A Unifying Framework for Resource Allocation in Mobile Information Centric Networks

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1. Introduction

Content distribution has become the predominant form of traffic over the Internet; yet, this shift has happened “over the top” from the point of view of the operator: the content is placed and distributed in content distribution overlays which relegate the operator to the role of a dumb pipe. However, content distribution would benefit from the operator’s involvement: the knowledge of the network, its topology, what features it supports, the congestion level of links, etc, would all improve the end-user experience while consuming content.

Information-Centric Networks (ICN)[1-6] have been proposed to help the operator route to content. The network architectures suggest using content name for routing, so as to direct a request for a specific piece of content to the copy which maximizes the utility of the operator. Requesting an item by name, rather than by address, frees the operator to decide which location to use. The operator can then make its decision based upon availability of the content at multiple locations and the network conditions between the user and these locations.

We argue further that Information-Centric Networks offer further benefits to the operator beyond selecting which cache to use. Namely, the use of a single globally unique name for content allows the operator to perform fine-grained resource allocation decision based on the properties of the content associated with this name.

In this letter, we describe an architecture initially presented in [7,8] to construct an Information-Centric Network architecture with a centralized content management plane. This architecture extracts content meta-data from the content going through the network and uses this meta-data for resource allocation. We argue that content is the proper granularity for resource allocation, as it makes the resource allocation problem more deterministic rather than probabilistic. We will see how this framework can be expanded for mobile networks.

2. ICN Overview and Background

Information-Centric Networks associate content with a unique name which is then used to request content. A typical request will have different semantics under different ICN proposals, but will be of the form GET(name).

In an ICN, because the request is for a specific name, it is not attached to any location, unlike IP. This gives the network operator the ability to use caching mechanisms to store the content within the network, and to route content requests to any copy of the content.

The idea to make routing decisions in a centralized manner has taken a new life recently with the emergence of Software-Defined Networks (SDN)[9]; in SDN, the forwarding plane is separated from the control plane, and the control plane has a global view of the network that allows a (logically) centralized controller to make routing decisions based on this view of the network’s conditions. The controller then enacts the routing decision by setting flow labels in the flow tables of the switches in the forwarding plane.

A flow is a natural primitive to work with in an IP context, as it is understood by the existing forwarding elements. However, it is the wrong granularity for content routing. In the remainder of this document, we assume that we have an architecture which supports a separation of control and forwarding planes; where the control plane sets up content forwarding rules in the data plane; and where the data plane is able to forward based upon content name.

Such an architecture can be built from scratch as in some ICN architectures (say, [10]), or can be constructed on top of IP (say, as an extension of OpenFlow as in [8]).

3. Resource Allocations in ICN

The conjunction of a centralized content management with uniquely named pieces of content allows for the network to transparently extract content meta-data [7]. The centralized controller includes a content management layer which keeps a database indexed by the content name which keeps track of its popularity, its size (as read by counting bytes through the network or by the memory footprint in a cache server) and its potential locations.

Content has explicit boundaries. Once the size of a piece of content is known, it is straightforward to know how much data is left in transit. This contrasts with flows in IP networks which have no explicit end.
semantics. Once a flow is allocated to a link, it is as
difficult to predict the link utilization as to predict
when the flow will terminate. This provides a
significant advantage for content-based resource
allocation.

Upon receiving a content request, the forwarding plane
invokes the control plane to resolve the content name
to a path in the network. The controller then identifies
the location of the content and the path that jointly
maximize some utility. For instance, a typical traffic
engineering goal would be to minimize the maximal
link utilization in the network. This is straightforward
once the additional load of adding the content to a path
is known.

The key insight is that a content-based architecture
transforms the resource allocation problem from a
probabilistic problem to a deterministic problem. This
in turn strongly diminishes the need for guard
bandwidth and other mechanisms to protect the
network from burstiness in the traffic, thus reducing
significantly the capex of the network.

4. Mobile Networks

We have seen how an information-centric architecture
allows for better resource allocation in wired networks,
and in particular for traffic engineering.

We now discuss through examples how an
information-centric architecture with a (logically)
centralized controller can improve resource allocation
in mobile networks, and how it would provide a
homogenous management framework for multiple
mobile optimizations which use different mechanisms.

There are multiple examples of content-based
optimizations for mobile networks, but we will focus
on two as an illustration of the need for an architectural
solution. These two mobile optimizations are Sprinkler
[11] and Infinity [12]. Many other optimizations would
match in such a framework, and this underlines the need
for the network to natively support such optimizations.

Infinity is an in-network storage system which
increases the wireless utilization by scheduling
transmission of files when the network conditions are
above a threshold. Sprinkler is a streaming system
which stores the content in the network by predicting
the user’s mobility.

These two mechanisms can be viewed as network
functions which require a programmatic framework at
the content level to be implemented satisfactorily.

Infinity can be implemented in the architecture of [7]
by having the mobile device request the content, tagged
with a deadline by which to transmit the content. This
request is then fulfilled once the link quality between
the mobile device and the user exceeds some threshold
or when the deadline expires.

Sprinkler can similarly be viewed as an information-
centric architecture, where the network schedules the
delivery based upon a predicted trajectory.

There are many other such mobile network
optimizations which can be expressed using a content-
based framework which supports relatively simple
network programmability.

The point is thus: resource allocation can gain from
being performed at the level of content, using a control
plane with a global network view in a network with the
ability to store content, in exactly the same way traffic
engineering benefitted in a wired network.

5. Summary and Outlook

Information-Centric Networking (ICN) has become an
active research topic for content delivery. One of the
unsung advantages of an ICN is that it allows resource
allocation at the granularity of content. Since content
has explicit semantics, and meta-data about the content
can be extracted at the network layer, the resource
allocation is more accurate than in an IP network where
it relies on statistical multiplexing for accuracy.

We have seen that an architecture with the following
set of features:

- The content is uniquely identified and
  requested by name;
- The forwarding plane can store content;
- The forwarding plane can extract content
  metadata;
- The centralized control plane keeps track of
  content and its metadata;
- A programmatic interface is provided to
  implement new network and content
  management functions in the controller;

would offer significant improvements for traffic
engineering. We also argue that such a framework
would allow implementing many mobile networking
optimizations which have been proposed in the literature using a common underlying architecture.

References


Cedric Westphal is a Principal Research Architect with Huawei Innovations working on future network architectures, both for wired and wireless networks. His current focus is on Information Centric Networks. He also has been an adjunct assistant professor with the University of California, Santa Cruz since 2009. Prior to Huawei, he was with DOCOMO Innovations from 2007-2011 in the Networking Architecture Group. His work at DOCOMO has covered several topics, all related to next generation network architectures: scalable routing, network virtualization and reliability, using social networks for traffic offloading, etc. Prior to that, he was at Nokia Research Center from 2000 to 2006. He received a MSEE in 1995 from Ecole Centrale Paris, and a MS (1995) and Ph.D. (2000) in EE from the University of California, Los Angeles. Cedric Westphal has co-authored over fifty journal and conference papers, including several best paper awards; and been awarded twenty patents. He has been an area editor for the ACM/IEEE Transactions on Networking since 2009, an assistant editor for (Elsevier) Computer Networks journal, and a guest editor for Ad Hoc Networks journal. He has served as a reviewer for the NSF, GENI, the EU FP7, and other funding agencies; he has co-chaired the program committee of several conferences, including IEEE ICC (NGN symposium). He is a senior member of the IEEE.