Stefano Basagni

Statement of Research and Research Interests

I have always been very passionate about science and about how things work. One the reasons of this passion has to do with my conviction that science and engineering can contribute to make the world better. This passion was never satisfied by simply learning science, as my curiosity would bring me to ask questions for which there were still no answers. Becoming a researcher empowered me to contribute finding those answers. Particularly, pursuing degrees in computer science and engineering provided me with the technical tools to follow my passion for science, to contribute to progress science and engineering and especially to the advances that science and engineering can provide to the betterment of society.

In the following I will provide some research-oriented background on my academic career, summarize my past research contributions, and provide some perspectives on where my research is heading. A detailed list of my degrees, awards, and of all my publications with their impact can be found in my *Curriculum Vitae et Studiorum* (CV), available along with all my papers on my web page: http://www.ece.neu.edu/fac-ece/basagni/.

(References to current time are to July 2020.)

Background. I am an Associate Professor at Northeastern University (NU), in Boston, MA. I joined NU in January 2002 as a tenure track assistant professor and earned promotion to the rank of associate professor with tenure in July 2008. Since joining NU, I have been building my own research group that, in the years, has included several Ph.D. students, postdocs, and tens among M.S. and undergraduate students. Our research is supported by federal grants, mostly from the National Science Foundation, and by grants from MathWorks, Inc., the maker of MATLAB and Simulink. Key to my research standing is also the on-going collaboration with international colleagues, and primarily with professor Chiara Petrioli of "Sapienza," University of Rome, in Italy. Most of my summers in the past decade have been spent visiting professor Petrioli in Rome, working with the many Ph.D. students in her research group, as witnessed by the host of co-authored publications.

Broadly speaking, I am interested in *solving research challenges that will enable the next generations of mobile networks and wireless communications systems*. A common underlying methodological theme of my research concerns bridging theoretical and practical aspects of wireless systems research, which include devising new general methods and experimental evaluation in the field. My research also concerns a continuous effort to design and analyze networking algorithms from a holistic system perspective, with a cross-layer and cross-disciplinary approach. I have a strong interest in theory, including algorithmic design, complexity, modeling, and optimization of wireless networked and distributed systems. I am also actively working on experimental research and practical applications of terrestrial wireless (e.g., radio) sensor networks and of underwater wireless (e.g., acoustic and optical) networks, with emphasis on their seamless integration. The research groups I work with apply and develop state-of-the-art techniques from algorithmic theory, optimization, communication and signal processing to solve new exciting networking problems.

I have co-authored over 125 technical papers published in peer-reviewed international journals, conferences and as book chapters. According to the Google Scholar citation index, my *h-index* is 44. (The h-index of a researcher indicates the number *n* of her/his papers that have been cited at least *n* times. This index aims at providing an estimate of the importance, significance, and broad impact of the cumulative scientific outcomes of a researcher.) As reported by Google Scholar, the papers that I have co-authored have received over 11600 citations. Nineteen of my works have been cited over 100 times each. I am a member of the NSF-based *PAWR Project Office* (PPO), for which we garnered the NU COE Best Research Team award, with professors Chowdhury, Melodia, and Yeh. I am also a founding member of the *Institute for the Wireless Internet of Things* at Northeastern University. Finally, I am a *distinguished scientist* of the Association for Computing Machinery (ACM), a senior member of the Institute for Electrical and Electronics Engineers (IEEE), and a member of the Council on Undergraduate Research (CUR).

Past research contributions. The initial focus of my research concerned algorithmic solutions for what, at the time (mid to late nineties), was a new networking paradigm, namely, that of Mobile Ad hoc NETworks (MANETs) and for their offshoot, Wireless Sensor Networks (WSNs). On this form on networking I have built the dissertations of my two Ph.D.s and co-edited three books, which have been cited over a thousand times. A MANET is a self-organizing collection of mobile wireless nodes without any supporting infrastructure. Typical applications include emergency operations after a disaster that destroyed existing infrastructure, special operations in law-enforcement, and strategic missions in hostile and/or unknown territory. WSNs emerged from industry and leveraged MANET research. Among my seminal contributions to the field of MANETs research, four major ones are i) The first location-based routing protocol, ii) The first general formulation of the problem of clustering for ad hoc networks, iii) the first protocols for building multi-hop networks of Bluetooth devices ("scatternets"), and iv) fundamental contributions to the field of using the mobility of network elements for optimized performance. My works on these topics have been cited *thousands* of times and are considered highly influential. My papers "A distance routing effect algorithm for mobility, DREAM" (ACM MobiCom 1998) and "Distributed clustering for ad hoc networks" (I-SPAN 1999; single author) have been cited over 2100 and 1400 times each, respectively (Google Scholar). My contributions to Bluetooth scatternet formation total well over 1000 citations as well, and so have my papers on exploiting mobility.

i) Geographical routing for MANETS. Our protocol "DREAM" was the first to use node locations for data packet forwarding in all mobile, all wireless networks. Every node between the source of the packet and its destination, independently of its identity and of why it is there, forwards the packet in the direction of the destination. While directional routing was not a totally novel concept, the way DREAM applies it to MANETs and the way we propose to deal with location management are unique and original. This was a completely novel approach to routing, since previous solutions relied heavily on the specific identity of the nodes between the source and the destination. We applied this concept to several other network primitives, including broadcast and multicast. More recently, this same approach proved successful for routing in WSNs, for which we provided several solutions, many of which are implemented in networked systems for the Internet of Things (IoT).

Noteworthy publications:

- S. Basagni, I. Chlamtac, V. R. Syrotiuk, and B. A. Woodward. A distance routing effect algorithm for mobility (DREAM). In *Proceedings of ACM/IEEE MobiCom 1998*, pages 76-84, Dallas, TX, October 25-30 1998. *(Cited 2163 times.)*
- C. Petrioli, M. Nati, P. Casari, M. Zorzi, and S. Basagni. ALBA-R: Load-Balancing Geographic Routing Around Connectivity Holes in Wireless Sensor Networks. *IEEE Transactions on Parallel and Distributed Systems*, 24(3):529-539, March 2014. (*Cited 111 times.)*
- S. Basagni, I. Chlamtac, and V. R. Syrotiuk. Location aware, dependable multicast for mobile ad hoc networks. *Computer Networks*, 36(5-6):659-670, August 2001. (*Cited 94 times.)*

ii) Clustering for MANET and WSNs. *Clustering* is the process of partitioning the nodes of a MANET into groups, often with a group leader, called the *clusterhead*, and with some *ordinary nodes* affiliated with the clusterhead. The advantages of using clustering are multifold, ranging from enabling efficient operations in larger networks (*scalability*), easing resource management and tracking, to simplifying control and distributed operations. Two of my papers (of whom I am the single author) proposed a general clustering method for efficiently partitioning the network into groups and for maintaining the group structure in the face of node mobility. These papers created a great deal of interest for clustering in the MANET community, and my research on this topic has been cited thousands of times. I have continued to explore clustering, its properties and applications since those seminal works. Particularly, we have demonstrated its usefulness in providing scalable solutions for information dissemination in WSNs. Our research in this field prompted us to develop simulator extensions and testbeds that are widely used by many researchers.

Noteworthy publications:

- S. Basagni. Distributed clustering for ad hoc networks. In A. Y. Zomaya, D. F. Hsu, O. Ibarra, S. Origuchi, D. Nassimi, and M. Palis, editors, *Proceedings of I-SPAN 1999*, pages 310-315, Perth/Fremantle, Australia, June 23-25 1999. (*Cited 1443 times.)*
- S. Basagni. Distributed and mobility-adaptive clustering for multimedia support in multi-hop wireless networks. In *Proceedings of VTC 1999 Fall*, volume 2, pages 889-893, Amsterdam, The Netherlands, September 19-22 1999. (*Cited 346 times.)*
- S. Basagni, M. Mastrogiovanni, A. Panconesi, and C. Petrioli. Localized protocols for ad hoc clustering and backbone formation: A performance comparison. *IEEE Transactions on Parallel and Distributed Systems, Special Issue on Localized Communication and Topology Protocols for Ad Hoc Networks (S. Olariu, D. Simplot-Ryl, and I. Stojmenovic, editors)*, 2006. 17(4):292-306, April 2006. (*Cited 202 times.)*

iii) Bluetooth Networking. *Bluetooth* is a wireless technology initially intended for cable replacement. As of today, billions of Bluetooth devices have been sold, and every smart phone, headset, tablets, as well as many keyboards and mice can get connected wirelessly through Bluetooth. The Bluetooth specifications allow Bluetooth devices to form multi-hop networks (called *scatternets*), but no specific algorithm is indicated for this task. We proposed the *first* protocol, termed *BlueTrees*, for building scatternets. Our proposed method opened the area of scatternet formation algorithms (the “BlueTrees paper” has been cited *almost 500 times*). After

BlueTrees I have continued to explore scatternet formation problems with colleagues and students, publishing contribution in selective journals and conferences that also garnered hundreds of references.

Noteworthy publications:

- G. Záruba, S. Basagni, and I. Chlamtac. BlueTrees-Scatternet formation to enable Bluetooth-based personal area networks. In *Proceedings of the IEEE International Conference on Communications, ICC 2001*, volume 1, pages 273-277, Helsinki, Finland, June 11-14 2001. *(Cited 497 times.)*
- C. Petrioli, S. Basagni, and I. Chlamtac. Configuring BlueStars: Multihop scatternet formation for Bluetooth networks. *IEEE Transactions on Computers, Special Issue on Wireless Internet (Y.-B. Lin and Y.-C. Tseng, editors.)*, 52(6):779-790, June 2003. *(Cited 229 times.)*
- C. Petrioli, S. Basagni, and I. Chlamtac. BlueMesh: Degree-constrained multihop scatternet formation for Bluetooth networks. *ACM/Kluwer Journal on Special Topics in Mobile Networking and Applications (MONET), Special Issue on Advances in Research of Wireless Personal Area Networking and Bluetooth Enabled Networks (G. Zaruba and P. Johansson, editors)*, 9(1):33-47, February 2004. *(Cited 132 times.)*

iv) Exploiting mobility. One of the major problems of wireless sensor networks is that the flow of data towards the collector node ("the sink") goes through a limited number of nodes in close proximity of the sink (a phenomenon known as *data funneling*). To obviate to the energy depletion of these closer nodes, and therefore to the isolation of the sink (and death of the network!), we turned the "curse of mobility" into a blessing: Moving the sink in the areas of different group of nodes, thus balancing both traffic and energy consumption. We observed that our approach would improve the usability of the network (its *lifetime*) of orders of magnitude. Our paper on how to exploit sink mobility, possibly the first on this topic, has been cited more than 580 times, and opened up a research area, that of mobile data collection, still highly investigated today (where the data collectors are flying sinks, a.k.a., *drones*).

Noteworthy publications:

- Z. M. Wang, S. Basagni, E. Melachrinoudis and C. Petrioli. Exploiting Sink Mobility for Maximizing Sensor Networks Lifetime. In *Proceedings of HICSS 2005*, pages 1-9 (287a), Big Island, Hawaii, January 3-6 2005. *(Cited 582 times.)*
- S. Basagni, A. Carosi, E. Melachrinoudis, C. Petrioli, and Z. M. Wang. Controlled sink mobility for prolonging wireless sensor networks lifetime. *ACM/Springer Wireless Networks*, 14(6):831-858, December 2008. *(Cited 440 times.)*
- S. Basagni, A. Carosi, C. Petrioli, and C. A. Phillips. Coordinated and Controlled Mobility of Multiple Sinks for Maximizing the Lifetime of Wireless Sensor Networks. *ACM/Springer Wireless Networks*, 17(3):759-778, April 2011. *(Cited 67 times.)*

Current research and new research directions. My research on MANETs and on WSNs has continued and is continuing successfully through present time. My research work has now a more experimental flavor, with demonstration of our ideas in the field, especially for what concerns i) *underwater wireless networking*, ii) new solutions to enable the *wireless Internet of things* (IoT), and iii) *5G/cellular networks*.

i) Bringing the wireless Internet underwater. While underwater wireless *communication* issues have been investigated for quite some time, providing insights on the nature of the underwater communication channel and on how to deal with its time and space-varying nature, underwater wireless *networking* is still largely uncharted territory. Clearly, covering large areas of the submerged world wirelessly requires multiple nodes and protocols at all layer of the networking protocols stack, largely unavailable. Using protocols defined for terrestrial, predominantly radio networking would not be effective, as RF communication are not possible underwater, and the acoustic and optical links that work underwater have profoundly different characteristics from the RF links on land. During the past decades my works on this topic have provided new hardware (e.g., a new acoustic modem and a "smart buoy") and software (MAC and routing protocols) that have single-handedly transported underwater wireless networks into the 21st century. Supported by two grants from the National Science Foundation (one of which is still on-going), we set up to establish a testing facility to demonstrate the effectiveness of our solutions. Our testbed, comprising both commercial acoustic modems and modems of our design, has been deployed at the Northeastern University Marine Science Center in Nahant, MA. We took care of building not only the underwater infrastructure, made up of sensors and wireless communication devices, but also, instruments, e.g., smart buoys, that allow flexible control of the underwater testing facility from shore. We have designed multiple software solutions to control the system and to enable networking. Based on channel-awareness and/or on different forms of machine-learning techniques, our solutions embrace the challenges of the harsh underwater environment, and propose techniques never explored before, especially experimentally: Multi-modality (namely, using multiple forms of communications depending on current channel conditions), energy harvesting, and multi-route approach for higher performance. Some of these works have been published in extremely selective conferences (e.g., ACM MobiHoc 2018) and journals (e.g., IEEE JSAC 2019; Elsevier's Ad Hoc Networks 2019).
Noteworthy publications:

- S. Basagni, C. Petrioli, R. Petroccia, and D. Spaccini. CARP: A Channel-Aware Routing Protocol for Underwater Acoustic Wireless Networks. *Elsevier Ad Hoc Networks and Physical Communication, joint Special Issue on Advances in Underwater Communications and Networks (D. Pompili, T. Melodia, L. Yang and C. Petrioli, eds.)*, 34:92-104, November 27, 2015. *(Cited 115 times.)*
- S. Basagni, C. Petrioli, R. Petroccia, and M. Stojanovic. Optimized Packet Size Selection in Underwater WSN Communications.*IEEE Journal of Oceanic Engineering*, 37(3):321-337, July 2012. *(Cited 72 times.)*
- V. Di Valerio, F. Lo presti, C. Petrioli, L. Picari, D. Spaccini and S. Basagni. CARMA: Channel-aware Reinforcement Learning-based Multi-path Adaptive Routing for Underwater Wireless Sensor Networks. *IEEE Journal on Selected Area in Communications. Special issue on Machine Learning in Wireless Communications, D. Gesbert, P. de Kerret, M. van der Schaar, D. Gunduz, C. Murthy and D. Sidiropoulos, eds., 37(11): 2634-2647,* November 2019.

ii) Wireless networking for the IoT. The new networking paradigm of the *Internet of Things (IoT)* concerns countless devices of any form-factors, powered by the most different forms of energy sources, deployed everywhere, from inside one's body to the wider and farthest of places, which are interconnected to provide uninterrupted service anytime, anywhere, to

anybody (who is properly authorized to access them). In the field of providing wireless solutions for the IoT our contribution is multifold, ranging from channel characterization over wide portions of the RF spectrum (from few hundreds of MHz to several tens of GHz), to proposing AI-based and energy efficient new solutions for data gathering and data collection. An area of particular interest that we are investigating from a theoretical and an experimental perspective concerns the joint use of *wake-up radio technology* and *energy harvesting* for what we have defined as "green networking." Whether raking the benefit of machine learning, or making design choices based on expected harvestable energy, we devised and tested new methods for data gathering that improved network performance by orders of magnitude, thus enabling applications for the (wireless) IoT impossible before. Despite this being a recently opened research area, our works on energy harvesting and wake-up radio-based networking are already garnering considerable attention and references.

Noteworthy publications:

- D. Mishra, S. De, S. Jana, S. Basagni, K. R. Chowdhury, and W. Heinzelman. Smart RF Energy Harvesting Communications: Challenges and Opportunities. *IEEE Communications Magazine*, 53(4):70-78, April 2015. *(Cited 154 times.)*
- D. Spenza, M. Magno, S. Basagni, L. Benini, M. Paoli and C. Petrioli. Beyond Duty Cycling: Wake-up Radio with Selective Awakenings for Long-lived Wireless Sensing Systems. In *Proceedings of IEEE Infocom 2015*, pages 522-530, Hong Kong, China, April 26-30, 2015. *(Cited 119 times.)*
- G. Koutsandria, V. Di Valerio, D. Spenza, S. Basagni, and C. Petrioli. Wake-up Radio-based Data Forwarding for Green Wireless Networks. *Computer Communications. Special Issue on Machine Learning Approaches in IoT Scenarios, G. Maselli, L. Galluccio, I. Grida Ben Yahia, and N. Limam, eds.*, 160: 172-185, June 3 2020.

iii) Zero-touch and softwarized solutions for 5G networking and beyond. Research contributions to the exciting field of wireless networks of the "fifth generation" (and beyond) are a recent addition to my research interests, as these are networks of the "cellular type," i.e., based on infrastructure (while MANETs are typically infrastructure-less networks). This research stems from my participation to the Institute for the Wireless Internet of Things at Northeastern University, and as one of facilitators of the NSF-based PAWR program (see below). We recognize that to overcome the severe limitations of current (4G) "black box" wireless networks, a revolutionary transition to software-defined, open solutions is necessary, where optimization is automatic and highly distributed. In this realm, we are tackling the fundamental challenges of: Making system optimization completely autonomous, thus requiring no intervention of the telecom operator ("Zero-touch" networking), making the infrastructure as "softwarized" as possible, using software-defined networking technology and *network virtualization*, and providing new end-to-end solutions for securing communications, including physical layer steganography for *private cellular connectivity as a service*.

Noteworthy and upcoming publications:

- L. Bonati, S. D'Oro, L. Bertizzolo, E. Demirors, Z. Guan, S. Basagni, and T. Melodia. CellOS: Zero-touch Softwarized Open Cellular Networks. *Computer Networks. 1-15, in print*, June 2020.
- L. Bonati, M. Polese, S. D'Oro, S. Basagni, and T. Melodia. Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead. Computer Networks, 2020. Under review.

Research as team playing. When in January 2002 I started my career as an assistant professor in the ECE department at Northeastern University I was the only one among over 30 colleagues with research interest in computer and data networks, and I was certainly the only one in the College of Engineering in networking. (Research wise, professors Bruce McDonald and David Brady, were more concerned with communication systems and the physical layer---sadly, they left the department shortly after I joined Northeastern). In the years, I have had the honor and privilege to chair and participate to the work of many a hiring committee. That committee work led to attract fantastic networking faculty to our department. Today, I am proud to say that the computer networking group at Northeastern University, especially for what concerns wireless networked systems, is one of the premier research group in the United States and in the world. The cohesiveness and collaboration of its members has brought to the recent creation of the Institute for the Wireless Internet of Things at Northeastern University, whose over 100 members include professors Kaushik Chowdhury, Edmund Yeh, Stratis Ioannidis, Josep Jornet, Dimitrios Koutsonikolas, Tommaso Melodia, Mikiça Stojanovic, multiple other researchers from other department and colleges, and several dozen of post-graduate, graduate and undergraduate students. The Institute, of which I am founding member and to whose operation I participate "daily," is concerned with defining and influencing the *future of wireless* as enabled by a continuum of Artificial Intelligence-powered devices and networks, from driverless cars and drone swarms to implantable medical devices and smart cities. Participating in this kind of partnership has opened my research to opportunities well beyond those fostered by my usual, mostly one-on-one collaborations. Through privileged access to multi-million dollar programs such as the NSF-based PAWR (public-private partnership to establish city-scale wireless testing platform), or facilities like Colosseum (the largest wireless network emulator in the world) and Arena (wireless, software-defined indoor radio testbed), my research is now supported by and takes advantage of new possibilities, especially in unique experimental settings. This exciting new endeavor will also have broader impacts on education at Northeastern University, as the Institute is committed to introduce new programs to the COE curricula, research-informed minor in wireless IoT, new master concentration (in spectrum science and in IoT) and a new experiential Ph.D.

Research as participation. In my years of academic career, I have had and still have the honor and pleasure of being invited to co-edit special issues of international journals, books and book chapters, to participate to the organizing committee of major ACM and IEEE conference, and to be part of the Technical Program Committee (TPC) of several dozens of ACM, IEEE, IFIP, etc., conferences. I have also served as general co-chair or as TPC co-chair of many of these conferences. Although ascribable to the "service" category of academic life, I consider these activities as a further recognition of the impact of my research work and of how it has influenced the wireless networking community. Through this editorial and committee work we hone our skills, we are inspired to follow new directions, and we directly and indirectly, influence innovation and discovery for a better world.