ICT-2017 Tutorial

Title: WIRELESS CODED CACHING: A PARADIGM SHIFT IN COMMUNICATIONS

Presenter: Prof. Petros Elia (EURECOM, France)

Summary, Motivation and Goal of the tutorial

Brief Intro: This tutorial is about a new way of seeing caching, and it is about the recently discovered deep connections between memory/caching and the fundamentals of communication theory. The tutorial will about a new technology that – at first indications – has the potential to approach the long-sought holy grail of wireless communications, which is to serve an ever increasing number of users, with a fixed amount of bandwidth resources. The material spans theory and practice, as well as spans the PHY-part of ICT and the networking part of ICT.

Extended Summary: Toward the ultimate promise of having wireless communications with throughputs that scale with the number of network users, most envisioned technologies run into bottlenecks because they typically aim to reduce interference by *separating* users' signals. Recently though, for a basic broadcast configuration, a solution (*coded-caching*) was proposed that relied on caching coded data at the receiving devices in order – not to separate signals – but instead to mix them.

The goal of this tutorial is to help the audience understand how these classical communication "separation" techniques, are intimately intertwined with this novel caching techniques. We will explore how this combination of communications-techniques and caching can achieve unprecedented throughput gains, and how it promises to change the way PHY-based communications are conducted. While traditional caching (prefetching/data-push) methods mainly reduce the volume of the problem for the day after (reflecting the old saying "Do something today, so that you do not have to do it tomorrow"), the combination of advanced PHY and caching – instead of changing *the volume of the problem – seeks to* change *the structure of the problem*.

In the end, this tutorial will provide a new look at the recent efforts to employ memory-aided communications "on top" of physical layer communciations. The tutorial is among the very first to discuss the possible new directions that can come from realizing that the problem of caching (MAC) and of (PHY)-based communications are nonseparable, in the sense that you cannot just concatenate a powerful caching algorithm, to a powerful communication solution, and expect to get the best out of both. We will also discuss the different new directions that are inspired by the transition from the wired to the wireless medium; a transition that seems to entirely change the core of how memory must be used.

Content and Covered Topics

- Challenges in networks with memory
- Coded caching
- Fundamentals of memory-aided signal processing in wireless communications
- Using memory to improve the performance of communicationsss wireless networks
- Using caching to reduce the complexity of communications

Timeliness

This tutorial comes at a time when the use of memory (storage/caching) is gaining more and more traction as a key ingredient in wireless communications. It also comes at a time when it is becoming clear that memory by itself cannot achieve the long-sought throughput scaling for a variety of reasons. This brings to the fore the urgent need for research on how the powerful (albeit inadequate) resource of memory/caching can be used *in conjunction with other powerful classical communications-theoretic*

(PHY) resources in wireless networks. This is exactly the focus of this tutorial. Our tutorial will cover the early results that show these connections between resources that include memory, feedback, MIMO, as well as the connections between memory-based caching techniques and advanced PHY methods. This approach will render our tutorial of direct interest to a large subset of the ICT community.

Outline of the Tutorial, and Material to be covered

- Basic exposition of the challenges of modern wireless communications
  - Opportunities and bottlenecks in different PHY technologies like Massive MIMO, and multi-cell cooperation and densification
  - The need of a new communications technology
- Brief introduction to cache-aided solutions
  - Moore's Law for bandwidth
- Basic elements of coded caching
  - Local vs. global caching gains
- Centralized vs. decentralized coded caching in multicast settings
- Exploiting file popularity
  - Multiple groupcast index coding, and other techniques
- Performance outer bounds – basic exposition
- Source-coding view of coded caching
- Joint considerations of caching and network topology
- Exploiting small cache sizes
  - Joint caching-and-delivery algorithms designed for ultra-small cache sizes
- Exponential subpacketization of coded caching

- Fundamental differences between wired and wireless coded caching – non separability
- Caching in feedback-aided multiuser MIMO settings
  - Joint caching and precoding schemes
- Centralized multi-server problem: ripping the gains of both words
- Caching at both transmitters and receivers (Cache-aided interference channel)
- Benefits of caching in large MIMO systems
  - Cache-aided performance improvements
  - Cache-aided simplifications in implementation
- The fundamental interplay between coded-caching and feedback
- Competing + synergistic duality between feedback and caching
- Caching to achieve interference management
  - Caching at the transmitters to achieve interference alignment
  - Caching to give receivers, interference-reducing side information
- Caching to alleviate the backhaul in interference-limited settings
- Coded-caching as a means of creating joint-transmission opportunities
- Exploring the interplay between coded caching and feedback
  - Achieving an exponential utility of caching in massive MIMO settings
  - Combining multicast gains from caching, with broadcast gains from feedback-aided multiuser MIMO
  - Interesting (competing + synergistic) duality between feedback and memory (caching)
- Coded caching in a variety of wireless networks
  - Wireless multihop D2D caching networks
  - Cache-aided Wyner networks
  - Coded caching in erasure networks
  - Femtocaching
  - Caching on the edge
- Theoretical and practical open problems, and the need to incorporate advanced Signal Processing techniques (can be perceived as open problems)
  - The exponential refinement problem (exponential caching problem - possible alleviations)

- Topology (weakest guy brings down everyone, unless …).
- Linear barrier of coded caching (microscopic gains for modest-sized caches).

SHORT BIO:

Petros Elia received the B.Sc. degree from the Illinois Institute of Technology, and the M.Sc. and Ph.D. degrees in electrical engineering from the University of Southern California (USC), Los Angeles, in 2001 and 2006 respectively. He is now a professor with the Department of Communication Systems at EURECOM in Sophia Antipolis, France.

His latest research deals with the intersection of coded caching and feedback-aided communications in multiuser settings. He has also considered different problems in the area of complexity-constrained communications, MIMO, cooperative and multiple access protocols and transceivers, complexity of communication, as well as with isolation and connectivity in dense networks, queueing theory and cross-layer design, coding theory, information theoretic limits in cooperative communications, and surveillance networks. He is a Fulbright scholar, the co-recipient of the NEWCOM++ distinguished achievement award 2008-2011 for a sequence of publications on the topic of complexity in wireless communications, and the recipient of the ERC Consolidator Grant 2017-2022 on cache-aided wireless communications.

Previous Tutorial Experience

Petros Elia has presented tutorials in venues that include:

- 16th IEEE International Symposium on Signal Processing and Information Technology (Limassol): “Memory-aided wireless communications”.
- SIGMETRICS 2016 (Antibes): "Caching perspectives from information-theory and network theory" (w. Georgios Paschos).
- ICC 2016 (Kuala Lumpur): "Wireless caching for 5G: network coding and PHY".

As well as

- SPAWC 2015 (Stockholm): "MIMO channels towards 5G: feedback and topology" (w. Dirk Slock).
- ICASSP 2014 (Florence): "Bits and Flops: complexity in wireless communications " (w. Joakim Jaldén).
- WCNC 2014 (Istanbul): "MIMO Broadcast and Interference Channels towards 5G" (w. Dirk Slock).