26th International Conference on Telecommunications
Hanoi, Vietnam | 08 – 10 April 2019

Recent advances in HARQ Communications

Presented by

Pierre Duhamel (CNRS/Centrale Supelec, France) and Leszek Szczecinski (INRS, Canada)

Co-authors

Philippe Ciblat (Telecom ParisTech, France) and Francesca Bassi (CNRS/CentraleSupelec, France)

Importance and timeliness

Adaptive modulation and coding (AMC) and hybrid automatic repeat request (HARQ) are two transmission strategies commonly used in modern wireless systems to communicate over error-prone and time-varying channels. In broad terms, AMC consists in adjusting the transmission parameters (such as the modulation type, the coding rate, and/or the transmission power) to the channel conditions; these are most often defined by a predefined set of modulation/coding schemes (MCSs). The receiver selects a suitable MCS and conveys its index to the transmitter via a feedback channel.

Transmission errors, unavoidable in any practical system, are handled by the retransmission protocol known as automatic repeat request (ARQ), where the receiver uses a feedback channel to inform the transmitter about a successful decoding—via a positive acknowledgment (ACK) message— or about a decoding failure—via a negative acknowledgment (NACK) message, which triggers a new *transmission round* (or a *retransmission*). Increasing the number of retransmissions improves the chances for successful decoding. In this tutorial, we consider the retransmission protocol known as *hybrid* ARQ (HARQ) in which coding is done across the transmission rounds, and thus is intimately related to the AMC for which coding and modulation are the core elements.

In more general terms, both AMC and HARQ may be seen as transmission strategies with variable rate: the former, due to the explicit variation of the number of bits conveyed over the channel, the latter, due to the variability of the transmission time resulting from the variable number of transmission rounds. AMC and HARQ are thus naturally coupled and, in this work we want to clarify to what extent and how this coupling should be preserved or exploited.

Therefore, although the formalism of the communication layers tends to separate the AMC from HARQ, the practice may call for their holistic view. In particular, the Long Term Evolution (LTE) standard specifies the HARQ operation as part of the media access control (MAC) layer, whereas the channel measurements procedures are defined in the physical layer (PHY). However, the AMC, i.e., the way the MCS should be chosen based on the reported channel measurement is unspecified and left for implementation. We will thus consider the AMC and HARQ as mechanisms of PHY and the main objective of this tutorial is to present and explain various elements critical to the operation of AMC and HARQ placing them both in the theoretical framework relating it to the current practice of the modern wireless standards.

Tutorial content

1- Context: (Short) description of a wireless commutation scenario
- classical scheme
- AMC, description, allowing a short intro on channel coding
- uncertainties on the channel conditions : use of a feedback channel (trial and error : PHY and MAC)
- introduction to diversity

2- Classical ARQ/HARQ situations and their representation in the current standards
- Various ARQ schemes Stop and wait, etc…
- HARQ : CC and IR

3- Performance metrics and related applications (Pierre)

a) Definitions:
- PER
- efficiency
- delay

b) And their evaluation for ARQ/HARQ
- study of various situations

4- Degrees of freedom in the design of HARQ (and their relationship to the current standards)
- rate allocation and adaptation (Leszek)
- power allocation and adaptation (Leszek)
- non-orthogonal HARQ; reducing the delay and improving the throughput (Pierre)

5- HARQ and AMC; joint or separate design (Leszek)
- separate design: conflicting objectives and counterproductive actions
- joint design: complexity issues
- semi-joint design via layered coding

6- Wrap up
- conclusions on theoretical and practical issues
- possible extensions
  a) security: rate adaptation for secure HARQ (Leszek)
  b) cooperative communications (Pierre)

Brief CV of the speakers

Pierre Duhamel (Fellow, IEEE, 1998, Fellow, Eurasip, 2008, Grand Prix France Télécom of the French Science Academy, 2000) received the Eng. Degree in Electrical Engineering from the National Institute for Applied Sciences (INSA) Rennes, France in 1975, the Dr. Eng. Degree in 1978, and the Doctorat ès sciences degree in 1986, both from Orsay University, France. From 1975 to 1980, he was with Thomson-CSF (now Thales), Paris, France. In 1980, he joined the National Research Center in Telecommunications (CNET, now Orange Labs), Issy les Moulineaux, France. From 1993 to Sept. 2000, he has been professor at ENST, Paris (National School of Engineering in Telecommunications). He is now with CNRS/L2S (Laboratoire de Signaux et Systemes, Gif sur Yvette, France), where he developed studies in Signal processing for communications and signal/image processing for multimedia applications. He is currently investigating the connections between communication theory and networking. Dr Duhamel

published more than 100 papers in international journals, more than 300 papers in international conferences, and holds 29 patents. He is a co-author of the book ”Joint Source and Channel Decoding: A cross layer perspective with applications in video broadcasting” (2009, Academic Press). He successfully advised or co-advised 60 PhD students, two of them being now fellow, IEEE.

Leszek Szczecinski received the M.Eng. degree from the Technical University of Warsaw, Warsaw, Poland, in 1992, and the Ph.D. degree from INRS-Telecommunications, Montreal, QC, Canada, in 1997. From 1998 to 2001, he was Assistant Professor with the Electrical Engineering Department, University of Chile, Santiago, Chile. He is currently Professor with INRS, University of Quebec, Montreal. From 2009 to 2010, he was a Marie Curie Research Fellow with the Laboratory of Signals and Systems, CNRS, Gif-sur-Yvette, France and 20092013 he was Adjunct Professor with the Electrical and Computer Engineering Department, McGill University, Montreal. He co-authored the book Bit-Interleaved Coded Modulation: Fundamental, Analysis and Design (Wiley, 2015). His research interests are in the area of communication theory, modulation and coding, HARQ, wireless communications, and digital signal processing.

Previous tutorials

P. Duhamel:

- P.Duhamel and M. Kieffer. Joint Protocol-Channel decoding : Taking the best from noisy packets, February 2011. Half day tutorial presented at the 4th IFIP International Conference on New Technologies, Mobility and Security (NTMS) 7 - 10 February 2011, Paris - France.
- P.Duhamel and M. Kieffer. Signal Processing Meets Network Layers : Joint Protocol-Channel Decoding, March 2012. ICASSP 2012 Tutorial number T-3 (Half Day).
- P.Duhamel and M. Kieffer. Joint Source and Channel Decoding : An idea whose time has come. IEEE, 2007. Half Day Tutorial given at ICASSP 2007.
- P. Duhamel and O. Rioul. Joint source and channel coding. EURASIP, 2000. Half Day Tutorial given at EUSIPCO 2000.
- P. Duhamel. Blind Equalization. IEEE International Conference on Audio, Speech, and Signal Processing, 1995. Half Day Tutorial given at ICASSP 1995.

L. Szczecinski:

- L. Szczecinski and A. Alvarado, “Bit Interleaved Coded Modulation: Fundamentals, Analysis, and Design” European Wireless, Poznan, Poland, April 2012.
- L. Szczecinski and A. Alvarado, “Bit Interleaved Coded Modulation: Fundamentals, Analysis, and Design” IEEE Canadian Conference on Electrical and Computer Engineering, Niagara Falls, May 2011.
- L. Szczecinski and A. Alvarado, “Bit Interleaved Coded Modulation: Fundamentals, Analysis, and Design” IEEE International Conference on Communications Systems, Singapore, Nov. 2010.