

Radio Frequency Neural Networks

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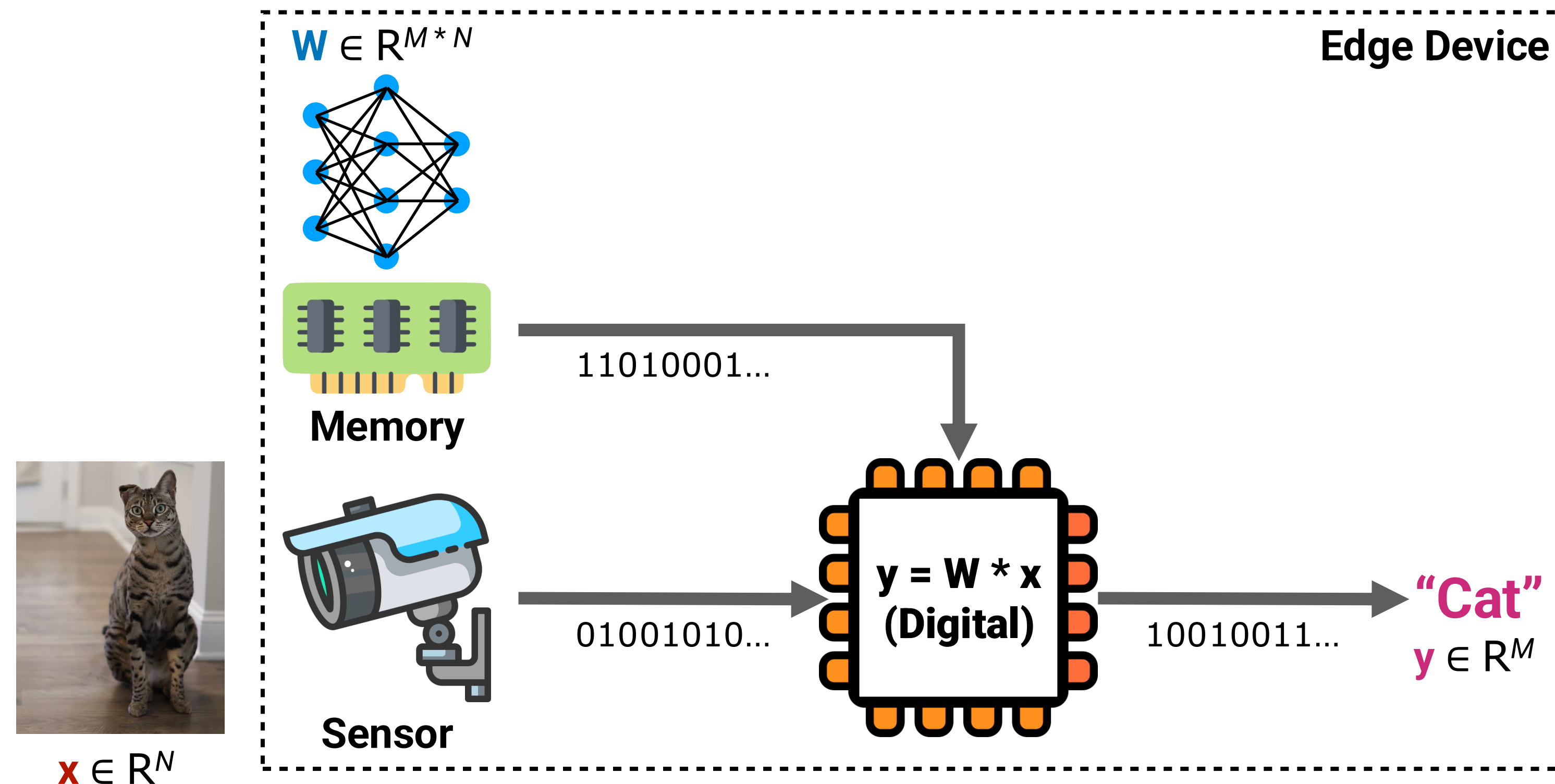
The 20th U.S.-Korea Forum on Nanotechnology
Sept. 15, 2026

Prof. Dirk Englund (MIT)



ML on Edge Devices

Modern edge devices leverage ML to support various intelligent applications



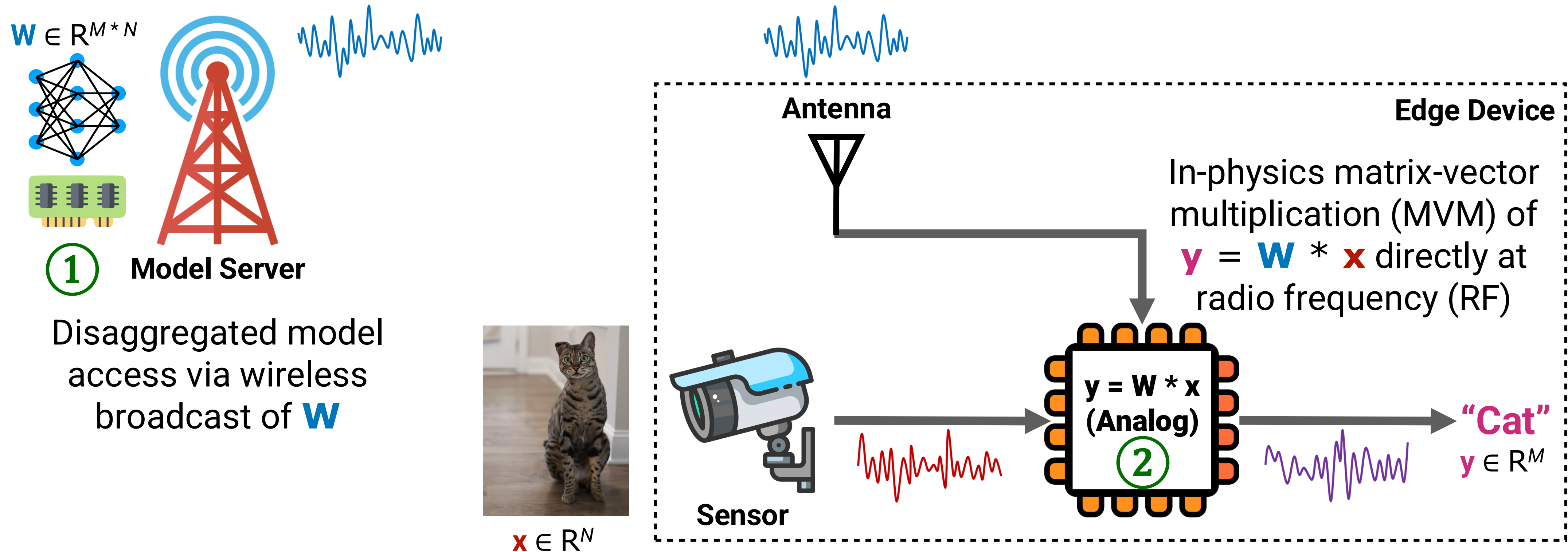
$$E_{\text{inference}} = E_{\text{load}} + E_{\text{comp,digital}}$$

$$\# \text{ of operations: } \sim \mathcal{O}(M \cdot N) \quad \sim \mathcal{O}(M \cdot N)$$

$$\text{energy per operation: } \sim 0.1 \text{ pJ/bit} \quad \sim 0.1 \text{ pJ/MAC}$$

A New Computing Paradigm for Wireless Edge Networks

How to overcome the energy efficiency barrier of conventional digital computing?

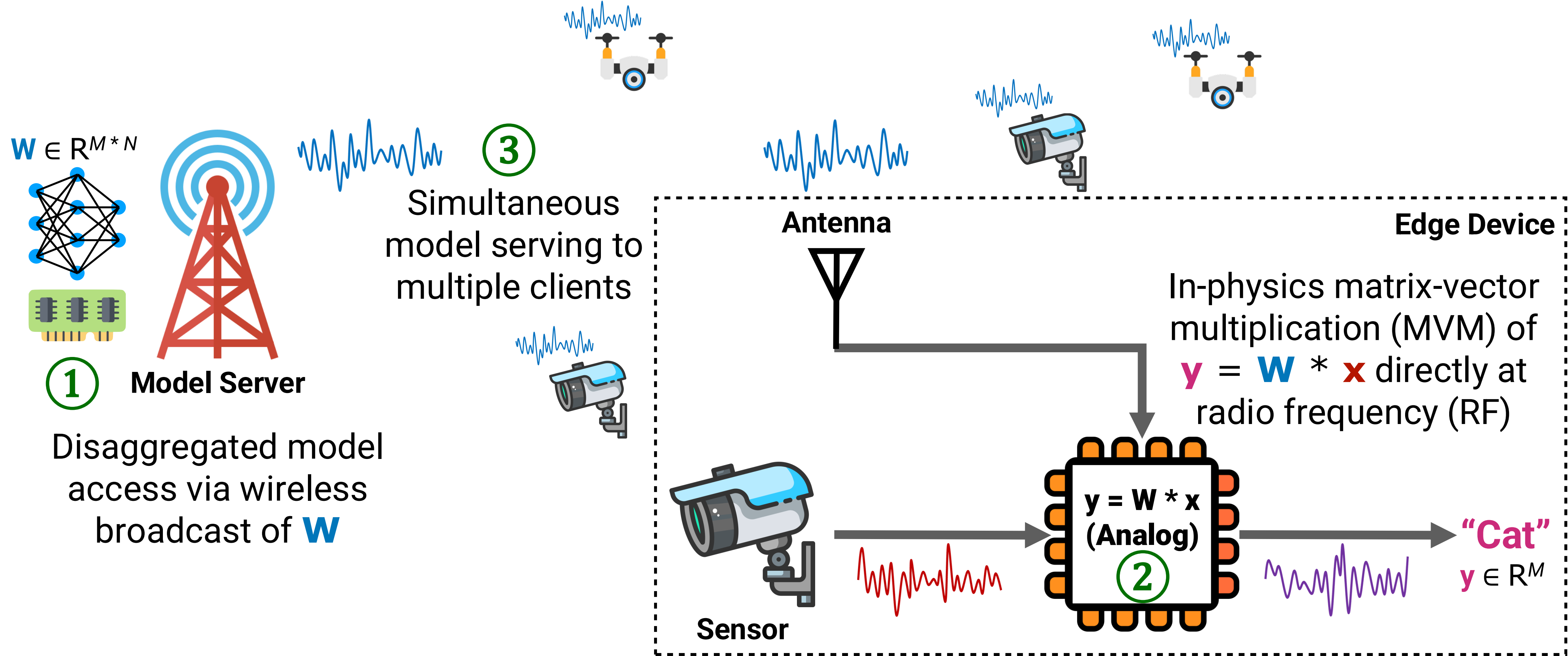


$$E_{\text{inference}} = E_{\text{load}} + E_{\text{comp,analog}}$$

of operations: $\sim \cancel{O(M \cdot N)}$ $\sim O(M \cdot N)$

energy per operation: $\sim 0.1 \text{ pJ/bit}$ $\sim 6 \text{ fJ/MAC}$

A New Computing Paradigm for Wireless Edge Networks

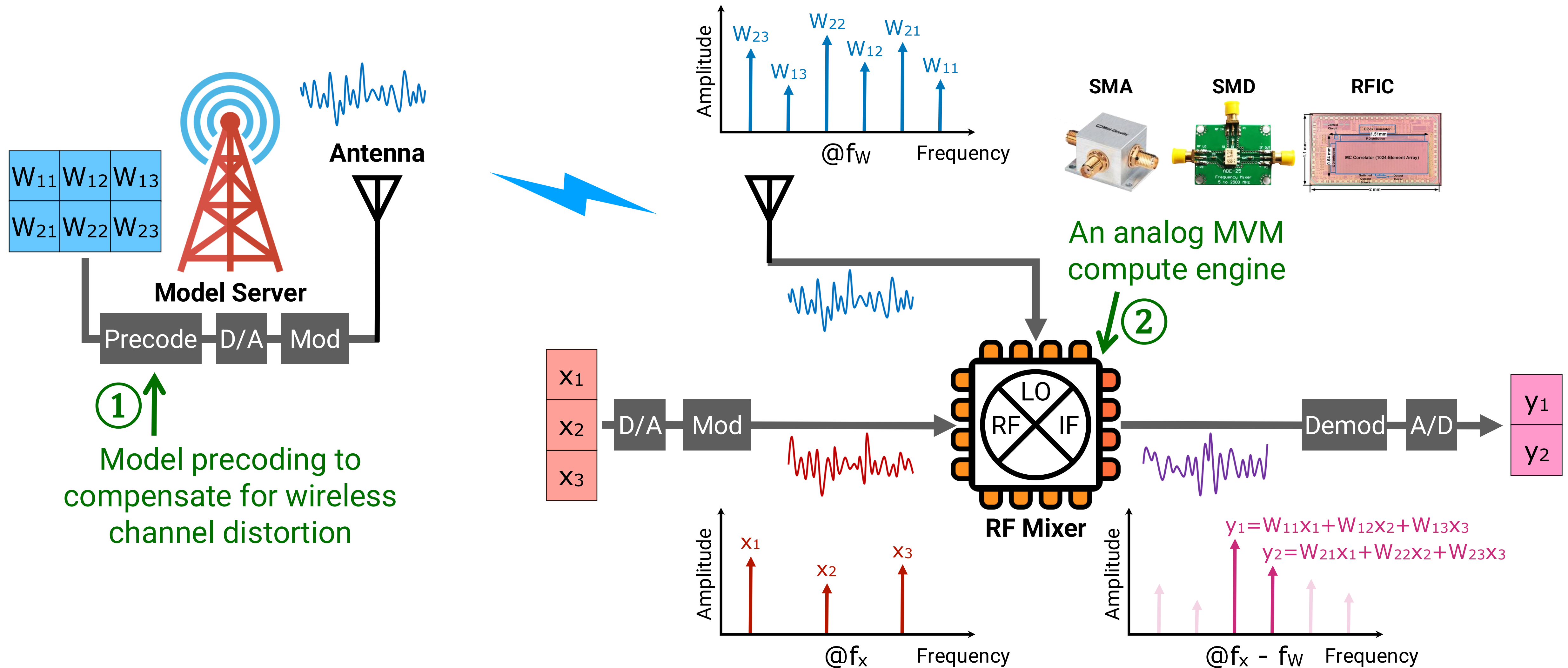


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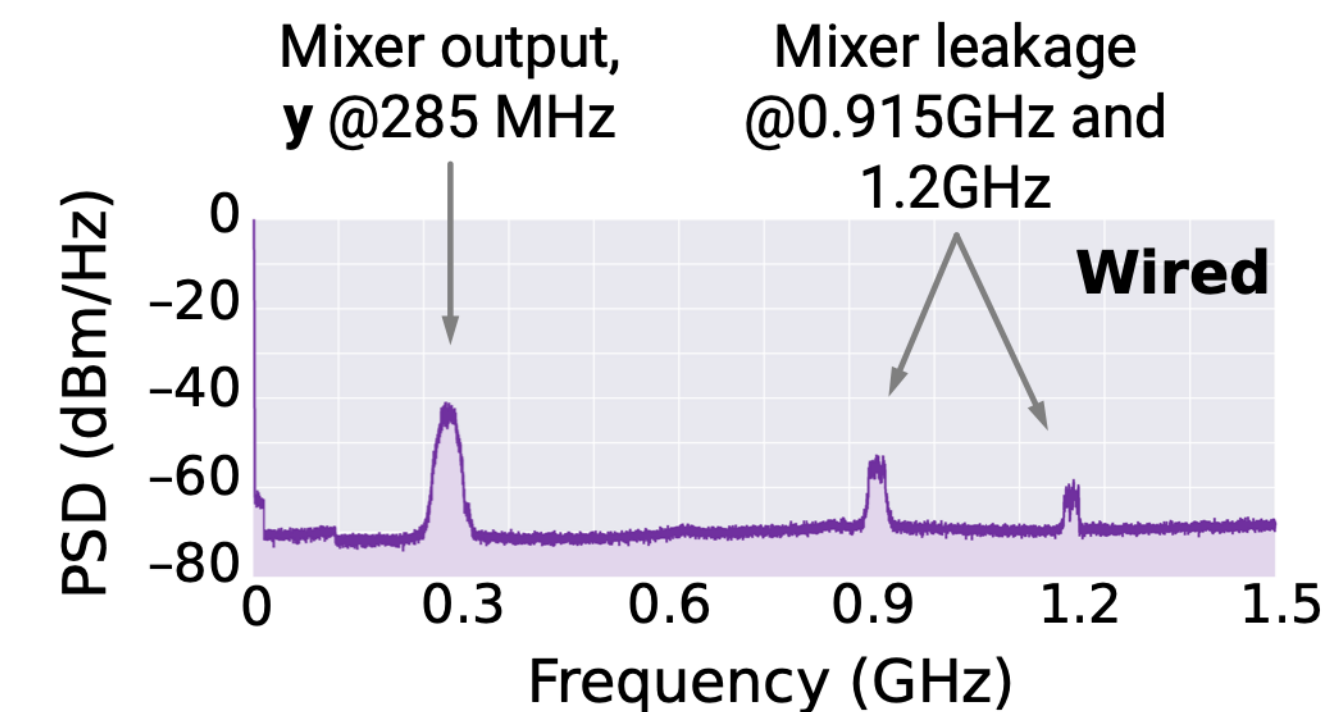
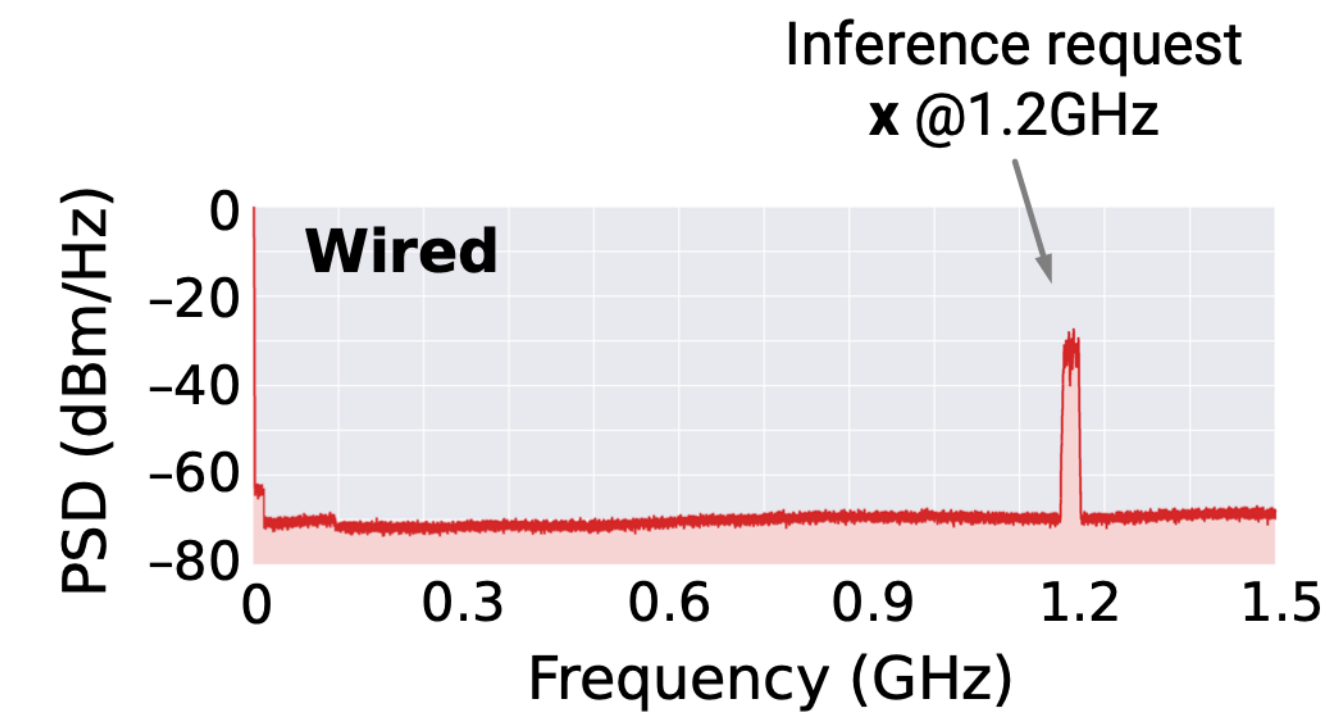
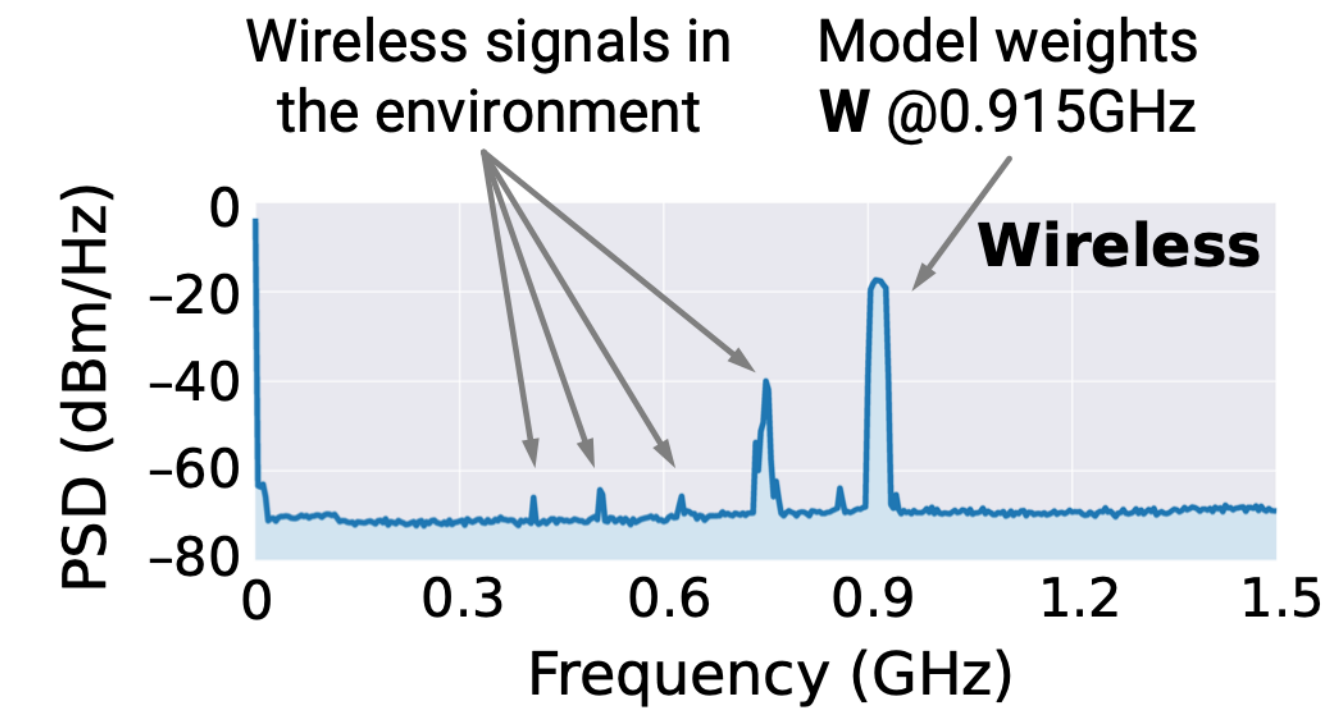
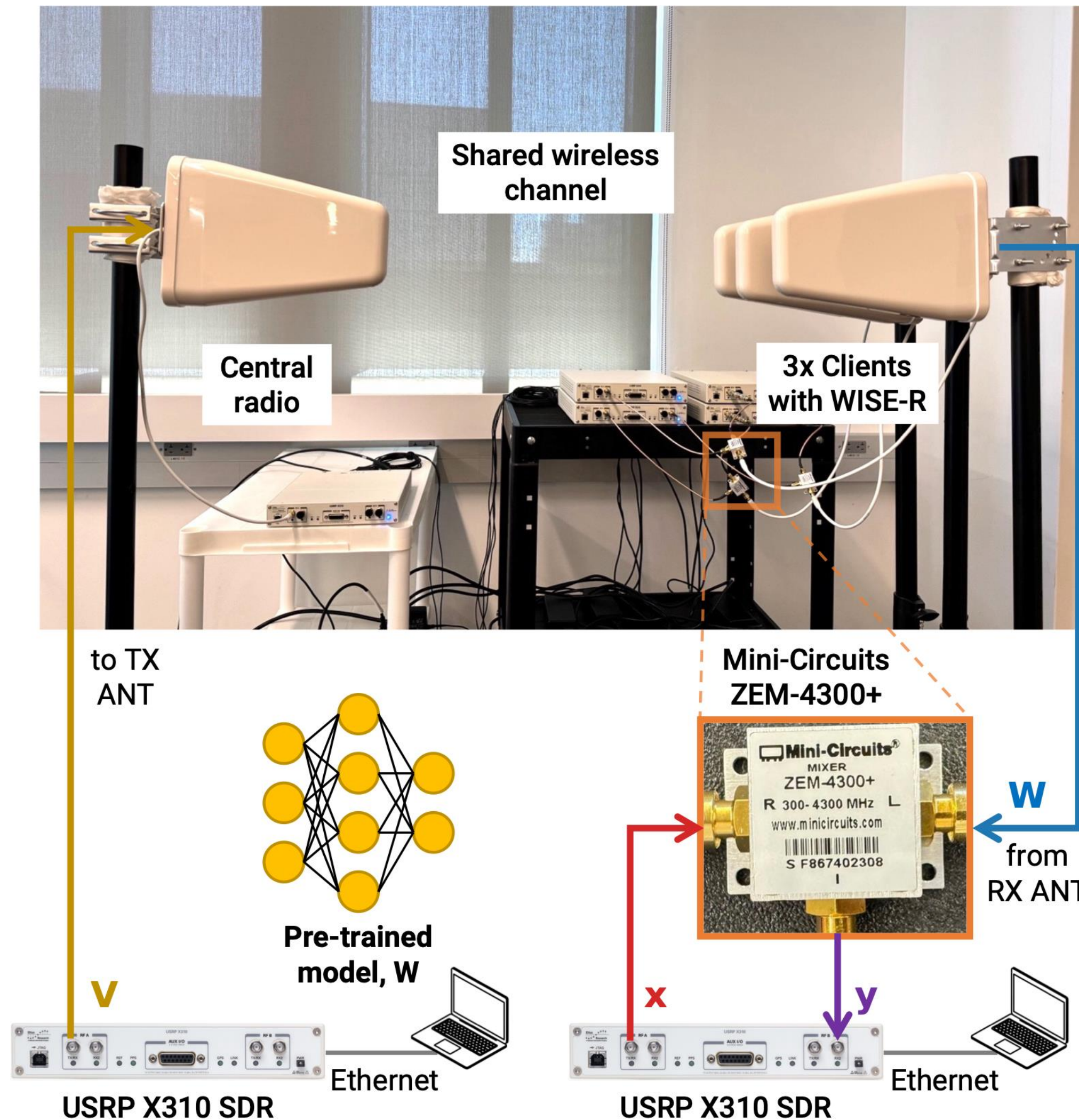
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Wireless Smart Edge Networks (WiSE): Principles

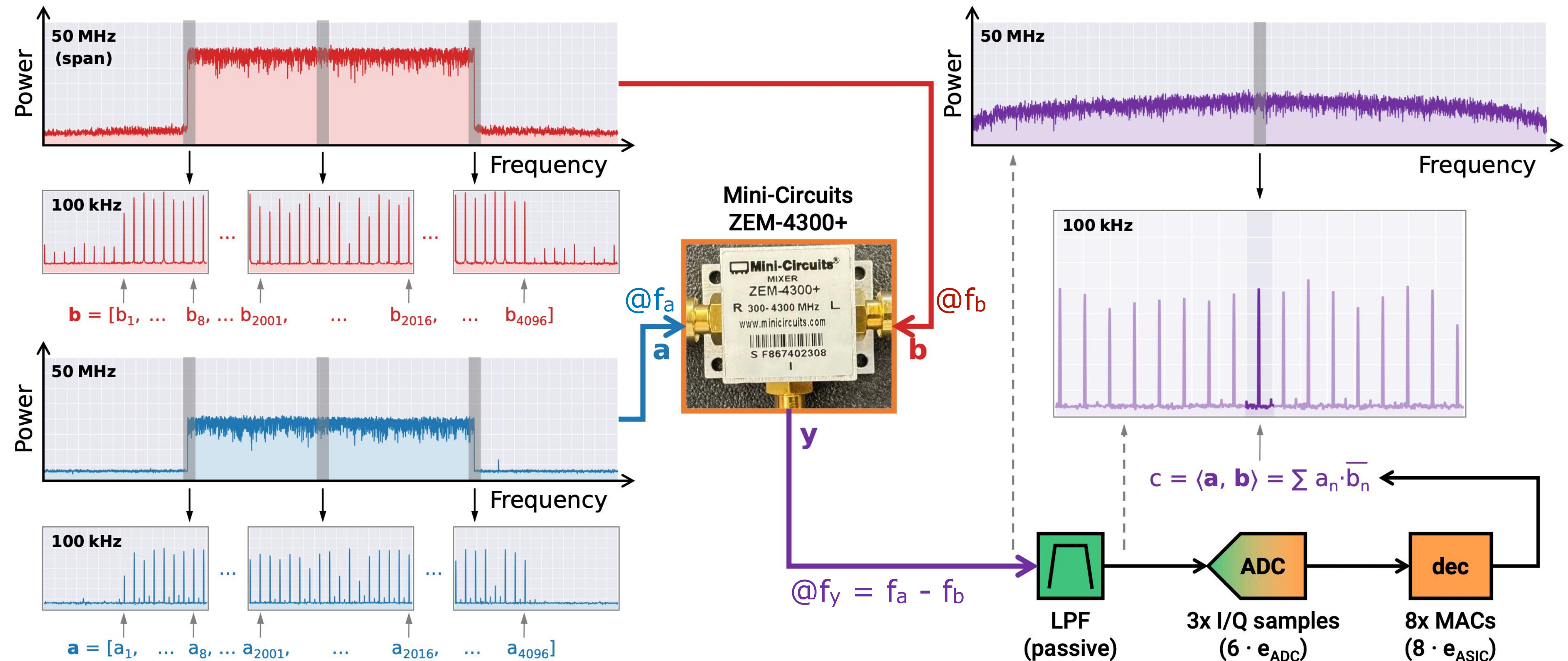


Wireless Smart Edge Networks (WiSE): Prototype



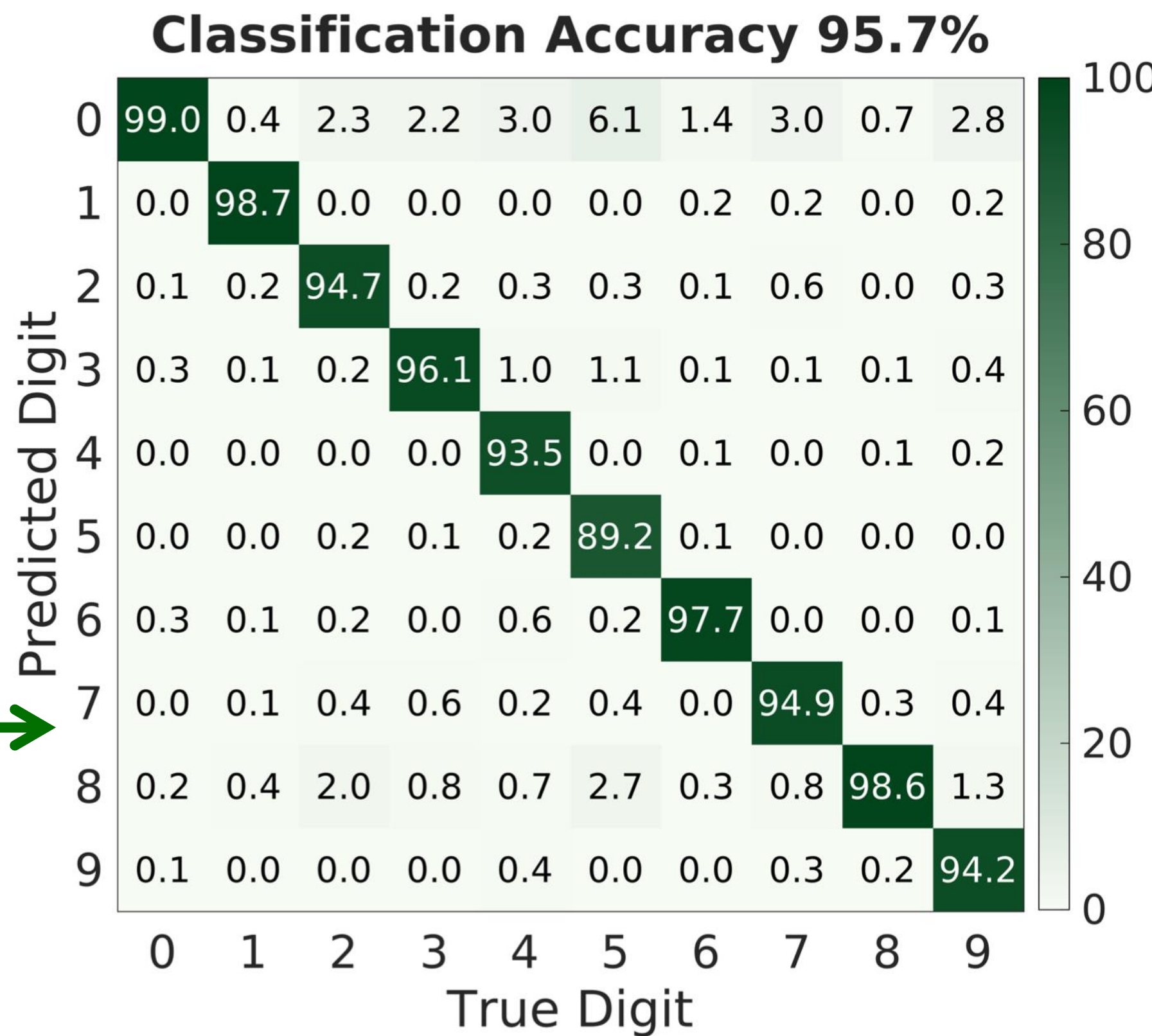
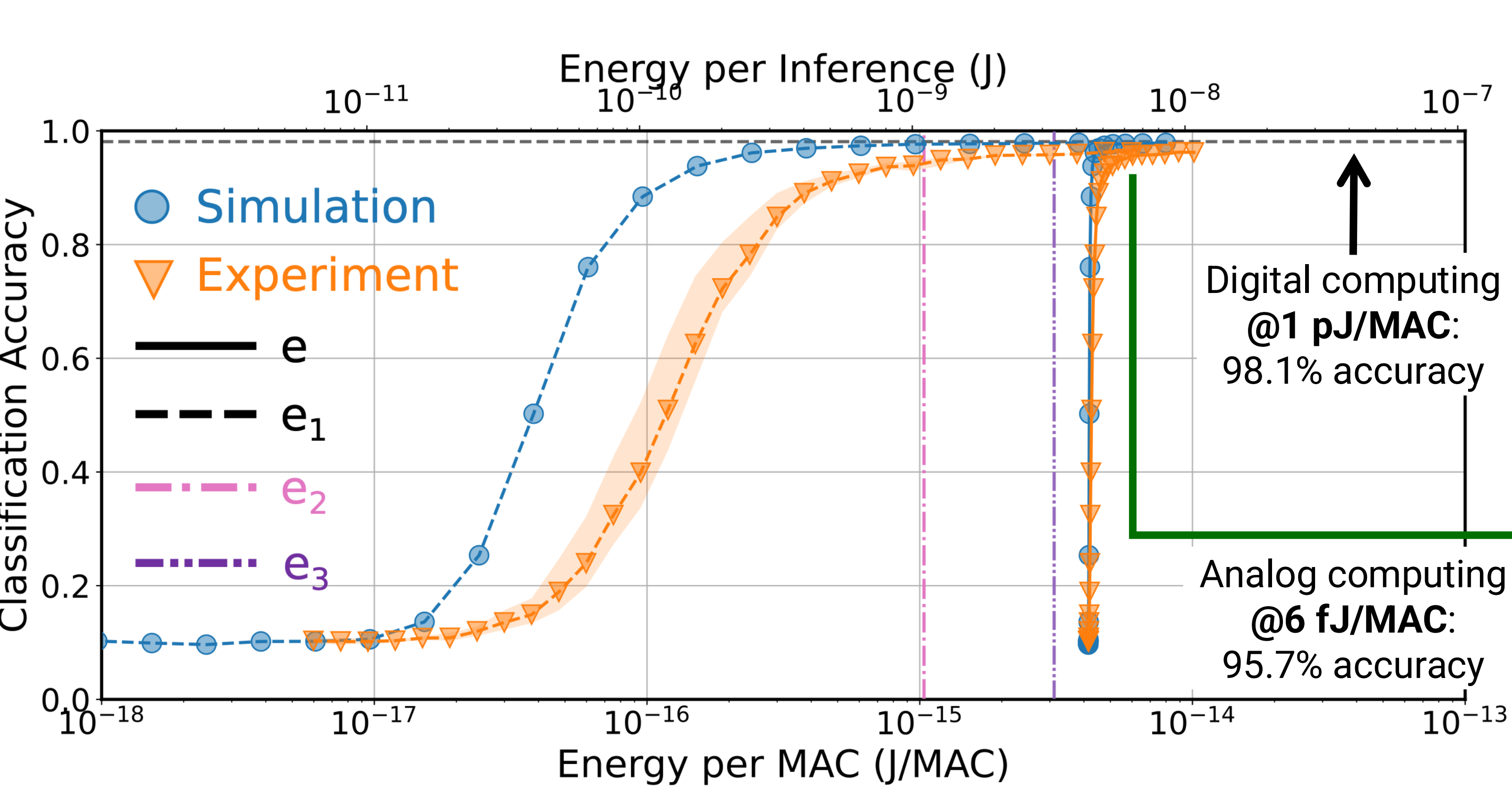
Analog Inner-Product Engine using a (passive) RF Mixer

Vectors **a** and **b** are encoded into the amplitude of the frequency components of signals **a(t)** and **b(t)**



Wireless Smart Edge Networks (WiSE): Energy Efficiency

Complex-valued LeNet-300-100 model on the MNIST dataset



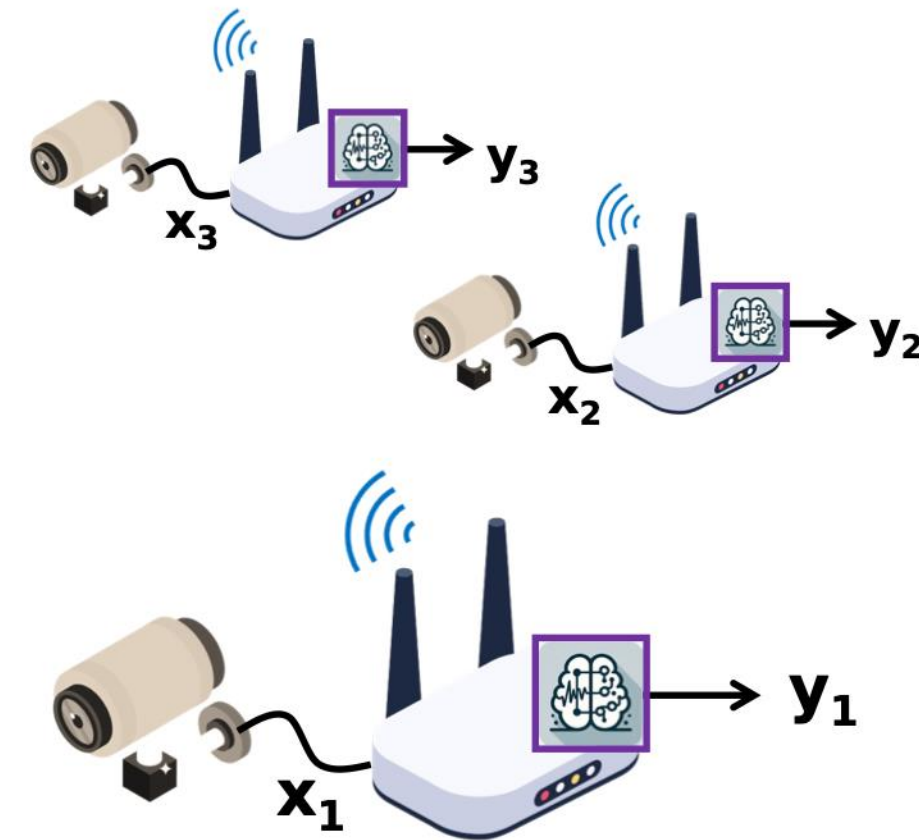
Breakdown of edge device energy consumption (e):
Radio (e_1) + sampling (e_2) + minimal digital signal processing (e_3)

2-3 orders of magnitude lower energy consumption for ML inference

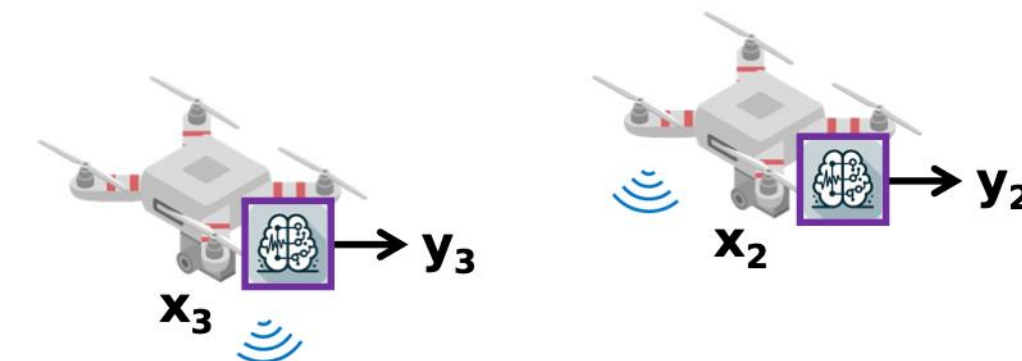
Wireless Smart Edge Networks (WiSE): Applications



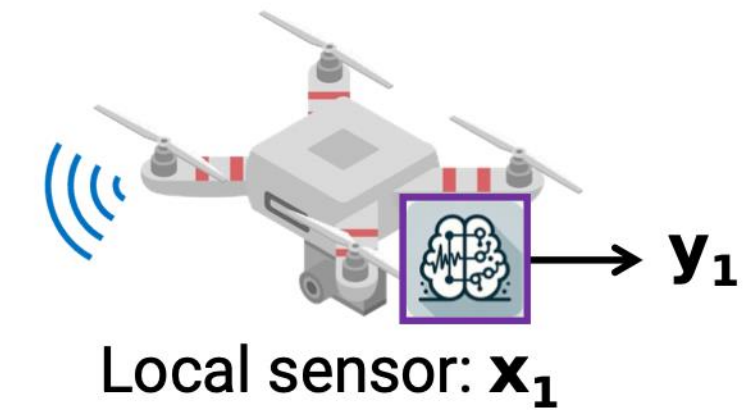
Base station w/
weight server



Cameras w/ SmartTRX



Radio unit w/
weight server



Local sensor: x_1
Drones w/ SmartTRX

Ideal for computing and sensing tasks on input is analog by nature (e.g., RF signals, analog sensors)

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