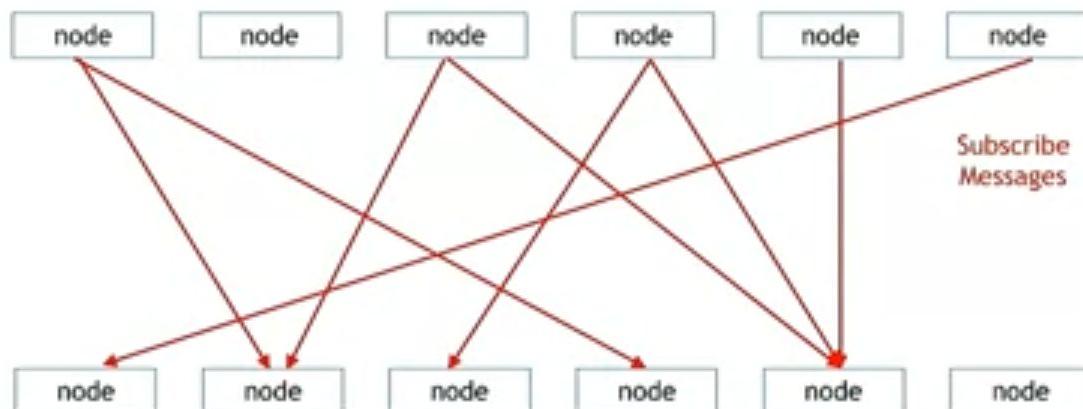
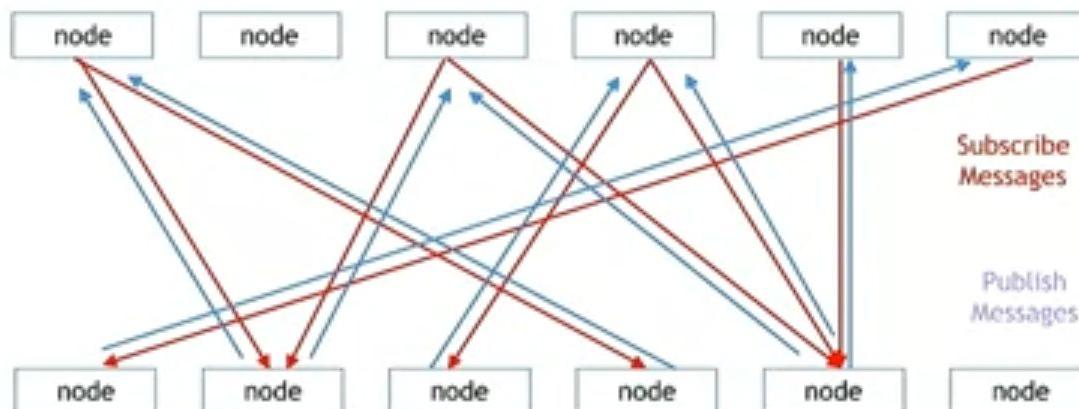


## Messaging Schemes (con't)



See also: [MQTT.org](#) A lightweight publish/subscribe M2M protocol

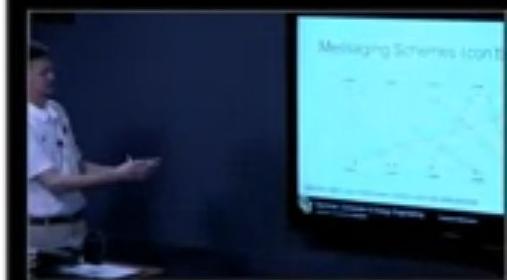
## Messaging Schemes (con't)



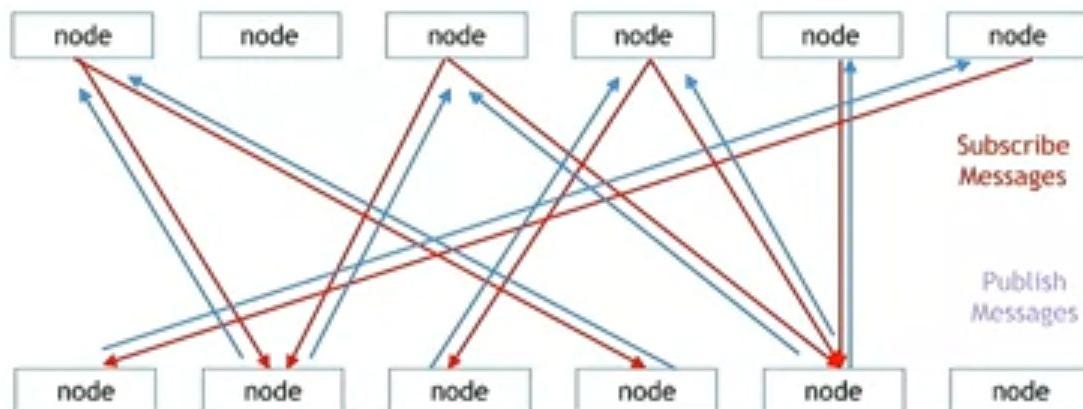
Subscribe  
Messages

Publish  
Messages

See also: [MQTT.org](#) A lightweight publish/subscribe M2M protocol



## Messaging Schemes (con't)



See also: [MQTT.org](#) A lightweight publish/subscribe M2M protocol



## Leading Wireless Protocols

- Long Range Wireless Communication protocols, and Low-Power Wide-Area-Network (LPWAN), aka Low-Power Network (LPN), aka Small-Cell Networks (SCN)
  - Cellular
  - LoRa (LoRaWAN)
  - Ingenu
  - WiMAX
- Short Range Wireless Communication protocols
  - ANT+
  - Bluetooth Smart (BLE)
  - ZigBee
  - WiFi
  - NFC
  - EnOcean
  - Wireless HART
  - Z-Wave
  - 6LoWPAN



## Cellular

- GSM, 4G/LTE
- You know the players in the US
- Range: 5 - 30 km
- Speed:
  - ATT LTE Denver, 28 Mbs down, 6.5 Mbs up
  - Verizon Denver, 4.9 Mbs down, 1.8 Mbs up (iPhone 5S)

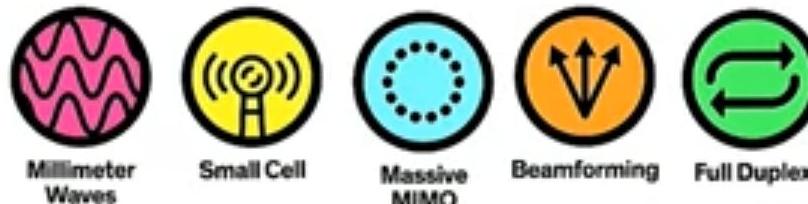


## Cellular - 5G

- [http://spectrum.ieee.org/video/telecom/wireless/  
everything-you-need-to-know-about-5g?  
utm\\_source=Tech+Alert&utm\\_medium=Email&utm\\_campaign=TechAlert\\_02-02-17&bt\\_ee=9+hbB4prLYKxB1Ew5QEbE4wCKC4KRCOiTbOEUPzSv8uKDcqCucXdaeyuYwzfZTtz&bt\\_ts=1486061848685](http://spectrum.ieee.org/video/telecom/wireless/everything-you-need-to-know-about-5g?utm_source=Tech+Alert&utm_medium=Email&utm_campaign=TechAlert_02-02-17&bt_ee=9+hbB4prLYKxB1Ew5QEbE4wCKC4KRCOiTbOEUPzSv8uKDcqCucXdaeyuYwzfZTtz&bt_ts=1486061848685)



# Cellular - 5G



Millimeter Waves

Small Cell

Massive MIMO

Beamforming

Full Duplex



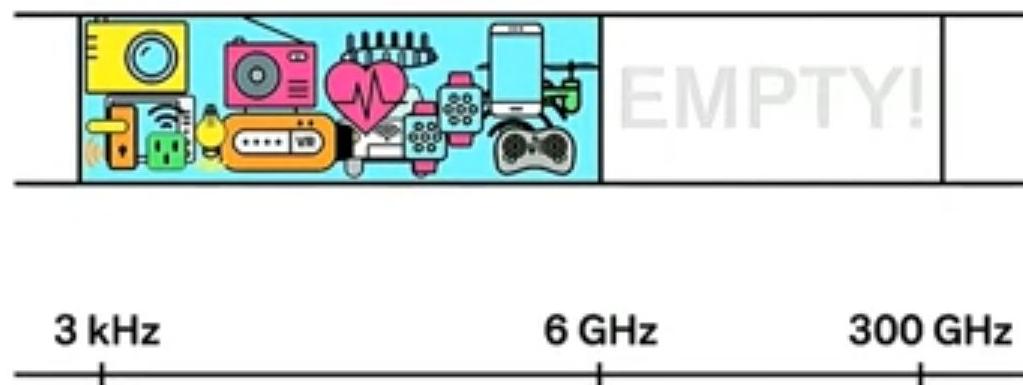
By Amy Nardino, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT



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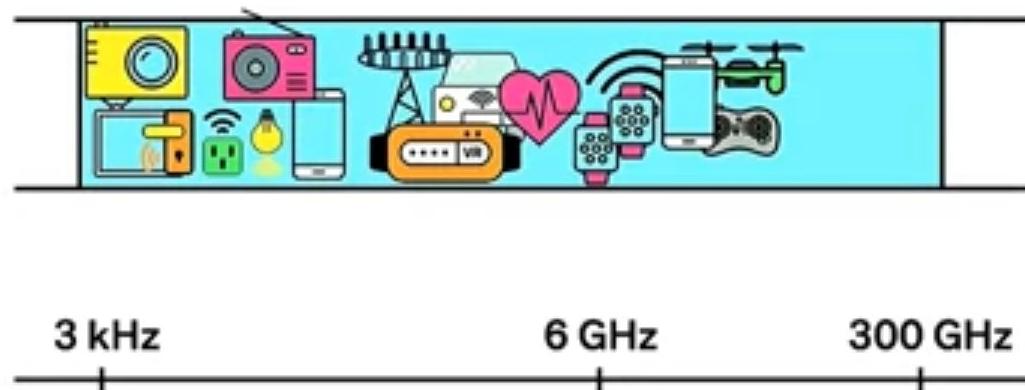
## Cellular - 5G



By Amy Noydum, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT



## Cellular - 5G



By Amy Nolden, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT



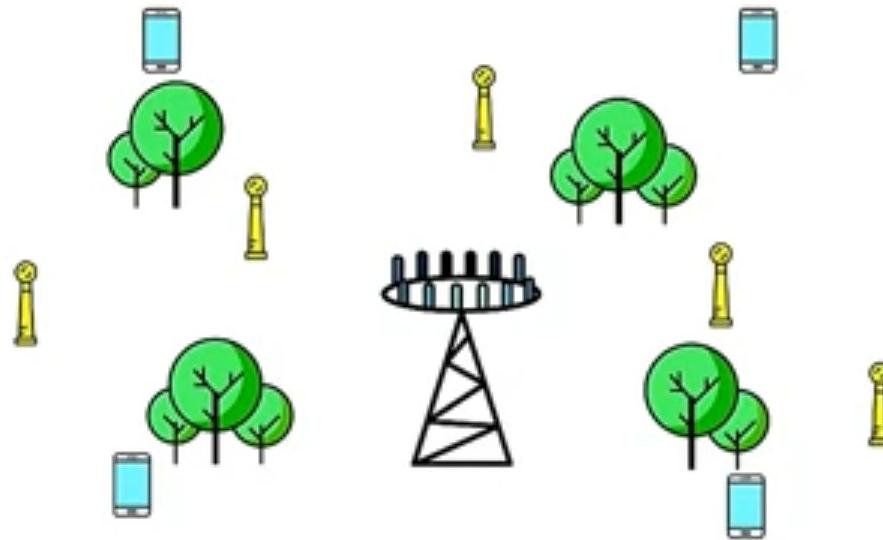
## Cellular - 5G



By Amy Nolden, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT



## Cellular - 5G



By Amy Nolden, Kristen Clark and IEEE Spectrum Staff

Posted 27 Jan 2017 | 19:00 GMT



## Cellular - 5G



# MIMO

Multiple Input Multiple Output



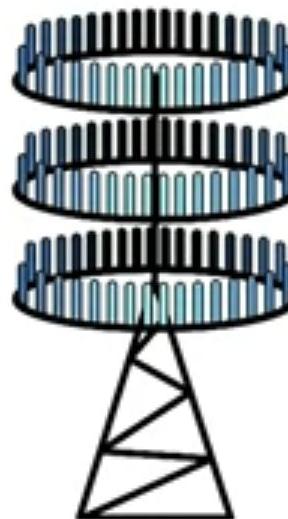
By Amy Nordrum, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT



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## Cellular - 5G

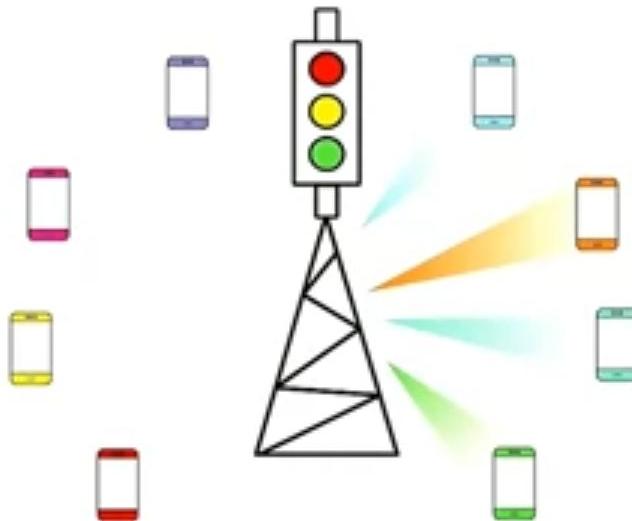


By Amy Nordrum, Kristen Clark and IEEE Spectrum Staff

Posted 27 Jan 2017 | 19:00 GMT



## Cellular - 5G

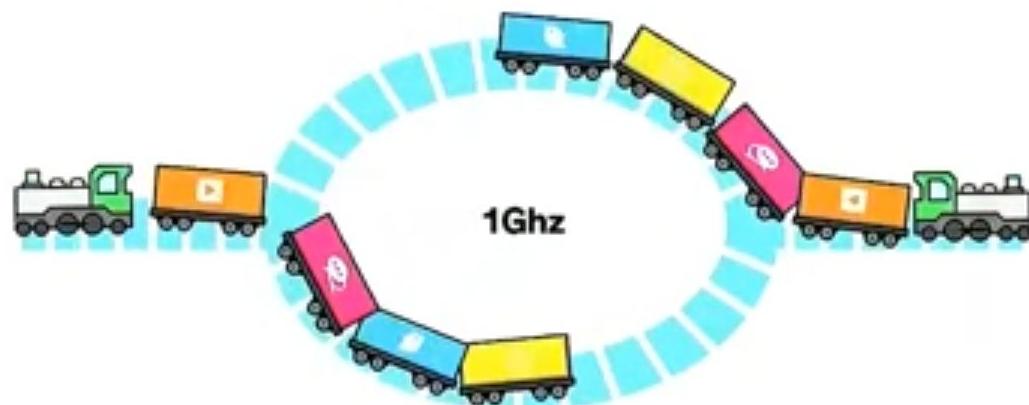


By Amy Nordrum, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT





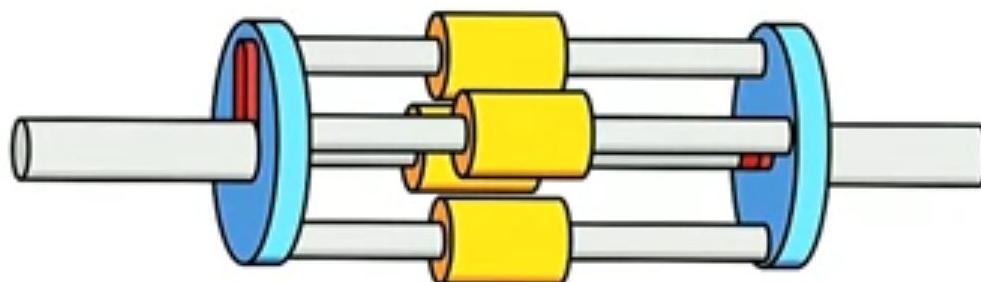
## Cellular - 5G



By Amy Nordrum, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT



## Cellular - 5G



By Amy Nolden, Kristen Clark and IEEE Spectrum Staff  
Posted 27 Jan 2017 | 19:00 GMT



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## LoRa WAN

- <https://www.lora-alliance.org/What-Is-LoRa/Technology>
- Topographies: Star
- Range: Several (1-3) km
- Speed: 0.3 to 50 Kbs



## LoRa WAN

**LoRa™**

**EASY TO INSTALL**  
**EXTREMELY ECONOMICAL**  
**FLEXIBLE TO ADAPT**  
**SCALABLE**  
**BI-DIRECTIONAL**  
**SECURE & ENCRYPTED**



## Ingenu

- <http://www.ingenu.com>
- Topographies: ? star
- Range: Up to 50km
  - 17 towers cover Dallas/Ft Worth area (2000 sq. miles)
- Speed: “low data needs”



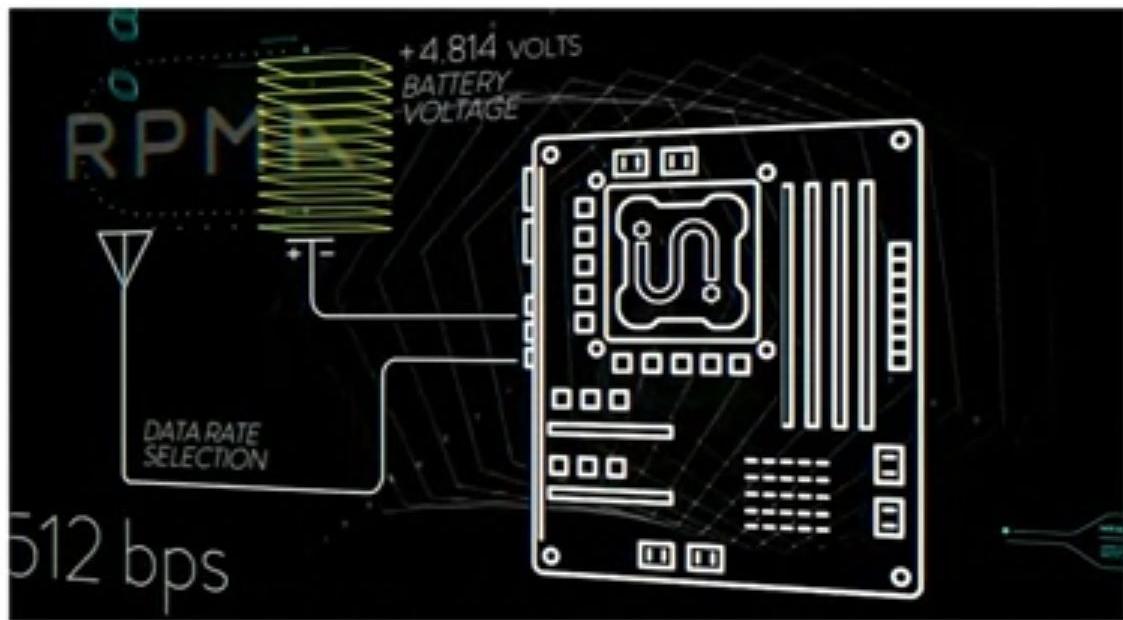


# Ingenu





# Ingenu



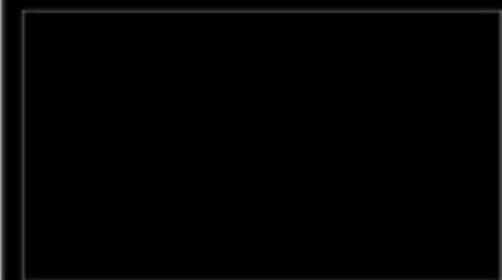


Ingenu



**INGENU**  
simply genius

[www.ingenu.com](http://www.ingenu.com)

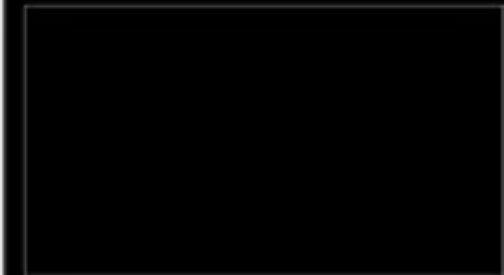


## WiMAX

- Worldwide Interoperability for Microwave Access
- Designed for the “last mile”
- Video/demo: <https://www.youtube.com/watch?v=Tzna27LgBSk&list=PL6D14AD2104D5BE40&index=4>
- <https://standards.ieee.org/about/get/802/802.16.html>
- Topographies: mesh
- 2-60 GHz, depends on the country
- Range: 10km
- Speed: ~ 70 Mbs (depending on antenna)



## WiMAX



# Short Range Wireless Protocols



## Bluetooth Smart (BLE)

- <https://www.bluetooth.com>
- Ultra low-power
- Topographies: Peer-to-peer, mesh
- 2.4 GHz
- Range: < 10m
- Speed: 1-2 Mbs



## ANT+

- <https://www.thisisant.com/consumer/ant-101/what-is-ant/>
- Ultra low-power
- Topographies: Star, peer-to-peer, mesh
- 2.4 GHz
- Range: < 10m
- Speed: 1-2 Mbs (competes with bluetooth)



## WiFi (802.11n)

- IEEE 802.11
- Topographies: Peer-to-peer
- 2.4 and 5 GHz
- Range: 20-80m
- Speed: 54 - 600 Mbs (54 is current)



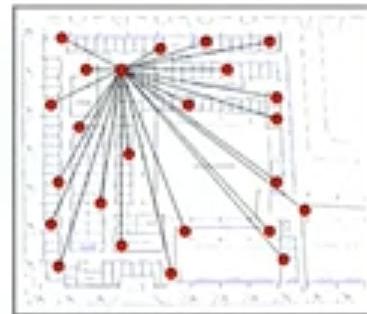
## ZigBee

- <http://www.zigbee.org>
- Ultra low-power
- Topographies: Mesh
- 2.4 GHz
- Range: ~20-80m
- Speed: 20 - 250 Kbs (competes with Wifi)



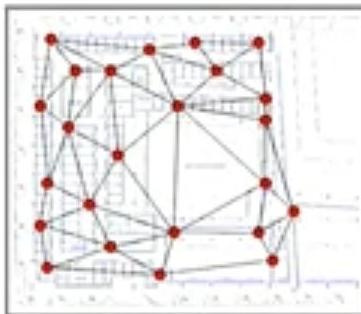
# ZigBee Architecture

## What is Mesh Networking



Star Network  
(e.g. 802.11)

In a Mesh architecture, every node can be a router for its neighbors. Network management and data flow is decentralized.



Mesh Network  
(e.g. ZigBee)

ember



## Wireless HART (WHART)

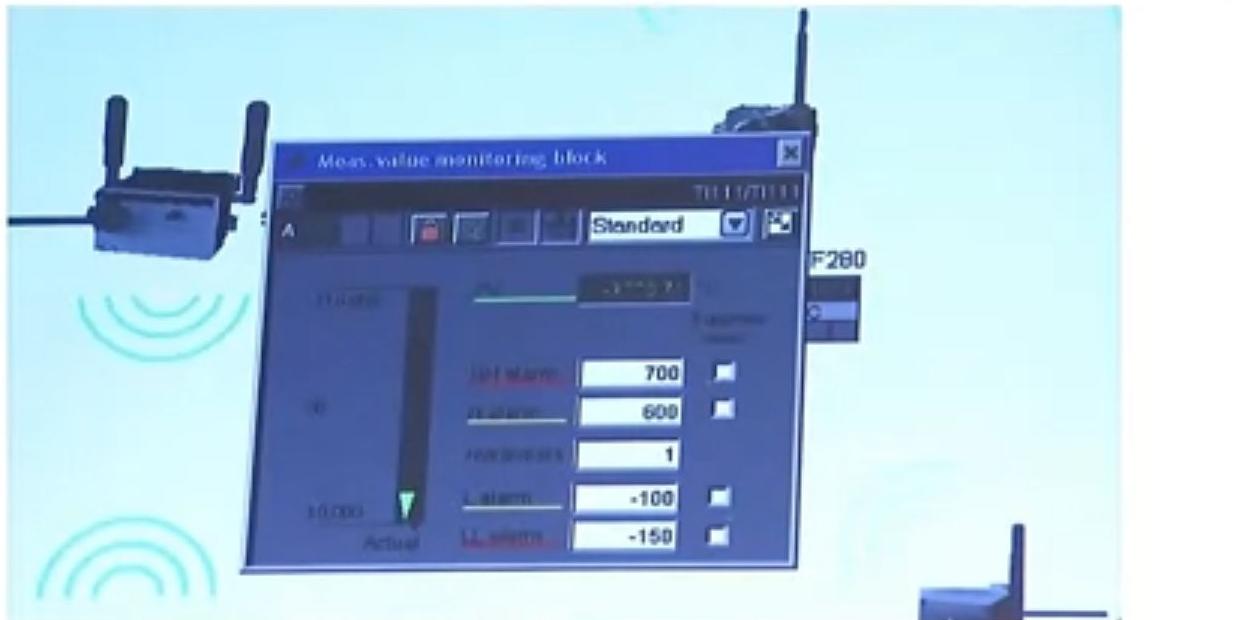
- <https://fieldcommgroup.org/technologies/hart/hart-technology>
- Topographies: Mesh
- 2.4 GHz
- Range: nominal ~ 200m
- Speed: 20 - 250 Kbs (competes with Wifi)
- Specific for industrial wireless sensing



## Wireless HART (WHART)



# Wireless HART (WHART)



## EnOcean

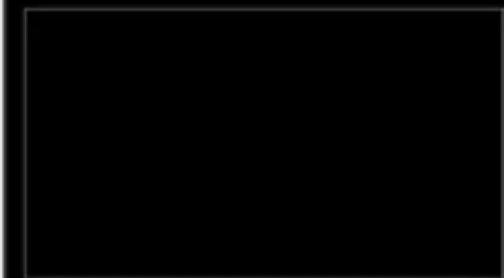
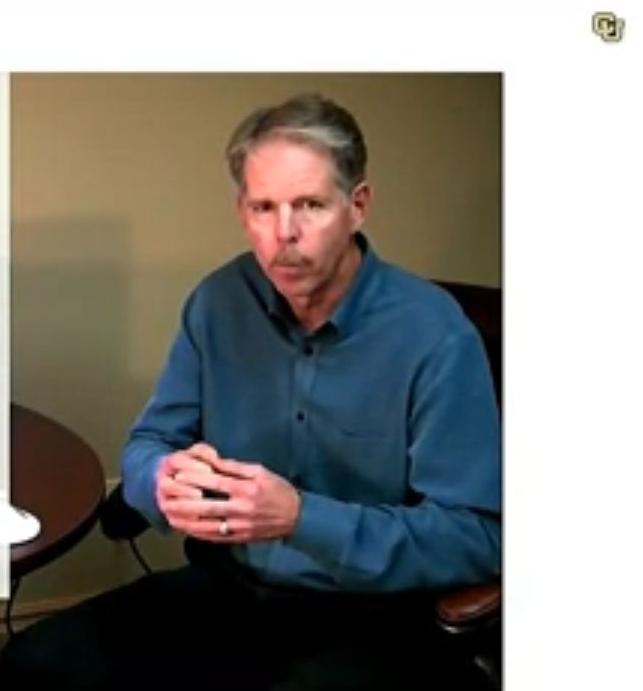
- <https://www.enocean.com/en/>
- Ultra low power, energy harvesting, self-powered
- Topographies: Peer-to-peer
- 800-900 MHz, 2.4 GHz
- Range: ~ 30m indoor range
- Speed: 2 Mbs (competes with Wifi, but lower speeds)
- Also supports ZigBee and Bluetooth Smart
- <https://www.youtube.com/watch?v=n0DEQlOZm8Y&list=PLXmn2hE1zXxpEnL0x0K6WH9nYpMwRuVnf>



EnOcean



# EnOcean



# EnOcean

Top 3 Things to Know about EnOcean Wireless:

- #1. Self-powered
- #2. Interoperable - one wireless standard
- #3. Field Proven



## Z-Wave

- <http://www.z-wave.com>
- Home automation focus: lights, locks, thermostats
- Topographies: Peer-to-peer
- 908.42 MHz
- Range: 100m (competes with Wifi)
- Speed: ~ 40 Kbs (but lower rates than Wifi)



## 6LoWPAN

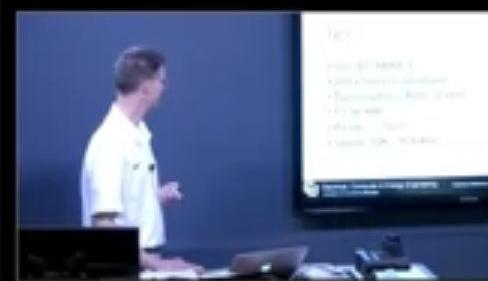
- IPv6 Low-rate Wireless Personal Area Network
- <http://https://standards.ieee.org/about/get/802/802.15.html>
- Topographies: mesh
- Basis of ZigBee and Wireless HART
- Started out as a 2.4 GHz spec, expanding: sub-1 GHz, Bluetooth Smart, Power-Line-Control (PLC), low-power WiFi



Source: <http://www.ti.com/lscds/ti/wireless-connectivity/6lowpan/overview.page>

## NFC

- ISO/IEC 18000-3
- Ultra low (or no) power
- Topographies: Peer-to-peer
- 13.56 MHz
- Range: ~ 10cm
- Speed: 106 - 424 Kbs



# Coming up in Module 5

Heads up students. The next module deals with security for IIoT devices. In the security module there is a graded assignment. The purpose of the assignment is to get some hands-on experience with security and then write a short paper (5-12 pages). The paper will be peer graded (graded by other students).