Wireless Small Cell Networks: Past, Present, Future

Abstract: Small cell networks (SCNs) are seen as a promising solution for boosting the capacity, coverage, and overall quality-of-service in wireless networks. In this tutorial, we provide a comprehensive overview on SCNs while highlighting key challenges, associated techniques, and future landscape. The tutorial starts by reviewing basic mathematical tools such as stochastic geometry required to better understand, model, and analyze SCNs. Then, we discuss latest developments on resource management techniques tailored to the unique features of next-generation SCNs. Beyond traditional concepts such as cell range expansion, cell association, and intercell and interference coordination (ICIC), we will introduce the novel paradigm of self-organizing, context-aware SCNs. In this respect, we show how ma- chine learning, game theory, and related techniques can be synergistically married while providing the network with the capability to: 1) exploit new information from the SCN, such as smartphone features, social ties, or mobility patterns and 2) proactively manage the SCN resources in a self-organizing manner. We conclude the tutorial by discussing the latest trends and future opportunities in small cell research such as SCN caching, cellular-WiFi integration, dual connectivity, network-assisted D2D, and related ideas that will pave the way to the much anticipated 5G wireless systems.

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Walid Saad received his B.E. degree in Computer and Communications Engineering from the Lebanese University in 2004, his M.E. in Computer and Communications Engineering from the American University of Beirut (AUB) in 2007, and his Ph.D degree from the University of Oslo in 2010. He is currently an Assistant Professor at the Bradley Electrical and Computer Engineering Department, Virginia Tech, where he leads the Network Science, Wireless, and Security (NetSciWiS) laboratory, as part of the Wireless@VT research group. Before joining VT, he was a faculty at the ECE Department of the University of Miami and, prior to that, he held several research positions at leading institutions such as Princeton University and the University of Illinois at Urbana-Champaign. His research interests include applications of game theory in wireless networks, small cell networks, cognitive radio, wireless security, network science, and smart grids. He has published over 90 international conference and journal articles in these areas. Dr. Saad is a recipient of three conference best paper awards as well as the NSF CAREER award in 2013 for his work on self-organizing small cell networks. He has led several tutorial presentations at flagship conferences. He has also chaired/co-chaired several workshops on HetNets, including the successful "SmallNets" Workshop series that has been regularly organized with *IEEE ICC*. Dr. Saad is on the editorial board of the *IEEE Transactions on Communications* and the *IEEE Communications Tutorials & Surveys*.

Mehdi Bennis received his M.Sc. degree in Electrical Engineering jointly from EPFL, Switzerland and Eurecom, France in 2002. From 2002-2004, he was a research engineer at IMRA-EUROPE investigating adaptive equalization algorithms for mobile digital TV. In 2004, he joined the Centre for Wireless Communications at the University of Oulu, Finland as a research scientist. In 2008, he was a visiting researcher at the Alcatel-Lucent chair on flexible radio, SUPELEC. He obtained his PhD in December 2009 on spectrum sharing for future mobile cellular systems. His main research interests are in radio resource management, heterogeneous networks, game theory, and machine learning in the context of broadband wireless communications. Dr. Bennis has published more than 90 research papers in international conferences, journals and book chapters. He co-chaired the 1st international workshop on small cell wireless networks (SmallNets) in conjunction with *IEEE ICC 2012*, 2nd workshop on cooperative heterogeneous networks (coHetNet) in conjunction with *IEEE ICCCN 2012*, 2nd/3rd/4th international workshops on small cell wireless networks (SmallNets) in conjunction with *IEEE ICC 2013-2014*. Recently, he gave tutorial presentations at *IEEE PIMRC 2012*, *IEEE GLOBECOM 2012*, *IEEE DySPAN 2014* and *IEEE WCNC 2014*.