, Istanbul, Turkey, 2013.

[10] Sergey Andreev, Olga Galinina, and Yevgeni Koucheryavy, “Energy-Efficient Client Relay Scheme for Machine-to-Machine Communication”, *In the Proc. of the 54th IEEE Global Communications Conference - GLOBECOM’11*, Houston, Texas, USA, 2011.

[11] Alexander Pyattaev, Sergey Andreev, Olga Galinina, and Yevgeni Koucheryavy, “System-Level Evaluation of Opportunistic Client Cooperation in Wireless Cellular Networks”, *In the Proc. of the 20th IEEE International Conference on Computer Communications and Networks - ICCCN’11*, Maui, Hawaii, 2011.

[12] “3GPP. Study on RAN Improvements for Machine-Type Communications (Release 11). TR 37.868”, 2011.

[13] “3GPP. System Improvements for Machine-Type Communications. TR 23.888”, 2011.

[14] “3GPP. Study on enhancements for MTC. TR 22.888”, 2012.

[15] P. Jain, p. Hedman, H. Zisimopoulos, “Machine Type Communications in 3GPP Systems”, *IEEE Communications Magazine*, November 2012.

[16] D. Astely, E. Dahlman, G. Fodor, S. Parkvall, J. Sachs, “LTE Release 12 and Beyond”, *IEEE Communications Magazine*, July 2013.

[17] V. Petrov, S. Andreev and Y. Koucheryavy, “An Applicability Assessment of IEEE 802.11 Technology for Machine-Type Communications”, *In the Proc. of the 11th Annual Mediterranean Ad Hoc Networking Workshop - MEDHOCNET’12*, Ayia Napa, Cyprus, 2012.

[18] Vodafone, ”Vodafone M2M usaceses prediction”, http://m2m.vodafone.com/images/2011/videos/m2m_city/index.jsp.

[19] N. Himayat, S. Talwar, K. Johnsson, S. Andreev, O. Galinina, A. Turlikov, “Proposed 802.16p Performance Requirements for Network Entry by Large Number of Devices”, *IEEE 802.16 C80216p-10/0006*, 2010.

[20] V. Petrov, S. Andreev and Y. Koucheryavy, “On IEEE 802.16m Overload Control for Smart Grid Deployments”, *In the Proc. of the 5th Conference on Internet of Things and Smart Spaces - ruSMART’12*, St.Petersburg, Russia, 2012.

[21] Machine-To-Machine (M2M) & Smart Systems Forecast 2010-2014. *Harbor Research Report*, 2009.

[22] Emmerson B. M2M: the Internet of 50 billion devices. *M2M Magazine*, 2010.

[23] Wu G., Talwar S., Johnsson K., Himayat N., Johnson K. M2M: From Mobile to Embedded Internet. *IEEE Communications Magazine*, 2011.

[24] ETSI. Machine-to-Machine communications (M2M); M2M service requirements. *TS 102 689*, 2010.

[25] Cho H., Puthenkulam J. Machine to Machine (M2M) Communication Study Report. *IEEE 802.16p-10/0005*, 2010.

[26] Machine-To-Machine (M2M) & Smart Systems Forecast 2010-2014. *Harbor Research Report*, 2009.