Advanced Modulation and Random Access Techniques for 5G Communication Systems

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Motivation

... an increase in available capacity
  1000x higher mobile data volumes, 10-100x higher end user rates

... an increase in the number of connected devices
  10-100x up to 300,000 devices per cell.

... an increase in offered reliability
  99.9999% for e.g. mission critical communications, control functionalities

... decreased latency
  down to the millisecond scale.

... increased efficiency
  resource utilization (e.g. energy and spectrum)

An in-depth re-design of the radio interface is needed to cope with 5G requirements
Outline

1) Advanced post-OFDM waveform designs (FBMC).

2) MAC protocol for massive random access (DQ).

3) Concluding remarks
Advanced post-OFDM Waveform Designs (FBMC)
Post-OFDM waveform designs

- Several post-OFDM waveforms under consideration for 5G
  - Filtered CP-OFDM, UFMC, UF-OFDM, GFDM, FBMC,…
  - Emphasis on **FilterBank MultiCarrier** (FBMC) solutions based on OQAM symbols.
  - These modulations achieve the **maximum spectral efficiency**.
Advantages of FBMC as 5G candidate

- The use of filterbank based multicarrier modulations (FBMC) guarantees good spectral localization and avoids cyclic prefix insertion (OFDM), leading to a much higher spectral efficiency.
- **Orthogonal modulation** under ideal (frequency flat) conditions.
- For mildly selective channels, **single tap equalization** (like OFDM) is sufficient.
- **Spectral coexistence with other systems** can be guaranteed.
**FBMC challenges…and solutions**

- **MIMO transceivers for FBMC:** In general, MIMO techniques designed for OFDM cannot be directly applied to FBMC/OQAM because:
  - Orthogonality in FBMC/OQAM is satisfied in the real domain.
  - In highly frequency selective channels, have to deal with inter-carrier/symbol/stream interference.

- **Simplified channel estimation equalization of FBMC signals:** FBMC/OQAM signals sensitive to high frequency selectivity.
  - Simple & computationally efficient equalization/channel estimation schemes developed at CTTC.

- **Prototyping and product development of FBMC signals.**
  - Based on both polyphase and fast convolution approaches.
  - Implementing MIMO processing.
  - Reconfigurable to support FBMC/OQAM, FMT and single carrier with a single transmitter architecture.

Parallelized transceiver architectures for MIMO FBMC/OQAM developed at CTTC.
FBMC prototyping: wireless

- FPGA-based implementation of flexible FBMC/OQAM based on fast convolution (ICT EMPHAtiC Project) and using MIMO.
- Main application: design of a broadband Professional Mobile Radio transmission that is able to co-exist with the narrowband legacy systems (TETRA-TEDS).

FBMC wideband PMR

Narrowband legacy PMR
FBMC prototyping: wireless (cont’d)

FBMC-based system is able to suppress subcarriers and coexist with current TETRAPOL terminals…OFDM is NOT.
FMBC product development: powerline

- Design and implementation of a Multicarrier filterbank Multicarrier Transceiver for High Voltage Power Lines (FPGA+DSP).
- This is now commercialized by a local company.

- It is a real-time TX+RX modem implementing a 10bit/s/Hz transmission
- Auto-configurable to avoid narrowband interference and maximize throughput.
- 3 DSPs + 1 FPGA at each modem.
Waveform design: CTTC experience

• **Research projects**: Active participation in several EU-funded and national research projects, (both algorithms and demos):
  
  
  • Enhanced Multicarrier Techniques for Professional Ad-Hoc and Cell-Based Communications *(ICT-318362)*, 2012–15. CTTC is the **Project Coordinator**.
  

• **Some publications**:
  
  
  
  
  • X. Mestre, D. Gregoratti, “*A parallel processing approach to filterbank multicarrier MIMO transmission under strong frequency selectivity*”, IEEE ICASSP, 4-9 May 2014, Florence (Italy).

• **Patent**:
  
MAC Protocol for Massive Random Access (DQ)
Interestingly...

• “Medium Access Control” is a popular research topic:
  • Google: 496,000 hits
  • Google Scholar: 107,000 hits
  • IEEE Xplore: 6,169 papers

  …as of 21st April 2016.

• However in

Random Access mechanisms mostly based in ALOHA and variants
(Frame Slotted with/out feedback, Dynamic FSA, Diversity FSA, + Successive Interference Cancellation, + Duty Cycling, + Reservation)
Interestingly…

- New stringent requirements for future wireless systems (MTC, 5G)
  - Huge number of devices (10x-100x), simultaneous access.
  - Small Data Transmissions (few bps)
  - Constraints on maximum latency/access delay.
  - Energy efficient operation, extended lifetime, energy harvesting.
- Lots of research on random access enhancements:
  - Go for an alternative approach?
Distributed Queuing Random Access

- “Infinite” number of connected devices.
- Overall performance independent of network size / composition.
- Congestion-free under any load conditions:
  - Random access -> reservation access.
- Fair allocation of radio resources.
- Traffic prioritization: QoS-enabled
- Collision-free data transmissions
- Minimization of idle periods (no random backoff).
- PHY-layer agnostic.
Distributed Queuing Random Access

• Frame structure:

![Frame structure diagram]

• Collision Resolution Algorithm (CRA) separate from Data Transmission.
  • If CRA faster than DT → stable system.
  • No random back-off mechanism…just queues !!

• Two (virtual) distributed queues
  • Data Transmission Queue (DTQ):
    • For devices with successful access requests (ARS).
    • Device in the first position of DTQ transmits data (DATA) in next frame.
  • Collision Resolution Queue (CRQ)
    • For devices with collisions when requesting access (ARS).
    • Devices in the first position of CRQ send new requests (ARS) in next frame.
Example of DQ with 6 devices

(a) Tree-splitting algorithm

- 6 data packets transmitted in 8 frames…just 2 idle frames!!
Experimental validation: IoTWorld

Frame slotted-ALOHA (5 slots, 5 devices)

DQ (5 slots, 5 devices)

DQ – Maximum stable performance

Others suffer from congestion

Traffic load (number of devices)

DQ (5 slots, 10 devices)
Current Status and Prospects

• Extensively validated at the simulation level: LTE, WiFi, WBAN, 3G.
  • A. Laya, L. Alonso, and J. Alonso-Zarate, "Efficient Contention Resolution in Highly Dense LTE Networks for Machine-Type Communications", in Proc. of to IEEE Globecom 2015, December 2015.

• Research projects:
  • Advanced Communications and Information processing in smart grid systems (FP7-607774), ADVANTAGE, Jan 2014 - Dec 2017.

• Potential application areas:
  • Next generation cellular communications (MMC-Massive Machine Communications, 3GPP, 5G, RACH-LTE-A).
  • Evolution of Wi-Fi / short-range communication standards (amendments).
  • RFID…
CONCLUDING REMARKS
Concluding remarks

- Presented research work @ CTTC on:
  - Advanced waveform and transceiver design based on FBMC
  - Novel MAC protocols for massive random access (DQ)
- Extensively validated via simulations and/or prototyping/product development.
- Outcome of publicly-funded research projects and/or industrial contracts.
- Widely described in publications from the literature.
- Ready for standardization work / additional product development?
THANKS FOR YOUR KIND ATTENTION!

QUESTIONS?

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