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at Northeastern University

Can AI-Driven Techniques Revolutionize IEEE 802 Standards?

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Disclaimer

- Will focus on wireless protocols (my research focus)

- Similar techniques can be extended to wired 802 standards

The IoT Spectrum is Crowded

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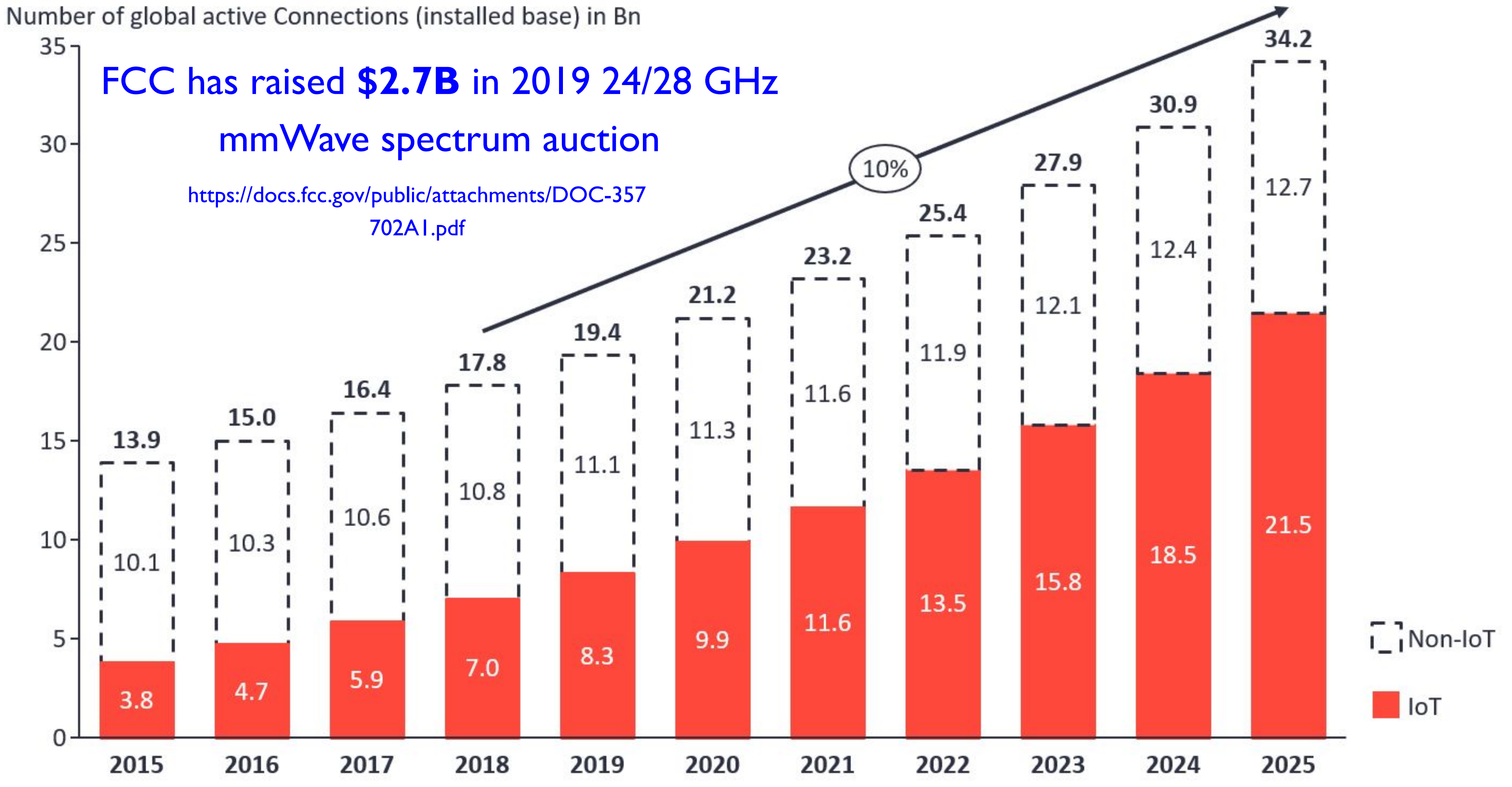
> 4x Human Population!

FCC has raised **$2.7B** in 2019 24/28 GHz mmWave spectrum auction

https://docs.fcc.gov/public/attachments/DOC-357702A1.pdf



Note: Non-IoT includes all mobile phones, tablets, PCs, laptops, and fixed line phones. IoT includes all consumer and B2B devices connected – see IoT break-down for further details
Source: IoT Analytics Research 2018

Why is the IoT Really Different?

Source: https://becominghuman.ai/

Living Beings

Objects

Technologies

Consequences?

The IoT environment changes unpredictably and the millisecond level (optimistically)

Static, manual, explicit resource optimization is likely to not be the best option

Security, reconfigurability, adaptability, resilience must be embedded in the IoT by design

Hold on a second...

~~Radio Fingerprinting~~

~~Modulation Recognition~~

~~Spectrum Sensing~~

~~Dynamic Spectrum Access~~

NOT IN IEEE 802 STANDARDS!

How wireless networks are optimized today

Traditional Approach: Model-Driven

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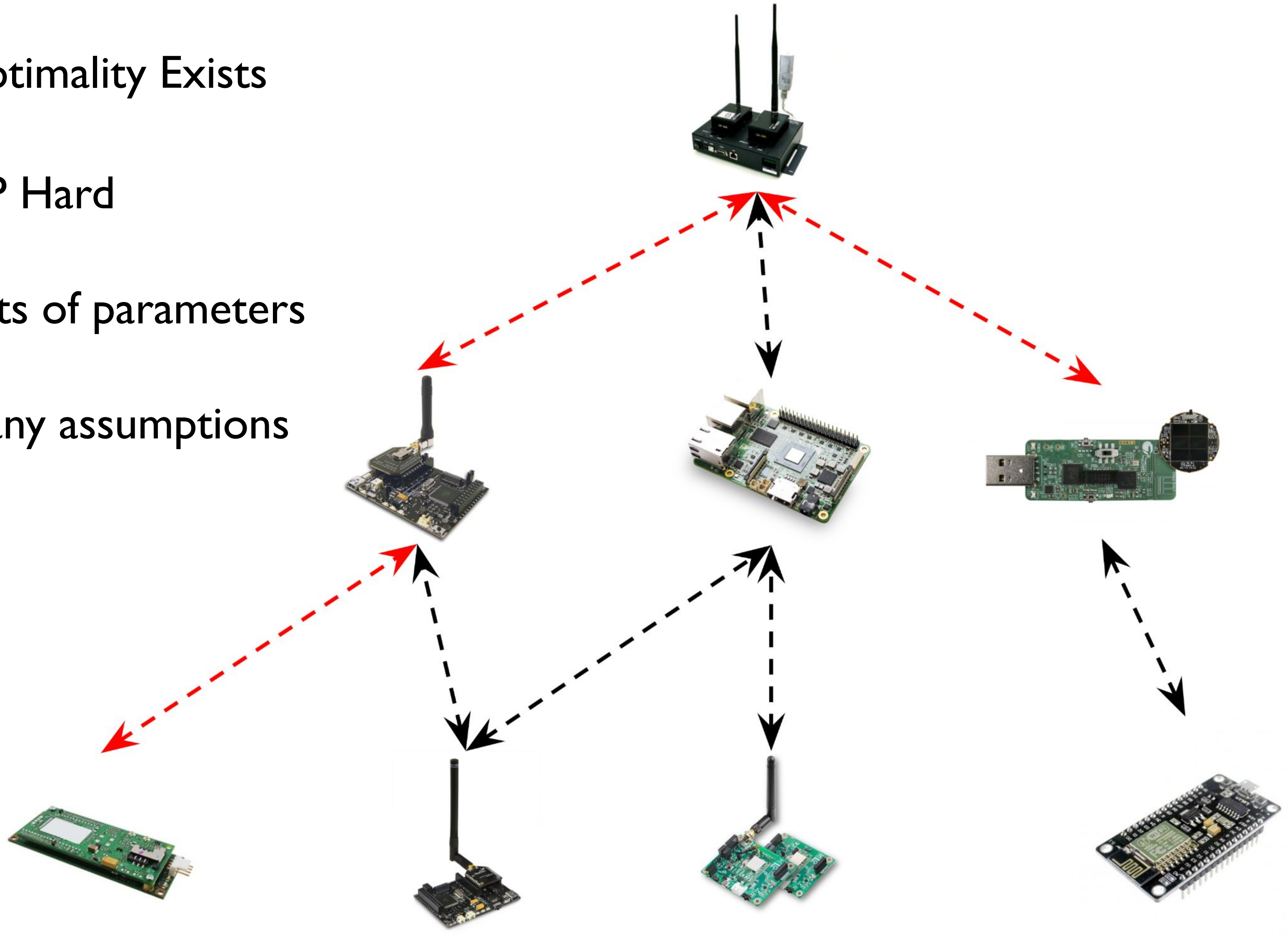
- ✔ Optimality Exists
- ✘ NP Hard
- ✘ Lots of parameters
- ✘ Many assumptions



Model

- Network
- Channel
- Interactions

Constraints

- Physical
- Economical

Solve

- Inner-point
- Gradient descent
- ...

Traditional Approach: Protocol-Driven

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- ✓ Simple, Feasible Approach
- ✗ Not Generalizable
- ✗ Limited Spectrum Agility
- ✗ Heuristic Algorithms

Wi-Fi™ (802.11)

(802.15.1)

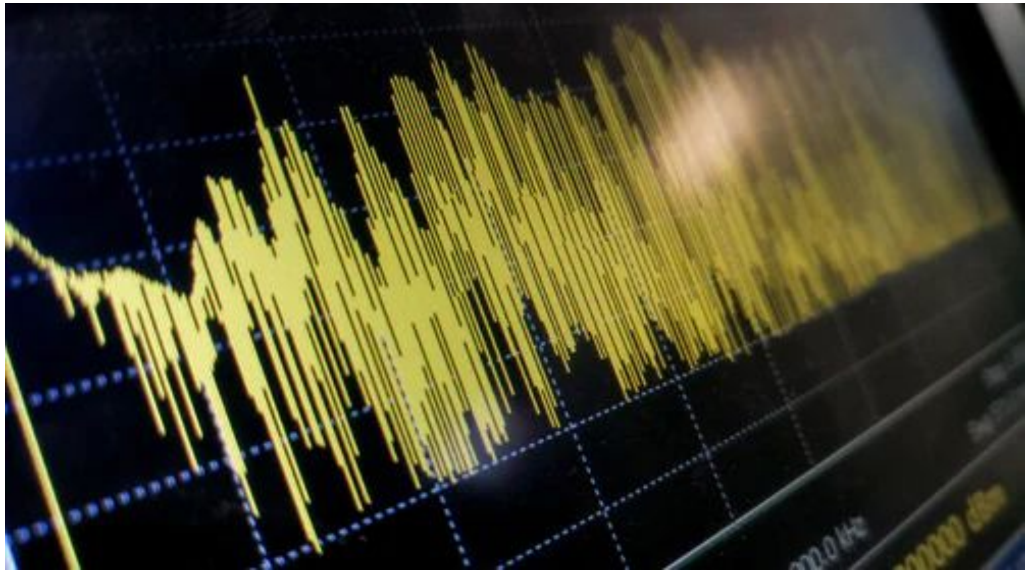
zigbee (802.15.4)

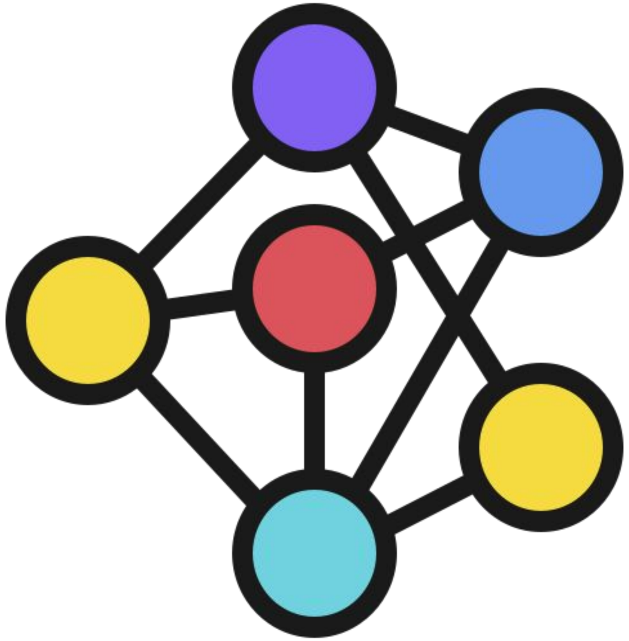
We must rethink how to do network optimization

Model-Driven **Protocol-Driven**

Effective AND Real-Time

Our Approach: Data-Driven Optimization





Advantages of Deep Spectrum Learning

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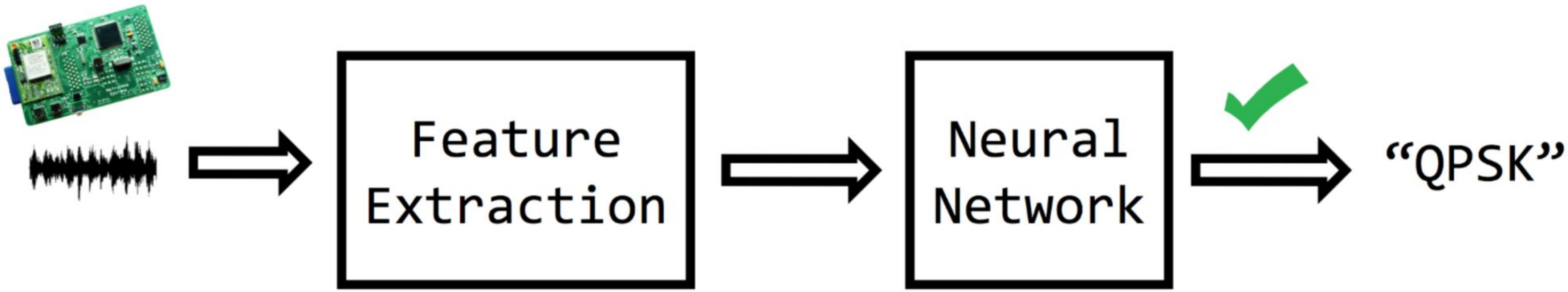
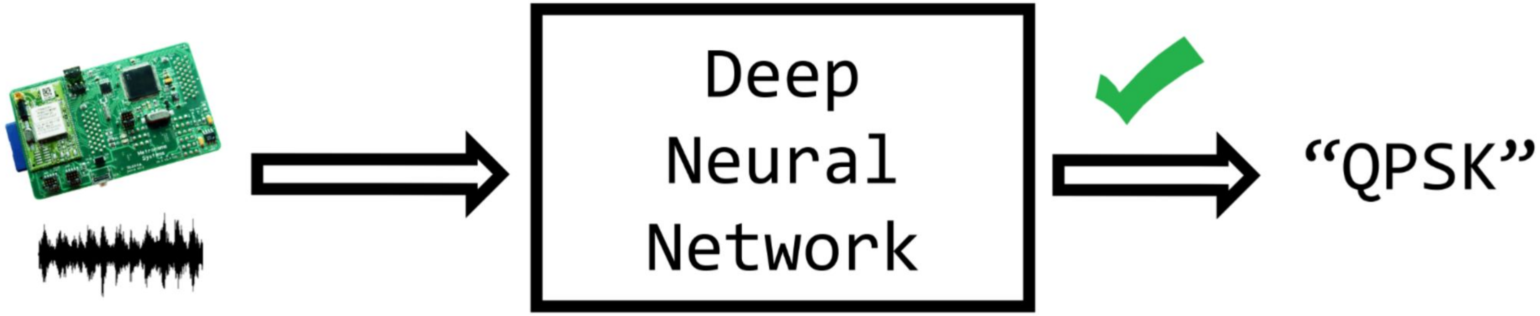
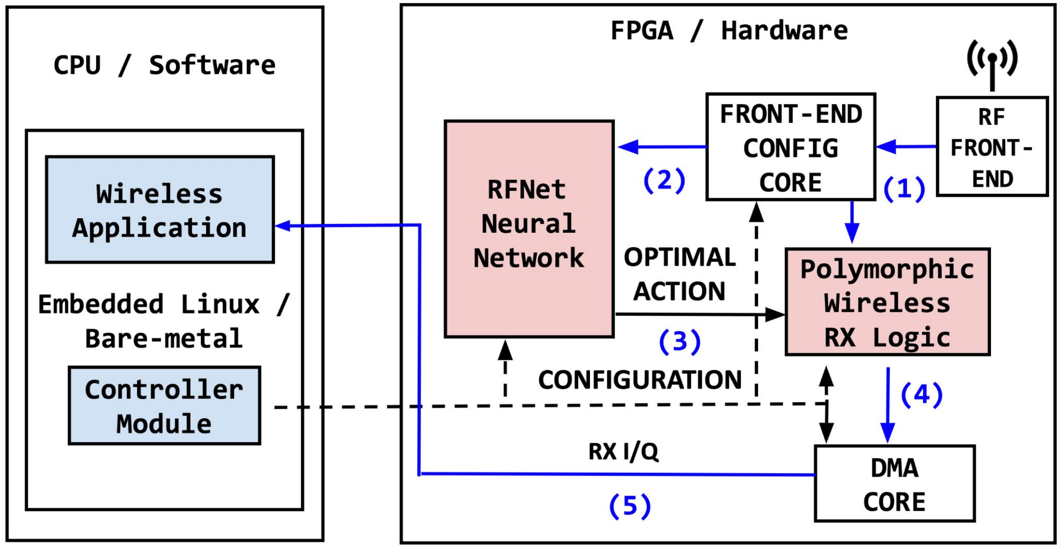


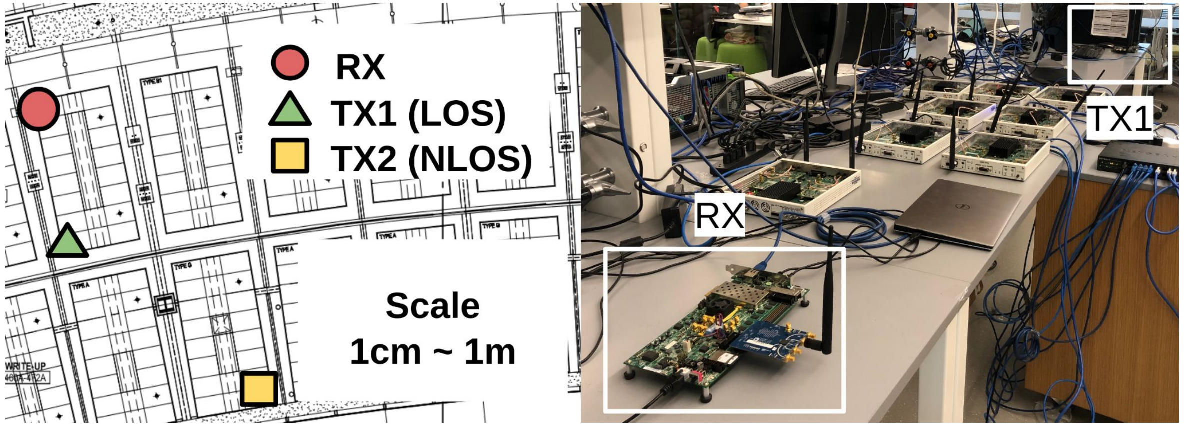
What are the "**right**" features?

What if I want to **change** classification problem?



Self-Adaptive Spectrum-Aware Receivers





F. Restuccia and T. Melodia, "Big Data Goes Small: Real-Time Spectrum-Driven Embedded Wireless Networking Through Deep Learning in the RF Loop," **IEEE INFOCOM 2019**

F. Restuccia and T. Melodia, "PolymoRF: Polymorphic Wireless Receivers Through Physical-Layer Deep Learning," **ACM MobiHoc 2020, SIGMOBILE Research Highlights 2020, Communications of the ACM Research Highlight.**

Self-Adaptive Spectrum-Aware Transmitters

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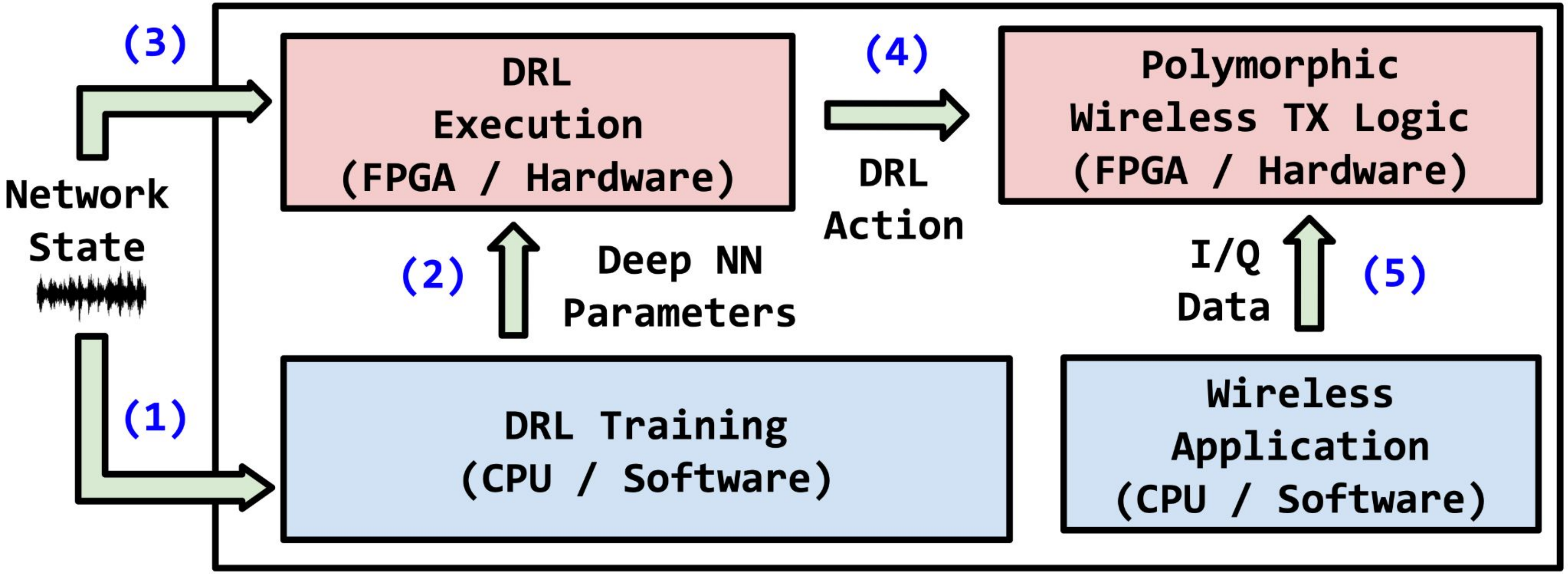

F. Restuccia and T. Melodia, "DeepWiERL: Bringing Deep Reinforcement Learning to the Internet of Self-Adaptive Things," **IEEE INFOCOM 2020**

Deep Learning for Beam Management

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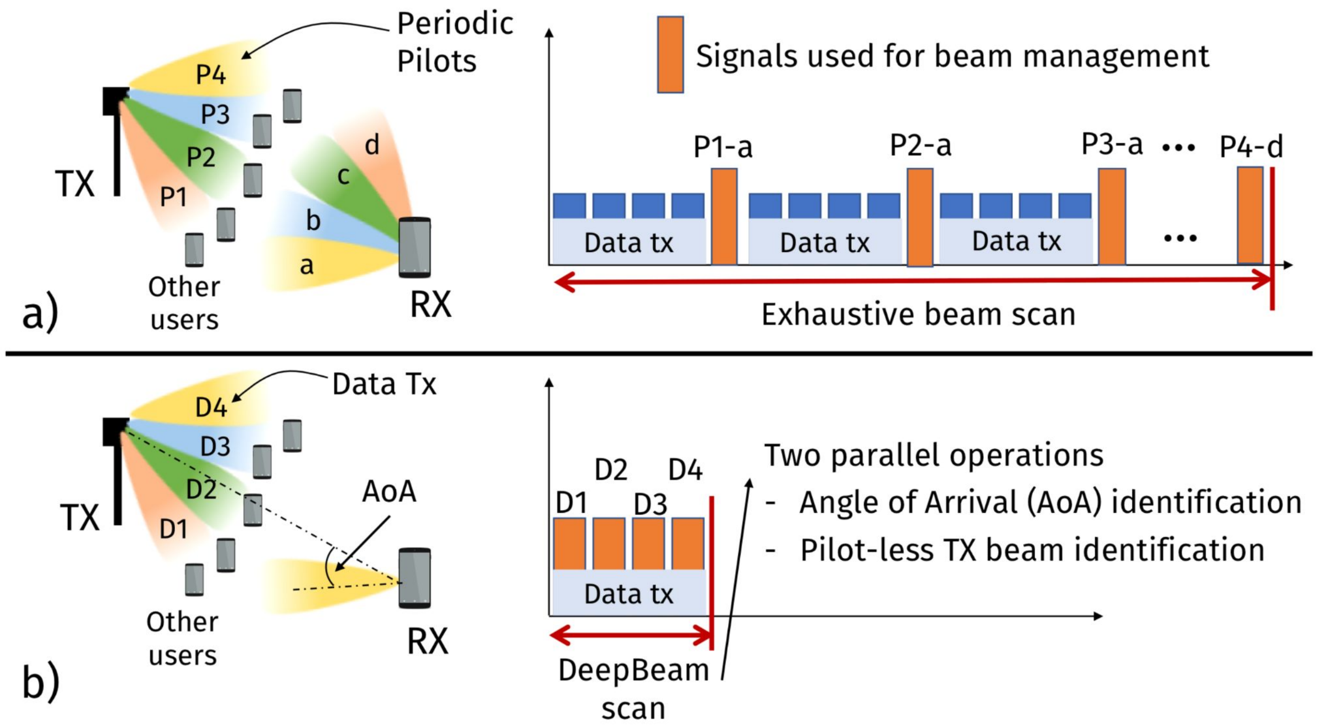

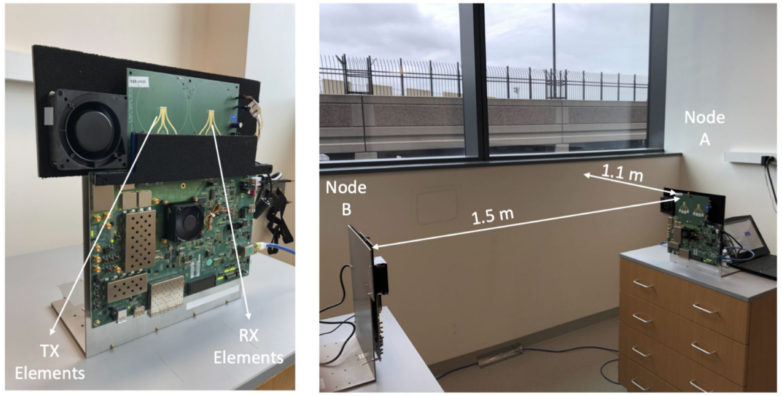

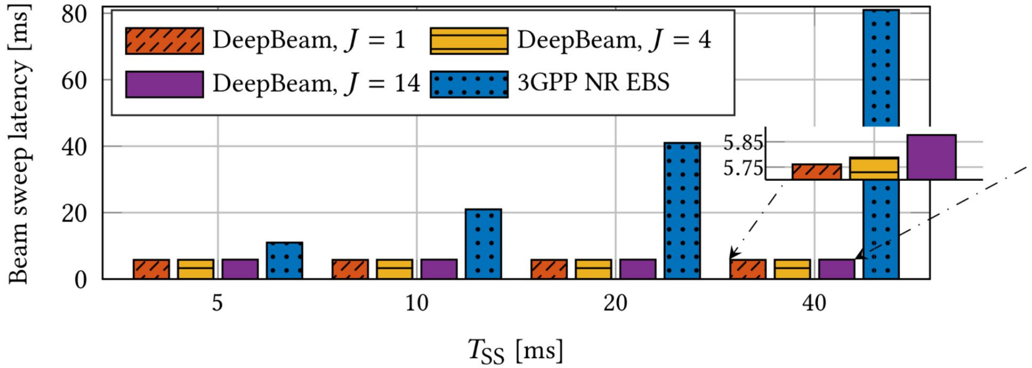

M. Polese, F. Restuccia, and T. Melodia, "DeepBeam: Deep Waveform Learning for Coordination-Free Beam Management in mmWave Networks," **ACM MobiHoc 2021**.

Deep Learning for Radio Fingerprinting

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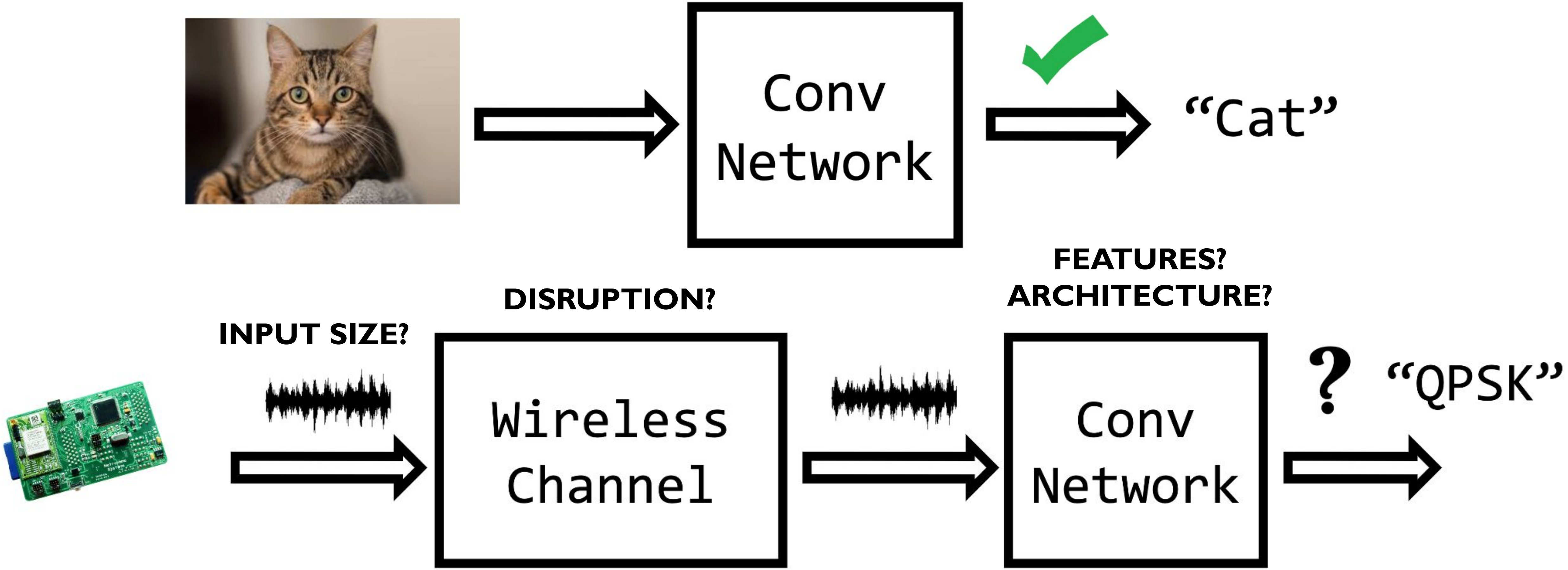
Task	Description	# of Devices
A1	Very High Population	10,000
A2	High Population	1000
A3	Medium Population	500
A4	Low Population	100
B1	Train One Day Test Another	50
B2	Train on a Mix of Days Test on a Mix	100
B3	Train and Test on a Single Day	100
C1	SNR: Train High Test Medium	100
C2	SNR: Train High Test Low	100
C3	SNR: Train Medium Test High	100
C4	SNR: Train Medium Test Low	100
C5	SNR: Train Low Test High	100
C6	SNR: Train Low Test Medium	100

Task	Testing Accuracy Per-Slice / Per-Transmission Accuracy (PSA/PTA)			
	WiFi			
	Raw I/Q before FFT		Equalized	
	Baseline	ResNet-50-1D	Baseline	ResNet-50-1D
A1	0.082 / 0.130	**0.164 / 0.262**	0.062 / 0.101	0.014 / 0.030
A2	(0.299 / 0.378	**0.393 / 0.612**	0.327 / 0.434	0.392 / 0.555
A3	0.354 / 0.398	**0.467 / 0.629**	0.454 / 0.478	0.430 / 0.549
A4	0.335 / 0.575	0.490 / 0.631	**0.762 / 0.639**	0.699 / 0.637
B1	0.017 / 0.016	0.013 / 0.012	**0.232 / 0.335**	0.175 / 0.258
B2	0.444 / 0.695	**0.520 / 0.811**	0.678 / 0.674	0.751 / 0.735
B3	0.310 / 0.598	**0.441 / 0.746**	0.210 / 0.432	0.308 / 0.542

A. Al-Shawabka, F. Restuccia, S. D'Oro, T. Jian, B. Costa Rendon, N. Soltani, J. Dy, K. Chowdhury, S. Ioannidis and T. Melodia, *"Exposing the Fingerprint: Dissecting the Impact of the Wireless Channel on Radio Fingerprinting,"* **IEEE INFOCOM 2020.**

Challenges of Deep Learning in Wireless



F. Restuccia and T. Melodia, "Deep Learning at the Physical Layer: System Challenges and Applications to 5G and Beyond," **IEEE Communications Magazine,** Vol. 58, Is. 10, October 2020.

Also, let's not forget...

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Next Steps

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- We now understand AI/ML can be a tremendous resource
- Lingering issues:

- How do we transition from research to 802 standard?
    - Bridge the existing gap b/w academia/standard communities

- How do we make these models smaller, faster, more accurate?
    - Great research & development opportunities

Thanks!
Questions?