Unlicensed Massive Machine Type Communications

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Machine-type communications (MTC) is a non-human centric concept introduced under the umbrella of IoT for the future communications technology, 5G, which can support a high number of connectivity in the network and can provide different quality of services.

energy efficiency massive machine type communications poisson point process spectrum sharing unlicensed spectrum access

1. Introduction

Internet of things has revolutionized the way communication works and is slowly becoming a part of our daily lives. Many applications are currently becoming IoT based, from remotely controlling your house to different processes in an industrial setting [1]. Billions of devices are expected to join the Internet by the year 2020, which while providing a big economic impact, will also create new challenges such as the availability of spectrum resources [2][3]. This makes finding ways to efficiently use the spectrum more valuable than ever. Machine-type communications (MTC) is a non-human centric concept introduced under the umbrella of IoT for the future communications technology, 5G, which can support a high number of connectivity in the network and can provide different quality of services [4].

MTC can be divided into three categories based on the expected properties, (i) enhanced mobile broadband (eMBB); which should be able to provide connectivity with high peak rates in addition to moderate rates for the cell-edge users; (ii) ultra-reliable MTC (uMTC), which focuses on making ultra reliable and low latency connections in the networks possible and (iii) massive machine type communication (mMTC), whose main goal is to provide massive connectivity for a large number of nodes (in the order of 10 times higher than the current number of connected devices) with different quality of service (QoS) [5][6]. A mMTC network usually consists of billions of low-complexity low-power machine-type devices as nodes. A good example of this type of networks are smart grids where the data from a very large number of nodes (smart meters) needs to be collected [7][8][9]. Industrial control is also another application of mMTC. In both of these examples, the reliability level of the network needs to be high, and it also should be able to handle critical situations [10]. A very good recent study on why 5G and MTC are needed in order to achieve the expected performance in smart grids, specifically with regards to grid protection and control is done in [11]. Motivated by this, in our work, we focus on throughput optimization and energy efficiency in a mMTC network in the presence of retransmissions.

The spectrum resources are limited, and hence, the availability of spectrum is a never ending challenge for wireless communications. Considering that mMTC is going to connect billions of devices together, this notion is becoming even more challenging in the upcoming 5G networks. Thus, studying different ways to efficiently use the available spectrum is very important [8]. This is specifically important in the future 5G technology, specially mMTC, since suitable spectrum resources below 6 GHz are limited. Moreover, it is not really possible to use mmWave for mMTC applications since they are limited in terms of resources and are mostly implemented in locations where we could face propagation problems, such as indoor or underground locations [12].

Keeping all these in mind, spectrum sharing can provide useful tools which can help mMTC networks to use the spectrum more efficiently [13][14][15][16]. One of these methods is the unlicensed spectrum access, which is a suitable option for low-power IoT-based networks and is also the spectrum access method used in this paper. It should be noted that while the studied model here is based on the concept of cognitive radios and spectrum sharing, the focus is not on design and issues related to these networks but rather on evaluating different performance metrics important to these kinds of networks. Our analysis is motivated by the aforementioned lack of spectrum resources and better ways to use these limited resources and increase the spectral efficiency of the network.

2. Discussion

A valuable study has been done in [17] where the authors study the energy grid as an important case of mMTC and propose and evaluate using the LTE network as a communication tool in these networks. Moreover, in [18][19], the previously mentioned unlicensed spectrum access model is studied, where the unlicensed users use the licensed nodes uplink channel too. In there, they show that the positions of the unlicensed users are fixed, which makes it reasonable to use highly directional antennas and limited transmit power in the unlicensed network in order to avoid interference from this network affecting the licensed network. However, this does not prevent the licensed nodes from causing interference on the unlicensed users. Since these works are limited to smart grids applications, later on we expanded these works in [20], by following the work done in [21][22], to make the model more generalized and compatible with other wireless networks. In [23], authors propose a spectrum sharing method for a MTC network in LTE with large number of nodes where simultaneous transmissions are possible. In this model, dynamic spectrum access is possible for a dense network with low data rates. The advantage of this model is that there is no need for signaling procedures that are going to need channel reservation. Moreover, in [24], authors introduce interesting new schemes which make implementing cognitive radio and spectrum sharing methods in smart gird applications easier. They also study a number of routing protocols and interference mitigation schemes related to smart grids. A valuable study has been done in [25] regarding the resource allocation in different spectrum sharing networks such as SINR-based, transmission power-based, and centralized and distributed methods of decision making. In [26], Liu et al. propose a novel multichannel IoT scheme for dynamic spectrum sharing in 5G networks. In their work, an IoT node is able to do two different types of communications at the same time, both 5G and IoT communications. This is done by allocating different sub-channels for these two communication modes.

All the above mentioned works have done great works with regards to addressing spectrum sharing in IoT and machine type communications; however, they do not aim at optimizing the performance of the system while having different reliability constraints, which is one of the main pillars of future 5G. In this paper, we expand one of the scenarios in our previously published work [27] and follow the same model as in[18][20][28] to prove that the approximation used in those papers for the average number of retransmission attempts is in fact a tight approximation. We show why it is worth to use limited number of retransmission, and optimize the throughput as a function of the SIR threshold and number of retransmissions. Moreover, we also study the energy efficiency of the proposed model in this paper. Energy efficiency is one of the most important issues that needs to be considered in wireless networks, specifically in ultra dense networks [29]. As was previously mentioned, mMTC networks are designed to support massive connectivity between billions of sensors and IoT devices with minimum human interactions [5], most of which are low powered. Most of theses devices are battery supplied, and hence, they have a limited energy supply (wireless sensor networks for instance). It also happens often that these mMTC networks are deployed in critical or hard to access locations, which makes changing the batteries and renewing the energy resources very difficult [30][31][32]. All these reinforce the importance of the energy efficiency in mMTC in general.

Valuable works have been done in the field of energy efficiency. In [33], authors study different challenges and metrics with regards to reducing the total power consumption of the network while in [34][35], maximizing the energy efficiency by optimizing the packet size and constrained by an outage threshold in non-cooperative and cooperative wireless networks is studied respectively. In [36], a new scheduling algorithm based on frame aggregation is proposed in order to achieve energy efficiency in IEEE 802.11n wireless networks. In terms of the physical properties of the battery equipped machine type devices, two interesting medium access control protocol and power scheduling schemes are proposed in [37][38] in order ro preserve battery life. Moreover in [39], Takeshi Kitahara et al. introduce a data transmission control method based on the well-known electrochemical characteristics of batteries, which makes increasing the discharge capacity possible.

While the above mentioned works are interesting and valuable, none of them really addresses the massive connectivity issue and how the energy efficiency needs to be handled in a mMTC network. In [40], the authors investigate access control algorithms for machine type nodes, which can reduce the energy consumption in the uplink channel. There, the machine type nodes access to the base station is maximized by means of grouping and coordinator selection. However, in this paper, we evaluate the energy efficiency of an unlicensed mMTC network and optimize the energy efficiency constrained by an outage threshold and maximum number of retransmissions. We also show the effect of different network parameters such as network density and the SIR threshold on the behavior of the energy efficiency.

References

1. Cerwall, P.; Jonsson, P.; Möller, R.; Bävertoft, S.; Carson, S.; Godor, I. Ericsson mobility report. On the Pulse of the Networked Society. Hg. v. Ericsson. Available online: https://edna.iea-

4e.org/files/otherfiles/0000/0438/11_-_Ericsson_Mobility_Report_-_Patrik_Cerwall.pdf (accessed on 21 April 2020).

2. Manyika, J.; Chui, M.; Bisson, P.; Woetzel, J.; Dobbs, R.; Bughin, J.; Aharon, D. Unlocking the Potential of the Internet of Things; McKinsey Global Institute: Washington, DC, USA, 2015. [Google Scholar]
3. Perera, C.; Liu, C.H.; Jayawardena, S.; Chen, M. A survey on internet of things from industrial market perspective. IEEE Access 2014, 2, 1660–1679. [Google Scholar] [CrossRef]
4. Ali, A.; Hamouda, W.; Uysal, M. Next generation m2m cellular networks: Challenges and practical considerations. IEEE Commun. Mag. 2015, 53, 18–24. [Google Scholar] [CrossRef]
5. Popovski, P.; Trillingsgaard, K.F.; Simeone, O.; Durisi, G. 5g wireless network slicing for embb, urllc, and mmtc: A communication-theoretic view. IEEE Access 2018, 6, 55765–55779. [Google Scholar] [CrossRef]
6. Dawy, Z.; Saad, W.; Ghosh, A.; Andrews, J.G.; Yaacoub, E. Toward massive machine type cellular communications. IEEE Wirel. Commun. 2017, 24, 120–128. [Google Scholar] [CrossRef]
7. Bockelmann, C.; Pratas, N.; Nikopour, H.; Au, K.; Svensson, T.; Stefanovic, C.; Popovski, P.; Dekorsy, A. Massive machine-type communications in 5g: Physical and mac-layer solutions. IEEE Commun. Mag. 2016, 54, 59–65. [Google Scholar] [CrossRef]
8. Nielsen, J.J.; Madueño, G.C.; Pratas, N.K.; Sørensen, R.B.; Stefanovic, C.; Popovski, P. What can wireless cellular technologies do about the upcoming smart metering traffic? IEEE Commun. Mag. 2015, 53, 41–47. [Google Scholar] [CrossRef]
9. Niyato, D.; Lu, X.; Wang, P. Machine-to-machine communications for home energy management system in smart grid. IEEE Commun. Mag. 2011, 49, 53–59. [Google Scholar] [CrossRef]
10. Durisi, G.; Koch, T.; Popovski, P. Toward massive, ultrareliable, and low-latency wireless communication with short packets. Proc. IEEE 2016, 104, 1711–1726. [Google Scholar] [CrossRef]
11. Hovila, P.; Syväluoma, P.; Kokkoniemi-Tarkkanen, H.; Horsmanheimo, S.; Borenius, S.; Li, Z.; Uusitalo, M. 5g networks enabling new smart grid protection solutions. In Proceedings of the CIRED 2019, Madrid, Spain, 3–6 June 2019. [Google Scholar]
12. Sharma, S.K.; Wang, X. Towards massive machine type communications in ultra-dense cellular IoT networks: Current issues and machine learning-assisted solutions. IEEE Commun. Surv. Tutor. 2019, 22, 426–471. [Google Scholar] [CrossRef]
13. Haykin, S. Cognitive radio: Brain-empowered wireless communications. IEEE J. Sel. Areas Commun. 2005, 23, 201–220. [Google Scholar] [CrossRef]

14. Akyildiz, I.F.; Lee, W.-Y.; Vuran, M.C.; Mohanty, S. Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey. Comput. Netw. 2006, 50, 2127–2159. [Google Scholar] [CrossRef]
15. Cormio, C.; Chowdhury, K.R. A survey on mac protocols for cognitive radio networks. Ad Hoc Netw. 2009, 7, 1315–1329. [Google Scholar] [CrossRef]
16. Darsena, D.; Gelli, G.; Verde, F. An opportunistic spectrum access scheme for multicarrier cognitive sensor networks. IEEE Sens. J. 2017, 17, 2596–2606. [Google Scholar] [CrossRef]
17. Madue no, G.C.; Nielsen, J.J.; Kim, D.M.; Pratas, N.K.; Stefanović, Č.; Popovski, P. Assessment of lte wireless access for monitoring of energy distribution in the smart grid. IEEE J. Sel. Areas Commun. 2016, 34, 675–688. [Google Scholar] [CrossRef]
18. Nardelli, P.H.; de Castro Tomé, M.; Alves, H.; de Lima, C.H.; Latva-aho, M. Maximizing the link throughput between smart meters and aggregators as secondary users under power and outage constraints. Ad Hoc Netw. 2016, 41, 57–68. [Google Scholar] [CrossRef]
19. Tomé, M.C.; Nardelli, P.H.; Alves, H.; Latva-aho, M. Joint sampling-communication strategies for smart-meters to aggregator link as secondary users. In Proceedings of the 2016 IEEE International Energy Conference (ENERGYCON), Leuven, Belgium, 4–8 April 2016; pp. 1–6. [Google Scholar]
20. Ramezanipour, I.; Nardelli, P.H.; Alves, H.; Pouttu, A. Increasing the throughput of an unlicensed wireless network through retransmissions. In Proceedings of the 2018 IEEE 87th Vehicular Technology Conference (VTC Spring), Porto, Portugal, 3–6 June 2018; pp. 1–5. [Google Scholar]
21. Nardelli, P.H.; Kaynia, M.; Cardieri, P.; Latva-aho, M. Optimal transmission capacity of ad hoc networks with packet retransmissions. IEEE Trans. Wirel. Commun. 2012, 11, 2760–2766. [Google Scholar] [CrossRef]
22. Nardelli, P.H.; Kountouris, M.; Cardieri, P.; Latva-Aho, M. Throughput optimization in wireless networks under stability and packet loss constraints. IEEE Tran. Mob. Comput. 2014, 13, 1883–1895. [Google Scholar] [CrossRef]
23. Beyene, Y.; Malm, N.; Kerttula, J.; Zhou, L.; Ruttik, K.; Jäntti, R.; Tirkkonen, O.; Bockelmann, C. Spectrum sharing for MTC devices in LTE. In Proceedings of the 2015 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), Stockholm, Sweden, 29 September–2 October 2015; pp. 269–270. [Google Scholar]
24. Khan, A.A.; Rehmani, M.H.; Reisslein, M. Cognitive radio for smart grids: Survey of architectures, spectrum sensing mechanisms, and networking protocols. IEEE Commun. Surv. Tutor. 2015, 18, 860–898. [Google Scholar] [CrossRef]
25. Tsiropoulos, G.I.; Dobre, O.A.; Ahmed, M.H.; Baddour, K.E. Radio resource allocation techniques for efficient spectrum access in cognitive radio networks. IEEE Commun. Surv. Tutor. 2014, 18,

824–847. [Google Scholar] [CrossRef]

26. Liu, X.; Jia, M.; Zhang, X.; Lu, W. A novel multichannel Internet of things based on dynamic spectrum sharing in 5G communication. IEEE Internet Things J. 2018, 6, 5962–5970. [Google Scholar] [CrossRef]
27. Ramezanipour, I.; Nouri, P.; Alves, H.; Nardelli, P.H.; Souza, R.D.; Pouttu, A. Finite blocklength communications in smart grids for dynamic spectrum access and locally licensed scenarios. IEEE Sens. J. 2018, 18, 5610–5621. [Google Scholar] [CrossRef]
28. Ramezanipour, I.; Nardelli, P.H.; Alves, H.; Pouttu, A. Energy efficiency of an unlicensed wireless network in the presence of retransmissions. In Proceedings of the 2018 IEEE 87th Vehicular Technology Conference (VTC Spring), Porto, Portugal, 3–6 June 2018. [Google Scholar]
29. Osseiran, A.; Boccardi, F.; Braun, V.; Kusume, K.; Marsch, P.; Maternia, M.; Queseth, O.; Schellmann, M.; Schotten, H.; Taoka, H.; et al. Scenarios for 5g mobile and wireless communications: The vision of the metis project. IEEE Commun. Mag. 2014, 52, 26–35. [Google Scholar] [CrossRef]
30. Akyildiz, I.F.; Su, W.; Sankarasubramaniam, Y.; Cayirci, E. Wireless sensor networks: A survey. Comput. Netw. 2002, 38, 393–422. [Google Scholar] [CrossRef]
31. De Oliveira Brante, G.G.; Kakitani, M.T.; Souza, R.D. Energy efficiency analysis of some cooperative and non-cooperative transmission schemes in wireless sensor networks. IEEE Trans. Commun. 2011, 59, 2671–2677. [Google Scholar] [CrossRef]
32. Vardhan, S.; Wilczynski, M.; Portie, G.; Kaiser, W.J. Wireless integrated network sensors (wins): Distributed in situ sensing for mission and flight systems. In Proceedings of the Aerospace Conference Proceedings, 2000 IEEE, Big Sky, MT, USA, 25 March 2000; Volume 7, pp. 459–463. [Google Scholar]
33. Hasan, Z.; Boostanimehr, H.; Bhargava, V.K. Green cellular networks: A survey, some research issues and challenges. IEEE Commun. Surv. Tutor. 2011, 13, 524–540. [Google Scholar] [CrossRef]
34. Wang, S.; Nie, J. Energy efficiency optimization of cooperative communication in wireless sensor networks. EURASIP J. Wirel. Commun. Netw. 2010, 2010, 1–8. [Google Scholar] [CrossRef]
35. Sadek, A.K.; Yu, W.; Liu, K. On the energy efficiency of cooperative communications in wireless sensor networks. ACM Trans. Sens. Netw. (TOSN) 2009, 6, 5. [Google Scholar] [CrossRef]
36. Zhihui, G.; Anzhong, L.; Taoshen, L. Eefa: Energy efciency frame aggregation scheduling algorithm for ieee 802.11 n wireless network. China Commun. 2014, 11, 19–26. [Google Scholar] [CrossRef]

37. Ma, C.; Yang, Y. A battery aware scheme for energy efficient coverage and routing in wireless mesh networks. In Proceedings of the GLOBECOM'07 2007 Global Telecommunications Conference, Washington, DC, USA, 26–30 November 2007; pp. 1113–1117. [Google Scholar]

38. Jayashree, S.; Manoj, B.; Murthy, C.S.R. A battery aware medium access control (bamac) protocol for ad hoc wireless networks. In Proceedings of the 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2004, Barcelona, Spain, 5–8 September 2004; Volume 2, pp. 995–999. [Google Scholar]

39. Kitahara, T.; Nakamura, H. A data transmission control to maximize discharge capacity of battery. In Proceedings of the 2008 Wireless Communications and Networking Conference, WCNC 2008, Las Vegas, NV, USA, 31 March–3 April 2008; pp. 2951–2956. [Google Scholar]

40. Tu, C.-Y.; Ho, C.-Y.; Huang, C.-Y. Energy-efficient algorithms and evaluations for massive access management in cellular based machine to machine communications. In Proceedings of the 2011 IEEE Vehicular Technology Conference (VTC Fall), San Francisco, CA, USA, 5–8 September 2011; pp. 1–5.