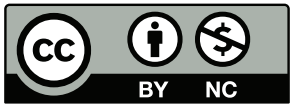
IoT: The Internet of Things



What is the "Internet of Things"?

OED A proposed development of the internet in which many everyday objects are embedded with microchips giving them network connectivity, allowing them to send and receive data.

Merriam-Webster The networking capability that allows information to be sent to and received from objects and devices (such as fixtures and kitchen appliances) using the Internet.

Wikipedia A system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

Me Non-computer objects that both contain a CPU and can communicate over a wide-area network.

Excluded

- Devices with only a CPU, e.g., my toaster and coffeemaker
- Devices with only local networking, e.g., RF remote controls for ceiling fans
- Special-purpose CPUs embedded in larger, networked objects or computers, e.g., USB flash drives, Apple's Lightning connectors, laptop cameras, keyboards, etc

☞ Must distinguish IoT from *embedded systems*

Attributes of IoT Devices

- Not a computer, and hence often lacks conventional I/O devices: a screen, a keyboard, a mouse or touchscreen, etc.
- Users generally cannot reprogram them
- Generally cannot run outside software (though that may change).
- By definition, connected to a physical device

Questions

Standard questions

- What are we trying to protect?
- Against whom?

But. . .

- Why is IoT security different?
- How do we protect IoT

What Are We Trying to Protect?

- The computer
- The physical device(s) it monitors and/or controls
- Perhaps its network bandwidth

Against Whom?

- Who the enemies are depends on the attached physical device
- Russia has supposedly been poking at the power grid
- Iran has been accused of going after dams

IoT Security Concerns

- Why is IoT different?
- No antivirus
- Limited support lifetime
- Poor user interface
- The programmers are not battle-hardened
- The computer is connected to a physical device

Antivirus and IoT

- Antivirus software requires patterns of known malware, and there aren't many patterns
- Antivirus software requires a subscription and payment, and there may not be an economic model
- Besides—is it helpful or harmful?

Support Lifetime

- Who pays for support? What is the economic model?
- How long will the chips last? How long will they be available?
- When vendors switch to newer chips (because they have to), will older code run on new chips? Will new code run on old chips?

Desktop and Laptop Computers

- Typical product life: about five years, with a long tail
- Businesses replace gear more often, but keep old operating systems longer
- Vendor support lifetime is often a crucial issue

OS Support Lifetimes

- Windows: about 11 years
- MacOS: about 3 years
- Ubuntu: about 5 years

N.B. OS compatibility with new hardware can be much longer—it's not necessary to buy a new Mac every three years

Phones

- Apple supports its phone hardware for about five years
- Android: a bit over two years at best
- N.B. The Android marketplace is more fragmented

Economics

- Phones cost $500–1000
- Computers cost at least that much, often more
- Many IoT gadgets cost a lot less
- For expensive devices, the lifetime support cost is bundled into the OS (and maybe hardware) price
- That doesn't work for cheap IoT devices

IoT Device Lifetime

- How long does a light switch last? A smart light switch?
- How long does a thermostat last? A smart thermostat?
- Home routers? Security cameras? A multicooker?
- What about toys? Home appliances? Cars?

Update Desires

- Assume that updates are available? How often will they be installed?
- For phones and computers, the impetus is often new features
- What are the new features I would want that would induce me to upgrade a smart lightbulb?
- How will I know if my washing machine needs an update?

User Interface

- In general, IoT devices offer a poor *user experience*
- Things that are simply on a computer, e.g., typing a password, are very unpleasant on, say, a lightbulb
- Ergo, authentication is often poor
- There is no display to indicate system state or to make requests of users

Programmers

- Programming is not the same as secure programming; the latter has to be learned separately
- Secure programs—and secure architectures—need all manner of defensive techniques, including paranoid input checking and extensive fault recovery, plus liberal helpings of crypto
- Organizations that are used to fighting hackers have learned many such lessons the hard way. Newcomers often need to learn.

Physical Devices

- For ordinary computers, the target is usually the data, though sometimes it's network connectivity
- IoT devices rarely have much interesting data, though they do have network connections
- But—they're attached to physical devices
- This can attract hackers. . .

If That's the Structure. . .

- From these structural issues, it's clear that IoT security is hard
- But—security people don't get to decide if IoT is a good idea
- Our challenge: securing things anyway

Terminology

Thing The networked computer that talks to a physical device

Hub An intermediary between (some) Things and the Internet. Hubs often use a local, non-TCP/IP link to talk to Things

Manager A local controller for Things. Managers may be built into Hubs or may be separate boxes

Vendor A vendor server with which Things or Hubs must associate

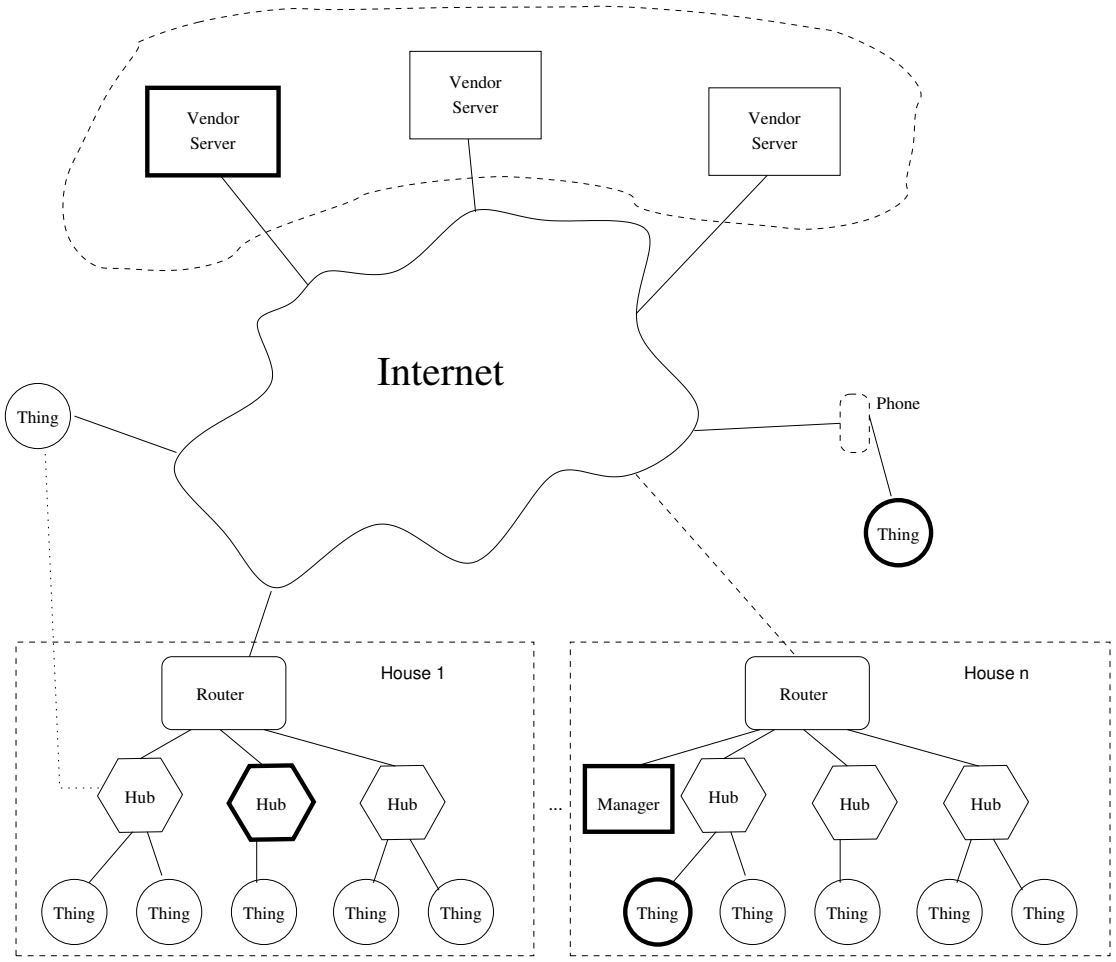
Questions About Operational Environment

- Is the *Thing* directly connected to the Internet?
- If not, it behind a firewall or NAT, or is it behind a *Hub*?
- Must the Thing use a Hub to talk?
- Must Vendors be involved

Why Vendors?

- In the consumer world, remote access to Things is often needed: think of thermostats, alarm systems, and more
- But—it's hard to talk directly to consumer devices; they're almost always behind NATs and usually don't have stable IPv6 addresses
- Battery-operated devices can't be online 100% of the time, but they can poll the vendor at reasonable intervals
- Usability is a problem: most consumers would have trouble learning an IP address and setting up a DNS entry for each of their devices
- The usual solution: consumers talk to their devices indirectly, via the vendor
- This means that vendor security is part of our concern

A Possible Architecture



Analytic Approach

- Metanote: assume that the attacker's ultimate goal is the physical device
- Identify vulnerable entities
- Identify what is at risk from their compromise, i.e., what the desired execution environment is for attackers
- Identify the weak points and devise defense

Who Can Attack Whom?

- Hubs can attack Things—but a Hub can be a firewall for its Things (and we'll lump Managers with Hubs)
- Of course, Things can attack Hubs. . .
- Vendors can attack Hubs and Things, either directly or by pushing out nasty firmware updates
- Hubs and Vendors (and some Things) are subject to direct Internet attacks or attacks from compromised home computers
- In other words: this is an environment with many threats, and with threats to all components

Mandatory Minimum Security

- Encrypt all links
- Partly for confidentiality, but often more for integrity
- Addresses vulnerabilities of all parties
- But—encrypted to *whom*? Who is the endpoint for each communication?

Encryption: End-to-End or Hop-by-Hop?

- If a Thing needs to talk to a Vendor, where does its encryption terminate?
- End-to-end is the ideal, but we need intrusion detection
- IDS is hard for Things; they're low-powered and can't easily yell for hep
- So: encrypt hop-by-hop, but use end-to-end integrity checks
- (A privacy risk? The user owns the Hubs and the Things. There may be privacy issues with respect to the vendors, but end-to-end encryption won't solve that problem.)

Protecting Things: Hubs

- Things can be attacked by Hubs—how?
- Two obvious ways: something impersonating a Hub, and by a compromised Hub sending malicious commands
- The first can be dealt with by strong authentication
- For the second, use *good* input parsing and sanity checks (stay tuned)

Introducing Endpoints

- How does a Thing know the proper Hub?
- How does it know the Hub's authentication credentials?
- What happens if you sell the Thing? How does the new owner reset it?
- What happens if you replace the Hub?

The Resurrecting Duckling

- No great solutions! No keyboards, no screens, setting lots of passwords is a pain, etc.
- Best solution: let Things *imprint* on the first Hub they talk to
- Take advantage of physical proximity for initial pairing
- Have a physical reset button to restart
- ☞ Or: use a phone app as an intermediary
- Use NFC (or maybe Bluetooth), QR codes with cameras, and more
- Can exchange strong secrets—no passwords!

Protecting Things: Vendors

- A compromised Vendor can send evil commands through the Hubs
- It can also push malicious firmware
- Do intrusion detection on the Hubs *and* the Things
- Why on the Hubs? They're more capable
- Why on the Things? They have to protect themselves from compromised Hubs, too
- All firmware updates *must* be digitally signed

Digitally Signed Firmware

- Vendors have developers and a server
- Strongly separate the two halves, and protect the signing key
- Vendor developer compromise is *extremely* serious—but consumers can't tell if vendors are doing things properly
- No ducklings needed here—the vendor can manufacture in its certificate
- (But what if the vendor signing key is compromised? What if that certificate has to be revoked?)

Sanity Checks

- For some devices, improper commands can have serious consequences
- Solution: separate sanity checks, preferably in hardware
- Example: a low temperature circuit for an IoT thermostat
- Danger: watch out for sanity checks only in regular firmware (but cheap devices probably can't do better)

User Accounts

- What protects user accounts on the Vendor?
- We *know* how vulnerable most folks' passwords are
- MFA is best—but how to force adoption? And what about recovery from lost credentials?
- And: *must* have hardware reset on Things, in case they're sold by someone who forgets to execute some handover mechanism
- Example: IoT light switches, conveyed with a house in an estate sale

We've Had Problems!

- Some devices, e.g., security cameras, have used default passwords and been directly exposed on the Internet
- Attackers have used these documented default passwords, which many users never change
- Sanity checks help here, too

Structural Problems

- We still haven't solved our structural problems
- Sill have limited support lifetime, poor user interface, inexperienced programmers
- Plus: if we assume reliance on Vendors, what if the Vendor turns off the servers or goes bankrupt?

Economic, Not Technical

- These issues are fundamentally economic, not technical
- In other words, a purely technical approach cannot solve them
- Even “purely” technical problems have an economic dimension—what will force adoption of expensive solutions?

☞ This means that the solutions will have to be economic and/or regulatory

Abandonware

- Perhaps: mandatory second sourcing of abandoned services and devices
- That is: a law requiring that code for all IoT devices and their services be escrowed
- When some device or service is EOLed or discontinued, the relevant code *must* be offered for sale, and released to the public after 90 days if not picked up
- Exercise: what about code-signing keys?
- Exercise: how should Things or Hubs be rehomed to a new server, or to a personal server?

Suicide Switch

- Should unpatched and unpatchable devices be allowed to exist?
- Liability laws might help with companies that still exist, but what about devices left behind by abandoned companies?
- Sue the owners? Is that fair?
- Maybe Things should have a finite lifetime. . .
- (Idea due to Dan Geer)

Lifetimes and Costs

- What is the normal lifetime of a Thing, independent of these security issues?
- Cars last 10–15 years, and sometimes longer—having them die after five years is unacceptable
- Major home appliances may last ten years—but they're still too expensive to discard
- Light switches are cheap, but installation isn't—most folks would need to hire an electrician
- And some bugs aren't economically fixable, e.g., boot ROM issues
- But—the cost of an unpatched bug is imposed on society, and that's an economic issue, too

No Perfect Answers!

- Support costs money
- Vendor servers cost money
- Lack of support and lack of vendor servers cost money
- The ultimate questions: who should pay, and how?
- Front-loading—demanding payment on first purchase—can be economically feasible, but it drives up prices; without regulation, that doesn't work in the market
- And if you think it's bad for consumer gear, what about industrial control systems?