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Survey Paper

# Content-centric wireless networking: A survey

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ABSTRACT

Content-Centric Networking (CCN) is a candidate future Internet architecture that gives favourable promises in distributed wireless environments. The latter ones seriously call into question the capability of TCP/IP to support stable end-to-end communications, due to lack of centralized control, node mobility, dynamic topologies, intermittent connectivity, and harsh signal propagation conditions. The CCN paradigm, relying on *name-based forwarding* and *in-network data caching*, has great potential to solve some of the problems encountered by IP-based protocols in wireless networks.

In this paper, we examine the applicability of CCN principles to wireless networks with distributed access control, different degrees of node mobility and resource constraints. We provide some guidelines for readers approaching research on CCN, by highlighting points of strength and weaknesses and reviewing the current state of the art. The final discussion aims to identify the main open research challenges and some future trends for CCN deployment on a large scale.



## 1. Introduction

Modern mobile devices such as smartphones, laptops, and tablets, enabled with wireless Internet connectivity and sensing capabilities, are steadily growing in popularity and market penetration. They can provide users with mobility and flexibility in accessing and generating information *anywhere* (e.g., in home, office, shops, cars) and at *any* time. Wireless networking is expected to play a crucial role in the future Internet, not only to sustain direct interactions between personal users' devices, but also as a means to provide connectivity on a large scale while involving resource-constrained devices like sensors and smart objects. Conventional networking protocols designed to support stable end-to-end communications between nodes that are uniquely identified through an IP address, fail in wireless distributed environments due to dynamic changes in the network topology caused by the node mobility, frequent link failures or the presence of energy-constrained nodes running out of battery.

In addition, it is also evident that the traditional *host-centric* Internet model mismatches the dominant *information-centric* usage of the current Internet. Today, applications such as video downloading, file sharing, social networking, and cloud services, massively drive content retrieval and dissemination in the Internet. To support the efficient and reliable delivery of such applications, a number of research initiatives has recently advocated a shift from the traditional Internet networking model to a novel paradigm that considers the *content* (or *information*) as the first class network citizen and decouples it from the identity of the node(s) storing it.

Information-centric networking has become one of the main potential architecture of the future Internet and several related projects are active worldwide [1]. In this research arena, the Content-Centric Networking (CCN) architecture proposed in the seminal work of Jacobson

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et al. [2] has rapidly gained consensus and it is now at the basis of many research initiatives running worldwide, including Named-Data Networking (NDN) [3] and others cited in [4].

In CCN, each piece of data is associated with a *location-independent* name that is directly used by the applications for content search and retrieval. Communication is driven by the receiver, which uses an *Interest* packet to request a content "by name". The content source, or any other network node that temporarily stores the requested content, replies with a *Data* packet that contains the named content and additional authentication and data integrity information. Each Data packet is a self-identifying and self-authenticating unit; and this enables seamless in-network caching and content replication.

It is the authors' convincement that CCN is an effective networking paradigm that well matches the features of wireless environments. Indeed, CCN can overstep the inefficiencies of TCP/IP in handling node mobility, unreliability of wireless links, and resource-constrained devices by relaxing the need of creating and maintaining stable sessions between end-points. Moreover, CCN may leverage the broadcast channel nature and help the content sharing between neighbouring nodes.

Some good surveys have addressed information-centric solutions [1,4] and covered topics ranging from naming to mobility management and caching, e.g., [5–7]. This paper differs from the previous ones since it focuses specifically on the CCN paradigm, and it provides a comprehensive overview and a clear identification of the applicability, potentialities, weaknesses and future challenges of this paradigm in wireless networks.

The rest of the paper is organized as follows. In Section 2, we introduce the CCN basics and major functionalities. In Section 3, we present the main features of wireless sensors, mobile and vehicular ad hoc networks and we identify the benefits of CCN in such environments. In Sections 4–10 different aspects of the CCN applicability to wireless environments are analyzed, including naming, routing and forwarding, caching, security, and transport issues, as well as evaluation platforms and prototypes. Section 11 summarizes the open challenges and future perspectives. Section 12 concludes the paper.

## 2. The CCN architecture

The CCN model [2] provides a new network architecture that supports content retrieval in the future Internet by using Interest/Data packets exchange.

Each CCN name is persistent, unique and hierarchical and it can be represented as a Uniform Resource Identifier (URI). Integrity and authenticity are supported at a packet-level by piggybacking the data publisher's signature and other authentication information (e.g., publisher public key digest) in the Data packet.

Since each Data is a *self-contained* unit, caching is facilitated in network nodes. Depending on local constraints and policies, a subset (or all) of the network nodes can cache contents and speed up data retrieval while reducing the overhead. A CCN node that maintains a cached copy of the content can act as a *provider* like the original source.

As shown in Fig. 1, CCN inherits the hourglass model of the IP architecture, but the narrow waist leverages names of content chunks instead of IP addresses for data delivery.

Each CCN node maintains three data structures: (i) a Content Store (CS) for temporary caching of incoming Data packets; (ii) a routing table named Forwarding Information Base (FIB) used to guide the Interests towards Data; and (iii) a Pending Interest Table (PIT), which keeps track of the forwarded Interest(s) that are not yet satisfied with a returned Data packet.

Routing in CCN serves the purpose of computing the FIBs entries to be used for Interest forwarding. Given the hierarchical name structure, CCN facilitates global routing via prefix aggregation.

The CCN forwarding plane is a two-step process that involves Interests forwarding from the consumers to the retrieved data, and Data packets flowing back along the same path to the consumers. Each CCN node receiving an Interest makes its forwarding decision based on the following algorithm. First, it searches for a name prefix longest-match in its CS. If a match is found, then the node sends the Data back to the incoming interface of the processed Interest. Otherwise, if there is a matching PIT entry (another consumer has already asked for the same Data), the Interest is discarded and the new incoming interface is added to the existing PIT entry. Otherwise, a new PIT entry is created and the Interest is further forwarded to the interface stored in the FIB.

When a Data packet is retrieved, its name is used to look up the PIT. If a matching entry is found, then the node sends the packet to the interface(s) where the Interest was received, it stores the data in the CS, and deletes the PIT entry. So, Data packets follow the chain of PIT entries back to the requester(s). If a match is not found in the PIT then the Data packet is considered unsolicited and it is dropped.

For the sake of clarity, Fig. 2 sketches CCN packets processing and forwarding. Upon receiving the Interest from node *A*, the intermediate node *C*, not finding a match in its CS or in the PIT, forwards the Interest to the source node *D*. Once receiving the Data packet from *D*, node *C* forwards it back to *A*, and subsequently it serves *directly* the request for the same content coming from *B* with its cached copy.

CCN achieves one-to-one flow balance by letting each Interest be consumed by a single Data packet. Moreover, it permits to specify different transport services at the

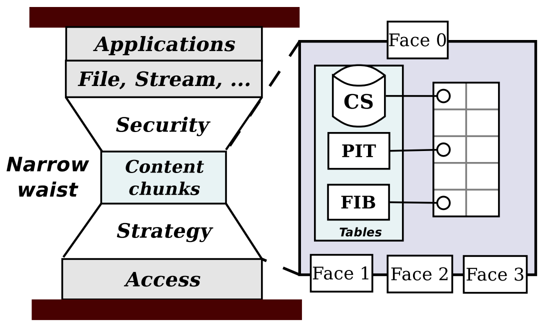


**Fig. 1.** CCN hourglass and node architecture.