UDC 621.39

Success Access Probability Analysis Using Virtual Preambles Via Random Access Channel

Ivan E. Sinitsyn*, **Elvira R. Zaripova***,
Yulia V. Gaidamaka*†, **Vsevolod S. Shorgin**†

* *Department of Applied Probability and Informatics*
Peoples' Friendship University of Russia (RUDN University)
6 Miklukho-Maklaya st., Moscow, 117198, Russian Federation
† *Institute of Informatics Problems, Federal Research Center*
"Computer Science and Control" of the Russian Academy of Sciences
44-2 Vavilova st., Moscow, 119333, Russian Federation

Email: iesinitsyn@gmail.com, zaripova_er@rudn.university,
gaydamaka_yuv@rudn.university, vshorgin@ipiran.ru

Now rapid growth of number of the devices communicating among themselves in LTE (Long-Term Evolution) communication networks is observed, especially growth of number of machine-to-machine (M2M) devices should be noted because the number of devices will exceed 50 billion in recent years.

To simplify low-cost network connection of a set of devices, communications of machine type (Machine-type communications, MTC) evolved in low-cost MTC (LC-MTC) in 3GPP standarts. LC-MTC have to cope with intensive access through a set of narrow-band channels of random access (RACH) of LTE frequencies appropriated in the range effectively. With increase in quantity and density of placement of MTC-devices the scheme of random access for LC-MTC RACH has to be improved. In this paper we suggest to use the concept of virtual preambles in the random access procedure and we carry out the success access probability and an average delay analysis via a random access channel.

Key words and phrases: random access channel, collision, access success probability, low-cost MTC, preamble.

In: K. E. Samouylov, L. A. Sevastianov, D. S. Kulyabov (eds.): Selected Papers of the VIII Conference "Information and Telecommunication Technologies and Mathematical Modeling of High-Tech Systems", Moscow, Russia, 20-Apr-2018, published at http://ceur-ws.org

1. Introduction

Machine-to-machine communications are extremely important for effective data transmission from devices in a communication network for ensuring various services of the Internet of Things, for example, such as applications for the smart house, logistic tracking, health care, safety, observation and clever measurement [1–5]. It is expected that more than 50 billion devices will be connected to network to serve the needs of Internet of Things and the demand for the effective systems of MTC communications considerably will increase [2]. The 3rd Generation Partnership Project (3GPP) has started process of standardization of machine-type communications based on LTE and LTE-Advanced technologies. MTC is standardized in the 10th release (Release-10) and evolved in low-cost MTC (LC-MTC) in release 13 for cost-effective connectivity at a large number of MTC devices.

To reduce the cost of LC-MTC equipment the 3GPP RAN working group has offered new structure of RACH where the LTE network appropriates several narrow-band random access channels (NarrowBand-RACH, NB-RACH) within its bandwidth. The LC-MTC device chooses one of available NB-RACH channels, performing a session initiation procedure for the chosen RACH channel. Unlike the classical procedure where the MTC device doesn't choose the physical channel, in new structure with the additional identifier the choice of the concrete channel can reduce the collisions arising at session initiation procedure. Thus, introduction of additional identifiers will reduce the consumed amount of energy [6]. The growing number of MTC devices has led to many studies being carried out on alleviation of overloads and on reduction of the possible collisions emerging at session initiation on a radio channel of RACH [7].

Standard solutions on alleviation of possible overloads in RACH can be two types: based on push and pull technology. In the decisions based on push technology, the procedure of session initiation is started by autonomous requests from MTC devices. For avoidance of collisions each MTC device has to generate a unique preamble for session initiation within the restrictions [8], predetermined or provided by network, besides sending a preamble is possible in a certain time-slot (Access Grant Time Interval, AGTI) [9]. In the decisions based on pull technology, the session initiation procedure is operated by commands of the base station (eNodeB, eNB). The base station synchronizes access for each MTC device or group of devices via the paging channel. Then the MTC devices are only called to initiate the procedure of random access [10].

In this paper the concept of virtual preambles for more effective recognition of LC-MTC devices and reduction of collisions is offered.

2. Concept of Virtual Preamble

The session initiation procedure, by the so-called rule of four handshakes, assumes successful sending a preamble on the first step and successful reception of the response message of RAR (Random-Access-Response) on the second step.

The existing session initiation procedure on a radio channel of RACH means existence of N_{pr} preambles, N_{PRACH} physical channels PRACH (Physical Random Access Channel) for sending a preamble and PDCCH channel (Physical Downlink Control Channel) on the descending communication line for a mandrel of the response message of RAR.

The new scheme session initiation offered for LC-MTC RACH uses new channel EPDCCH (Enchanced Physical Downlink Control Channel) which number can be the additional identifier in a so-called virtual preamble instead of PDCCH channel [2]. The sheaf with the EPDCCH channel number increases quantity of virtual preambles by the coefficient equal to the number of EPDCCH channels, Fig. 1.

For LC-MTC the device can choose the EPDCCH channel number for the response message of RAR, then for the base station such preamble will differ from other preambles [2]. In the existing scheme of a preamble transfer from the MTC device to the base station for the existing session initiation procedure without binding to the PRACH index. In the presence of one identifier with number of a preamble perhaps at once of time it is unique to distinguish no more than N_{pr} preambles. In the presence of the second identifier in the form of EPDCCH channel the base station will distinguish a preamble by not only according to her number but on a linking of number of a preamble with the virtual identifier of EPDCCH channel. When receiving two preambles with one number of a preamble the base station will distinguish these preambles on the virtual identifier of EPDCCH channel, and such approach will reduce the arising collisions that will serve increase in success access probability, reduction of average access delay and other measures.

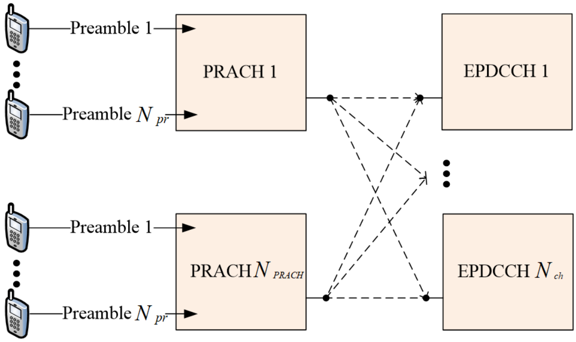

Figure 1. Virtual preambles identifications

The number of virtual identifiers of a preamble can linearly be scaled with the number of the integrated indexes of PRACH. In the offered LC — MTC RACH structure each EPDCCH channel can be logically connected to several PRACH channels.

In the course of session initiation the virtual preamble actually isn't transferred, but implicitly distinguished between the base station and LC-MTC devices. Therefore the LC-MTC devices using the offered scheme can be compatible to those MTC devices which use the outdated scheme of session initiation.

3. Success access probability and average delay analysis

We analyze the following measures: collision probability, defined as the ratio between the number of occurrences when two or more MTC devices send a random access attempt using exactly the same preamble and the overall number of opportunities (with or without access attempts) in the period; access success probability, defined as the probability to successfully complete the random access procedure within the maximum number of preamble transmissions; an average access delay, defined as the delay for each random access procedure between the first random access attempt and the completion of the random access procedure, for the successfully accessed MTC devices.

The dependence of session initiation procedure measures on a collision probability is investigated in [1]. The same methods of a Markov chain construction were applied in [11–13]. An influence of introduction of the additional identifier of EPDCCH channel on these characteristics remains interesting.

The success access probability is presented by a formula (1) [1]:

$$P(\omega) = 1 - (p + (1-p)g^{M+1})^{N+1} \qquad (1)$$

where p — the collision probability of a preamble, and g — probability of unsuccessful transfer of the HARQ message Msg3, N and M — restrictions for the number of retranslations of a preamble and the HARQ message respectively. The probability of a preamble collision p is estimated by a formula (2) [8]:

$$p = 1 - e^{\gamma/L} \qquad (2)$$

where γ — intensity of session initiation requests.

Number L — of the reserved session initiation opportunities (attempts) in a second is presented by formula (3) [14]:

$$L = N_{ch} * N_{pr} * 200. \qquad (3)$$

Also we analyse an average session initiation delay D using formula (4) [1]:

$$D = (\Delta_1 + \Delta_3 + \Delta_4) + \Delta_4 \cdot \frac{g - (M+1)\, g^{M+1} + M g^{M+2}}{(1-g)\,(1-g^{M+1})} + \\ + (\Delta_1 + \Delta_2) \cdot \frac{\beta\left(1 - (N+1)\,\beta^N + N\beta^{N+1}\right)}{(1-p)\,(1-g^{M+1})\,(1-\beta^{N+1})} + \\ + (\Delta_3 + M\Delta_4 - \Delta_2) \cdot \frac{g^{M+1}\left(1 - (N+1)\,\beta^N + N\beta^{N+1}\right)}{(1-g^{M+1})\,(1-\beta^{N+1})}, \qquad (4)$$

where $\beta = p + g^{M+1}(1-p)$ is the probability of preamble retransmission.

4. Numerical experiment

We analyze the dependence of a collision probability (Fig. 2)and success access probability (Fig. 3) on number of LC-MTC devices in a cell and number of EPDCCH channels on which RAR messages are transferred. Data from Table 1 is used for estimations.

With introduction of the additional identifier in the form of the EPDCCH channel number reduction of collision probability and increase in success access probability in connection for the subsequent transfer of small data is observed. Graphics in Fig. 2 and Fig. 3 $N_{ch} = 1$ show measures for the existing session initiation procedure.

All measures change their values when we apply an additional EPDCCH channel. For the case $N_{ch} = 2$ for 7 000 LC-MTC devices the collision probability of a preamble will decrease by 1.7 times. Let us show results for the case with two additional EPDCCH channels. For this case with 30 000 LC-MTC devices the collision probability falls from value 0.95 to 0.62, at the same time the success access probability rises up from value 0.45 to 0.99.

Average access delay is also decreasing with the growth of number of physical channels as shown on Fig. 4 for 30 000 LC-MTC devices average access delay with $N_{ch} = 1$ equals 142 ms, for $N_{ch} = 2$ channels the value is lower by 1.5 times and for $N_{ch} = 3$ channels the value drops by 2.15 times.

5. Conclusions

The additional identifier approach allows to reduce the collision probability that influences all the indicators participating in the session initiation procedure for MTC devices on RACH radio channel. Introduction of additional identifiers increases the success access probability and reduces the average access delay. The analysis of success access probability and average delay is shown in the current paper.

As further research we plan to apply this approach for analysis of new RACH mechanisms, for example, so called CAM RACH (critical alarm messages RACH) for Emergency Alarm Messages, or to another preliminary measures [15–22].

Table 1

Random access related system parameters

Parameters	Notation	Value
Total number of RACH opportunities	L	10800; 21600; 32400
Maximum number of preamble (Msg1) retransmissions	N	90
Maximum number of HARQ retransmissions for Msg3	M	250
Total number of preambles in a RA slot	N_{pr}	240
Probability of unsuccessful transfer of the HARQ message (Msg3)	g	130
Number of physical channels	N_{ch}	1; 2; 3
Time interval before sending Msg3 or preamle retransmission	Δ_1	10.5 ms
Time interval for Backoff window	Δ_2	20 ms
Time interval between successful receiving Msg2 and sending Msg3	Δ_3	5 ms
Time interval for sending Msg3, waiting and processing Msg4	Δ_4	6 ms

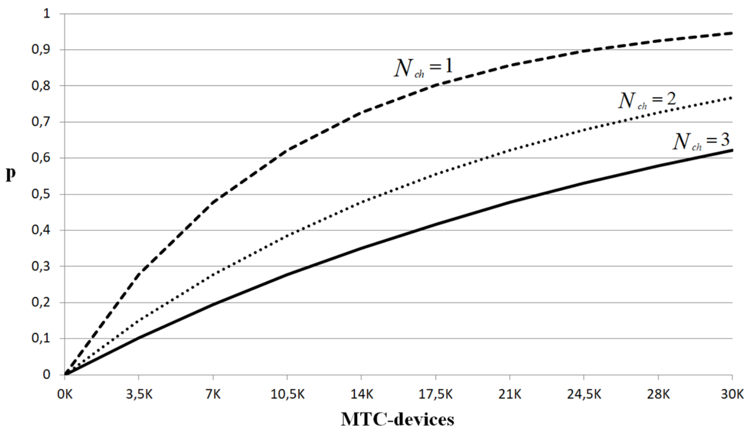

Figure 2. Collision probability

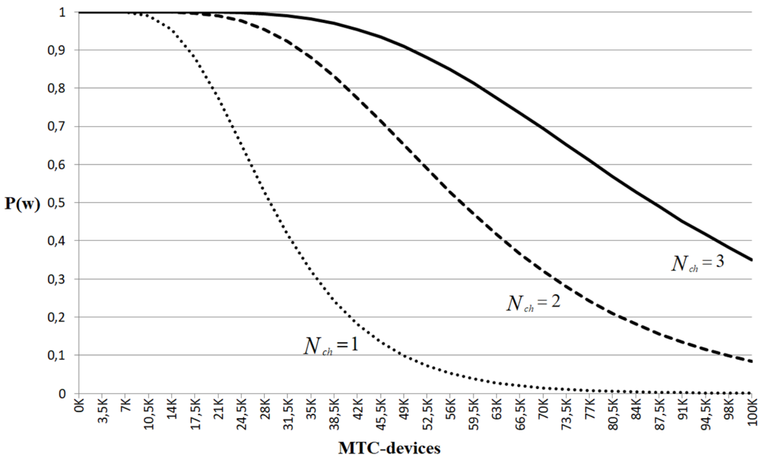

Figure 3. Success access probability

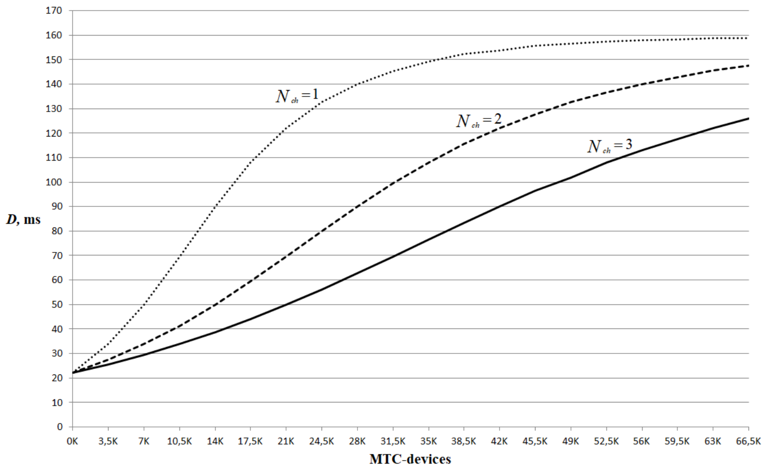

Figure 4. Average access delay

Acknowledgments

The publication has been prepared with the support of the "RUDN University Program 5-100" and funded by RFBR according to the research projects No 17-07-00845, 16-07-00766.

References

1. K. E. Samouylov, Y. V. Gaidamaka, I. A. Gudkova, E. R. Zaripova, S. Y. Shorgin, Baseline Analytical Model for Machine-Type Communications over 3GPP RACH in LTE-Advanced Networks, T. Czachórski et al. (Eds.): ISCIS 2016, CCIS **659** (2016) 203–213.
2. J. S. Kim, S. Lee, M. Y. Chung, Efficient Random-Access Scheme for Massive Connectivity in 3GPP Low-Cost Machine-Type Communications, IEEE Transactions on Vehicular Technology **66** (7) (2017).
3. M. Islam, A. E. Taha, S. Akl, A Survey of Access Management Techniques in Machine Type Communications, IEEE Communications Magazine, **52** (4) (2014) 74–81.
4. 3GPP TS 22.368 v13.1.0, Technical Specification Group Services and System Aspects; Service Requirements for Machine-Type Communications (MTC); Stage 1 (Release 13), Dec. 2014.
5. A. Metnitzer, Nokia Siemens Networks Machine2Machine Solution, In Proc. International Convention of MIPRO, May 2011, pp. 386–388.
6. T. Taleb and A. Kunz, Machine Type Communications in 3GPP Networks: Potential, Challenges, and Solutions, IEEE Communications Magazine **50** (3) (2012) 178–184.
7. M. Hasan, E. Hossain, and D. Niyato, Random Access for Machineto-Machine Communication in LTE-Advanced Networks: Issues and Approaches, IEEE Communications Magazine **51** (6) (2013) 86–93.
8. 3GPP TR 37.868 v11.0.0, Technical Specification Group Radio Access Network; Study on RAN Improvements for Machine-type Communications, Sep. 2011.
9. S. Y. Lien, K.-C. Chen, and Y. Lin, Toward Ubiquitous Massive Accesses in 3GPP Machine-to-Machine Communications, IEEE Communications Magazine **49** (4) (2011) 66–74.
10. C. H. Wei, R. G. Cheng, and S. L. Tsao, Performance Analysis of Group Paging for Machine-Type Communications in LTE Networks, IEEE Transactions on Vehicular Technology **62** (7) (2013) 3371–3382.
11. A. Ometov, E. Sopin, I. Gudkova, S. Andreev, Y. V. Gaidamaka, Y. Koucheryavy, Modeling Unreliable Operation of mmWave-Based Data Sessions in Mission-Critical PPDR Services, IEEE Access **5** (2017), art. no. 8055435, pp. 20536-20544.
12. D. Efrosinin, K. Samouylov, I. Gudkova, Busy period analysis of a queueing system with breakdowns and its application to wireless network under licensed shared access regime, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), LNCS **9870** (2016) 426–439.
13. K. Samouylov, V. Naumov, E. Sopin, I. Gudkova, S. Shorgin, Sojourn time analysis for processor sharing loss system with unreliable server, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) **9845** (2016) 284–297.
14. Ericsson R1-061369 TSG-RAN WG1 45 LTE random-access capacity and collision probability, Shanghai, China, May 8–12, 2006.
15. D. Sijabat, R. Harwahyu and R. G. Cheng, Energy-Efficiency of RACH-Based small data transmission scheme in LTE networks, 2017 40th International Conference on Telecommunications and Signal Processing (TSP), Barcelona (2017) 106–109.
16. N. Jiang, Y. Deng, M. Condoluci, W. Guo, A. Nallanathan and M. Dohler, RACH Preamble Repetition in NB-IoT Network, in IEEE Communications Letters, no. 99 (2018) 1–11.

17. A. H. E. Fawal, A. Mansour, F. Le Roy, D. Le Jeune and A. Hamié, RACH overload congestion mechanism for M2M communication in LTE-A: Issues and approaches, 2017 International Symposium on Networks, Computers and Communications (ISNCC), Marrakech (2017) 1–6.
18. S. Vural, N. Wang, P. Bucknell, G. Foster, R. Tafazolli and J. Muller, Dynamic Preamble Subset Allocation for RAN Slicing in 5G Networks, in IEEE Access **6** (2018) 13015–13032.
19. K. Taleb Ali, S. Ben Rejeb and Z. Choukair, A congestion control approach based on dynamic ACB of differentiated M2M services in 5G/HetNet, 2017 13th International Wireless Communications and Mobile Computing Conference (IWCMC), Valencia (2017) 1126–1131.
20. V. Schrader, M. Vilgelm and W. Kellerer, On Random Access Channel Performance and M2M Support in Standalone LTE Unlicensed, GLOBECOM 2017 — IEEE Global Communications Conference, Singapore (2017) 1–7.
21. L. Tian, C. Yan, W. Li, Z. Yuan, W. Cao and Y. Yuan, On uplink non-orthogonal multiple access for 5g: opportunities and challenges, in China Communications **14** (12) (2017) 142–152.
22. Chih-Min Chao and Chia-Tsun Chen, Ratio adjustable channel hopping enhancement for heterogeneous cognitive radio networks, 2017 IEEE International Conference on Communications Workshops (ICC Workshops), Paris (2017) 1093–1098.