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Deterministic and cognitive wireless communication system with jamming-resistant capabilities for tactical or industrial communications

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Motivation

- Time-critical and mission-critical application (automotive, aerospace, military…) requirements:
  - Short latency, minimal jitter, deterministic data delivery time, high reliability…
- Traditional challenges:
  - Severe multipath (metallic environments), electro-magnetic interferences, interferences from other wireless communication systems
- New threats:
  - Signal jammers

- Motivation
  - Traditional wireless communication systems do not overcome these challenges and fulfill the requirements at the same time

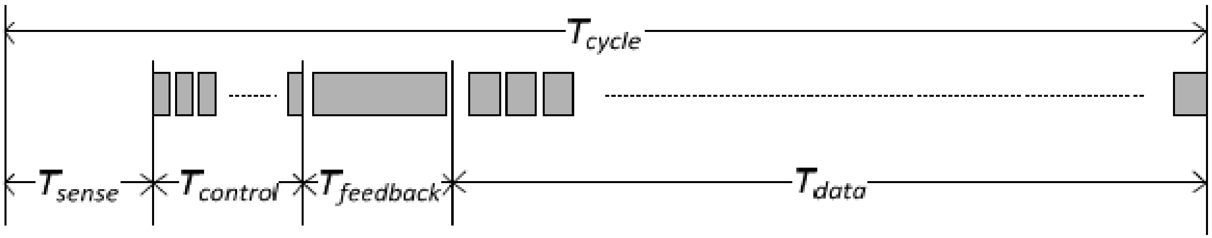
- Technological answer:

Wireless communication systems with:
Deterministic, real-time and cognitive Medium Access Control (MAC) layer

OFDM MODEM OVER FPGA

- OFDM transmitter and receiver
  - Compatible with IEEE 802.11a/g standard at physical layer
- Configurable data rates:
  - 6, 12, 24, 36 and 54 Mbits/s
- FPGA implemented
  - Fully customizable
- HW platform: Nutaq ZeptoSDR
  - ZedBoard (Xilinx Zynq-7000 all programmable SoC)
    - Programmable logic: OFDM modem
    - ARM core + FreeRTOS: MAC layer
  - Nutaq Radio420S reconfigurable front-end
    - Frequency: 300 MHz – 3.8 GHz
    - BW: 1.5 MHz – 28 MHz

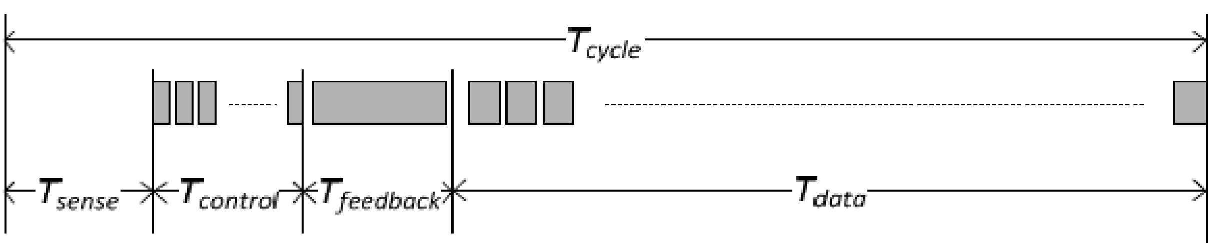
- General characteristics
  - TDMA frame structure
    - Tsense:
      - Nodes and coordinator sense the spectrum
    - Tcontrol:
      - Nodes send spectrum sensing info to coordinator
      - Coordinator acknowledges the reception



DETERMINISTIC, REAL-TIME AND COGNITIVE MAC

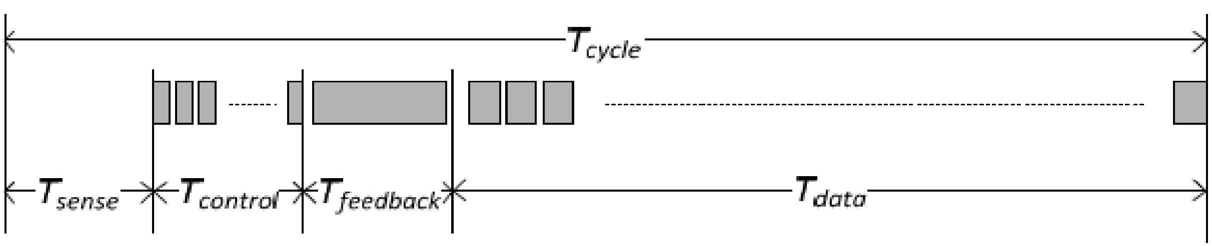
General characteristics

- TDMA frame structure
  - Tfeedback:
    - Coordinator generates a Sorted Channel List (SCL) and sends it to the nodes
    - Least busy channel is the first channel in the list
    - All devices in the net update their working frequency in the next frame
  - Tdata:
    - Normal data transfers between net devices



DETERMINISTIC, REAL-TIME AND COGNITIVE MAC

- Cognitive/Anti-jamming characteristics
  - Sorted Channel List (SCL)
    - Always the least busy channel is used
  - Complete communication jamming detection
    - Info in 'Tcontrol' and ACK from coordinator are compulsory communications
    - A loss of any of these packets is considered an error
    - Jammers cause bursty losses so, after "N" consecutive errors it is considered that a jammer is blocking the communication
    - Every node in the network hops to another band using the SCL



DETERMINISTIC, REAL-TIME AND COGNITIVE MAC

- Theoretical analysis of the packet delivery delay (no interference)
  - Analysis carried out with Network Calculus
  - Maximum delay:

$$d \leq M \cdot c + t_{tx}$$

- d: maximum delay in correct packet delivery
- M: maximum number of retransmissions
- c: frame length
- ttx: transmission time (depends on packet length and bit rate)

DETERMINISTIC, REAL-TIME AND COGNITIVE MAC

- Theoretical analysis of system recovery time under interference
  - Analysis carried out with Network Calculus:
  - Maximum recovery time:

$$rt \leq N \cdot l \cdot c + t_{tx}$$

- rt: maximum recovery time under interference
- N: numbers of bands simultaneously interfered
- l: number of consecutive communication errors that the network accepts
- c: frame length

DETERMINISTIC, REAL-TIME AND COGNITIVE MAC

FS	SS	N1	FB	TX	RX	Tx Service	Rx Service
150 us	450us	600us	600us	600us	600us	350us	500us

- Real implementation
  - Frame length: 3850 us
  - Maximum supported communication errors: 3
  - Maximum number of retransmissions: 4
  - Modem configuration: 12 Mbps – 50 Byte messages
  - Available frequencies: 868 MHz, 1.1 GHz, 1.2 GHz, 2.4 GHz
- Maximum packet delivery delay

$$d \leq 4 \cdot 3850 + 600 \xrightarrow{yields} d \leq \ 16\ ms$$

- Maximum system recovery time (2 interfered bands)

$$rt \leq 2 \cdot 3 \cdot 3850 + 600 \xrightarrow{yields} rt \leq \ 23.7\ ms$$

MEASUREMENTS

- FPGA implementation
  - FPGA resource utilization

TABLE I: FPGA RESOURCE UTILIZATION

	SLICE	REGISTER	LUT	DSP	BRAM 18 kbits
Number	11612	38637	33805	180	140
Percentage	87%	36%	63%	81%	25%

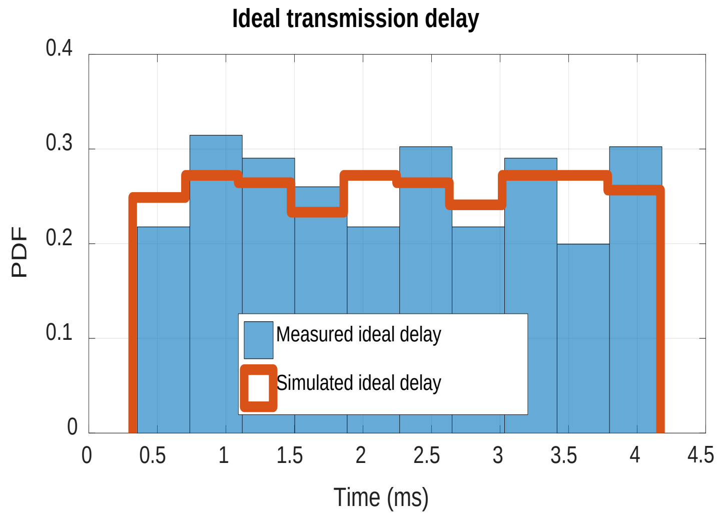
  - RF front-end frequency change time

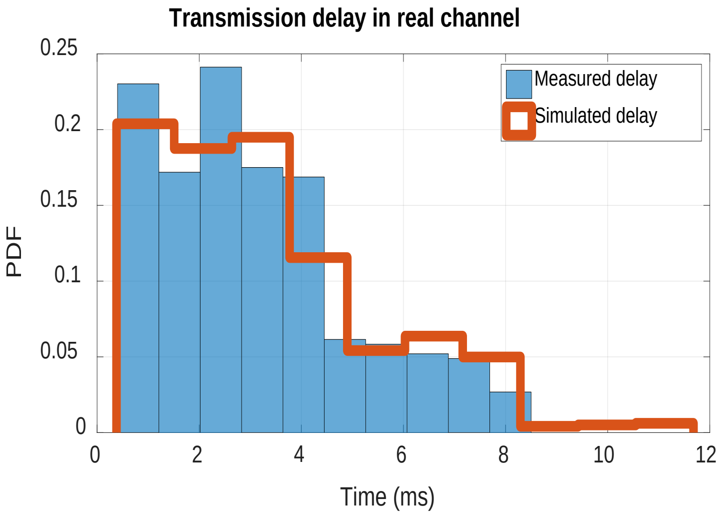
TABLE II: FREQUENCY CHANGE TIME

	Change Time
Band change	191 us
Channel change	50 us

Deterministic and real-time behaviour

– OPNET simulations + real measurements





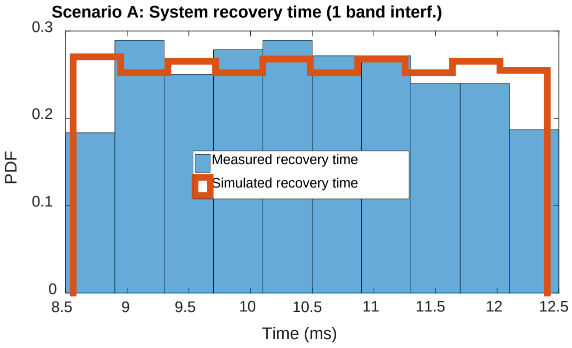
- No interference, no packet loss, no retransmissions
- Delay bounded to a single frame length

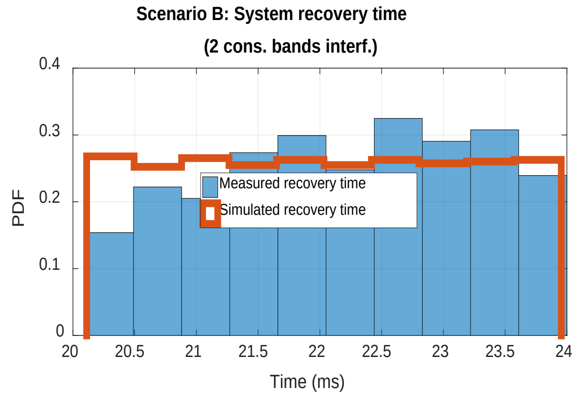
- WiFi interferences. Sporadic packet loss
- Handoff algorithm disabled
- 0 ,1 or 2 retransmissions
- Delay < 16 ms (theoretical result)

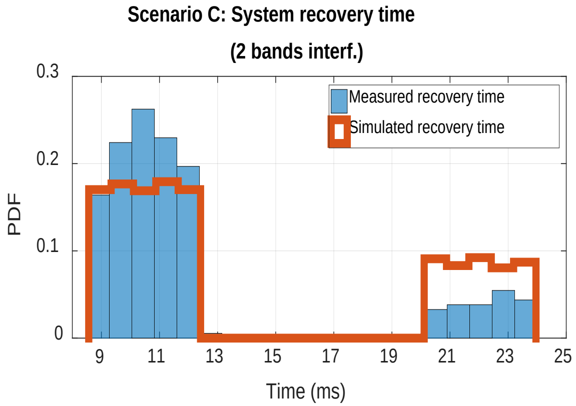
- Jamming-resistant behaviour
  - OPNET simulations + real measurements
  - Handoff algorithm enabled
  - Scenarios
    - A: Only the frequency in which the communication system is working is interfered. Single frequency hop
    - B: The frequency in which the communication system is working and the next one in the SCL are interfered. Two frequency hops.
    - C: The frequency in which the communication system is working and another band are interfered. Randomly, depending on the state of the SCL, one or two frequency hops happen.

MEASUREMENTS

Jamming-resistant behaviour





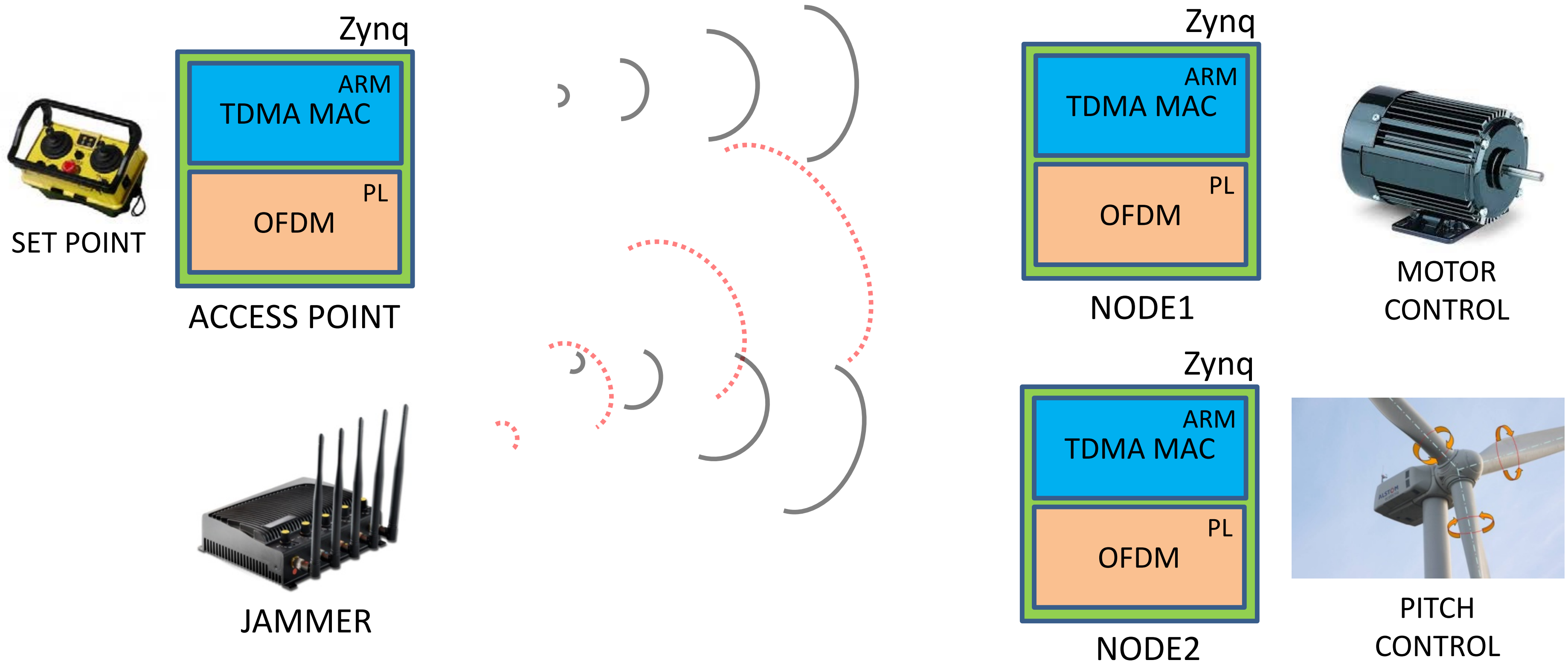


- Recovery time is bounded between 8.5 and 12.5 ms
- 2 to 3 frames plus a slot of the next one
- Loss of 3 consecutive feedback messages or ACKs

- Recovery time is bounded between 20 and 23.7 ms
- Loss of 5 to 6 consecutive frames
- Two consecutive recovery processes
- Recovery time < 23.7 ms (theoretical result)

- Recovery time is bounded between 8.5 and 23.7 ms
- Mixture of previous scenarios
- SCL effect in the real scenario
- Recovery time < 23.7 ms (theoretical result)

DEMONSTRATOR



Main features:

- 1 Access point (set point) and 2 nodes (motor control and pitch control)
- 868 MHz, 1GHz, 1.2 GHz and 2.4 GHz bands
- Jammer and USRP interference sources

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DEMONSTRATOR

CONCLUSIONS AND FUTURE WORK

Conclusions

- Small form factor OFDM communication system
- Proposed MAC layer:
  - Behaves in a real-time and deterministic way, achieving bonded data delivery times
  - Its cognitive features, which provide the system with jamming-resistant features, allow the communication system to recover from a malicious interference in a short and deterministic time
- Presented system can be used in time-critical and mission critical industrial or tactical applications

Future work

- Improvement of the spectrum sensing algorithm
  - Cyclostationary signal detector -> distinguish different interference types

QUESTIONS