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Dynamic Spectrum Allocation Algorithms Implementation on FPGA for SDR Systems

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***Abstract*— Dynamic Spectrum Access (DSA) is an innovative approach to managing radio frequency resources that allows adapting to changing air conditions. With the growing number of wireless devices and a shortage of free spectrum, this technology is becoming key for modern communication systems. The paper examines the implementation of DSA based on a bundle of software-defined radio (SDR) and Field-Programmable Gate Arrays (FPGAs), providing high flexibility and performance. Algorithms for spectral sensing, adaptive modulation and device coordination, as well as practical aspects of their implementation are considered. Particular attention is paid to the challenges: algorithm complexity, legal restrictions and security. The report demonstrates the potential of DSA for Internet of Things (IoT), 5G/6G and cognitive radio (CR).**

Keywords*— Dynamic Spectrum Allocation, SDR, FPGA, Cognitive Radio, Spectral Sensing, TV White Spaces, Adaptive Algorithms, IEEE 802.22

I. Introduction

The growing shortage of radio frequency spectrum caused by the exponential increase in the number of wireless devices requires fundamentally new approaches to resource management. Dynamic Spectrum Access (DSA) solves this problem by adaptively redistributing frequency channels based on an analysis of the current airtime load [1]. The technology has become especially relevant with the development of cognitive radio (CR), where intelligent systems independently make decisions on the selection of transmission parameters [2].

The integration of DSA with software-defined radio (SDR) and Field-Programmable Gate Arrays (FPGAs) opens up unique possibilities: SDR provides software reconfiguration of signal parameters, and FPGAs provide high-speed data processing in real time. The paper analyzes algorithms, architectural solutions and practical examples of DSA implementation on this platform.

II. Historical context

The evolution of DSA began in the 1920s–1940s with manual frequency tuning, but the real breakthrough came in the 1990s with the work of Joseph Mitola on cognitive radio (CR) [3]. In the 2000s, the IEEE 802.22 (Wireless Regional Area Network – WRAN) standard became the first industrial application of DSA, using TV band white spots (TV White Spaces – TVWS) [4]. Since the 2010s, the technology has been actively implemented in 5G, Internet of Things (IoT), and civil systems (e.g., Citizens Broadband Radio Service – CBRS in the USA), which was facilitated by the spread of SDR platforms (USRP, RTL-SDR) [5].

III. DSA principles and key technologies

DSA is based on three processes:

1. Dynamic frequency allocation – redistribution of channels between users based on their current load.
2. Spectral sensing – detection of unoccupied areas of the spectrum (e.g., Energy Detection or Cyclostationary Feature Detection) [6].
3. Device coordination – collision avoidance using Medium Access Control (MAC)-layer algorithms.

Practical implementations include:

- TV White Spaces (TVWS) – use of free TV frequencies,
- Licensed Shared Access (LSA) – division of licensed spectrum,
- Citizens Broadband Radio Service (CBRS) – dynamic access in the 3.5 GHz range [7].

IV. Implementation of DSA on SDR and FPGA

3.1. The Role of SDR

SDR platforms (USRP, HackRF) provide flexibility: frequency, modulation and bandwidth tuning by software. For example, the GNU Radio + RTL-SDR bundle allows deploying a spectrum analysis system in a few hours [8].

3.2. Advantages of FPGA

FPGAs (Xilinx Zynq, Intel Cyclone) solve delay-critical tasks:

- Parallel Fast Fourier Transform (FFT) processing for spectrum detection,
- Real-time signal filtering,
- Adaptive coding (QPSK → 16-QAM transition with increasing Signal-to-Noise Ratio – SNR) [9].

3.3. Example of a technology stack

1. Hardware layer: Antenna + Analog-to-Digital Converter / Digital-to-Analog Converter (ADC/DAC) (e.g., AD9361 chip).
2. FPGA: Low-level signal processing (VHDL/Verilog).
3. SDR drivers: USRP Hardware Driver (UHD) for radio parameter control.
4. DSA Algorithms: Python/C++ for the Cognitive Cycle (executed on the Central Processing Unit – CPU) (Fig. 1).

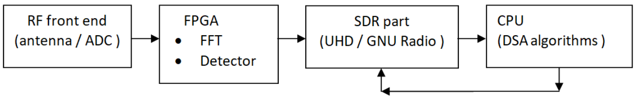

Figure 1 – Architecture of the DSA system on FPGA + SDR

V. Challenges and Prospects

Advantages:
- Spectrum efficiency (increase in network capacity up to 40% [10]),
- Support for mass IoT communications,
- Compatibility with 6G.

Problems:
- Complexity of algorithms (require optimization for FPGA),
- Security vulnerabilities (e.g., primary user emulation attacks on spectral sensing),
- Legal barriers (frequency licensing).

Promising directions:
- Integration with Artificial Intelligence (AI): Predicting "windows" in the spectrum using neural networks,
- Quantum sensors for improved sensing accuracy,
- Blockchain for secure resource distribution [11].

VI. Conclusions

DSA implemented on the basis of SDR and FPGAs forms the foundation for next-generation intelligent radio systems. The combination of software flexibility in SDR with high performance of FPGAs enables real-time dynamic spectrum management, critical for 5G/6G, IoT, and cognitive radio. Despite technical and regulatory challenges, the technology's potential is confirmed by successful implementations (IEEE 802.22, CBRS). Future advancements will leverage machine learning and standardized cross-domain solutions.

VII. References

[1] Mitola J. Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio. PhD Thesis, KTH, 2000.

[2] Federal Communications Commission. Spectrum Policy Task Force Report. ET Docket No. 02-135, 2002.

[3] Mitola J., Maguire G. Cognitive radio: making software radios more personal. IEEE Personal Communications. 1999;6(4):13–18.

[4] IEEE Standard 802.22-2011: Wireless Regional Area Networks.

[5] Zhao Q., Sadler B. A Survey of Dynamic Spectrum Access. IEEE Signal Processing Magazine. 2007;24(3):79–89.

[6] Haykin S. Cognitive radio: brain-empowered wireless communications. IEEE Journal on Selected Areas in Communications. 2005;23(2):201–220.

[7] Bajj M. et al. CBRS Spectrum Sharing. IEEE Wireless Communications. 2020;27(3):110–117.

[8] Blossom E. GNU Radio: tools for exploring the radio frequency spectrum. Linux Journal. 2004;122:4.

[9] Wang Y. et al. FPGA-Based Accelerator for Spectrum Sensing in Cognitive Radio. IEEE Transactions on Circuits and Systems. 2018;65(9):1201–1214.

[10] Palicot J., Moy C. Dynamic Spectrum Access: From Cognitive Radio to Network Reconfiguration. IET Communications. 2013;7(11):1029–1038.

[11] Chen X. et al. AI-Driven Dynamic Spectrum Sharing for 6G. IEEE Network. 2022;36(4):106–113.