The Hitchhiker's Guide to CCN

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Abstract
This report serves as a starting point and introduction to the 2014 Q2 **CCNx Technical Document Release**. CCN is a new disruptive communications technology. We present a brief overview of the motivations for CCN and its most general characteristics: Accessing information by name, securing the content, and moving more computation and memory into the network, especially at the edge. We then present a suggested reading path and an overview for each the 42 documents (including this one) that comprise this technical information package.

Keywords
Content Centric Networks

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Contents

Welcome

We welcome you to the 2014 Q2 (second quarter) **CCNx Technical Document Release**. This release includes 42 documents (including this guide) that provide an overview of the Content Centric Networking (CCN) research and development projects underway at PARC, a Xerox company. These documents are intended for a highly technical audience, however no prior exposure to CCN is required.

CCN is a disruptive communications technology — CCN holds significant promise to enable new services — *increasing revenue* as well as improving network performance while dramatically *lowering costs*. The benefits of CCN can accrue across all layers of the OSI model and even extend to applications, storage, sensors, cloud services, consumers, enterprises and government. ***CCN flattens the network, yet at the same time, provides application services traditionally the domain of operating systems and middleware software stacks***. Next-generation networks must be more dynamic, easier to manage, support comprehensive application services, and offer dramatic performance improvements: CCN delivers a 21st-century network and applications architecture.

CCN continues our 40+ year legacy at the forefront of research and development of networking and communications technologies; from the invention of Ethernet and the Parc Universal Packet (PUP) in 1973, key contributions to IPv4 in 1981, Etherphone in 1987, our groundbreaking security work in 1989, development of the Mbone and its adoption by IETF in 1992, IPv6 in 1994, recognition for our loop-free on-demand routing solutions work in 2005, to our present work creating CCN. PARC's CCN research began in 2006, and in 2012 we embarked on a journey to commercialization while continuing a deep research agenda.

We are honored to have the Information-Centric Networking (ICN) community embrace our work, especially the 175+ institutions that have experimented with our CCNx code base (since its release in 2009), the 3,000+ developers and researchers who've used our code, sent in error reports, suggestions, and shared their experiences using CCNx, and the many PARC Client Services customers (both commercial and government) that have engaged with us.

We are grateful to the 100+ institutions that have attended our CCNx Conferences held in Palo Alto, California in 2011, Sophia Antipolis, France in 2012 (co-hosted with INRIA), and again in Palo Alto, California in 2013.

We are proud to share this overview of our work and contributions to the field of Information Centric Networking (ICN) and specifically our solution: CCN. The label 'CCNx 1.0' refers to the currently in-development version of the **CCN Architecture**. CCNx 1.0 will replace our previously released implementation, referred to in these documents as either CCNx 0.8.x or CCNx 0.x.

I would like to thank the entire PARC team, past and present, for their amazing contributions to the CCN project.

I'd also like to thank the many interns, post-docs, visiting researchers, and visiting scholars that have contributed to the CCN project. Finally I'd like to thank our many commercial and government partners, clients, academic collaborators, and suppliers that have shaped our thinking, challenged our ideas, and contributed to the CCN project. Thank you!

It was not lost on us that this release consists of 42 documents. So it is with acknowledgment and homage to my friend Douglas Adams (1952-2001), author of "The Hitchhiker's Guide to the Galaxy" — that we remind everyone, "DON'T PANIC!"

A Context for CCN: The Internet at 25

Our development of the **CCN Architecture** and the **CCNx 1.0 Implementation** arrives at an interesting time in the evolution of the Internet. There's no question that the Internet has changed virtually every aspect of life, work, and commerce; well underway in the developed world, these changes are now reaching the developing world. We're seeing:

- ***An explosion of traffic*** — driven by video, big data, telemetry, and connected everything.
- ***An explosion of devices*** — driven by mobile gadgets and the Internet of Things (Everything).
- ***An explosion of complexity*** — driven by layers of brittle design using 50-year-old principles.
- ***An explosion of security failures*** — driven by naïveté, bad design, and indifference.
- ***An explosion of protocols & formats*** — driven by evolving use models and economics.

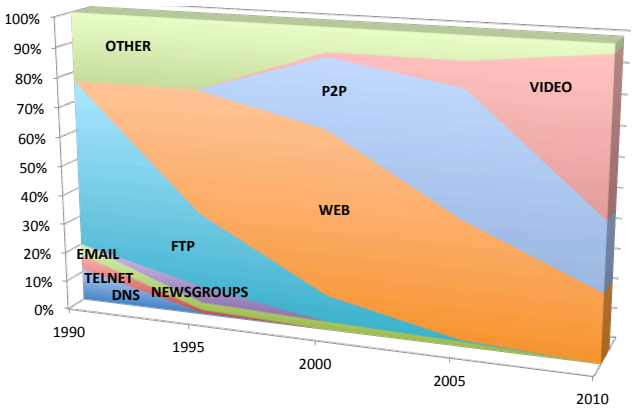

Figure 1. Evolution of Internet traffic

Modern telecommunications and the Internet are clearly a 'success disaster' driven by Bob Metcalfe's realization that "*the value of a network is proportional to the square of the connected users of the network.*" ***Are we ready for 50 billion devices?***

The Internet carries unimaginable amounts of traffic every day and this volume has grown astonishingly in the past two decades. Further, there has been a dramatic shift in the traffic types as well, from FTP in the early 1990's to IP-based media delivery by over-the-top providers like Netflix, iTunes, and YouTube today.

Traditional business models of broadcasters, advertisers, carriers, and cable operators (along with their ecosystems of suppliers to customers) are being disrupted, competition is increasing, margins are under pressure and differentiation is challenging. Underlying this change is a brittle infrastructure that is rife with security risks. Add exponential traffic growth accompanied by increasing customer demands and you have a recipe for a *relentless parade of problems* — CCN offers a solution to many of these issues and we want to share these ideas with you!

A Very Brief Introduction to CCN and CCNx 1.0

CCN is the name we use to describe our **Architecture** for Information Centric Networking. **CCNx 1.0** is the name we use to describe our **Implementation** of the **CCN Architecture**.

CCN is based on a few simple key tenets:

- ***Access content by name, not machine address*** — networking and communications are better served by using **names** to access information as opposed to using machine addresses (connections based on source and destination addresses).
- ***Secure the content, not the connection*** — security must be the foundation of any network architecture: Securing the data is more important (and useful) than securing the connections.
- ***Add computing and memory into the network*** — computation and memory continue to decline in cost, making it feasible to add computation and memory to routers and, as a result, maintain state and optionally content and/or object stores.

These three simple ideas form the foundation of the **CCN Architecture** — in the context of CCN, these simple tenets have far reaching and disruptive consequences: They can ***improve network performance and economics*** as well as enable a new wave of ***dynamic and secure network-aware applications***.

Some of the consequences of the **CCN Architecture** are:

- ***CCN packets address named content independent of location*** — packets have no source or destination addresses and information is requested by name.
- ***CCN signs data and optionally encrypts data*** — security does not rely on secure end-points or secure communication channels.

- ***CCN caches content opportunistically*** — essentially creating a fully-managed peer-to-peer network without losing control of content.
- ***CCN enables simple mobility, broadcast and load balancing*** — as well as extremely fine grained, real-time network optimization.
- ***CCN enables distributed information systems that meet the challenges of compliance*** — information provenance and auditing enabled at the network rather than at the application layer.

CCN benefits include:

- ***Manageable*** — caching lowers costs, improves broadcast, mobility and management.
- ***Secure*** — replacing Virtual Private Networks with Virtual Private Data, resistant to attacks.
- ***Resilient*** — dynamic behavior, error recovery, and fault-tolerance.
- ***Smart*** — fine-grained profiling without requiring deep packet inspection.
- ***Flexible*** — flattens the network, integrates with SDN, NFV, SON, and NC.

The documents included in this **CCNx Technical Document Release** present and illustrate the **CCN Architecture** concepts across a wide sampling of topics in networking, communications, and applications. This set of documents represents a limited view into our research and development agenda and only scratches the surface of what CCN enables, its disruptive potential, and our comprehensive research and development program. There are many other facets of our CCN work that we wanted to include but were unable to at this time.

Guide to the Documents

This **CCNx Technical Document Release** is not yet complete, however we wanted to get as much information as we could to technology evaluators as soon as possible. We will update the specification documents in the June timeframe to correct errors and omissions as well as resolve any contradictory information. We would be grateful and appreciate any feedback as you review the contents of this document release.

> *Please do not distribute these documents outside of your Company or Institution.*

All the documents are provided in PDF format. The types of documents include:

- ***Papers*** — previously published or yet-to-be published papers, some of which we include for their historical or tutorial perspective.
- ***RFC*** — RFC-style technical specification proposals prepared by the PARC Networking, Distributed Systems, and Security team.
- ***Tech Report*** — Technical Reports prepared by present and past members of the PARC Networking, Distributed Systems, and Security team.
- ***Deck*** — slide decks (i.e., PowerPoint or Keynote presentations converted to PDF format) prepared by the PARC Networking, Distributed Systems, and Security team.

A note on the slide decks — these decks were originally intended to be shared in an interactive session during an in-person, face-to-face meeting. These slide decks inevitably will be more difficult to follow without narrative by the author or presenter. Our highest priority with this documentation release is to share as much content as possible, as soon as possible, with technology evaluators and partners. If you have questions, please feel free to contact us via the multiple contact points provided at the end of this guide.

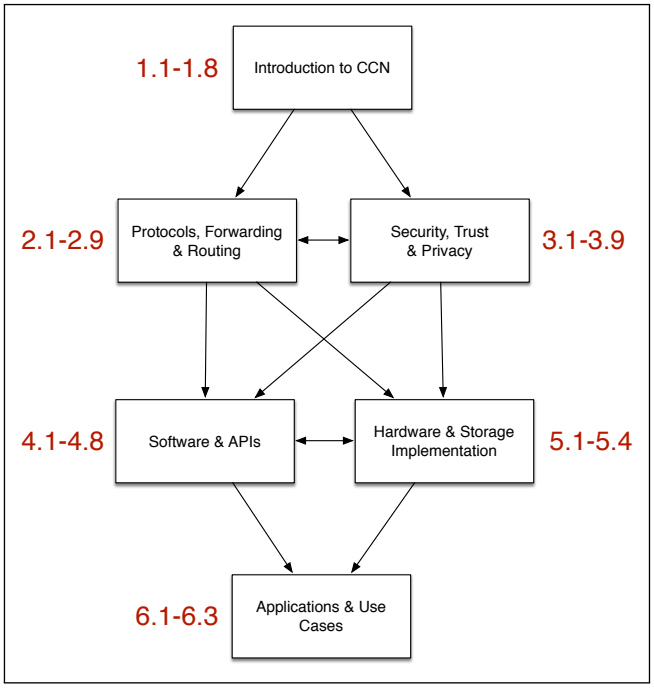

Figure 2. Overview of the Documents

The documents are categorized into six groups as follows:

1. ***Introduction to CCN*** — a general introduction to CCN including tutorials.
2. ***Protocols, Forwarding, and Routing*** — detailed information on the CCN wire formats and protocol specifications as well as discussions on forwarding and routing.

3. ***Security, Trust, and Privacy*** — a wide ranging exploration of security, trust and privacy issues in CCN with an emphasis on the security advantages of CCN.

4. ***Software and APIs*** — an overview of the software architecture, components, and APIs of CCNx 1.0 as well as an overview of streaming, catalogs, discovery, and CCN's support for Internet of Things.

5. ***Hardware and Storage Implementation*** — an exploration of the implications of CCN on router and storage system design.

6. ***Applications and Use Cases*** — a brief introduction into applications using CCN and an overview of our CCNmp solicitation.

Figure 2 Overview of the Document illustrates a suggested path through the document collection. We recommend you start with **Introduction to CCN**, then move to either (or both) **Protocols, Routing, and Forwarding** and **Security, Trust, and Privacy**. If your interests are predominantly software, then read **Software and APIs**. Read **Hardware and Storage Implementation** if your interests are predominantly hardware implementations of CCN. Finally read the **Applications and Use Cases,** which provides an overview of experiments, proof-of-concepts, and prototypes created with CCN (this includes PARC projects as well as third-party projects that have used PARC code or protocols).

1. Introduction to CCN

Content-Centric Networking (CCN) is a new information distribution and network-aware application architecture developed by PARC over the past nine years. During that period of experimentation, we developed the first practical implementation of an Information Centric Networking system. Working with our commercial partners, we explored many alternatives in protocol design. Last year, we started a major revision to the previous experimental efforts resulting in CCNx 1.0. We incorporated feedback from the community and our commercial partners to enhance and streamline the protocols.

This section serves as a beginner's guide to CCN, providing both an overview and the motivation for CCN. We assume basic familiarity with networking and the current Internet architecture. We assume no prior knowledge of CCN. We include a variety of documents that detail how the CCN architecture is different from today's Internet Protocol (IP) and how the CCN network functions as a whole. The documents in this section also provide details of our CCNx 1.0 protocol suite and describe many use cases and example scenarios.

There are eight introductory documents to CCN as briefly described in the following paragraphs.

1.1 CCNx 1.0 Protocol Introduction — This document describes the CCNx 1.0 protocols from the wire format up through the message semantics. The protocol use cases and many examples are presented.

#	Document Title
1.1	CCNx 1.0 Protocol Introduction
1.2	CCNx 1.0 Tutorial
1.3	CCNx 1.0 Motivation & Overview
1.4	CCNx 1.0 Overview CCN 101
1.5	CCNx 1.0 Naming — Transforming Addresses to Application Value
1.6	CCN and Contemporary Network Technologies
1.7	CCNx 1.0 Evolution From Experiments
1.8	Networking Named Content

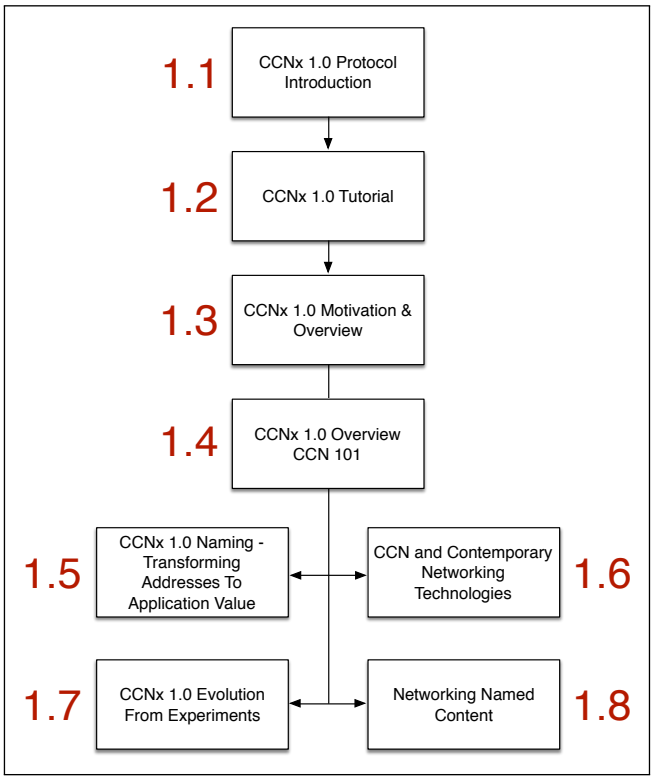

Figure 3. Introduction to CCN

1.2 CCNx 1.0 Tutorial — This document presents an overview of CCN and serves as a beginner's guide to CCN. It explains the operational details of a CCN node. It also addresses system-level issues such as transport and flow balance, management, and monitoring in a CCN network. In addition, it illustrates how several sample applications work in a CCN network.

1.3 CCNx 1.0 Motivation & Overview — This document shows how networks evolved from connection-oriented systems to information distribution systems, emphasizing how CCN can dynamically optimize newer forms of networks. It introduces the CCNx Interest and Content Object with examples of protocol exchanges.

1.4 CCNx 1.0 Overview CCN 101 — This document is a general overview of CCNx 1.0. It covers the basic concepts,

the protocol, and organization. It describes how CCN operates and illustrates a few simple applications. It covers the CCNx 1.0 protocol primitives and messages, the packet formats, and naming structure.

1.5 CCNx 1.0 Naming — Transforming Addresses to Application Value — This document describes where names come from, their form, and use. Several example applications illustrate the role names play in CCN-based networks. Names are an essential ingredient in CCN networks — they are the new addressing.

1.6 CCN and Contemporary Network Technologies — This document presents a high-level view of CCN's relationship to contemporary network technologies including Software Defined Networking (SDN), Network Function Virtualization (NFV), Self-Organizing Networks (SON), and Network Coding (NC). All of these technologies will shape the 21st century and CCN can work with, and in some cases simplify, these advances. Network coding is particularly interesting and our work indicates the benefits are significantly greater than what can be achieved with TCP/IP-based implementations. A document presenting our work with Network Coding and CCN is in preparation.

1.7 CCNx 1.0 Evolution From Experiments — This document describes the evolution, improvements, enhancements, and extensions to the earlier CCN protocols. We trace the progress from the CCNx 0.x research prototype to the CCNx 1.0 production specification and upcoming release. A large number of documents presenting CCNx 1.0 tools and APIs are in preparation.

1.8 Networking Named Content — This document is the first CCN academic paper that presents the motivation for a content-centric approach to networking. It provides an overview of an early CCN architecture.

2. Protocols, Forwarding, & Routing

This section will present information to help you understand the CCNx 1.0 protocol routing and forwarding. One of the primary functions of a network is to transmit and retrieve information between nodes. The **CCNx 1.0 Protocol Specification** defines the core protocols that fulfill this role. Additional protocols built on top of the core protocols add services such as discovery, content chunking, and versioning.

We have worked with many partners to shape the new CCNx 1.0 core protocols and will continue to work with the Internet Research Task Force for interoperable systems. A significant update of the specification is in progress, and we would appreciate feedback and suggestions on the technical merits, readability, or accessibility.

CCNx forwarding specifies how a node routes Interest messages to publishers or content repositories using a forwarding table and returns Content Objects using state stored in the forwarder. Intelligent forwarding strategies work around hot spots, reduce network traffic through aggregation, and dynamically adapts to network conditions. Because CCN forwarding operates on application-derived names, it is more agile than today's protocols over IP networks.

We describe two CCNx 1.0 routing protocols that use knowledge of the network graph to construct loop-free routes to publishers and content repositories, and populate the routing table used by the forwarder. We present two ICN approaches in documents 2.6 and 2.7, based on our earlier work, that describe routing content in *ad hoc* networks. We continue to research new CCNx routing methods and will release more documents as they become available.

There are nine documents on Protocols, Forwarding and Routing. The following paragraphs present a brief summary of the contents of each document.

#	Document Title
2.1	CCNx 1.0 Forwarding Introduction
2.2	An Overview of Routing Solutions
2.3	Name-based Content Routing in ICN Using Distance Information
2.4	Custodian-based Information Sharing
2.5	CCNx 1.0 Acyclic Core Object Routing Functional Specification
2.6	Robust Content Dissemination in Disrupted Environments
2.7	DOT Dual-ordered Object Transport
2.8	CCNx 1.0 Wire Format
2.9	CCNx 1.0 Protocol Specification Roadmap

2.1 CCNx 1.0 Forwarding Introduction — This document illustrates several of the important properties of CCN forwarding. It shows how a CCNx Forwarder handles Interest and Content Object exchanges.

2.2 An Overview of Routing Solutions — This document contrasts and compares routing in traditional IP networks with routing in CCN networks.

2.3 Name-based Content Routing in ICN Using Distance Information — This document describes a distance-based routing algorithm for ICN architectures. The proposed system is more scalable than prior approaches.

2.4 Custodian-based Information Sharing — This document describes Custodian-Based Information Sharing, a system that we implemented over CCN. This system allows simple, secure, and distributed information sharing between a user's devices, family, and friends. This system implements a new routing protocol that operates in a dynamic and mobile environment, and is scalable and robust as shown by its performance measurements.

2.5 CCNx 1.0 Acyclic Core Object Routing Functional Specification — The Acyclic Core Object Routing protocol uses a shared, core-based multicast approach to routing in CCN networks. The protocol and implementation details are

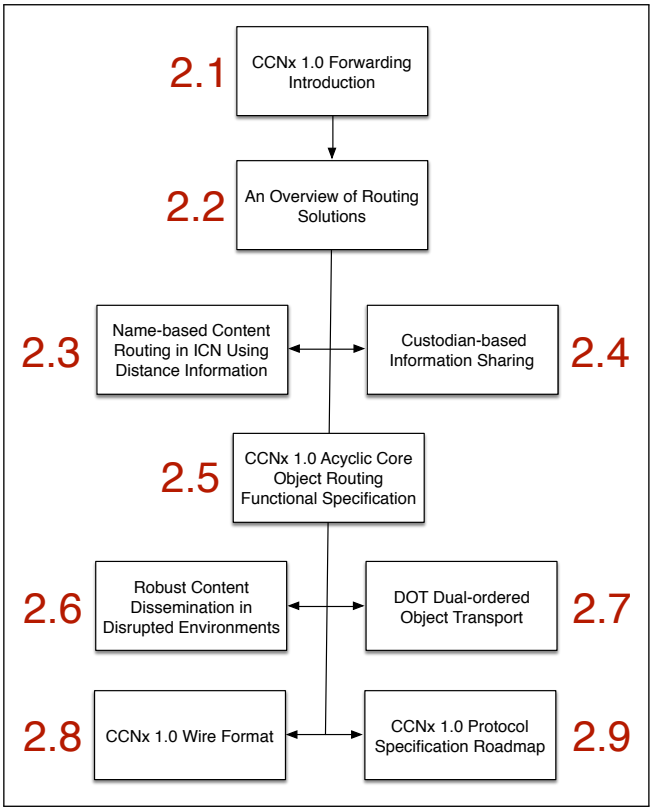

Figure 4. Protocols, Forwarding and Routing

presented.

2.6 Robust Content Dissemination in Disrupted Environments — This paper describes the DIRECT protocol (Disruption Resilient Content Transport). It is a content centric protocol to route and transfer information in a DTN (Disruption Tolerant Network).

2.7 DOT Dual-ordered Object Transport — This is a technical report for the DOT (Dual-ordered Object Transport) protocol that was part of DARPA's DTN (Disruption Tolerant Network) program. DOT's efficiency comes from simultaneously querying for and announcing content.

2.8 CCNx 1.0 Wire Format — This document describes the CCNx 1.0 wire format. The format is a type-length-value (TLV) using a fixed header and an optional set of network headers.

2.9 CCNx 1.0 Protocol Specification Roadmap — This document describes the CCNx 1.0 protocols. It includes RFC-style protocol specifications of the core protocol as well as extensions such as versioning, chunking, and collection selectors. This document was originally shared at the IETF88 meeting in Vancouver, British Columbia, Canada in November of 2013. A significant update of this document is in preparation to correct inconsistencies between some of the RFCs.

3. Security, Privacy & Trust

With the realization that current Internet protocols contribute to the frequent security failures that have become all to common, CCN has treated security and privacy as fundamental architectural requirements. CCN's design features make the infrastructure harder to attack and enable intrinsically secure communication. CCN promotes high availability in part to its natural support for replication and failover, as well as resistance against most known Denial of Service attacks. By requiring all content to be directly or indirectly signed, CCN enables verifiability of integrity, provenance, and correctness of each data packet in the network. In this section, we first present an overview of CCN's security goals and features and continue by presenting our initial results on the particular security topics of trust management, access control, DoS protection, and privacy. We continue our active research program on these topics and will share more results with our partners. A set of documents that describe our comprehensive design for access control in CCNx 1.0 and a set of security APIs for trust and access control are in preparation.

This section includes the following nine documents, briefly summarized in the following paragraphs.

#	Document Title
3.1	CCNx 1.0 Security Overview
3.2	CCNx 1.0 Elements of Trust
3.3	Securing Network Content
3.4	CCNx (Pre 1.0) Access Control Specifications
3.5	Flexible DRM in CCN
3.6	DoS and DDoS in Named Data Networking
3.7	Interest Flooding Attack and Countermeasures
3.8	Privacy in Content Oriented Networks
3.9	Anonymous Named Data Networking Application

3.1 CCNx 1.0 Security Overview — This document describes the security, privacy, and resilience properties of CCN and compares them to IP networks. CCN treats security and privacy as fundamental networking features provided to all applications.

3.2 CCNx 1.0 Elements of Trust — This document introduces a trust management and enforcement architecture for CCNx 1.0. The requirement for content objects to be digitally signed poses two challenges for detecting fake content in CCNx 1.0 routers: First, overhead due to signature verification, and second, lack of trust context (i.e., what public key is trusted to verify which content). This document explores these issues in detail.

3.3 Securing Network Content — This document describes the mechanism of securing and authenticating content in CCN. CCN suggests a more scalable security model wherein content itself is secured, rather than the connections over which it travels.

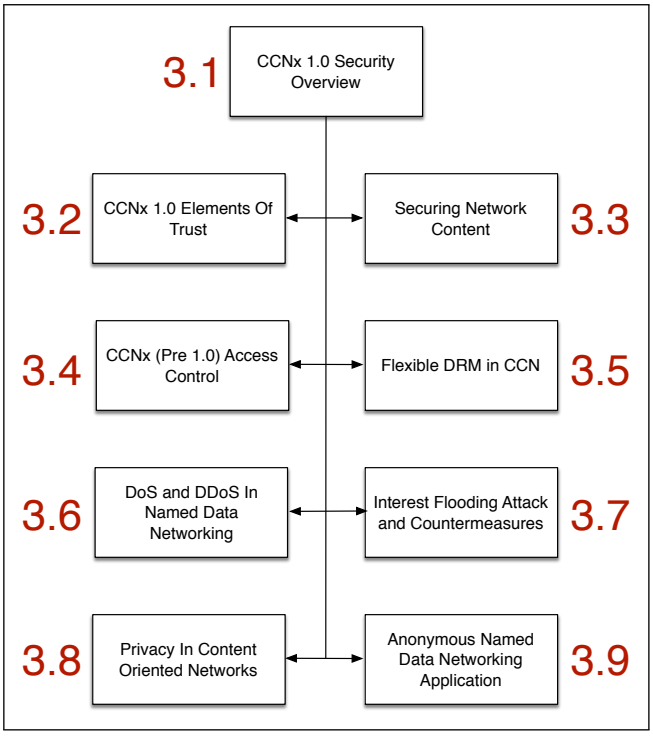

Figure 5. Security, Trust & Privacy

3.4 CCNx (Pre 1.0) Access Control Specifications — This document describes the support for encryption and access control in earlier CCNx 0.x releases. It begins with the documentation of signing and signature formats used by CCNx 0.x. It then presents a description of the content encryption and access control mechanisms provided by the CCNx 0.7 Java library. A CCNx 1.0 Access Control specification is under preparation and will supersede this document.

3.5 Flexible DRM in CCN — This document discusses the requirements for cache-friendly DRM (Digital Rights Management) schemes in CCN. It evaluates the applicability of popular DRM schemes used today and introduces a new secure content distribution architecture based on proxy re-encryption.

3.6 DoS and DDoS in Named Data Networking — This document presents a first step towards assessment and possible mitigation of DoS attacks in NDN (Named Data Networking). After identifying and analyzing several new attack vectors, it investigates their variations, impacts, and counter-measures. Most of the attacks described in this document are mitigated in CCNx 1.0.

3.7 Interest Flooding Attack and Countermeasures — This document investigates the impact of Interest flooding attacks in CCN networks and details several strategies to mitigate them. The document shows the effectiveness of our mitigation techniques in shutting down malicious attacks without degrading legitimate traffic.

3.8 Privacy in Content Oriented Networks — This document presents a systematic analysis of privacy threats in CCN and potential countermeasures. It compares ICNs and IP Networks with respect to privacy concepts such as anonymity, censorship, traceability, and confidentiality. We believe that CCN provides a number of advantages to preserve privacy.

3.9 Anonymous Named Data Networking Application — This document examines privacy-relevant characteristics of earlier CCN systems and presents an onion-routing approach to achieve communication privacy. This solution has significantly less overhead than Tor, a popular anonymity tool for IP networks.

4. Software & APIs

PARC has invested significant effort into software architectures, system design, software engineering and code development to create the **CCNx 1.0 Implementation**. This section describes these activities at a very high-level. A set of documents that describe our Programmer's Library, API Reference, Style & Design Guide are in preparation and will be made available in a future **CCNx 1.0 Technical Document Release**. Additional documents are being prepared for our Algorithms Library, Security Toolset, and Unit Testing Framework.

Our software design and implementation emphasize clean protocols, clean code, and clean APIs. Several factors drive our agile development process and reflect our four overarching goals for the system:

#	Document Title
4.1	CCNx 1.0 Software APIs Architectural Overview
4.2	CCNx 1.0 Network Software
4.3	CCNmq Message Queue Architectural Overview
4.4	CCNx 1.0 Internet of Things Architectural Overview
4.5	CCNx 1.0 Bidirectional Streams
4.6	CCNx 1.0 Collection Synchronization with Secure Catalogs
4.7	CCNx 1.0 Collection Synchronization
4.8	CCNx 1.0 Simple Service Discovery for Content Centric Networks

- ***Accelerate adoption*** — software designs prioritize modularization, extensibility, and separation of concerns, emphasizing clarity, and robustness, employing the best practices of modern software engineering focused on production quality results.

- ***Enable experimentation*** — software designs and implementations are written to elucidate and educate. With an eye toward the future, software and interfaces are designed for extensibility with components that can be readily substituted without changing the architecture of the system.

- ***Improve Stability*** — stable implementations of software modules and their frameworks include the best testing and documentation practices that fully support performance analysis, product development and test, and production deployment.
- ***Increase Productivity*** — coupled with the basic principles of clarity, testing, transparency, and economy, programmers are guided with the aid of style and design guides that encourage the best techniques for clean protocols, clean code and clean APIs.

This section includes the following eight documents, briefly summarized in the following paragraphs.

4.1 CCNx 1.0 Software APIs Architectural Overview — This document provides an overview of two fundamental APIs that use CCN to implement a socket-like interface and a distributed key-value store. The socket interface reflects a traditional network view of sending and receiving packets, and the key-value store abstracts away the networking specifics and enables programming at a higher level. The APIs are used to illustrated an implementation of Simple Service Discovery for CCN.

4.2 CCNx 1.0 Network Software — This document provides an overview of the CCN Network Software stack, a modular, component-based architecture designed for both experimentation and extensibility as well as stable, streamlined implementations. The CCN Network Software is the foundation of an application's use of CCN ranging from simple to complex object protocols.

4.3 CCNmq Message Queue Architectural Overview — This document presents a simple message-queue programming API that enables applications to use CCN as a queueing message passing system. This enables application designs to permit synchronous or asynchronous interaction and is particularly suited to Internet of Things (IoT) or Internet of Everything (IoE) applications.

4.4 CCNx 1.0 Internet of Things Architectural Overview — This document provides a description of a CCN IoT protocol aggregator unifying multiple IoT protocols with CCN, providing computation, storage, and federating CCN aggregators. The design includes providing a CCN name space to IoT protocols, operations, and devices. This permits applications to use the IoT as a programming substrate.

4.5 CCNx 1.0 Bidirectional Streams — This document describes Bidirectional Streams in CCNx, a method to build two named interest and content object exchanges for transferring arbitrary binary data. It includes provisions to authenticate both parties and encrypt the session.

4.6 CCNx 1.0 Collection Synchronization with Secure Catalogs — This document illustrates how secure catalogs improve the performance and security of collection synchronization. Because only the secure catalogs are signed, not individual chunks of the manifest, multiple producers of the same manifest will generate the same content object hashes, improving the cache reuse of these objects.

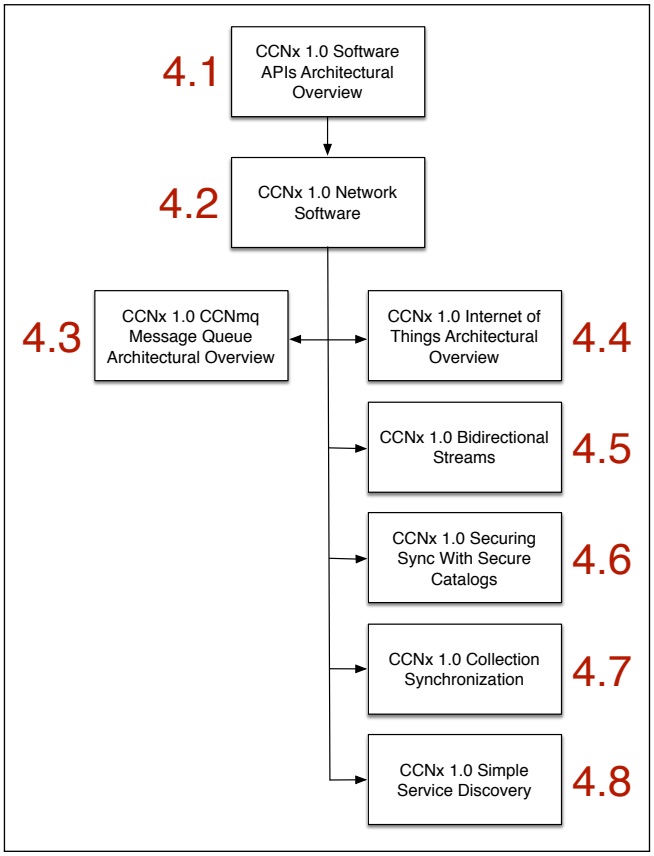

Figure 6. Software & API's

4.7 CCNx 1.0 Collection Synchronization — This document examines collection synchronization over CCNx 1.0. The system exchanges named manifests of collection contents through an advertisement notification and data transfer channel.

4.8 CCNx 1.0 Simple Service Discovery for Content Centric Networks — This document provides a description of a CCN protocol to implement general purpose service discovery, including both hardware device and software service discovery. The protocol is suitable for small to enterprise level software service and hardware device discovery implementations. The protocol can be modified to accommodate simple hardware devices and proxy services. Additional documents describing our extensive work in device and service discovery in large-scale networks is in preparation.

5. Hardware & Storage Implementation

CCN-based networks are highly efficient and flexible, due in part to an expanded role for network nodes including routers. New thinking is required to optimize physical implementations of CCN-based hardware and software. This section

illustrates the system design tradeoffs and technical considerations required to realize a CCNx 1.0 protocol stack at wire speed. We share our key findings regarding implications of CCN functional blocks on high speed router design. A brief overview of our router research platform, a powerful 11.2 Terabit router built in collaboration with a partner is presented.

Network Function Virtualization (NFV) requires a flexible, virtualized router platform. Our modified virtual kernel runs Quagga on the Switch Controller card, and we have implemented a fully distributed forwarding plane. Our high-availability features enable multi-tenancy, process recovery, and in-service software updates.

Storage is a critical component of future networking infrastructure at every level, from caches to mass storage. We share a hint of our work on novel ideas for storing content objects within the network, the technical boundaries and solutions to caching, and some creative approaches to content streaming. Additional documents which describe our network-bases storage are in preparation.

This section includes the following four documents, briefly summarized in the following paragraphs.

#	Document Title
5.1	CCNx 1.0 Implications for Router Design
5.2	CCNx 1.0 Virtual Machine for Content Routers:
5.3	CCNx 1.0 Rank Statistics For High Speed Content Stores
5.4	CCNx 1.0 Streaming Storage

5.1 CCNx 1.0 Implications for Router Design — This document describes system design considerations for building routers running CCNx 1.0 at modern high line rates. The document illustrates CCNx 1.0 functional requirements, the PARC Router Research Platform (hardware and software), and a collection of CCN implementation notes.

5.2 CCNx 1.0 Virtual Machine for Content Routers — This document describes the system software and virtual machine architecture developed in-house that runs on the PARC Router Research Platform. The document presents the open-source Quagga control plane, distributed forwarding plane, command-line interface, and outlines the benefits of virtual machine-based routers.

5.3 CCNx 1.0 Rank Statistics For High Speed Content Stores — This document describes how rank statistics can measure the popularity of cached content using a high-speed calculation over very large data sets. Our algorithm uses an exponentially weighted moving average over the rate of object requests.

5.4 CCNx 1.0 Streaming Storage — This document presents Streaming Storage as a technique for high-speed opportunistic caching. Our design uses a fast in-memory index to mass storage that optimizes performance.

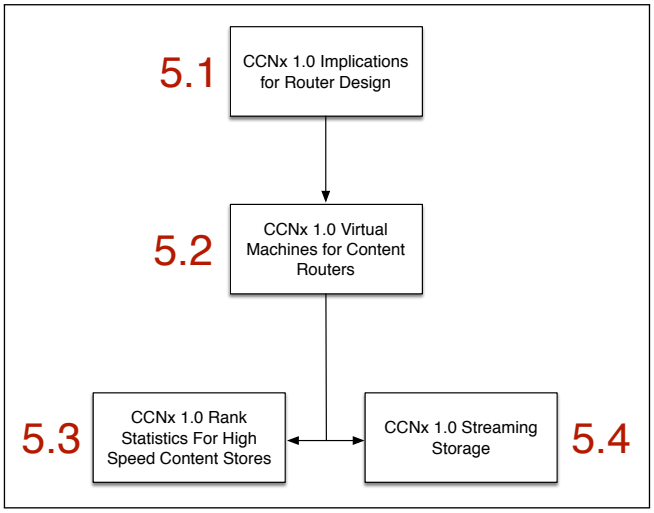

Figure 7. Hardware & Storage Implementation

6. Applications & Use Cases

In addition to Bob Metcalfe's realization about network effects and value he also likes to recount "I didn't make money inventing Ethernet, I made money selling it." With a nod to Bob's sage advice, this section presents an overview of past projects and proof of concepts leveraging CCN as well as a specific application of CCN to VoIP (Voice over Internet Protocol). We also include a very brief overview of our CCN Multi-client Program or CCNmp. This program provides a select and small number of companies to work directly with PARC to shape the future of CCN. Several additional documents are in preparation that describe applications and benefits of CCN to various vertical and horizontal application domains.

This section includes the following three documents, briefly summarized in the following paragraphs.

#	Document Title
6.1	CCN Case Studies
6.2	VoCCN Voice Over Content Centric Networks
6.3	CCNmp Multi-Client Program

6.1 CCN Case Studies — This document presents a catalog of PARC and non-PARC projects related to CCN. Projects range from academic research, consumer electronics, network equipment providers, and government customers. This document is primarily intended to show the breadth of past work leveraging CCN.

6.2 VoCCN Voice Over Content Centric Networks — This document describes how any conversational protocol running over IP today can be run over a content-based paradigm. The paper describes a prototype implementation of VoIP over CCN.

6.3 CCNmp Multi-Client Program — This one-page docu-

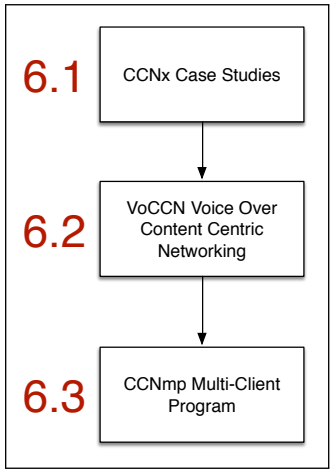

Figure 8. Applications & Use Cases

ment highlights our CCN Multi-Client Program that includes significant access to PARC's intellectual property, commercial code, and research and development staff. For more information on the CCNmp program, please contact the business development team (see the PARC Contacts section).

7. Conclusion

CCN is a new disruptive communications technology. It holds significant promise to enable new services and create a new category of applications software — **network-aware applications**. This technical report presented an introduction to CCN and a roadmap to a comprehensive set of documents included in the **2014 Q2 CCN Technical Document Release**. Our present work explores the implications of CCN on hardware router design, storage, network performance, security, trust, privacy, and applications development. Our CCN architecture and implementation operates in a wide range of network environments, from sensors and smartphones to servers and spaceships.

8. CCN & PARC Contact Points

We welcome your feedback, suggestions, ideas, and, of course, any errors, omissions, or contradictions that you might find in the documents. We look forward to hearing from and engaging with you.

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9. Master List of Documents

#	File Prefix	Document Title / File Name	Type
1	0.1	Hitchhiker's Guide to CCNx 1.0 (this document)	Tech Report
2	1.1	CCNx 1.0 Protocol Introduction	Tech Report
3	1.2	CCNx 1.0 Tutorial	Tech Report
4	1.3	CCNx 1.0 Motivation & Overview	Tech Report
5	1.4	CCNx 1.0 Overview CCN 101	Deck
6	1.5	CCNx 1.0 Naming — Transforming Addresses to Application Value	Tech Report
7	1.6	CCN and Contemporary Network Technologies	Deck
8	1.7	CCNx 1.0 Evolution From Experiments	Tech Report
9	1.8	Networking Named Content	Paper
10	2.1	CCNx 1.0 Forwarding Introduction	Deck
11	2.2	An Overview of Routing Solutions	Deck
12	2.3	Name-based Content Routing in ICN Using Distance Information	Paper
13	2.4	Custodian-based Information Sharing	Paper
14	2.5	CCNx 1.0 Acyclic Core Object Routing Functional Specification	Tech Report
15	2.6	Robust Content Dissemination in Disrupted Environments	Paper
16	2.7	DOT Dual-ordered Object Transport	Tech Report
17	2.8	CCNx 1.0 Wire Format	Tech Report
18	2.9	CCNx 1.0 Protocol Specification Roadmap	RFC
19	3.1	CCNx 1.0 Security Overview	Tech Report
20	3.2	CCNx 1.0 Elements of Trust	Tech Report
21	3.3	Securing Network Content	Paper
22	3.4	CCNx (Pre 1.0) Access Control Specifications	Tech Report
23	3.5	Flexible DRM in CCN	Paper
24	3.6	DoS and DDoS in Named Data Networking	Paper
25	3.7	Interest Flooding Attack and Countermeasures	Paper
26	3.8	Privacy in Content Oriented Networks	Paper
27	3.9	Anonymous Named Data Networking Application	Paper
28	4.1	CCNx 1.0 Software APIs Architectural Overview	Deck
29	4.2	CCNx 1.0 Network Software	Deck
30	4.3	CCNmq Message Queue Architectural Overview	Deck
31	4.4	CCNx 1.0 Internet of Things Architectural Overview	Deck
32	4.5	CCNx 1.0 Bidirectional Streams	Tech Report
33	4.6	CCNx 1.0 Collection Synchronization with Secure Catalogs	Tech Report
34	4.7	CCNx 1.0 Collection Synchronization	Tech Report
35	4.8	CCNx 1.0 Simple Service Discovery for Content Centric Networks	Tech Report
36	5.1	CCNx 1.0 Implications for Router Design	Tech Report
37	5.2	CCNx 1.0 Virtual Machine for Content Routers	Deck
38	5.3	CCNx 1.0 Rank Statistics For High Speed Content Stores	Tech Report
39	5.4	CCNx 1.0 Streaming Storage	Tech Report
40	6.1	CCN Case Studies	Deck
41	6.2	VoCCN Voice Over Content Centric Networks	Paper
42	6.3	CCNmp Multi-Client Program	Brochure