How We Learned to Stop Worrying and Love Middleboxes

Keith Winstein

[+ Amit Levy, Kexin Rong, James Hong, Yu Yan, Greg Hill, Judson Wilson, Henry Corrigan-Gibbs, Riad Wahby, Laurynas Riliskis, Dan Boneh, and Philip Levis]

Stanford Computer Science Department

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How We Learned to Stop Worrying and Love ~~Middleboxes~~ Smart IoT Gateways

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Most communications applications are built on **one venerable abstraction**:

Venerable abstraction

An **end-to-end inviolable** channel **between two endpoints**

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- TLS enforces it (no more Web caches)

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- TCP provides it (app to app)
- TLS enforces it (no more Web caches)
- QUIC and Mosh enforce it even for control information (no more accelerators)

- The Internet owes much of its success to the view that the network should avoid meddling in endpoints' affairs.

- Traditional view:
  "The endpoints are the principals."

- Here are five ways the Internet **of Things** can benefit from smarter gateways:

Idea #1: multiplexing and access control for Bluetooth

Challenges with Bluetooth API:

- Only one app can open stream to device
  - Can't make: "is any device low on batteries?" app
- Access is all-or-nothing
- App must run on the gateway

Amit A. Levy, James Hong, Laurynas Riliskis, Philip Levis, and Keith Winstein. *Beetle: Flexible Communication for Bluetooth Low Energy.* In Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys '16) (presented yesterday!)

Solution: Beetle, an OS Service for BLE

Sharing

Apps can share access to peripherals.

Access Control

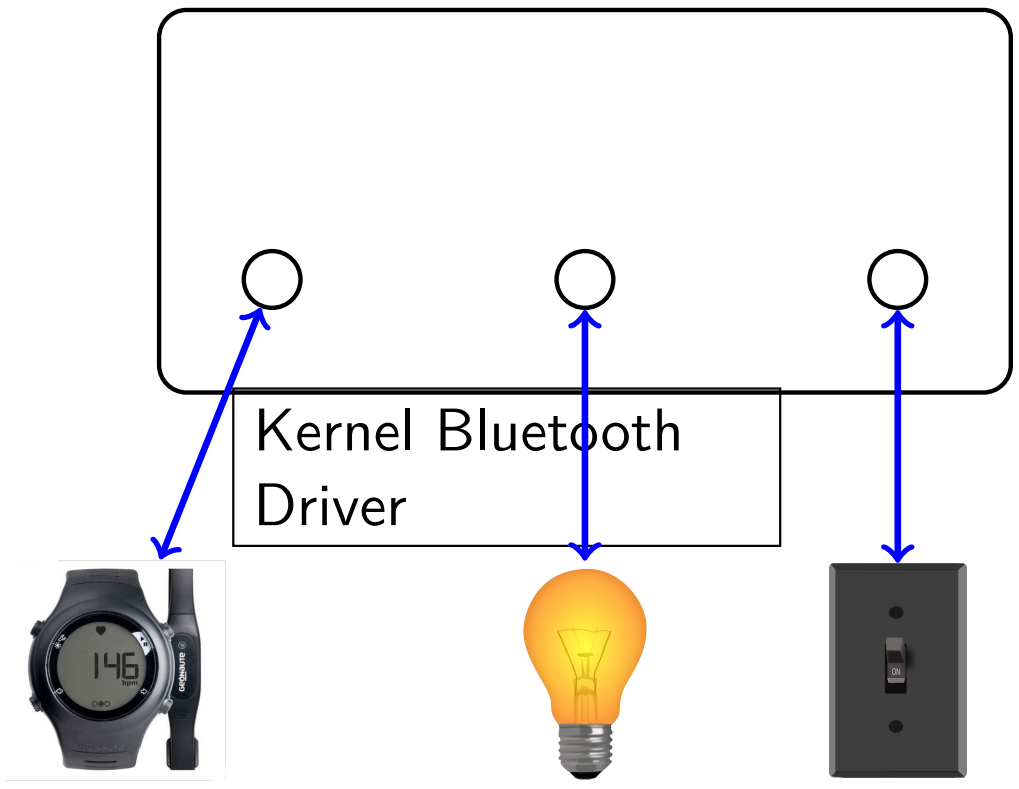
Users can specify access policies on peripherals and apps.

Communication flexiblity

Communication between peripherals, gateway and cloud apps.

Backwards compatible

No changes to existing peripherals or applications.



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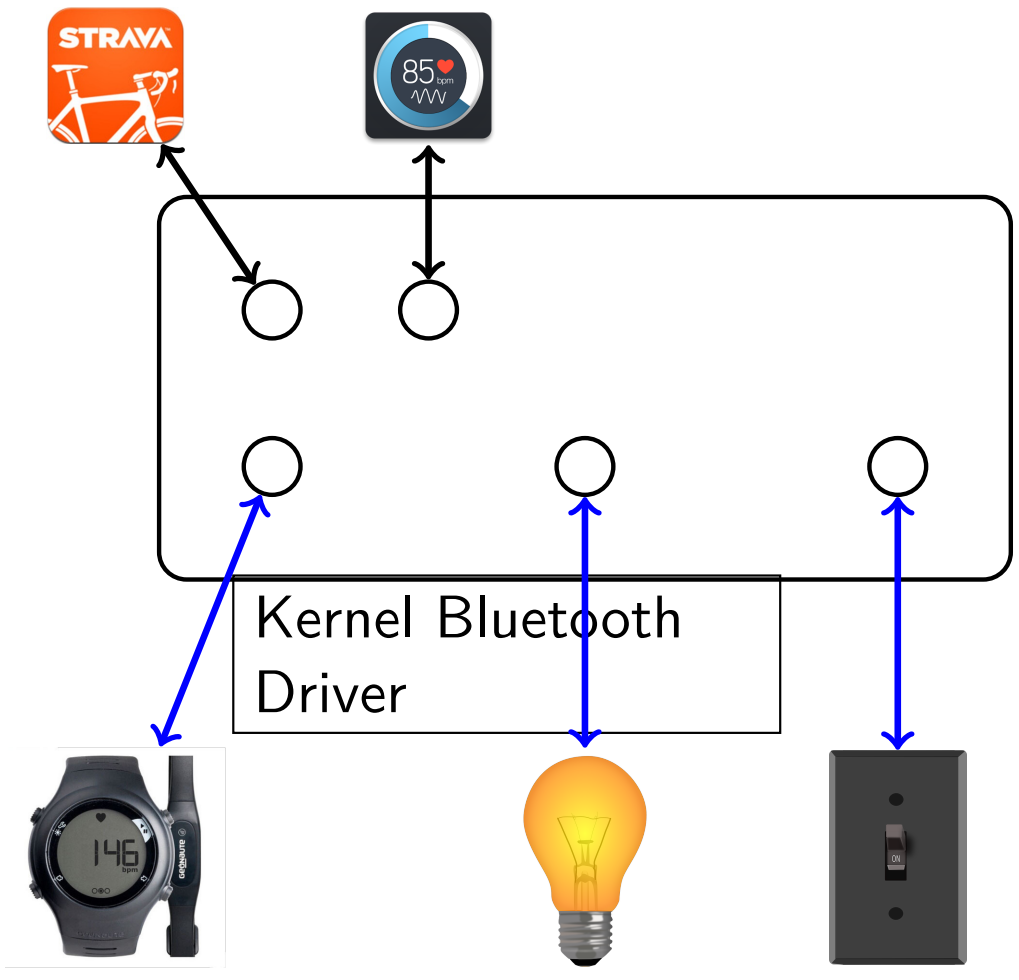

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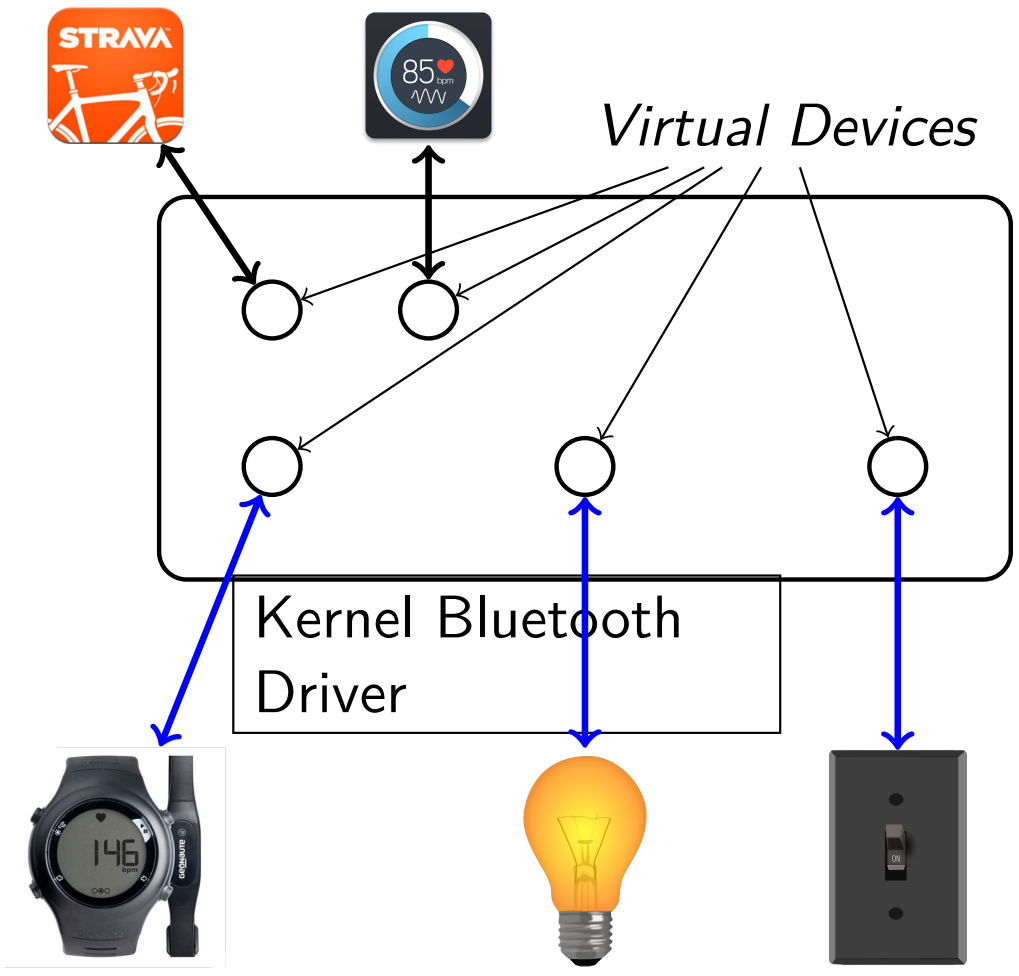

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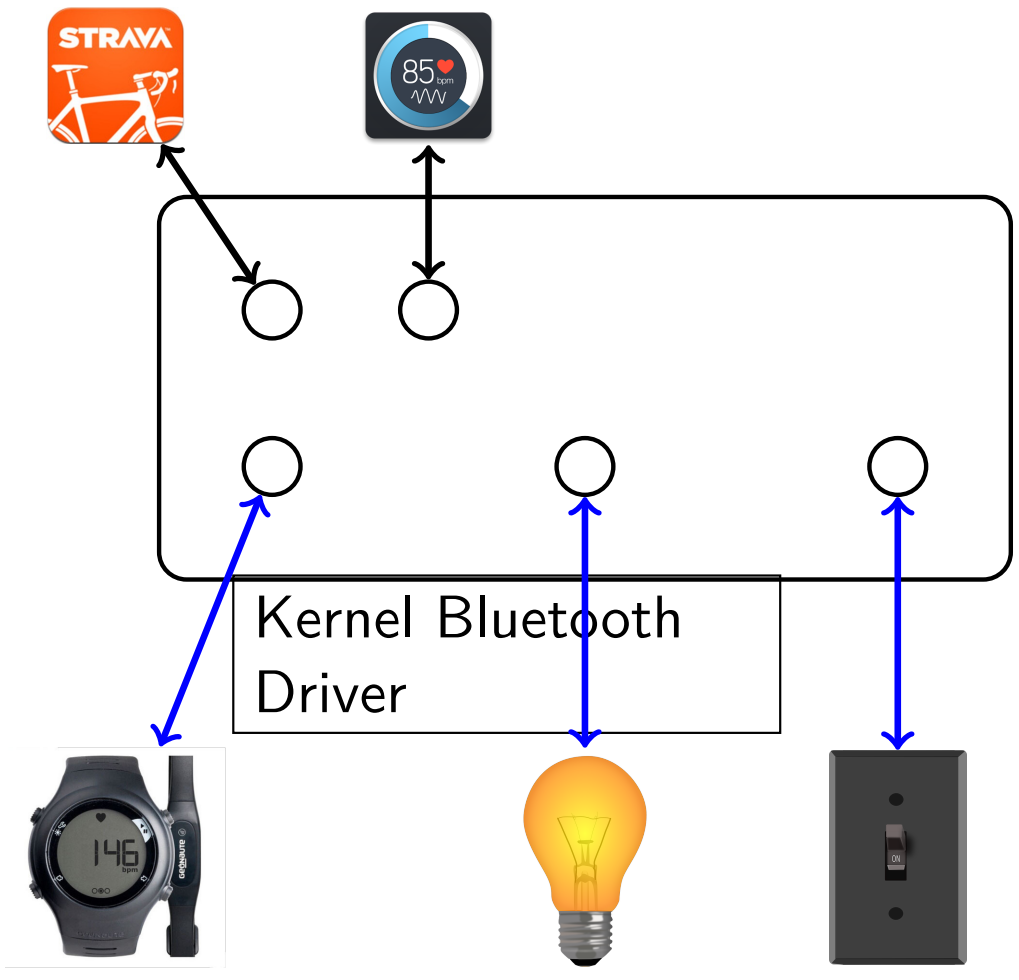

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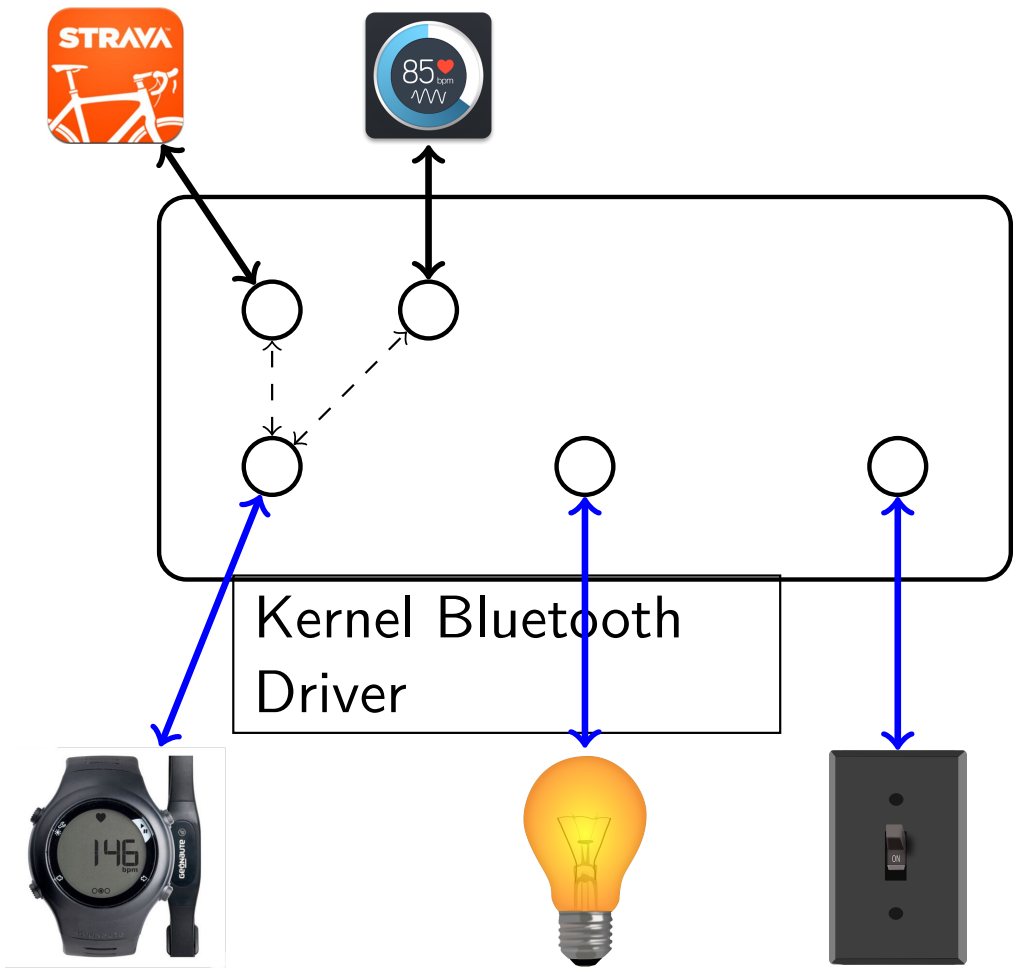

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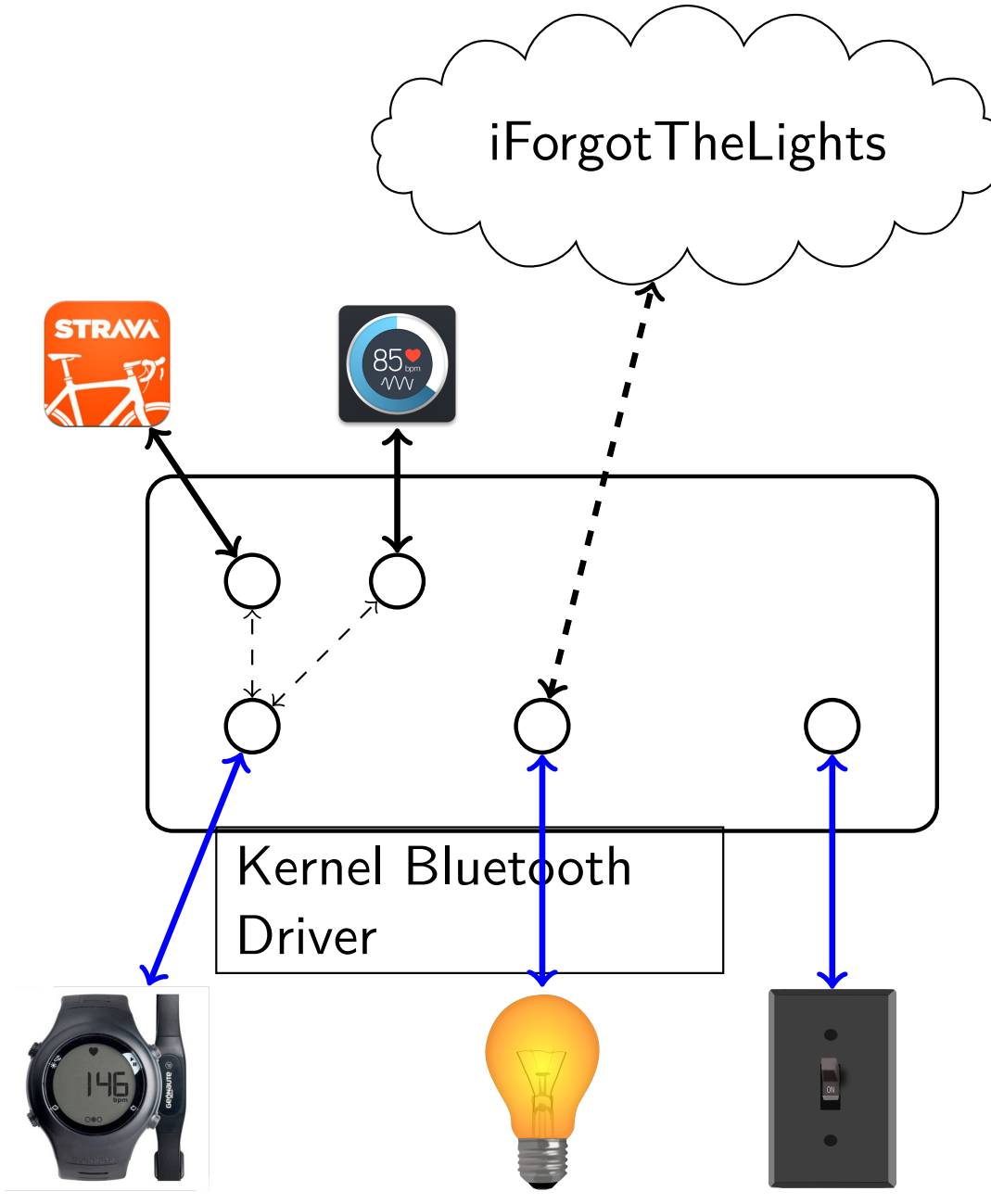

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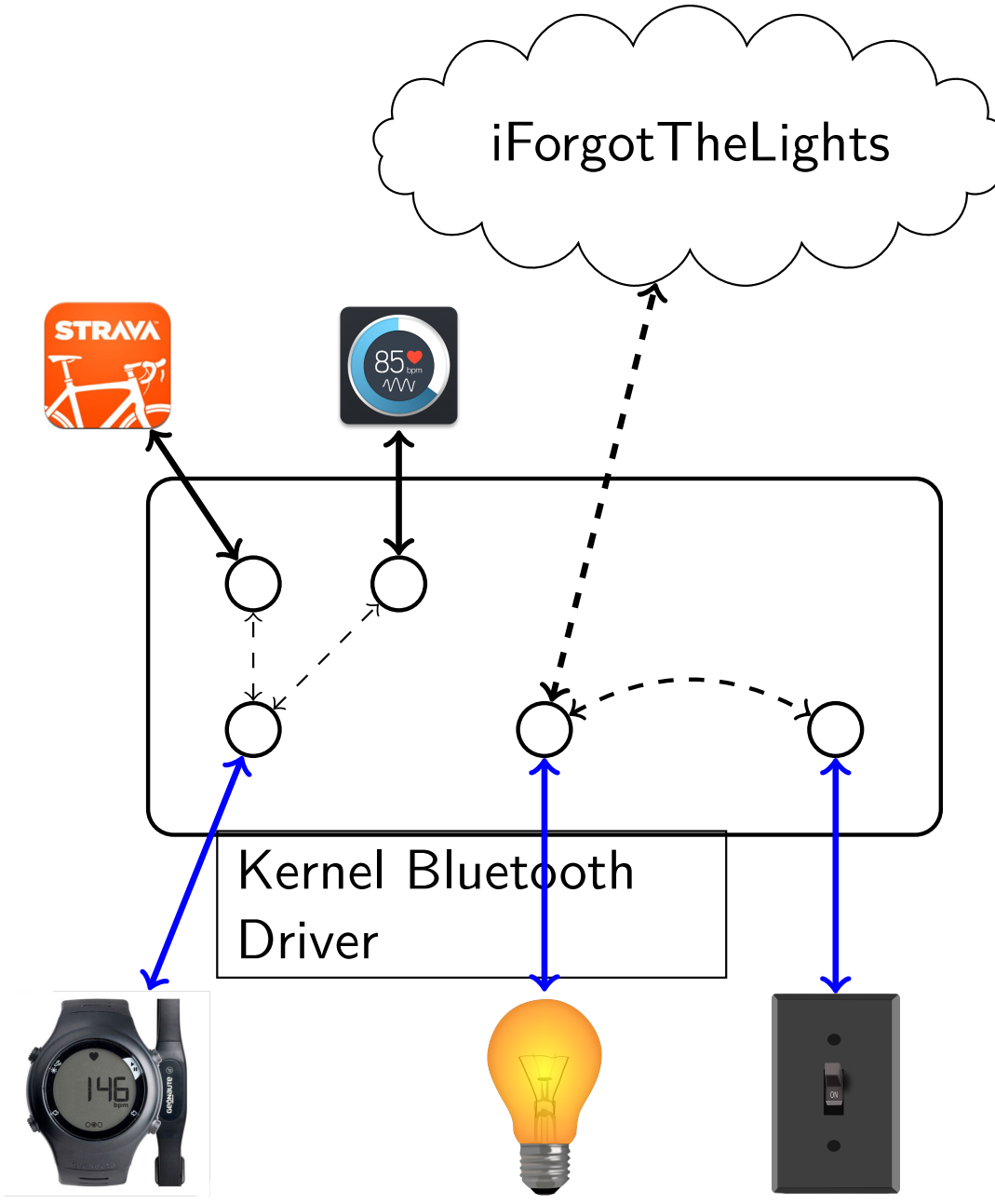


Beetle: Key insight

Bluetooth application protocol amenable to multiplexing:

- Unified data model
- Standardized data types
- Transactions are meaningful to applications

Interposing on application layer can provide

- Sharing by multiplexing transactions from different clients
- Flexible communication by allowing transactions over any link
- Access control by mapping handle space

Idea #2: comprehensible, user-controllable access control

More challenges with Bluetooth API:

- Every app does its own access control.
- No common notion of identity.
- No common language for what's permitted.

Bark, fine-grained access control at gateways

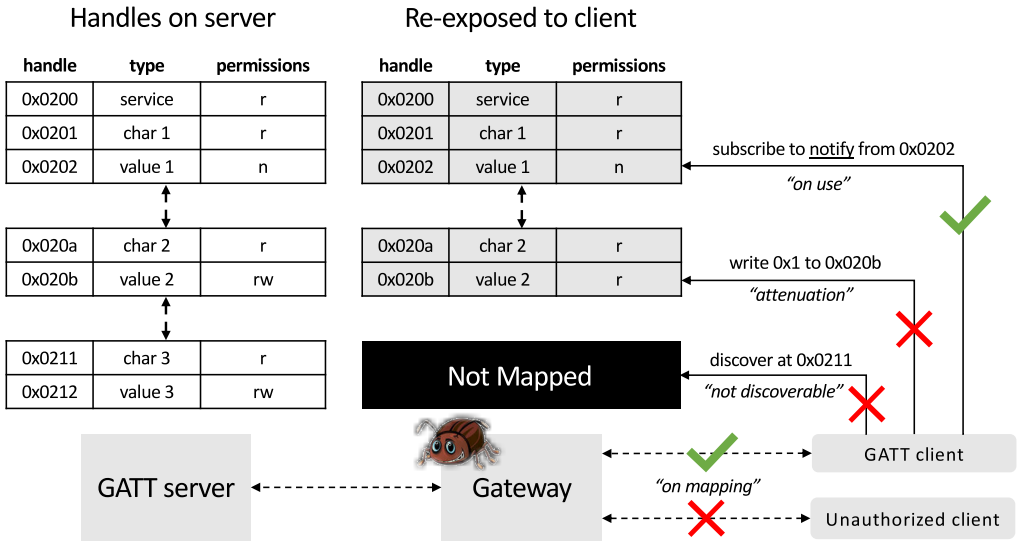


Figure 1: Enforcing fine-grained access control at gateways.

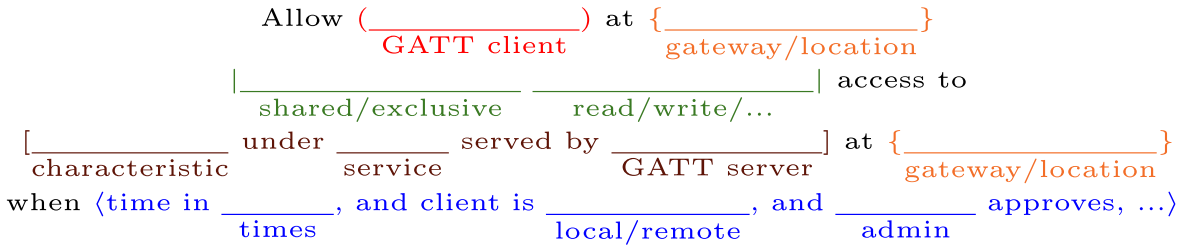


Figure 2: Beetle access control policies have simple English interpretations. ((who), [what], {where}, ⟨when⟩, |how|)

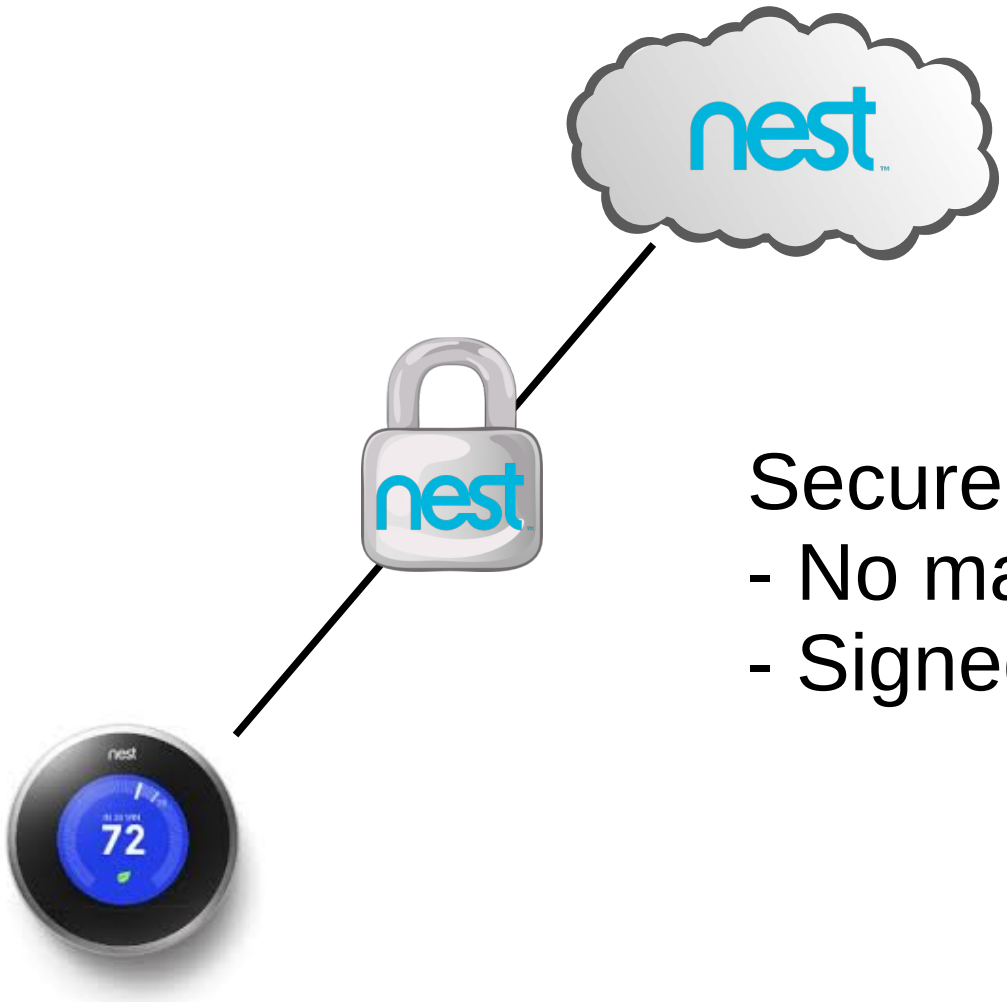
James Hong, Amit Levy, and Philip Levis. *Demo: Building Comprehensible Access Control for the Internet of Things with Beetle* (MobiSys '16)

Idea #3: who watches the IoT?

- Web browsers and smartphones allow user to install a CA cert.
  - Allows "auditors": IDS, virus scan, curious researcher, Underwriters Laboratories...
- Today's IoT devices **don't** allow user-installed CA cert. Device talks to manufacturer with end-to-end encryption.
- Our view: users should be able to listen in on what their own devices are saying about them.
- But auditor only needs **read-only access.**

Judson Wilson, Henry Corrigan-Gibbs, Riad Samir Wahby, Dan Boneh, Philip Levis, and Keith Winstein. *Auditing IoT Communications with TLS-RaR* (working draft)

How can we audit TLS communication between our IoT devices and the cloud?

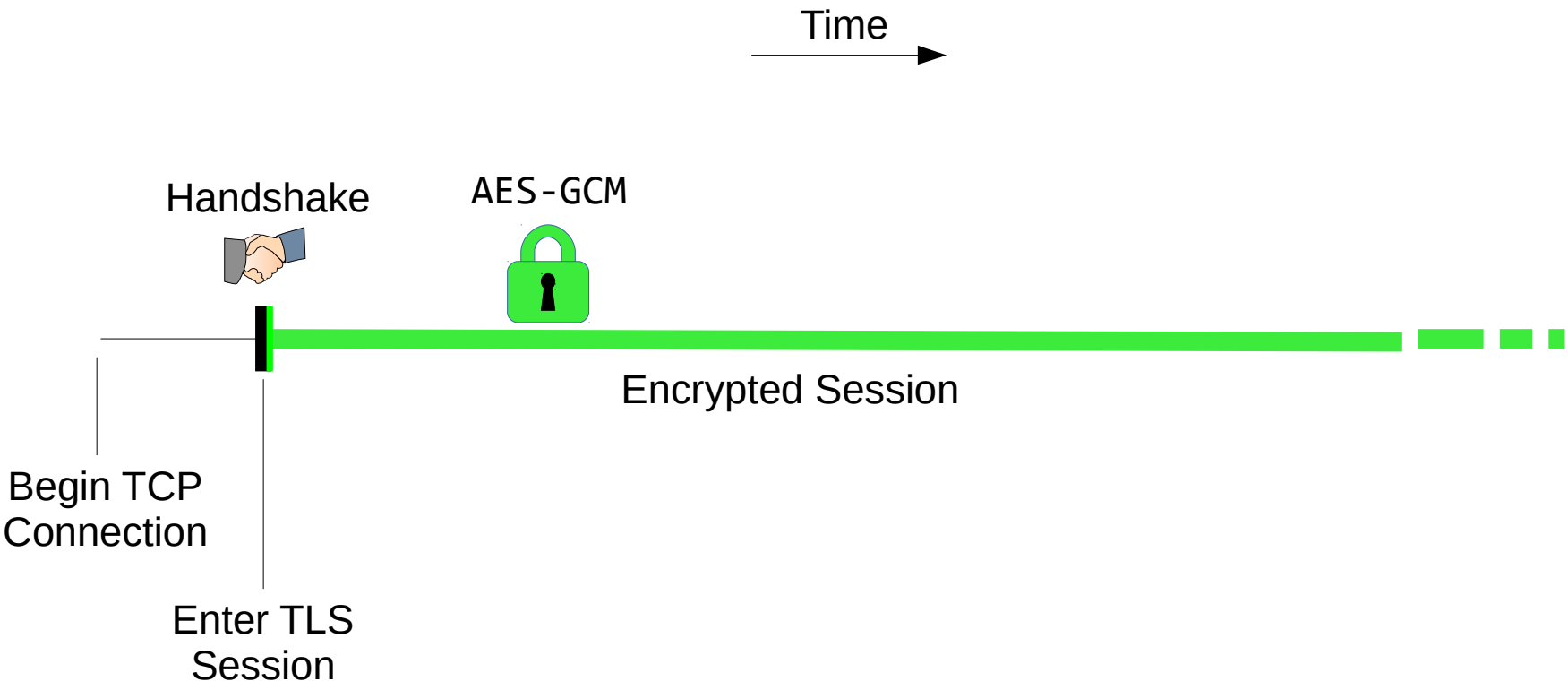


Secure Devices:
- No man-in-the-middle
- Signed firmware

*Nest used for illustrative purposes only.

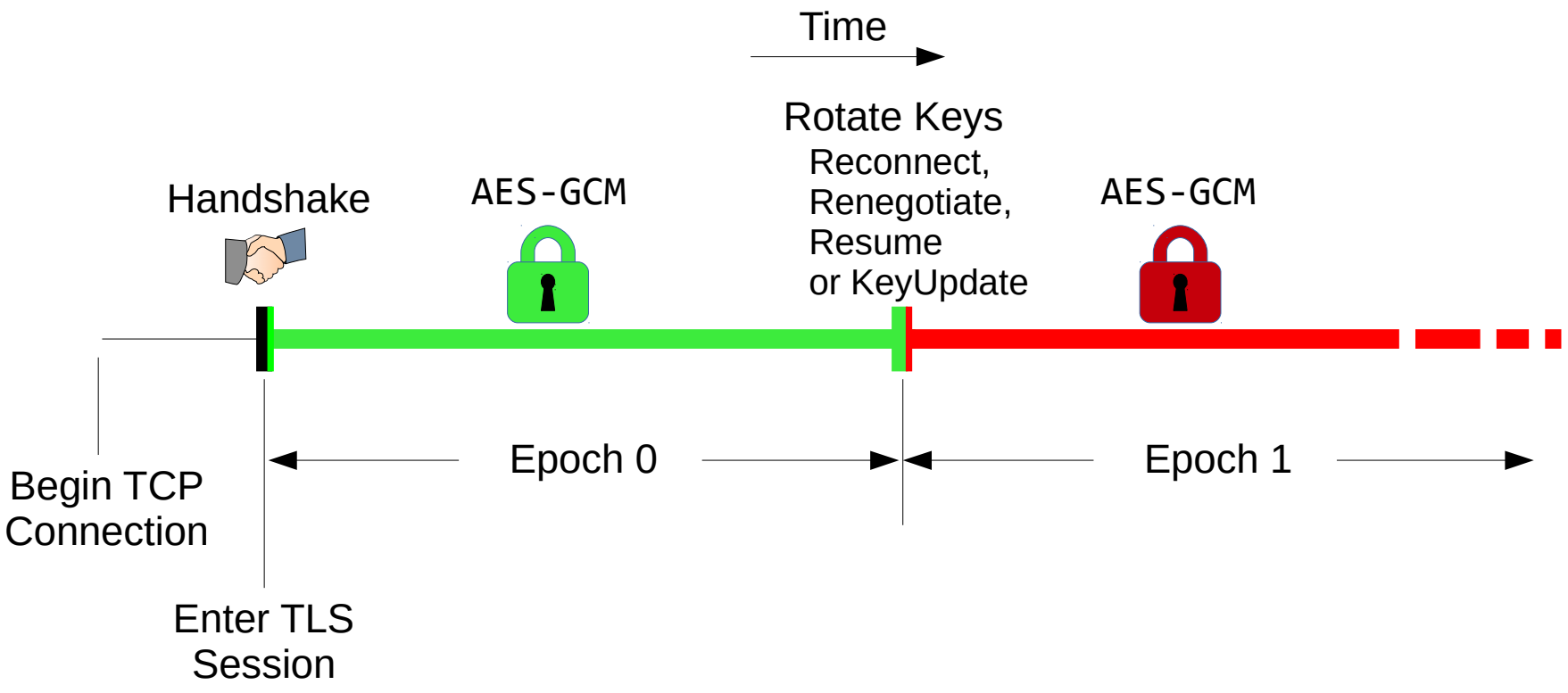
Solution: TLS-RaR

A standard TLS connection...



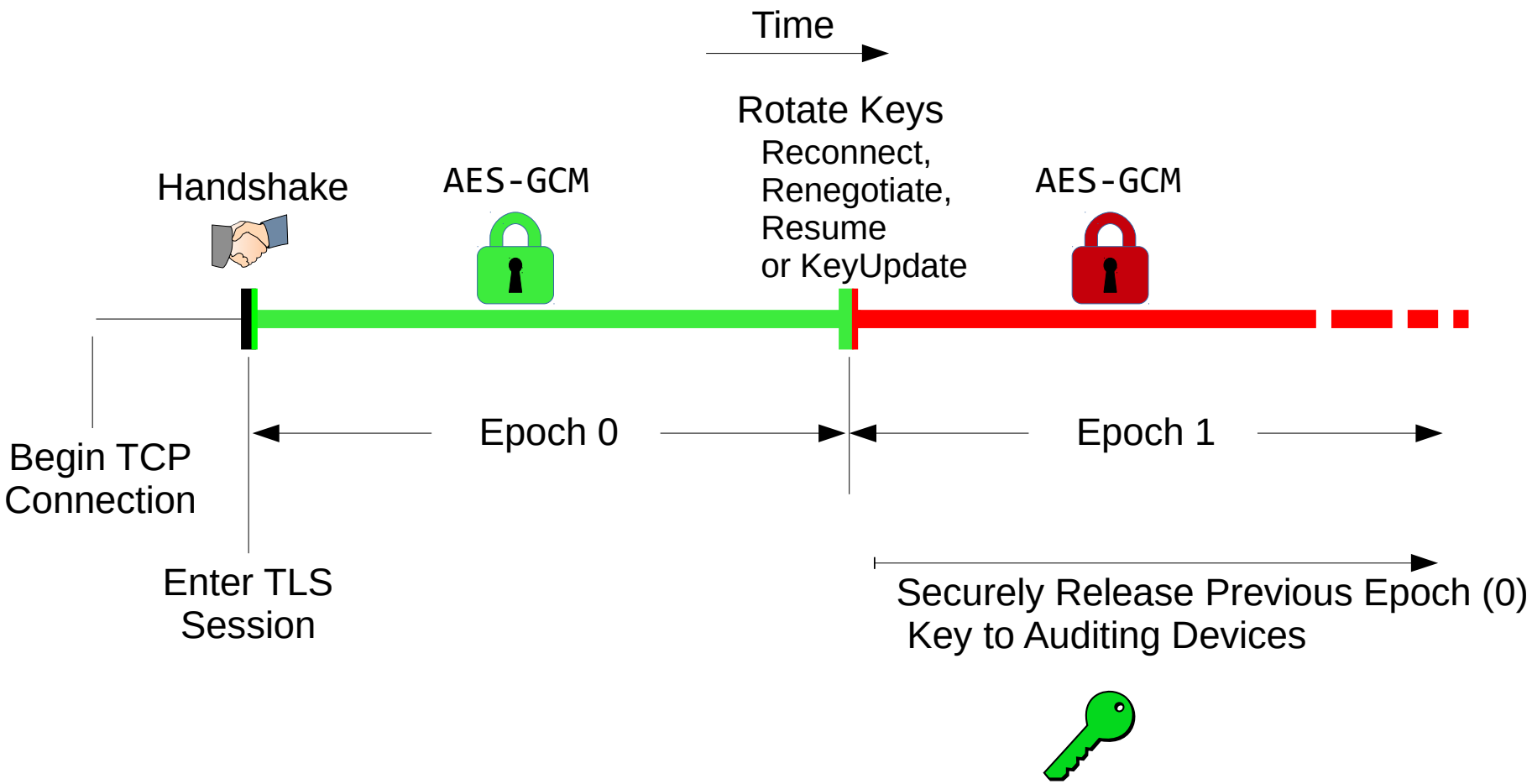
Solution: TLS-RaR

Use standard TLS features to **R**otate keys,



Solution: TLS-RaR

Use standard TLS features to **R**otate keys, **a**nd then securely **R**elease the previous keys to auditing devices.



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  - ➔ Guaranteed tamper-proof communication.

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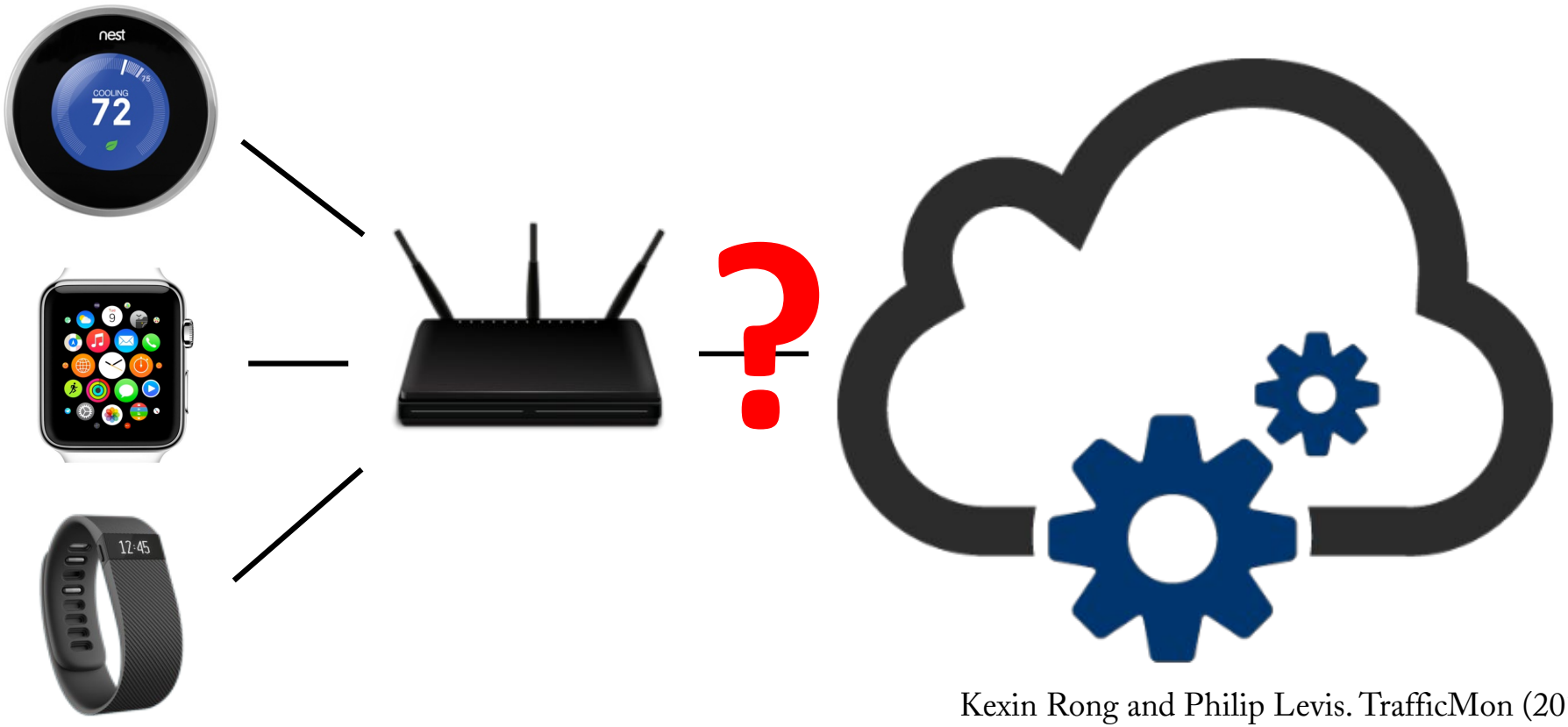
Idea #4: **Who are my devices talking to?**



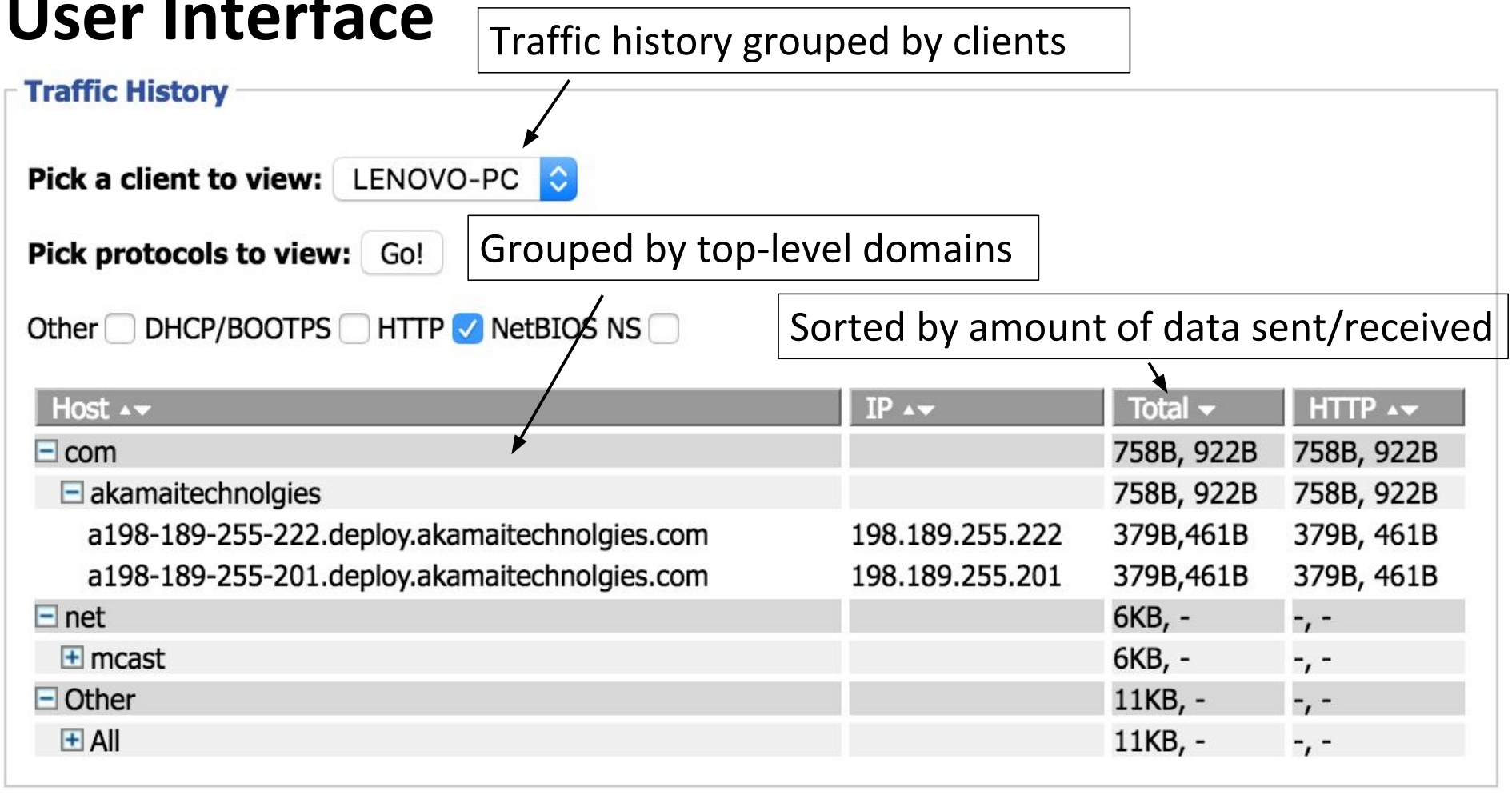
Kexin Rong and Philip Levis. TrafficMon (2015)

TrafficMon: Home Gateway Monitoring System

Currently running on DD-WRT, a Linux based open source firmware

- Capture
  - Capture packets to and from each home device, up to 18,000 packets per second
  - Based on *libpcap*, a system-independent interface for user-level packet capture
- Extract
  - Extract header information such as source, destination, port, packet length
- Log
  - Logs are exported as text files to a USB drive connected to the gateway
  - Also accessible via DD-WRT's web interface

User Interface



Idea #5: Dealing with developing-world networks

Problems in the developing world:

- Medical devices work poorly across African cellular networks

- Current solution: staffer collects a week's data on a USB drive, takes motorcycle to hilltop with better coverage, uploads from there.

CLINTON HEALTH ACCESS INITIATIVE

Greg Hill, Yu Yan, and Keith Winstein.

Our solution: a smart gateway that breaks the abstraction

- Collect all the (encrypted) data on a gateway.
- Strategy 1: Use better congestion control and error-correction.
- Strategy 2: Offer **anybody** $1 per GB for successfully getting that chunk to the cloud. Doesn't matter how.
  - More motorcyclists?
  - Wi-Fi network?
  - New cell tower?

Congestion control and error correction for fragile networks

- Frank (Yu) Yan has assembled the Pantheon of Congestion Control

  [https://github.com/StanfordLPNG/pantheon]

  - Every relevant congestion-control scheme
  - In one place, with one interface
  - Linux CUBIC, QUIC CUBIC, LEDBAT, PCC, Verus, SCReAM, WebRTC GCC, Sprout, Koho...
  - CI tests and perf measurements for all schemes
  - Anybody can submit a pull request to add more

- Greg Hill is building the Observatory of Congestion Control

  - Goal: run the entire pantheon, every day, from 10+ developing-world cellular networks
  - Intent: **create a platform for anybody to do developing-world wireless networking research**
    - (Including automatic protocol-synthesis tools)

How We Learned to Stop Worrying and Love Gateways

1. **Beetle**: multiplexing and access control for BLE IoT devices [Levy/Hong/Riliskis/Levis/Winstein]

2. **Bark**: sane access-control policies for the IoT [Hong/Levy/Levis]

3. **TLS-RaR**: read-only audits of IoT communications [Wilson/Corrigan-Gibbs/Wahby/Boneh/Levis/Winstein]

4. **TrafficMon**: who are my devices talking to? [Rong/Levis]

5. **RAIL**: developing-world networks [Hill/Yan/Winstein]