Designing an Energy Aware Operating System

Bringing the Smartphone Power Model to Windows PCs

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Introducing Connected Standby

- Connected Standby (CS) is a screen-off low-power *active* state
  - Targeted at Intel and ARM System on Chip (SoC) systems

- “Smartphone Power Model”
  - Instant on/off
  - Extended standby battery life
  - Fresh content & real-time notification handling

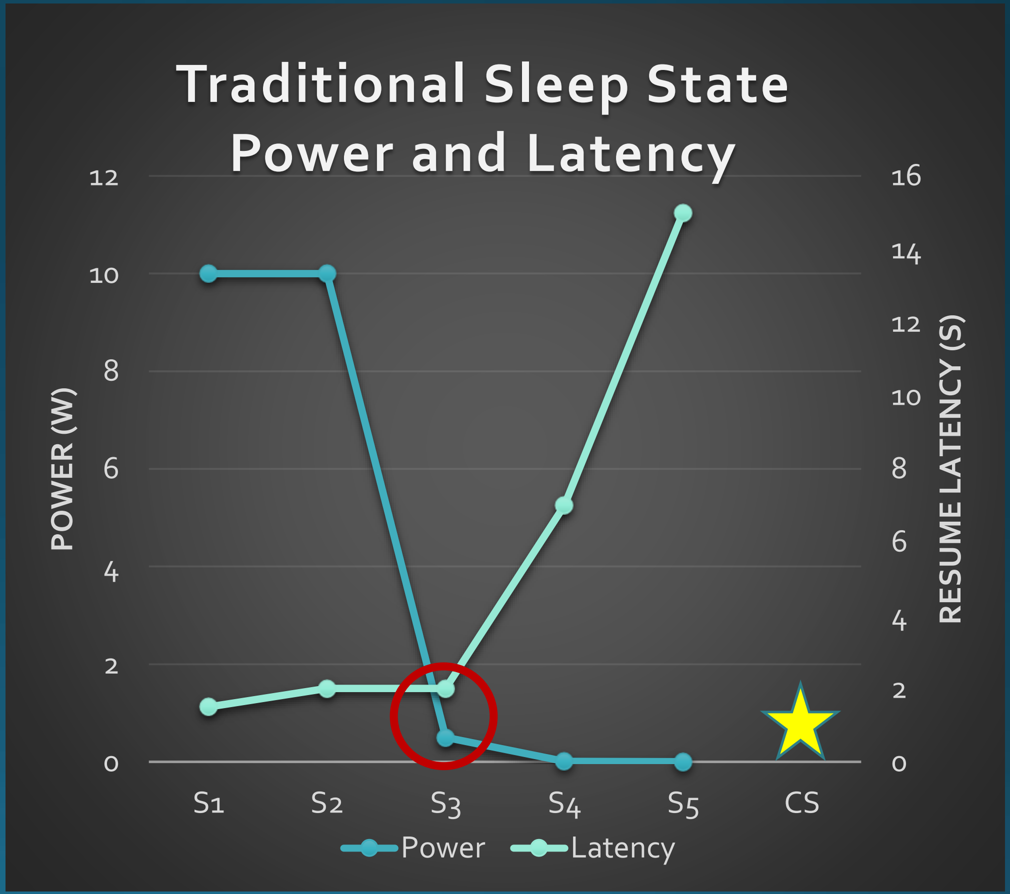
- Supported platforms include:
  - All Windows RT ARM tablets
  - Intel Clovertrail tablets
  - Next-generation Intel Haswell ultrabooks and Baytrail tablets

What about Standby and Hibernate?

- Traditional PCs support multiple power states
  - Standby: *Suspend-to-RAM / S3*
  - Hibernate: *Suspend-to-Disk / S4*
  - Off: *Shutdown / S5*

- Globally-Coordinated Transitions
  - All hardware and software components are either on or off

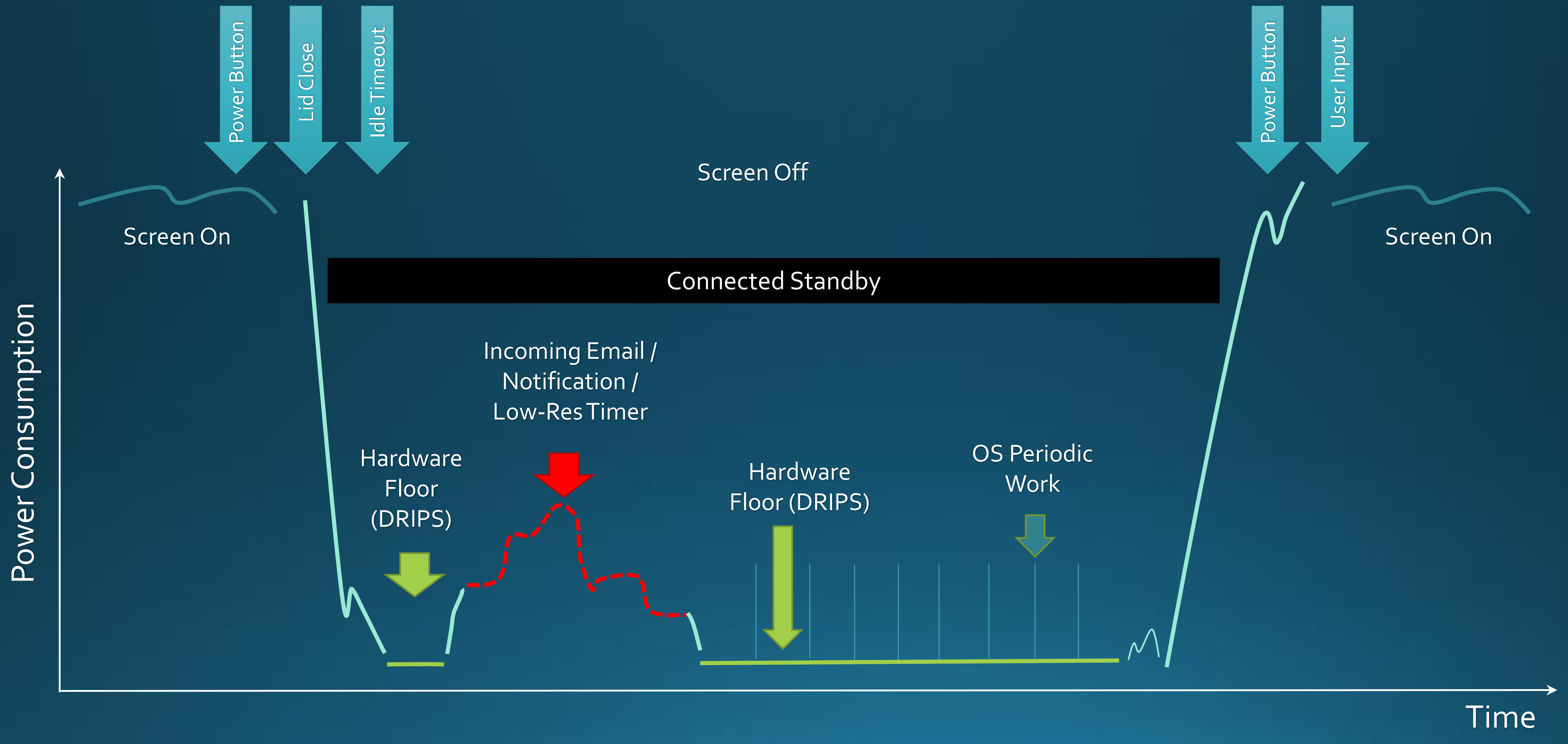
- Problems:
  - Tradeoff power and on/off latency
  - No network connectivity when "off"
  - "Partially" active states not possible



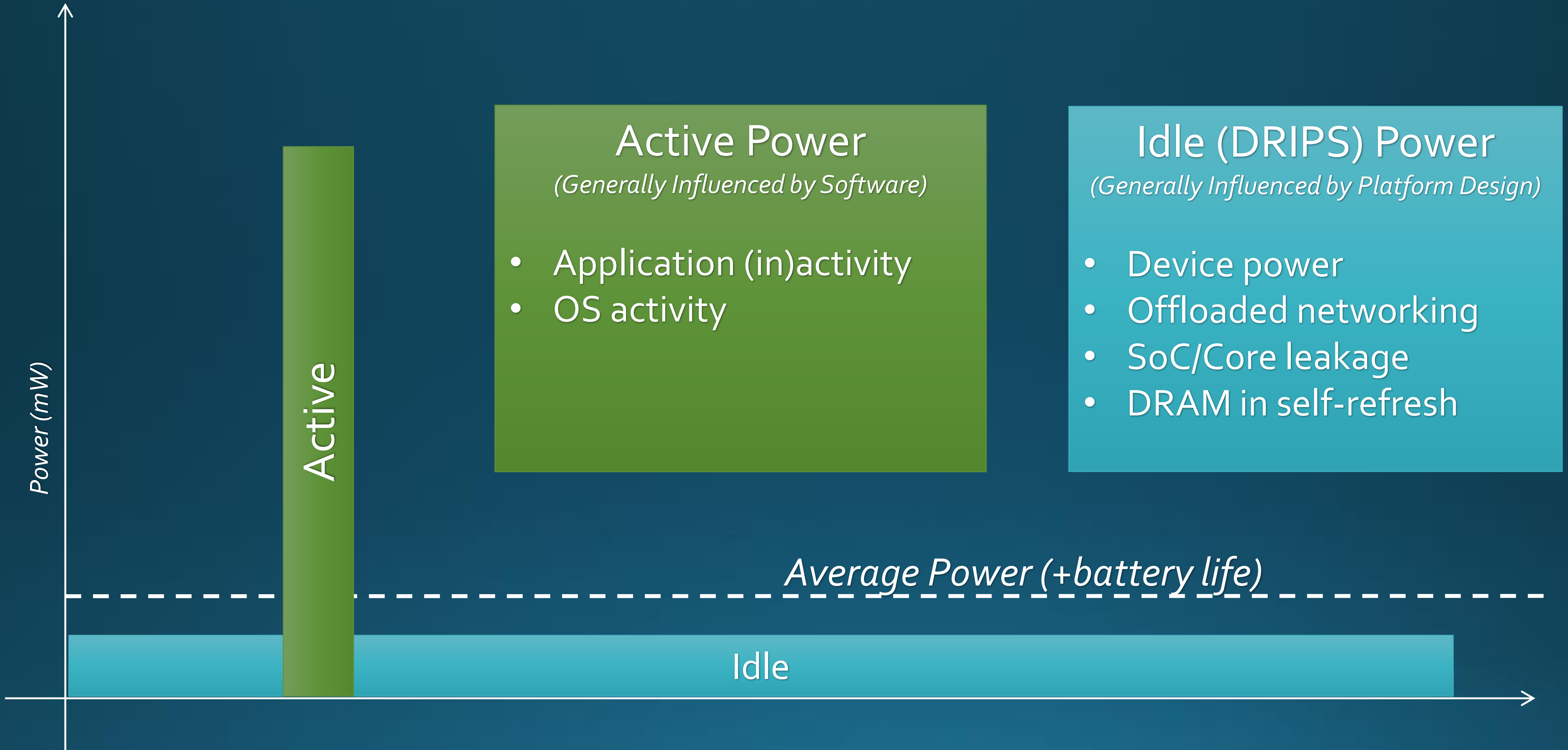
Design Goals for CS Systems

- Windows devices and Store applications are able to provide an always-on, always-connected experience
- 14 days of CS time on a full battery charge for the typical system design
- Devices continue to deliver exceptional battery life regardless of the number of Store applications
- Maintain compatibility for existing Win32 applications

A Connected Standby Session



Active, Idle, and Average Power in CS

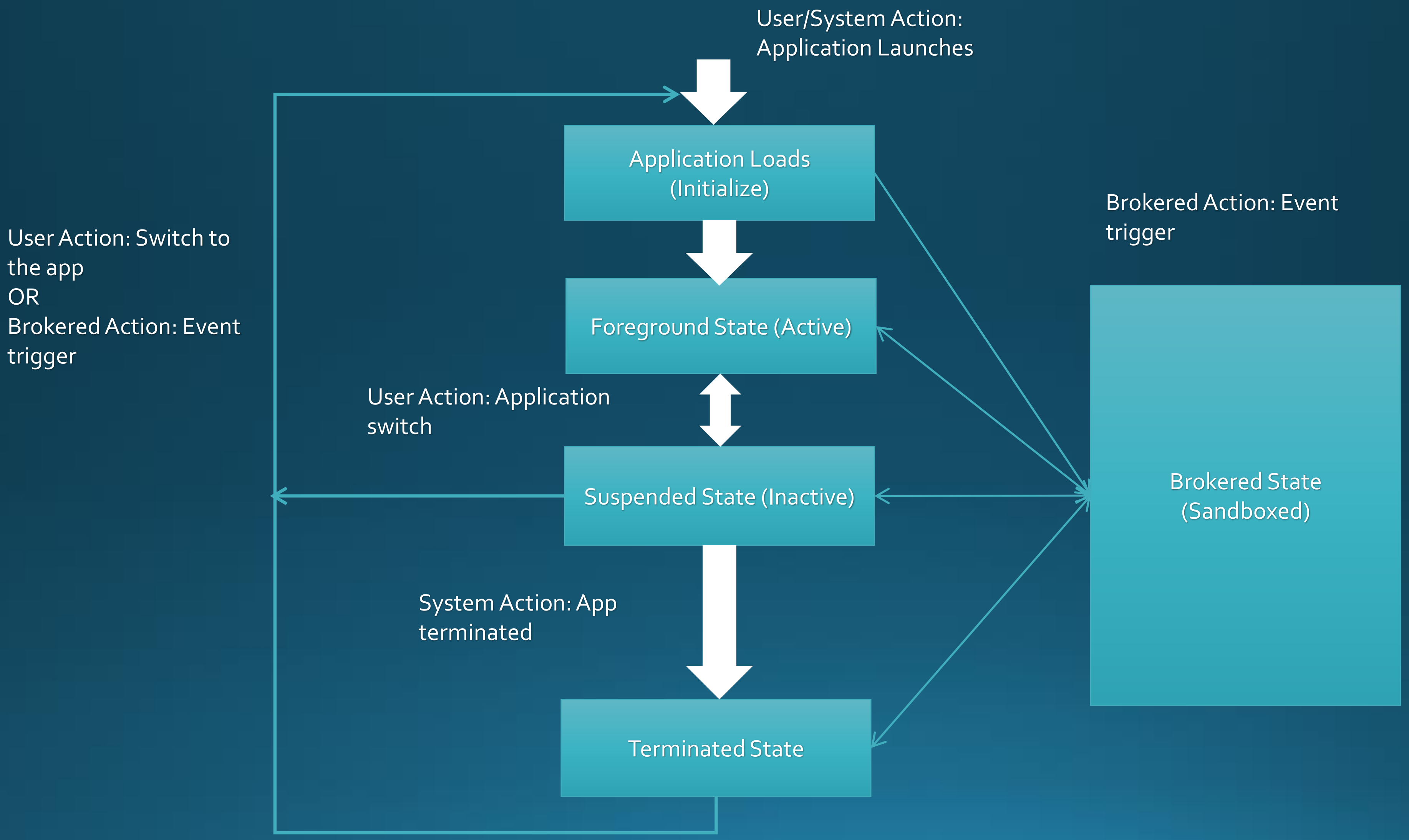


Long Battery Life = Maximizing DRIPS residency

Challenges with Connected Standby

- **Background execution**
  - **Enabling multi-tasking scenarios while preserving battery life**
- Device power management
  - Devices and SoC must enter low-power mode
- Network Connectivity
  - Maintain connectivity even while the SoC is off
- Staying Idle
  - Confine periodic tasks performed by the OS

Windows 8 Execution Model



Background Tasks

- *Brokered background tasks* are the only way to achieve arbitrary background execution

- Applications communicate with system *brokers* to arrange for brokered events
  - Two types of events: *triggers* and *conditions*
  - Brokers: Time, Real-Time Communication (RTC), Windows Notification Service (WNS), and System Events
  - Events: 15-minute timer, remote wake, keep-alive, internet available, geofence, etc.

- Applications associate a *background task* with a set of events
  - Applications create a logical expression using a trigger and zero or more conditions
  - Example: Run mail download every 15 minutes, but only when the internet is available

Controlling Background Execution

- Sandbox policy consists of multiple elements
  - Limited CPU cycles and network time [battery preservation]
  - Reduced CPU, I/O, and memory priority [foreground responsiveness]

- Sandbox policy only applies when the application is in the background state

- Applications are classified by the user as *lock screen* capable or not
  - Lock screen is designed to show status for always on, always connected applications (7 applications maximum)
  - Limited quota for background resources (2 CPU seconds and 4 network seconds every 15 minutes)
  - Non-lock screen applications generally *cannot* execute in the background

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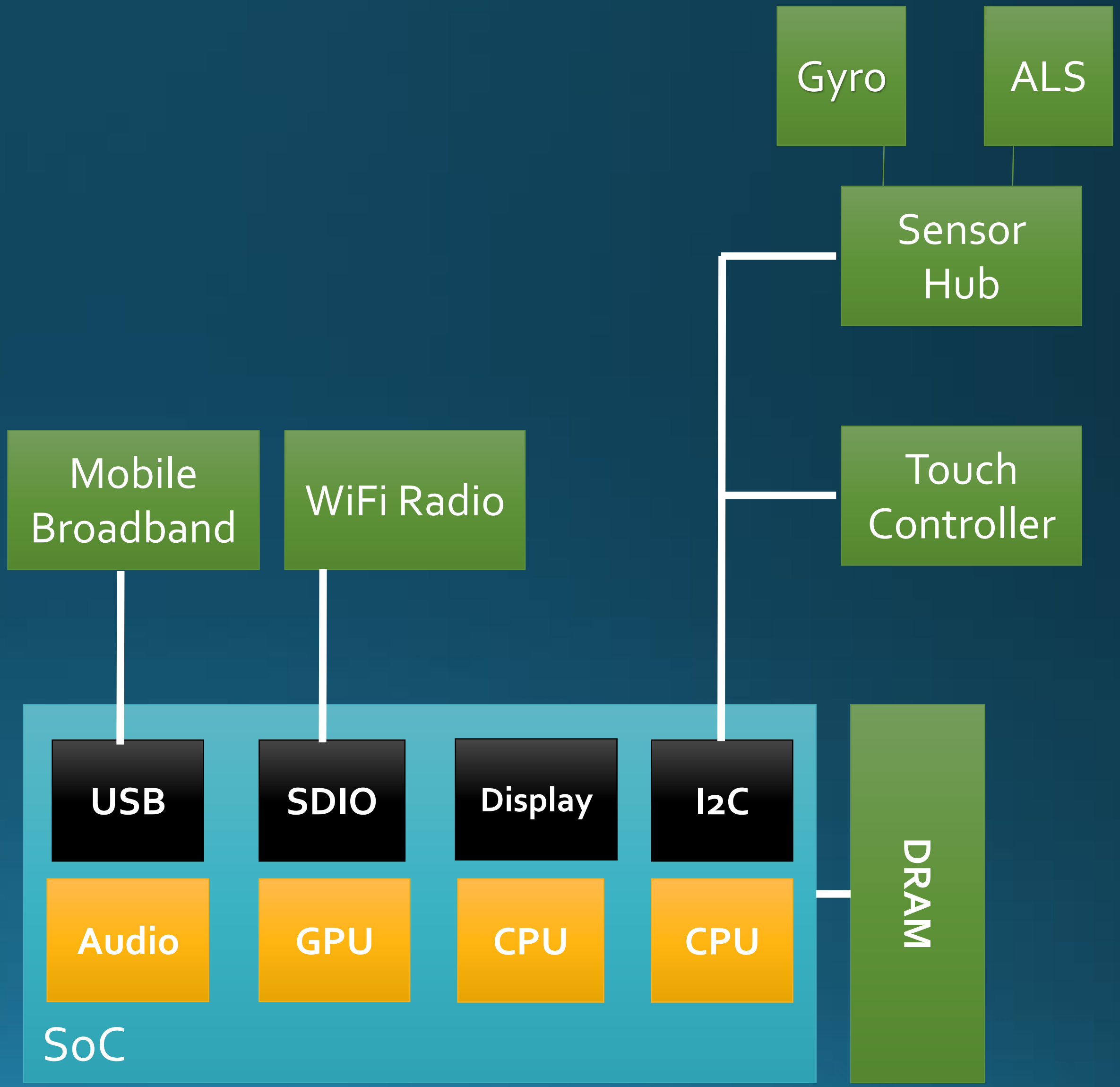
Device Power Management

- DRIPS (*deepest resident platform idle state*) requires:
  - All CPUs in deep idle
  - On-SoC device state saved
  - Platform (off-SoC) devices in low-power mode
  - DRAM is in self-refresh
  - Network in offload mode

- All devices should participate in runtime power management (PoFx)
  - Monitor and track application interaction (active handles, operation count, etc.)
  - Runtime idle to D3 (off) when not in use



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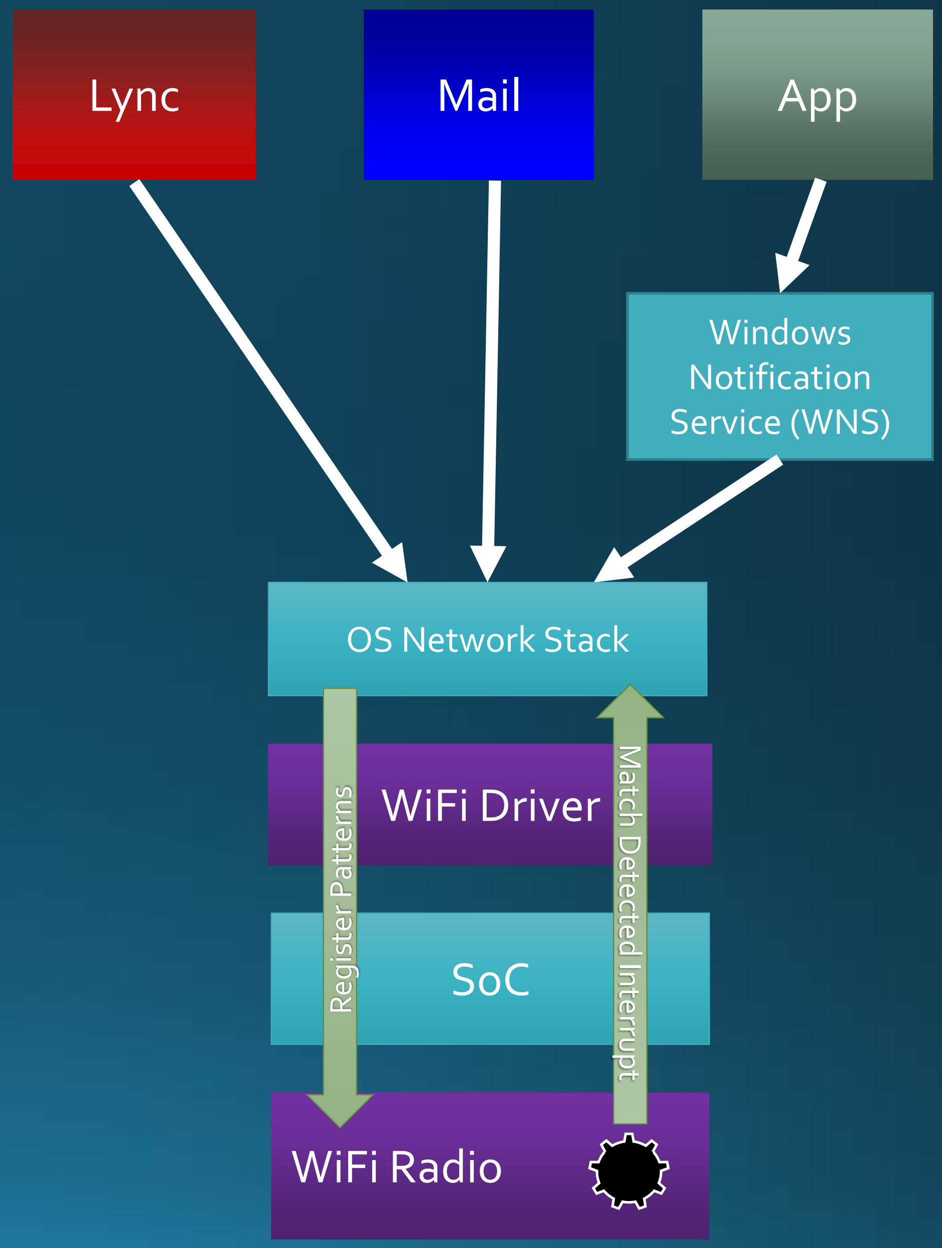
Offloading Connectivity

- CS depends on the network adapter to efficiently maintain connectivity through *offloads*
  - ARP/NS protocols
  - Network List Offload (NLO)
  - Wireless GTK rekey
- Windows can register a set of "wake patterns" on the adapter
  - Used by RTC and WNS brokers
  - When matched, CPU will be interrupted
- Network remains connected at all times!
  - No reconnect as in wake/resume from S3/S4



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Resiliency Technologies

- Despite revamped application model, device power management, and network offload, periodic Windows system activity can prevent DRIPS

- *Resiliency* dampens and coalesces activity to boost DRIPS residency

- Resiliency technologies consist of multiple telescoping tiers
  - *Desktop Activity Moderator (DAM)* reduces activity from traditional services and applications
  - *Network Quiet Mode (NQM)* reduces power and limits network software stack activity
  - *I/O Coalescing* caches I/Os from registry, cache manager, etc. in RAM to prevent disk access

- System behavior is not deterministic when resiliency technologies are engaged
  - OS manages requests from system components to turn off resiliency tiers as appropriate
  - Example: NQM is disabled by the OS when executing background tasks that require network

Achieving Exceptional Battery Life

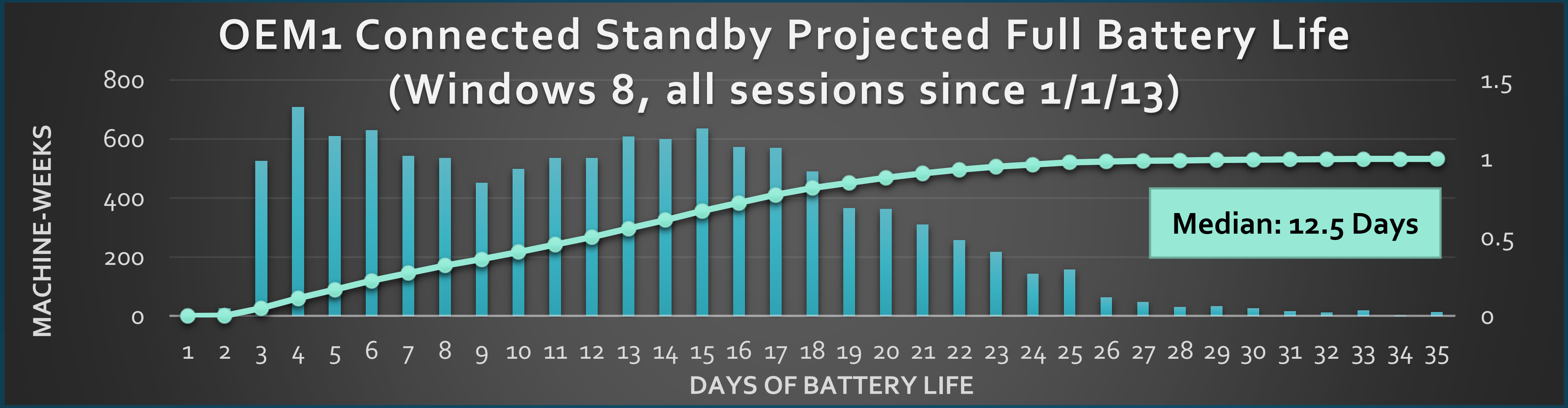
- Battery life dependent on how long the system can stay in DRIPS

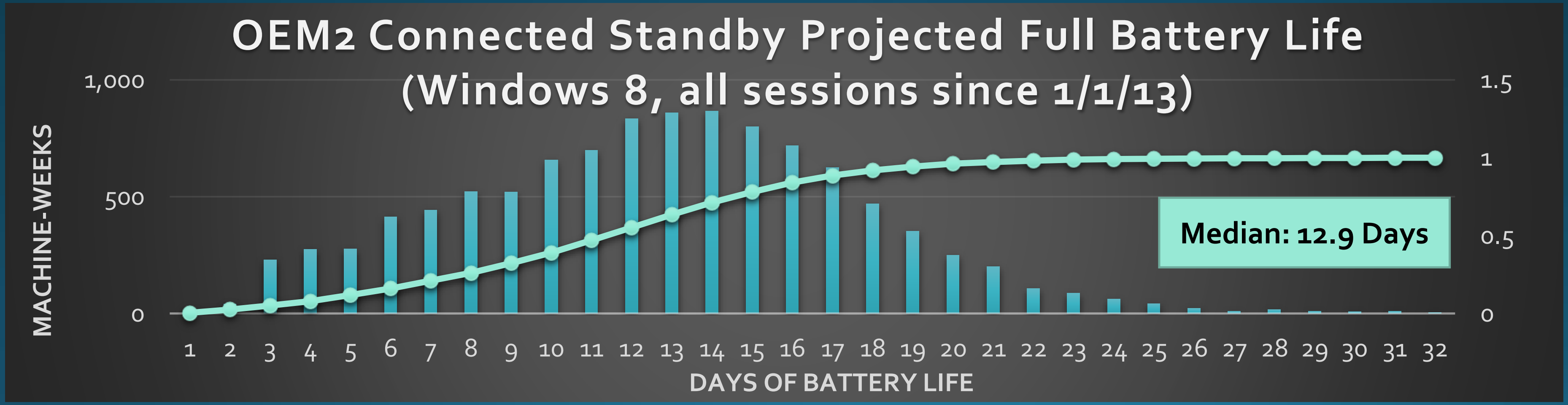
- Multiple inputs feed into platform idle state selection
  - *System latency*: User responsiveness requirement (15ms in active, 150ms in CS)
  - *Idle residency*: Expected idle time for CPUs (function of the hardware interrupt frequency)
  - *Device state*: Power state of the devices (D0 – D3)

- Entering CS lowers latency requirement (user no longer present), increases idle residency (applications suspended), and enables devices to power down

- Kernel consumes the above information and selects the appropriate platform idle state
  - Examples: NV LP0, QC PXO Shutdown, Intel S0i3
  - SoC vendor's *Power Engine Plugin* (PEP) executes actual state transition
  - System ultimately enters DRIPS

Results


OEM1 Connected Standby Projected Full Battery Life
(Windows 8, all sessions since 1/1/13)
MACHINE-WEEKS
800
600
400
200
0
1.5
1
0.5
0
Median: 12.5 Days
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
DAYS OF BATTERY LIFE


OEM2 Connected Standby Projected Full Battery Life
(Windows 8, all sessions since 1/1/13)
MACHINE-WEEKS
1,000
500
0
1.5
1
0.5
0
Median: 12.9 Days
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
DAYS OF BATTERY LIFE

Future Directions

- Expanding CS to more form factors
  - Ultrabooks, desktops, servers, all-in-ones (AIOs)
- Reducing hardware cost requirements on CS
  - Replace SSDs with hybrid rotational disks
  - Replace LP-DDR with memory power management
- Improve fidelity of background resource policy
  - Expand energy resource accounting to include disk, GPS, etc.
- Shift to *adaptive* application power model
  - Allow an unbounded number of applications to run in the background
  - Accurately measure application power usage online
  - Only throttle applications with unexpected energy consumption

Questions?

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