SWIFT: Exploiting Application Semantics in Intelligent Cross-Layer Design to Enhance End-to-End Spectrum Efficiency

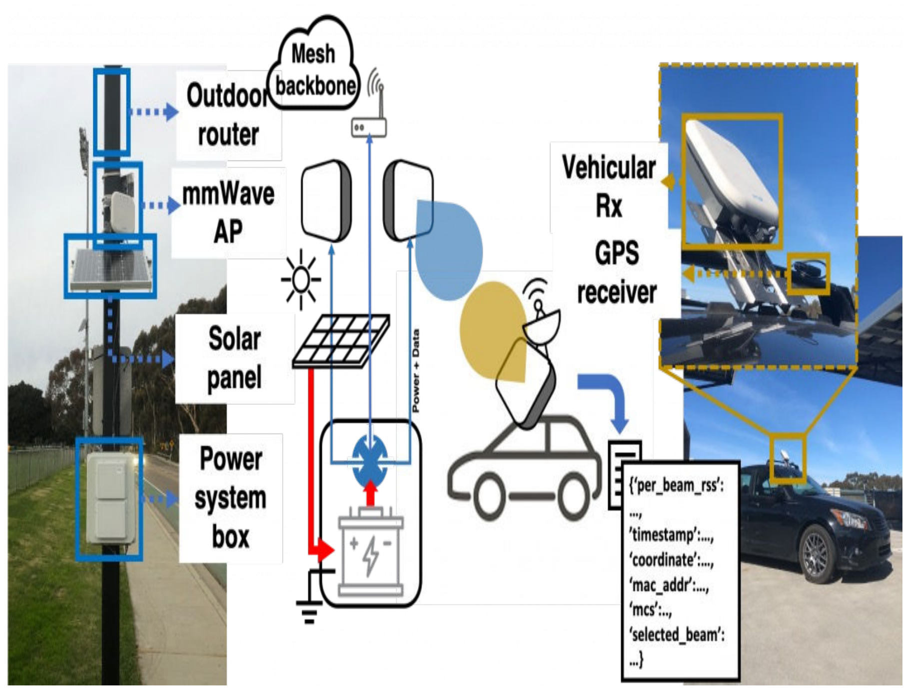
Zhi-Li Zhang, Feng Qian (U. of Minnesota/U. of Southern California, CNS-2128489)
Xinyu Zhang (U. of California San Diego, CNS-2128588)

Project Vision, Objectives, Research Thrusts and Key Approaches

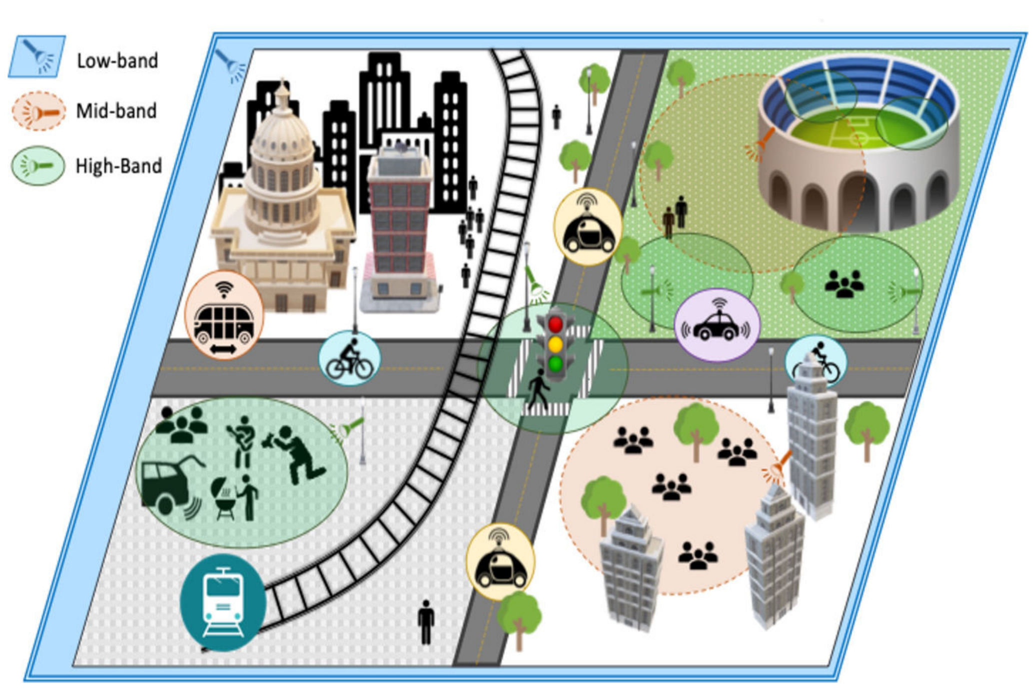
End-to-end Spectrum Efficiency: Instead of merely measuring the spectrum utilization efficiency at PHY/MAC or radio networks alone, we argue that it is important to quantify spectrum efficiency from the end-to-end application perspective – thus the notion of *end-to-end spectrum efficiency*: namely, what is the "utility" of data being transported over radio networks (with the allocated spectrum resources) to the application?

Proposed Research Thrusts:

- Thrust 1. Semantics-Oriented Data Refactoring and Environment/Contextual Learning
- Thrust 2. Exploiting Application Semantics for Cross-Layer PHY/MAC Mechanisms
- Thrust 3. Upper Layer Mechanisms for End-to-End Spectrum Efficiency & Co-Existence
- Thrust 4. Measurement, Prototype Development & V2X Experiments & Evaluation



(a) UCSD V2X testbed



(b) V2X scenario

(c) Multi-Modal 5G Measurement Setup

Design Principles & Approaches for Maximizing End-to-End Spectrum Efficiency:

a) Exploiting Application Semantics via Data Refactoring as well as Radio Diversity to Enable Intelligent Radio Network Decision Making

b) Built-in, Collaborative, Long-Term Continual & Contextual Learning

c) Intelligent Cross-Layer, Dynamic Resource Allocation and End-to-End Adaptation

Research Progress – Intellectual Merit:

- Developed a novel cross-medium communication system that extends the RF spectrum underwater, which includes novel underwater antenna design and passive 3D printed bianisotropic metasurface to expand spectrum utilization under water
- Developed a semantics-aware, fine-grained, cross-layer NextG RAN architecture to enhance end-to-end spectrum efficiency
- Built a smart band switching system to select and optimize diverse 5G band spectrum efficiency for best application QoE
- Conducted extensive measurements of commercial 5G networks in both the US and Europe, including in-depth studies of mid-band 5G, MIMO, carrier aggregation, SA vs. NSA performance

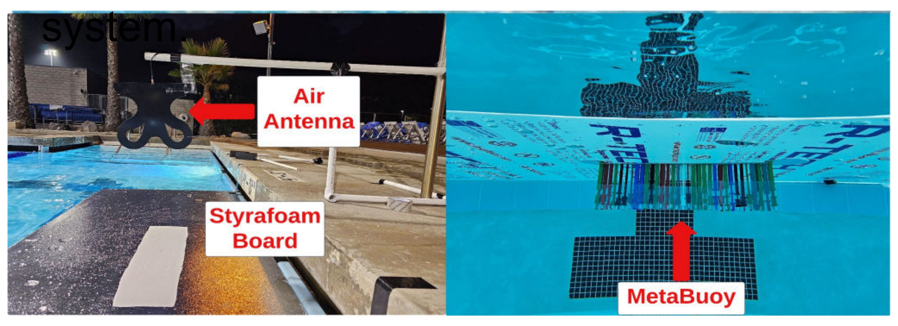
Research Progress – Broader Impacts & Products:

- Close collaboration with industrial partners such as AT&T, Cisco, InterDigital
- Integration of 5G/NextG technologies in graduate level courses at UCSD & UMN
- Training underrepresented (women, Black and Hispanic) students
- Involving a large group of undergraduate students in research (paper co-authors)
- New antenna and 3D printable metasurface design, extending underwater RF communication range from a few cm to 29m
- Large commercial 5G measurement datasets; Other open-source software artifacts; ~15 research publications including SIGCOMM, Mobicom, INFOCOM

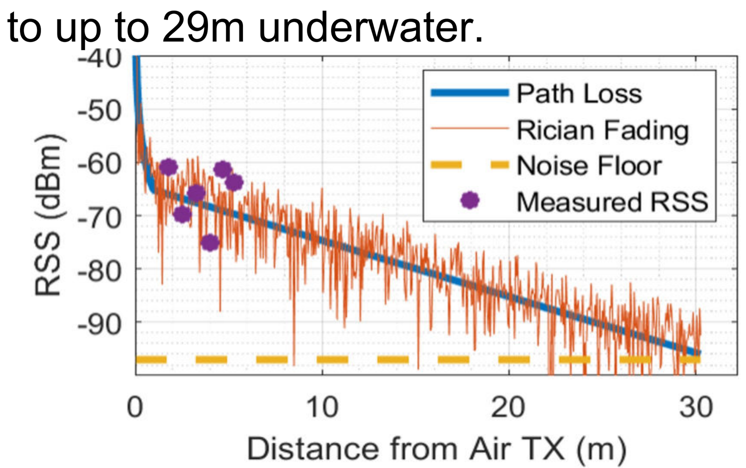
Sample Research Results

(a) MetaBuoy: Expanding Spectrum to underwater

- Experimental setup for evaluating the MetaBuoy system

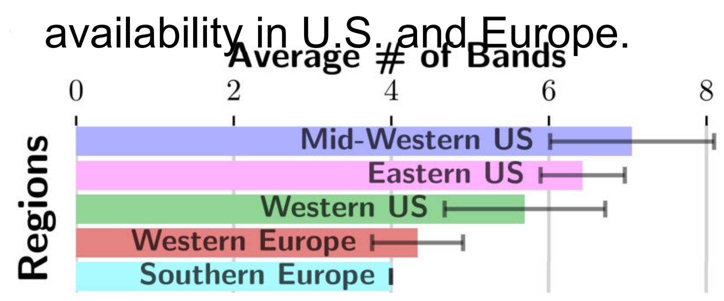


- Experimental result: MetaBuoy can potentially extend communication range to up to 29m underwater.

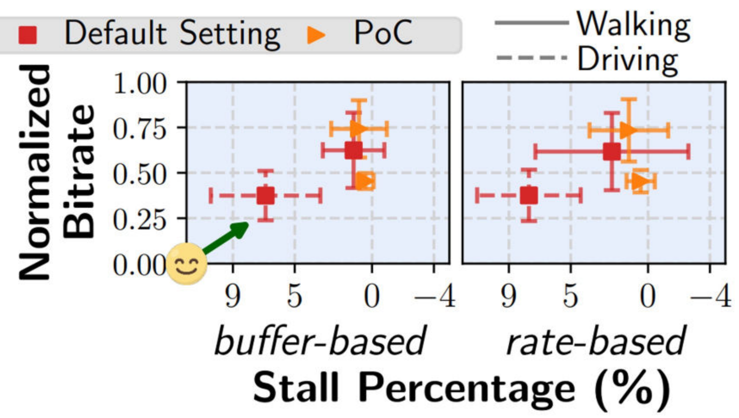


(b) BASS: Smart Band Switching for 5G/xG Networks

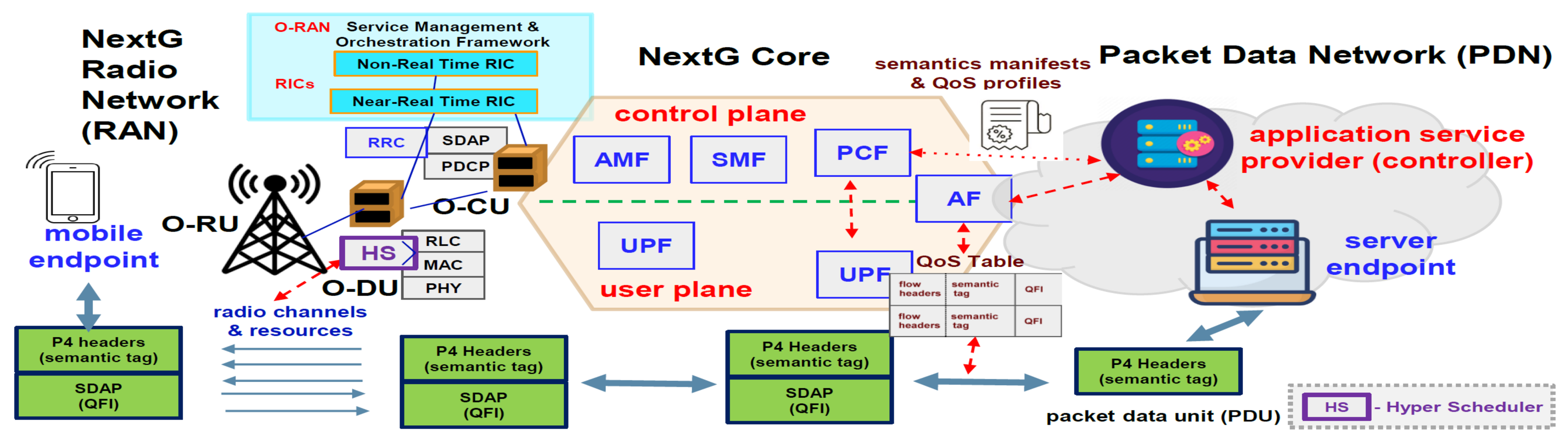
- In-the-wild measurement of band availability in U.S. and Europe.



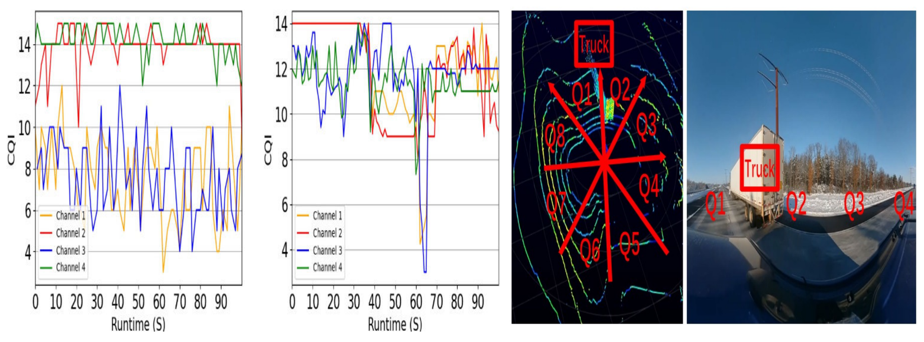
- Preliminary results of proof-of-concept (PoC) band switching system for ABR video streaming.



(c) semantics-aware, fine-grained, cross-layer NextG framework



- Qualities (CQIs) of 5G bands/channels vary drastically over time: *no channel is always best*
- intelligently mapping application data/streams dynamically to radio bands/channels based on semantics is imperative in enhancing end-to-to spectrum efficiency: LiDAR case study



Approach	Quad.	Packets Discarded By Policy	Time Packet In Queue (S)	Avg Sample Latency (S)	Avg Sample Loss %
Static Channel Mapping	1	0%	4.25 ± 2.97	0.877 ± 0.747	97.9%
	2	0%	1.57 ± 1.40	1.614 ± 1.328	93.1%
	3	0%	1.37 ± 1.13	1.475 ± 1.105	92.9%
	4	0%	3.07 ± 2.25	1.475 ± 1.105	92.8%
HyperRAN EP2	1	93.98%	0.036 ± 0.046	0.130 ± 0.191	99.1%
	2	92.95%	0.040 ± 0.024	0.118 ± 0.163	98.8%
	3	93.27%	0.038 ± 0.077	0.131 ± 0.184	98.9%
	4	93.23%	0.044 ± 0.032	0.131 ± 0.184	98.9%