Faculty Exchange Program – Final Report

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The research efforts during the time I stayed in the Department of Engineering and Public Policies from Carnegie Mellon University, CMU (from May until August 2016) focused on carrier aggregation for heterogeneous 4G and beyond networks with small cells, resource usage in WPANs, topics of spectrum sharing and the analytical formulation for resource reuse in small cell scenarios, as well as ongoing publishing activities on different related topics. The most remarkable characteristic of my stay were the very lively discussions and the interaction with CMU researchers and Ph.D. students, mainly from Prof. Jon Peha group.

In particular, the four month collaborations lead to very fruitful discussions of individual and joint research, participation in the Departmental Seminars, presentation of my own work for a broader audience in the Department, as well as the establishment of some links between the CMU team and European colleagues.

Research on spectrum sharing focused a scenario where there are two or more mobile operators each of which operates a macro cellular network in dedicated spectrum. Carrier aggregation between two frequency bands is considered between a macro cellular layer and a small cell layer from a HetNet. When spectrum sharing is considered, there is also spectrum that will be used for small cells, and this will be “shared” spectrum between two distinct operators. The research challenge is to understand what the benefits are of considering this shared spectrum, and with which novel sharing strategies. As the ITU-R propagation model for small cells is considered, a breakpoint distance is assumed in the path loss model, resulting in restrictions in the use of the shortest coverage distances, i.e., shorter than the break point distance, and advantage of considering distances larger than the breakpoint distance.

In the joint research work we first considered full cellular coverage where small cells from operator 1 are deployed whilst considering the influence one single/several cell alone from operator 2, in a given zone. Initially, different relative positions have been considered for cells from operators 2. Next phase includes to consider several cells from operator 2 and study their interference and underlying influence in the optimization of system capacity. As different cells sizes need to be considered for optimization purposes the range of values for the transmitter power are chosen considering a normalization procedure the guarantees that average carrier-to-noise-plus-interference ratio throughout the cell is kept constant for different cells sizes.

To understand how operators will manage carrier aggregation in the framework of shared spectrum, the design process may consider a database of actual location of network communications in a city. Frequencies will be assigned from among *n* frequency bands, using a frequency reuse algorithm. The placement of pico-cells considers location of hotspots. Given the geographical locations of the eNode B (eNB) in a given zone, by considering the mapping toolbox from Matlab®, the algorithm selects an eNB while assigning its frequency and transmitter power. Considering the neighbour eNBs the frequency to be assigned is chosen among the ones from the most distant eNBs, to avoid high co-channel interference. Given the frequency assignment from all base stations, e.g., that static assignment, we are evaluating the impact of interference into system capacity. Another option is to dynamically assign frequencies to eNBs. Assuming that time is divided into short periods, operator can reassign frequencies, transmitter power and encoding for each period.

After studying the basic limits by considering the developed algorithmic tools through an analytical approach, we will consider a packet level simulator, e.g., LTE-Sim (and its evolution to 5G), while studying the performance of HetNets without/with carrier aggregation in scenarios that may consider (or not) shared spectrum. Such evaluation will include to determine throughput, latency and packet error ratio not only as a function of the number of users but also as a function of the coverage distances for the cells. The output of the simulations will enable RRM and cost/revenue optimization.

My individual work also included co-authoring a book on Wearable Technologies and Wireless body sensor Networks for Healthcare, to be published by IET, as well as Research on Energy Efficient Spectrum Resources Usage in WPANs and their IEEE 802.15.4 MAC Sub-layer Protocols, including the co-authoring of a book in this field, to be published by River Publishers, and the submission of a journal paper (IEEE) on the performance enhancement of IEEE 802.15.4 by employing RTS/CTS with packet Concatenation, in the non-beacon mode, which explores the use of block acknowledgment as well.

Besides, ongoing research work addressed joint Radio Resource Management (RRM) for the efficient sharing of TV White Spaces with LTE with an underlying throughout literature review on frequency assignment algorithms. Additionally, an overview of carrier aggregation and multi-band scheduling algorithms is being submitted to an IEEE journal.

This summer collaboration was certainly a very productive stay and the opportunity to establish joint research by setting the ground for joint work between Prof. Jon Peha's team and my Portuguese team (including Ph.D. Students), plan future publications, develop new computational tools for spectrum management, and start the preparation of future joint project proposals. I am deeply grateful to the Portuguese Foundation for Science and Technology (FCT) and the leadership team of the Carnegie Mellon University Portugal programme for facilitating this opportunity of collaboration.

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