# Content Delivery Network Interconnection

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## Abstract

This draft gives an overview of Content Delivery Network Interconnection. Bandwidth intensive contents are a major load on today's networks which keeps increasing with technological evolution. The goal of Content Delivery networks is to bring closer multimedia content to the users for better end user experience. The closer the content is the better the experience as this will significantly reduce the latency and extend Content Delivery Networks' capabilities. This paper shows the architecture, benefit and challenges of Content Delivery Network Interconnection as these are major considerations for the adoption of the technology.

## Keywords

Content Delivery Network, Content Delivery Network Interconnection, Architecture, Telecommunication Standards, CDNI Operation Model, CDNI Deployment Model. Footprint & Capabilities Advertisement Interface FCI, Metadata Interface MI, Request Route Redirection Interface RI, Border Gateway Protocol BGP

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# 1. Introduction

The interconnection of content delivery networks (CDN's) is a major requirement to reduce the traffic traversing the internet and major datacenters around the world. Content delivery network interconnect is poised to reduce this traffic once these content delivery networks are able to interconnect with one another. This will provide a local cache close to the end user and provide shortest path from user to content thereby better user experience.

Content Delivery Network Interconnect (CDNI) is the technique for connecting the Content Delivery Networks to be able to extend their services and minimize overhead resource cost. Content Delivery Network Interconnect requires a standard non-proprietary interconnection protocol that the CDN's will use to connect with each other, the CDNs will require adoption of this technology as well as review the security implication of this interconnection.

Internet Engineering Task Force (IETF) pointed out the three CDNI use cases below;

Footprint Extension: CDN's that have a geographically limited presence would be able to provide services beyond their area of presence with CDNI. This includes geographic extension, Internet Service Provider handling of vendor contents and mobile users. Traffic Offload: Traffic offload from one CDN to another CDN via CDNI from an unexpected heavy traffic induced overload from a CDN. This also helps achieve high availability (HA) as traffic is redirected to another CDN when a failure occurs. CDN Capability: Network infrastructure services capability could be extended via CDNI allowing CDN's to provide services that they would not have been able to deliver autonomously.

These use cases will in no small measure reduce Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for individual CDN's as they will be able to do more with less.

This document reviewed the architecture of Content Delivery Network, autonomous and interconnected. It also looked at the operations of CDNI, delivery models, potential gains and challenges.

# 2. Overview

This document started with describing the Content Delivery Network and its network architecture. It then moved on to explain Content Delivery Network Interconnect and its network architecture, operations and delivery model.

It also looks at the different design and implementation model for a CDNI system that is capable of adapting to any standard and platform based on CDNI gateway. Part of the research work at Korean Advanced Institute of Science and Technology, was to develop CDNI system based on CDNI gateway model. The CDNI trial service consists of three internet service providers, a cable network provider and a Content Service Provider. The three-internet service provider and content service provider build four Content Delivery Network where the content service provider took the role of the publisher for this experiment. It was established that about 40% traffic reduction could be achieved with CDNI when compared with legacy CDN. The gains, delivery models, operations and challenges of the CDNI were also espoused.

# 3. Network Architecture of a Content Delivery Network and Content Delivery Network Interconnection

## 3.1 Introduction

Content can be described as an audio, video or/and picture files and has been around as long as human existence. Technology has helped in the enhancement, storage and distribution of these contents as mobility increases in human activity. The evolution of technology strives to make these contents available anywhere, anytime and efficiently. Communications networks with Content Service Providers are engineering solutions to get these contents closer to the user for great customer experience and reduce the Capital and Operations expenditures in doing this.

Content Delivery Networks (CDN) are systems for the efficient delivery of digital objects (e.g files with multimedia content as video on demand or other file types) and multimedia streams (e.g. live television streams) over IP networks to many end points and viewers [Binder 17].

CDN's are built via a mesh like network and managed by a functional entity that controls decisions about content distribution. This entity manages the records of content locations, distribution among all the nodes and makes the decision about the node that serves a client request. The figure below shows clusterized nodes representing CDN network where the parameter for putting them in a cluster may be due to geographic reason or content similarities.

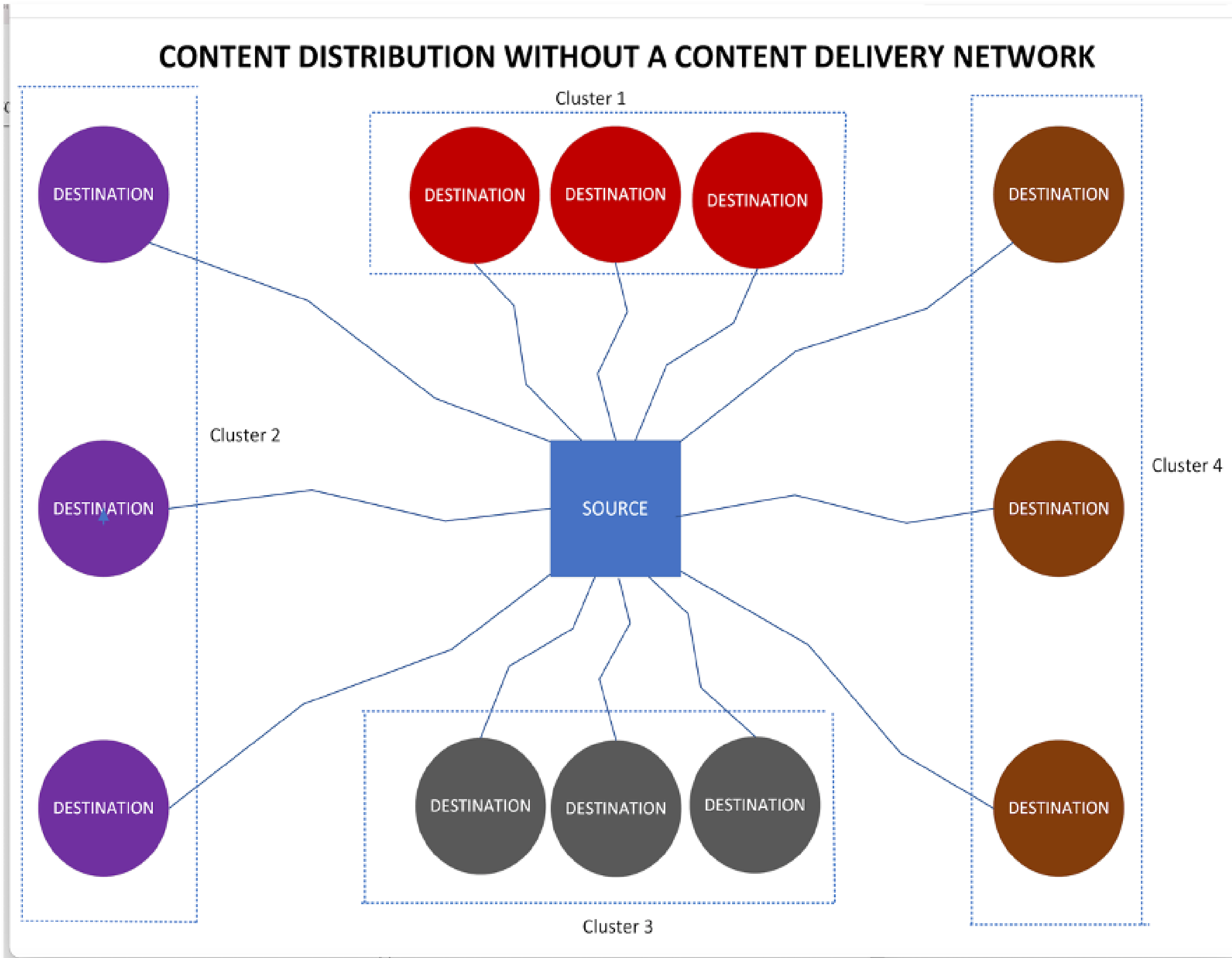


Fig 1: Content Distribution Without a Content Delivery Network

From fig 1 above, same traffic will have to move from one source to four destinations (cluster 1, cluster 2, cluster 3 and cluster 4) that may be in same geographical area. The destinations in a cluster may be close but without a CDN, same traffic will have to travel from source to destination for each request because traffic is not cached anywhere close. This is not an efficient use of resource.

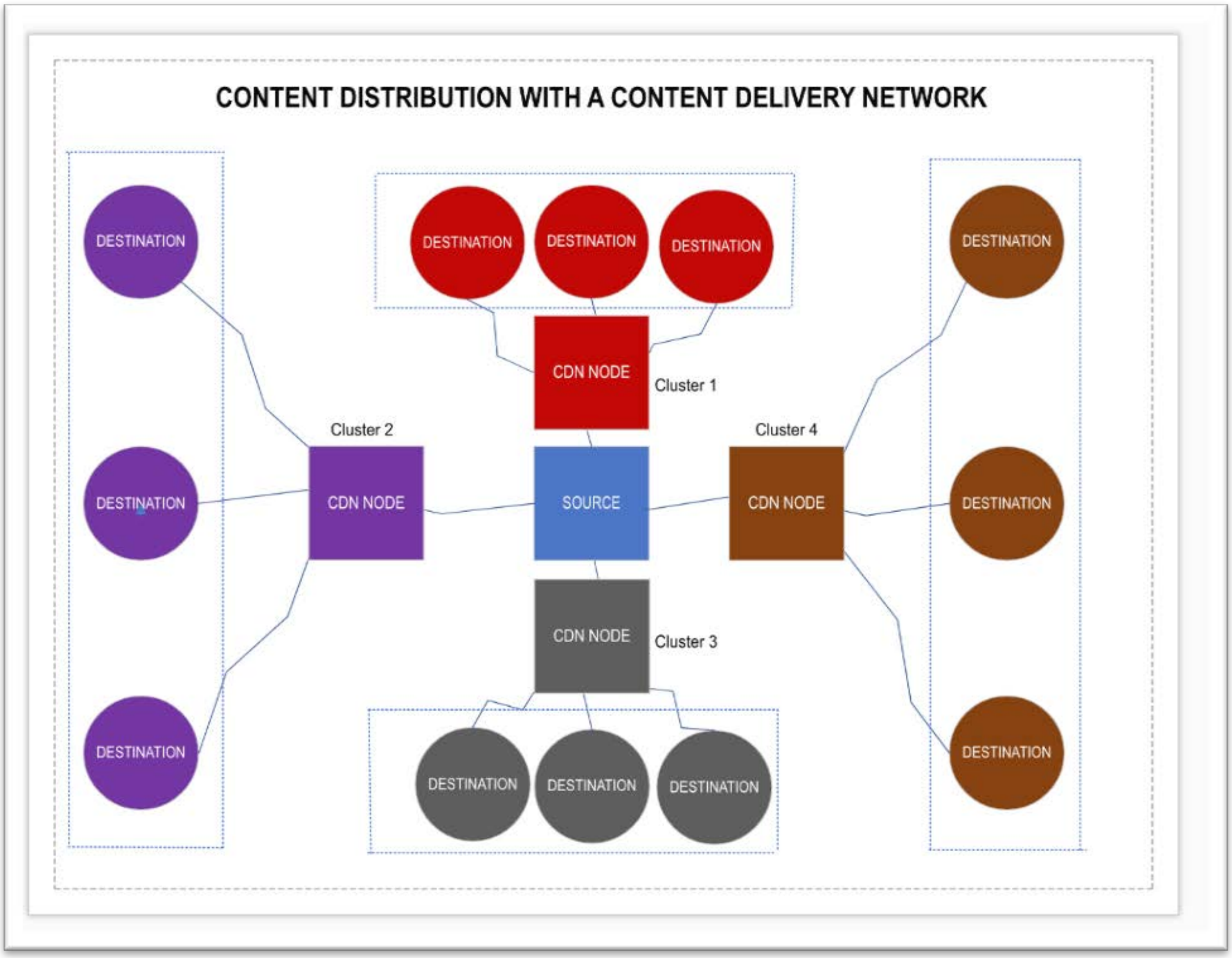


Fig 2: Content Distribution with A Content Delivery Network

A CDN as shown above in fig 2, brings traffic close to the destination and this make a huge difference in user experience and resource optimization. Each of the cluster will get traffic from the CDN node for its cluster. The CDN node gets content from the source and cache it so that any of the connected destination can get the content without having to go to the source.

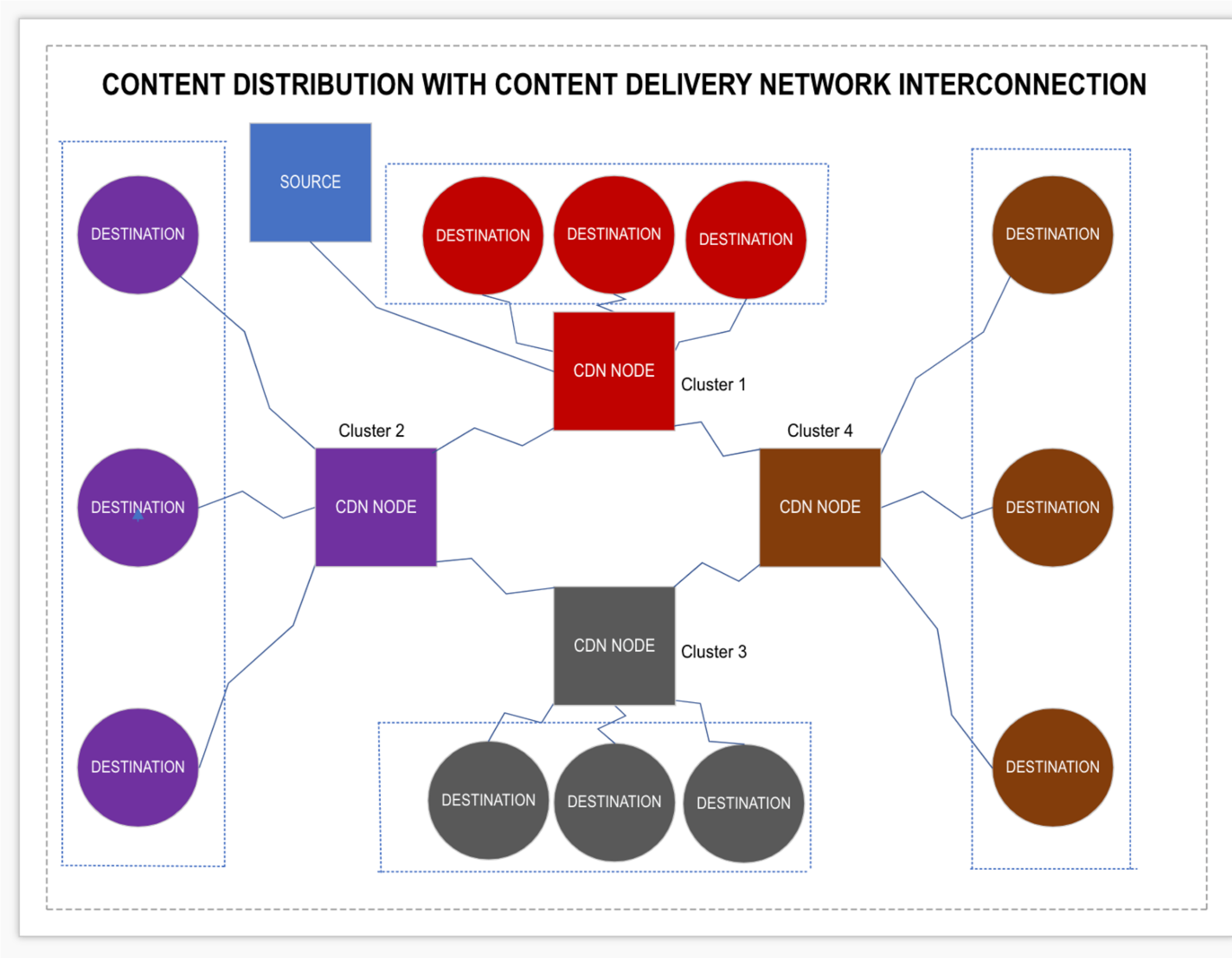


Fig 3: Content Distribution with Content Delivery Network Interconnection

Content Delivery Network Interconnection as shown in Fig 3, provides interconnection for all the CDN's thereby extending each of the CDN's footprint, overload traffic offload and capability. Each of the connected CDN can leverage on the infrastructure/services of any connected CDN to service the destination within its cluster.

High volume of content is transferred over the internet every second and the graphic representation of these interconnections shows the global internet backbone traffic will reduce with CDNI. This will be an efficient use of computing, storage and transport resource as traffic will not have to be resent over the long-haul and better user experience with lower latencies.

## 3.2 Summary

Content Delivery Network Interconnection brings a lot of gains when it comes to user experience, scalability and Total Cost of Ownership (TCO). The illustrations above show the longer distances content would travel without an interconnection of CDN's. This could lead to higher latencies, additional point of failure, higher operational cost, etc and potentially would affect the end user experience. We would then go into key terminologies to understand CDNI and its operation.

# 4. Content Delivery Network Interconnect Terminologies

## 4.1 Introduction

The terminologies below are frequently used in the description of CDNI operations and is required to be understood as we do a deep dive on CDNI.

CDNs require some basic features for interconnection. These features are required their design and operation;

Upstream CDN (uCDN) is one that redirects service request of its client to another CDN nodes for it to deliver the service to the client.

Downstream CDN (dCDN) is one that is serving content for the clients of another CDN.

Interconnection Control consist of CDN authentication, identification, exchange of basic data and bootstrapping of all the interfaces required for the proper execution of all other procedures.

Request routing is service redirection from one node of another CDN.

Content Distribution means sending content to dCDN.

Footprint Exchange consists of customers for which a downstream CDN can efficiently deliver content to.

Metadata Exchange: Metadata explains how a CDN manages content, this includes details of what to do with it and also who he can distribute it to. Metadata exchange functionality is accountable for information distribution from the uCDN to the dCDN when dCDN requires it.

Content Status Exchange permits the uCDN to get the status of content from the dCDN.

Report Exchange allows the uCDN to get specific data about the distribution process when a dCDN was delivering content for the uCDN.

Content Service Provider is a service provider that aggregates media content.

Footprint & Capabilities Advertisement Interface (FCI) Capability and footprint routing information to support dCDN choice for next user request is provided by this function.

Metadata Interface (MI) permits a dCDN to give content metadata. This is provided from uCDN.

Route Request Redirection Interface (RI) picks a delivery dCDN and redirects the service request accordingly. This ensures loop prevention for the service request.

Control Interface (CI) this function initiates an interconnection between two CDNs and bootstrap the interface of the other connected CDNI.

Logging Interface (LI) The exchange of content distribution and delivery log details via an interconnection is enabled by this function.

### 4.2 Summary

The explanation of the key words in CDNI operation sets a good foundation to proceed to the operations and lifecycle of a CDNI. This will enable the grasp of how a CDNI establishes a connection, operates and releases the connection. 360 degrees view of the operations gives a good understanding of CDNI lifecycle.

## 5. CDNI Lifecycle and Operations

### 5.1 Introduction

This section describes the lifecycle and operations of the CDNI. The lifecycle represents the period a request is made from CDNI - A to CDNI - B, the interconnection, user service processing and delivery and termination of the session. The operations here show the different operational model for establishing the interconnection.

Basic CDN Interconnection Lifecycle

The process starts when an Upstream CDN sends an interconnection request to downstream CDN, authentication happens and they both establish a connection. Once they are connected, they exchange footprint information which show the coverage and cost for each destination. They further exchange capability information so the CDN understand their service capabilities. The next thing will be to initiate specific content request and best path will be taken to provide requested service. Reporting and logging follows after which content is deleted.

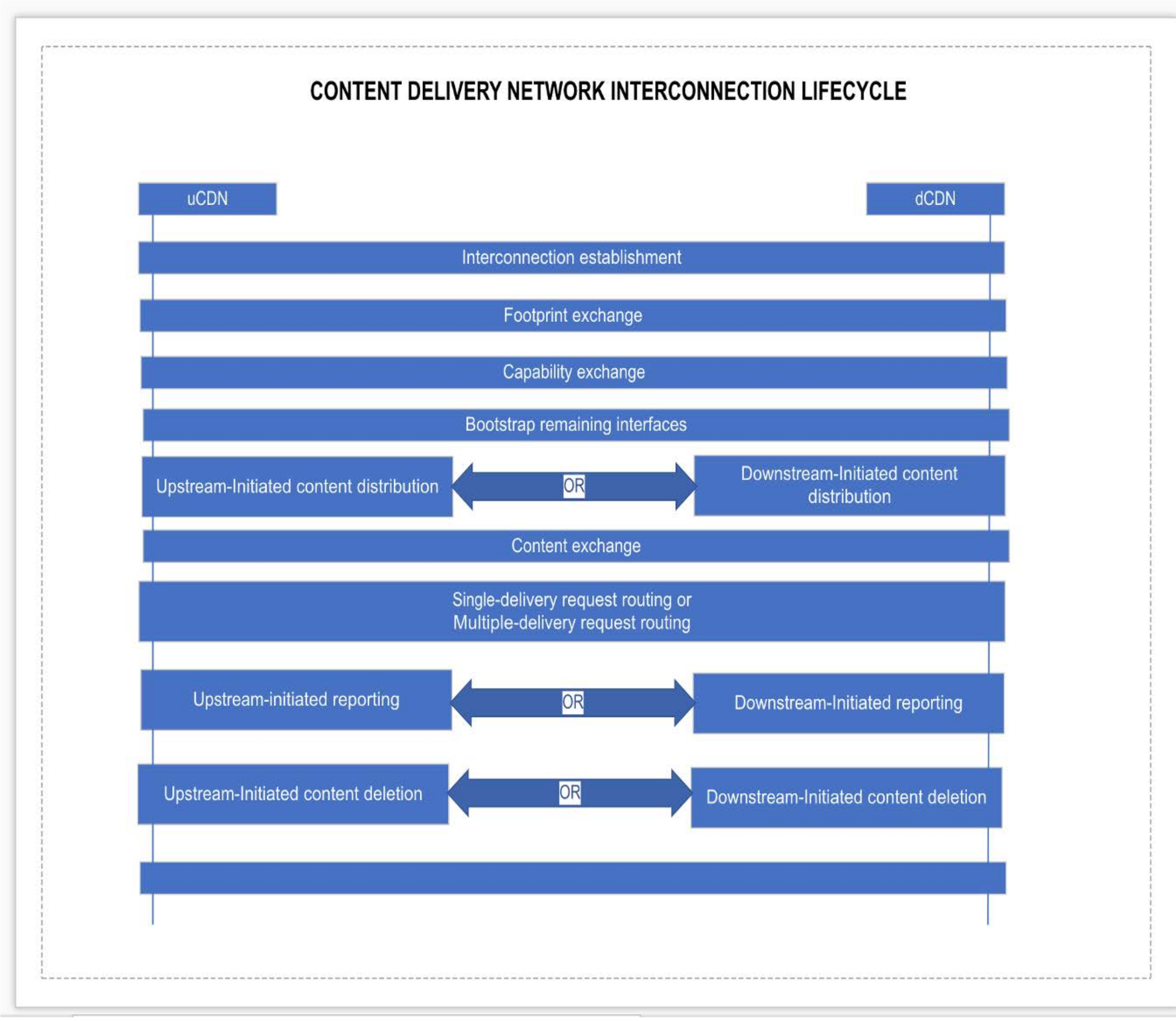


Fig 4: CDNI Interconnection Lifecycle

The figure 5 shows an operational model for a CDNI via a CDNI gateway.

It shows how a content service provider (CSP) establishes an agreement of content delivery service with a uCDN, which then makes another agreement of CDN interconnection with many dCDNs. If a remote user requests a Content Service Provider's content, the CDNI gateway of the uCDN will accepts this order on behalf of a CDN request router. It then checks the corresponding coverage information from the CDNI database to ascertain the adequate dCDN among the contracted dCDNs and subsequently allows the end user to request redirection to the dCDN.

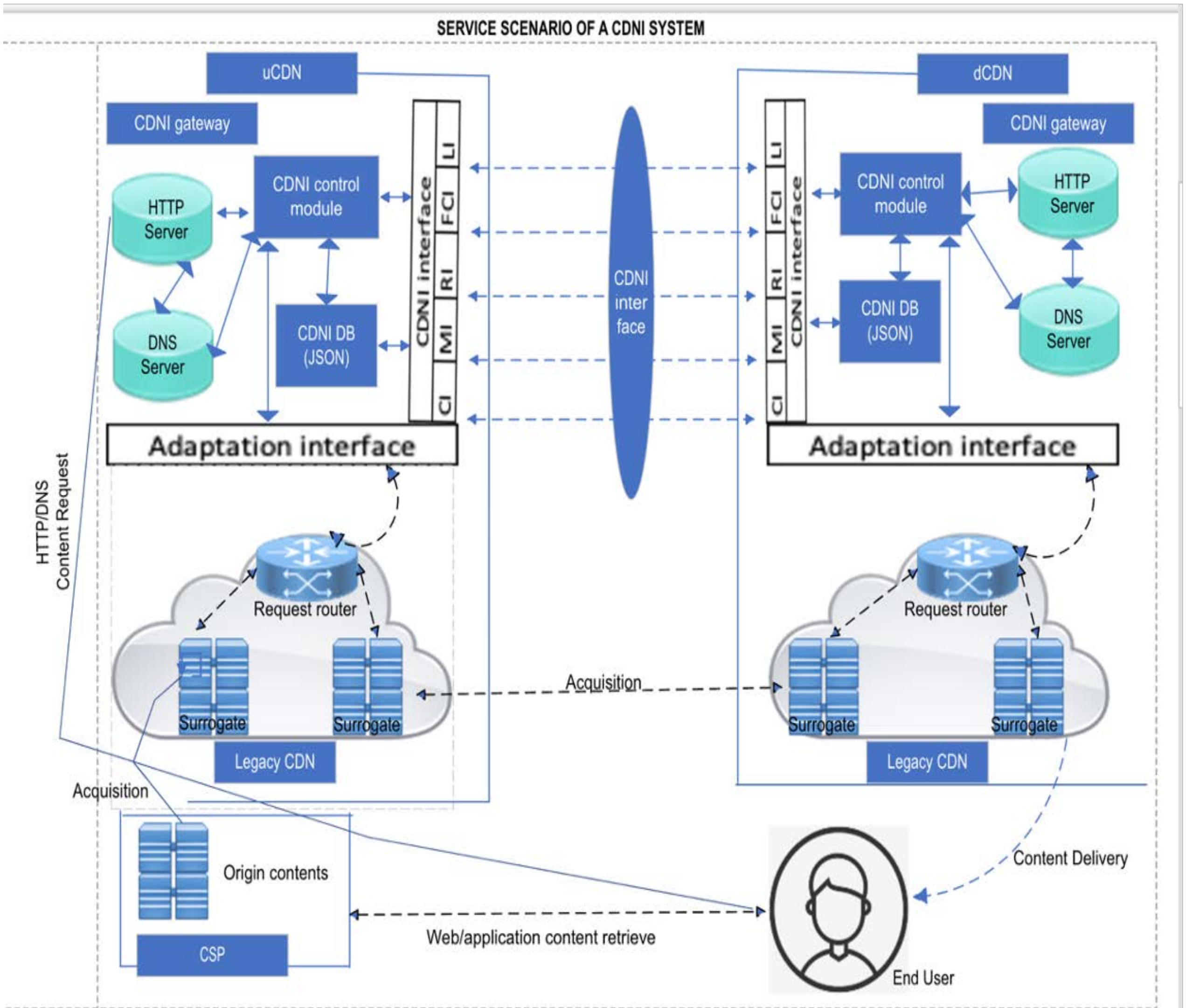


Fig 5: Service Scenario of a CDNI System

The dCDN receives this end user request and performs the same process the uCDN did, and it finally confirms there is no better dCDN than itself, it sends the order to its CDN request router to let the CDN deliver the content to the user.

The policy to ascertain the best dCDN drops the internet exchange link traffic clearly because content delivery in an internet exchange link only happens during the first acquisition by the uCDN for each service request.

Each surrogate of all CDNI participating CDN's keeps a greater quantity of content than a legacy CDN.

For looping/flooding prevention, a joint information of maximum number of allowed redirections hop count (MaxNumRedHops) and a CDN provider ID (CPI) list were used.

CDNI Operations Model

**Content Delivery Network Interconnection**

The figure below shows an operational model for a CDNI via traffic redirection;

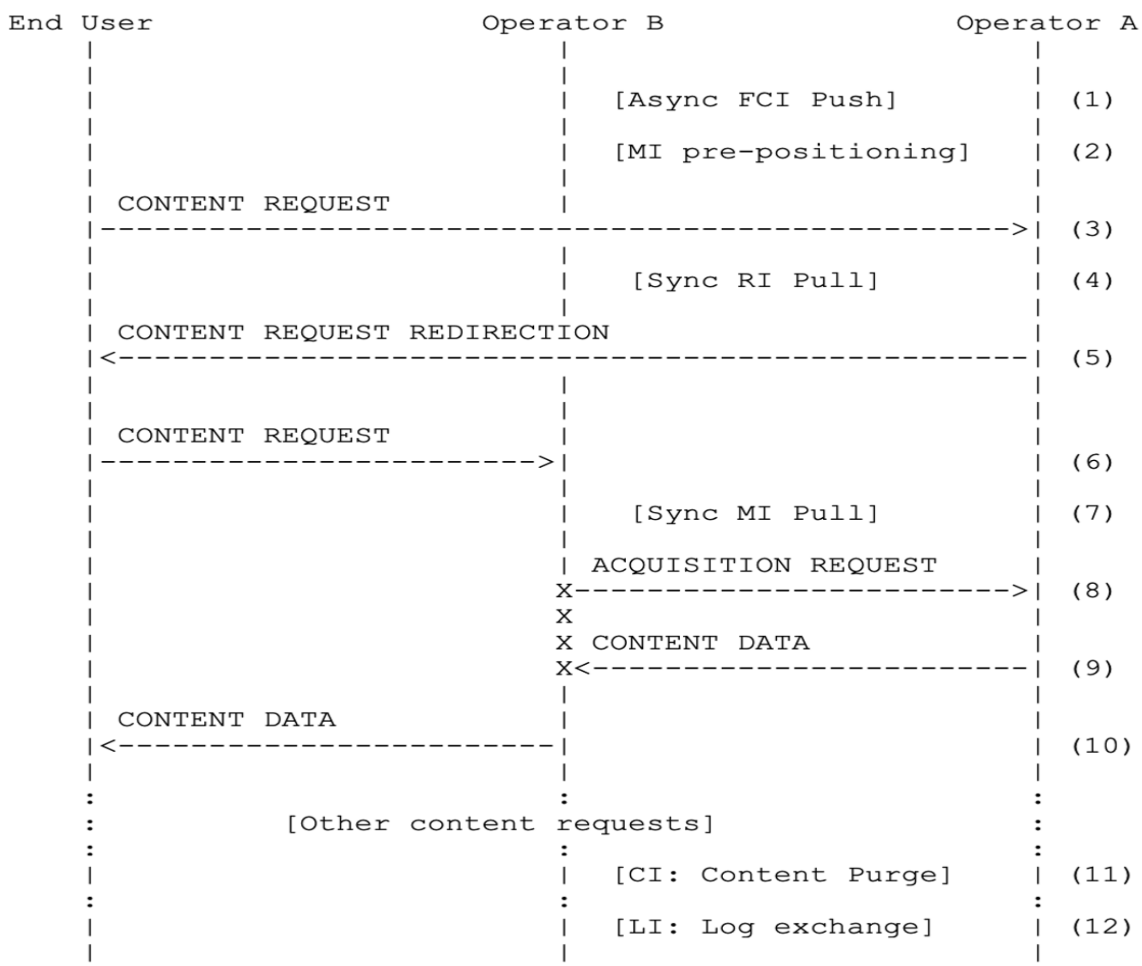


Fig 6: Overview of CDNI Operation [Peterson 14]

The operation shown in figure 6 above are as follows;

FCI is used by dCDN to advertise information relevant to its delivery coverage area and capabilities before any content request is redirected.

Before to any content request, the uCDN uses the MI to preposition CDNI Metadata to the dCDN, thereby making that metadata available in readiness for subsequent content requests.

A content request from an end user agent gets to the uCDN.

The uCDN may use the RI to synchronously request information from the dCDN regarding its delivery capabilities to decide if the dCDN is a suitable target for redirection of this request.

The uCDN redirects the demand to the dCDN by sending some responses (DNS, HTTP) to the user agent.

The user agent needs the content from the dCDN.

The dCDN may use the MI to synchronously request metadata associated with this content from uCDN, e.g, to decide whether to serve it.

If the content is not already in an appropriate cache in the dCDN, the dCDN may get it from the uCDN.

The content is sent to the dCDN from the uCDN.

The content is sent to the user agent by the dCDN.

Down the line, maybe at the request of the CSP (not shown) the uCDN may use the CI to instruct the dCDN to purge the content thereby ensuring it is not delivered again.

After one or more content delivery actions by the dCDN, a log of delivery actions may be provided to the uCDN using the link.

### 5.2 Summary

This section has explained the operational models of the CDNI and its lifecycle from service initiation through termination. This has given a good overview of the techniques used in establishing a connection and delivering service from source to destination. Terminologies like upstream CDN and downstream CDN is widely used in CDN interconnect. We can now look at different deployment models used in engineering a CDNI.

## 6. Deployment Models

### 6.1 Introduction

Deployment models represents different ways to interconnect the CDN for efficiency and high availability. This section will show different ways to connect CDN's and these have different input and output.

CDNI has different deployment models/topology as shown in this chapter and these models reflect the design and implementation configurations for resilience and efficiency;

Mesh CDNs

Wikipedia describes a mesh network as a local network topology where infrastructure nodes (i.e CDNs) connect directly, dynamically and non-hierarchically to as many other nodes as possible and cooperate with one another to efficiently route data from/to clients.

The idea of a mesh CDN is shown below as they all connect direct, dynamically and non-hierarchically as represented by a hub and spoke.

```
   -------------             -----------
  /    CDN A    \<==CDNI===>/   CDN B   \
  \             /           \           /
   -------------             -----------
        /\      \\                /\
        ||       \\               ||
       CDNI       \==CDNI===\\   CDNI
        ||                   \\   ||
        \/                   \/   \/
   -------------             -----------
  /    CDN C    \===CDNI===>/   CDN D   \
  \             /           \           /
   -------------             -----------
        /\
        ||
       CDNI
        ||
        \/
   -------------
  /    CDN E    \
  \             /
   -------------

===>  CDNI interfaces, with right-hand side CDN acting as dCDN
      to left-hand side CDN
<==>  CDNI interfaces, with right-hand side CDN acting as dCDN
      to left-hand side CDN and with left-hand side CDN acting
      as dCDN to right-hand side CDN
```

Fig 7: CDNI Meshing Example [Peterson 14]

CSP Combined with CDN

Content Service Provider can be combined with a Content Distribution Network. This will make the CDN house the CSP and give lowest cost to the content. As shown below any request to CSP in organization A will have to go through the CDNI established between organization A and organization B.

In this model, the Content service provider can be combined with the upstream or downstream content distribution network.

```
#####################################       ##################
#                                   #       #                #
#       Organization A              #       # Organization B #
#                                   #       #                #
#     --------       -------------  #       #  -----------   #
#    /   CSP  \     /   uCDN      \ #       # /   dCDN    \  #
#    |        |     |  +-----+    | #       # |  +-----+  |  #
#    |        |     |  | C   |    | #       # |  | C   |  |  #
#    |        |     |  +-----+    | #       # |  +-----+  |  #
#    |        |     |  +-----+    | #       # |  +-----+  |  #
#    |        |     |  | L   |    | #       # |  | L   |  |  #
#    |        |*****|  +-----+    |===CDNI===>|  +-----+  |  #
#    |        |     |  +-----+    | #       # |  +-----+  |  #
#    |        |     |  | RR  |    | #       # |  | RR  |  |  #
#    |        |     |  +-----+    | #       # |  +-----+  |  #
#    |        |     |  +-----+    | #       # |  +-----+  |  #
#    |        |     |  | D   |    | #       # |  | D   |  |  #
#    |        |     |  +-----+    | #       # |  +-----+  |  #
#    \        /     \             / #       # \           /  #
#     --------       -------------  #       #  -----------   #
#                                   #       #                #
#####################################       ##################

===>  CDNI interfaces, with right-hand side CDN acting as dCDN
      to left-hand side CDN
****  interfaces outside the scope of CDNI
C     Control component of the CDN
L     Logging component of the CDN
RR    Request Routing component of the CDN
D     Distribution component of the CDN
```

Fig 8: CDNI - CSP Combined with CDN [Peterson 14]

Combining CSP and uCDN

```
#####################################       ##################
#                                   #       #                #
#       Organization A              #       # Organization B #
#                                   #       #                #
#     --------       -------------  #       #  -----------   #
#    /   CSP  \     /  uCDN(RR)   \ #       # /  dCDN(RR) \  #
#    |        |     |  +-----+    | #       # |  +-----+    |  #
#    |        |*****|  | RR |==========CDNI=====>| RR |   |  #
#    |        |     |  +-----+    | #   RR  # |  +-----+    |  #
#    |        |     \             / #       # |           |  #
#    |        |      -------------  #       # |uCDN(C,L,D)|  #
#    |        |                     #       # |  +-----+  |  #
#    |        |                     #       # |  | C |    |  #
#    |        |*******************************|  +-----+  |  #
#    |        |                     #       # |  +-----+  |  #
#    |        |                     #       # |  | L |    |  #
#    |        |                     #       # |  +-----+  |  #
#    |        |                     #       # |  +-----+  |  #
#    |        |                     #       # |  | D |    |  #
#    |        |                     #       # |  +-----+  |  #
#    \        /                     #       # \           /  #
#     --------                      #       #  -----------   #
#                                   #       #                #
#####################################       ##################

===>  CDNI Request Routing Interface
****  interfaces outside the scope of CDNI
```

Fig 9: Combining CSP and Partial CDN [Peterson 14]

Internet Exchange Points (IXP)

This is another model where practitioners are advocating for internet exchange points to be thoroughly designed and interconnect for efficient routing of contents. If content service providers put their content at IXP, it will improve performance since all the local providers connect to IXP.

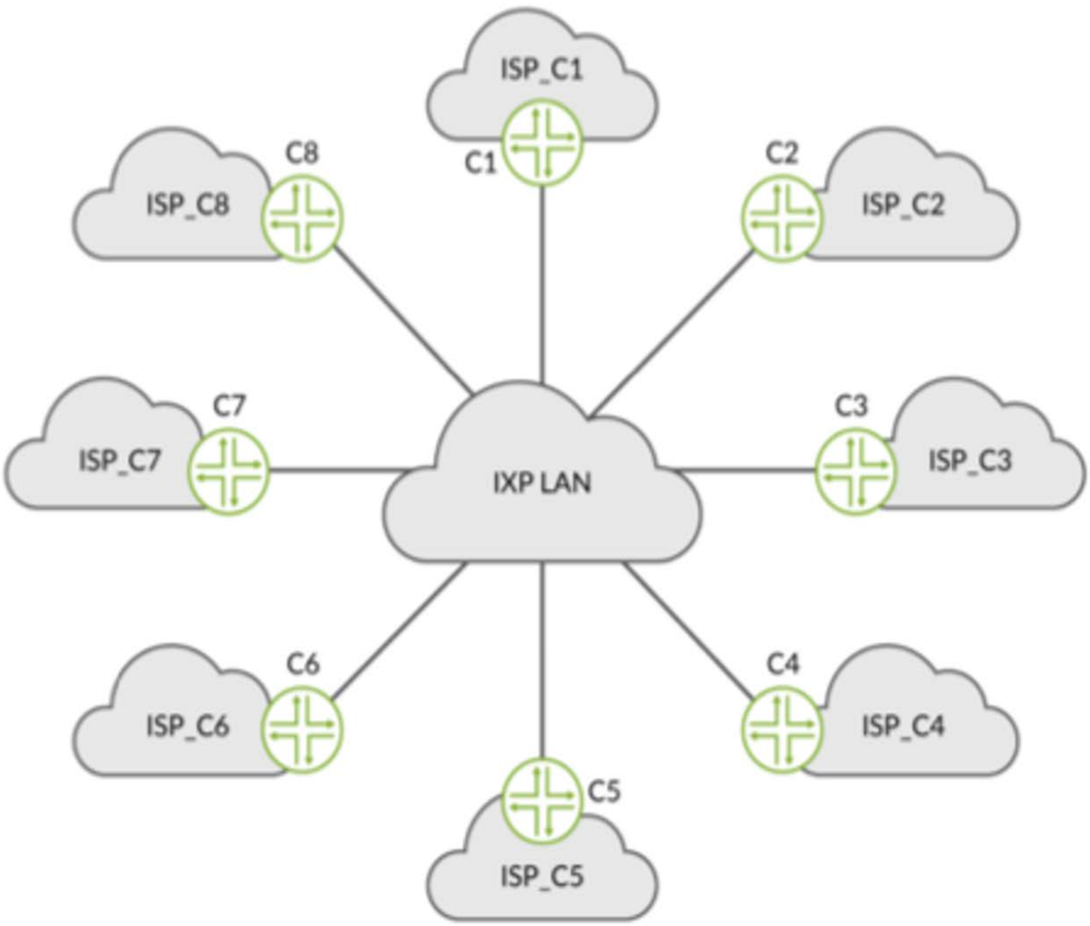


Fig 10: Internet Exchange Point (Source: Juniper)

Border Gateway Protocol (BGP) is used by the internet service providers to announce their prefix. Once service providers establish BGP peering, they are able to share routes which show cost to different destination. This enables a provider to follow the route with lowest cost.

### 6.2 Summary

CDNI deployment models has shown us different way of establishing a connection between CDNs. Each model has Pros and Cons that time has not permitted their enumeration.

We can draw some point from the models presented here that mesh network offers high availability as all the nodes are dynamically connected.

Internet exchange points will also be interesting to review alongside the other models as the interest is to engineer a solution that is very efficient with low cost.

## 7. Challenges of CDNI

### 7.1 Introduction

Together with the benefits of CDNI also comes with challenges of privacy, confidentiality, authorization, vulnerability exposures, etc. this section looks at different challenges of CDNI.

CDNs are increasingly deployed for their efficient content delivery and are often integrated with Software Defined Networks to achieve centrality and programmability of the network. These networks are also an attractive target for network attackers whose main goal is to exhaust network resources. An attack approach is to over-flood the OpenFlow switch tables containing routing information. Due to the increasing number of different flooding attacks such as DDoS, it becomes difficult to distinguish these attacks from normal traffic when evaluated with traditional attack detection methods [Nishat 18].

Most of the security incidents that come up in CDNI are related to the breach or lack of trust. Issues may arise when one CDN uses its ability to distribute content of another CSP to distribute it to parties who may not be authorized to receive it. Some geographical, cultural or political implications arise when this happens and could lead to litigation or diplomatic issues.

CDNs today use means like time-of-day restrictions, geo-blocking and URI signing to control access to content. This mechanism should be replicated for CDNI.

Each CDN peer needs to ensure it will not be used as "open proxy" to send content on behalf of a mischievous CSP.

Most of the CDNs are autonomously designed and managed by a single entity. This has limited them to scale and interconnect with other CDNs. Infrastructure overhaul will be required for them to interconnect with other CDNs before they can interoperate.

### 7.2 Summary

The challenges of the CDNI stated above requires careful consideration before global adoption as contents can reach thousands of miles in milliseconds but can have decades of effects of audience. There are a lot of litigations around content distribution and consumption.

# 8. Summary

In this draft, Content Delivery, Content Delivery Network and Content Delivery Network Interconnection (CDNI) were explained with network architectural diagram. The benefits of the CDNI were highlighted with tops being better resource utilization and user experience.

Different delivery models like mesh, Content Service Provider Combined with CDN, Content Service Provider with partial CDN and CDNI with a gateway were reviewed with the similar outcomes of resource optimization.

Operations of the CDNI particularly how traffic is redirected between the upstream CDN (uCDN) and downstream CDN (dCDN) was outlined.

We finally looked at the challenges of Content Delivery Network Interconnections like flooding, unauthorized distribution, accounting, and infrastructure interoperability which have to be put into consideration as CDNIs begin to be implemented.

CDNI promises better resource utilization and great user experience, however, the security and interoperability issues need to be strongly addressed before implementation.

# 9. List of Acronyms

- CDN - content delivery network
- CDNI - content delivery network interconnection
- CSP - content service provider
- uCDN - upstream content delivery network
- dCDN - downstream content delivery network
- URI - Uniform Resource Identifiers
- RR - Request Routing
- CAPEX - Capital Expenditure
- OPEX - Operational Expenditure
- IXP - Internet Exchange Point
- FCI - Footprint & Capability Advertisement Interface
- RI - Request Route Redirection Interface
- MI - Metadata Interface
- BGP- Border Gateway Protocol

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