The Impact of Spectrum Sharing Strategies on the E2E Performance of Machine Type Communication

M. V. M. Bassi, C. H. M. de Lima and A. A. Ferreira

Abstract— **This paper addresses spectrum sensing and sharing strategies for machine type communication in the cognitive networks. We assess how such solutions preserve the transmissions of the primary nodes, as well as their impact on the performance of the underlay secondary network. The system-level performance is evaluated by means of computer simulations using the Monte Carlo approach. Our results show that primary nodes significantly benefit from the proposed spectrum sharing strategies, whereas the secondary devices may be severely compromised depending on their relative disposition relative to nodes higher priority. Moreover, there exist an inherent trade off between the quality of service experienced by the primary user and the overall spectrum efficiency in terms of the number simultaneous transmission in the underlay secondary network.**

Keywords— **MTC, IEEE** 802.11**, cognitive radio, self-organization, spectrum sensing.**

I. Introduction

In the upcoming 5G networks, Machine Type Communication (MTC) are expected to have a determinant role to bring about the concept of a networked society with a multitude of new services and applications [1], [2]. The deployment scenarios are characterized by highly dense wireless and heterogeneous networks along with interactive devices [3]–[6]. In fact, anyone and anything is always connected and experience unlimited access to information at anytime and anywhere. Although, this concept opens up opportunities to create new business models, as well as develop new approaches to address fundamental problems such as urbanization, safety, poverty, education, healthy care, climate change and sustainable use of resources [7], it certainly leads to daunting technical challenges.

Over the past few years, the ever-increasing demand for high data rates and ubiquitous coverage, as well as the introduction of pervasive devices with high computational power have leveraged a significant paradigm shift in wireless communications regarding their design, deployment and operation. The traditional centralized and homogeneous structure of cellular systems has gradually changed to a more dynamic, heterogeneous and infrastructureless configuration in which legacy cellular systems and large scale deployments of low-power short-range access points coexist in an distributed manner [8], [9]. In these highly dense and dynamic deployments, even simple administrative tasks become expensive or impractical so that new operational methods that automate decisions and minimize the need for human intervention are of primary interest [10]. As a result of this movement, not only the deployment and operation of upcoming networks need to change, but also previously established and widely accepted methods to evaluate how these systems perform have to be updated accordingly [9], [11].

In this context, the available frequency spectrum became a scarce radio resource due to increased data access demand, high transmission rate and strict quality of service requirements. Unfortunately, legacy spectrum utilization schemes are static and underuse the available spectrum, because they neglect the temporal and spacial diversity which are intrinsic to wireless communication systems. This limitation motivated the development of dynamic spectrum allocation schemes which exploit idle frequency groups on the space and time domains [12].

Herein, opportunistic access to idle frequencies of the licensed spectrum are studied so as to improve the utilization of the radio resources and increase the capacity of the systems under study. In this regard, it is worth mentioning that opportunistic accesses are implemented preserving the ongoing operation of the licensed communications. From [13], [14], dynamic spectrum sensing is identified as a promising alternative whereby secondary users (with lower priority) transmit only if the licensed band is available, *i.e.* no primary user with higher priority is detected. This technique is particularly interesting due to its low implementation cost and backward compatibility with legacy systems (Long Term Evolution (LTE) advanced cellular networks). In fact, being able to identify available frequency bands, reliably and autonomously, is a enabling feature of self-organizing networks under study [15], [16].

The remainder of this paper is organized as follows. Section II describes the communication, the network deployment models used to carry out the computer simulations and the multihop routing protocol. The proposed strategies for the spectrum sensing are introduced in Section III. We present the numerical results in Section IV, and evaluate the overall system performance by means of the SIR experienced by the primary and secondary users. Finally, we provide final observations and draw conclusions in Section V.

II. System Model

The spectrum sensing and sharing strategies were initially developed along with a single hop experimental testbed based on proprietary spectrum analyzer firmware. Using that initial framework, it is shown that underused frequency bands can be effectively exploited on a time basis [17]. Equally important, the aforesaid strategies were evaluated in a large-scale deployment throughout a system-level simulator (implemented from

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scratch) using the Monte Carlo approach. Then, the Signal-to-Interference Ratio (SIR) performance of both primary and secondary devices were assessed in multihop deployment scenarios. Here, we extend those results by investigating how the performance of the secondary network is affected by the primary user.

The propagation and network deployment models is initially presented, and thereafter we detail our which are used to run our computer simulations.

A. Propagation and Network Deployment Model

A system-level simulator is used to evaluate the impact of the aforesaid spectrum sensing and sharing strategies on the overall network performance (regarding both primary and secondary devices). Primary and secondary devices share the whole spectrum and are randomly scattered over the network deployment area following a Poisson distribution. Nodes communicate using antennas with omni directional radiation pattern and fixed power. The primary and secondary nodes transmit at a maximum power level of $24\,\mathrm{dBm}$ (maximal output from a UMTS/3G mobile phone). Radio links are affected by path-loss attenuation and large-scale shadowing which are assumed to be mutually independent and multiplicative phenomena [18].

The received power at the node of interest r_0 (tagged with index 0) from an arbitrary transmitter t_i located d_{i0} meters away is

$$Y_{i0} = p_{i0}\; d_{i0}^{-\alpha} x_{i0}, \tag{1}$$

where p_{i0} yields the transmit power of the ith node, α is the path-loss exponent and x_{i0} represents the Log-Normal (LN) shadowing.

The network deployment model is given by a spatial Poisson Point Processes (PPPs) Φ^{PRI} (Φ^{SEC}), whose random points φ represent the locations of primary (secondary) nodes. The large-scale fading is associated as random marks to each point of the above processes [19] and is assumed to be independent over distinct communicating nodes and positions. From the Marking theorem [20], the resulting processes constitute Marked Point Processes (MPPs) on the product space $\mathbb{R}^2 \times \mathbb{R}^+$, whose random points φ^{PRI} (φ^{SEC}) denote the locations of primary (secondary) transceivers, namely

$$\widetilde{\Phi}^{\mathsf{PRI}} = \left\{ (\varphi, x)\, ; \varphi \in \Phi^{\mathsf{PRI}} \right\}. \tag{2}$$

Note that $\widetilde{\Phi}^{\mathsf{PRI}}$ and $\widetilde{\Phi}^{\mathsf{SEC}}$ are independent spatial PPPs.

Considering an arbitrary tagged receiver (either primary or secondary), the corresponding power is given by

$$Z_0 = \sum_{(\varphi_j, x_j) \in \widetilde{\Phi}^{\mathsf{PRI}}} Y_{j0} + \sum_{(\varphi_k, x_k) \in \widetilde{\Phi}^{\mathsf{SEC}}} Y_{k0}, \tag{3}$$

Then, the corresponding SIR is,

$$\mathsf{SIR} = \frac{Y_{i0}}{Z_0}. \tag{4}$$

where Y_{i0} yields the received power at the receiver of interest and the denominator is the aggregate interference caused by co-channel primary and secondary transceivers and depends on the strategy employed to share the spectrum (as described in section III).

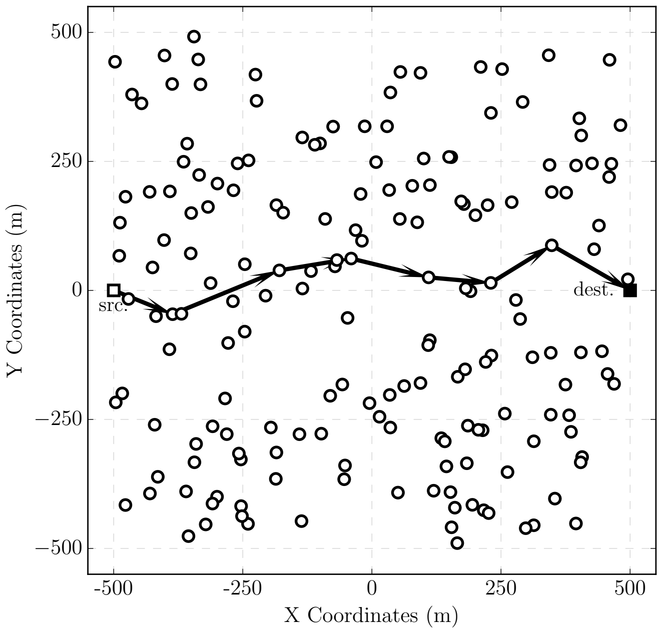

Fig. 1. Multihop link between source and sink nodes in the reference deployment scenario.

B. Multihop Routing

In the secondary network, nodes communicate over multi-hop links in which intermediary relays are selected based on a dynamic selection procedure as established in [21]. Secondary nodes communicate with each other using a contention-based channel-access method (random-access protocol) through Request to Send (RTS)/Clear To Send (CTS) handshake so as to enable frequency sensing in Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The source initiates the relay selection transactions by issuing a RTS packet. Neighboring nodes that listen to the source's request split themselves randomly and independently based on a common probability that dictates the likelihood of accessing the shared medium. If the CTS packets of eligible relays collide, nodes that have transmitted in the previous slot decide to retransmit or to refrain based on the Standard Tree Algorithm (STA). The source node selects the next relay greedily from all the candidate relays within range – a node can only be selected as the next hop relay if the experienced SIR satisfies its requirements. Fig. 1 illustrates a multihop link for the reference scenario (with no primary user), in which circles represent potential relays, arrows identify each hop on the way to the final destination, while source and destination are represented by hollowed and filled squares, respectively.

III. Spectrum Sharing Strategies

Secondary devices share the primary user spectrum throughout two strategies: (i) Change to Another Carrier (CAC); and (ii) Incremental Power Control (IPC). With the former, after detecting the primary user, secondary devices change to another carrier. Thereby, secondary nodes inside the primary detection region do not contribute to the aggregate interference. By using the latter, secondary users inside the primary

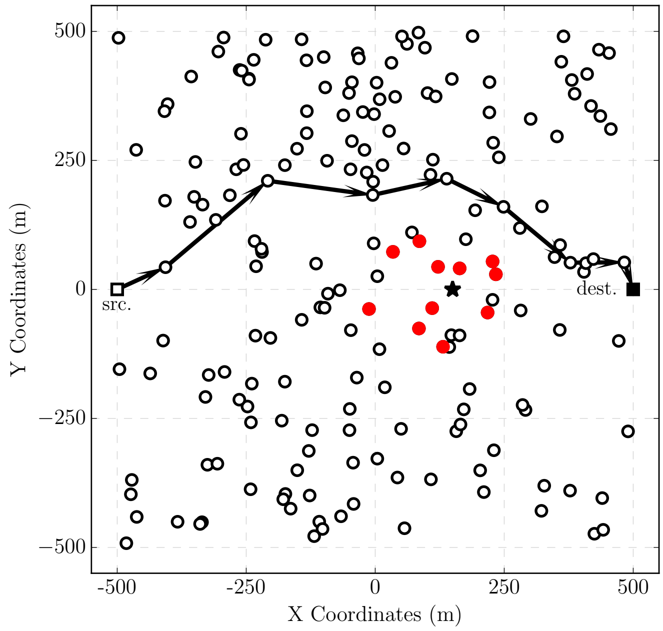

Fig. 2. Multihop link between source and sink nodes in the CAC deployment scenario.

detection region continue to transmit on the same carrier, though at lower power level. We use a discrete power control, based on the experimental testbed results, that decreases the transmission power by fixed steps of 6dB [17]. It is worth noting that by using the CAC strategy, the potential next hop relays consist of secondary devices that do not detect the primary user in their surroundings; on the other hand, all the secondary users operating with IPC are entitled to become intermediate relays, even though they forward the message at lower power levels, contributing to the aggregate interference.

IV. Performance Evaluation

In this section, we evaluate how the spectrum sensing and sharing strategies impact on the communication of the secondary cognitive network in terms of the multihop link length (number of hops) and the probability of successful end-to-end data transmission (between source and sink devices). To do that, various investigation scenarios are initially built by considering distinct propagation conditions and network configurations and then evaluated using a system-level computer simulator – we use the Monte Carlo approach to collect samples over 50000 snapshots for each scenario. The main configuration parameters are summarized in the Table I.

TABLE I

Parameters	Value
Path loss exponent, α	3
LN shadowing standard deviation, σ	4 dB
Transmission power	24 dBm
PC step	-6 dB

In addition, the secondary source and sink nodes are positioned at the opposite ends of the network deployment area, namely, points $(-500, 0)$ and $(500, 0)$, respectively. The primary transmitter is positioned at the location $(150, 0)$ to compromise the establishment of the shortest routes towards the final destination (see Fig. 2). The received power detection threshold P_{th} (considering that an idealized energy detection was used for spectrum sensing at the moment) is set equal to -40 dBm, whereby secondary nodes detect the presence of the primary user in their vicinity.

A. Numerical Results

Figs. 3 and 4 present the resulting SIR experienced by the primary and secondary users, respectively, with the aforesaid spectrum sensing and sharing strategies, namely CAC and IPC. As it can be seen, from Fig. 3, at the 5th percentile (horizontal dashed line), we observe a gain about 10dB for the CAC strategy, whereas the IPC provides 8dB only when compared to the reference deployment scenario. We can also see, from Fig. 4, a loss of approximately 0.7dB for the CAC strategy, whereas the IPC provides 1.6dB when compared to the reference scenario.

Note that interfering devices in the secondary network behave differently depending on the spectrum sharing strategy: with CAC, they change carrier after detecting the primary user, while secondary users with IPC continue to interfere with the primary transmission though at much lower power (PC step of 6dB). With respect to the primary user, the CAC is more beneficial and outperforms the IPC strategy in terms of the experienced SIR in the scenarios under study. In fact, the interference from the underlay secondary network is significantly reduced by silencing nodes within the exclusion region. On the other hand, the CAC strategy increases the number of hops needed to reach the final destination throughout the multi-hop connections in secondary network. In that regard, the IPC strategy becomes more beneficial to the secondary devices. Therefore, there is a trade off between the quality of service experienced by the primary user and the number of simultaneous trey missions in the secondary network. In other words, IPC allows for greater number of simultaneous transmission at expense of higher interference at the primary node and the secondary users remain on the same carrier.

For the spectrum sharing strategies, Figs. 5 and 6 show the frequency histogram of the multihop links established by the underlaid (lower priority) secondary devices. In the latter, we consider the SIR experienced by secondary users to choose the next relay. In this configuration, the IPC typically outperforms CAC strategy in number of needed intermediary hops to reach the final destination, since secondary users inside the detection region may still be selected as relays though at lower transmission power level (step of -6dB). The IPC requires fewer hops to establish multihop links between source and destination and its End-to-End (E2E) packet delivery rate is nearly 43% and 40.06% considering the SIR. For the same network deployment, the CAC requires more hops (much longer routes in order to circumvent the primary exclusion region as can be seen from Fig. 2) with lower E2E delivery rate of approximately 33% and 1.45% considering the SIR. In the latter, we observe that primary user's position is harmful to the choice of a potential relay. Succinctly, from Figs. 3 and 5, Figs. 4 and 6 there is a trade off between IPC and CAC strategies

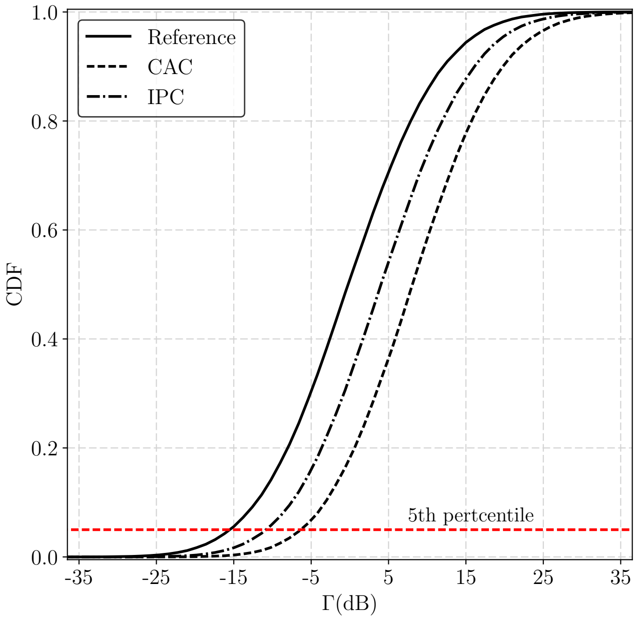

Fig. 3. SIR at the primary user for the spectrum sharing strategies.

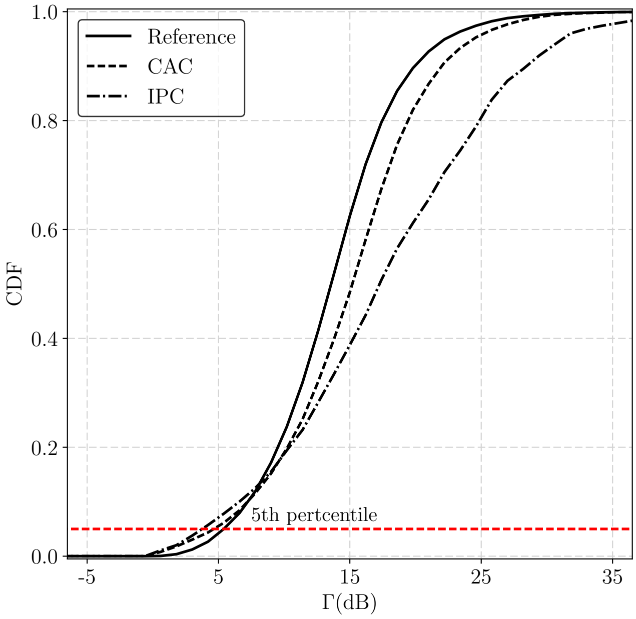

Fig. 4. SIR at the secondary user for the spectrum sharing strategies.

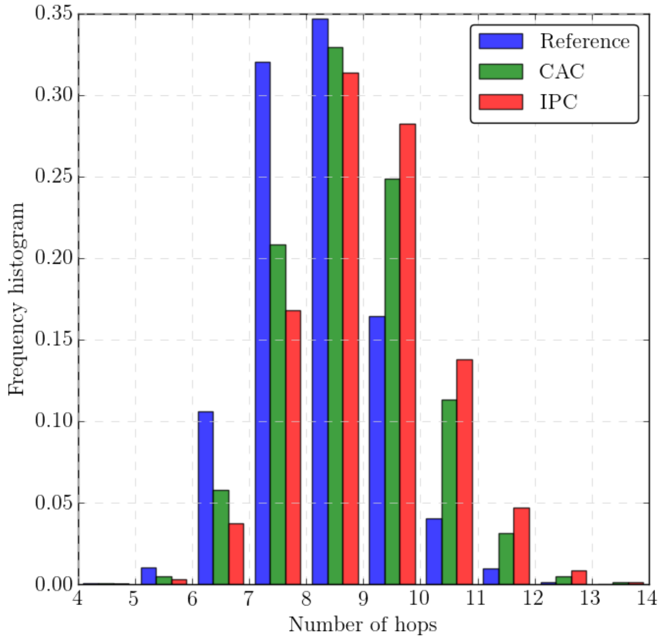

Fig. 5. Frequency histogram of the multihop links between source and sink.

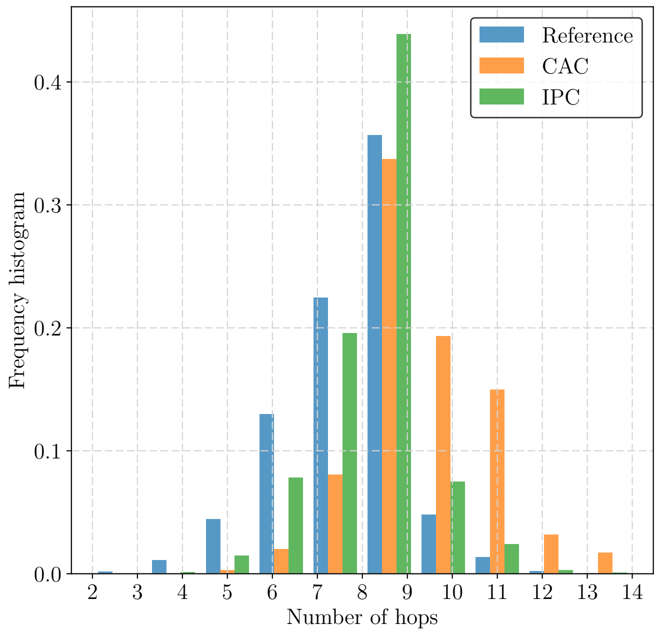

Fig. 6. Frequency histogram of the multihop links between source and sink, considering the SIR experienced by secondary users.

when compared to the reference deployment scenario: since secondary users do not change to another carrier with the former, a much higher number of simultaneous transmissions is achieved; however, the multihop links are longer with the latter. And, from Figs. 3 and 6, to the primary network the CAC strategy is more beneficial, but at the secondary network, this strategy harms the quality of service, because there are almost any E2E delivery rate.

V. Conclusions and Perspectives

In this work, we studied the impact of spectrum sensing and sharing strategies on the performance of the underlay primary and secondary networks with machine type communication. Regarding this cognitive radio setup, two spectrum sharing strategies are developed using our experimental testbed, *i.e.* Change to Another Carrier (CAC) and Incremental Power Control (IPC), and then evaluated by means of a system-level simulator. We observed that the primary user proximity is detrimental to secondary users, as evidenced by the lower end-to-end packet delivery rate between source and sink, as well as longer multihop links (length given in number hops) compromising the communication and quality of service. Indeed, there is a trade off between IPC and CAC strategies when compared to the reference scenario: while the former allows for higher number of simultaneous transmissions in the underlay network (secondary users do not change to another carrier), the latter generates less interference towards the primary user but typically requires much longer routes because secondary users need to avoid the primary exclusion region.

As perspectives, we intend to enhance our simulator by implementing energy detection for spectrum sensing and more elaborated radio channel models (for example, Nakagami – m).

REFERENCES

[1] "The Metis2020 project – laying the foundation of 5G," www.metis2020.com, acessado: 2015, Outubro 19.

[2] "Mobile and wireless communications enablers for twenty-twenty (2020) information society," metis-ii.5g-ppp.eu, acessado: 2015, Outubro 19.

[3] Ericsson, "The networked society is here," accessado: 2015, Novembro 02.

[4] J. vanDijk, *The Network Society*, 3rd ed. SAGE Publications, 2012.

[5] M. Castells, *The Rise of the Network Society – The Information Age: Economy, Society, and Culture*, 2nd ed. Wiley–Blackwell, 2009.

[6] N. Luhmann, *Social Systems*. Stanford University Press, 1996.

[7] E. Commission, "Horizon 2020: the framework programme for research and innovation – impact assessment report," ec.europa.eu/programmes/horizon2020/en/official-documents, accessado: 2015, Novembro 02.

[8] J. Akhtman and L. Hanzo, "Heterogeneous networking: an enabling paradigm for ubiquitous wireless communications," *Proceedings of the IEEE*, vol. 98, no. 2, pp. 135–138, Feb. 2010.

[9] A. Ghosh, N. Mangalvedhe, R. Ratasuk, B. Mondal, M. Cudak, E. Visotsky, T. Thomas, J. Andrews, P. Xia, H. Jo, H. Dhillon, and T. Novlan, "Heterogeneous cellular networks: from theory to practice," *IEEE Commun. Mag.*, vol. 50, no. 6, pp. 54–64, Jun. 2012.

[10] C. Prehofer and C. Bettstetter, "Self-organization in communication networks: principles and design paradigms," *IEEE Commun. Mag.*, vol. 43, no. 7, pp. 78–85, Jul. 2005.

[11] S. Mukherjee, "Distribution of downlink SINR in heterogeneous cellular networks," *IEEE J. Sel. Areas Commun.*, vol. 30, no. 3, pp. 575–585, Apr. 2012.

[12] S. Geirhofer, L. Tong, and B. Sadler, "Dynamic spectrum access in the time domain: Modeling and exploiting white space," *IEEE Commun. Mag.*, vol. 45, no. 5, pp. 66 – 72, May 2007.

[13] A. Ghasemi and E. Sousa, "Spectrum sensing in cognitive radio networks: requirements, challenges and design trade-offs," *Communications Magazine, IEEE*, vol. 46, no. 4, pp. 32–39, April 2008.

[14] T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," *Communications Surveys Tutorials, IEEE*, vol. 11, no. 1, pp. 116–130, First 2009.

[15] O. Aliu, A. Imran, M. Imran, and B. Evans, "A survey of self organisation in future cellular networks," *IEEE Commun. Surveys Tuts.*, 2012, IEEE early access articles.

[16] "Heterogeneous networks in LTE," www.3gpp.org/technologies/keywords-acronyms/1576- hetnet, accessed: 2015, Janeiro 07.

[17] M. V. M. Bassi, A. T. Jr, A. A. Ferreira, and C. H. M. de Lima, "Spectrum sharing strategies for machine type communication in cognitive networks," in *XXXIII Simposio Brasileiro de Telecomunicacoes*, Juiz de Fora, MG, Sep, 1–4 2015.

[18] J. Ilow and D. Hatzinakos, "Analytic alpha-stable noise modeling in a poisson field of interferers or scatterers," *IEEE Trans. Signal Process.*, vol. 46, no. 6, pp. 1601–1611, Jun. 1998.

[19] A. Ghasemi and E. S. Sousa, "Interference aggregation in spectrum-sensing cognitive wireless networks," *IEEE J. Sel. Areas Commun.*, vol. 2, no. 1, pp. 41–56, Feb. 2008.

[20] J. F. C. Kingman, *Poisson Processes*. Oxford Univ. Press, 1993.

[21] C. H. M. de Lima and G. T. F. de Abreu, "Analysis of contention-based relay selection mechanisms in autonomous multi-hop networks," in *IEEE Information Theory Workshop on Networking and Information Theory*, Volos, Greece, Jun. 2009.