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Towards an Information-Centric Internet with more Things
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Abstract

The Internet is already made of things. However, we expect there to be many more less-capable things, such as sensors and actuators, connected to the Internet in years to come. In parallel, Internet applications are more and more being used to perform operations on named (information) objects, and various Information-Centric Networking (ICN) approaches are being researched in order to allow such applications to work effectively at scale and with various forms of mobility and in networking environments that are more challenging than a traditional access network and data center. In this position paper, we outline some benefits that may accrue, and issues that arise, should the Internet, with many more things, make use of the ICN approach to networking and we argue that ICN concepts should be considered when planning for increases in the number of things connected to the Internet.

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1. Motivation

This position paper has been submitted to the IAB "Interconnecting Smart Objects with the Internet Workshop" IAB-WS [ref.iabws] to be held in Prague in March 2011. In addition to IAB workshop attendees, this document may also be useful to those working on Information-Centric Networking (ICN), but who may be less familiar with the issues involved in dealing with less capable devices and networks.

The Internet is already made of things. (If that's not the case then we have a serious case of mass hysteria:-) For this reason, we prefer not to refer to a so-called "Internet of Things," nor to use the IoT acronym. Where it is necessary to distinguish our imperfect expectation of the future from the current Internet, we instead speak about the Internet with many more things but otherwise we just talk about the Internet.

Aside from ICN, we recognize that there is work to be done before many more less-capable things can be successfully connected to the Internet. That includes work at each layer of the stack, as well as work on security and management. We do not attempt to discuss those issues in detail, other than as they may affect ICN.

However, we do disagree with a position that claims that all or most of the many more things to be connected to the Internet will be extremely challenged in terms of one or more of CPU, memory, power or connectivity. New devices are developed and deployed much faster than the timeframe in which IETF work really changes the deployed Internet. We expect that in that timeframe, (perhaps 5 years), there will be many devices used as sensors and actuators that have similar capabilities to today's smartphones. Put another way, we should not plan only for TinyOS, but we must allow for TinyOS.

2. Information-Centric Networking

In ICN, the principal paradigm is accessing named content -- not host-to-host communication as in the network layer of the current Internet architecture. ICN was the topic of a recent dagstuhl workshop [dag.icnws] from which emerged a survey describing ICN. [dag.icnsurvey]

Based on observations of how the Internet is mainly used -- as a platform for distributing content over different application protocols and overlay infrastructures such as the Web, CDNs, and P2P networks, ICN aims to provide a native networking infrastructure that enables efficient and secure access to named content in an application-independent way.

An important ICN concept is that objects and copies thereof be uniquely named, independent of their locations in a network graph, thus enabling access to object (copies) without having to deal with locators in a network-topology-based addressing system. Consequently if the same information can float around in the network and be accessed by a unique name, it may be necessary to establish some amount of trust that a given object actually represents an answer to a query -- in other words some level of trust in a name-to-object binding is required. This can be achieved using different means -- one possible approach is to establish a secure name binding through hashing or public-key cryptography, with the latter case probably requiring additional infrastructure.

Based on such a naming concept, it is then possible to access copies of named objects that may be present in caches or other in-network storage systems. Such copies could be created explicitly (through pro-active hot content distribution such as in CDNs) or as a result of answering queries (as for a web proxy cache).

An ICN infrastructure could provide efficient forwarding of requests to nearby nodes (according to some metric), based on a routing mechanism that is able to manage routing state for all named objects in a network. Requirements and characteristics of such routing protocols depend on the actual naming scheme, network size and router technology development.

Leveraging caching in such a system leads to a deviation from established end-to-end communication paradigms -- in many cases it is not required (or not possible) to access the origin server for some object -- if an identical copy of the object can be obtained from a in-network storage node closer to the requester. Similarly, transport protocols would be designed a bit differently under the assumption that the network can cache (pieces of) named objects. For instance, if re-transmission requests can be answered by on-path caching nodes, it would be possible to employ optimized transport strategies between nodes (like hop-by-hop transport) to enhance performance and robustness, and in general to give the receiver more control over transport interactions (receiver-oriented transport).

There are several benefits that are expected from taking an ICN approach.

o the approach of accessing named content fits naturally with many important applications today: names are not tied to topological locations, they don't change as objects or nodes change locations;

o the ability to leverage in-network storage as a fundamental service improves efficiency and allows synergy effects and

interoperability between otherwise incompatible or organizationally separate content distribution and caching infrastructures; and

o employing dedicated optimized transport strategies between certain nodes or within certain networks can improve efficiency and robustness, especially in mobile, challenged scenarios.

ICN is perhaps just one example of a broader issue that impacts on how many more, less capable things might interact with the Internet. Since it would clearly be undesirable to sandbox off all these new things, we should be looking for the best ways in which they can be integrated with both current, and future services that run on the Internet.

3. Relevant IETF/IRTF Acvitivities

There are a range of ongoing IETF and IRTF activities that we expect to be relevant to ICN when the Internet has many more things. These fairly obviously include the outputs of the 6lowpan, roll and core IETF working groups, but also the decade and alto working groups and the IRTF's delay-tolerant networking research group. We briefly consider how each of those might affect ICN and how ICN may be of use to applications making use of the relevant technologies.

3.1. 6lowpan

The IETF 6lowpan [ietf.6lowpan] working group is defining ways to use IPv6 and IEEE 802.15.4 in networks mainly consisting of low power devices. This includes a specification of IP packet encapsulation for IEEE 802.15.4, stateless address auto-configuration, header compression, and neighbor discovery.

In order for those devices to be a part of an ICN, there needs to be a way to name them and/or the information objects that reside on those objects. In order to scale to the Internet, ICN names are likely to include things like the outputs of hash functions, and/or long hierarchical names, but those names may not be suited for use with small packets. This could call for an ability to use some kind of shorter alias within a local area.

Since many PANs may use radios, with inherent broadcast capabilities, there may be a benefit in considering caching of objects within the PAN, both for performance reasons and to support mobility. However, if object names are guessable then this may create a need for some local access control which could be (overly) complex.

3.2. roll

The IETF roll [ietf.roll] working group is developing a routing framework and protocols for low power and lossy networks, (LLNs) targeting specific scenarios such as urban networks, industrial networks and home/building automation networks. The routing solution consists of an IPv6 Routing Protocol for Low Power and Lossy networks (RPL [I-D.ietf-roll-rpl]), based on a pro-active distance vector approach, Routing Metrics used for Path Calculation in Low Power and Lossy Networks [I-D.ietf-roll-routing-metrics], and an efficient information dissemination algorithm called Trickle ([I-D.ietf-roll-trickle]) that allows nodes in a lossy shared medium to exchange information in a robust and efficient manner.

There may be benefit in aligning routing as done by RPL with whatever ICN routing is used to move an object towards its destination. This could possibly take the form of an ICN-specific RPL objective function. In principle, it could be the case that an ICN-specific objective function could result in overall power savings.

3.3. core

The IETF core [ietf.core] working group is defining an application-layer protocol that runs over UDP for use in resource-constrained networks. CoAP, the Constrained Applications Protocol, is a web transfer protocol with an HTTP-like request/response interaction model that is based on an URI concept and is aiming to enable RESTful communication in M2M similar environments.

CoAP, together with HTTP gateways, could provide a very useful substrate on which to build ICN applications. Comparing and contrasting the work of the CORE WG with the IRTF's DTNRG in this context (see below) could provide interesting insights into how to handle an Internet with many more things.

3.4. dtnrg

The IRTF dtn [irtf.dtnrg] research group has developed an architecture for Delay-Tolerant Networking [RFC4838] and the Bundle Protocol (BP) [RFC5050] as an end-to-end protocol for message-oriented communication in Delay-Tolerant Networking.

The BP provides transport for application data, with in-network storage to handle disrupted hops along a path through the network. The authors of this position paper, with others, have recently defined an extension to the BP (BPQ) [I-D.farrell-dtnrg-bpq] aiming to add ICN-like features to a DTN. Other similar proposals have also been made in the past.

In contrast to the core working group, the dtnrg's focus is on an overlay that can work end to end spanning heterogeneous lower (convergence) layers, including ones that don't use IP. Core in contrast appears to have taken a more ALG-like approach assuming a mapping from CoAP to HTTP at gateway nodes. In our opinion the former approach may be more flexible, however, the ALG-like approach with CoAP may allow for greater optimization for constrained devices. (Having said that, networking constraints due to reduced capability devices have not in the past tended to be such a problem in the longer term, once there has been a use-case/application developed that users actually want to use.)

3.5. decade and alto

The IETF decade [ietf.decade] working group is developing an architecture and protocols for accessing in-network storage systems such as caches that can enhance P2P protocol performance and efficiency. The idea is that such in-network storage system could be used within a certain application context to share information object chunks. An application instance would be able to upload content to a decade server and refer other applications instances such as other peers in a P2P context to that content.

The alto working group [ietf.alto] is addressing a related problem - the selection of a topologically "nearby" peer for P2P applications, again with BitTorrent to the fore.

Both decade and alto provide examples of leveraging in-network storage to significantly improve network functionality and application performance for specific applications and network domains (here: peers in a P2P network, possibly challenged by home network and/or mobile communications access networks constraints). We believe that there are other applications that could benefit from in-network storage infrastructures however decade and alto are (entirely reasonably) taking a very focused approach and are not really aiming to be usable for a broad range of applications. Nonetheless, the fact that in-network storage can benefit existing P2P applications like BitTorrent does imply that the same may well be true for other applications.

4. Sample Scenario

In this section we sketch an ICN based solution for an application involving many things. The point is not to recommend this solution, but rather to provide an argument that future work should also take into account ICN aspects, in particular, named objects as first-class items, in-network caching and disruption tolerance.

We focus on a use-case that has (as far as we know) not been explored by the various groups mentioned above. While the focus of some of those groups is currently on extremely constrained devices, we expect that hardware will develop faster than IETF standards will achieve widespread deployment, so it is valuable for a workshop to explore beyond currently available devices.

There are various photo "stitching" services available today on the Internet, for example Microsoft's "PhotoSynth" [ref.ps]. In the near future one can envisage a similar service for video, with live (or recent) camera feeds, perhaps with a mixture of small, cheap cameras connected to an "urban" LLN and with cameras that are more capable and better connected. Note that this putative application deals with information from both challenged and more capable devices and networks.

An ICN approach for this kind of application might call for an ability to automatically (e.g. based on position) find video feeds from relevant cameras and to integrate those into a "pseudo-live" combined video where the viewer can change the viewing point.

In the case of video feeds from "popular" locations, it would be likely that many viewers would simultaneously be accessing and processing those feeds, so that in-network caching, both within the LLN parts of the Internet, and the better connected/provisioned parts of the Internet should be beneficial.

Viewers will not be at all interested in the names or addresses of the devices concerned, but rather with the feeds and their properties (some transcoding might occur within the network). Instead, viewers will be interested in the named, combined, "feed."

This could be implemented in an ICN style by emitting requests for such named objects, routing them to the relevant processing devices and cameras resulting in a stream of bits being returned to the requester. We're not saying that this is trivial, but for now, only that it is well within the bounds of what will be possible in the relevant time frame.

Our putative ICN application allows a user to send a request for a name that represents a video stream for a specific location, (e.g. something like "icn://videosynth/lat/long/alt") which is routed, using ICN name-based routing, to instances of cameras/servers that have relevant content. (There could of course be an iterative process where more and more precise positions are established, here we only consider the final "zoom" level.)

A single ICN request message could be routed to more than one camera or server and so video content could be returned to the requester or elsewhere for processing and eventually to a user.

Since popular cameras are likely to be viewed by many viewers their content can be cached in the network, thanks to ICN features. The ICN approach may also offer some advanced options for optimization. Since most camera streams will have static background, that background could be periodically extracted out and stored in the network so that only the pixels showing changes need to be transmitted end to end.

ICN and DTN techniques could also be used to offer a "most recent" version of a scene, should "live" sources be offline or otherwise unavailable.

Given the appropriate distributed video processing algorithms, we could enviage a solution based on the BP and BPQ extension and DTN routing. One could equally envisage a solution based on CoAP, HTTP and gateways, or even based on decade plus alto. (We of course prefer the first:-)

5. Summary

Our scenario is intended to illustrate how ICN techniques might benefit the Internet when many more things are attached.

In this postition paper we propose that what is sometimes called the "Internet of Things" would be better characterized as an "Internet of Information" -- an Internet that has many more things attached. A useful way to deal with this increase in nodes and information it to make access to named data a fundamental and dominating function. Thus, we recommend not to develop specific architectures for "Internet of Things", "Machine-to-Machine communication" etc., but to apply the general Information-Centric Networking principle to these networks (while not ignoring specific requirements such as low power operation).

Anticipating the future development of computing, storage, battery, and communication technology, we envision many network nodes will generally to be able to store (cache) more bits, thus enabling named data access, information replication, and robust and efficient distribution.

6. IANA Considerations

Evntually.

7. Security Considerations

There certainly are:-)

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