Low Data Rate Links for IoT

Walt Maclay
President, Voler Systems
Product Development
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

   ![Diagram of smart device directly to cloud]

2. Sensor to gateway to cloud

   ![Diagram of sensor to gateway to cloud]

3. Sensor to cell phone to cloud

   ![Diagram of sensor to cell phone to cloud]
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
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
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

<table>
<thead>
<tr>
<th></th>
<th>LTE-M</th>
<th>NB-IOT</th>
<th>Sigfox</th>
<th>LoRa</th>
<th>BTLE Mesh</th>
<th>Zigbee</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td>1-50 km</td>
<td>1-50 km</td>
<td>10-50 km</td>
<td>2-50 km</td>
<td>10m</td>
<td>50m</td>
</tr>
<tr>
<td><strong>Data rate</strong></td>
<td>1 Mbit/s</td>
<td>20-250 Kbit/s</td>
<td>300 bit/s</td>
<td>200-50 Kbit/s</td>
<td>20 Kbit/s</td>
<td>40 Kbit/s</td>
</tr>
<tr>
<td><strong>Supports Audio</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Network</strong></td>
<td>Public</td>
<td>Public</td>
<td>Public</td>
<td>Public or Private</td>
<td>Private</td>
<td>Private</td>
</tr>
<tr>
<td><strong>Available</strong></td>
<td>Limited coverage</td>
<td>Limited coverage</td>
<td>Limited coverage</td>
<td>Yes Limited public</td>
<td>Limited</td>
<td>Mature</td>
</tr>
</tbody>
</table>
Small wearable device sensor data to cloud every minute and battery that last for weeks

<table>
<thead>
<tr>
<th>Technology</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluetooth LE Mesh</td>
<td>Need gateway</td>
</tr>
<tr>
<td>Zigbee</td>
<td>Need gateway</td>
</tr>
<tr>
<td>LoRa</td>
<td>Need gateway if service not available</td>
</tr>
<tr>
<td>Sigfox</td>
<td></td>
</tr>
<tr>
<td>LTE-M</td>
<td>Higher data charges</td>
</tr>
<tr>
<td>NB-IoT</td>
<td>Higher data charges</td>
</tr>
</tbody>
</table>
Small device sensor data one mile every hour with battery that last for a year

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>LoRa</td>
<td>Need gateway if service not available</td>
</tr>
<tr>
<td>Sigfox</td>
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</tr>
<tr>
<td>LTE-M</td>
<td>Higher data charges</td>
</tr>
<tr>
<td>NB-IoT</td>
<td>Higher data charges</td>
</tr>
</tbody>
</table>
Network of IoT devices that transmits data a mile every minute with battery that lasts for at least a year

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LoRa</td>
<td>Need gateway if service not available</td>
</tr>
<tr>
<td>Bluetooth LE Mesh</td>
<td>Only with large mesh. Need gateway</td>
</tr>
</tbody>
</table>
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
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
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
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
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?

<table>
<thead>
<tr>
<th></th>
<th>10 bytes/sec</th>
<th>1 Kbytes/sec</th>
<th>1 Mbytes/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lowest power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>highest power</td>
</tr>
</tbody>
</table>

All units in mW

9/26/17 for IEEE Consumer Electronics Society
## LPWAN Compared to Others

**Power - How much? How far?**

<table>
<thead>
<tr>
<th></th>
<th>100 bps</th>
<th>10K bps</th>
<th>40K bps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 m</td>
<td>BLE4/Zigbee 0.15</td>
<td>BLE4/Zigbee 7.5</td>
<td>Zigbee 30</td>
</tr>
<tr>
<td></td>
<td>BLE Mesh 0.15</td>
<td>BLE Mesh 7.5</td>
<td>LoRa 20</td>
</tr>
<tr>
<td></td>
<td>LoRa 0.5</td>
<td>LoRa 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sigfox 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 m</td>
<td>Zigbee 20</td>
<td>Zigbee 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LoRa 0.5</td>
<td>LoRa 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sigfox 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 km</td>
<td>LoRa 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sigfox 30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Cellular IoT Compared to Others

### Power - How much? How far?

<table>
<thead>
<tr>
<th>Distance</th>
<th>100K bps</th>
<th>1M bps</th>
<th>100M bps</th>
</tr>
</thead>
<tbody>
<tr>
<td>10m</td>
<td>WiFi</td>
<td>100</td>
<td>WiFi</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100m</td>
<td>LTE-M</td>
<td>160</td>
<td>LTE-M</td>
</tr>
<tr>
<td></td>
<td>NB-IOT</td>
<td>?</td>
<td>NB-IOT</td>
</tr>
<tr>
<td></td>
<td>3G/LTE</td>
<td>210</td>
<td>3G/LTE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1Km urban cell tower</td>
<td>LTE-M</td>
<td>250</td>
<td>LTE</td>
</tr>
<tr>
<td></td>
<td>NB-IOT</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3G/LTE</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

All units in mW

9/26/17 for IEEE Consumer Electronics Society
<table>
<thead>
<tr>
<th>Cost</th>
<th>Device module</th>
<th>Infrastructure</th>
<th>Network Connectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTE-M</td>
<td>$15</td>
<td></td>
<td>$0.30 to $2/mo</td>
</tr>
<tr>
<td>NB-IOT</td>
<td>$10-15</td>
<td></td>
<td>$1/mo and up</td>
</tr>
<tr>
<td>LoRa Private</td>
<td>$5</td>
<td>$300</td>
<td>&lt;$1/mo</td>
</tr>
<tr>
<td>Sigfox</td>
<td>$3</td>
<td></td>
<td>$0.15/mo and up</td>
</tr>
<tr>
<td>BLE Mesh</td>
<td>$1</td>
<td>Use phone or tablet</td>
<td>none</td>
</tr>
</tbody>
</table>

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
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
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

- Alkaline
- Lithium Ion (rechargeable)
- Lithium
- Gasoline

$\text{MJ/L}$
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**
Wireless

• Trade off between
  • Low transmission power
  • High data rates
  • Long transmission distances

• Different standards optimized for different trade-offs
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

- Turn on time
- Transmit data
- Turn off time

- Overhead
- Data (payload)
- CRC
Overhead vs Data

- 1k bytes: turn on time & overhead, data
- 100 bytes: turn on time & overhead, data
- 10 bytes: turn on time & overhead, data

not very efficient
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
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
Signup for our newsletter to get a forthcoming article
Agenda

- Wireless
- Displays
- Sensors
- Microprocessors
- Software
Display Technologies

Cost

Digital paper
LCD (grayscale)

Energy Usage

OLED
Color LCD backlit LED

uW  mW  Watts
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
How much power do sensors use?

- Camera chip: 300mW
- Illumination for camera at night: 200mW
- GPS (Position): 20mW
- Load cell (Weight): 10mW
- Pulse Oximeter (Blood Oxygen): 10mW
- EKG/Heart Rate: 1mW
- 9-axis Motion Sensor: 0.5mW
- Microphone: 0.1 to 10mW
- Light Intensity: 0.1 to 10mW
- 3-axis Accelerometer: 00.1 to 0.1mW
Agenda

☑ Wireless
☑ Displays
☑ Sensors
  • Microprocessors
  • Software
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
Agenda

✓ Wireless
  • LEDs
  • Displays
  • Sensors
  • Microprocessors
  • Software
## LEDs & lumen-per-watt efficacy

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

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
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 – 300 mW
- 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
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