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

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- Introduction
 - Motivation
 - Technological answer
- Implementation
 - OFDM modem over FPGA
 - Deterministic, Real-Time and Cognitive MAC
- Measurements
- Demonstrator
- Conclusions and future work
- Questions

● 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), electromagnetic 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:

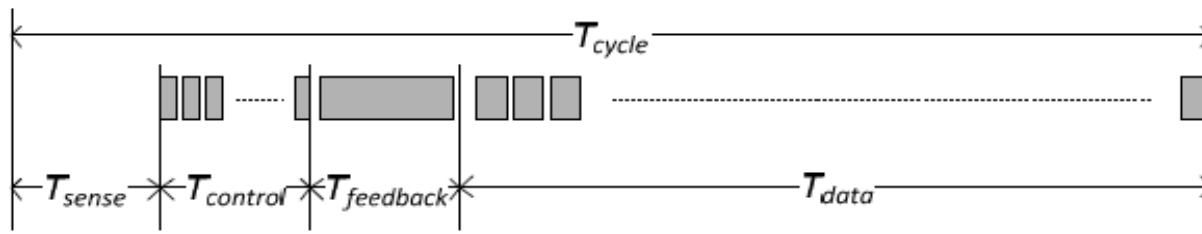
Wireless communication systems with:
Deterministic, real-time and cognitive Medium
Access Control (MAC) layer

- OFDM 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

- T_{sense} :
 - Nodes and coordinator sense the spectrum
- $T_{control}$:
 - Nodes send spectrum sensing info to coordinator
 - Coordinator acknowledges the reception



General characteristics

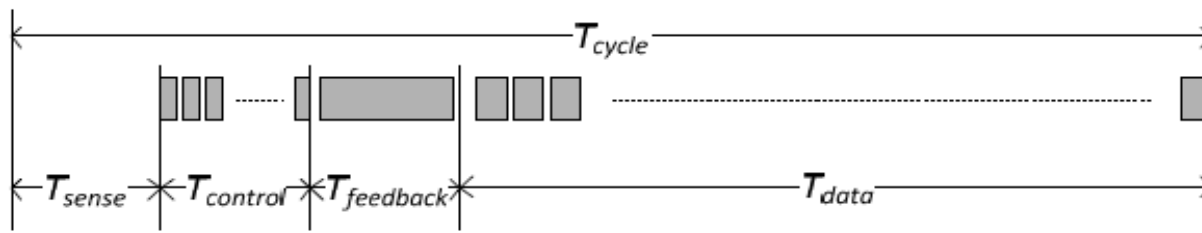
– TDMA frame structure

• T_{feedback}:

- 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

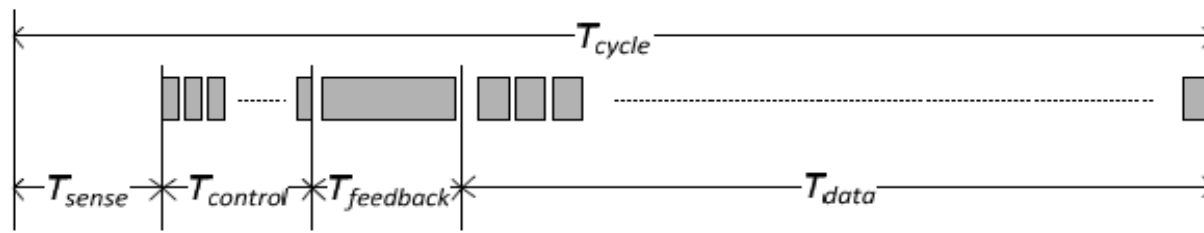
• T_{data}:

- Normal data transfers between net devices



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



● 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)

● Theoretical analysis of system recovery time under interference

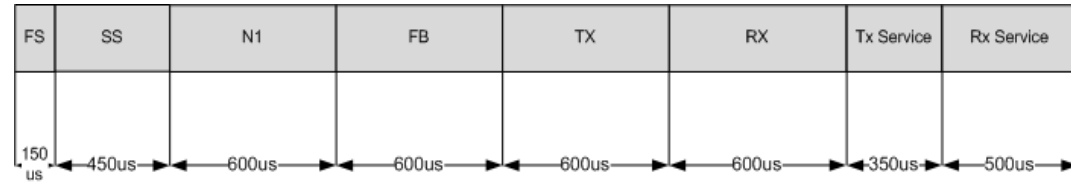
- Analysis carried out with Network Calculus:
- Maximum recovery time:

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

- 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

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

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

Maximum system recovery time (2 interfered bands)

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

● 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%

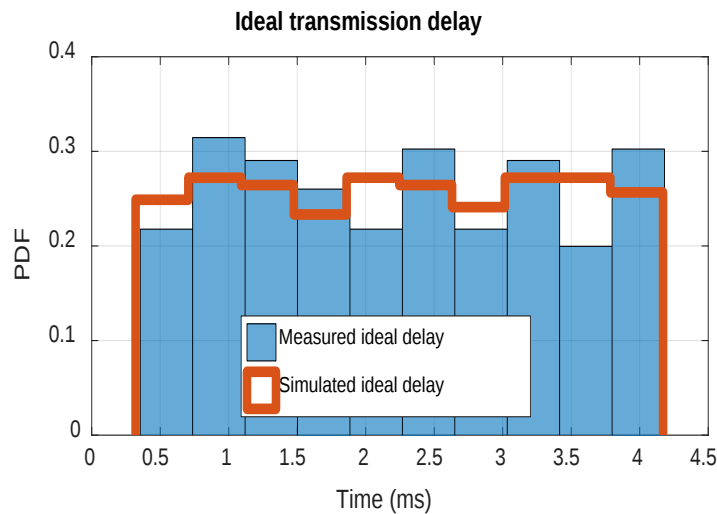
- RF front-end frequency change time

TABLE II: FREQUENCY CHANGE TIME

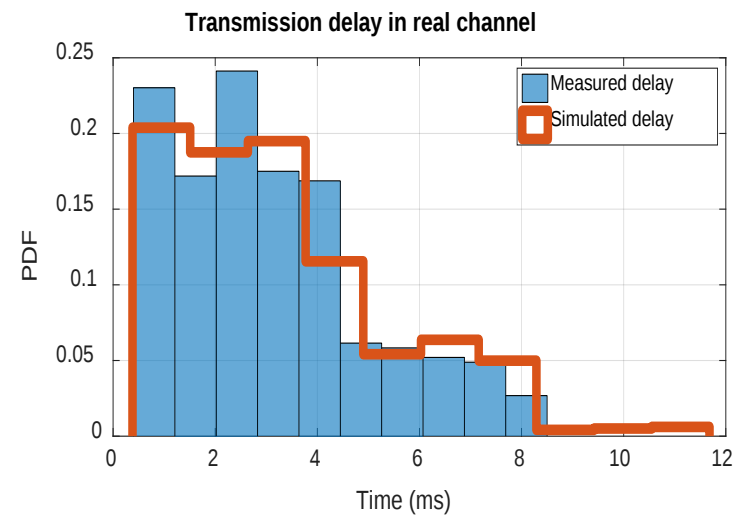
	Change Time
Band change	191 us
Channel change	50 us

Deterministic and real-time behaviour

- OPNET simulations + real measurements



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

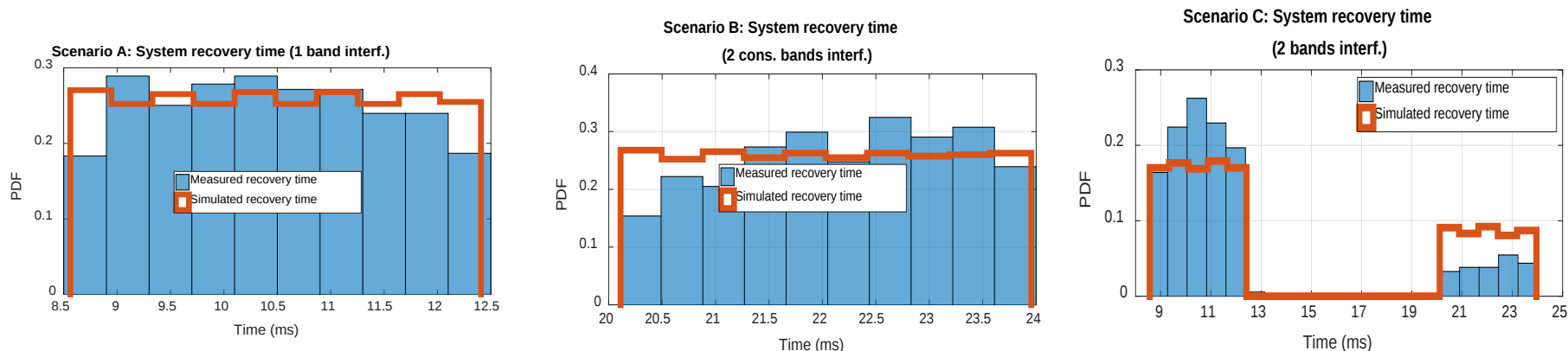


- WiFi interferences. Sporadic packet loss
- Handoff algorithm disabled
- 0 ,1 or 2 retransmissions
- Delay < 16 ms (theoretical result)

● 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.

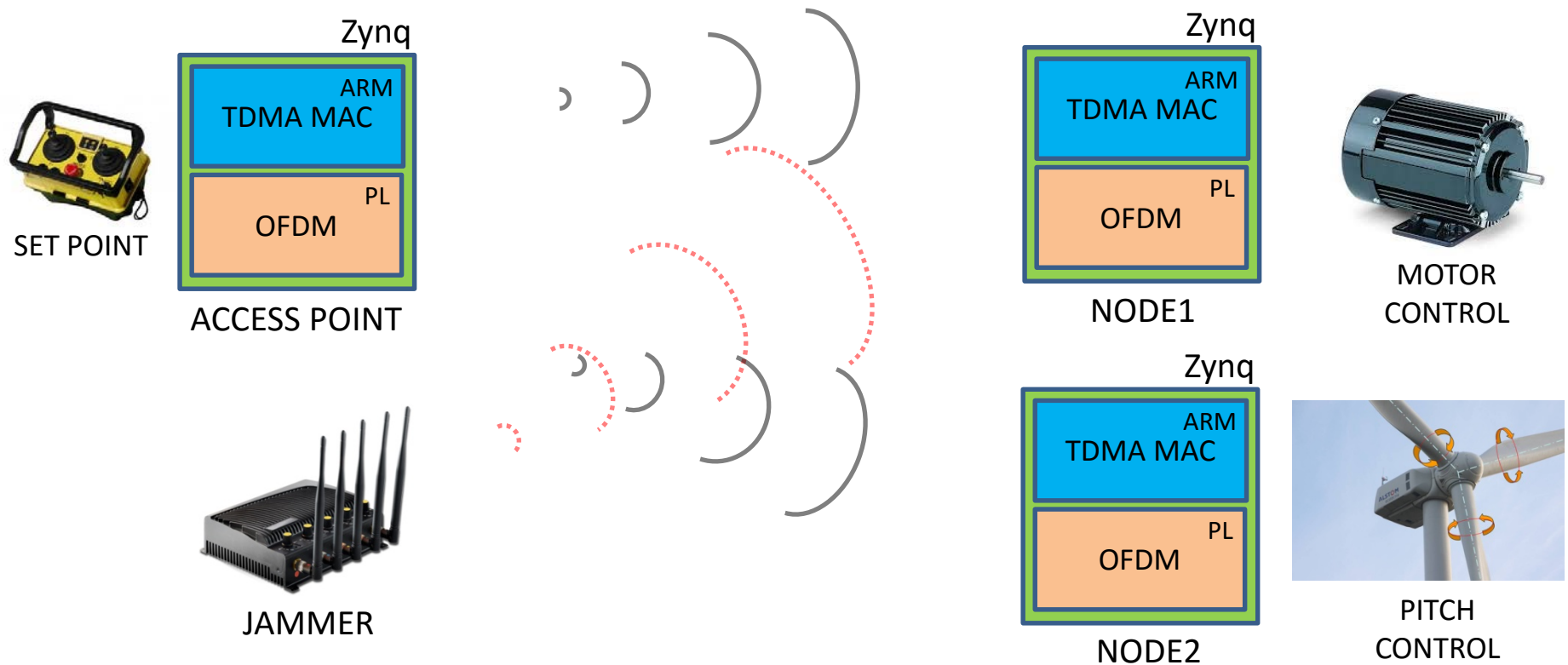
Jamming-resistant behaviour



- 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)



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



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

