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Internet of Things, Home Networking, Smart Cities, and Emerging Services

A Comparison of the Energy Consumption properties of Wi-Fi, Backscatter and Bluetooth IoT Devices

Arun Ravisankar

Principal Engineer
Comcast Labs Comcast Cable

2021 Fall Technical Forum
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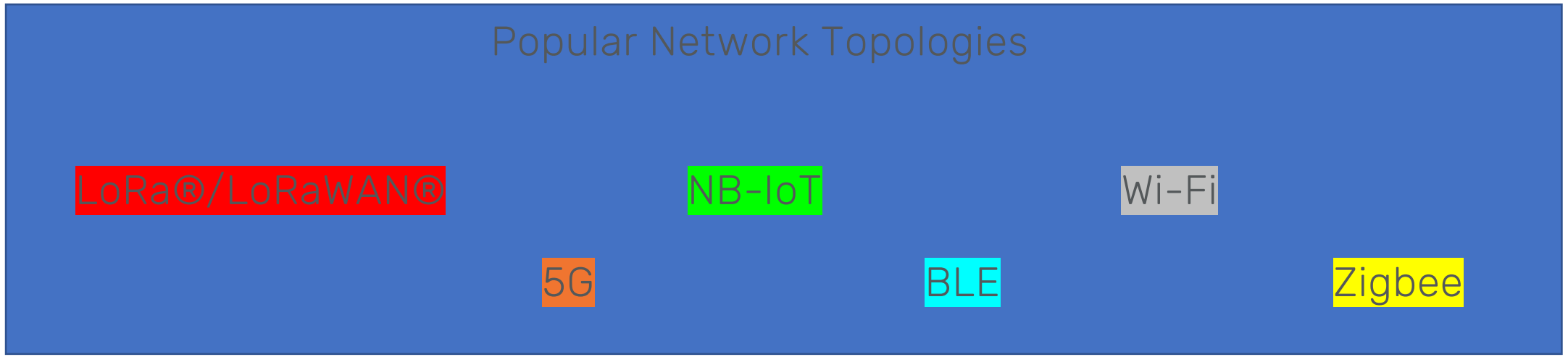
IoT Devices; A Fad or Here to Stay

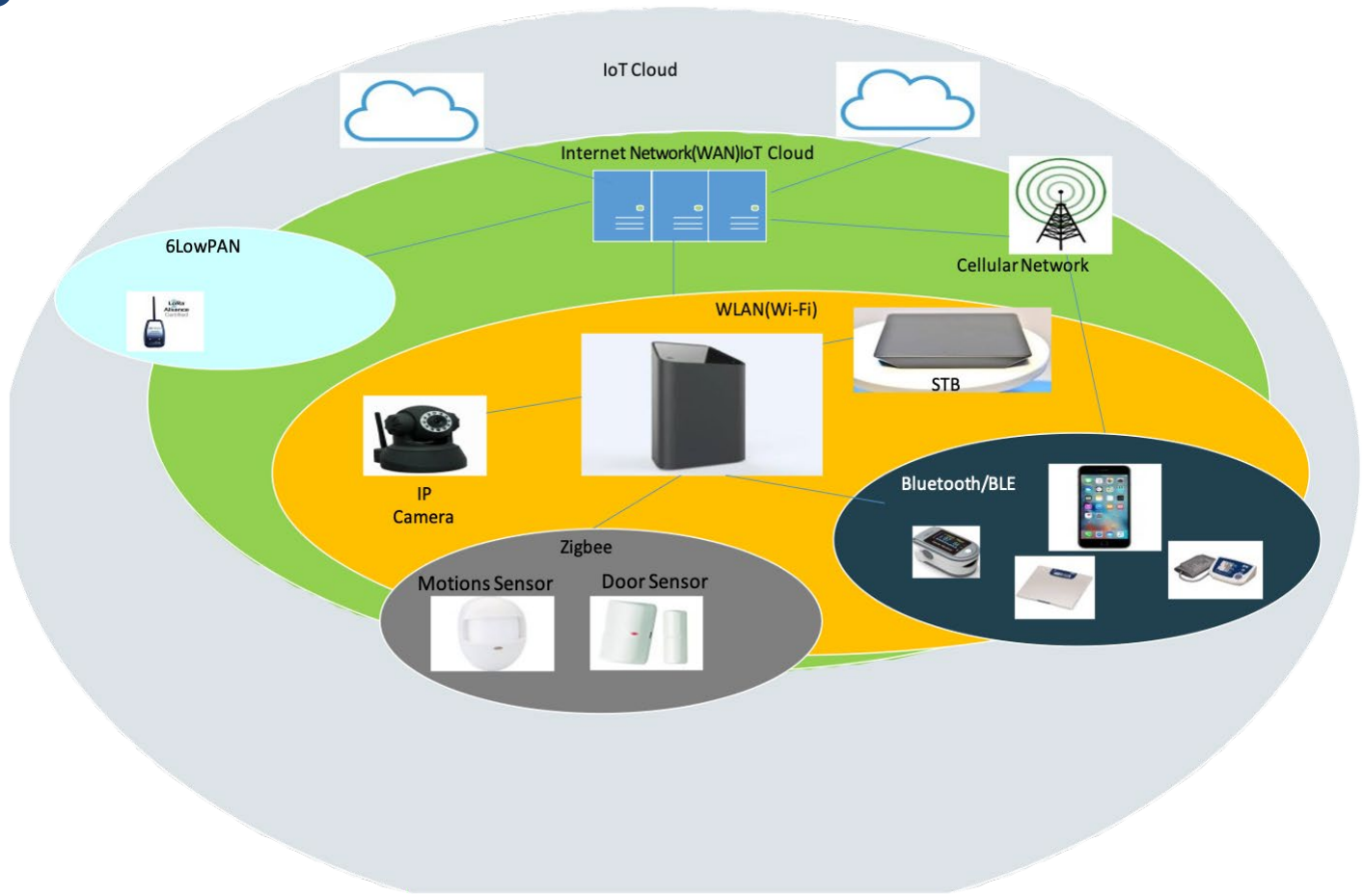
It's tough to get the actual number of IoT devices out there today.

- 8.74 B in 2020 going to 16.44B in 2025 according to Statista 2021 report
- All the way up to an estimate in Security Today at 30B today going to 75B in 2025
- Pick up 5 different reports you will end up with 5 different estimates
- I think it's safe to say IoT is here to stay regardless of the varied estimates

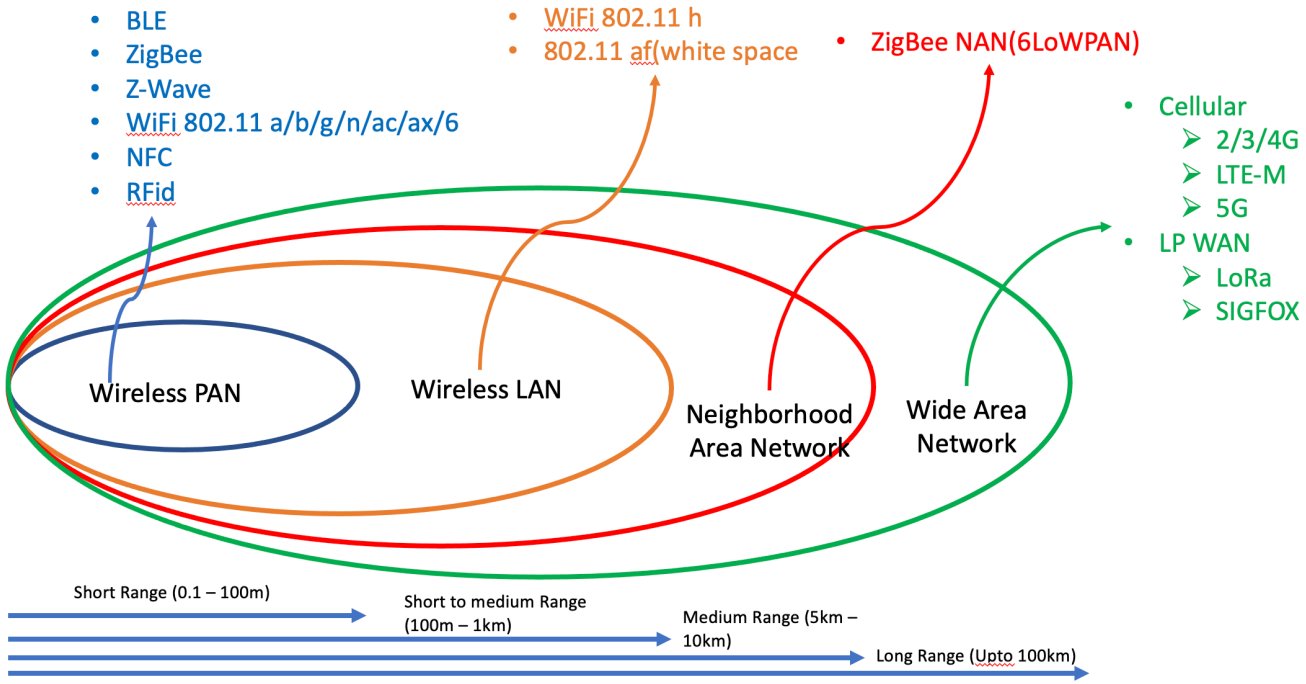


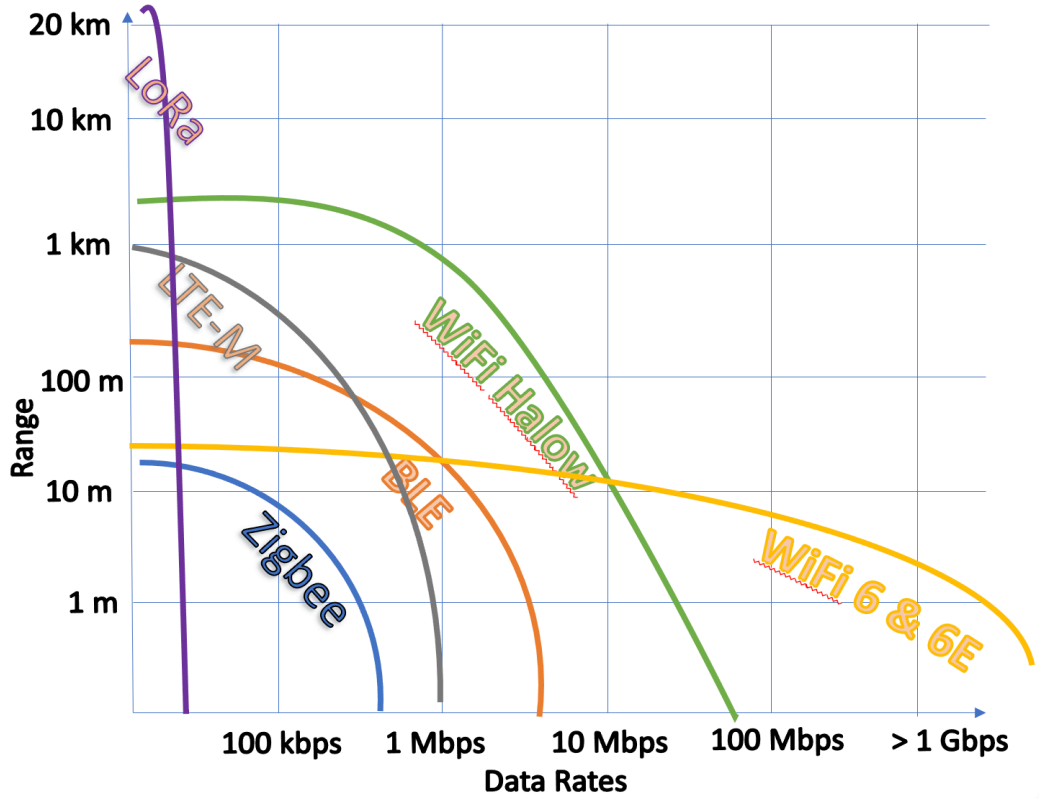
The Right Tool for the Right Problem

- PAN (Personal Area Networks)
  - Short Range, Low Latency
  - NFC, Rfid, BLE, Zigbee
- LAN (Local Area Networks)
  - Short to Medium Range, Low Latency
  - IP addressable on the local network
  - WiFi.
- NAN (Neighborhood Area Networks)
  - Medium Range(5-10Km), Medium Latency
  - Often covers a community or an area
  - 6LowPAN
- WAN (Wide Area Networks)
  - Long Range(Upto 100 Km), Medium Latency
  - Covers longer distances, low data rates
  - Cellular
  - LPWAN(LoRA, SIGFOX)



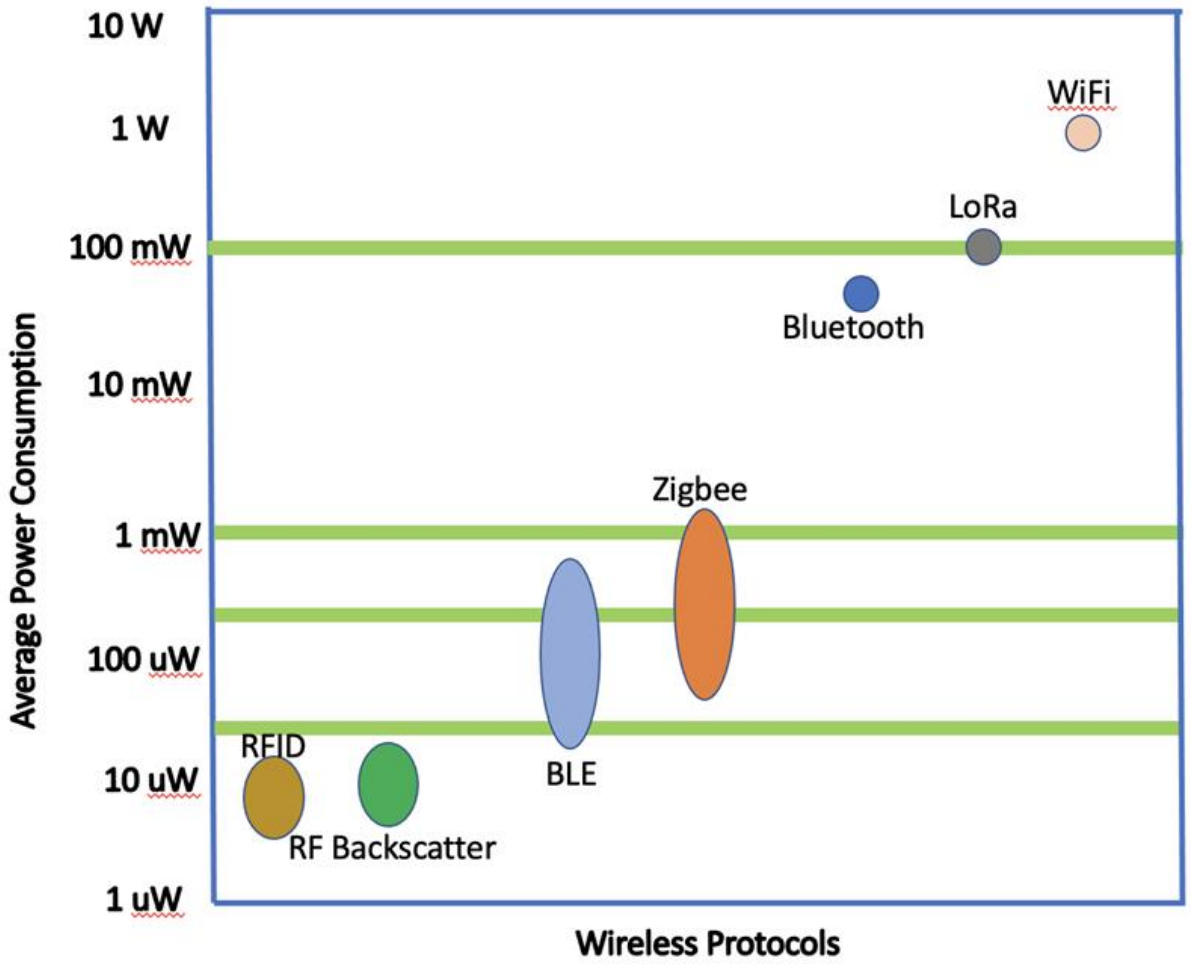
Wireless Networks, Range and Throughput





Network Power Footprint

- RFiD and Backscatter networks consume the least power
- Newer 5G chips promise low power consumption
- Power consumption normally a combination of the reach of the network, data rate and transmission rate



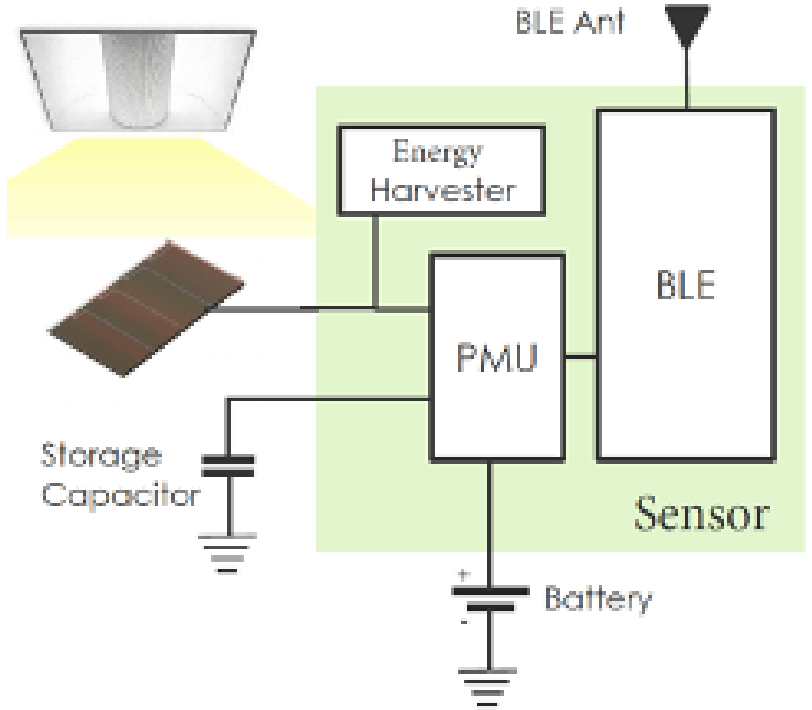
How can we extend device life?

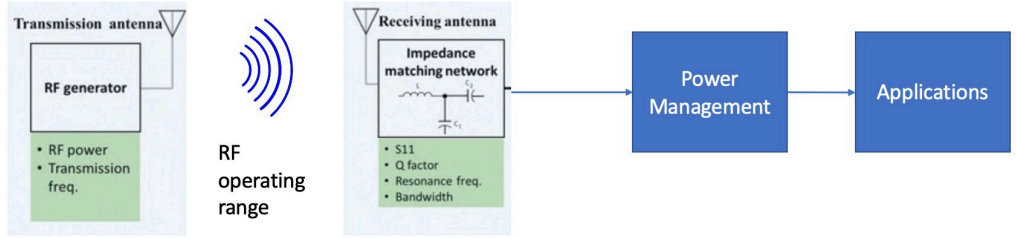
- Three typical device states
  - Sleeping
    - Variable depending on the technology
  - Data gathering
    - Sensor specific
  - Transmitting
    - Varies depending on technology, data rate and distance from gateway

Power	Energy Harvesting	Protocol Optimization
•Connected to Power Grid •Staying connected is not a concern unless there is a power outage	• Augment battery life with energy harvested from natural or artificial sources • Examples include ➢Solar/Photovoltaic ➢RF based harvesting ➢Thermal ➢Kinetic	• Design and optimize transmission protocols. • Power needed to stay connected and transmit information, has an impact on the battery life. • Optimizing RF protocols could help lower power consumption. ➢ RF Backscatter ➢ BLE

Typical Energy Harvesting Components

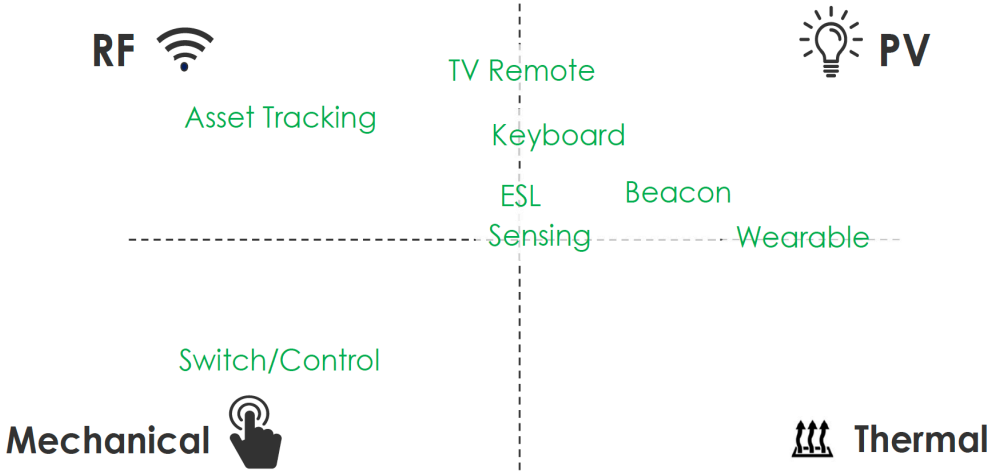
- Energy Source
  - RF, PV, Thermal, Mechanical
- PMU
  - Power management unit
- Energy Harvester
  - Converts external energy into usable or storable power
- Storage capacitor
  - Can be used as a standalone or in conjunction with a battery
- Battery
  - Energy storage device





Energy Harvesting

- Energy Harvesting technologies can help make sensors
  - Battery Free
  - Extend Battery Life
  - Help extend the life cycle of the sensor
- Photovoltaic harvesters use ambient light to harvest energy
- RF harvesters can harvest energy from ambient source or energy transmitted from a source
- Thermal harvesters use heat and temperature variation as their main source to generate power
- Mechanical harvester use devices called Nanogenerators can convert small amounts of mechanical energy into electric current



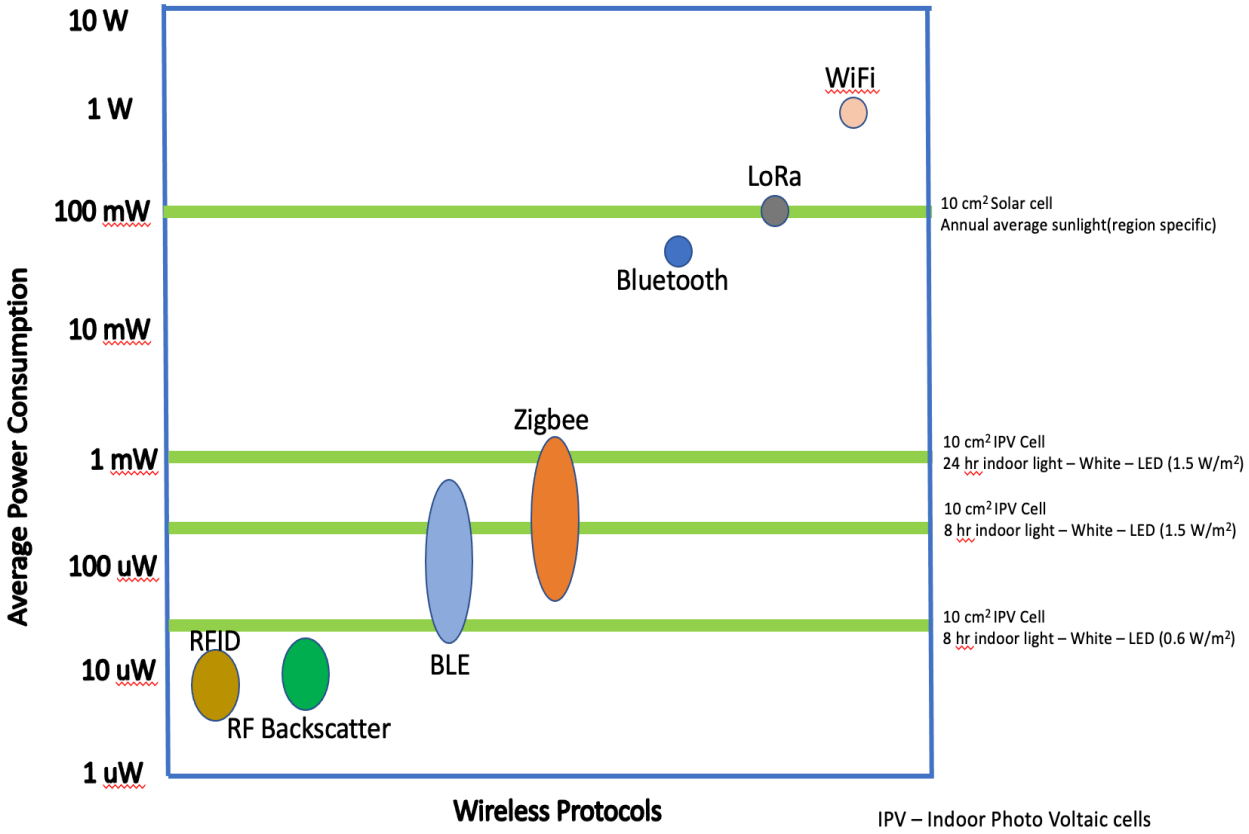
Source	Power Density
Mechanical/Piezoelectric	[0.11 – 7.31] mW g2/cm3
Radiofrequency	1.2*10^{5}–15 mW/cm2
Solar	[0.006–15] mW/cm2
Thermoelectrical	[15–60] _W/cm3
Wind	[0.065–28.5] mW/cm2

Energy Harvesting Technologies

Photo Voltaic	RF Harvesting	Thermal	Mechanical
Pros: • Proven technology • Extended lifetime • Easily modify collector size based on system need	Pros • Ambient harvesting leverages existing signals present • Active harvesting could harvest higher power levels	Pros • Normally a biproduct of other operations • Good solution for manufacturing and data center environments	Pros • Under correct operating conditions, provides a consistent source of energy • Good for manufacturing and large sites
Cons • Additional cost • Doesn't work at night • Variable harvesting based on light level • Scalable space needed for collector	Cons • Relatively low amounts of power harvested in energy harvesters • Very distant dependent from energy sources • Active harvesting normally requires additional power transmitters	Cons • Very low conversion efficiency • Need and environment with temperature variation	Cons • Not suited for residential applications • Requires good operating conditions

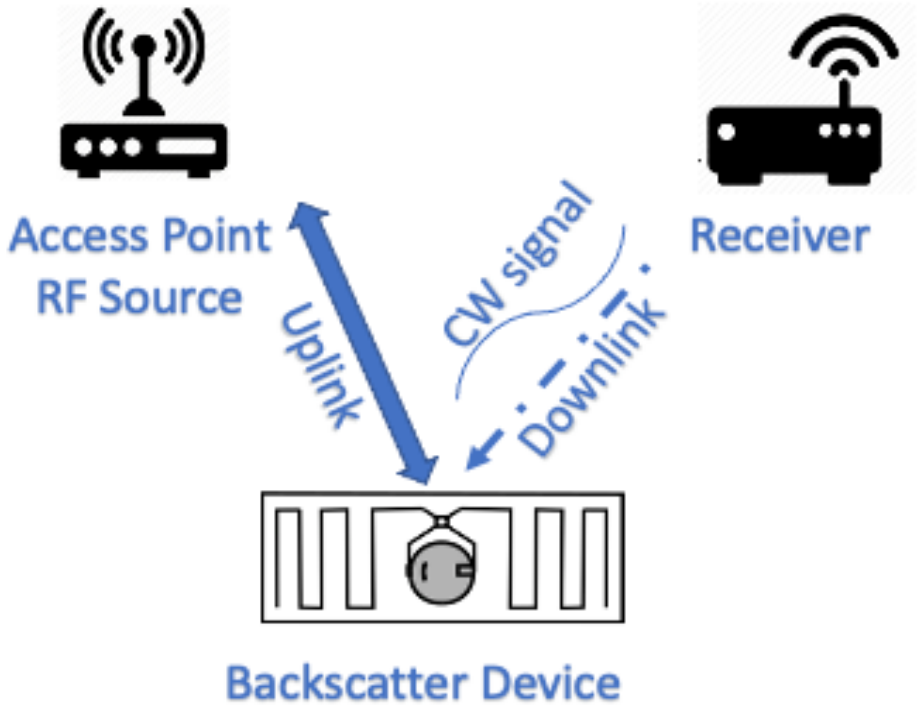
Mapping Wireless Networks to Energy Harvesting

- This example uses a PV cell as the energy harvester.
- Power consumption among most network protocols can be powered by harvesters.
- Question would be on the power consumption of the actual sensor.
  - Motion, Door/Window Sensor
  - Temperature, Humidity and other sensors



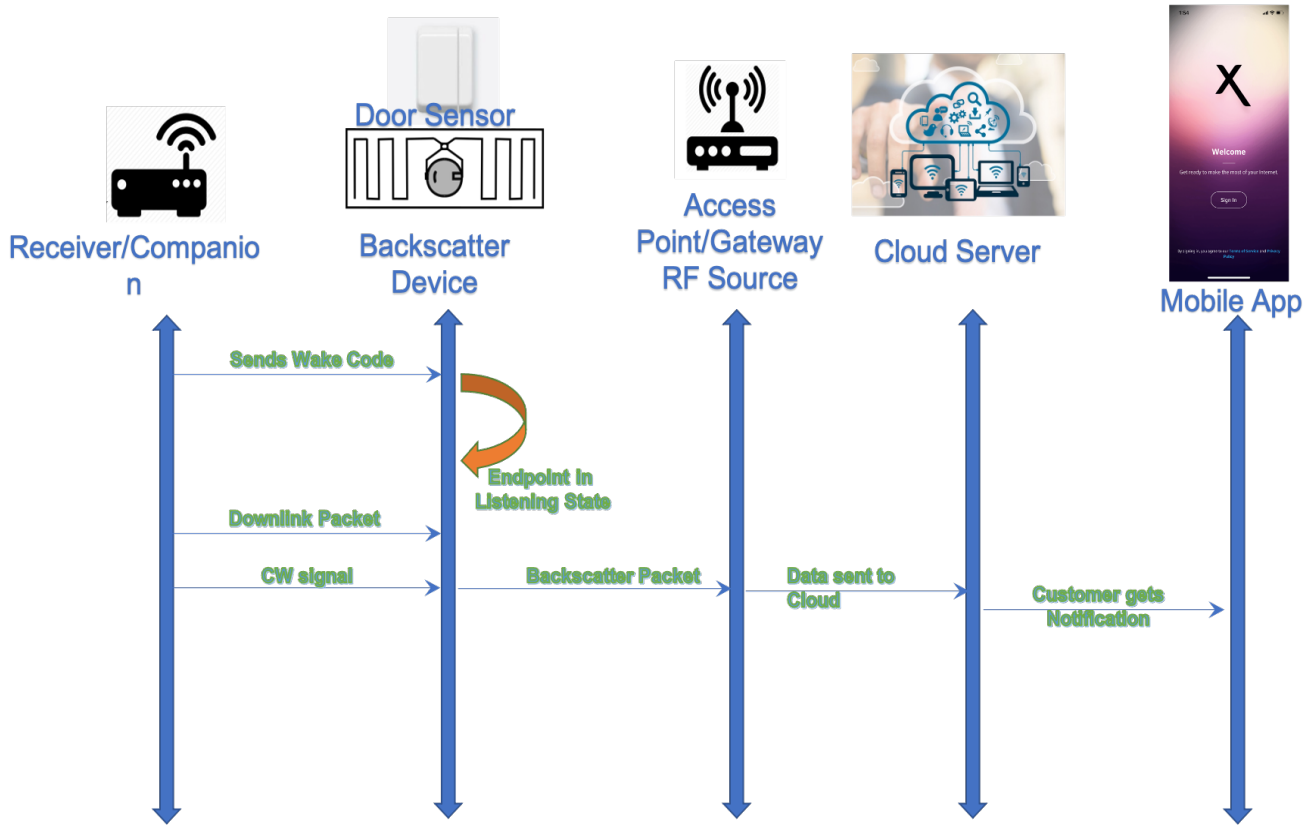
RF Backscatter Technology

- In RF backscatter networks, multiple network topologies are possible.
  - Ambient
  - Using WiFi-LoRa
  - Full Duplex
- Best suited for battery free systems.
  - RF harvesting a popular choice as we could use the antenna for both power and data



RF Backscatter Technology

- A Full Duplex network topology consists of
  - *Endpoint:* The sensor which is the source of the data in the network
  - *Gateway/Access point:* The gateway also serves as a bridge/hub between the backscatter network and another PAN or WAN
  - *Companion:* The companion enables Backscatter communication by transmitting a brief CW (Continuous Wave) signal for each uplink transmission.



Next Steps

- Partnered with leading vendors in each category with the goal of building IoT POCs to evaluate the impact on the cost of ownership of the systems
- Components
  - Energy harvesting: Photo Voltaic/RF
  - Protocol implementation: RF Backscatter
  - Power management: Low Power PMU
  - Energy storage: Capacitors, rechargeable batteries, single use batteries
- Metrics
  - Lifetime
  - Cost
  - Efficiency
  - Latency
  - Sustainability
  - Footprint

Conclusion

- IoT devices and their networks are supplying critical information from sensors, but to keep the information flowing, these devices need to stay powered up and there's only so many options available.
- We can extend the life of these devices
  - By improving the efficiency of the communication protocols used
  - By deploying energy harvesting to extend the battery life
- In IoT applications and networks, where devices are deployed in a stand-alone fashion and expected to function for an extended period normally measured in years as opposed to days. This is where changes in power consumption can have enormous impacts on the life of the devices.

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Thank You!

Arun Ravisankar & Ty Pearman

Principal Engineer
Comcast
Arun_Ravisankar@Comcast.com