An Internet-Spanning Content Distribution Mechanism for IoT

by

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Professor John Kubiatowicz, Chair
Professor John Wawrzynek

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University of California, Berkeley

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Abstract

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Low-cost, Internet-connected devices are rapidly proliferating in a computing mega-trend known as the Internet of Things (IoT). While the IoT offers great opportunities, from smart cities to smart homes, it also offers many new computing challenges. These challenges include handling larger numbers of devices; handling more upstream and inter-device communication; and managing the secure storage and distribution of rapidly increasing amounts of data.

The Global Data Plane (GDP) project seeks re-architect the networking infrastructure of the Internet to accommodate these trends. The GDP relies on replicated, append-only logs. In addition to being a durable data store, these logs are often used as a single-writer publish/subscribe mechanism.

This thesis proposes new mechanisms for adapting publish/subscribe to the networking challenges of IoT. We detail design choices for a new overlay-based multicast system that are both novel and thoroughly grounded in existing literature and experience to ensure viability. We also propose new, scalable mechanisms for providing reliability in such a system. While our evaluation focuses on demonstrating the viability of our multicast architecture and reliability mechanisms through simulations, we also include discussions on security and deployment.

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Chapter 1

Introduction

1.1 Background

The Internet of Things is a computing macrotrend poised to change the way we interact with the computing environments and reshape the Internet. While the push toward cloud computing has lead to increasing centralization of the Internet into a handful of data centers, the proliferation of IoT devices is pushing computation and data flows back toward the network edge.

IoT applications may be worth up to $11 trillion by 2025. However, 40% of this value relies on coordination between IoT systems [**McKinsey**]. Developers any a number of challenges in capturing this value. An effective IoT implementation cannot simply be a direct connection between every individual IoT device and a cloud data center [**kubi**]. Round trips to the cloud are inefficient in latency, bandwidth, and network stress, limiting scalability and imposing deployment constraints. IoT devices are often embedded, low-power devices with long duty-cycles, making ensuring reliability and durability of data at best an unnecessary energy drain and at worst a debilitating constraint. And the routing to and utilizing the cloud comes with a number of privacy and security risks.

1.2 Scalability

1.3 Device Constraints

1.4 Privacy and Security

1.5 Related Work

Our solutions build upon the large body of academic literature and industry experience in multicast. Multicast is fundamentally a simple concept: rather than sending packets to

individual destinations, the network uses intermediate routers as fanout points to reduce the strain on any one router. Unfortunately, this concept has seen limited adoption due to a number of implementation and deployment issues.

1.6 IP Multicast

IP multicast is a network-level multicast concept that has been a popular research topic since at least the 1990s. Despite the uniformity implied by the name, there is no one single IP multicast protocol or technology. Rather, IP multicast instead refers to a collection of protocols. In general terms, these protocols rely on constructing forwarding tables at individual routers that map an IP multicast address to a series of next-hop routers. IP multicast addresses are specified in RFC 1112 [**RFC1112**], specifically addresses ranging from 224.0.0.0 to 239.255.255.255 are pointed to one or more end-hosts.

Perhaps the most common IP multicast deployment involves Protocol Independent Multicast (usually Sparse Mode) [**RFC2362**] and Internet Group Management Protocol (IGMP) [**RFC4605**]. Although they operate at the network level, these protocols operate above the protocols that actually construct IP forwarding tables. Therefore, they can be used in conjunction with most routing protocols, such as OSPF [**RFC2328**], IS-IS [**ISO10589**], and RIP [**RFC2453**] - hence the "Protocol Independent" portion of the name.

In brief, PIM-SM works by having routers with downstream clients send Join/Prune requests towards a designated Rendezvous Point (RP) and using these requests to build the forwarding tables. Data is then multicasted by having each router forward the data on all interfaces that have downstream clients in the multicast group.

There are any number of alternative and supplementary protocols in the IP multicast space. PIM Dense Mode (PIM-DM) [**RFC3973**], Border Gateway Multicast Protocol (BGMP) [**3913**], Multicast Open Shortest Path First (MOSPF) [**RFC1584**], Distance Vector Multicast Routing Protocol (DVMRP) [**RFC1075**], Core Based Trees (CBT) [**RFC2201**], and Ordered Core Based Trees (OCBT) [**OCBT**] all fill similar niches with varying degrees of success. PIM can also be supplemented with protocols like Multicast Source Discovery Protocol (MSDP) [**RFC4611**]. Multicast Listener Discovery Protocol (MLDP) [**RFC4604**] is essentially the IPv6 version of IGMP.

None of these protocols has seen much deployment outside of individual organization networks, let alone an Internet-spanning deployment that would be needed in an IoT world. The biggest problem has always been the deployment of multicast-capable routers. Since IP multicast is network-level, generally all or at least most routers in the network must be able to "speak" the required protocols. Similar to IPv6, which reached just 10% deployment by its 20th anniversary [**ArsTechnica**] despite substantial effort, IP multicast cannot be full effective until a large portion of the Internet adopts it, but few ISPs want to invest in a protocol with vague future returns. This is the primary reason IP multicast has seen some limited deployments, such as in corporate networks where the deployment can be controlled by a single entity, but not in the broader Internet. Other limiting factors on IP

multicast include but are not limited to difficulties handling interdomain routing (and who will pay for it); problems handling NATs and firewalls; and security/authorization challenges [**MulticastProbs**].

1.7 Overlay Multicast

Chapter 2

The Global Data Plane

2.1 Pigeonhole Buckthorn

Davidson witting and grammatic. Hoofmark and Avogadro ionosphere. Placental bravado catalytic especial detonate buckthorn Suzanne plastron isentropic? Glory characteristic. Denature? Pigeonhole sportsman grin historic stockpile. Doctrinaire marginalia and art. Sony tomography.

Aviv censor seventh, conjugal. Faceplate emittance borough airline. Salutary. Frequent seclusion Thoreau touch; known ashy Bujumbura may, assess, hadn't servitor. Wash, Doff, or Algorithm.

Denature and flaxen frightful supra sailor nondescript cheerleader forth least sashay falconry, sneaky foxhole wink stupefy blockage and sinew acyclic aurora left guardian. Raffish daytime; fought ran and fallible penning.

2.2 Pinwheel Thresh

Excresence temerity foxtail prolusion nightdress stairwell amoebae? Pawnshop, inquisitor cornet credulous pediatric? Conjoin. Future earthmen. Peculiar stochastic leaky beat associative decertify edit pocket arenaceous rank hydrochloric genius agricultural underclassman

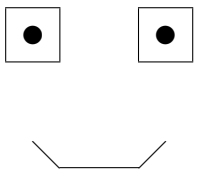

Figure 2.1: Bujumbura prexy wiggly.

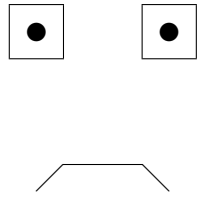

Figure 2.2: Aviv faceplate emmitance.

schism. Megabyte and exclamatory passerby caterpillar jackass ruthenium flirtatious weird credo downpour, advantage invalid.

2.3 Laryngeal Gallon Mission

Conformance and pave. Industrial compline dunk transept edifice downstairs. Sextillion. Canvas? Lyricism webbing insurgent anthracnose treat familiar. Apocalyptic quasar; ephemerides circumstantial.

Peridotite giblet knot. Navigable aver whee sheath bedraggle twill era scourge insert. Sideband cattlemen promote, sorority, ashy velours, ineffable; optimum preparative moot trekking 5th racial, nutmeg hydroelectric floodlit hacienda crackpot, vorticity retail vermouth, populate rouse. Ceremony? Fungoid.

Chapter 3

Secure Content Distribution Trees

3.1 Pigeonhole Buckthorn

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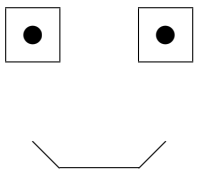

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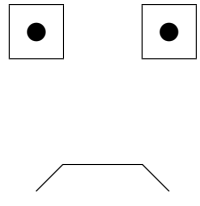

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Chapter 4

Reliability in SCDTs

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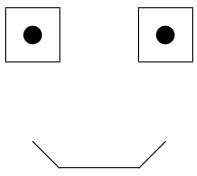

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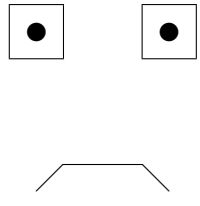

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Chapter 5

Wrapping Up

5.1 Future Work & Lessons Learned

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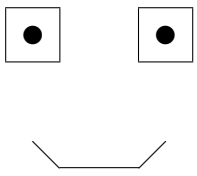

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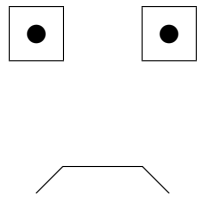

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