IEEE 802 Tutorial

Energy Efficiency and Regulation

Bruce Nordman, David Law, Hugh Barrass, John Nels Fuller, Kapil Sood, Masoud Olfat, Mike Bennett, Philippe Klein, Steven Lanzisera, Wael Diab

July 13, 2009
Agenda

Energy Context
• Energy and Networks
• Existing Policies

802 Topics
• Energy Efficient Ethernet
• Link Layer Discovery Protocol
• Audio Video Bridging / EEE
• Testing
• Audio Video Bridging / Idle
• WiFi
• WiMAX

Open Discussion

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Why care about electronics, energy?

• Core
  – Carbon
  – Energy
  – $$€€£¥$

• Extreme conditions
  – Power deserts (no mains)
  – Power oceans (datacenters)
  – Power ponds (e.g. notebook)

• Most energy policy for “power reservoirs”
  – Man-made, controlled, increasingly burdensome
Networks and Energy

**Network** equipment ....
Routers, switches, modems, wireless APs, ...

... vs **networked** equipment

**Electronics**: PCs, printers, set-top boxes, ...
**Non-electronics**: lighting, heating, appliances, ...

How networks drive energy use

**Direct**
- Network interfaces (NICs)
- Network products

**Induced** in Networked products
- Increased power levels
- Increased time in higher power modes
  (to maintain network presence)

**Network induced consumption > all direct**
Electronics energy use (U.S. only)

- Over 10% of buildings electricity (residential & commercial)
  - Buildings about 70% of all electricity
  - Electronics nearly 300 TWh/year or about $30 billion/year
- Almost 60% in residential buildings
  - Well under 20% in data centers
- An increasing portion are digitally networked

“Non-Electronics”

- Everything else: Lighting, Heating/Cooling, Appliances, etc.
- Will be increasingly networked
  - Need low-energy technologies
  - Energy invested in network connection - hope to save more
- Test procedures and standards need to account for this
Challenges networks bring to public policy

- Maximize efficiency of network equipment
  - In typical use
- Fairly measure, evaluate products with network interfaces
- Define goals for new technologies or standards
  - Functional
  - Energy/power
- Need and desire for persistent availability
Public policy and energy efficiency

• Basic goal: Obtain energy savings that also save money
  – Response to rampant market failures
  – To meet energy security and environmental goals

• Many tools
  – Orientation: consumer, retailer, manufacturer, standards, utility, public purchasing, …
  – Rebates and other economic incentives
  – Energy standards: buildings, appliances, lighting, …
  – Mandatory and voluntary
  – Modal (power) vs. Annual (energy) vs. Non-energy
  – Horizontal vs. Vertical

• Challenge: Find right mix of tools for each circumstance
**Existing policies**

European Union - Codes of Conduct

- Broadband Equipment and Set-top boxes
  - Customer and service provider
  - Base levels for many product types
    - Per-port for service provider equipment
  - Power levels by mode
  - Levels drop over time
  - Power adders for additional interfaces
  - Test procedure not defined

- Data Centers
  - Not specific about networks

http://re.jrc.ec.europa.eu/energyefficiency/
EU “Energy Using Products” (EUP)

- “Lot 6” - Standby Losses
  - Products - includes CE and IT for “domestic environment”
  - Did not cover modes with network connectivity
    “When the EuP is in Lot 6 standby according to (iii.) and offers either a remote network reactivation and / or network integrity communication, then the product is considered to be in Networked Standby mode.” (emphases added)
  - Levels
    - 2011 - 1 W (2 W with display)
    - 2014 - 0.5 W (1 W with display)

ecostandby.org (“documents” page)
Existing policies

EU “Energy Using Products” (EUP)

“Lot 26” - Networked Standby Losses
– Research initiated June, 2009
– Final report due December, 2009
– Expect will attempt to coordinate / harmonize with rest of world
– In scope: Residential and commercial, IT and CE, phones, “building sensors and control”
– Interest in both 802 layers and higher
– **Opportunity**: Collectively develop principles to embody in Lot 26 and elsewhere

ecostandby.org
Existing policies

Energy Star

• General: Expect to add requirement for EEE when feasible

• PCs
  – Test with network connection active at highest speed capable of
  – Requirements for presence of Wake-On-LAN
  – Reward for systems that implement “Proxying”
    • see: efficientnetworks.lbl.gov/enet-proxying.html

• Imaging Equipment (printers, copiers, etc.)
  – Test with 1-3 data/network connections active
  – Sleep power level “adders” for interfaces
## Existing policies

### Energy Star, cont.

Imaging Equipment Sleep power “adders” (W)
- “Primary” = active; “Secondary” = unconnected

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wired &lt; 20 MHz</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>USB 1.x, IEEE488, IEEE 1284/Parallel/ Centronics, RS232, and/or fax modem</td>
<td></td>
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</tr>
<tr>
<td>Wired (\geq 20) MHz and &lt; 500 MHz</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>USB 2.x, IEEE 1394/FireWire/i.LINK, and 100Mb Ethernet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wired (\geq 500) MHz</td>
<td>1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1 G Ethernet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wireless</td>
<td>3.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Bluetooth and 802.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wired card/camera/storage</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Infrared</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Existing policies

Energy Star, cont.

- Network equipment
  - Preliminary study - no formal announcement yet
  - Consumption and potential savings seem to warrant labeling program
  - Separate processes for small and large devices
    - Small: soon - Large: next year
  - First focus - products with largest total consumption and where label appropriate
  - For announcements: kaplan.katharine@epa.gov
Existing policies

Horizontal standards

- Test procedures or requirements applied to many different product types
- Common elements of “vertical” test procedures, requirements

Examples

- IEA “1-watt” initiative
- DOE/FEMP standby requirements for federal purchasing
- EU EUP “Standby and Off” requirements
- Energy Star external power supply specification
- IEC 62301 low power mode measurement procedure
The “Smart Grid” and 802

• An important topic, but not for this tutorial
  – “Using network to reduce non-electronic energy use”

• Our topics
  – Energy use of network interfaces
  – Energy use of network equipment
  – Energy use of other electronic products

Other Physical Layers?

• Consider “Internet 0” — cba.mit.edu/projects/I0/
ng.cba.mit.edu/show/09.04.i0_PHY.html
METI and ATIS

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METI Top Runner - overview

- Top Runner is…
  - Japan’s approach to energy usage reduction
  - First introduced in 1999 (development from 1979)
  - More than 20 products (from trains to rice cookers)
  - Voluntary compliance – advantages for “top runners”

- How Top Runner works…
  - Targets set based on extensive product testing
  - (generally) New products should match current top 20%
  - Targets updated regularly
  - Rewards technology leaders

More info.

Please refer to the following URL for more information about METI Top Runner Program

The Energy Conservation Center, Japan: [http://www.eccj.or.jp/index_e.html](http://www.eccj.or.jp/index_e.html)

Top Runner Program brochure (English): [http://www.eccj.or.jp/top_runner/img/32.pdf](http://www.eccj.or.jp/top_runner/img/32.pdf)
Top Runner for networking

• Small routers, L2 switches – introduced 2008
  – Routers (max 200Mb/s, no VPN), wired/wireless/DSL
  – L2 switch, managed/unmanaged – 100M, 1G, 10G
  – Each set divided to subcategories
  – Target power per system (or per port for L2 switching)
  – Also covers PoE

• Other routers, L3 switches – target 2010
  – Testing in progress, analysis of results
  – Categorization still being decided
  – Test traffic based on minimal functions
  – Other features disabled

Energy saving label
ATIS – TEER approach

• Full system testing – no targets
  – Covers most large (wired) network devices
  – Philosophically – measure max throughput & typical power
  – Categories define test environment
  – Test is intended to replicate realistic usage

• General comments
  – Measuring typical power reflects real-world energy costs
  – Recognizes the useful function of networks
    • Availability of capacity is key
  – Rewards scalable design:
    • High max throughput, low power at low utilization
  – Fits well with 802.3az philosophy
Other approaches to metrics

• Power per function approach
  – (e.g. EuP Broadband Code of Conduct)
  – Simplistic – one power target for a function
    • Does not differentiate quality of function
    • Does not reward scalability

• Max throughput / max power approach
  – Encourages “magazine test” optimized architecture
  – Does not reflect real world energy usage
  – Similar problems with idle power only approach

• Specific feature (check box) approach
  – Recognizes holistic effect of some features
  – Useful alongside other metrics (e.g. used in Energy Star)
Testing and Evaluation

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Evaluation Structure

- Test conditions
- Test procedures
- Metrics
- Specifications
  - Structures
  - Values
Test Procedure Issues

- Want to estimate typical energy use
  - Number of features × Number of configurations
  - Most equipment provisioned for peak load
  - Peak power vs. Idle power vs. Typical power

- Must test a subset of features & configurations
  - Need to account for features present & operating

- Preferred approach
  - Test max throughput & typical power

- Other approach
  - Test max throughput and power only
  - Test low throughput and power only
Metrics & Specifications

• Define metrics
  – Capacity (throughput, number of ports)
  – Power (typical, maximum, idle, etc)

• Specifications that are not specific
  – Provide meaningful differentiation
  – Reduce energy while maintaining performance
  – Provide choice to the consumer (features, manufacturers)
  – Do not rely on proprietary technology
Test Conditions for 802

• General
  – Traffic patterns (ATIS vs METI approach)
  – Multi rate selection
  – Capabilities of connected devices

• Wired technologies
  – Cable length (Automatic power selection)

• Wireless
  – Radio environment issues
Energy Context Summary

• Align public policy with current and future technology

• Align roadmaps with energy policy goals

• As much horizontal uniformity as possible
  – Test conditions & procedures
  – Requirements structures & values
  – Across product types, countries, time
Energy Efficient Ethernet

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What is Energy Efficient Ethernet (EEE)

• Also known as IEEE 802.3az
• EEE is a method to facilitate transition to and from lower power consumption in response to changes in network demand
  – In the process of being specified for these copper PHYs
    • 100BASE-TX (Full Duplex)
    • 1000BASE-T (Full Duplex)
    • 10GBASE-T
    • 10GBASE-KR
    • 10GBASE-KX4
    • 1000BASE-KX
  – Uses Low Power Idle (LPI) to save energy
What is Low Power Idle?

• Concept: Transmit data as fast as possible, return to Low-Power Idle

• Saves energy by cycling between Active and Low Power Idle
  – Power reduced by turning off unused circuits during LPI
  – Energy use scales with bandwidth utilization
What is Low Power Idle?

- **A closer look**
  
  - PHY Wake Time values are in the order of 10’s of microseconds

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep Time (Ts)</td>
<td>Duration PHY sends Sleep symbols before going Quiet.</td>
</tr>
<tr>
<td>Quiet Duration (Tq)</td>
<td>Duration PHY remains Quiet before it must wake for Refresh period.</td>
</tr>
<tr>
<td>Refresh Duration (Tr)</td>
<td>Duration PHY sends Refresh symbols for timing recovery and coefficient synchronization.</td>
</tr>
<tr>
<td>PHY Wake Time (Tw_PHY)</td>
<td>Duration PHY takes to resume to Active state after decision to Wake.</td>
</tr>
<tr>
<td>System Wake Time (Tw_System)</td>
<td>Wait period where no data is transmitted to give the receiving system time to wake up.</td>
</tr>
</tbody>
</table>
Optimizing Energy Efficiency

- Energy Efficiency can be optimized by using link-partner communications after the link is established
  - Use Link Layer Discovery Protocol (LLDP) to change wake times.
  - The longer the wake time, the longer the delay till frames can pass, i.e. latency increases
  - Trade-off between energy savings and latency

- There are system power savings opportunities in addition to PHY power savings
State of the standard

- Hoping to go to 802.3 Working Group Ballot at the end of the week
- If we stay on track, should be finished Sept. 2010
Final thoughts ...

• The 802.3az Task Force estimated 75% of PHY power savings possible using Low Power Idle
  – Assuming 100% adoption in the US alone that translates to roughly $300M to $470M per year in savings
    • Does not include cooling or additional system power savings

• Test specifications are currently being developed
  – This should ease the task of specifying qualifications for Energy Star, etc.

• More work to do?
  – Energy Efficient Ethernet is not specified for optical PHYs and some copper PHYs
    • For example, 802.3ba
  – Should there be a higher layer power management specification?
Using LLDP for Saving Energy in 802.3

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802.3at’s and 802.3az’s Layer 2

- Officially called “Data Link Layer”
- Communications based energy policy enables enhanced savings
- Several Components: (a) Transport (b) State machine (c) MIB (d) Features
- In EEE allows for the dynamic negotiation of wake up time for RX
  - Allows for cascaded interfaces
  - Deeper sleep modes
  - Fallback
  - Efficient buffering
- In PoEP allows for the dynamic negotiation of power allocation for PD
  - Power budgeted when it is needed, supplies operate at near optimal efficiency point, power backup systems and batteries optimized for load (e.g. UPS)
  - Smart allocation: Features scalability with power budget
- Nearly identical SMs for PoEP and EEE

LLDPDU Format

<table>
<thead>
<tr>
<th>Chassis ID TLV</th>
<th>Port ID TLV</th>
<th>Time To Live TLV</th>
<th>Optional TLV</th>
<th>dot3at TLV</th>
<th></th>
<th>Optional TLV</th>
<th>End Of LLDPDU TLV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
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</tr>
</tbody>
</table>

State 1
def <= True

abc = True

State 2
def <= False

dot3at local system MIB

aLocDef

dot3at remote system MIB

aRemAbc
PoE/P Enhanced Layer 2 Operation

1. Detection
2. Classification (Optional)
3. Startup
4. Operation
5. Disconnect

PoE/P can also be completely turned off. Ethernet communication can be used to turn other subsystems off also.

Classic operation requires worst case budgeting, allocation.

In-efficient, wasteful use of power supplies, backup (UPS).

Dynamic power budgeting raises system, supply efficiencies. Smart allocation allows feature scalability with power budget.

Continuous Power
Re-Classification via L2
EEE Enhanced Layer 2 Operations

- Opportunity to save additional power within a box (link partner)
  - Additional circuits beyond the PHY can be turned off
- Additional RX wakeup time negotiated using 802.3az’s Layer 2 standards based
Audio/Video Bridges
and
Energy Efficient Ethernet

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Why Worry about AVB & EEE?

• In the future, many consumer devices will be connected with AVB over 802 networks, both wired and wireless

• If AVB use precludes the energy saving modes of the network then the result is more energy costs to the consumer, especially in a lightly loaded home environment

• This presentation will focus on AVB and EEE, but other work is proceeding to address AVB and 802.11 power saving modes
Why does AVB care about EEE?

• AVB transports stream frames from a talker to a listener with a guaranteed maximum delivery latency

• Time to access the media could mean that additional latency is added to the worst case

• But AVB knows something about its traffic that can help know when energy savings are possible
What will AVB do about EEE?

• Make sure transmission selection works so that EEE media access latency and other components of worst case latency are mutually exclusive
• Allow EEE media access latency to grow only when streams are not active on a link
• Define when EEE goes to low power — such as, between stream frames
What should you do?

For all networking standards

• Look for power savings in your standard
• Make sure your standard isn’t in the way of power savings by another standard it relies on
• Help your standard’s clients save power
Enabling Power Savings In An AVB Cloud

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Enabling Power Savings In An AVB Cloud

• 802.1as protocol includes periodic messages sent between time-aware nodes (bridge or stations)

• 802.1as did not expect clock discontinuities in the receiver
  – this would have forced the receiver to keep its clock running in any state

• Power management support was addressed late in the development but early enough to allow the protocol to be modified

• A new signaling message was added to
  - allow the message receiver to specify the periodicity of the messages it wish to receive from the sender
  - to permit the receiver to indicate whether the timing information provided in the response message is valid or not
802.11 Wireless LAN (WiFi)

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Enterprise Distribution Network – WiFi Access

- WiFi operates in unlicensed band:
  - Highly variable signal strengths
  - Short range, limited coverage, interference
- AP infrastructure is always ON
  - Reliable WLAN, efficient client roams
- Clients’/AP collaborative reliance for PS
  - Clients are ultimate energy beneficiaries

802.11 Power Save

- AP infrastructure is always ON
- Clients’/AP collaborative reliance for PS
- Clients are ultimate energy beneficiaries
802.11 Power Save Features

• **Power Save (PS-Poll) – 802.11-2007**
  
  A STA enters PS mode, and while in PS mode it listens to selected beacons. If beacon indicates packets buffered for that STA, the STA sends a PS-Poll frame to the AP to fetch the packets.

• **Automatic Power Save delivery (APSD) – 802.11-2007**
  
  The power save mechanism for Quality-of-Service (QoS) enabled STA and APs and allows per-stream (Access Category) power save.

• **Fast BSS Transition – Pub. 802.11r-2008/802.11mb**
  
  A STA can roam between 2 APs in a power efficient manner. Fast BSS transition allows use of a security key hierarchy and QoS negotiation during the fast transitions process.

Approved
802.11 Power Save Features

• **Proxy ARP – 802.11v, WiFi Alliance (WFA)**
  The AP has the ability to proxy ARP frames for the STA. This is intended to enable the STA to remain in power-save for longer periods of time.

• **TIM Broadcast – 802.11v**
  AP periodically transmits a TIM frame, which is shorter than Beacons and transmitted at a higher rate, to indicate traffic buffered for a STA.

• **WNM Sleep Mode - 802.11v, WFA**
  WNM Sleep Mode is an extended STA power save mode in which a STA need not listen for every DTIM Beacon frame, and AP does not perform GTK/IGTK updates.

*In-Development*
802.11 Power Save Features

• **BSS Termination Notification – 802.11v, WFA**
  An AP notifies STAs that the AP will be powering-down, e.g. during non-peak hours. This enables STA to sleep longer, wake when the AP wakes, or STA can transition to a wake AP.

• **Traffic Filtering Service – 802.11v, WFA**
  Allows AP to send only traffic that matches STA-specified filters. This can reduce the number of non-essential frames from being sent to the STA, allowing STA to remain in Standby.

• **Flexible Multicast System (FMS) – 802.11v**
  AP sends multicast/broadcast frames at multiples of the DTIM interval, and at higher data rate, allowing longer power save state for STA.

• **IBSS Mode Power Save – 802.11-2007**
  Power Save mode for 2 STAs in IBSS (adhoc) mode, where STAs co-ordinate Sleep duration and interval. Problematic due to vendor-specific heuristics.
802.11 Power Save Observations

- AP Infrastructure enables power-save on Clients devices
  - Regulate infrastructure for lowering Client energy usage
- Legacy (PS-Poll) and QoS (APSD) Power Save
  - Algorithms are vendor-specific implementations
  - Results are dependent upon deployment and configuration
  - VoIP Application can save 15-40% power (WiFi Alliance WMM Power Save) over PS-Poll
- Considerable new energy savings effort (802.11v) underway
  - WiFi Alliance, Field deployment results anticipated (’10/’11)
- IBSS/Peer-Peer Power Save
  - Not widely deployed – current usage is Infrastructure mode
  - Emerging with P2P use cases
WiMAX / IEEE 802.16: Energy Saving Aspects

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WiMAX in a Snapshot

- Flat IP architecture
- Multiple Carrier frequencies supported, roadmap for global roaming
- Point to multi-point structure
- Channel BW: 5, and 10MHz (roadmap for 15, and 20MHz)
- Scalable OFDMA based DL and UL
- TDD Duplexing mode (Supports FDD in future releases)
- Optimized for Multiple Antenna technology support
- Efficient Power Saving modes (sleep and Idle mode)
- Advanced Security

- Efficient QoS for multimedia
- Optimized hard handoff mobility (with Fast Cell Selection in future release)
- Power Saving modes (sleep and Idle mode)
- Advanced Security
- Adaptive Modulation and Coding
- Link adaptation
- Multicast/broadcast services
Energy Saving Aspects

• Downlink (Forward Link): From base station to mobile stations
  – Coverage enhancement techniques
  – Advancements in developing equipments

• Uplink (Reverse Link): From mobile stations to base station
  – Power Saving modes
  – Coverage enhancement techniques
  – Peak to Average ratio reduction
  – Advancements in developing equipments
Downlink

- Coverage enhancement techniques requires less Transmit powers to reach the signal to the cell edge
  - Multiple antenna schemes
  - HARQ
  - Interference management
  - Enhanced receive mechanisms in the mobile stations

- Advancements in developing equipments
  - More efficient Power amplifiers
  - Higher antenna gains
  - lower noise figures
  - Etc.
Uplink

• Power Saving modes for prolonging device battery life and reducing consumed energy
  – Three states: active, sleep, and idle mode
  – Sleep mode
    • happens more frequently
    • faster transition to active mode
    • device is still registered at the BS
    • conserves less power than idle mode
  – Idle mode
    • device is not registered at the BS
    • happens less frequently
    • slower transition to active mode
    • requires paging to return to active mode (or activation from device)
    • conserves very high amount of power
Some Power Save Observations

• Coverage enhancement techniques requires less Transmit powers to reach the signal to the cell edge
  – Multiple antenna schemes (next release for CPEs)
  – HARQ
  – Interference management
  – Enhanced receive mechanisms in the base station

• Peak to Average ratio reduction
  – Reduces power amplifier backoff
  – Increases the power amplifier efficiency
  – Requires less generated power for the same transmit power

• Advancements in developing equipments
  – Using small size dices for chipsets, reducing average power consumption
  – More efficient Power amplifiers
  – Higher antenna gains
  – lower noise figures
  – Etc.
WiMAX Chipset Evolution

**WiMAX Wave1**
- Process = 180-90nm
- Avg. Pwr = ~1.2W
- Avg. Size ~625mm2
- WiMAX only 2 chip solution
- Dominant Devices:
  - CPE Modem
  - PC Card

**WiMAX Wave2**
- Process = 90-65nm
- Avg. Pwr = ~800mW
- Avg. Size ~400mm2
- WiMAX 2 chip solution
- Dominant Devices:
  - CPE / PC-card
  - Laptop
  - UMPC

**WiMAX + WiFi**
- Process = 65-45nm
- Avg. Pwr = ~600mW
- Avg. Size ~225mm2
- WiMAX and WiFi SoC Combo solutions
- Dominant Devices:
  - MID
  - PMP
  - PND
  - General CE Devices

**WiMAX+WiFi +GPS, BT etc. Multi-Mode**
- Process = 45nm
- Avg. Pwr = ~450mW
- Avg. Size ~100mm2
- WiMAX+WiFi SoC with Other RF tech. integration
- Dominant Devices:
  - General CE Devices
  - Handset/Mobile Phone

- Avg. Pwr = Full WiMAX Module power consumption including PA under certain Operation mode
- Avg. Size = Full WiMAX Module size

*Source: Data from Sprint WiMAX Chipset Ecosystem Program*
Open Discussion