RFSoC Implementation of Runtime Reconfigurable Numerologies for 5G New Radio

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Introduction

5G New Radio (5G NR) provides benefits to environments which require increased bandwidth and ultra-low latency compared to 4G LTE. To enable these requirements and use the Radio Frequency (RF) spectrum as effectively as possible across both sub-6GHz and mmWave frequency bands, 5G NR requires maximum flexibility.

This work aims to focus on this flexibility requirement to create an adaptive, hardware based single-chip transmitter targeted towards the RFSoC 4x2 platform which can switch between Subcarrier Spacing (SCS) numerology options at runtime through AMD PYNQ control.

RFSoC & PYNQ

AMD RFSoC devices combine multi-GHz radio frequency receivers & transmitters, Programmable Logic (FPGA fabric) and an Arm-based Processing System (PS) on a single silicon chip. Noteably, the RFSoC 4x2 (pictured below) has 2 RF-DAC channels and 4 RF-ADC channels, which can operate at 10Gsps and 5Gsps respectively.

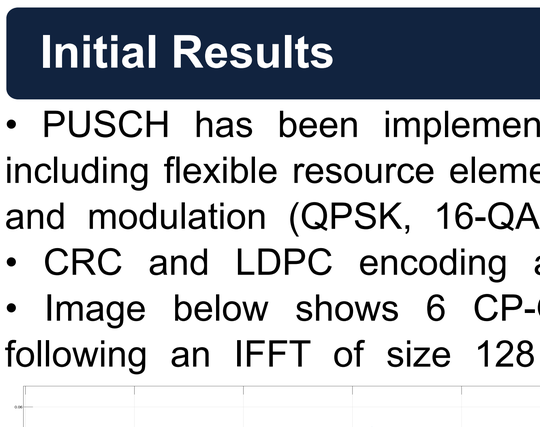

Figure 2: RFSoC 4x2 Development Platform from AMD

This project utalises the PYNQ open-source project from AMD which provides productivity-focused Linux OS images for AMD SoC-based boards, including the RFSoC 4x2 allowing for Python based control of the 5G system.

Applications of Flexible RFSoC 5G NR

- Accessible, easily reconfigured 5G NR transmitter to aid research, utalising RFSoC as a UE for differing deployment senarios, frequency bands and use cases.
- Flexible numerology enabling a radio system which can adapt to changing conditions, such as interference and multipath propogation enabling simulated environment studies using RF capable hardware.

Initial Results

- PUSCH has been implemented through HDL Coder, including flexible resource element usage, information bits and modulation (QPSK, 16-QAM, 64-QAM, 256-QAM).
- CRC and LDPC encoding and rate matching.
- Image below shows 6 CP-OFDM PUSCH symbols, following an IFFT of size 128 (BW = 1.4 MHz)

Figure 4: Initial CP-OFDM Results from 5G NR PUSCH

Sponsor & Special Thanks

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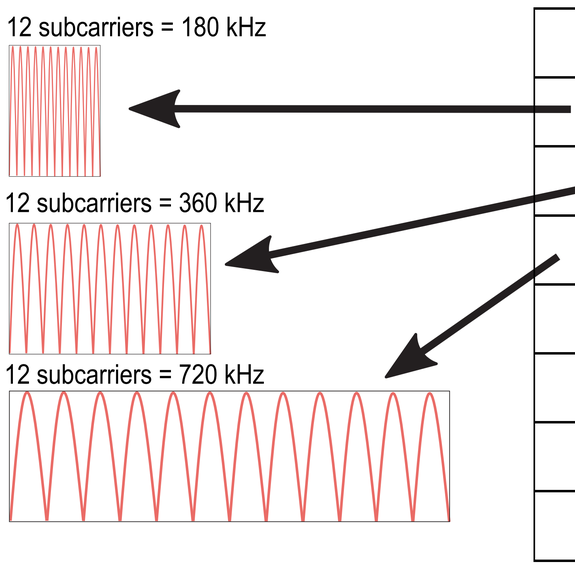
CP-OFDM Numerologies

One of the key aspects of 5G NR flexibility are the seven Cyclic Prefix OFDM (CP-OFDM) numerologies (μ in the table below) which define a range of supported carrier modulation options. These impact subcarrier spacing, Cyclic Prefix length and slot duration, enabling the single 5G NR standard to support a range of applications and frequency bands. For example, at sub-6GHz frequencies spectrum is at a premium and so a small SCS such as μ = 0, 1, 2 are preferred, whereas mmWave frequencies are more susceptable to transmission errors which are easier to mitigate with space between subcarriers, so SCS option such as μ = 3, 4, 5, 6 are often chosen.



μ	$\Delta f = 2^{\mu} \times 15$ [kHz]	**Cyclic Prefix**
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal
5	480	Normal
6	960	Normal

Figure 1: Supported Transmission Numerologies and Associated CP-OFDM Waveforms as of 3GPP 38.211 v17.2

System Concept

- Implementation of a full hardware solution 5G NR transmitter using an RFSoC 4x2
- Uplink transmission, with the RFSoC 4x2 acting as User Equipment which could send data to a basestation
- Includes Physical Uplink Shared Channel (PUSCH) and Physical Broadcast Channel Synchronisation Signal (PBCH/SS) to the 3GPP Release 17 standard.
- Loopback configuration - transmit and receive on a single platform.
- Radio Resource Control (RRC) parameters through user friendly PYNQ GUI alongside runtime reconfigurable subcarrier spacing options enabling the system to generate adaptable radio frames, with variable slot sizes and PBCH/SS transmission patterns.

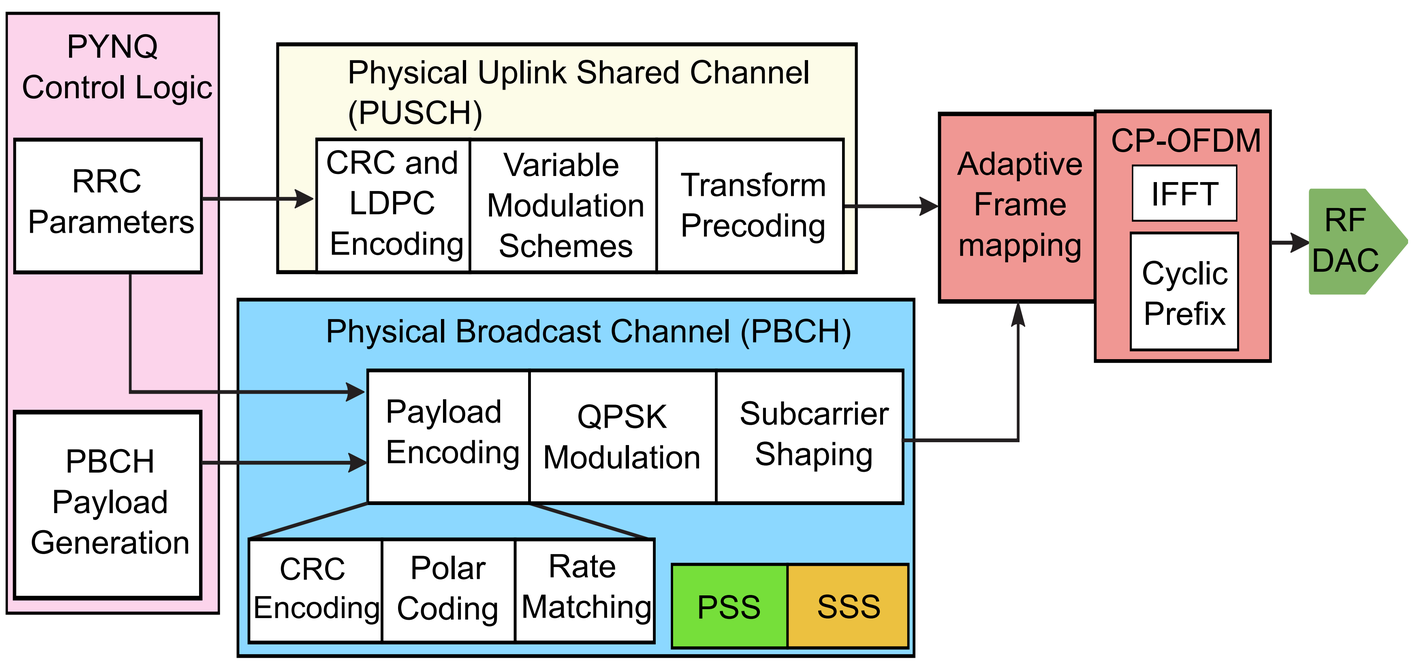


Figure 3: High Level Overview of the Proposed 5G NR Transmitter System

Future Work

This work can extended through the implemention of reconfigurable Carrier Bandwidth Parts on the RFSoC 4x2, utalising a contiguous subset of subcarriers within the bandwidth of the base station for mutliplexed mixed numerology URLLC applications. Such bands could be dynamically switched between, enabling low power monitoring or mixed mobile traffic.

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See StrathSDR GitHub for open source material related to RFSoC and SDR.