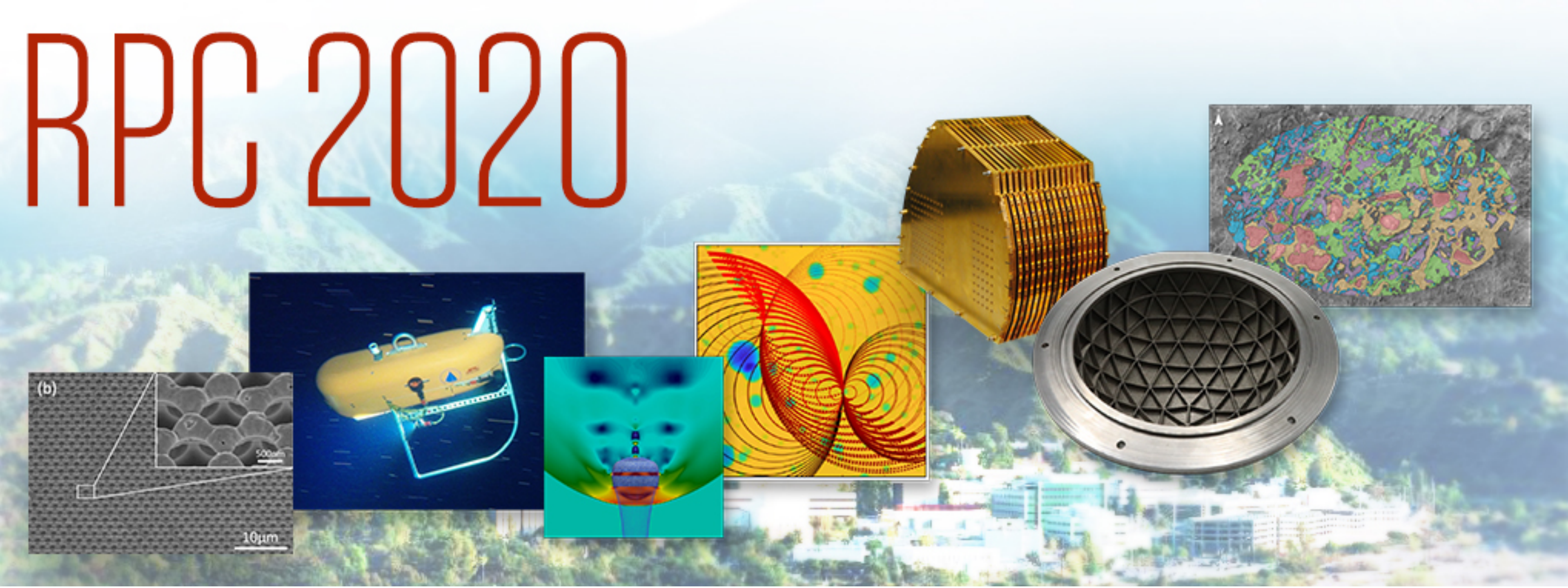

Virtual Research Presentation Conference

Low SWaP Telecom and Radio Metrics via Snapdragon

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Tutorial Introduction

Abstract

Modern-day mobile processors, such as the Qualcomm Snapdragon are capable of an enormous amount of processing, while consuming very little power. JPL is currently working with Qualcomm to develop this technology for flight projects such as avionics and co-processors.

This SRTD, on the other hand, concentrates on the use of the Snapdragon SoC as a basis for a JPL radio. We believe that this technology can meet telecom and radio metric requirements while consuming a fraction of the power of traditional radios.

With this SRTD, we performed initial implementation of CCSDS compatible processing on the Snapdragon and studied the power requirements as well as the performance for telecom.

The Snapdragon SoC consists of:

- 8-Core ARM CPU (**Kyro**)
  - Up to 2.84GHz
  - Capable of general purpose processing (fixed-point, floating-point, and branching)
- Leading GPU Technology (**Adreno**)
  - > 500MHz clock frequency
  - Optimized for floating-point vector/matrix processing
  - Used for efficient machine learning inference
- DSP Capability (**Hexagon**)
  - 15 TOPS
  - Up to 2GHz fixed-point processing capability, including vector and matrix arithmetic
  - Used for modem processing
  - Used for efficient machine learning inference
- WiFi, Bluetooth, 4G, and 5G Modems

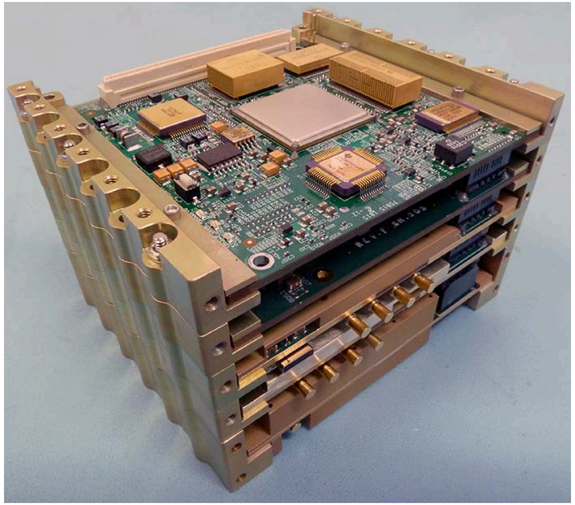
Problem Description

a) The lowest Size, Weight, and Power (SWaP) Deep Space qualified radio is the software defined Iris radio at 1.1 kg and 16 watts DC sans RF amplifier. This SWaP is not very amiable for mass, power and energy challenged missions such as Mars Helicopter-2 and power starved small craft supporting outer planet missions. For example, Mars Helicopter *Ingenuity* uses a COTS Zigbee radio that does not utilize CCSDS standard signaling.

b) A Snapdragon based flight transponder was initially estimated at 200 grams, 5.5 watts in Tx/Rx operation, 3.5 watts in Rx-only mode and 0.3 watts in standby. This would be a huge benefit for highly integrated missions (such as helicopters, impact landers) or outer planet missions that have very tight power and energy constraints.

c) JPL is currently partnering with Qualcomm to develop a Snapdragon-based platform for avionics and processing. If future missions were to use this platform for CDH and/or processing, then it would be also advantageous to integrate telecommunications and radio metrics within the same platform.

JPL Iris Radio

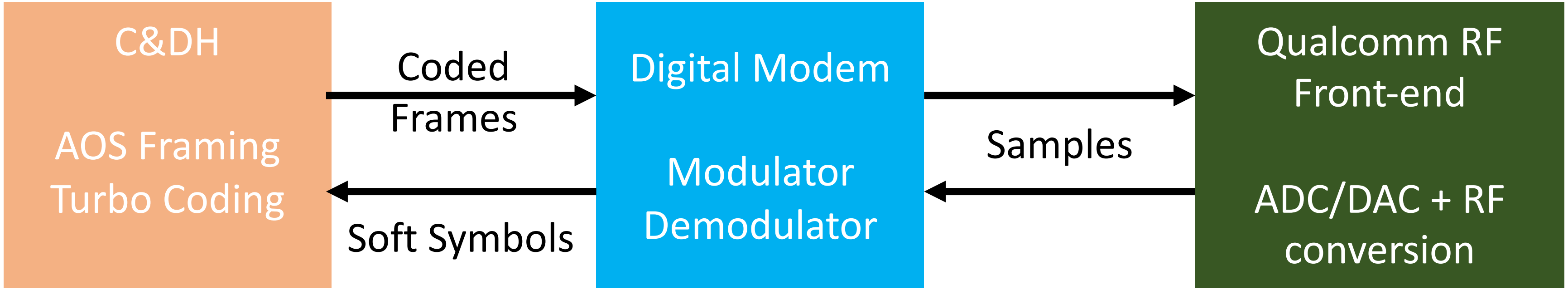


Methodology

a) Characterization of phase-noise and phase-coherence performance requires active collaboration with Qualcomm. Since this was not available during this SRTD, we concentrated on the digital processing capability of the Snapdragon radio to support telecom and radio metrics.

b) We divided the study into four parts:

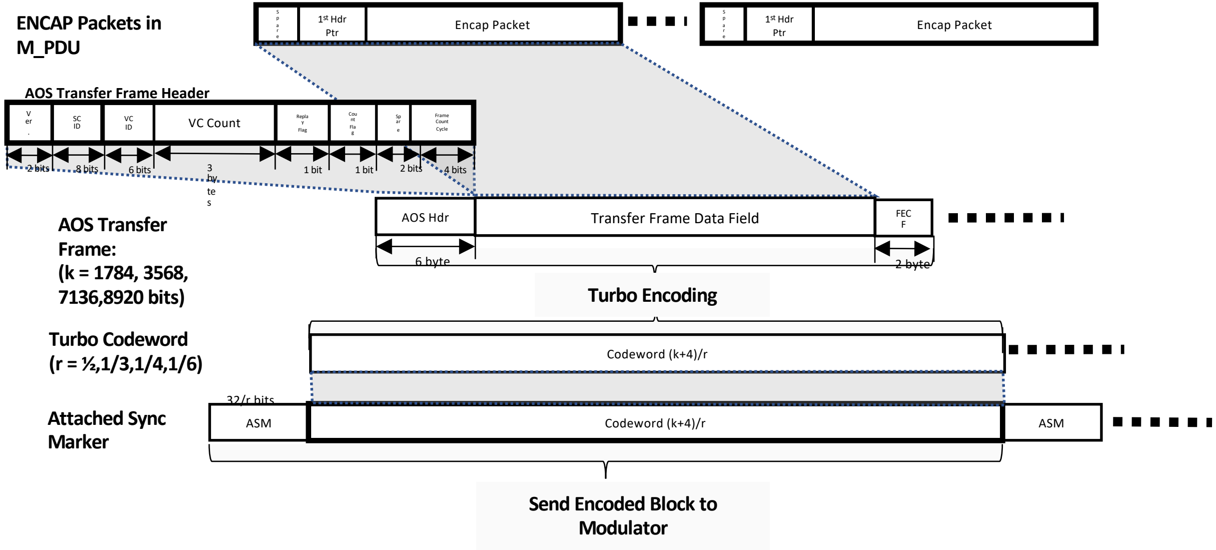
1) Evaluation of the Snapdragon capability for AOS framing and frame Turbo and Reed-Solomon encoding.
2) Evaluation of the Snapdragon capability for signal processing for CCSDS waveform standards.
3) Evaluation of the Snapdragon's DSP subsystem capability for power optimization.
4) Evaluation of the Snapdragon's Neural Network capability.



Results (1/4): AOS Framing and Encoding

Ported and tested CCSDS Encapsulation and AOS Protocols stack for both transmit and receive sides on Snapdragon sm8150 development board

1. Accepts variable-length data blocks from C&DH function
2. Multiplex and de-multiplex up to 4 virtual channels simultaneously
3. Integrated with Turbo encoder to provide coded frame to modulator



Results (2/4): Signal Processing

- Implementation of current CCSDS modems cannot be done trivially for the Snapdragon as it is not firmware.
- The following waveforms were implemented for the modulator:
  - Subcarrier modulation with configurable modulation-index
  - Direct Carrier Modulation (Residual Carrier, Bi-Phase) with configurable modulation-index.
  - Direct Carrier Modulation (Suppressed Carrier, NRZ) with configurable modulation-index.
- The following waveforms were implemented for the demodulator:
  - Direct Carrier Modulation (Residual Carrier, Bi-Phase).
  - Direct Carrier Modulation (Suppressed Carrier, NRZ).
- The demodulator consisted of:
  - Automatic Gain Control
  - Carrier Tracking Loop
  - Carrier Tracking Loop Lock Detector
  - Symbol Tracking Loop
  - Symbol Tracking Loop Lock Detector

Configuration	Achieved Rate on ARM Processor
Modulation NRZ ½ Turbo (K=8920)	4+ Mbps
Demodulation NRZ uncoded	2.6+ Mbps
Modulation Biphase ½ Turbo (K=8920)	4+ Mbps
Demodulation Biphase uncoded	1.6+ Mbps
Modulation 281.25KHz Subcarrier ½ Turbo (K=8920)	64+ kbps (generally subcarrier modulation is for low bitrates such as 4 to 8 kbps)

Results (3/4): Digital Signal Processor

- While we were able to achieve satisfactory performance by implementing the signal processing blocks on the Snapdragon's ARM CPUs, Significant power savings are potentially realized by instead porting them to the Snapdragon's DSP subsystem. Thus, we ported the modulator to the DSP.
- A single-threaded modulator executed on the DSP was demonstrated to achieve 2.4Mbps for the NRZ (Suppressed Carrier) waveform. This utilized approximately 100mW of power over the baseline Snapdragon power requirement.
- The modulator is also parallelizable, and the scaling on the DSP was found to follow:

Number of Threads	Scaling
1 Thread	1.00x
2 Threads	1.88x
3 Threads	2.56x
4 Threads	2.88x
5 Threads	3.30x
6 Threads	3.20x

- The DSP only has 4 hardware threads. During the three-thread operation of the modulator (achieving >5Mbps), a power requirement of 400mW was measured (over the baseline Snapdragon power requirement).

Results (4/4): Machine Learning

- We utilized a standard benchmark neural network for comparison of the Snapdragon Neural Network processing capability to standard platforms.

Platform	Per Image Inference Time (µs)	Per Image Energy Utilization (J)
3.3 GHz i7-6567U, up to 3.6 GHz, 2C (MacBook Pro 2016)	58500	1.64
4.0 GHz i7-4790K, up to 4.3 GHz, 4C (Desktop Machine from 2014)	33300	1.33
nVidia GTX 1080Ti (High-end GPU from 2017)	2840	0.23
Snapdragon 855 Development Board from 2019, CPU Engine	**97120**	**0.60**
Snapdragon 855 Development Board from 2019, GPU Engine	**19380**	**0.10**
Snapdragon 855 Development Board from 2019, DSP Engine	**9620**	**0.03**

- The DSP inference subsystem on the Snapdragon was found to provide the best trade-off between speed and energy consumption.
  - However, when the DSP is unavailable (due to being utilized for other functions), the GPU also provides satisfactory performance.

Result Summary and Future Work

a) We were able to assess the *digital* capability of the Snapdragon and found that it is sufficient for mid-to-high bitrate applications (on the order of 1Mbps to 10Mbps) at power consumption levels of a couple of Watts. In addition, the machine-learning capability of the Snapdragon was evaluated and found to be comparable (only 3x slower) than high-power desktop GPUs while simultaneously requiring 10x less energy per inference as a modern desktop GPU.

b) We believe that the digital capability of the Snapdragon is more than sufficient for telecom highly integrated missions. Given the nature of the Snapdragon modem (i.e., telecommunications), we believe that the Snapdragon RF chain would also be able to support CCSDS telecom.

c) However, further work must be done to ensure that the RF chain is satisfactory for radio metrics and navigation waveforms. Unfortunately, we have not been able to evaluate the RF chain of the Snapdragon radio due to limited funding. We hope that this can be accomplished in the future, with Qualcomm on contract to support such evaluation.

Publications and References

Future Publication:

Z. J. Towfic and O. B. Pooladzandi, "On-Board Spacecraft Radio Anomaly Detection via Time-Series Analysis," to be submitted.