           Architectural Considerations in Smart Object Networking

Abstract

   The term "Internet of Things" (IoT) denotes a trend where a large
   number of embedded devices employ communication services offered by
   Internet protocols. Many of these devices, often called "smart
   objects", are not directly operated by humans but exist as components
   in buildings or vehicles, or are spread out in the environment.
   Following the theme "Everything that can be connected will be
   connected", engineers and researchers designing smart object networks
   need to decide how to achieve this in practice.

   This document offers guidance to engineers designing Internet-
   connected smart objects.

Status of This Memo

Table of Contents

1. Introduction

   RFC 6574 [RFC6574] refers to smart objects as devices with
   constraints on energy, bandwidth, memory, size, cost, etc. This is a
   fuzzy definition, as there is clearly a continuum in device
   capabilities and there is no hard line to draw between devices that
   can run Internet protocols and those that can't.

   Interconnecting smart objects with the Internet enables exciting new
   use cases and products. An increasing number of products put the
   Internet Protocol Suite on smaller and smaller devices and offer the
   ability to process, visualize, and gain insight from the collected
   sensor data. The network effect can be increased if the data
   collected from many different devices can be combined.

Developing embedded systems is a complex task, and designers must
make a number of design decisions such as:

o How long is the device designed to operate?

o How does it interact with the physical world? Is it a sensor or
   actuator or both?

o How many "owners" does it have? One? Many? Is the owner likely
   to change over the lifetime of the device?

o Is it continuously or intermittently powered? Does it sleep?

o Is it connected to a network, and if so, how?

o Will it be physically accessible for direct maintenance after
   deployment? How does that affect the security model?

While developing embedded systems is itself a complex task, designing
Internet-connected smart objects is even harder since it requires
expertise with Internet protocols in addition to software programming
and hardware skills. To simplify the development task, and thereby
to lower the cost of developing new products and prototypes, we
believe that reuse of prior work is essential. Therefore, we provide
high-level guidance on the use of Internet technology for the
development of smart objects, and connected systems in general.

Utilize Existing Design Patterns

   Design patterns are generally reusable solutions to a commonly
   occurring design problem (see [Gamma] for more discussion).
   Existing smart object deployments show communication patterns that
   can be reused by engineers with the benefit of lowering the design
   effort. As discussed in the sections below, individual patterns
   also have an implication on the required interoperability between
   the different entities. Depending on the desired functionality,
   already-existing patterns can be reused and adjusted. Section 2
   talks about various communication patterns.

Reuse Internet Protocols

   Most smart object deployments can make use of the already-
   standardized Internet Protocol Suite. Internet protocols can be
   applied to almost any environment due to their generic design and
   typically offer plenty of potential for reconfiguration, which
   allows them to be tailored for the specific needs. Section 3
   discusses this topic.

   The Deployed Internet Matters

      When connecting smart objects to the Internet, take existing
      deployment into consideration to avoid unpleasant surprises.
      Assuming an ideal, clean-slate deployment is, in many cases, far
      too optimistic since the already-deployed infrastructure is
      convenient to use. In Section 4, we highlight the importance of
      this topic.

   Design for Change

      The Internet infrastructure, applications, and preferred building
      blocks evolve over time. Especially long-lived smart object
      deployments need to take this change into account, and Section 5
      is dedicated to that topic.

2. Smart Object Communication Patterns

   This section illustrates a number of communication patterns utilized
   in the smart object environment. It is possible that more than one
   pattern can be applied at the same time in a product. Developers
   reusing those patterns will benefit from the experience of others as
   well as from documentation, source code, and available products.

2.1. Device-to-Device Communication Pattern

   Figure 1 illustrates a communication pattern where two devices
   developed by different manufacturers are desired to interoperate and
   communicate directly. To pick an example from [RFC6574], consider a
   light switch that talks to a light bulb with the requirement that
   each may be manufactured by a different company, represented as
   Manufacturer A and B. Other cases can be found with fitness
   equipment, such as heart rate monitors and cadence sensors.

```
                          _''''      ''''
                         /       _'``      \
                         |  Wireless    |
                         \  Network      |
                         /  Network       \
  ,'''''''|      /                .         ,'''''''|
  | Light  | ------|------------------\------| Light  |
  | Bulb   |        .                 |     | Switch |
  |........'        `'-              /      |........'
                      \      _-...-`
      Manufacturer          `. ,.'              Manufacturer
          A                   `                      B
```
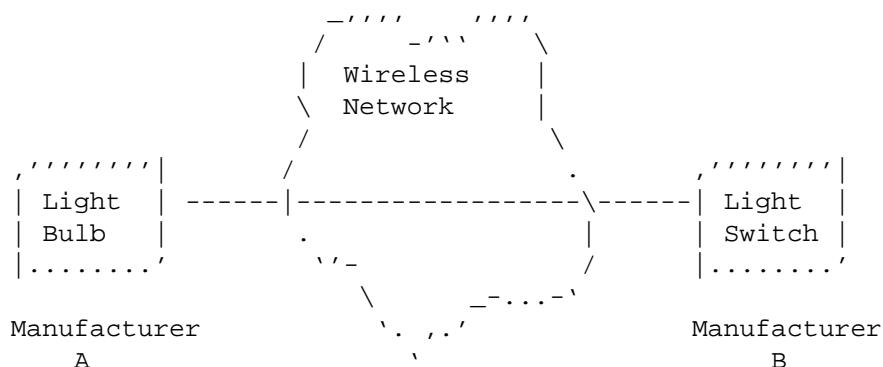
              Figure 1: Device-to-Device Communication Pattern

   In order to fulfill the promise that devices from different
   manufacturers are able to communicate out of the box, these vendors
   need to agree on the protocol stack. They need to make decisions
   about the following protocol-design aspects:

   o Which physical layer(s) should be supported? Does it use low-
      power radio technologies (e.g., Bluetooth Smart, IEEE 802.15.4)?

   o Can devices be IPv6-only, or must they also support IPv4 for
      backward-compatibility reasons? What IPv4-IPv6 transition
      technologies are needed?

   o Which IP address configuration mechanism(s) is integrated into the
      device?

   o Which communication architectures shall be supported? Which
      devices are constrained, and what are those constraints? Is there
      a classical client-server model or rather a peer-to-peer model?

   o Is there a need for a service-discovery mechanism to allow users
      to discover light bulbs they have in their home or office?

   o Which transport-layer protocol (e.g., UDP) is used for conveying
      the sensor readings/commands?

   o Which application-layer protocol is used (for example, the
      Constrained Application Protocol (CoAP) [RFC7252])?

   o What information model is used for expressing the different light
      levels?

   o What data model is used to encode information? (See [RFC3444] for
      a discussion about the difference between data models and
      information models.)

   o Finally, security and privacy require careful thought. This
      includes questions like: What are the security threats? What
      security services need to be provided to deal with the identified
      threats? Where do the security credentials come from? At what
      layer(s) in the protocol stack should the security mechanism(s)
      reside? What privacy implications are caused by various design
      decisions?

   This list is not meant to be exhaustive but aims to illustrate that
   for every usage scenario, many design decisions will have to be made
   in order to accommodate the constrained nature of a specific device
   in a certain usage scenario. Standardizing such a complete solution

   to accomplish a full level of interoperability between two devices
   manufactured by different vendors takes time, but there are obvious
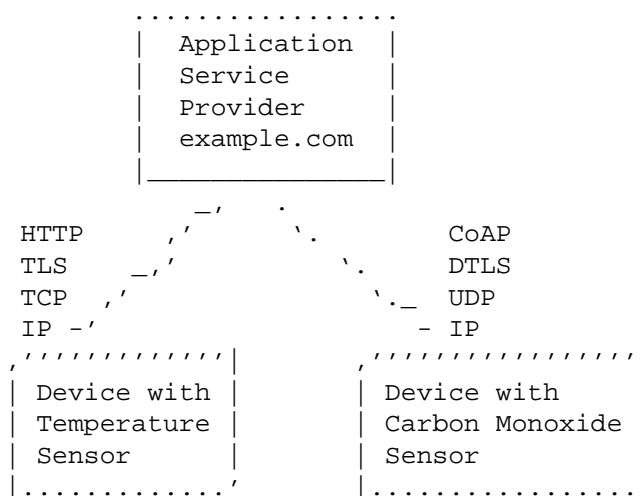   rewards for end customers and vendors.

2.2. Device-to-Cloud Communication Pattern

   Figure 2 shows a communication pattern for uploading sensor data to
   an application service provider. Often the application service
   provider (example.com in our illustration) also sells smart objects.
   In that case, the entire communication happens internal to the
   provider and no need for interoperability arises. Still, it is
   useful for example.com to reuse existing specifications to lower the
   design, implementation, testing, and development effort.

   While this pattern allows using IP-based communication end to end, it
   may still lead to silos. To prevent silos, example.com may allow
   third-party device vendors to connect to their server infrastructure
   as well. For those cases, the protocol interface used to communicate
   with the server infrastructure needs to be made available, and
   various standards are available, such as CoAP, Datagram Transport
   Layer Security (DTLS) [RFC6347], UDP, IP, etc., as shown in Figure 2.
   A frequent concern from end users is that a change in the business
   model (or bankruptcy) of the IoT device/service provide might make
   the hardware become unusable. Companies might consider the
   possibility of releasing their source code for the IoT device or
   allowing other IoT operating systems (plus application software) to
   be installed on the IoT device.

   Similarly, in many situations it is desirable to change which cloud
   service a device connects to, such as when an application service
   provider changes its hosting provider. Again, standard Internet
   protocols are needed.

   Since the access networks to which various smart objects are
   connected are typically not under the control of the application
   service provider, commonly used radio technologies (such as WLAN,
   wired Ethernet, and cellular radio) together with the network access
   authentication technology have to be reused. The same applies to
   standards used for IP address configuration.

```
                ..................
                |  Application   |
                |  Service       |
                |  Provider      |
                |  example.com   |
                |_____|
                  _,'     .
  HTTP       ,'        `.          CoAP
  TLS     _,'            `.        DTLS
  TCP   ,'                `._  UDP
  IP  -'                   - IP
,',',',',',',',|        ,',',',',',',',',',|
| Device with |        | Device with       |
| Temperature |        | Carbon Monoxide   |
| Sensor      |        | Sensor            |
|............,'         |..................,'
```

   TLS = Transport Layer Security

            Figure 2: Device-to-Cloud Communication Pattern

2.3. Device-to-Gateway Communication Pattern

   The device-to-cloud communication pattern, described in Section 2.2,
   is convenient for vendors of smart objects and works well if they
   choose a radio technology that is widely deployed in the targeted
   market, such as Wi-Fi based on IEEE 802.11 for smart home use cases.
   Sometimes, less-widely-available radio technologies are needed (such
   as IEEE 802.15.4) or special application-layer functionality (e.g.,
   local authentication and authorization) has to be provided or
   interoperability is needed with legacy, non-IP-based devices. In
   those cases, some form of gateway has to be introduced into the
   communication architecture that bridges between the different
   technologies and performs other networking and security
   functionality. Figure 3 shows this pattern graphically. Often,
   these gateways are provided by the same vendor that offers the IoT
   product, for example, because of the use of proprietary protocols, to
   lower the dependency on other vendors or to avoid potential
   interoperability problems. It is expected that in the future, more
   generic gateways will be deployed to lower cost and infrastructure
   complexity for end consumers, enterprises, and industrial
   environments. Such generic gateways are more likely to exist if IoT
   device designs make use of generic Internet protocols and not require
   application-layer gateways that translate one application-layer
   protocol to another one. The use of application-layer gateways will,
   in general, lead to a more fragile deployment, as has been observed
   in the past with [RFC3724] and [RFC3238].

   This communication pattern can frequently be found with smart object
   deployments that require remote configuration capabilities and real-
   time interactions. The gateway is thereby assumed to be always
   connected to the Internet.


```
                  ................
                  |  Application  |
                  |  Service      |
                  |  Provider     |
                  |  example.com  |
                  |_____|
                         |
                         |
                         |  IPv4/IPv6
                  ................
                  |    Local      |
                  |    Gateway    |
                  |               |
                  |_____|
                       _,'          .
    HTTP          ,'              `.          CoAP
    TLS       _,' Bluetooth Smart  `.      DTLS
    TCP     ,'      IEEE 802.11       `._   UDP
    IPv6 -'        IEEE 802.15.4         - IPv6
   ,''''''''''''|          ,'''''''''''''''|
   | Device with |         | Device with     |
   | Temperature |         | Carbon Monoxide |
   | Sensor      |         | Sensor          |
   |............'          |................'
```
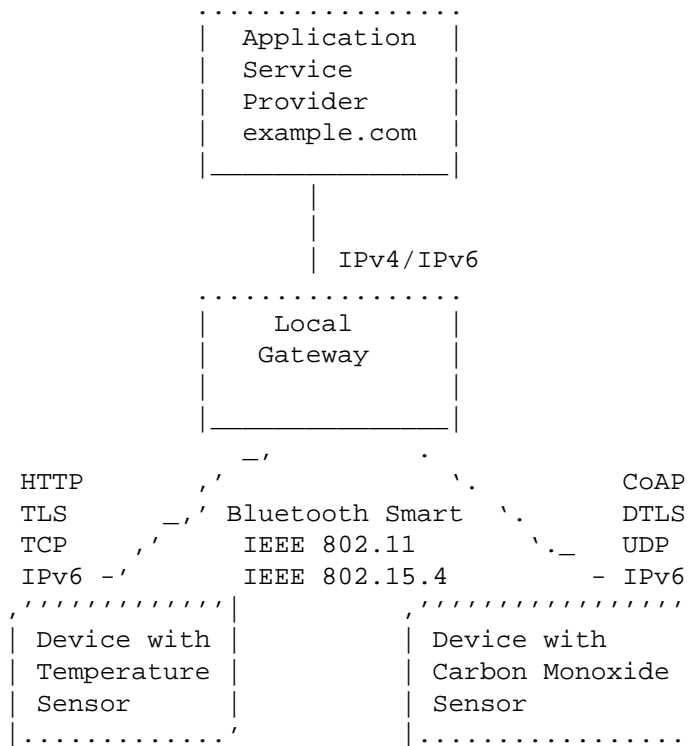
             Figure 3: Device-to-Gateway Communication Pattern

   If the gateway is mobile, such as when the gateway is a smartphone,
   connectivity between the devices and the Internet may be
   intermittent. This limits the applicability of such a communication
   pattern but is nevertheless very common with wearables and other IoT
   devices that do not need always-on Internet or real-time Internet
   connectivity. From an interoperability point of view, it is worth
   noting that smartphones, with their sophisticated software update
   mechanism via app stores, allow new functionality to be updated
   regularly at the smartphone and sometimes even at the IoT device.
   With special apps that are tailored to each specific IoT device,
   interoperability is mainly a concern with regard to the lower layers
   of the protocol stack, such as the radio interface, and less so at
   the application layer (if users are willing to download a new app for
   each IoT device).

It is also worth pointing out that a gateway allows supporting both
IPv6 and IPv4 (for compatibility with legacy application service
providers) externally, while allowing devices to be IPv6-only to
reduce footprint requirements. If devices do not have the resources
to support both IPv4 and IPv6 themselves, being IPv6-only (rather
than IPv4-only) with a gateway enables the most flexibility, avoiding
the need to update devices to support IPv6 later, whereas IPv4
address exhaustion makes it ill-suited to scale to smart object
networks. See [RFC6540] for further discussion.

2.4. Back-End Data Sharing Pattern

The device-to-cloud pattern often leads to silos; IoT devices upload
data only to a single application service provider. However, users
often demand the ability to export and to analyze data in combination
with data from other sources. Hence, the desire for granting access
to the uploaded sensor data to third parties arises. This design is
shown in Figure 4. This pattern is known from the Web in case of
mashups and is, therefore, reapplied to the smart object context. To
offer familiarity for developers, typically a RESTful API design in
combination with a federated authentication and authorization
technology (like OAuth 2.0 [RFC6749]) is reused. While this offers
reuse at the level of building blocks, the entire protocol stack
(including the information/data model and RESTful Web APIs) is often
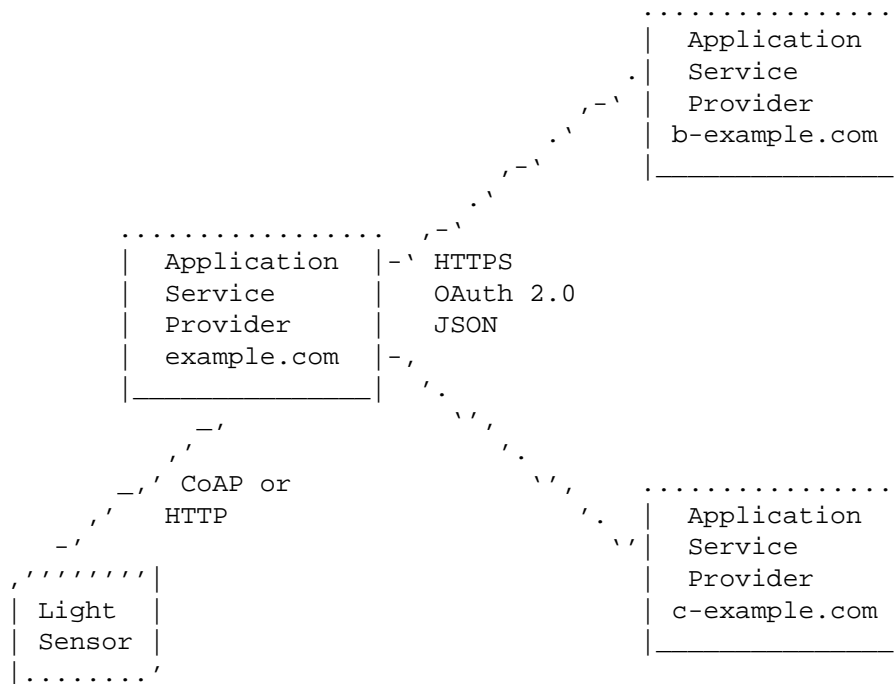not standardized.

```
                                          ..................
                                          | Application    |
                                        .| Service         |
                                     ,-` | Provider        |
                                   .`     | b-example.com  |
                                 ,-`      |_____|
                               .`
         ..................  ,-`
         | Application    |-` HTTPS
         | Service        |   OAuth 2.0
         | Provider       |   JSON
         | example.com    |-,
         |_____|  `.
            _,'               ``',
           ,'                    `.
         _,' CoAP or              ``',  ..................
        ,'   HTTP                    '. | Application    |
      _-'                          ``| Service         |
   ,'''''''|                         | Provider        |
   | Light  |                        | c-example.com  |
   | Sensor |                        |_____|
   |........'
```

             Figure 4: Back-End Data Sharing Pattern

3. Reuse Internet Protocols

   When discussing the need for reuse of available standards versus
   extending or redesigning protocols, it is useful to look back at the
   criteria for success of the Internet.

   RFC 1958 [RFC1958] provides lessons from the early days of the
   Internet and says:

      The Internet and its architecture have grown in evolutionary
      fashion from modest beginnings, rather than from a Grand Plan.

   And adds:

      A good analogy for the development of the Internet is that of
      constantly renewing the individual streets and buildings of a
      city, rather than razing the city and rebuilding it.

   Yet, because building very small, battery-powered devices is
   challenging, it may be difficult to resist the temptation to build
   solutions tailored to specific applications, or even to redesign
   networks from scratch to suit a particular application.

   While developing consensus-based standards in an open and transparent
   process takes longer than developing proprietary solutions, the
   resulting solutions often remain relevant over a longer period of
   time.

   RFC 1263 [RFC1263] considers protocol-design strategy and the
   decision to design new protocols or to use existing protocols in a
   non-backward compatible way:

      We hope to be able to design and distribute protocols in less time
      than it takes a standards committee to agree on an acceptable
      meeting time. This is inevitable because the basic problem with
      networking is the standardization process. Over the last several
      years, there has been a push in the research community for
      lightweight protocols, when in fact what is needed are lightweight
      standards. Also note that we have not proposed to implement some
      entirely new set of 'superior' communications protocols, we have
      simply proposed a system for making necessary changes to the
      existing protocol suites fast enough to keep up with the
      underlying change in the network. In fact, the first standards
      organization that realizes that the primary impediment to
      standardization is poor logistical support will probably win.

   While [RFC1263] was written in 1991 when the standardization process
   was more lightweight than today, these thoughts remain relevant in
   smart object development.

   Interestingly, a large number of already-standardized protocols are
   relevant for smart object deployments. RFC 6272 [RFC6272], for
   example, made the attempt to identify relevant IETF specifications
   for use in smart grids.

   Still, many commercial products contain proprietary or industry-
   specific protocol mechanisms, and researchers have made several
   attempts to design new architectures for the entire Internet system.
   There are several architectural concerns that deserve to be
   highlighted:

   Vertical Profiles

      The discussions at the IAB workshop (see Section 3.1.2 of
      [RFC6574]) revealed the preference of many participants to develop
      domain-specific profiles that select a minimum subset of protocols
      needed for a specific operating environment. Various
      standardization organizations and industry fora are currently
      engaged in activities of defining their preferred profile(s).

Ultimately, however, the number of domains where smart objects can
be used is essentially unbounded. There is also an ever-evolving
set of protocols and protocol extensions.

However, merely changing the networking protocol to IP does not
necessarily bring the kinds of benefits that industries are
looking for in their evolving smart object deployments. In
particular, a profile is rigid and leaves little room for
interoperability among slightly differing or competing technology
variations. As an example, Layer 1 through 7 type profiles do not
account for the possibility that some devices may use different
physical media than others, and that in such situations, a simple
router could still provide an ability to communicate between the
parties.

Industry-Specific Solutions

The Internet Protocol Suite is more extensive than merely the use
of IP. Often, significant benefits can be gained from using
additional, widely available, generic technologies, such as the
Web. Benefits from using these kinds of tools include access to a
large available workforce, software, and education already geared
towards employing the technology.

Tight Coupling

Many applications are built around a specific set of servers,
devices, and users. However, often the same data and devices
could be useful for many purposes, some of which may not be easily
identifiable at the time the devices are deployed.

In addition to the architectural concerns, developing new protocols
and mechanisms is generally more risky and expensive than reusing
existing standards, due to the additional costs involved in design,
implementation, testing, and deployment. Secondary costs, such as
the training of technical staff and, in the worst case, the training
of end users, can be substantial.

As a result, while there are some cases where specific solutions are
needed, the benefits of general-purpose technology are often
compelling, be it choosing IP over some more specific communication
mechanism, a widely deployed link layer (such as wireless LAN) over a
more specific one, web technology over application-specific
protocols, and so on.

However, when employing these technologies, it is important to
embrace them in their entirety, allowing for the architectural
flexibility that is built into them. As an example, it rarely makes

sense to limit communications to on-link or to specific media.
Design your applications so that the participating devices can easily
interact with multiple other applications.

4. The Deployed Internet Matters

Despite the applicability of Internet protocols for smart objects,
picking the specific protocols for a particular use case can be
tricky. As the Internet has evolved, certain protocols and protocol
extensions have become the norm, and others have become difficult to
use in all circumstances.

Taking into account these constraints is particularly important for
smart objects, as there is often a desire to employ specific features
to support smart object communication. For instance, from a pure
protocol-specification perspective, some transport protocols may be
more desirable than others. These constraints apply both to the use
of existing protocols as well as designing new ones on top of the
Internet protocol stack.

The following list illustrates a few of those constraints, but every
communication protocol comes with its own challenges.

In 2005, Fonseca, et al. [IPoptions] studied the usage of IP
options-enabled packets in the Internet and found that overall,
approximately half of Internet paths drop packets with options,
making extensions using IP options "less ideal" for extending IP.

In 2010, Honda, et al. [HomeGateway] tested 34 different home
gateways regarding their packet dropping policy of UDP, TCP, the
Datagram Congestion Control Protocol (DCCP), the Stream Control
Transmission Protocol (SCTP), ICMP, and various timeout behavior.
For example, more than half of the tested devices do not conform to
the IETF-recommended timeouts for UDP, and for TCP the measured
timeouts are highly variable, ranging from less than 4 minutes to
longer than 25 hours. For NAT traversal of DCCP and SCTP, the
situation is poor. None of the tested devices, for example, allowed
establishing a DCCP connection.

In 2011, the behavior of networks with regard to various TCP
extensions was tested in [TCPextensions]: "From our results we
conclude that the middleboxes implementing layer 4 functionality are
very common -- at least 25% of paths interfered with TCP in some way
beyond basic firewalling."

Extending protocols to fulfill new uses and to add new functionality
may range from very easy to difficult, as [RFC6709] explains in great
detail. A challenge many protocol designers are facing is to ensure

incremental deployability and interoperability with incumbent
elements in a number of areas. In various cases, the effort it takes
to design incrementally deployable protocols has not been taken
seriously enough at the outset. RFC 5218 on "What Makes For a
Successful Protocol" [RFC5218] defines wildly successful protocols as
protocols that are widely deployed beyond their envisioned use cases.

As these examples illustrate, protocol architects have to take
developments in the greater Internet into account, as not all
features can be expected to be usable in all environments. For
instance, middleboxes [RFC3234] complicate the use of extensions in
basic IP protocols and transport layers.

RFC 1958 [RFC1958] considers this aspect and says "... the community
believes that the goal is connectivity, the tool is the Internet
Protocol, and the intelligence is end to end rather than hidden in
the network." This statement is challenged more than ever with the
perceived need to develop intermediaries interacting with less
intelligent end devices. However, RFC 3724 [RFC3724] has this to say
about this crucial aspect: "One desirable consequence of the
end-to-end principle is protection of innovation. Requiring
modification in the network in order to deploy new services is still
typically more difficult than modifying end nodes." Even this
statement will become challenged, as large numbers of devices are
deployed, and it indeed might be the case that changing those devices
will be hard. But RFC 4924 [RFC4924] adds that a network that does
not filter or transform the data that it carries may be said to be
"transparent" or "oblivious" to the content of packets. Networks
that provide oblivious transport enable the deployment of new
services without requiring changes to the core. It is this
flexibility that is perhaps both the Internet's most essential
characteristic as well as one of the most important contributors to
its success.

5. Design for Change

How to embrace rapid innovation and at the same time accomplish a
high level of interoperability is one of the key aspects for
competing in the marketplace. RFC 1263 [RFC1263] points out that
"protocol change happens and is currently happening at a very
respectable clip...We simply propose [for engineers developing the
technology] to explicitly deal with the changes rather [than] keep
trying to hold back the flood."

In [Tussles], Clark, et al. suggest to "design for variation in
outcome, so that the outcome can be different in different places,
and the tussle takes place within the design, not by distorting or
violating it. Do not design so as to dictate the outcome. Rigid

designs will be broken; designs that permit variation will flex under
pressure and survive." The term "tussle" refers to the process
whereby different parties, which are part of the Internet milieu and
have interests that may be adverse to each other, adapt their mix of
mechanisms to try to achieve their conflicting goals, and others
respond by adapting the mechanisms to push back.

In order to accomplish this, Clark, et al. suggest to:

1. Break complex systems into modular parts, so that one tussle does
    not spill over and distort unrelated issues.

2. Design for choice to permit the different players to express
    their preferences. Choice often requires open interfaces.

The main challenge with the suggested approach is predicting how
conflicts among the different players will evolve. Since tussles
evolve over time, there will be changes to the architecture, too. It
is certainly difficult to pick the right set of building blocks and
to develop a communication architecture that will last a long time,
and many smart object deployments are envisioned to be rather long
lived.

Luckily, the design of the system does not need to be cast in stone
during the design phase. It may adjust dynamically since many of the
protocols allow for configurability and dynamic discovery. But,
ultimately, software update mechanisms may provide the flexibility
needed to deal with more substantial changes.

A solid software update mechanism is needed not only for dealing with
the changing Internet communication environment and for
interoperability improvements but also for adding new features and
for fixing security bugs. This approach may appear to be in conflict
with classes of severely restricted devices since, in addition to a
software update mechanism, spare flash and RAM capacity is needed.
It is, however, a trade-off worth thinking about since better product
support comes with a price.

As technology keeps advancing, the constraints that technology places
on devices evolve as well. Microelectronics have become more capable
as time goes by, often making it possible for new devices to be both
less expensive and more capable than their predecessors. This trend
can, however, be in some cases offset by the desire to embed
communications technology in even smaller and cheaper objects. But
it is important to design communications technology not just for
today's constraints but also for tomorrow's. This is particularly
important since the cost of a product is not only determined by the

cost of hardware but also by the cost of not reusing already-
available protocol stacks and software libraries by developing custom
solutions.

Software updates are common in operating systems and application
programs today. Without them, most devices would pose a latent risk
to the Internet at large. Arguably, the JavaScript-based web employs
a very rapid software update mechanism with code being provided by
many different parties (e.g., by websites loaded into the browser or
by smartphone apps).

6. Security Considerations

Security is often even more important for smart objects than for more
traditional computing systems, since interacting directly with the
physical world can present greater dangers, and smart objects often
operate autonomously without any human interaction for a long time
period. The problem is compounded by the fact that there are often
fewer resources available in constrained devices to actually
implement security (e.g., see the discussion of "Class 0 devices" in
Section 3 of [RFC7228]). As such, it is critical to design for
security, taking into account a number of key considerations:

o A key part of any smart object design is the problem of how to
   establish trust for a smart object. Typically, bootstrapping
   trust involves giving the device the credentials it needs to
   operate within a larger network of devices or services.

o Smart objects will, in many cases, be deployed in places where
   additional physical security is difficult or impossible.
   Designers should take into account that any such device can and
   will be compromised by an attacker with direct physical access.
   Thus, trust models should distinguish between devices susceptible
   to physical compromise and devices with some level of physical
   security. Physical attacks, such as timing, power analysis, and
   glitching, are commonly applied to extract secrets
   [PhysicalAttacks].

o Smart objects will, in many cases, be deployed as collections of
   identical or near identical devices. Protocols should be designed
   so that a compromise of a single device does not result in
   compromise of the entire collection, especially since the
   compromise of a large number of devices can enable additional
   attacks such as a distributed denial of service. Sharing secret
   keys across an entire product family is, therefore, also
   problematic since compromise of a single device might leave all
   devices from that product family vulnerable.

o Smart objects will, in many cases, be deployed in ways that the
   designer never considered. Designers should either seek to
   minimize the impact of misuse of their systems and devices or
   implement controls to prevent such misuse where applicable.

o It is anticipated that smart objects will be deployed with a long
   (e.g., 5-40 years) life cycle. Any security mechanism chosen at
   the outset may not be "good enough" for the full lifespan of the
   device. Thus, long-lived devices should start with good security
   and provide a path to deploy new security mechanisms over the
   lifetime of the device.

o Security protocols often rely on random numbers, and offering
   randomness in embedded devices is challenging. For this reason,
   it is important to consider the use of hardware-based random
   number generators during early states of the design process.

A more detailed security discussion can be found in the "Report from
the Smart Object Security Workshop" [RFC7397] that was held prior to
the IETF meeting in Paris, March 2012, and in the report from the
National Science Foundation's "Cybersecurity Ideas Lab" workshop
[NSF] that was held in February 2014. For example, [NSF] includes,
among other recommendations, these recommendations specific to the
Internet of Things:

   Enhance the Security of the Internet of Things by Identifying
   Enclaves: The security challenges posed by the emerging Internet
   of Things should be addressed now, to prepare before it is fully
   upon us. By identifying specific use segments, or "enclaves",
   Internet of Things infrastructure stakeholders can address the
   security requirements and devise event remediations for that
   enclave.

   Create a Framework for Managing Software Updates: The Internet of
   Things will challenge our current channels for distributing
   security updates. An environment must be developed for
   distributing security patches that scales to a world where almost
   everything is connected to the Internet and many "things" are
   largely unattended.

Finally, we reiterate that use of standards that have gotten wide
review can often avoid a number of security issues that could
otherwise arise. Section 3.3 of [RFC6574] reminds us about the IETF
work style regarding security:

   In the development of smart object applications, as with any other
   protocol application solution, security has to be considered early
   in the design process. As such, the recommendations currently
   provided to IETF protocol architects, such as RFC 3552 [RFC3552],
   and RFC 4101 [RFC4101], apply also to the smart object space.

   In the IETF, security functionality is incorporated into each
   protocol as appropriate, to deal with threats that are specific to
   them. It is extremely unlikely that there is a one-size-fits-all
   security solution given the large number of choices for the 'right'
   protocol architecture (particularly at the application layer). For
   this purpose, [RFC6272] offers a survey of IETF security mechanisms
   instead of suggesting a preferred one.

7. Privacy Considerations

   This document mainly focuses on an engineering audience, i.e., those
   who are designing smart object protocols and architectures. Since
   there is no value-free design, privacy-related decisions also have to
   be made, even if they are just implicit in the reuse of certain
   technologies. RFC 6973 [RFC6973] and the threat model in
   [CONFIDENTIALITY] were written as guidance specifically for that
   audience and are also applicable to the smart object context.

   For those looking at privacy from a deployment point of view, the
   following additional guidelines are suggested:

   Transparency: Transparency of data collection and processing is key
      to avoid unpleasant surprises for owners and users of smart
      objects. Users and impacted parties must be put in a position to
      understand what items of personal data concerning them are
      collected and stored, as well for what purposes they are sought.

   Data Collection / Use Limitation: Smart objects should only store
      personal data that is adequate, relevant, and not excessive in
      relation to the purpose(s) for which they are processed. The use
      of anonymized data should be preferred wherever possible.

   Data Access: Before deployment starts, it is necessary to consider
      who can access personal data collected by smart objects and under
      which conditions. Appropriate and clear procedures should be
      established in order to allow data subjects to properly exercise
      their rights.

   Data Security: Standardized data security measures to prevent
      unlawful access, alteration, or loss of smart object data need to
      be defined and deployed. Robust cryptographic techniques and
      proper authentication frameworks have to be used to limit the risk
      of unintended data transfers or unauthorized access.

   A more detailed treatment of privacy considerations that extend
   beyond engineering can be found in a publication from the Article 29
   Working Party [WP223].

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