

COOPMEDIA: Cooperative Multimedia Transmission over Wireless Networks

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15 December 2012

Project Objectives

Multimedia transmission over mobile devices is one of the most prominent emerging applications in mobile communications. With the rapid proliferation of 3G systems worldwide, multimedia services has become a regular part of our daily mobile communications experience. Mobile video traffic exceeded 50 percent of the total mobile data traffic for the first time in 2011. This ratio is expected to surpass 70 percent by 2016. Wireless networks are critically sensitive to the load in the network, and the users' quality of experience (QoE) is under a risk of significant decline with this growth. Network providers are already having problems supporting this growth within the current network architecture. To avoid a potential network meltdown, one approach is to increase the capacity of the wireless networks. However, simply increasing the network capacity, without taking into account the specific characteristics of the underlying multimedia signals will simply postpone the catastrophe. A more fundamental approach is to go beyond the layered network architecture, and study the underlying problem from a joint source-channel coding (JSCC) perspective.

The objective of COOPMEDIA is to advance our understanding on the fundamentals of cooperative multimedia transmission over wireless networks by defining the appropriate performance measures for different applications and developing the tools to improve the system performance with respect to these performance measures. In particular, COOPMEDIA focuses on the information and communication theoretical aspects of multimedia transmission, and strives to identify the fundamental limits of joint source-channel coding in networks while taking practical constraints and performance metrics into account.

Milestones In the First Period

The first two years of the project has been dedicated to the theoretical study of joint source-channel coding in multi-user networks. We have focused on identifying relevant performance measures and system models that accurately model wireless multimedia networks. In particular, we have studied point-to-point as well as multi-user systems such as broadcast, multi-access and multi-cast channels. We have studied lossless transmission of correlated information, such as sensor networks which observe correlated physical phenomena, as well as lossy transmission of continuous amplitude sources, such as multimedia signals, over wireless links in the presence of fading side information at

the receiver. We have studied streaming of multimedia signals over wireless channels, modeling real-time video broadcasting to mobile devices. We have also studied the energy efficiency in battery limited and energy harvesting communication systems.

Main Project Results

- **Joint Source-Channel Coding with Fading Side Information:** In this research line, we have studied transmission of a Gaussian source over a multiple input-multiple output (MIMO) fading channel with time-varying correlated side information at the decoder. Focusing on the high SNR behavior of the end-to-end distortion, we have identified the optimal transmission scheme in certain regimes of operation.
- **Joint Source-Channel Cooperative Transmission over Networks** We have focused on lossless transmission of correlated sources over various multi-user networks. In particular, we have focused on relay-broadcast networks and multiple access relay channel (MARC).

In the case of relay-broadcast networks, we have identified two types of transmission strategies: i) semi-regular encoding with backward decoding, and ii) regular encoding with sliding-window decoding. We have shown that these coding schemes achieve the optimal source-channel coding rate for physically degraded relay channel with degraded side information and the relay broadcast channel with arbitrary side information.

In MARCs, we have considered separate source channel coding as well as correlation preserving mapping, and showed that either transmission scheme can be superior depending on the sources and the channels.

- **Streaming of Multimedia Signals** In this part of the project, we have focused on multimedia streaming. We have considered a streaming transmitter such that the data packets arrive at the transmitter over time and has to be broadcast to a group of receivers within a certain deadline. We have also studied a streaming receiver, in which the data packets need to be received in a certain order within their corresponding deadlines. We have studied the average transmission rate as well as the maximum delay among consecutive packets.
- **Energy Efficient Multimedia Transmission** Energy efficiency is a fundamental concern in almost all communication systems, but especially for mobile networks which are limited by the stored energy in the battery. In this project, we have introduced the novel concept of *energy-distortion trade-off* which measures the fundamental limit of energy efficiency in transmitting sources over wireless channels when the bandwidth ratio between the channel and the source is relaxed. Moreover, we have also studied energy harvesting communication systems, which are not limited by the stored energy, but can harvest ambient energy to sustain transmission over longer periods of time than allowed by the battery capacity.

Milestones In the Second Period

In the second part of the project we have continued our theoretical study on various

aspects of joint source-channel coding in multi-user networks. We have obtained new results on both point-to-point and multi-user settings. We have finalized our study of lossless transmission of multi-relay networks, and our paper on this problem has been accepted for publication (see below). Moreover, we have extended our work on streaming multimedia and have submitted a journal paper on this problem. We have considered various new network scenarios for energy harvesting communication systems considering point-to-point, multi-hop and broadcasting scenarios.

Main Project Results

- **Joint Source-Channel Coding with Fading Side Information:** In the first year of the project we have focused mainly on the high SNR behavior of the end-to-end distortion in this problem. In the second year, we have extended our study to the moderate SNR levels what will be faced in practical systems. As a surprising result, we have shown that for single input-single output (SISO) systems in the case of bandwidth match, that is, when the source and the channel bandwidths are the same, uncoded transmission achieves exactly the optimal performance. Note that, our high SNR study from the first year has shown that uncoded transmission is exponentially worse and coded schemes when there are multiple antennas or bandwidth expansion/ compression. This points to an interesting result which implies that for simple SISO systems coding might not be needed, simplifying significantly the operation of the devices. Such results were previously obtained for some special multiple access scenarios, but this is the first such result in the case of fading channel and side information.
- **Joint Source-Channel Cooperative Transmission over Networks** We have finalized the first stage of our study on the relay networks and multiple access relay channel (MARC) with correlated sources and submitted two journal papers. We have continued our study on MARCs and have achieved new transmission schemes based on joint source-channel coding which improve our previous results.
- **Streaming of Multimedia Signals** In this part of our research we continued our work on data streaming transmission over a block fading channel. We have proposed various novel transmission schemes and compared them with an informed transmitter upper bound in terms of the average decoded rate. We show that the adaptive joint encoding (aJE) scheme is asymptotically optimal; that is, it achieves the ergodic capacity as the transmission deadline goes to infinity; and it closely follows the upper bound in the case of finite transmission deadline. On the other hand, in the presence of multiple receivers with different signal-to-noise ratios (SNR), memoryless transmission (MT), time sharing (TS) and superposition transmission (ST) schemes are shown to be more robust than the joint encoding (JE) scheme as they have gradual performance loss with the decreasing SNR.
- **Energy Harvesting Communication Systems** We have extended our study of energy harvesting (EH) communication systems in several directions. We have considered multi-hop relay networks in which both the source and the relay terminal

harvests energy from their environment. We have identified the optimal transmission strategy for this communication channel such that the stochastically arriving energy is utilized optimally by the nodes. We have also considered leakages in the energy storage units and optimized the scheduling of node transmission in order to minimize the leaked energy from the battery, and maximize the end-to-end throughput.

Publications that have been produced within the COOPMEDIA project:

Journals:

1. G. Cocco, D. Gündüz and C. Ibars, "Streaming transmitter over block fading channels with delay constraint," under revision, *IEEE Trans. Wireless Communications*, August 2012.
2. P. Blasco, D. Gündüz, M. Dohler, "A learning theoretic approach to energy harvesting communication system optimization," under revision, *IEEE Trans. Wireless Communications*, August 2012.
3. Y. Murin, R. Dabora, D. Gündüz, "Source-channel coding theorems for the multiple-access relay channel," under revision, *IEEE Trans. Information Theory*, 2011.
4. E. Tuncel and D. Gündüz, "Identification and lossy reconstruction in noisy databases," under revision, *IEEE Trans. Information Theory*, 2011.
5. D. Gündüz, E. Erkip, A. J. Goldsmith and H. V. Poor, "Joint source-channel cooperative transmission over relay-broadcast networks," accepted, *IEEE Trans. Information Theory*.
6. D. Gündüz, A. Yener, A. J. Goldsmith and H. V. Poor, "The multi-way relay channel," *IEEE Trans. Information Theory*, vol. 59, no. 1, pp. 51-63, Jan. 2013.
7. A. Jain, D. Gündüz, S. R. Kulkarni, H. V. Poor and S. Verdú, "Energy-distortion tradeoffs in Gaussian joint source-channel coding problems," *IEEE Trans. Information Theory*, vol. 58, no. 5, pp. 3153-3168, May 2012.
8. B. Devillers and D. Gündüz, "A general framework for the optimization of energy harvesting communication systems with battery imperfections," to appear, *Journal of Communications and Networks, Special Issue on Energy Harvesting in Wireless Networks*, vol. 14, no. 2, pp. 130-139, Apr. 2012.

Conference Proceedings:

1. O. Orhan, D. Gündüz and E. Erkip, "Optimal packet scheduling for an energy harvesting transmitter with processing cost," submitted to, *IEEE Int'l Conf. on Communications (ICC)*, Budapest, Hungary, Jun. 2013.
2. G. Cocco, D. Gündüz and C. Ibars, "Throughput and delay analysis in video streaming over block-fading channels," submitted to, *IEEE Int'l Conf. on Communications (ICC)*, Budapest, Hungary, Jun. 2013.

3. O. Tan, D. Gündüz, H. V. Poor, "Smart meter privacy in the presence of energy harvesting and storage devices," *IEEE Int'l Conf. on Smart Grid Communications*, Tainan City, Taiwan, Nov. 2012.
4. P. Blasco, D. Gündüz, M. Dohler, "A learning theoretic approach to scheduling in energy harvesting communication systems," *IEEE Globecom Int'l Workshop on Machine-to-Machine Communications*, Anaheim, CA, Dec. 2012.
5. O. Orhan, D. Gündüz and E. Erkip, "Throughput maximization for an energy harvesting communication system with processing cost," *IEEE Information Theory Workshop (ITW)*, Lausanne, Switzerland, Sep. 2012.
6. I. E. Aguerri and D. Gündüz, "The capacity of a class of relay channels with state," *IEEE Information Theory Workshop (ITW)*, Lausanne, Switzerland, Sep. 2012.
7. Y. Murin, R. Dabora, D. Gündüz, "Mixed joint source-channel coding schemes for the multiple-access relay channel," *IEEE Int'l Symp. on Wireless Comm. Systems (ISWCS)*, Paris, France, Aug. 2012.
8. Y. Murin, R. Dabora, D. Gündüz, "Joint source-channel coding for the multiple-access relay channel," *IEEE Int'l Symposium on Information Theory (ISIT)*, Cambridge, MA, July 2012.
9. D. Gündüz and B. Devillers, "Two-hop communication with energy harvesting," *IEEE Int'l Workshop Comput. Adv. in Multi-Sensor Adaptive Proc. (CAMSAP)*, San Juan, PR, Dec. 2011.
10. B. Devillers and D. Gündüz, "Energy harvesting communication system with battery constraint and leakage," *IEEE Globecom*, Houston, TX, Dec. 2011.
11. Y. Murin, R. Dabora, D. Gündüz, "Source-channel coding for the multiple-access relay channel," *IEEE Int'l Symp. on Wireless Comm. Systems (ISWCS)*, Aachen, Germany, Nov. 2011.
12. G. Cocco, D. Gündüz and C. Ibars, "Realtime broadcasting over block fading channels," *IEEE Int'l Symp. on Wireless Comm. Systems (ISWCS)*, Aachen, Germany, Nov. 2011.
13. N. Liu, D. Gündüz and W. Kang, "Capacity results for a class of deterministic Z-interference channels with unidirectional receiver conferencing," *6th Int'l ICST Conference on Comm. and Networking (CHINACOM)*, Harbin, China, Aug. 2011.
14. I. E. Aguerri and D. Gündüz, "Distortion exponent in fading MIMO channels with time-varying side information", *IEEE Int'l Symposium on Information Theory (ISIT)*, St. Petersburg, Russia, July 2011.
15. I. E. Aguerri and D. Gündüz, "Expected distortion with fading channel and side information quality," *IEEE Int'l Conf. on Communications (ICC)*, Kyoto, Japan, June 2011.

16. G. Cocco, D. Gündüz and C. Ibars, "Throughput analysis in asymmetric two-way relay channel with random access," *IEEE Int'l Conf. on Comm. (ICC)*, Kyoto, Japan, June 2011.
17. I. E. Aguerri and D. Gündüz, "Wireless source transmission with time-varying side information", *IEEE Int'l Symp. on Modeling and Optim. in Mobile, Ad Hoc, and Wireless Networks, 3S Workshop*, Princeton, NJ, May 2011.
18. G. Cocco, C. Ibars, D. Gündüz and O. del Rio Herrero "Collision resolution in multiple access networks with physical-layer network coding and distributed fountain coding," *IEEE Int'l Conf. Acous., Speech, Sig. Proc. (ICASSP)*, Prague, Czech Republic, May 2011.
19. G. Cocco, C. Ibars, D. Gündüz and O. del Rio Herrero "Collision resolution in slotted ALOHA with multi-user physical-layer network coding," *IEEE Vehicular Technology Conference (VTC-Spring)*, Budapest, Hungary, May 2011.
20. I. E. Aguerri and D. Gündüz, "Expected distortion with fading channel and side information quality," *Inf. Theory and Applic. Workshop (ITA)*, San Diego, CA, Feb. 2011.
21. I. E. Aguerri and D. Gündüz, "Hybrid digital-analog transmission for the Gaussian one-helper problem," *IEEE Global Communications Conf. (Globecom)*, Miami, FL, Dec. 2010.
22. T. Renk, H. Jäkel, F. K. Jondral, D. Gündüz and A. Goldsmith, "Outage capacity of bursty amplify-and-forward with incremental relaying," *IEEE Int'l Symposium on Inform. Theory and its App. (ISITA)*, Taichung, Taiwan, Oct. 2010.
23. D. Gündüz and M. Payaró, "Gaussian two-way relay channel with arbitrary inputs," *IEEE Int'l Symp. Per., Indoor & Mobile Radio Comm. (PIMRC)*, Istanbul, Turkey, Sep. 2010.
24. D. Gündüz and O. Simeone, "On the capacity region of a multiple access channel with common messages," *IEEE Int'l Symp. on Inf. Theory (ISIT)*, Austin, TX, June 2010.
25. E. Tuncel and D. Gündüz, "Identification and lossy reconstruction in noisy databases," *IEEE Int'l Symposium on Information Theory (ISIT)*, Austin, TX, June 2010.
26. D. Gündüz, E. Erkip, A. Goldsmith and H. V. Poor, "Cooperative relaying in sensor networks," *Int'l Conference on Cognitive Radio Oriented Wireless Networks and Communications*, Cannes, France, June 2010.