N-ZERO: Near-Zero Power Sensing

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ARPA-E Energy-Smart Farm Workshop

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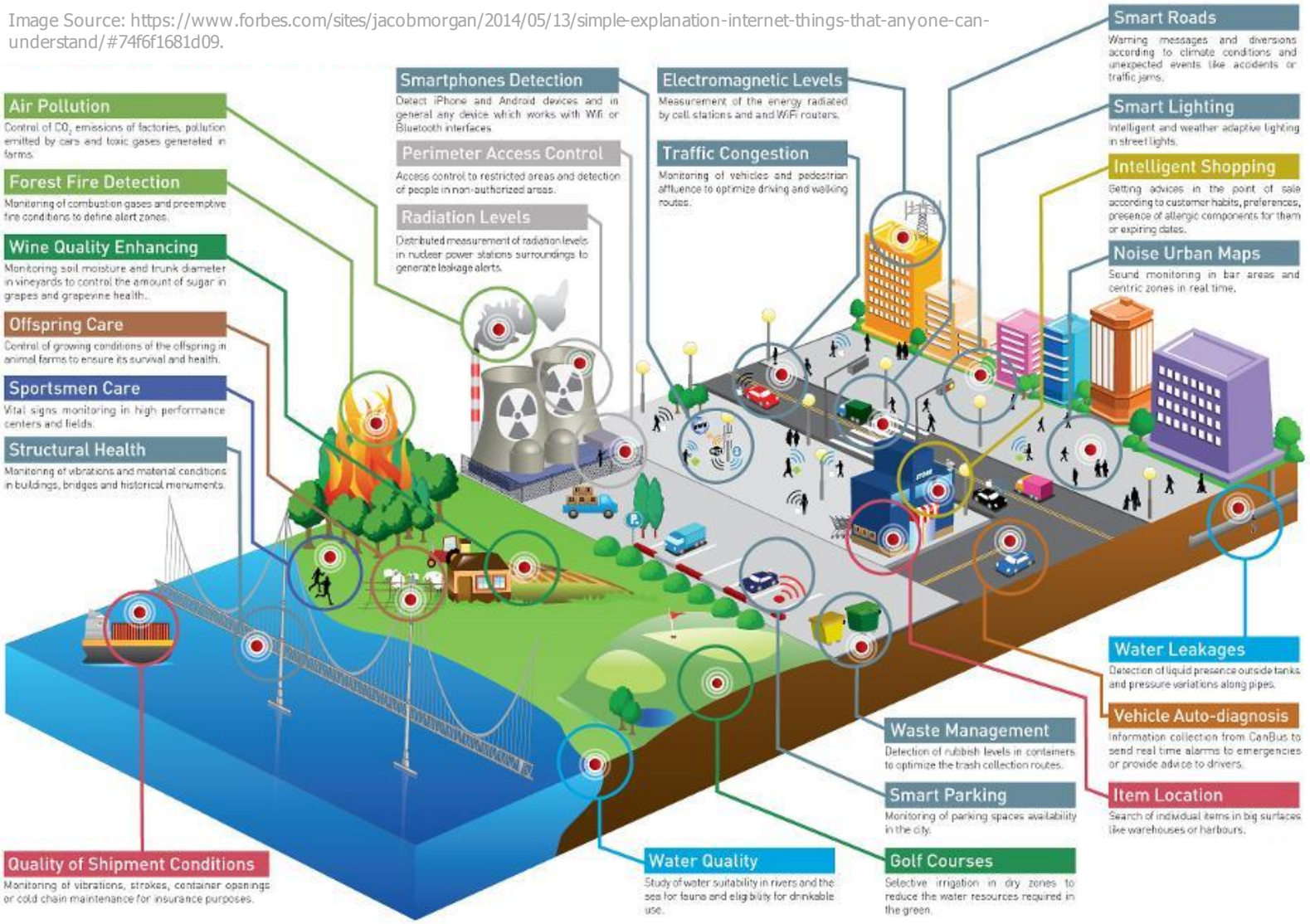
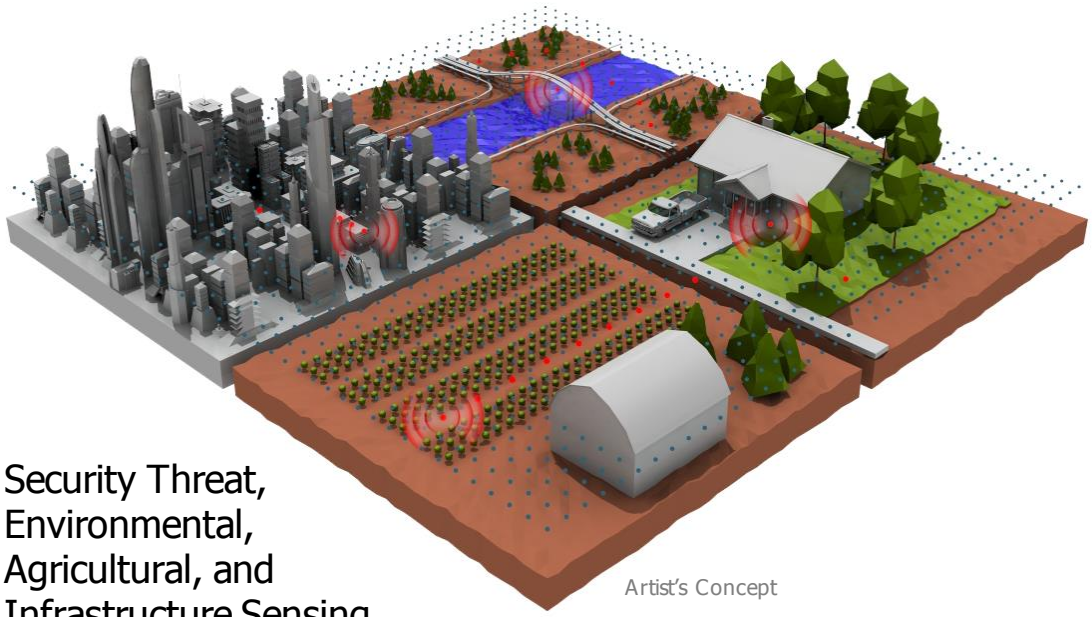
The Promise of the Internet of Things (IoT)

Image Source: https://www.forbes.com/sites/jacobmorgan/2014/05/13/simple-explanation-internet-things-that-anyone-can-understand/#74f6f1681d09.



Persistent Sensing Challenges and Applications at the Edge



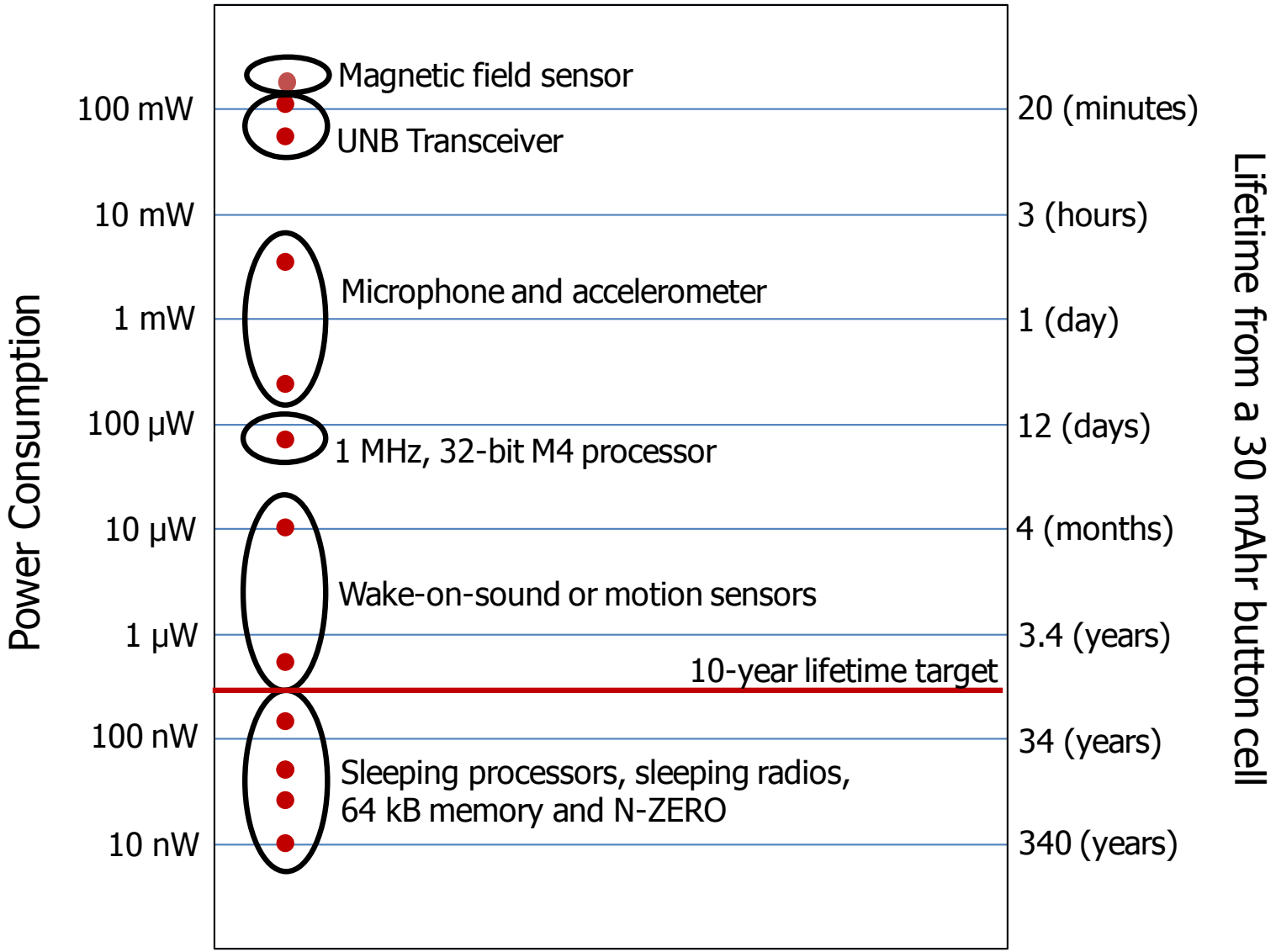
Artist's Concept

Security Threat, Environmental, Agricultural, and Infrastructure Sensing

- Sensor nodes must be deployed for long durations at low cost
- Energy consumption is extremely limited
- Data is continuously processed but rarely worthy of communication
- Sensing is often time critical, as the source may only briefly be in proximity of the sensor
- Communication of a sensing event is often time critical
- New Low Power Wide Area Network (LPWAN) standards (e.g. LoRa and SigFox) are emerging but these have some limitations

Persistent sensing requires new low-energy and long-life communications and sensing technologies

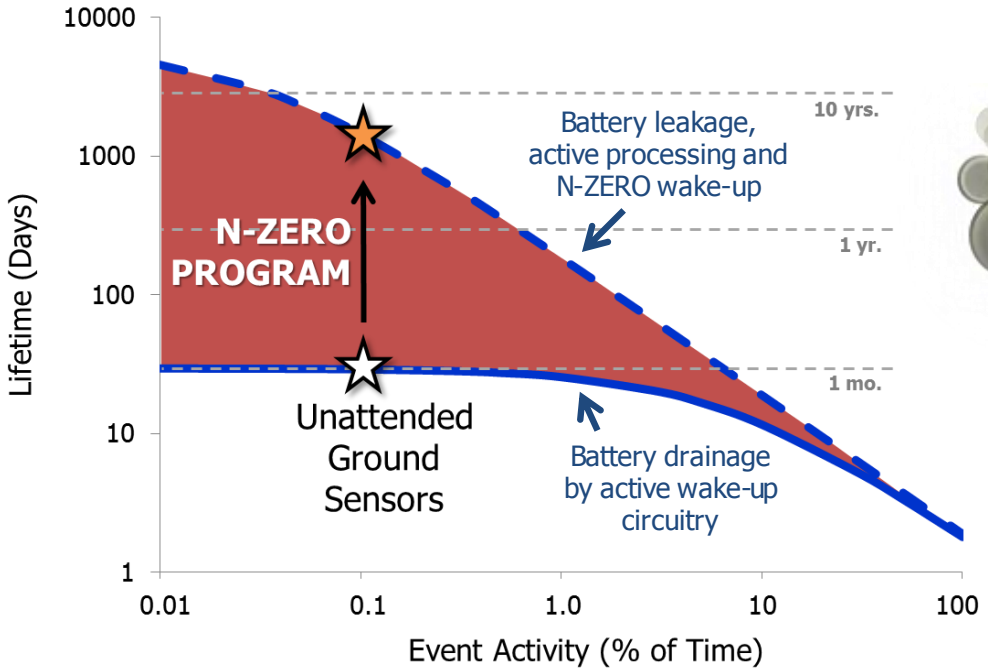
Power Consumption and Lifetime of Unattended Sensor System Components

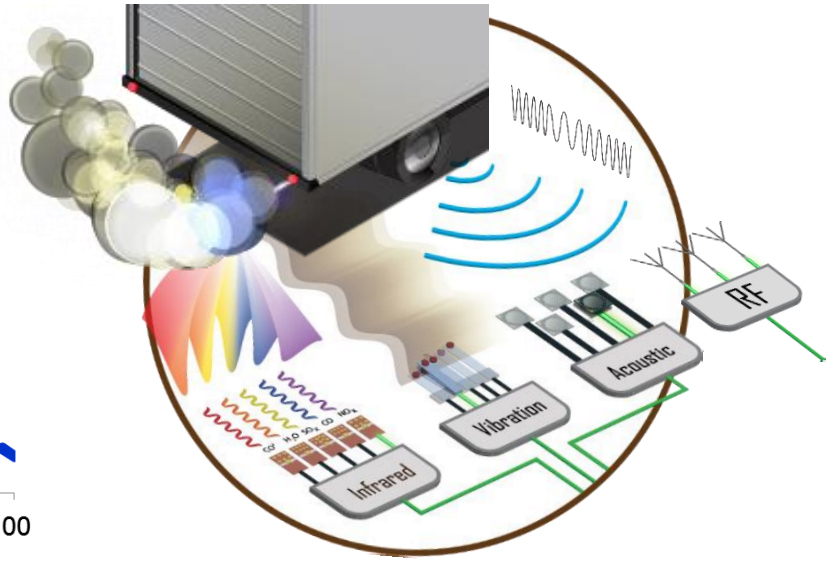


N-ZERO Vision: OFF but ALERT!

N-ZERO passive sensor wake-up:

- Continuous operation and near-zero power processing
- Persistent sensing with greatly extended lifetime and reduced cost





Devices are OFF (zero power consumption) yet continually ALERT!

N-ZERO Metrics

RF Sensors

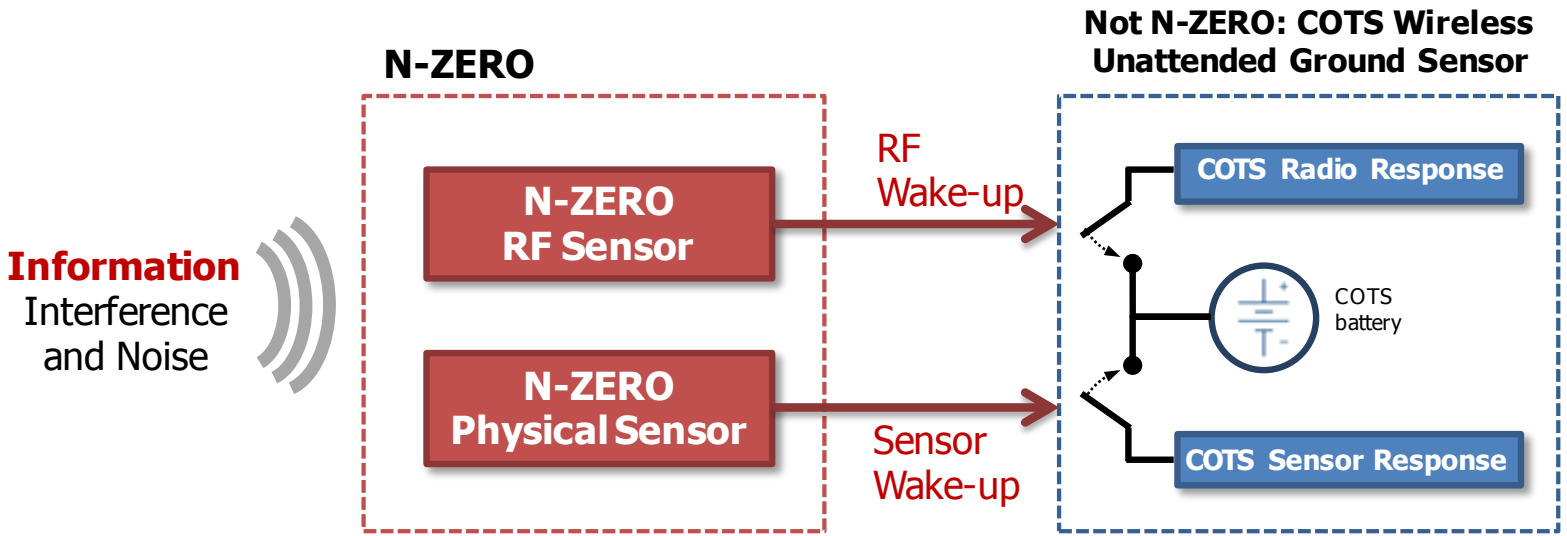
Metrics	Phase III
Detected signature	Coded RF Waveform
RF level at sensor input	≤ -100 dBm
Probability of detection	95%
False alarm rate	< 1 per hour
Environment	high interference background
Power Consumption	< 10 nW

Physical Sensors

Metric	Phase III	
Items to detect	Generator, car, truck	
Distance	≥ 10 m	**Range**
Probability of detection	95%	**Selectivity**
False alarm rate	< 1 per hour	**Specificity**
Environment	Urban	**Specificity**
Power Consumption	< 10 nW	**Persistence**

N-ZERO Concept

- N-ZERO senses the environment 100% of the time at near-zero power
- N-ZERO uses energy in the signals to perform signal processing to detect information while rejecting noise and interference
- Detection of an event triggers activation of the COTS module for further processing and follow-up action



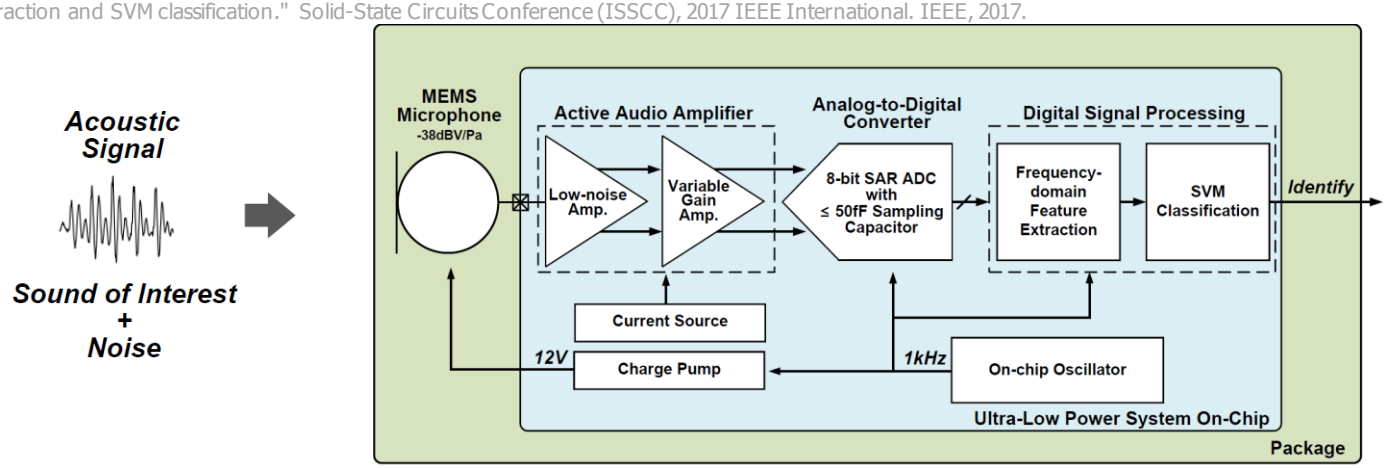
N-ZERO does not replace COTS functionality. N-ZERO will reduce COTS "on" time, thereby dramatically increasing the sensor's useful lifetime.

N-ZERO Sensor Performance

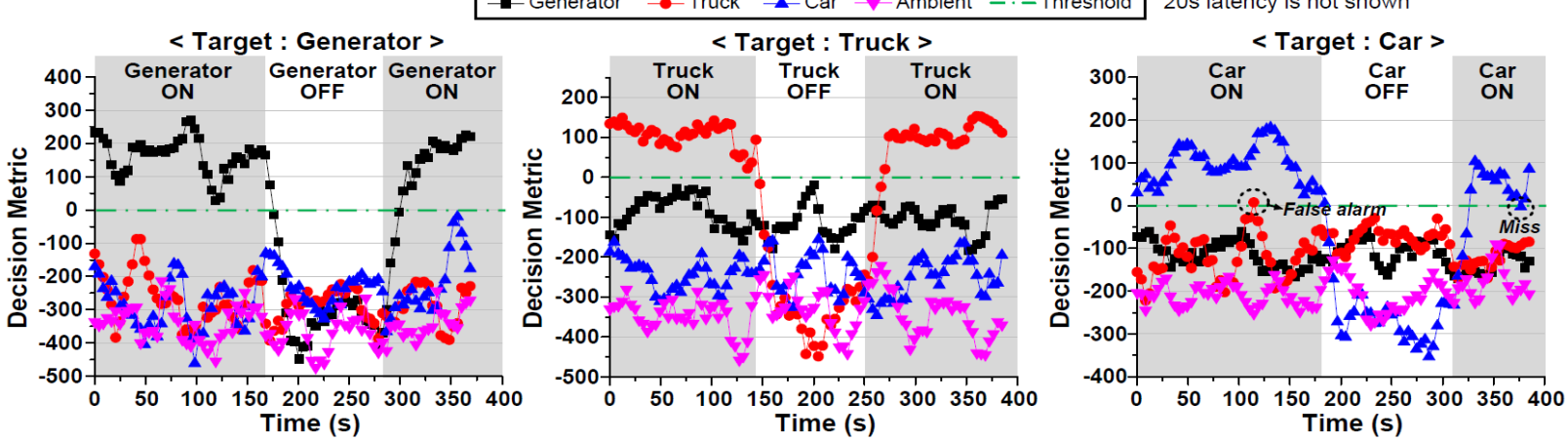
Sensor Type	Signature Detected > 95% POD	Interference w/ Specificity	Standby Power (nW)	Example Agriculture Applications
Acoustic	Vehicle at 5 m	Urban	0 - 12	Bees, pests, UAVs
Infrared	Wavelength specific IR	Broadband thermal & other wavelengths	0	Temperature, IR emissions
Chemical	26 ppm of 1,5-diaminopentane	Ambient and pentane	0	Fertilizer, plant response to pests and disease, pesticides
Acceleration	Stationary vehicle < 1 m	Urban	6	Tree sway
RF	-90 dBm coded waveform	Urban	6	Data transfer, communications, remote wake-up

Acoustic Wake-up Sensor

S. Jeong, et al. "21.6 A 12nW always-on acoustic sensing and object recognition microsystem using frequency-domain feature extraction and SVM classification." Solid-State Circuits Conference (ISSCC), 2017 IEEE International. IEEE, 2017.



< Identification Results for 3 Different Target Objects >

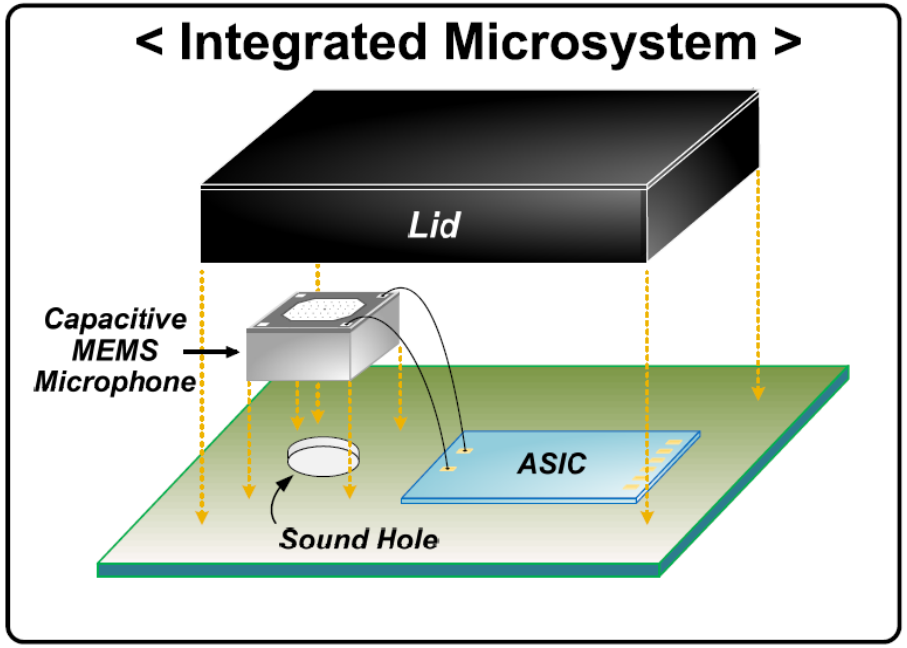


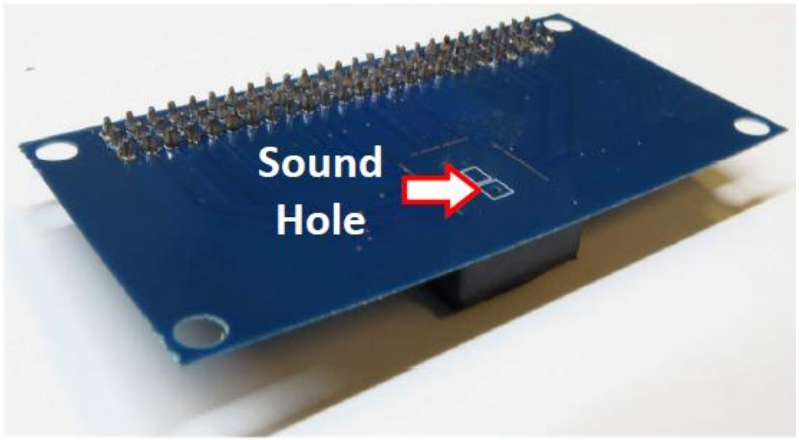
Target	Generator	Truck	Car
Detection Accuracy (*N*=512, *K*=8, *m*=5)	100% No false alarm	100% No false alarm	95% 1.5% false alarm (w/ Truck input)

Wake-up to generator and truck at > 5m with 12 nW of power consumption

Programmable Microphone Wake-up

S. Jeong, et al. "21.6 A 12nW always-on acoustic sensing and object recognition microsystem using frequency-domain feature extraction and SVM classification." Solid-State Circuits Conference (ISSCC), 2017 IEEE International. IEEE, 2017.





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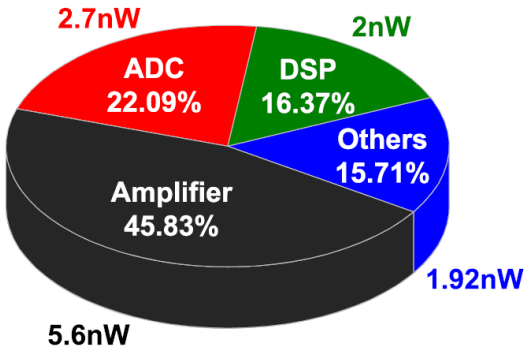
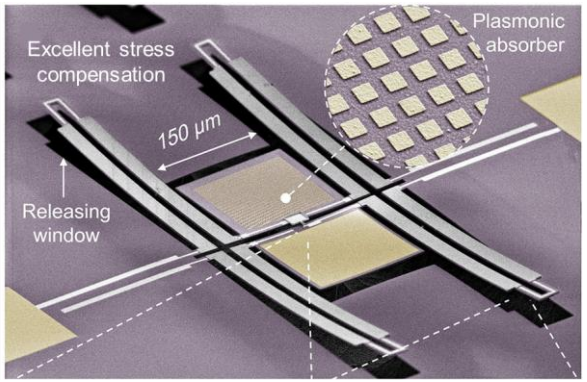
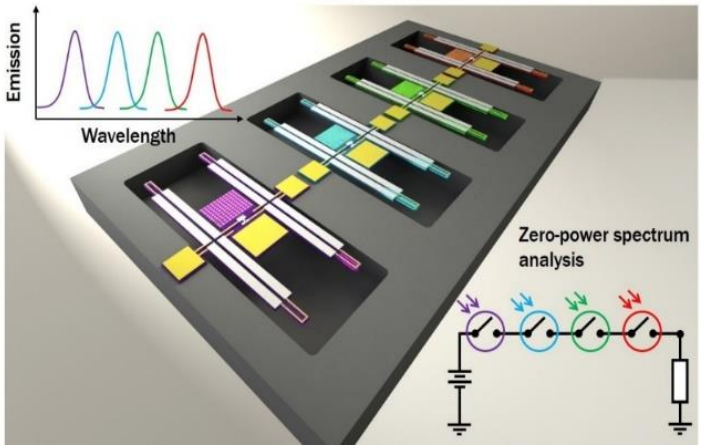


IR Sensing Without Power



Z. Qian, S. Kang, V. Rajaram, C. Cassella, N. E. McGruer and M. Rinaldi., "Zero-power infrared digitizers based on plasmonically enhanced micromechanical photoswitches." *NATURE NANOTECHNOLOGY*, vol. 12, Oct. 2017.

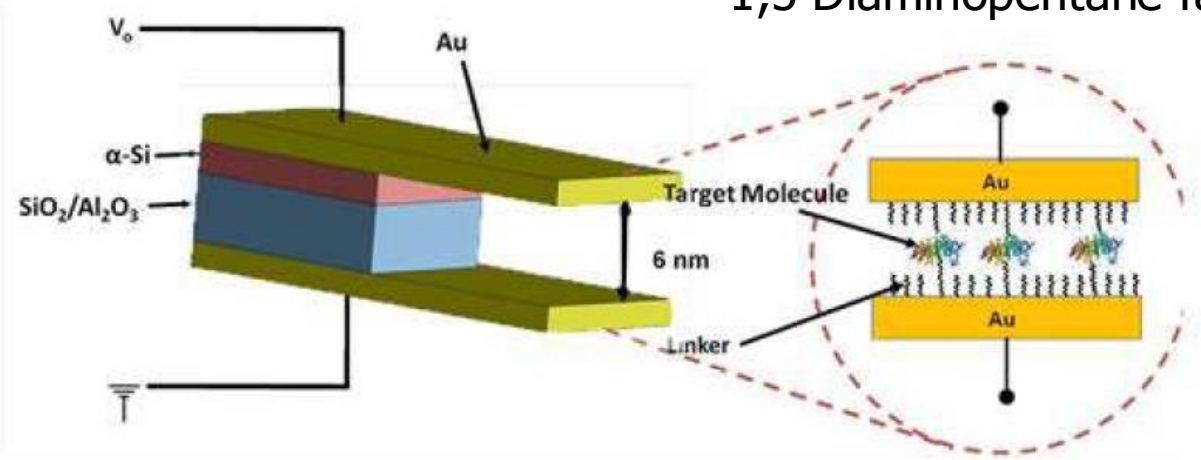


- A **passive microsystem** combines **sensing** and **signal processing**
- Produces **a digitized output bit** in the presence of the unique **IR spectral signature**

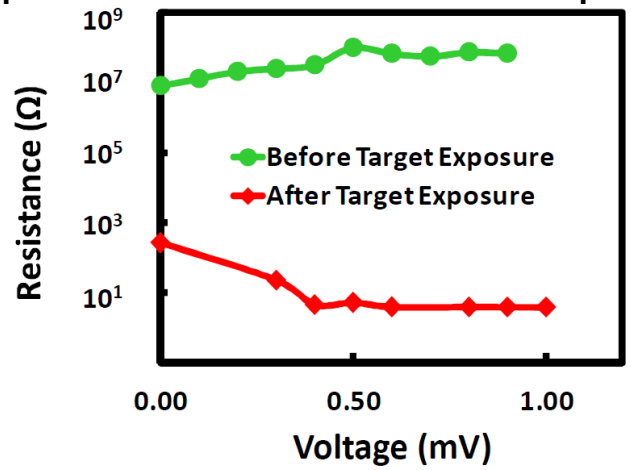
Chemical Percolation Wake-Up

Banerjee, A., et al. "Picowatt gas sensing and resistance switching in tunneling nano-gap electrodes." SENSORS, 2016 IEEE. IEEE, 2016.

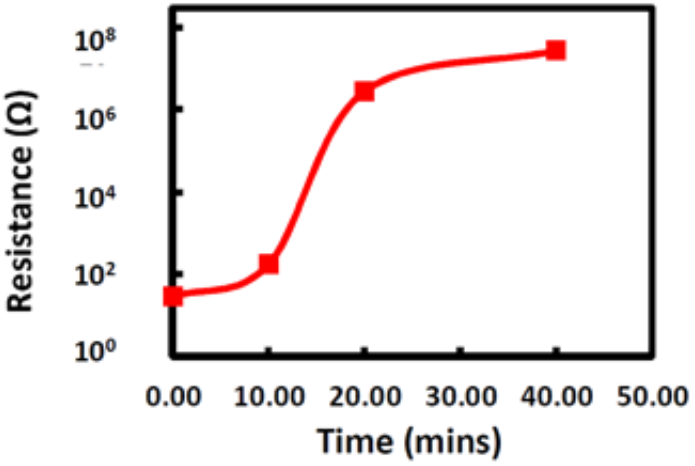
1,5 Diaminopentane Target



Expose sensor to chemical in petri dish

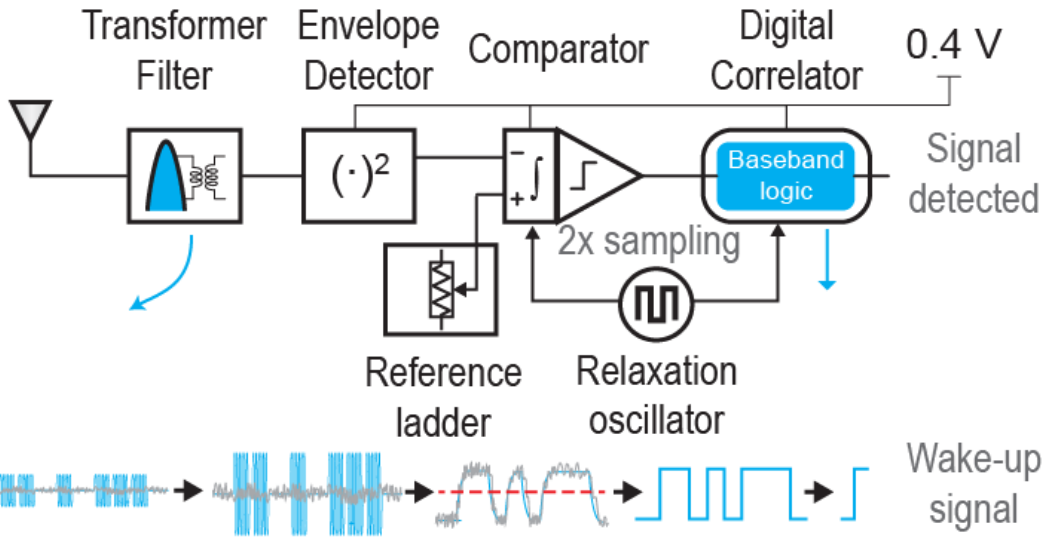


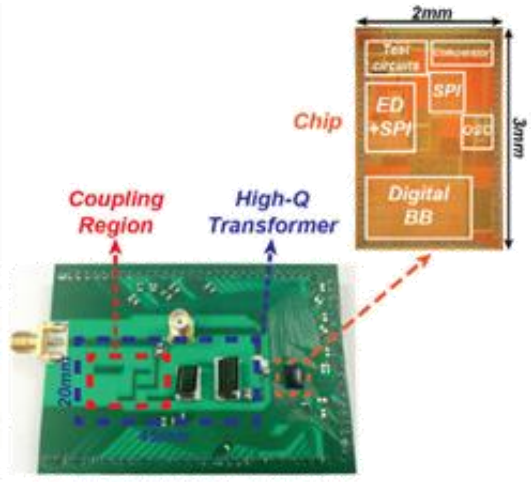
Remove sensor from chemical gas

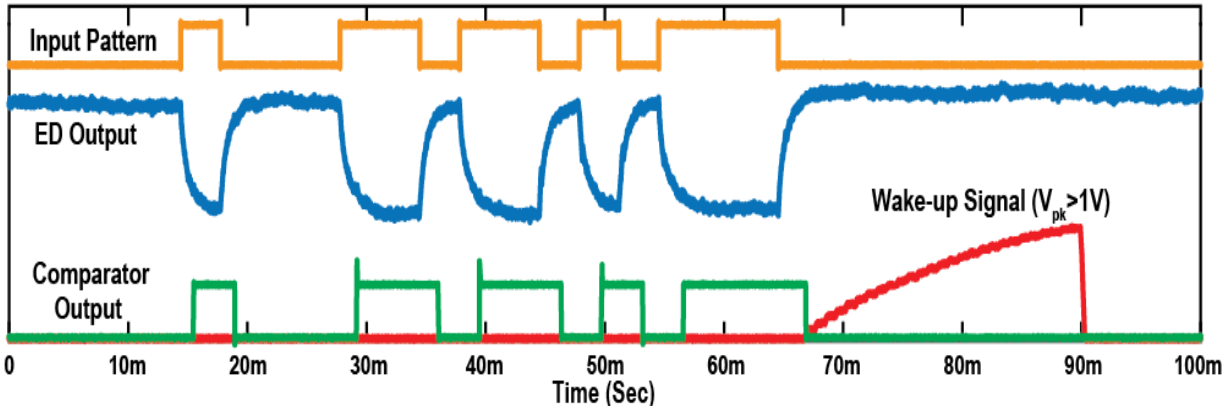


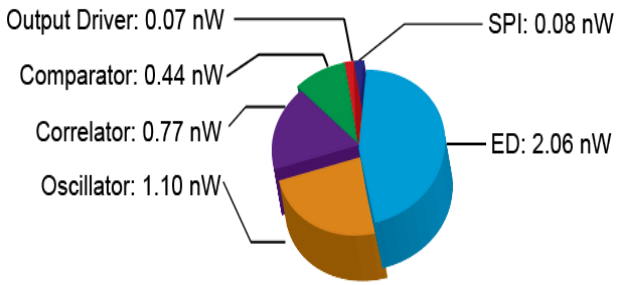
Passive detection of chemical agents with zero power

Near Zero Power RF Wake-up Receiver







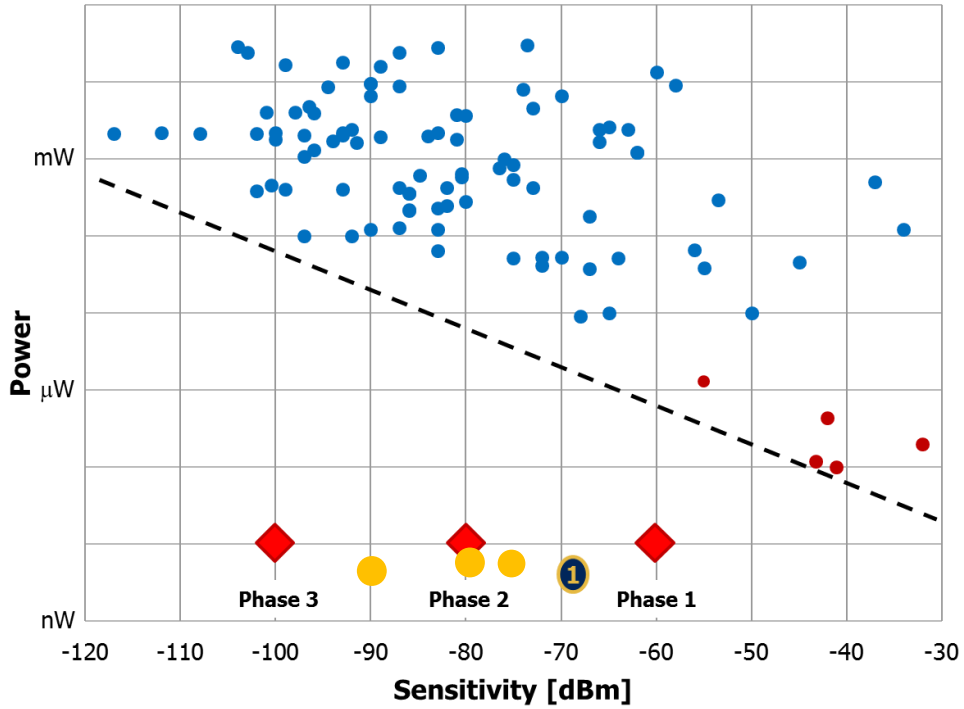


H. Jiang, et al. "24.5 A 4.5 nW wake-up radio with−69dBm sensitivity." Solid-State Circuits Conference (ISSCC), 2017 IEEE International. IEEE, 2017.

4.5 nW N-ZERO wake-up receiver with -69 dBm sensitivity

N-ZERO Has Significantly Advanced Low-Power RF

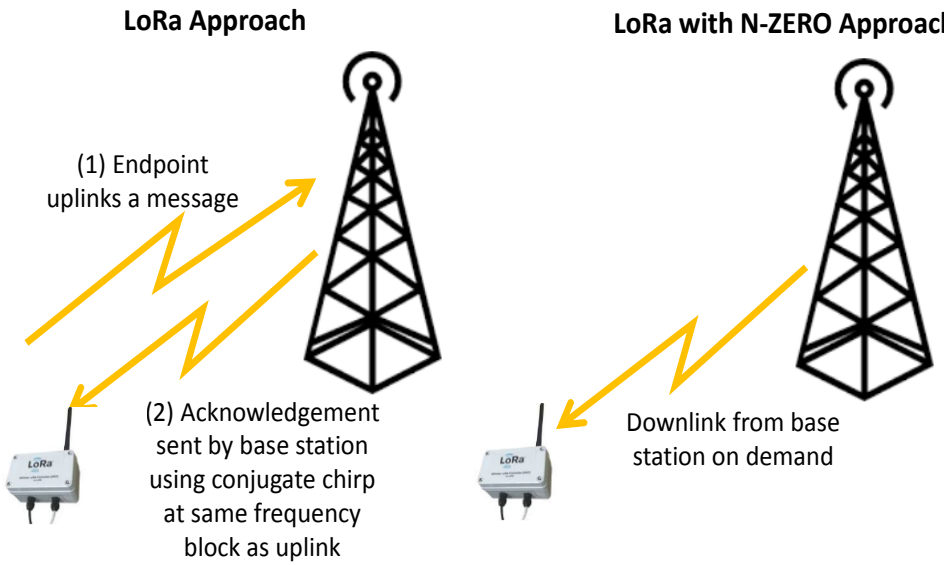
David D. Wentzloff, "Low Power Radio Survey," [Online]. www.eecs.umich.edu/wics/low_power_radio_survey.html



Current Results	Phase II Goals	UCSD (1)	N-ZERO Performers
Power Consumption [nW]	≤10	4.5	~ 8
Sensitivity [dBm]	≤-80	-69	-73 - -90
Frequency [MHz]	50 - 1000	114	100 - 450
False Alarm Rates [#/hour]	≤1	0.64	< 0.1
Probability of Detection [%]	95	≥95	> 99

Remotely wake-up a circuit without drawing stand-by power

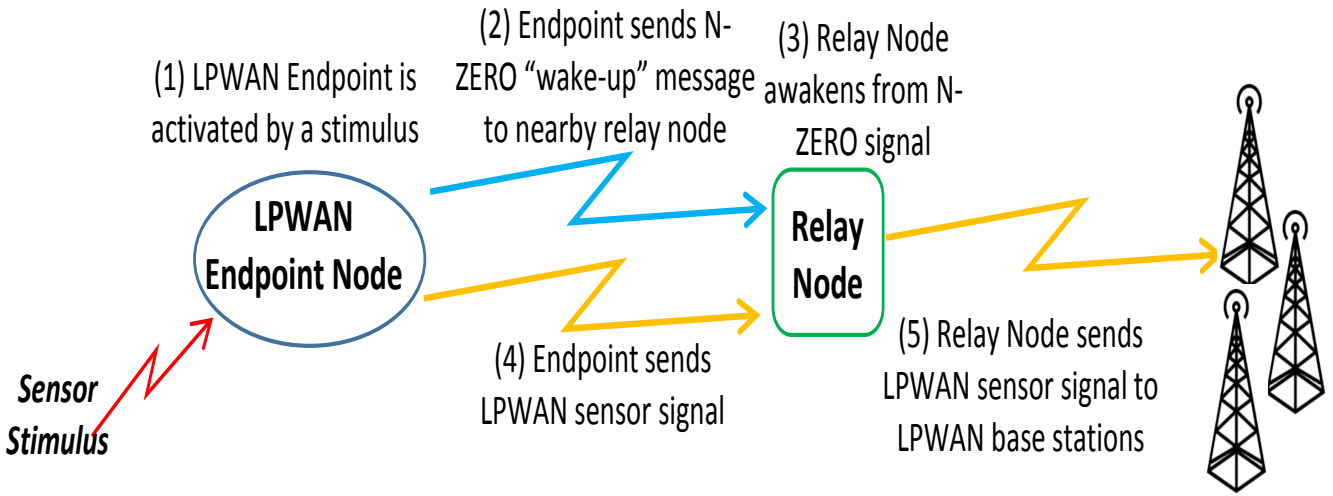
Extending the Range and Capabilities of IoT Sensors



Today each IoT node must communicate directly with the base station and the IoT node must initiate all communications

B. Epstein and R. H. Olsson III, "IoT Networks: Frequency Control Considerations," *IEEE Frequency Cntrl Symp.*, May 2018.

New low SWAP-C RF technologies can enable hopping through nodes to greatly extend range



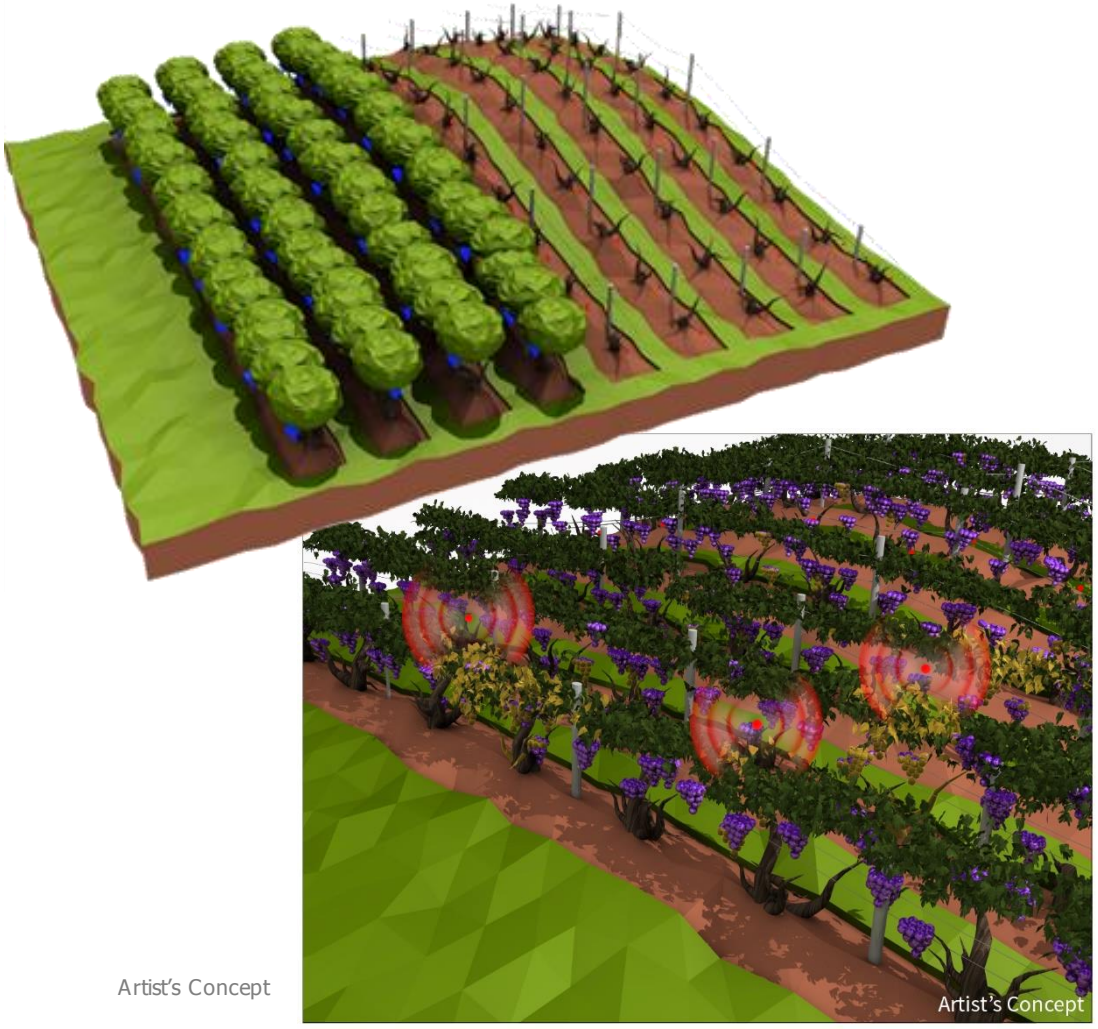
Low-Power Processing

- ARM Cortex-M33 with DSP extensions
- Battery voltage: 1-1.5V
- Functional temperature range: 0-85C
- Shutdown power: 10nW at 25C
- ROM capacity: 128kB
- RAM capacity: 16kB active + 4kB shutdown
- Shutdown RAM breakeven time: 1s for full 4kB transfer
- Performance: 0.1-50MHz
- Active power: 10uW-2mW

} Under SW control – slower is more efficient

- Interfaces: SPI with up to 3 chip selects or up to 5 GPIO

Agricultural Persistent Sensing Opportunities and Questions



- How can emerging sensor and communications technologies be used to improve agriculture and increase crop yields?
- What are the key pieces of information that need to be sensed?
- How densely should the sensors be deployed, over how large an area and how often should they be interrogated?
- What cost needs to be achieved?

New persistent sensing and communications technologies are being developed that could enable low-cost, long life agricultural sensing

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