Tutorial T-8: Output Feedback in Wireless Networks

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Tutorial Overview

In future communications systems, e.g., 5G cellular networks, the notion of centrality, in the sense of one central controller governing the entire system, might fail to hold given the expected growth of the number of network components, applications and users. This is basically because, at a given point, there would be either a strong constraint to estimate the global state of the network or a lack of centralized computing capability to process the large amount of data needed to determine the optimal behavior of each network component. Therefore, a foreseeable and natural solution is the decentralization of communications networks by giving autonomy either partially or entirely to some components. This technological trend can be evidenced today by the inclusion of new devices or infrastructure entirely detached from the control system of existing cellular networks, such as small-cells, or network components entirely managed by end-users, e.g., ad hoc home networks based on Wi-Fi, Bluetooth, etc. Other types of networks are typically decentralized as a central control is not possible due to the lack of fixed infrastructure or due to their critical deployment conditions or applications, e.g., law enforcement, disaster relief, body-area, medical instruments, space, and indoor/outdoor commercial applications.

Feedback has been an important part of wireless networks since their very beginnings in ALOHA style networks that relied on ACK/NACK feedback for their operation. And, of course, feedback of partial channel state information is a key part of several aspects of current and emerging wireless networks, including multiuser MIMO systems, coordinated multi-point, etc. However, the use of channel-output feedback has not been widely exploited in practice, but as we shall see in this tutorial, it presents considerable potential for improving the performance of wireless networks, and in particular decentralized wireless networks. In general, when a transmitter receives a feedback signal from its intended receiver, it obtains a degraded version of the sum of its own transmitted signal and the interfering signals from other transmitters. This implies that, subject to a finite delay, transmitters know at least partially the information transmitted by other transmitters in the network. This induces a type of cooperation between transmitters in the sense that they share their transmitted signals. This effect is a consequence of the broadcast nature of wireless channels, and thus, even if this sort of cooperation is not explicitly desired by the transmitters, it incontestably appears and strongly enlarges the set of achievable and stable transmission rates, e.g., the equilibrium region.

More specifically, channel-output feedback allows the existence of network equilibria (in the sense of Nash) that lie in the Pareto optimal boundary of the capacity region, e.g., the set of sum-rate optimal transmitter-receiver configurations. Interestingly, these benefits hold even in the case in which feedback signals are subject to additive noise. More importantly, it has been recently shown that the set of rate pairs that are achievable and stable in the case of channel-output feedback is at least equal to the set without feedback and can be larger.

The objectives of this tutorial are threefold:

- To highlight channel-output feedback as a promising technique for interference management in highly densified networks, e.g., 5G communications systems.
- To show the benefits of feedback in both centralized and decentralized scenarios via very simple, yet insightful, multi-user scenarios. For this purpose, the capacity region and equilibrium region of the two-user interference channel is approximated using linear deterministic models and both achievability and converse theorems are discussed.
- To identify the main challenges of the use of channel-output feedback in decentralized networks. For this purpose, the impact of noise in the feedback links, knowledge of the codebooks of other transmitter-receiver pairs and global network synchronization are thoroughly discussed.

Presenter Biographies

Samir M. Perlaza (Ph.D., Telecom ParisTech 2011) is a research scientist with the Institut National de Recherche en Informatique et en Automatique (INRIA), France, and a visiting research collaborator at the School of Applied Science at Princeton University (NJ, USA). He received the M.Sc. and Ph.D. degrees from Ecole Nationale Sup´erieure des T´el´ecommunications (Telecom ParisTech), Paris, France, in 2008 and 2011, respectively. Previously, from 2008 to 2011, he was a Research Engineer at France T´el´ecom - Orange Labs (Paris, France). He has held long-term academic appointments at the Alcatel-Lucent Chair in Flexible Radio at Sup´elec (Gif-sur-Yvette, France); at Princeton University (Princeton, NJ) and at the University of Houston (Houston, TX). His research interests lie in the overlap of signal processing, information theory, game theory and wireless communications. Dr. Perlaza was a recipient of an Alban Fellowship of the European Union in 2006 and the Best Student Paper Award in Crowncom in 2009. In 2014, he was one of the finalists of the Coor Baayen Award, a prize of ERCIM -the Eureopean Research Consortium for Informatics and Mathematics- awarded each year to a promising young researcher in computer science and applied mathematics.

Ravi Tandon (Ph.D., University of Maryland, 2010) received the B.Tech. degree in Electrical Engineering from the Indian Institute of Technology, Kanpur (IIT Kanpur) in May 2004. He received the Ph.D. degree in Electrical and Computer Engineering from the University of Maryland, College Park (UMCP) in June 2010. His Ph.D. advisor at Maryland was Prof. Sennur Ulukus. From July 2010 till July 2012, he was a post-doctoral research associate at Princeton University , working with Prof. H. Vincent Poor. From July 2012 to August 2014, he was a Research Assistant Professor in the Bradley Department of Electrical and Computer Engineering and the Hume Center for National Security and Technology at Virginia Tech. Since Sep. 2014, he is a Research Assistant Professor in the Department of Computer Science and the Discovery Analytics Center at Virginia Tech. He is a recipient of the Best Paper Award at GLOBECOM 2011. His current research interests include wireless communications, interference management techniques, multi-user MIMO systems, cyber-security and machine learning.

H. Vincent Poor (Ph.D., Princeton 1977) is the Michael Henry Strater University Professor at Princeton University, where he is also the Dean of the School of Engineering and Applied Science.

From 1977 until he joined the Princeton faculty in 1990, he was a faculty member at the University of Illinois at Urbana-Champaign. He has also held visiting appointments at a number of other universities, including most recently at Imperial College and Stanford. His research interests are primarily in the area of wireless networks and related fields. An IEEE Fellow, Dr. Poor is a member of the U. S. National Academy of Engineering and the U. S. National Academy of Sciences, and is a foreign member of the Royal Society. He is also an a fellow of the American Academy of Arts and Science, the Royal Academy of Engineering of the UK, and the Royal Society of Edinburgh. He received the Marconi and Armstrong Awards of the IEEE Communications Society in 2007 and 2009, respectively. Recent recognition of his work includes the 2014 URSI Booker Gold Medal, and honorary doctorates from Aalborg University, Aalto University, the Hong Kong University of Science and Technology, and the University of Edinburgh.