Low Data Rate Links for IoT

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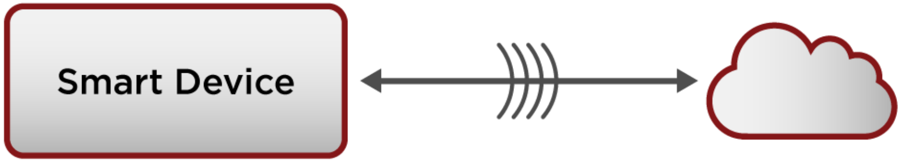
Agenda

- Ways to get IoT data into the cloud
- New technologies compared to old
- Tradeoff considerations
- Use cases
- Detailed considerations
  - LoRa
  - Sigfox
  - LTE-M
  - NB-IOT
  - Zigbee
  - Bluetooth LE Mesh

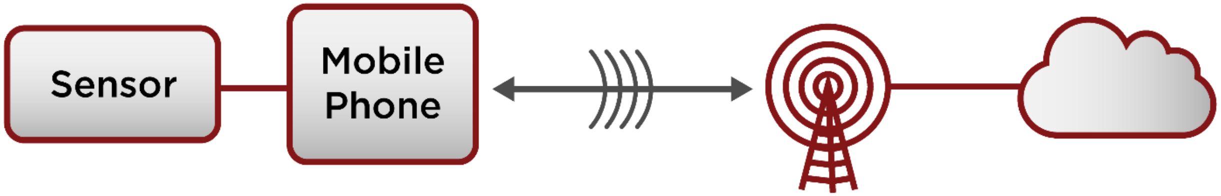
Three ways to get data into the cloud

1. Smart device directly to cloud



2. Sensor to gateway to cloud

3. Sensor to cell phone to cloud



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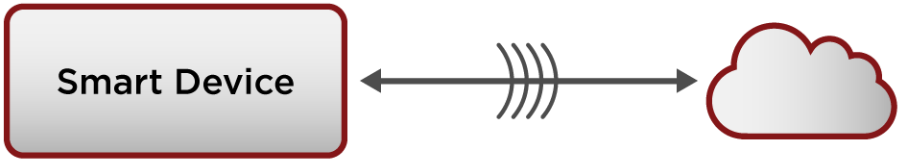
Smart device directly to cloud



- Cellular and WiFi mainly
- Power requirements are high
- Expensive for small data packets
- Traction: automotive, consumer devices
- Limited traction for large number of end devices

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Sensor to gateway to cloud

- Inconvenient and expensive for consumer products
- Private gateways, home security
- Traction with enterprise level devices
  - May avoid access to corporate WiFi

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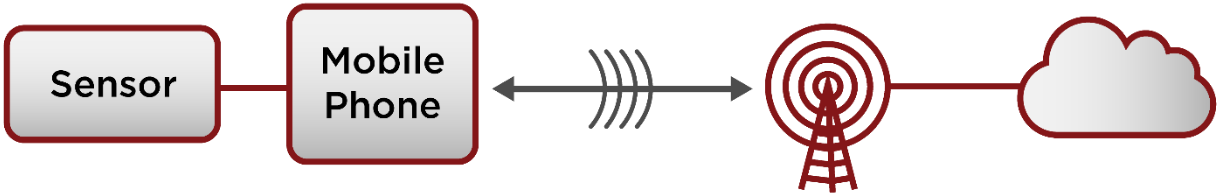
Sensor to cell phone to cloud



- Low power devices rely on cell phone for gateway
- Usually for wearable devices
- Traction for consumer devices
- Limited traction with enterprise level devices
  - Companies don’t want to rely on employees cell phone

Why are new technologies needed?

- Distance
- Data rate – most IoT data is slow
- Power requirements – battery operated
- Cost

Note: with emerging technologies parameters are imprecise and subject to change.

New IoT Data Rate Links

- LoRa
- Sigfox
- LTE-M
- NB-IoT
- Bluetooth LE Mesh
- Nwave
- Z-Wave
- Others

What should be considered for tradeoffs?

- Data rate
- Transmission distance
- Battery size
- Cost
- Licensed vs unlicensed spectrum
- Carrier deployed vs customer deployed
- Mature but not obsolete
- Density of end devices
- Where it gets deployed
- Firmware updates
- Drivers for your OS
- Component/ module selection
- Antennas

Comparison of IoT Wireless Standards

	LTE-M	NB-IOT	Sigfox	LoRa	BTLE Mesh	Zigbee
Range	1-50 km	1-50 km	10-50 km	2-50 km	10m	50m
Data rate	1 Mbit/s	20-250 Kbit/s	300 bit/s	200-50 K bit/s	20 Kbit/s	40 Kbit/s
Supports Audio	Yes	Yes	No	No	No	Yes
Network	Public	Public	Public	Public or Private	Private	Private
Available	Limited coverage	Limited coverage	Limited coverage	Yes Limited public	Limited	Mature

Small wearable device sensor data to cloud every minute and battery that last for weeks

Bluetooth LE Mesh	Need gateway
Zigbee	Need gateway
LoRa	Need gateway if service not available
Sigfox	
LTE-M	Higher data charges
NB-IoT	Higher data charges

Small device sensor data one mile every hour with battery that last for a year

LoRa	Need gateway if service not available
Sigfox	
LTE-M	Higher data charges
NB-IoT	Higher data charges

Network of IoT devices that transmits data a mile every minute with battery that lasts for at least a year

LoRa	Need gateway if service not available
Bluetooth LE Mesh	Only with large mesh. Need gateway

Private vs Public Network

- Private
  - Both ends of communication owned privately
  - Can be installed anywhere
  - Unlicensed spectrum
  - Cost to install base stations and end points
  - No monthly fee
- Public
  - Network owned by provider – for example cellular
  - Only works where base stations exist
  - Easy roaming
  - Licensed spectrum
  - Monthly charge for use of the network

LPWAN vs Cellular IoT

- LPWAN = Low Power Wide Area Network
  - LoRa, Sigfox, etc.
- Cellular IoT
  - Verizon, AT&T, Sprint, etc.
  - LTE-M, NB-IoT, etc.

LoRa Consideration

- Public or private networks – LPWAN, not cellular
- Base station network being installed by Senet
- Low power
- Trade off power and data rate
- Best for infrequently sending small messages
- Bidirectional transmission
- Unlicensed band - Potential interference
- Cost
  - Gateways available for $300
  - <$1/month for service

LoRa Traction

- Available in the US, Australia, New Zealand, Taiwan, and the Netherlands
- Traction in enterprise
  - Doesn’t require access to corporate network or employee phones
  - Cost effective for hundreds of devices
- Parking
- Desk utilization

Sigfox Considerations

- Public network only – LPWAN, not cellular
- Base station network being installed
- Low Power
- Only low data rates
- Best for infrequently sending small messages
- Mainly unidirectional transmission
- Base stations are expensive compared to LoRa
- Unlicensed band - Potential interference
- Cost
  - >$3 per module
  - >$1.50 per year for service – varies widely

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Sigfox Traction

- Very Little US coverage
  - Plan to cover 100 US cities (no date given)
- Good European coverage – mainly in France, 21 other countries
- Utility meters
- City light poles

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Bluetooth LE Mesh Consideration

- Low Power – same as Bluetooth LE
- Short distance – same as Bluetooth LE
  - In mesh the distance is as large as the mesh
- Private network
- Typically connects to phones or tablets

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Bluetooth LE Mesh Traction

- Announced July 2017
- First sensor devices in 2018
- Some smartphones and tablets have it now
- Home automation
  - Lighting, heating/cooling, security

Zigbee Considerations

- Low power
- Short distance
- Can have a mesh network
  - In mesh the distance is as large as the mesh
- Private network only
- Not in phones or PCs

Zigbee Traction

- Introduced in 2003
- Well established in a few niche markets
- Market growing slowly
- Smart metering
- Industrial monitoring
- Lighting

LTE-M Considerations

- Narrow band cellular – cellular IoT
- High power transmitting, but can go to deep sleep
- Best for frequent or infrequent messages, low latency, higher data rates
- Cost
  - Modules currently >$10
  - Monthly charge $0.30 to $2 per month

LTE-M Traction

- Good US coverage – Verizon, AT&T
- European coverage growing - 2019
- Not yet in phones or tablets
- Asset tracking, digital signs

NB-IoT Considerations

- Narrow band cellular – cellular IoT
- High power transmitting, but can go to deep sleep
- Best for infrequently sending small messages
- Not suited for moving devices
- Cost
  - Modules currently >$10
  - Monthly charge >$1 per month

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NB-IoT Traction

- Good coverage in Spain, soon in Ireland, Germany, Netherlands, China
- T-Mobile in US in 2018, maybe Sprint
- Behind LTE-M in development
- Gas metering, agricultural sensors, municipal lighting

Power- How much? How far?

	10 bytes/sec	1 Kbytes/sec	1 Mbytes/sec
1 m	lowest power	data rate	
100 m	distance		
1 km			highest power

All units in mW

LPWAN Compared to Others
Power- How much? How far?

	100 bps	10K bps	40K bps
1 m	BLE4/Zigbee 0.15 BLE Mesh 0.15 LoRa 0.5 Sigfox 0.5	BLE4/Zigbee 7.5 BLE Mesh 7.5 LoRa 10	Zigbee 30 LoRa 20
50 m	Zigbee 20 LoRa 0.5 Sigfox 0.5	Zigbee 30 LoRa 20	
1 km	LoRa 30 Sigfox 30		

All units in mW

Cellular IoT Compared to Others
Power- How much? How far?

	100K bps	1M bps	100M bps
10 m	WiFi 100	WiFi 300	WiFi 500
100 m	LTE-M 160 NB-IOT ? 3G/LTE 210	LTE-M 500 LTE 320	LTE high
1K m (urban cell tower)	LTE-M 250 NB-IOT ? 3G/LTE 400	LTE 700	

All units in mW

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Cost

	Device module	Infrastructure	Network Connectivy
LTE-M	$15		$0.30 to $2/mo
NB-IOT	$10-15		$1/mo and up
LoRa Private	$5	$300	<$1/mo
Sigfox	$3		$0.15/mo and up
BLE Mesh	$1	Use phone or tablet	none

Cost

- Module is built into devices
- Infrastructure – to connect to the Internet
- Network connectivity – recurring charge

SUMMARY of Low Data Rate Links

- ✓ It is not yet clear which standards will win or lose
- ✓ There is room for several standards with different best applications
- ✓ The winners should become clear in the next one to two years

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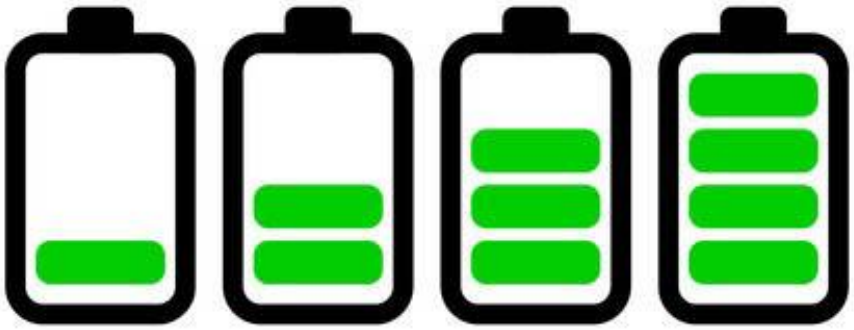
Power

- **Battery limitations**
- Saving power

Battery Limitations

- Slow pace of improvement
  - If improved like semiconductors:
  - Size of a pin head, could power your car, cost 1 cent
- Must always work around limitations
  - Long time between charging vs small size
- Battery life per charge



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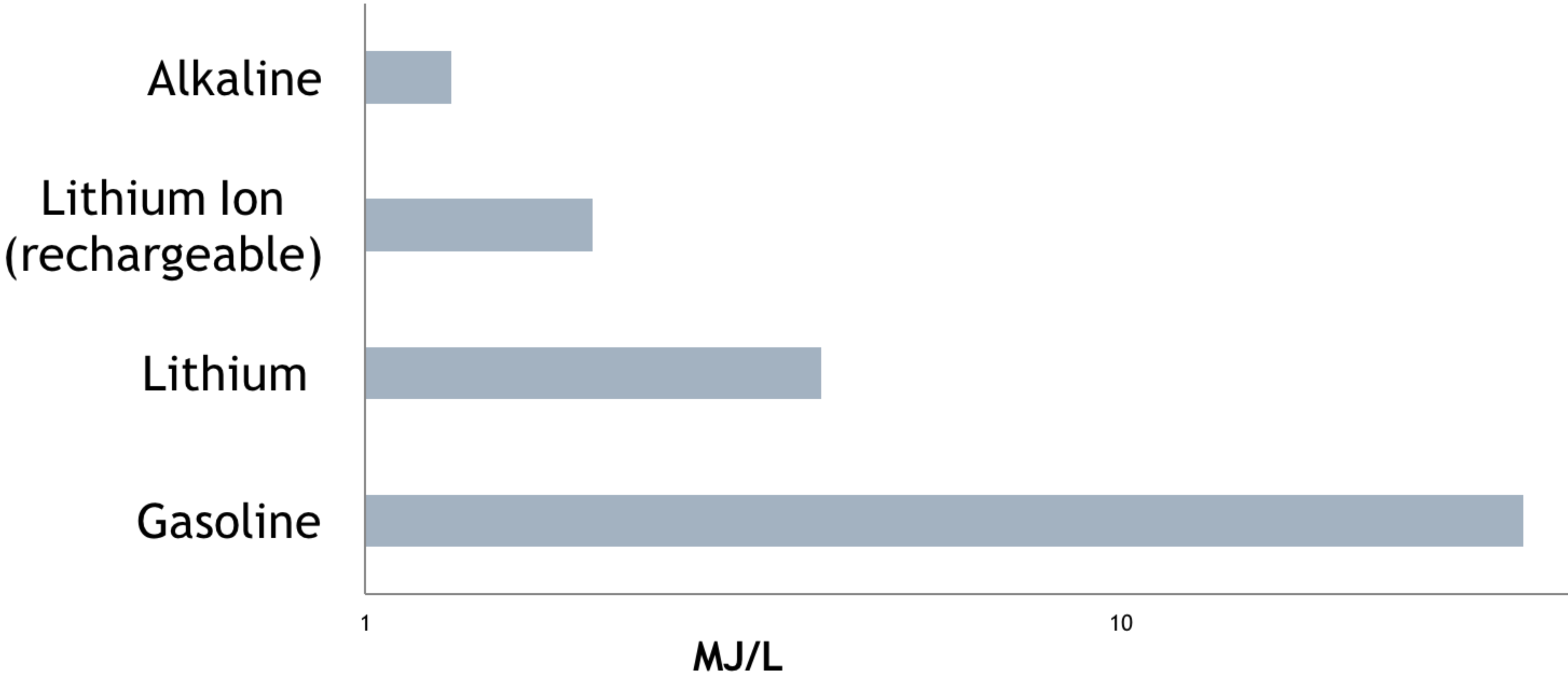
When will battery technology improve?

- Chemical energy storage is approaching the limit of its efficiency
- Nuclear energy is out of the question
- A lot of research being done on higher density and better safety
  - Perhaps 2 times higher density in a few years
  - Will safety suffer?

Energy Density



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Energy Density and Safety

- As energy density has increased, safety has become more of a problem
- Safety circuits are required on Lithium batteries
- Poorly designed batteries can catch fire even with safety circuit
- Shipping of Lithium batteries is restricted and regulated
  - Cells without safety circuit cannot ship by air

Power

- Battery limitations
- **Saving power**

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Wireless

- Trade off between
  - Low transmission power
  - High data rates
  - Long transmission distances
- Different standards optimized for different trade-offs

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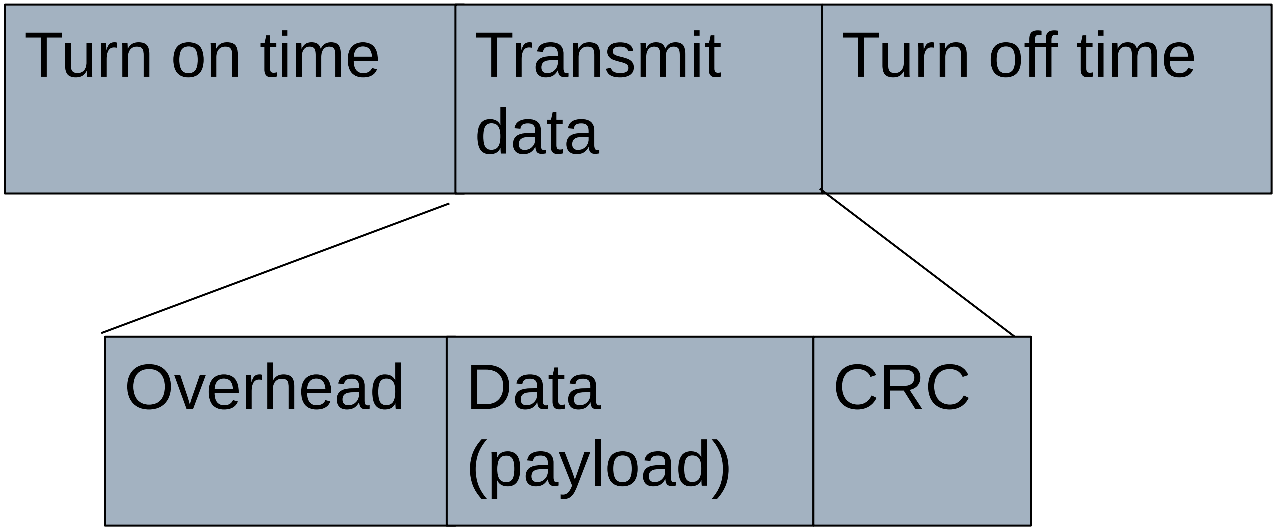
Wireless Power Saving Tips

- Select the right wireless technology
  - Distance
  - Data rate
  - Power
  - Need for receiving device
- Sleep whenever possible
  - Continuous data transmission like audio and video is not ultra low power
  - Video is hundreds of milliwatts (WiFi)
  - Audio is milliwatts (Bluetooth)
  - Send burst of data then sleep (IoT)
- Send as little data as possible

Short On-Time - Less Efficient



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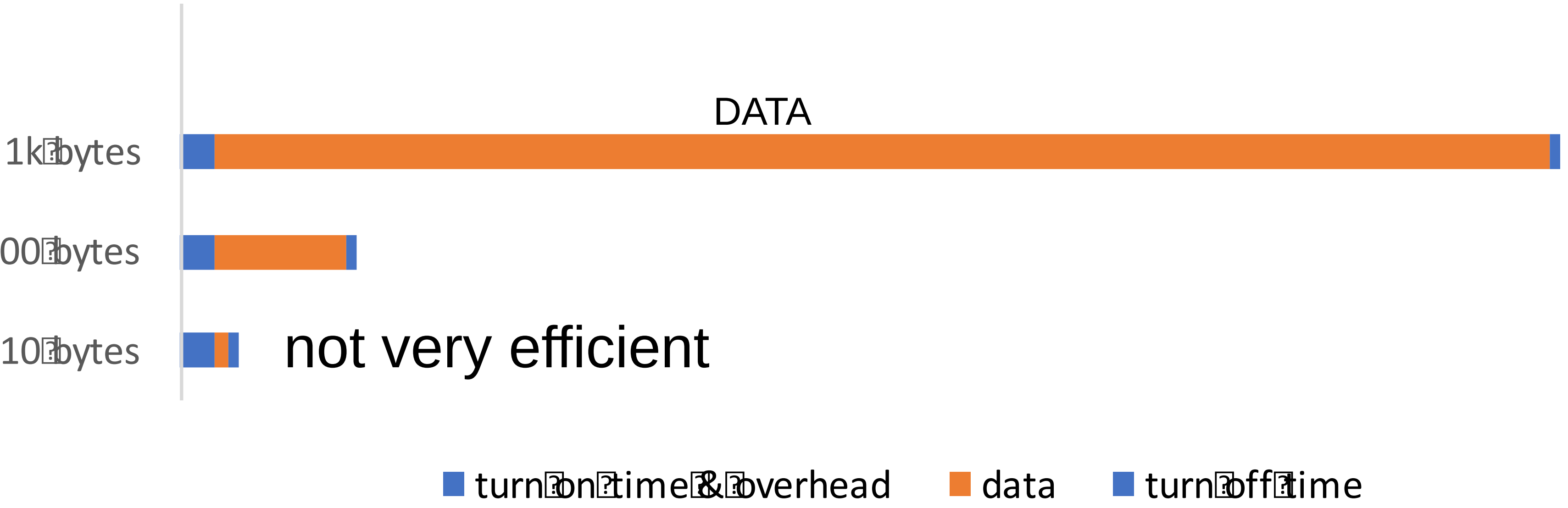
Overhead vs Data



Low Power Example

- Sensor + Processor + Display + Wireless
- Average power of total system: 0.01 mW
  - 3 axis accelerometer
  - Processor asleep
  - No display
  - Bluetooth LE sends one sample every hour
- Runs years on a coin cell

Medium Power Example

- Sensor + Processor + Display + Wireless
- Average power of total system: 1 mW
  - GPS every minute
  - Processor making decisions
  - LCD display
  - No backlight
  - WiFi transmits once a minute
- Runs 2 months on one AA Alkaline battery

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High Power Example

- Sensor + Processor + Display + Wireless
- Average power of total system: 1000 mW
  - Many sensors
  - High power processor
  - Color LCD display with backlight
  - Always connected to WiFi and cellular
  - This is a cell phone
- Runs a few hours between charging

Latency for the Same Examples

- Low Power, 1 Hour latency
  - Bluetooth LE sends one sample every hour
- Medium Power, 1 Minute Latency
  - WiFi transmits once a minute
- High Power, Latency of milliseconds
  - Always connected to WiFi and cellular

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Sensor Interfaces

Wireless

Motion Control

Medical Devices

Slides are available at volersystems.com/news/low-data-rate-links

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Agenda

- ✓ Wireless
- Displays
- Sensors
- Microprocessors
- Software

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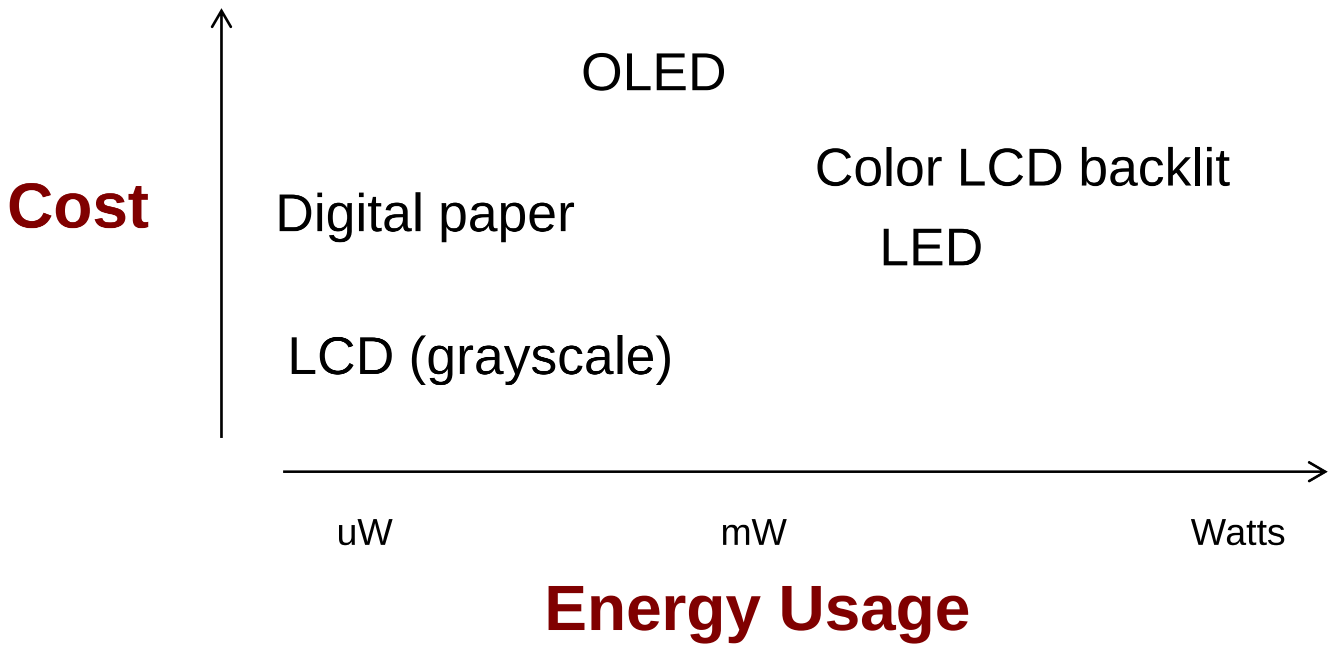
Display Technologies



Emerging Technology: Digital Paper (eInk)

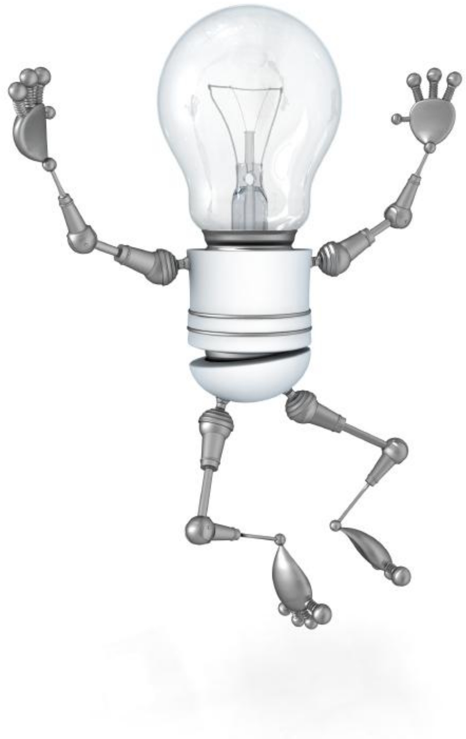
- Nearly zero power when not changing

But:

- Not available in color (this is changing)
- Slow – can’t display video
- eInk kept prices high until they lost a patent fight in 2015
  - Market may expand now

Agenda

- ✓ Wireless
- ✓ Displays
- Sensors
- Microprocessors
- Software



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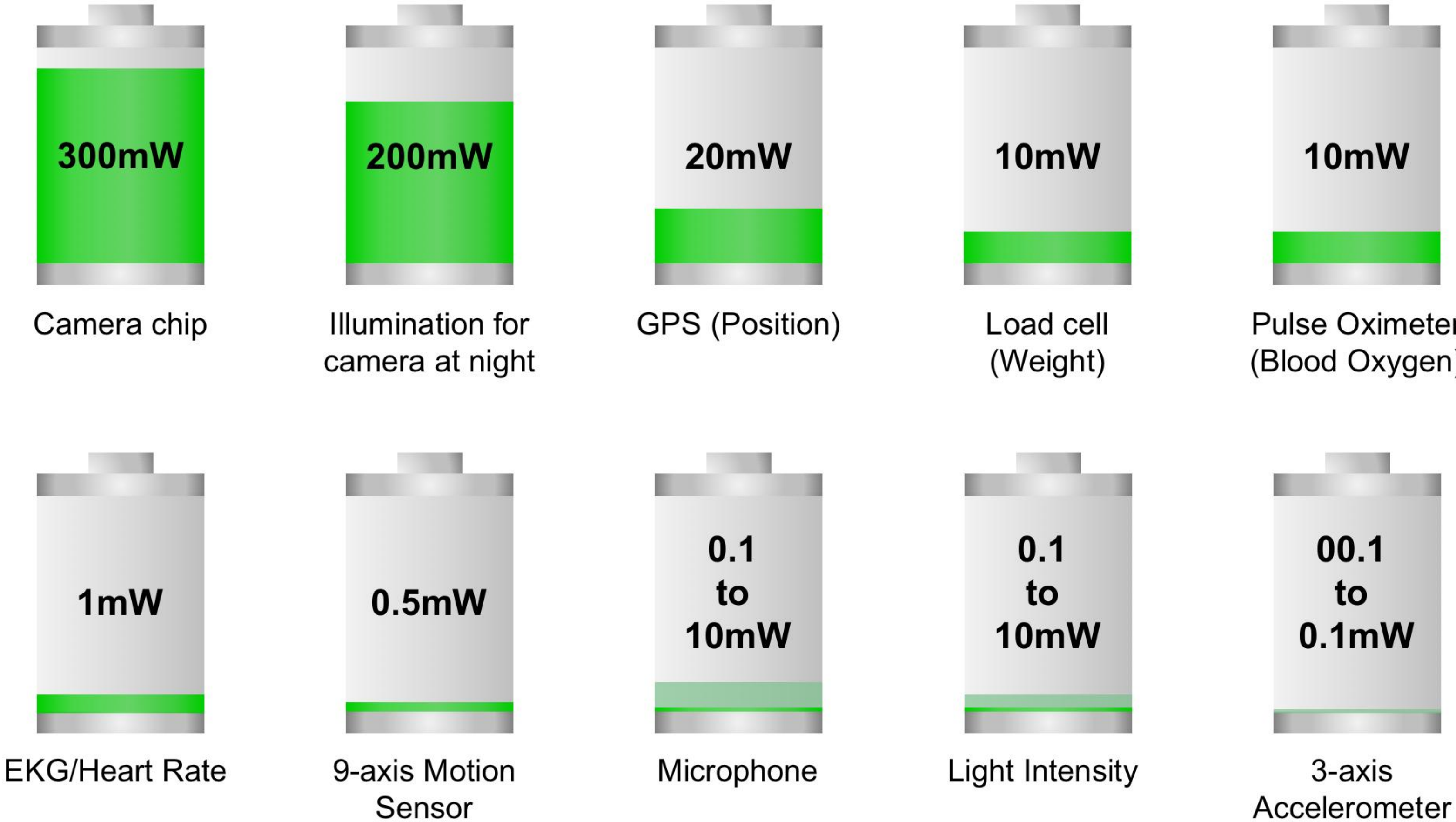
How much power do sensors use?



Agenda

- ✓ Wireless
- ✓ Displays
- ✓ Sensors
- Microprocessors
- Software

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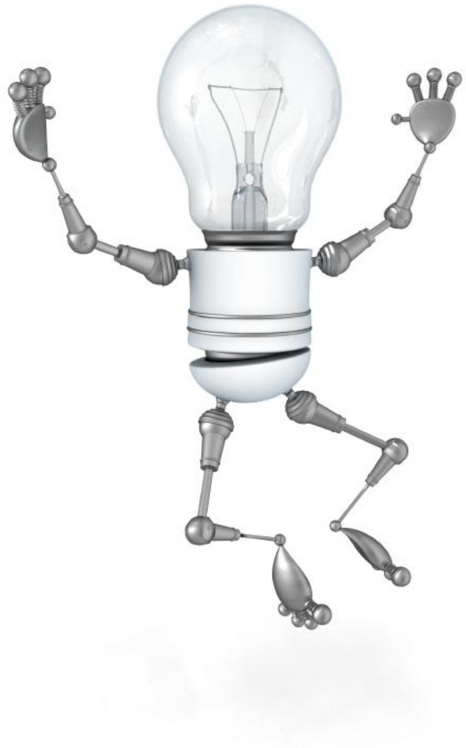
Microprocessor Power

- Low data rate sensor data collection: 1 to 10 mW
- Audio Compression: 10 to 100 mW
- Video Compression: 100 to 1000 mW
- Multi-processor running several Windows tasks: 5 to 50 Watts

Agenda

- ✓ Wireless
- ✓ Displays
- ✓ Sensors
- ✓ Microprocessors
- Software



Common causes of power consumption issues

- Inefficient use of the cellular & WiFi network
  - Sending small data packets
- Not putting the processor to sleep
- Keeping the display backlight on too long
- Sampling data too often
- Using high power sensors when lower power sensors are available
- Inefficient (frequent) messages from an app

Energy Harvesting

- Gather energy from environment
  - Motion, temperature difference, radio frequencies
- Smaller battery
  - Usually need some storage
- Major limitation – only microwatts of power
- Few devices can operate on so little power
- Photovoltaic cells can provide more power
  - Large size
  - Small strip (as in a calculator) generates microwatts

6 areas that impact power

- Wireless
- Displays
- Sensors
- Microprocessors
- Software

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Agenda

- ✓ Wireless
- LEDs
- Displays
- Sensors
- Microprocessors
- Software

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LEDs & lumen-per-watt efficacy

	Color	Wavelength range (nm)	Typical efficiency coefficient	Typical efficacy (lm/W)
	Red	$620 < \lambda < 645$	0.39	72
	Red-orange	$610 < \lambda < 620$	0.29	98
	Green	$520 < \lambda < 550$	0.15	93
	Cyan	$490 < \lambda < 520$	0.26	75
	Blue	$460 < \lambda < 490$	0.35	37

Source:https://en.wikipedia.org/wiki/Light-emitting_diode

LED indicator uses 10 to 50 milliwatts
LED illumination much more
Bottom line: LEDs are not ultra low power

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LED Power Saving Tips

- Turn them on only when being viewed
- Blinking them can dramatically reduce power
- Turning on an LED for 50 mS every second is quite visible
- 10 mW becomes 0.5 mW

Displays

- Gray scale LCD displays are lowest power
- Backlights are very power hungry
- Color LCD requires backlighting

Display Power Saving Tips

- Avoid back lighting or turn it on only when needed
- Consider gray-scale LCD or digital paper displays
- Don’t change the image frequently
  - Digital paper especially
- Smaller displays use less power
- Use sound or a single LED for user interface
- Send data to a phone for display

How much power do sensors use?

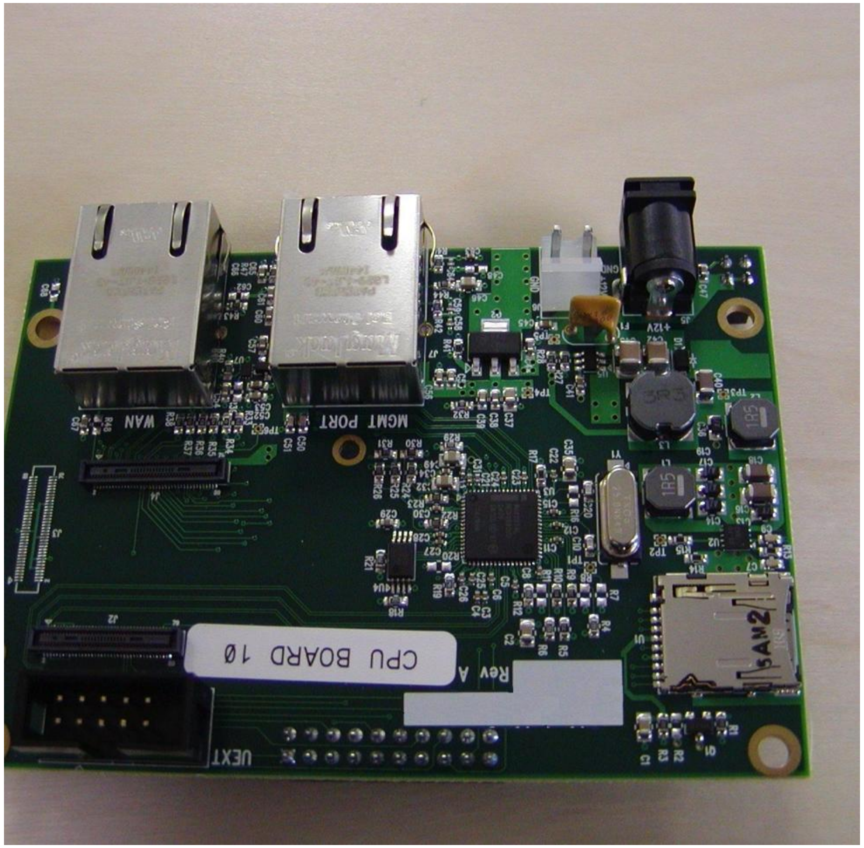
- Camera chip – 300mW
- Illumination for camera at night – 200 mW
- GPS (Position) – 20 mW
- Load cell (Weight) – 10 mW
- Pulse Oximeter (Blood Oxygen) – 10 mW
- EKG/Heart Rate – 1 mW
- 9-axis Motion Sensor – 0.5 mW
- Microphone – 0.1 to 10 mW
- Light Intensity – 0.1 to 5 mW
- 3-axis Accelerometer – 0.01 to 0.1 mW

Sensor Power Saving Tips

- Turn off sensors to save power
  - If not sampling frequently
  - Audio and Video often require continuous sampling
- Use lower power sensors
  - Capacitance load cell instead of resistance type
  - ie: Motion sensing chip instead of GPS
    - Lower power, but less accurate
- Use camera or GPS in cell phone instead

Microprocessors

- Many microprocessors have ultra low power
  - Few milliWatts
  - Depends on processing power
- Sleep and draw even less
  - microWatts
- Interrupt line is often used to wake them up with an event from a sensor



Sleeping Adds Delay

- Reduced power but with a trade-off
- Short delay with interrupt
  - Sensor must be on to generate interrupt
- Long delay with polling – wake up to see if anything needs to be done
  - Latency determined by time between polling

Microprocessor Power Saving Tips

- Select the right processor for the task
- Minimize power hungry processing
- Sleep whenever possible
- Compressing takes processing power but compressed data usually saves more on wireless transmission power

Software has a huge impact on power

Software Power Saving Tips

- Power down subsystems when not being used
- Dim the display when no input from user
- Use wireless connections efficiently
    - Transmit bursts of data
    - Do not sleep too long (cellular & WiFi need to re-establish connection)
- Off-load energy intensive processing to mobile application or cloud
- Use a motion sensor instead of GPS

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GPS power saving tip: Use motion sensor chip

- Baseband Technologies has firmware solution that provides location as good as GPS alone
- Achieved by mixed use
  - Motion sensor chip 75% of the time
  - GPS 25% of the time
- < 2 milliseconds to calculate position
- Cuts power 75%

Software Testing

- Testing can be tricky because of the many different states
- Some of the states only happen briefly, such as the high power states
- Low power states require careful testing – can't use software to query the status of a microprocessor that is asleep
- Result of incomplete testing – more power use than there should be

LTE-M vs. NB-IOT vs. Sigfox vs. LoRa vs. BT Mesh