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A Review on Content Delivery Networks and Emerging Paradigms

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Abstract- In telecommunications, Content Delivery Networks (CDN) main objective is to overcome the essential challenges of the Internet. The core principal at the foundation of this technology is the geographical distribution of contents from servers on the network edge closer to the customers, improving the customer's perceived performance while restricting the costs. "Content delivery via the Web, as an intrinsic part of improving Web performance – maximize bandwidth, improve accessibility, and maintain correctness via content replication - ensuring fast, reliable applications and Web services for the customers." This paper focuses on CDN, pointing out the components, existing emerging paradigms and review of literatures on the existing strategies for content distribution.
Index Terms- content delivery, networks, web services, emerging paradigms, replication, distribution

1. INTRODUCTION

According to (Mukaddim, Rajkumar, & Athena, 2008) and (Citrix, 2014) Content Delivery Networks (CDNs) are large distributed infrastructures of replica servers placed in strategic geographical locations. "By duplicating content of origin server on replica servers, the content is delivered transparently and effectively to end-users with reduced latency. A CDN is an overlay network that gives more control of asset delivery while monitoring network load. It strategically places servers closer to the user, reducing response time and network congestion. Thereby, overcoming the vital limits of the Internet such as user perceived quality of service when accessing Web content (Al-Mukaddim & Rajkumar, 2007). Content Delivery Networks have gained a prevalent role among application service providers (ASPs) and recently telecom operators. The rapid acceptance of broadband access among other factors, has caused massive growth in network traffic as users perceived the growth of the Internet, over the last decades. The rapid developing nature of the Internet brings new challenges in managing and delivering robust contents (Mukaddim, Rajkumar, & Athena, 2008).

A Content Delivery Network (CDN) has a combination of a number of components that work together to achieve its aims. Components such as content delivery, request-routing, distribution and billing." The content delivery comprises of a set of replica servers on the network edge, also called surrogates, that deliver duplicates of content to end-users. The request-routing handles the responsible to directing user's request to appropriate replica servers. "This in turns, networks with the distribution, to keep an updated view of the content stored in the replica servers and ensures consistency of content in the cache storages. The billing keeps logs of network accesses and records the usage; for traffic reporting and usage-based billing (Al-Mukaddim & Rajkumar, 2007). CDNs that utilizes conventional web technologies for its replica servers are also called traditional CDNs. The replica servers are either dedicated or storage space in a shared infrastructure e.g. Akamai, Limelight and Level 3. In recent times, new paradigms for CDN architectures has emerged such as cloud computing and Network Functions Virtualization (NFV) (Jagruti, Mohammad, Roch, Halima, & Wessam, 2016).

The major drive for CDN customers is to distribute and deliver robust content to the end-users on the Internet in a reliable and timely manner." These customers include media and Internet advertisement companies, data centers, Internet Service Providers (ISPs), online music retailers, mobile operators, consumer electronics manufacturers, and other carrier companies. In practice, for dynamic Web content, CDNs are typically utilized in hosting static Web content (Al-Mukaddim & Rajkumar, 2007).

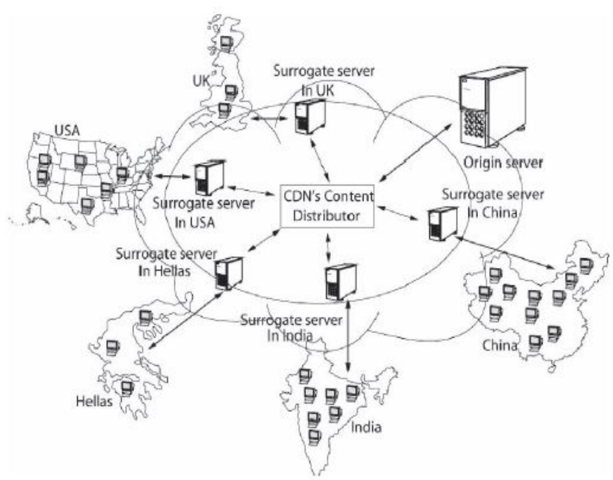

Figure 1: Model of a Content Delivery Network (Mukaddim, Rajkumar, & Athena, 2008)

1.1 History of Content Delivery Network

(George & Athena, Insight and Perspectives for Content Delivery Networks, 2006) highlighted a brief historical background of Content Delivery Network along with some notable events as stated below:

In 1998 CDNs first appeared and companies recognize they could earn and save more money by hosting more of their

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Websites on CDNs, providing better reliability and scalability without expensive hardware. “This increased the profits of several companies in 1999, by becoming the specialists in providing fast and reliable delivery of Web content. Following this in 2000, CDN is a vast market producing million with the potential to keep rising through time. 2001 witnessed the flash crowd event which occurred as a result of many users accessing a Website simultaneously, flooding popular news sites with requests about the terrorist attacks in the U.S., caused a serious caching problem; thus, making the websites unavailable (Jaeyeon, Balachander, & Rabinovich, 2002).” These events earn more sales income for CDN providers, as CDNs provides the preferred level of protection to Websites against them. This prompted large-scale Internet Service Providers to build their own CDN functionality, providing customized services as at 2002.

By 2004, over 3,000 companies use CDNs, spending millions monthly as many CDN providers are working on bringing Web services closer to users. “In recent times, CDN revenue for both streaming video and Internet radio is projected to grow, spending millions in the conveyance of news, film, sports, music, and entertainment; with the adoption of new and emerging paradigms.

1.2 Content Delivery Network Paradigms

a. Traditional CDN

A traditional CDN architecture comprises of the following components: origin server, replica server and end users. The origin server houses the actual content and it’s the content provider’s main server. Replica servers’ stores duplicates of the content and are retained and managed by CDN providers. The operations of a CDN can be characterized into three distinct phases; Content Distribution – contents in the origin server are replicated on replica servers; Request Routing – end user’s requests are redirected to appropriate replica servers; and Content Delivery – content is retrieved from replica servers and delivered to the end users (Jagruti, Mohammad, Roch, Halima, & Wessam, 2016).

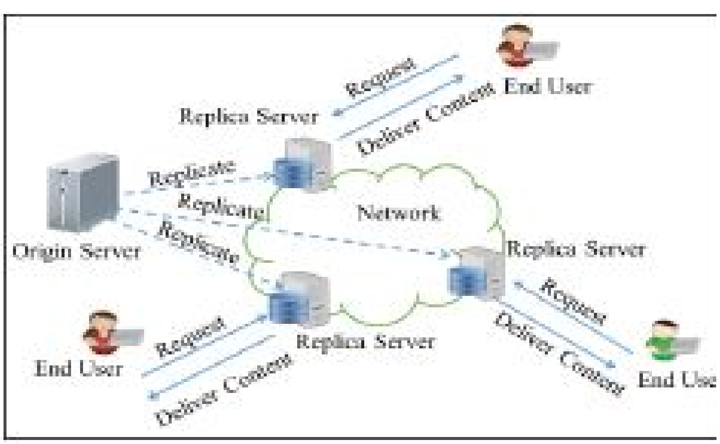


Figure 2: General view of a Traditional CDN (Jagruti, Mohammad, Roch, Halima, & Wessam, 2016)

b. Cloud-based CDN

A cloud-based CDN has the three distinct phases of CDN operations present in a traditional CDN architecture.” The CDN provider offers its own cloud based CDN by leasing Infrastructure as a Service (IaaS) resources from cloud providers and utilizing virtual networking technology to deliver a network overlay between diverse cloud providers from access network providers. For replica server placement, the CDN provider first recognizes potential end-users in a geographically defined service area called clusters, partitioned from the service area. “With each cluster assigned a cloud provider, the replica servers are then executed and placed on cloud sites. The execution and placement of the replica servers are done with consideration to the necessities of end users located in the service cluster (Chrysa, Aris, & Symeon, 2013) (Jagruti, Mohammad, Roch, Halima, & Wessam, 2016).

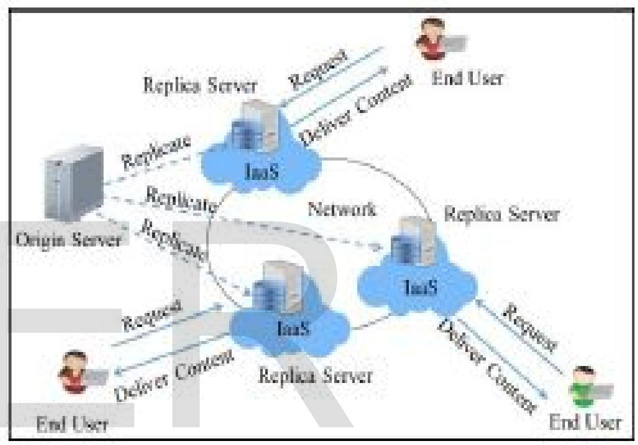
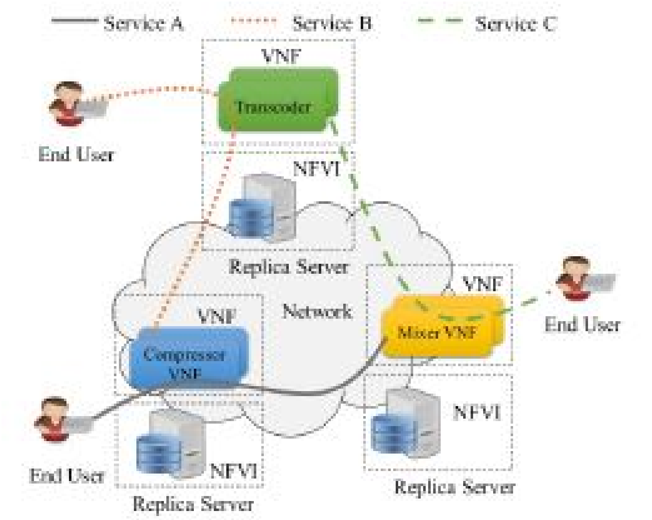


Figure 3: General view of a Cloud-Based CDN (Jagruti, Mohammad, Roch, Halima, & Wessam, 2016)

c. Network Functions Virtualization (NFV) Based CDN

NFV for virtualizing CDN entities such as cache nodes, request routers, was specified by European Telecommunications Standards Institute (ETSI). This design is a combination of several components such as cache nodes and CDN controller. The CDN controller is a centralized component and the Nodes are distributed within the network. The objective of the CDN controller is to select a cache node or more for responding to end user request and redirecting the end user to the designated cache Node.” “The cache node answers the end user request and deliver the requested content to the end user (ETSI, 2013).” A current advance in NFV based CDN show use of NFV paradigm for robust content delivery where transcoding functionality is virtualized in addition to the CDN entities (Niels, et al., 2015).



“Figure 4: General view of a NFV-Based CDN (Jagruti, Mohammad, Roch, Halima, & Wessam, 2016)

1.3 Components of a Content Delivery Network

For CDN to be efficient for a substantial number of users, the replica servers (also called Surrogates) must be made available at different geographically spread locations in amass.” The detailed distribution of the replica servers can optimize performance and reliability of the CDN. (Novella, Emiliano, & Salvatore, 2004) highlighted some important components required in the establishment of a CDN, namely:

Replica placement mechanisms – This select the replica server locations and pre-fetches the appropriate content prior to the request arrival. Thus, the replica servers are pro-actively updated. This is required to actively handle the fluctuating traffic state.

Content update mechanisms – This actively and automatically check for changes, retrieves and updates content from the origin server to the replica servers on the network edges, guaranteeing content newness.

Active measurement mechanisms – “This is supplementary to the cooperative access routers for real-time picture access of the Internet traffic, allowing faster routing of user request to the replica servers in any type of traffic circumstances.

Replica selection mechanisms – This is supplementary to the cooperative access routers to precisely detect the nearest and most accessible replica server from which the end user’s requests can be retrieved and required content delivered.” A robust service uses access control and load balancing to keep servers from getting overloaded.

Re-routing mechanisms – This allows swift re-routing of content requests in response to traffic bursts and congestion.

1.4 Types of Content and Services in a Content Delivery Network

Over the years, a number of architectures and technologies have been accepted in designing and developing a CDN, considering the heterogeneous nature of the content to be delivered. These contents often referred to as digital content or rich multimedia includes audio/video streaming media, html pages, images, formatted documents or applications. The contents are provided by third parties such as media companies, large enterprises, broadcasters, web/Internet service provider and so on.” The characteristics of these contents were analyzed by (Novella, Emiliano, & Salvatore, 2004) as follows:

Static web based and Web storage services – These are static content (static html pages, images, document, software patches, audio and/or video files) or content that change with low frequency or timely. For web storage, Supplementary features for processing at the origin server or at the replica server such as log management and secure file transfer.

File transfer services – Global software delivery (patch, virus definition), e-learning, video-on-demand, comprehensive medical information shared between doctors and hospitals, and so on.

“E-commerce services – Shopping charts for online shopping stores can be stored and maintained at the replica server. Also billing and payment transactions can be handled at the network edge: requiring trusted transaction-enabled replica servers.

Web application – The upside to utilizing a CDN infrastructure with dynamic web pages is to retain the application and its processing activity on the origin server while filling the replica servers with the content that most frequently constitutes the dynamic web pages.” An alternative method is to duplicate both the application and the content at the replica server.

Directory services – In some cases, frequent query results or a subset of directories can be cached at the network edge. Thus, providing access to database servers.

Live or on-demand streaming – In this case, the replica server must have streaming capability.

2. CLOUD-BASED CONTENT DELIVERY NETWORK

2.1 How it Works

The Internet Protocol makes communication between various network entities within the Internet possible. The requirement dates as far back as 1981 and was very simple in design conception; therefore, routers could operate at increasing speeds pushing intelligence towards network edges. “Some efforts are being made in the requirement of IPv6 to adapt the protocol, such as address namespace and scalability. CDNs redirects depending on the geographical state in the network according to the previous placement of the replica servers. The performance of the redirection mechanism is very important and done at several levels. However, CDNs have to work at superior application layers for lack of anycasting. Respecting transport layers, both Transfer Control Protocol (TCP) and User Datagram Protocol (UDP) are utilized by CDNs;” the former allows a slow but reliable communication of control and content information, while the latter allows a non-reliable but fast delivery

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mechanism, both for resolution and streaming processes (Molina, Palau, Esteve, & Lloret, 2004).

The following steps highlights how the CDN works (Jussi, 2009) (John, et al., 2016):

a. Client sends HyperText Transfer Protocol (HTTP) content request to origin server
b. Once Domain Name Server (DNS) resolves the replica server's name
c. The client's request is directed to the replica server on the network edge
d. Which then requests content from the appropriate source
e. "And satisfies the client's request by serving the content from the replica server closest to the end-user, and records its completion

2.2 Benefits of Content Delivery Network

(Jagruti, Mohammad, Roch, Halima, & Wessam, 2016) stated the following as the primary benefits offered by a CDN:

a. It reduces load on origin servers by divesting the delivery tasks to replica servers,
b. It reduces latency by hosting content closer to end-users,
c. It improves content availability due to several delivery points, and
d. It reduces network backbone overhead and diminish congestion by avoiding long distance broadcast of contents such as videos.

2.3 Advantages of a Cloud-Based Content Delivery Network

Cloud-based CDN has introduced a number of opportunities and advantages that sets it apart from the traditional CDN. These advantages are discussed by (Meisong, et al., 2015) and includes:

Pay-as-you-go model: This allows the users to consume the content utilizing a pay-as-you-go model. Hence, making it more cost-effective than owning the physical infrastructure.

Increased point-of-presence: The content is moved closer to users, due to the omnipresence of cloud. This reduces the transmission latency, thus increasing the range and visibility of the CDN on-demand.

Interoperability: The cloud allows content providers to reach new markets, new geographical regions and support roaming users." Content providers can take advantage of current cloud providers in the different regions to dynamically host replica servers.

Support for variety of applications: The cloud been able to support dynamic changes in load, will facilitate the sustenance of diverse kinds of applications.

2.4 Drawbacks of Content Delivery Network

Some drawbacks of content delivery network were highlighted on the AccuWebHosting website by (Vaghasia, 2017) and it's has follows:

a. You will have to spend some more cash to avail this service.
b. Sensitive information stored on the content delivery network are opened to potential security vulnerabilities.
c. Application developers may find it difficult to use content delivery network as it may contain most updated static data.
d. Additional DNS lookup is required, since content will be served from replica servers.
e. This creates additional "point of failure". If the content delivery network goes down, you may lose content visibility.

3. REVIEW OF EXISTING RESEARCH WORKS

The focus of related work is to study the possible ways in which contents are being delivered and the existing tools and techniques employed in content delivery. Other studies also support the conclusion that, with the rapid adoption of broadband services and the erratic change in customer usage patterns, content delivery network should be utilized to deliver a better customer experience.

"Over the years, several frameworks have been proposed to deliver a better customer experience to broadband users." An open network architecture was proposed by (Hans-Jorg, Peter, & Erik, 2001) based on broadcast and telecommunication systems respectively. All radio access can tunnel IP packets, multicast as well as unicast and can be transmitted using broadcast. Considering that for individual point-to-point communications, broadcast offers great capacity and efficiency compared to the telecommunication systems, because of the asymmetry economical area coverage. "Also, the advent of broadband access networks, the request for streaming video is increasing. With the traditional Web service model, IP-based streaming content can be useful, but the user quality of service cannot be compared with cable, satellite, or broadcast television. Subsequently, broadcasting technologies allow little or no on-demand access to video content." Thus, limiting user's choices.

(Charles, et al., 2001) proposed a content delivery network architecture for distributing, storing, and delivering high quality streaming media over IP networks called Prism (Portal Infrastructure for Streaming Media). "This receives multimedia content from live sources and other portals, such as content provider, encode and packetize it, and then stream it into the Prism IP network infrastructure to be received and displayed by end-users. Thus, allowing it to be viewed on-demand, and make available fast-forward and rewind functions." (Molina, Palau, Esteve, & Lloret, 2004) provided further knowledge about Content Delivery Network protocols, applications and how intelligence is being pushed towards the network edges with significant deference to internetworking, the network and transport layer respectively. How content delivery networks work, by redirect client's requests depending on their geographical position in the network giving by the placement of replicas. Furthermore, the importance of the performance of the redirection mechanism. Considering that, since any-casting would not be available until IPv6, content delivery networks work at the application layers. Utilizing both Transfer Control Protocol and User Datagram Protocol, for resolution and streaming processes. This is effective for wide-area networks and the Internet, where network traffic may result in poor quality of service.

As the digital market grew with the increasing number of broadband access, so also was the widespread of evolving audiovisual services. With users persistently requesting state-of-the-art services for exchanging and sharing their own multimedia contents. In attempt to meet these needs, (Yolanda, José, Alberto, Manuel, & Martín, 2009) proposed a system that broadcasts user-generated audiovisual contents for devices in a mobile network based on the Digital Video Broadcasting-Handheld (DVB-H) broadcasting standard. "This utilizes IP DataCast (IPDC), for the delivery of contents and services, which includes a unidirectional DVB broadcast path and a bidirectional mobile path for interactivity purposes. Due to the limited battery life of handheld devices, DVB-H utilizes time-slicing technique—where burst of data is received periodically—thus leading to significant power savings. And also, offers diverse value-added services (such as quality of service), which in turn enhances user experience. Consequently, (Jernej, Miha, & Matevž, 2013) implementation Hybrid Broadcast Broadband Television (HbbTV). This utilizes the free digital terrestrial television (DTT) broadcasting frequency spectrum capacities to communicate selected Internet content and ensure a sort of Internet experience via TV devices." Digital broadcasting enables the delivery of web-based content through applications mechanism. "Providing an open technology platform that combines Television and Internet services as a method of content delivery.

Although, content delivery networks are a good source of revenue for Internet Service Providers (ISPs), they pose a significant challenge in terms of huge volume of content delivery traffic. While content delivery networks may consider the user's performance as an optimization criterion, they currently do not consider any of the ISP's constraints." Resulting in the ISP's "lost control" over a major part of its traffic. In attempt to overcome this deficiency, (Ingmar, et al., 2012) proposed an architecture called Provider-aided Distance Information System (PaDIS). "This improves how users are assigned to servers based on the observation of the ISP DNS resolver, and application of aggregation rules defined by the PaDIS administrator. Information are gathered about the network's state from numerous sources and an up-to-date view of the network is maintained. Furthermore, information about servers and up-to-date network view are combined to improve content delivery." Alternatively, the use of set-top boxes located within users' homes to aid content delivery based on geographically spread groups of "last-mile" CDN servers belonging to multiple ISPs. "(Joe, Stratis, Laurent, & Fabio, 2012) proposed a set of scalable, adaptive mechanisms to cooperatively manage content replication and request routing. Relying on primal-dual methods and fluid-limit techniques.

But, with the increasingly susceptibility to the flash crowd problem, in which requests overcomes some aspect of the network, or bandwidth, or transaction-processing infrastructure." The ensuing overload can bring down the network or cause abnormally high response times — translating into lost revenue or poor user experience. According to (John, et al., 2016), Akamai's infrastructure can handle flash crowds by assigning more servers to locations experiencing high request load, while serving all clients from nearby servers having the requested content. It governs this as follows: nearest to a server, availability of the server, likelihood of servers carrying the content for each user in a data center. An Akamai site might hold dozens or more servers within any data center; the system allocates content to the minimum number of servers to maximize system resources.

The emerging commercial over-the-top (OTT), on-demand and live content broadcasting platforms, ushering in new players called Content Providers (e.g. Akamai, Netflix); are faced with great challenges of accommodating large scale dynamic viewer populations. "Thus, unveiling the utilization of new computing paradigm such as cloud services, virtualization and multiple CDNs for content delivery. (Vijay, et al., 2012) unreeled Netflix, who recently has resorted to the use of cloud services (e.g. Amazon AWS), multi-CDNs, and other public computing services (e.g. Amazon SimpleDB, S3, Cassandra, UltraDNS and Microsoft Silverlight). Also, (Bo, et al., 2017) proposed LiveJack, a novel network service to allow CDN servers to seamlessly leverage ISP network edge cloud resources. It can elastically scale the serving capacity of CDN servers by integrating Virtual Media Functions (VMF) in the network edge cloud to accommodate flash crowds for very popular contents." And utilizes transparent "session hijacking" techniques, to facilitate live content delivery with high scalability, bandwidth efficiency, and flexible service options.

4. DISCUSSION

From the literatures reviewed various content delivery architectures were proposed. These architectures aimed at providing contents (multimedia) to end users at optimum network performance.

These architectures are categorized into three groups: Hybrid, Novel and Emerging paradigms respectively. The categorization is based on the architectural components: hybrid comprises of broadcasting and telecommunication services; novel comprises of various innovative techniques; and emerging paradigms comprises of computing and networking technologies such as cloud computing and network functions virtualization services.

Table 1: Categorization of Proposed Architectures

s/n	Proposed Architectures	Literatures Reviewed

1	Hybrid	(Hans-Jorg, Peter, & Erik, 2001) (Jernej, Miha, & Matevž, 2013) (Yolanda, José, Alberto, Manuel, & Martín, 2009)
2	Novel	(Charles, et al., 2001) (Ingmar, et al., 2012) (Joe, Stratis, Laurent, & Fabio, 2012)
3	Emerging Paradigms	(Bo, et al., 2017) (John, et al., 2016) (Molina, Palau, Esteve, & Lloret, 2004) (Vijay, et al., 2012)

These proposed architectures, though effective in reaching their specific objectives; collectively suffers from matching the cost of acquiring traditional infrastructures, the cost of positioning at the network edge closer to the users, the quality of service and content delivery. Therefore, there is a need to improve on existing content delivery networks to mitigate the aforementioned issues.

5. CONCLUSION

In this paper, a state-of-the-art survey of CDN and an insight into various literatures on existing content delivery technologies was presented. CDNs rely on a proactive distribution of content replicas to geographically distributed servers on the network edge closer to the end users." The redirection of a request to the best suitable replica is achieved by cooperative access routers that are capable of taking measures regarding the performance of the available replica servers and performing the replica selection and the request redirection to the selected replica. "After analyzing the ongoing content networking trend, we can anticipate the integrated uses of existing emerging paradigms to augment the effectiveness and boost the efficiency of future CDN infrastructures. We also perceive that there is a possible shift change in the CDN industry as cloud-based CDN and NFV-based CDN are evolving. Therefore, this paper can be used as a basis to provide an overview and understanding of CDN, as well as, current and future trends in the content distribution.

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