

CONTENT DELIVERY NETWORKS (CDN): OPPORTUNITIES, CHALLENGES AND FUTURE PERSPECTIVES

N.Hasanov (hasanov@uztelecom.uz)

Tashkent University of Information Technologies named after Muhammad al-Khwarizmi

ANNOTATION

The Internet was created as a means of communication between two nodes and has now evolved from a network of communication into a global platform for business, entertainment, and media. Billions of different devices go online every day, and the amount of information stored on the network is already calculated in hundreds of exabytes.

Due to the fact that the Internet was not originally intended for the wide distribution of a wide variety of digital information and for providing reliable and fast access to it for users, over the past decades, many solutions have appeared to adapt the Internet to modern needs [1].

One such solution is various caching mechanisms [2]. The main point of such solutions is to create a buffer with quick access, but a relatively small volume, which contains exactly the information that is more likely to be in demand. As an example of a caching network, this article will consider content delivery networks (CDNs).

CDN is an overlay network consisting of a set of strategically located servers that copy and distribute content, providing greater reliability and better performance [3], [4]. The first CDN, Akamai [5], was founded in 1999 as part of a research project at the Massachusetts Institute of Technology (MIT) aimed at solving the problem of flash crowds (server failure due to a sudden increase in traffic). CDNs such as Akamai and Amazon CloudFront [6] charge content providers for content delivery and allow them full control over the content caching process. Content moves from the content provider and is distributed to CDN servers, and users access content from the CDN. CDNs are a compelling solution for content providers as they take on the responsibility of hosting and distributing content. A large number of geographically distributed content servers owned by CDNs (thousands) provide high availability, easy access and lower latency for users [7].

On a regular network, the user's request is redirected to a Domain Name Server (DNS), which translates the website's name into its IP address, and the request is redirected to the origin server, which responds to the user's request. In the CDN architecture shown in Figure 1, the content distributor is responsible for distributing the origin server's content between the CDN content servers.

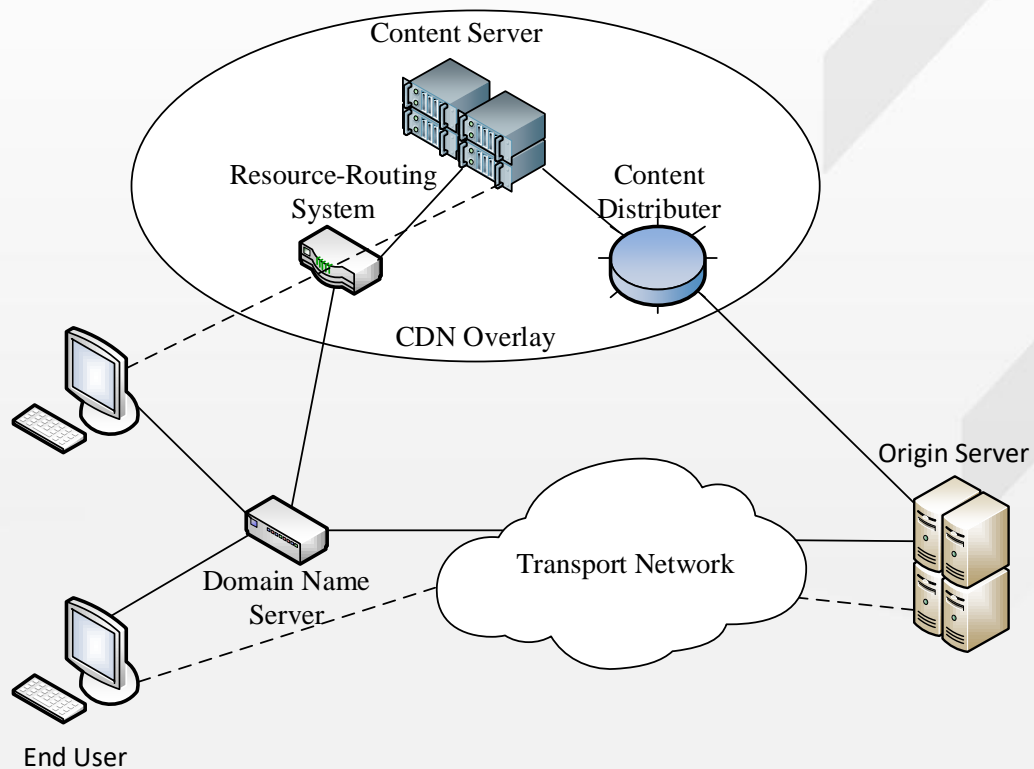


Figure 1. CDN architecture

When a user request is received in DNS, it is routed to the Request Routing System (RRS), which is responsible for directing users to the appropriate CDN content server [8]. The choice of a content server depends on the availability of the content, the distance between the user and the content server, the cost of delivery and load balancing. To optimize content delivery, CDN performs network measurements to keep information about content location and network status up to date.

Overview of the CDN market

The global content delivery network (CDN) market is expected to reach approximately US\$105.55 billion by 2032 and will grow at a significant CAGR of 18.31% during the forecast period from 2023 to 2032 [8]. The growing demand for rich video content among increasing online users and the trend of digitization in organizations across the end user vertical are boosting the overall demand in the CDN market.

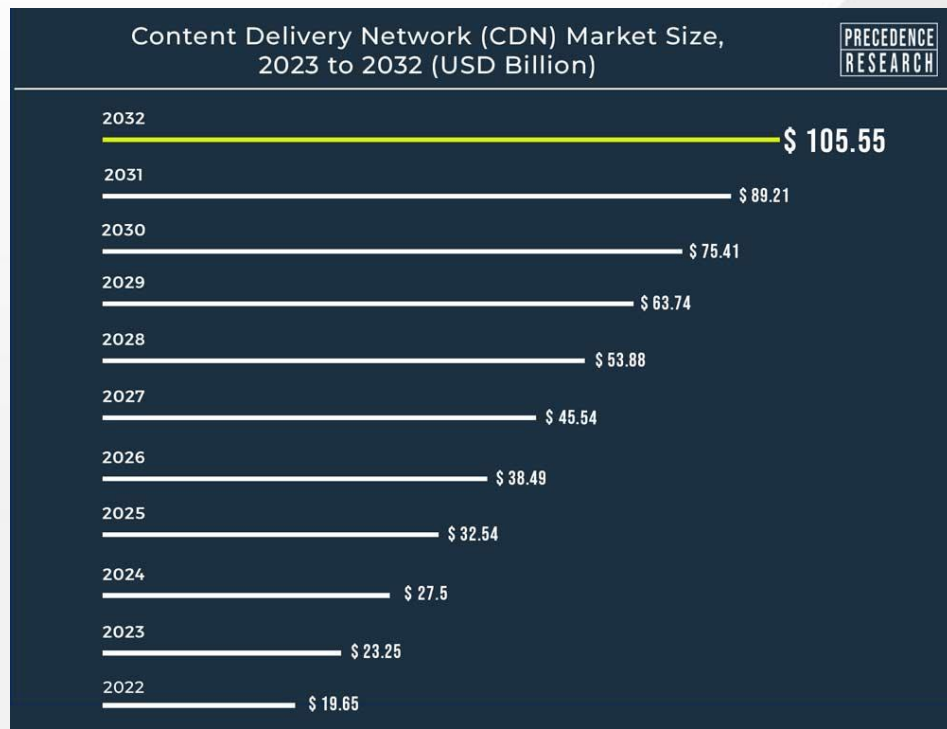


Figure 2. CDN market size 2023 to 2032 [8]

By 2023, almost two-thirds of the world's population will have access to the Internet. By 2023, the total number of Internet users will reach 5.3 billion (66 percent of the world's population), compared to 3.9 billion (51 percent of the world's population) in 2018. According to the Cisco Visual Networking Index, IP video will account for 79% of online traffic by 2018 [9]. This indicates a growing trend of online video services. Online gaming is one of the main areas where CDNs are gaining importance. Gaming companies are increasingly investing in CDNs to provide high quality content to provide a better user experience.

With the increasing use of the Internet and smart devices, a huge amount of data is being generated every day that needs to be intelligently managed. Web performance optimization solutions focus on reducing latency. The success of these solutions will increase demand from major retailers, the media and the entertainment industry.

Media delivery is expected to take a significant market share:

- The total world population using the Internet is 56.3%, which is the reason for the growing amount of online content. The advent of 4K/UHD TVs, high-definition content that supports smart gadgets, and improved connectivity are raising viewers' expectations for high-quality content.
- Many media organizations are moving to a digital distribution model. These transitions open up great market opportunities for CDN providers. CDN providers are increasingly focusing on web performance optimization techniques to meet mobile and dynamic content requirements.
- The volume of mobile traffic for media services was about 45% and is expected to increase in the future. The demand for mobile compatible content is expected to increase due to

the expected growth in data consumption to around 4.5 GB per month, which currently averages 900 MB.

- The volume of CDN data is increasing due to the emergence of peer-to-peer (P2P) technology, 5G, wearable devices, the Internet of Things, virtual reality, augmented reality, and the promotion of technological innovation.

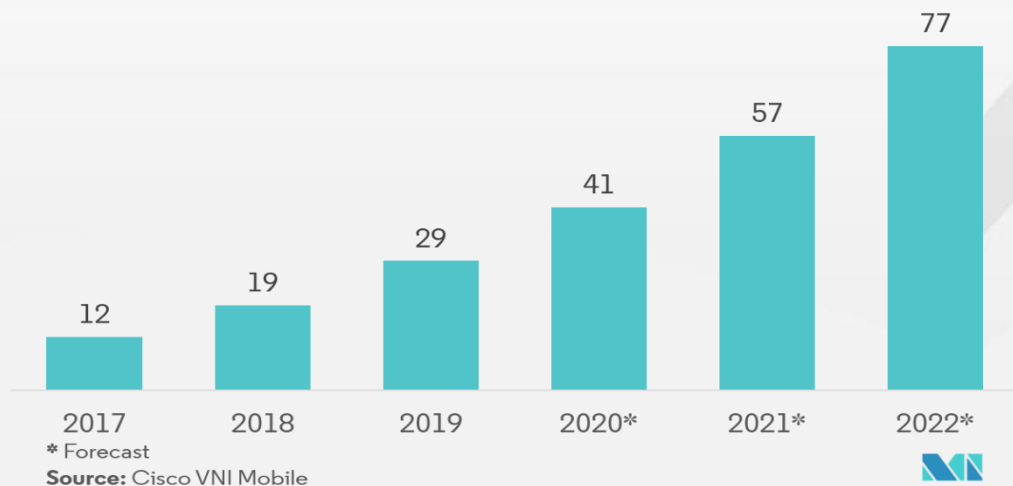


Figure 3. Internet traffic data volume of the content delivery network [9, 10]

North America holds the largest share of the content delivery network market.

North America has high internet penetration, which is expected to drive content growth in the region. With the presence of market leaders and early adoption of technology across various end-user verticals, North America has emerged as the leading regional market and is expected to maintain its dominance during the forecast period.

The number of viewers of online gaming content is also constantly growing. The growth of gaming video content is also fueling the growth of CDNs around the world.

In the United States, PayTV usage is also declining. An increasing number of consumers have been found to prefer online media content over pay TV. Cord-cutting has been accelerating recently, with about 22.2 million cord-cuttings expected to be made in the coming years, highlighting the move to on-demand content.

The content delivery network is highly fragmented due to companies having benefits such as improved accessibility to increase mobile content delivery, storage and availability. With new technological innovations in the world, the scale of entering the CDN market is quite exciting. Some of the key players in the market are Amazon Web Services Inc., Akamai Technologies Inc., Google LLC., Verizon Digital Media Services (Oath Inc.), Limelight Networks Inc., Tata Communications. These players are constantly innovating and updating their product offerings to meet the growing demand in the market.

February 2019 - Amazon's cloud division Amazon Web Services (AWS) expanded its presence in India [11] by launching two new edge locations for its Amazon Cloud Front and AWS Direct Connect offerings in Hyderabad and New Delhi.

May 2018 - Akamai Technologies Inc. released a new Akamai connector for Salesforce Commerce Cloud [6]. Commerce Cloud enables brands to deliver personalized experiences to shoppers online, mobile, social, and in-store.

April 2018 - Edgemesh Inc. launched Edgemesh 2.0 [12], a second generation adaptive decentralized edge delivery system that facilitates the distribution and security of content on the web.

CDN remains an important technology for speeding up the loading of web pages, the delivery of streaming video and music, gaming applications, and other content formats. The CDN market is expected to continue to grow in the coming years, and service providers will continue to evolve their services by providing new and higher performance content delivery methods.

Opportunities

Content Delivery Networks (CDNs) provide a wide range of options to improve the performance of a website and speed up the delivery of content to end users. Here are some of the most significant features:

- **Faster content loading:** A CDN allows you to speed up the loading of content on websites, which improves the user experience and speeds up page loading. Therefore, many sites use CDNs to improve the speed and accessibility of their content. There are many CDN providers such as Cloudflare, Amazon Cloudfront, Google Cloud CDN, etc. They provide CDN services for a fee and can be easily configured and integrated on the site;

- **Reduced load on the server** - this is one of the main advantages of using a CDN: by placing most of the content on the CDN, the server becomes less loaded, which makes it more efficient. When a user requests content (such as an image, video, or HTML page) on a site, the request is passed to a nearby CDN server that stores copies of that content. This means that the main server of the site will not be overloaded with a large number of requests from users, but, on the contrary, the load is distributed among the CDN servers. When a CDN is used, the site's main server only needs to process the requests that are needed to generate dynamic content. Static content such as images, JavaScript files, etc. is served by a CDN server;

- **Global availability:** Global availability is another benefit of using a CDN. CDN servers are located in various countries and regions of the world, which allows you to speed up the delivery of content to users in various parts of the world. When a user requests content on a site,

they automatically receive a copy of the content from the CDN server closest to them. If the site does not use a CDN, users located in remote regions may experience delays in downloading content. This can lead to user churn and loss of customers. Using a CDN allows you to expand the global reach of a site and deliver content faster and more efficiently to all users, regardless of their location. This can help keep more visitors on the site, increase conversions, and improve overall user experience. Thus, CDN plays an important role in increasing the global availability of the site, as well as in increasing user satisfaction and their loyalty to the site;

- **Enhanced security:** CDNs provide an additional layer of protection against DDoS attacks and other types of cyber threats. A CDN can be an effective tool to protect a website from DDoS (Distributed Denial of Service) attacks. A DDoS attack is one of the most common types of attacks on the Internet, when a website is overwhelmed with a huge number of requests, causing the server to stop or slow down. One of the basic principles of CDN operation is load distribution between servers located in different parts of the world. When a large number of requests begin to arrive at the site's servers, exceeding the allowable loads generates a DDoS attack. In this case, the CDN reduces the load on the main site server by redirecting requests to CDN servers located in different parts of the world, which can more effectively manage such load. This prevents the website from going down and provides higher site availability, which can reduce negative business impacts. In addition, a CDN can provide improved site security through the use of various security mechanisms, including DDoS protection, firewalls, SSL encryption, authentication, and more. This allows you to protect the site from various types of hacker attacks, increasing the level of security in general. Thus, the use of CDN is an effective way to protect the site from DDoS attacks and other types of hacker attacks, as well as to improve the security level of the site as a whole.;

- **Reduced latency:** content delivery latency (delay) is reduced due to the presence of multiple servers that store cached website content;

- **Cost savings:** A CDN can help reduce hosting costs and improve website performance, which can lead to cost savings and increased profitability.

Challenges

CDNs face a number of challenges, mainly due to the high demand for content and the dynamic nature of video delivery. The following is a summary of these issues.

1. **Cost of content delivery.** The huge commercial competition for content delivery has forced CDN operators to deploy a large number of content servers around the world, which has increased the cost of maintenance. Consequently, content delivery revenues are monopolized by

large CDN companies, and only large content providers can use CDN services [13]. The challenge is to reduce the cost of running a CDN to expand the market.

2. Energy consumption for content delivery. Provisioning and maintaining a network is a challenge for ISPs as traffic fluctuates with changes in content and its popularity. As a result, ISPs provide maximum traffic, which consumes excessive energy. The challenge is to develop a model that accurately predicts network traffic and required network equipment to use the fewest devices to minimize power consumption.

3. Wrong user location. During the CDN content delivery process, the Request Routing System (RRS) receives requests from the underlying network Domain Name Server (DNS) rather than from end users. The user is assumed to be near the requesting DNS (which is not always true) and therefore directed to the content server near the DNS. This leads to a mislocation problem that results in content being delivered to the user from a remote content server [13]. The goal is to include the user's IP address in the request forwarded to the RRS to improve the content server selection decision.

4. Bottlenecks in the network. Network bottlenecks are a problem faced by CDNs because traffic flow is not always optimized. The reason is that, despite the excessive network measurements that CDNs perform, maintaining accurate and up-to-date information about the state of the network due to traffic fluctuations and distributed sources and destinations is a difficult task [14].

5. Complexity. Implementing a CDN can be complex and may require an experienced team to set it up and deliver optimal performance.

6. Data loss: CDN is not immune to data loss, which can occur in the event of a hardware failure, network outage, or cyber attack.

7. Network problems. Network issues can impact CDN performance, causing slow content delivery, increased latency, and decreased availability.

8. Content Management: A CDN requires careful content management to ensure that all content across all servers on the network is in sync and up to date.

9. Safety. Security is a key concern for CDNs as it involves the transmission of sensitive data over networks that can be subject to cyberattacks or other forms of security breaches.

Today, the most popular CDNs carry a significant portion of total daily Internet traffic, estimated at 15% to 30% [15]. Therefore, addressing these issues can have a significant impact on the overall performance of video delivery over the Internet. A serious problem is the high power consumption of the CDN, which must be reduced in order to reduce CO₂ emissions and operating costs. This thesis concerns the high power consumption of CDNs by caching content

on the core network to minimize power consumption when delivering video. Chapters 4 to 7 explain the proposed models in detail.

To mitigate these issues, companies can work with experienced CDN providers and implement proper content management processes to ensure data is accurate and timely. In addition, they must have robust security protocols in place to protect data from cyber threats and various forms of attack.

Future Perspectives

The future of Content Delivery Networks (CDNs) is exciting, and many new advancements and enhancements are expected to increase speed, reliability, and functionality. Here are some of the trends we can expect in the future:

1. **Artificial Intelligence (AI) integration:** AI is being integrated into the CDN to improve content delivery speed and reduce latency.
2. **Edge Computing:** CDN is moving towards distributed edge computing architectures that provide faster access to content and applications across networks.
3. **5G technology.** With the introduction of 5G technology, CDN networks will continue to evolve to deliver content at lightning speed.
4. **Integration with the Internet of things.** IoT devices generate massive amounts of data that must be delivered quickly and reliably, and CDNs must adapt to the unique challenges of IoT integration.
5. **Containerization.** Containerization technology will be integrated into CDN to improve application performance and improve content delivery efficiency.
6. **Blockchain:** The use of blockchain technology will increase the security of the CDN because it provides a tamper-proof ledger for transactional data and can ensure that the content is not altered or modified in transit.

As CDN continues to evolve, it will become smarter, more secure, and more efficient. Companies will need to adapt and adopt these new technologies to keep their CDNs competitive and valuable to end users.

Conclusion

As a result of the research, it was revealed that CDN is one of the most important technologies for organizing effective content delivery on the Internet. Existing CDN services provide fast and reliable information transfer to the user, which improves the quality of user experience and customer satisfaction. However, due to the increase in the volume of transmitted information and the growing number of devices with Internet access, CDN has to constantly improve and expand its capabilities. Edge computing, IoT and 5G technologies can significantly

influence the development of CDN and will be key factors in its future. The future of CDN is connected with the development of new technologies, such as artificial intelligence, machine learning and data analytics, which will optimize content transfer processes and improve the quality of service. Also, expanding the geographical coverage and increasing the number of servers and nodes that provide content delivery will be one of the key directions for the development of CDN. Thus, CDN is a technology that is constantly being improved and developed to ensure fast and reliable transmission of content to the user. The future of CDN is connected with the development of new technologies and the expansion of geographic coverage, which will provide an even better and more comfortable experience for users.

Literature

1. Marcin Frąckiewicz, «Подход Viasat к обеспечению надежного и быстрого спутникового интернета» TS2 Space Sp. z o.o. 21 мая 2023
2. Сергей Кузнецов, “Когерентность кэшей в современных многоядерных процессорах” IEEE Computer Society, Vol. 46, No. 10, 2013
3. R. Buyya, M. Pathan, and A. Vakali, Content Delivery Networks. SpringerScience & Business Media, 2008.
4. G. Fortino and C. E. Palau, Next Generation Content Delivery Infrastructures: Emerging Paradigms and Technologies - Powell’s Books. Information Science Reference, 2012.
5. “Akamai.” [Online]. Available: <http://www.akamai.com/>
6. “Amazon Cloudfront.” [Online]. Available: aws.amazon.com/cloudfront/.
7. S. Saroiu, K. P. Gummadi, R. J. Dunn, S. D. Gribble, and H. M. Levy, “An Analysis of Internet Content Delivery Systems,” in The 5th Symposium on Operating Systems Design and Implementation, 2002, vol. 36, pp. 315–327.
8. Precedence research “Content Delivery Network Market Size to Hit USD 105.55 BN by 2032” Newswire Distribution Network & Management March 10, 2023
9. Cisco “Cisco Annual Internet Report (2018–2023) White Paper” Cisco Annual Internet Report – March 9, 2020
10. IANS, “AWS expands CloudFront and Direct Connect locations in India” Millenniumpost – 13 Feb 2019
11. Jess Phillips, “Akamai announces new integration with Salesforce Commerce Cloud” Intelligentciso – 23 May, 2018
12. Market Data Forecast, “Global Cloud Content Delivery Network Market Segmentation By Component (Solution, Services), Type (Video CDN, Non Video SDN), Organization Size (SMEs, Large Enterprises), Vertical (Advertising, Online Gaming, E-Commerce, Media & Entertainment, Healthcare, Education) – Forecast to 2027” March, 2023
13. J. P. Mulerikkal and I. Khalil, “An Architecture for Distributed Content Delivery Network,” in 15th IEEE International Conference on Networks, 2007, pp. 359–364.
14. B. Frank, I. Poese, G. Smaragdakis, A. Feldmann, B. M. Maggs, S. Uhlig, V. Aggarwal, and F. Schneider, “Collaboration Opportunities for Content Delivery and Network Infrastructures,” ACM SIGCOMM eBook: Recent Advances in Networking, vol. 1, 2013.
15. “The Akamai Internet.” [Online]. Available: http://www.akamai.com/html/riverbed/akamai_internet.html
16. Varlamova L. et al. Fuzzy logic traffic management model //InterConf. – 2020.

17. Muazzam A. Image constrict by the wavelet shrink //International Journal of Recent Technology and Engineering. – 2019. – Т. 8. – №. 1 S4. – С. 862-864.

18. Артиков Т. У., Ибрагимов Р. С., Артиков М. Т. Развитие сейсмического процесса в очаговых зонах сильных землетрясений Узбекистана и долгосрочный прогноз сейсмической активизации //Геология и минеральные ресурсы (Ташкент). – 2009. – №. 1. – С. 23.

19. Зайнидинов Х. Н., Артикова М. А., Фазлиддинович Д. Сплайн-метод анализа и обработки сейсмических сигналов //Автоматика и программная инженерия. – 2017. – №. 1 (19). – С. 54-57.