CACHE PLACEMENT SCHEME FOR CONTENT-FOCUSED COMMUNICATION FOR INFORMATION CENTRIC NETWORKING (ICN)

Prashanth Kumar P[1], Dr. Pramod Pandurang Jadhav[2]

Article History: Received: 02.11.2022 **Revised:** 18.11.2022 **Accepted:** 23.12.2022

Abstract:

The amount of internet traffic produced by wired and wireless networks has increased at a never-before-seen pace due to the quick development of networking technology and smart devices. Similar to how fast-developing wireless networks have emerged, the Internet of Things (IoT) has undergone a new revolutionary breakthrough. Today, a broad spectrum of IoT device users across many platforms are uploading and searching through enormous amounts of data. These devices generate a tremendous quantity of traffic, which has a significant impact on a number of domains, including smart cities, automotive networks, e-health, smart industries, etc. Multimedia material makes up a significant amount of all internet traffic and is projected to continue growing rapidly in the future. The typical host-centric IP network design is dependent on host-to-host communication; thus, it is not appropriate to meet the needs of a high number of devices for content delivery. Users of these devices are more interested in the requested material than they are in learning where it is. The existing internet architecture is failing more and more often as content-centric apps develop since the internet was not initially intended to be a distribution network. A future internet architecture designed specifically for content-focused communication is called Information Centric Networking (ICN). By providing content name-based routing and forwarding, ICN has circumvented the host-centric communication problem of IP address sharing. With less latency and a higher hit ratio, efficient content delivery may be supported by ICN's pervasive in-network caching capability. ICN-IoT is made up of the ICN since it may function as an IoT enabler. The framework for caching methods in ICN to enable user Quality of Experience (QoS) is the main topic of this thesis. The caching solutions for managing multimedia traffic in two distinct ICN-IoT scenarios, such as smart cities and vehicle networks, have been discussed from both theoretical and practical perspectives. This is because the needs of caching may vary for various ICN-IoT applications. By taking into account either content factors (such as content popularity, content freshness, and etc.) or node attributes (such as node location, node cache space, and etc.), the existing research offered options for enhancing network performance. The goal of this research project is to develop a caching approach that will enhance network speed while also delivering greater quality of experience. Further, the cache performance may be greatly enhanced by using the ideas of edge computing (EC) and machine learning (MC).

[1,2]Department of Computer Science & Engineering, Dr. A.P.J. Abdul Kalam University, Indore (M.P.) - 452010

DOI: 10.53555/ecb/2023.12.3.250

1. Introduction

The Information Centric Network (ICN), a paradigm alternative to the conventional internet, is progressively developing through boosting material diffusion via the internet using names. A fundamental aspect of ICN is its capacity to provide transparent and widespread in-network caching to improve network resource use and data distribution speed. The internet is now the most widely used instrument on earth. The conventional internet has evolved as a result of technological improvements throughout time. The internet has evolved primarily as a result of changes in user needs, user numbers, use habits, and application types [1]. A new paradigm known as the Internet of things (IoT) is created as a result of the extraordinary pace at which many physical items are connected to the internet [2]. The goal of the Internet of Things is to turn everyday items into intelligent ones by giving them the ability to communicate, hear, think, and see. The number of objects found in the current internet, such as sensors or systems like HVAC monitoring or learning thermostats, increases as a result of this interconnection, with each individual object acting as a host or router in an ad-hoc network or Wireless Sensor network (WSN) [3]. In general, everything is a little gadget with constrained battery life, memory, and computing power.

To address these problems, several potential future internet designs have been put forward. Information-centric networking (ICN) has emerged as a potential networking solution for Internet of Things (IoT) difficulties among all ideas due to the advantages presented in terms of dependability, effective data transmission, content security, and in-network caching. [7][8]. By implementing in-network caching, ICN is a viable paradigm for content delivery, retrieval, latency reduction, and energy savings for resource-constrained devices [8][9].

Researchers looked at ICN as a blank canvas and an original strategy to change the internet. As opposed to the host-centric IP-based communication paradigm, ICN treats content as a first-class member of the whole network. In the ICN network, nodes must be explicit about what they want rather than where it should be. Since ICN offers name-based routing, which separates contents from locations, mobility is enabled by default.

Information Centric Networking

One of the key outcomes of several global future Internet research programmes is the design of ICN. The present internet architecture is entirely based on hostcentric communication, in which communication between hosts occurs only once an end-to-end connection has been established. As an alternative, modifications in the design that emphasise Named Data Objects (NDOs) have been driven by the increasing need for efficient and highly scalable content distribution (such as movies, web pages, files, etc.). Through content replication, in-network caching, and cooperative models, the ICN's structure may affect multiparty communication. The networking community have given a lot of attention to the ICN research.

Caching in ICN

The current internet is designed from the ground up to send all content requests to the original source, which increases network strain, response latency, bandwidth usage, and retrieval delay. Additionally, there is no infrastructure for data distribution or efficient content retrieval on the current internet.

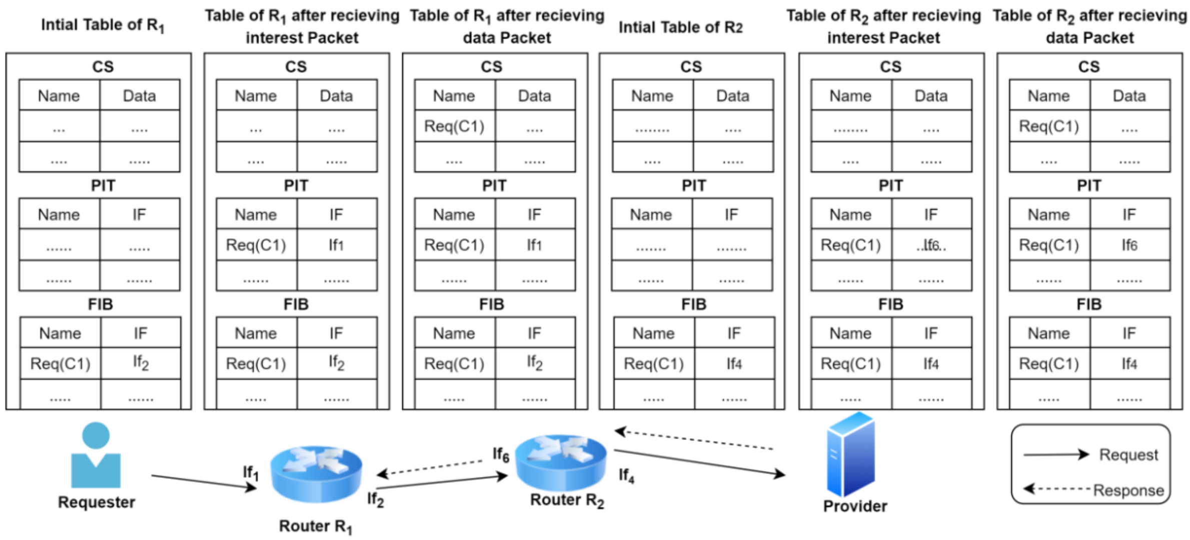


Figure 1: Caching in ICN

Content caching is essential for the low-cost distribution of information to the edges in order to address concerns with the current internet. Additionally, some IoT applications want new material that must be updated as newer versions become available, while others demand both. For instance, it is necessary to continuously update and check the value of room temperature. As a result, ICN implements caching at the network layer to deal with named information directly.

ICN content caching offers a number of advantages. By caching material from several sources, the content is removed from its original source, enabling transmission of the content regardless of location. Devices with limited resources may provide energy-efficient communication, and mobility is encouraged. By keeping numerous copies of the same material at many places and preventing a single point of failure, it improves network speed. As a result, it significantly helps to manage network congestion by lowering producer overhead. Additionally, it greatly reduces the stress on the network and the time it takes to get material. The goal of the project is to create ICN in-network caching decision rules that will enable ICN-IoT networks to function much better. The effectiveness of ICN in-network caching has been studied in the context of IoT-based automotive content-centric networks and smart cities to promote enhanced QoE.

2. Literature Survey

The authors suggested a caching strategy to increase caching effectiveness, maximise cache capacity, and speed up data searching from the content store found in NDN routers. A sum-up bloom filter based on request node collaboration caching (BRCC) was proposed to enhance network performance. In this filter, frequently requested content is cached in routers near the consumer and the dynamic lifetime of each item is determined by the frequency of requests. Caching Information Table (CIT) and an integrated sum up counting bloom filter are included in BRCC to increase caching effectiveness. On the Matlab simulation tool with C++ integrated environment, the effectiveness of the suggested strategy was evaluated for several metrics, including cache hit ratio, average routed hops, and average request latency, versus a number of other caching strategies, including LCE, WAVE, and ProbCache. The simulation results showed that BRCC performed better than baseline in terms of effective cache utilisation, greater cache hit ratio, and quicker content searching speed.

Because there are limited resources, such as battery power and storage space, in the ICN-IoT context, the authors developed the Packet Update Caching Approach (PUC). Major ICN-IoT problems with response time, hop count reduction, popularity of content, and access control were all addressed by the PUC. PUC uses methods including clustering, circular buffers, and data purging to cache material, update content that has already been cached, and replace content when the cache is full. On the NDN network simulator ndnSIM, where contents were cached close to the subscriber owing to energy-efficient transmission, the performance of PUC was compared to probCache. The simulation demonstrates that PUC outperforms probCache in terms of bandwidth and energy usage when cache size and popularity index are increased.

Based on a clustering and caching technique, the authors suggested a four layer design for effective caching at edge devices for IoT applications and to decrease content retrieval latency. The authors suggested cluster-based caching as a solution to the issues with hash and on-path caching. It is suggested to use two different methods, one to define a cluster inside the network and the other to choose a cluster leader. To determine the popularity of material worldwide independent of the computation at each individual network device, a novel global content popularity calculation approach is presented. By caching material near to edge devices, the popularity techniques will help decreasing content retrieval time, packet loss, and increasing content availability. To compare the effectiveness of the proposed strategy to already used caching techniques, simulations were run. The findings showed that the network has improved performance with lower latency and good content availability.

The authors suggested a fog caching system for IoT environments that is enabled by ICN. The fog was included into the ICN network to improve user QoE and speed up the process of retrieving requested material. The plan is based on three design features: a) fog clusters, which allow network routers and end user devices to cache popular material close to the user; b) near path caching, which allows off-path routers to store information; and c) full-time caching, which supports caching constantly in the network. When compared to caching benchmark schemes, the method produces better results for a variety of caching performance criteria.

The authors suggested a caching strategy for the 5G network in an edge computing-enabled ICN context. The suggested approach enables D2D communication—that is, communication between end user devices—as well as support for ICN at the base station's application layer. Additionally, a content pre-fetching technique leveraging ICN naming was added to cache dynamic contents. When compared to prior studies in this field, the simulation results showed a substantial improvement for obtaining high cache hit ratio with lower latency.

The authors suggested a data-driven caching system while taking user preferences into account. This study predicted the popularity of the content based on the reference distribution created by the reported noisy preference content data from users, taking into account the fact that each user's preferences have distinct sensitive features. This strategy's efficacy versus several current caching strategies was shown by the many simulations that were run on it.

3. Methodology

Future internet architecture called ICN has been suggested for effective content distribution between publisher and subscriber. In-network caching is made possible by ICN to assist quick content delivery. In addition to its many benefits, ICN caching faces a number of difficulties in order to ensure effective caching with optimal resource utilisation. There is a lot of ongoing study on caching in ICN, and several strategies have been put out in the past to address the problems we covered in the previous chapter. However, there are still a number of issues that need to be resolved in terms of cache space, content redundancy, energy-efficient caching, support for mobile nodes, and content replacement. Additionally, these methods include developing fresh caching strategies while focusing on one or two performance indicators. Some solutions suggested enhancing performance by taking into account content factors, while others suggested enhancing performance by employing node properties. The real problem is attempting to keep performance at a decent level while taking both content and node factors into account. Therefore, it is important to do research on ICN caching strategies that may result in more effective resource utilisation and increased network performance [10, 66]. The best course of action must be taken in order to address performance, caching, and advantages in various IoT application situations.

Cache Hit Ratio (CHR)

It is one of the most crucial metrics to consider when assessing the effectiveness of any caching solution. CHR is a metric for how many requests a cacheable node has fulfilled [13]. Any successful content searches and their impact on previously implemented caching strategies are always indicated by an increase in the hit ratio statistic. For the cluster-based caching strategy, a cache hit occurs when an intra-cluster node grants a request with the aid of its CH. Cache hit ratio is often determined using:

$$CHR_n = \frac{H_n}{req_n}$$

Hop Reduction Ratio (HRR)

Based on the number of hops, it is a statistic used to gauge how well a caching strategy works. When comparing the number of hops necessary to fulfil a content request by any intermediate node to the number of hops needed when the answer to the request was acquired from the originating source, HRR assesses the decreased number of hops [13]. HRR is calculated for a network using:

$$CHR_c = \frac{\sum_{i=1}^{nc} localhit_i}{nc}$$

Evaluation & Results - Icn Based Cache Placement Scheme

The design of an edge cache placing method built on ICN to manage multimedia data flows in IoT-based smart cities. Information-centric networking (ICN) as well as edge computing (EC) have been recognized as new technologies that will allow delivery of content closer to the user. Although ICN lets forwarding and routing of content by relying on the name of the content and directly, EC plans to provide local content by reducing the burden on core networks. The in-network cache capability makes it simpler for network nodes in the intermediate phase to save information.

ICN may help EC by empowering end users with communication capabilities. The effective handling of content distribution by EC and ICN when used together enhances user experience.

Cache Classification

There are three types of content caching described in the literature: ubiquitous, edge, and fog caching. CCN generally adheres to the principle of ubiquitous caching and places a strong emphasis on each network node along the delivery channel caching the material. But, as it offers the highest level of content redundancy across all nodes of the network, the widespread caching consumes resources, and it isn't generally seen as a sensible method. Since fog is a cloud which is located close to users, it permits content to be stored inside fog nodes, thereby reducing response times. As fog nodes possess limitations in their capacity for caching however, the caching task could be pursued. Edge caching can be a significant place to cache data for the administration of media traffic that is high-volume in smart cities, when as compared with the ubiquitous caching system or fog caching.

Additionally, ICN with Edge for 5G architecture is what drives edge caching, which makes advantage of the caching capabilities of end user devices, BSs or ICN on network nodes working that are in conjunction with the core network. This research considers edge caches, which utilize every network element that can be cached in addition to the core network.

Cache Capacity Reservation

The ability to cache material across all network nodes may be homogenous or heterogeneous. In order to discover an effective capacity reserve, the work in contrasted the two capacity allocations. The findings showed that owing to frequent topology changes and substantial producer mobility, there was very little improvement in heterogeneous reservation. Yet, numerous studies have taken homogeneous reservation into consideration when they build their systems to provide greater networking performance. Thus, by allowing each node to enjoy a consistent capacity, this study takes reservations for caches with homogenous capacity into account.

Cache Eviction

Every time ICN-IoT is implemented, the network nodes' storage capacity is exceeded by the high rate of content requests, responses, and in-network content caching. Therefore, it is strongly advised that each proposal include some content replacement tactics to make room for the new information by swapping out the old. The literature suggested many replacement techniques based on various replacement choices, including For instance, material is replaced based on recentness in cache eviction techniques like LRU. But of all other cache replacement policies, LRU is the one that is most frequently utilised because of its straightforward process. In order to preserve fairness during assessment, this research also took LRU into account in their suggested technique.

Proposed Framework

The suggested solution, in contrast to conventional caching methods, provides layered architecture by further subdividing the ICN network layer into a number of tiers and using node centrality-based caching with support for reproactive caching.

Layered architecture

The proposed method uses cache resources located at various end places to give the best benefit in terms of performance. Fig. 2 illustrates the basic structure of the network that shows how ICN is implemented on the BS application layer. In Fig. 3., the suggested structure of the layered scheme is illustrated. The core of the network is affected with the huge amount of big data is generated by smart cities. ICN was initially introduced in the end user device layer, which provides D2D communication to facilitate communication within smart cities which use EC as well as ICN to decrease traffic in the central network. Contents that are cached on other devices can be processed locally by D2D communication, instead of having to be transmitted directly to BSs and access points. The ICN network can also be organized as a network hierarchy that includes various levels of service when integrated into the application layer that is part of BS. Network nodes that are dispersed across the network can be arranged into clusters once customers request content. Every cluster will have multiple nodes of various tiers based on the architecture of the network.

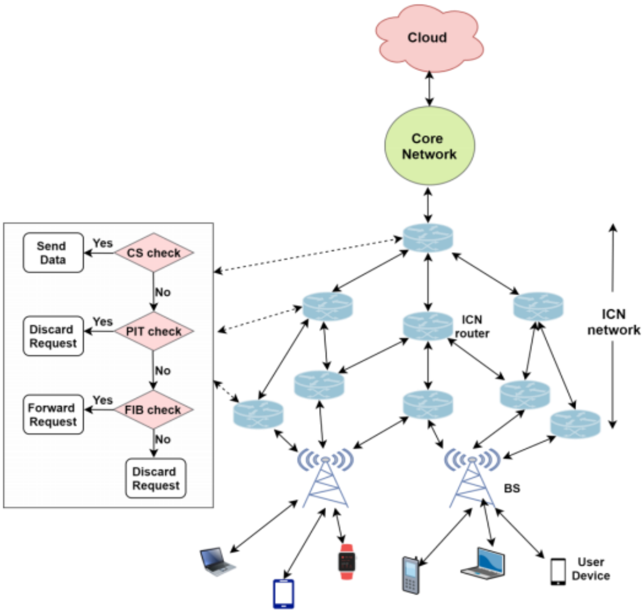


Figure 2: ICN configured network architecture

In addition, the caching capabilities of the nodes located further than a certain distance away from the edge devices isn't included in the calculation to decrease the available latency of the network during content fetching. This means that the area of the topology can be used to determine the top tiers of the ICN network ahead of time. Prior to moving onto higher tiers or even starting at tier-1 and progressing to tier_max, demands that come from the BSs will be reviewed first at the lower levels. Material requests are directed to the central network in the event that it is not dealt with by one of the tiers within the ICN network organization. The node with the greatest centrality value among the nodes present in the top tier receives the answer from the originating server and caches it. The benefit of adaptable clusters is that they may modify their design to accommodate changes in network topology.

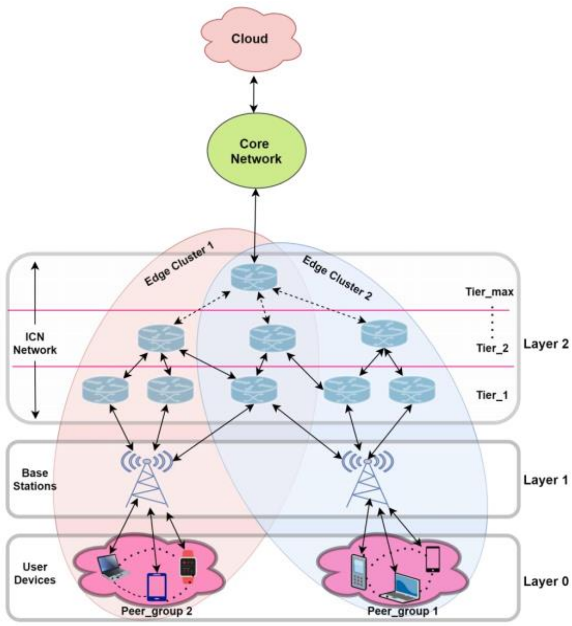


Figure 3: Proposed network architecture

On-path caching schemes are often recommended in the literature when it comes to content caching since they reduce the traffic of seeking for material outside of the delivery channel, which includes considerable network latency without providing cache hits. However, using solely the on-path nodes' caching capabilities to support the cache hit would waste the resources of neighbouring nodes. In providing caching in close proximity to the distribution channel The trade-off between higher search costs and efficient resource management can be overcome. In order to store the content it is the node that has the most centrality across all nodes within the same tier will be picked. Because of their large accessibility to the users the caching algorithm based on centrality is utilized. Centrality-based caching offers an equal opportunity to choose the node that will cache the content.

Implementation of the Proposed Framework

Network Formation

The formation is in charge of grouping the network into user request processing clusters. Any end user device (UDk) first makes the request for a certain piece of content. All end user devices must have a particular amount of cache capacity and D2D communication capability, according to the suggested method. Based on the criteria listed in Algorithm 1, the layer 0 end user devices create a peer cache group. If a response is available in any of its caches, the peer devices in contact with one another will transmit it in accordance with the ICN communication protocol. Local content delivery occurs at the level of the edge device as a consequence, which lowers traffic at the network core. The one hop neighbour, or BS at layer 1, receives the content request if it cannot be retrieved locally in the peer cache.

Algorithm 1: Peer_cache Composition

input: End user device requests content as m. UDk

Peer_cache group as output

Begin: 1 Perform for each end user device (UDl) in layer 0. If number of hops (UDl, UDk)

2 and UDk UDl, then

3 Include UDl in peer_cache group

4. group peer_cache

return

Experimental Setup

The efficacy of this method has been tested using experiments by using an Icarus simulator. It has four core components that include the creation of scenarios, orchestrating experiments as well as execution of experiments and data collection, the simulator was specifically developed specifically for ICN routing and caching.

The network is warmed up by executing 3 requests prior to the test. Prior to evaluating system performance Warm-up requests are messages that are sent to the network caching nodes, that instruct them to carry out cached content. When the network has been started to warm up, measured requests that have a priority of 6105 are sent out to evaluate the efficacy of the recommended approach. Every user has to send request messages that follow the distribution of Poisson, which is the one that most cache algorithm employs typically. Based on the Icarus configurations the rate of network requests is twelve requests per second across all users. The skewness value is a parameter of the Zipfian distribution that describes the popularity of the product can range from 0.6 up to 1.2. The level of popularity is related to the values of the Zipfian distribution. The more requests are made to the same item in cases where the value is higher. In this case, alpha=1.25 suggests that more individuals are interested in this similar request as alpha=0.8 is. The GARR network design is extensively utilized in recent research to aid testing performance, is used during the testing. To guarantee equal storage capacity every node's cache size is kept in a steady state. In the end, by taking the whole network's capacity for caching by the amount of content, every node's storage capacity uniformly determined. Since every node in the network has an identical cache reserves, or has a homogeneous capacity for caching the method takes this into account. The research examines various scenarios through the use of experiments to increase the network cache from.06 percent to 5%. In addition, the approach for the replacement of content is as important as creating instances of content placement. The LRU factor is included in the method suggested for changing caches because of its simplicity and strength, as well as integration with widespread caching systems.

The tests were carried out on four different popular content () value and six distinct capacities of a network's cache in a specific network architecture that took into consideration each of the above-described circumstances. In comparing our suggested method against benchmark methods for simulation, we ran the tests at least four times as well as the median value for each indicator of performance was considered. Table 1 lists the parameters we used in the simulation of our proposed method of caching.

Table 1 Simulation parameters

Parameter	Values
Network Cache	0.006, 0.01, 0.02, 0.03, 0.04, 0.05
Content Distribution α	0.6, 0.8, 1.0, 1.2
Number of Warmup Requests	3 * 10 ^ 5
Number of Measured requests	6 * 10 ^ 5
Network request rate	14
Cache_schemes	LCE, LCD, CL4M, ProbCache, Random
Data_collectors	CHR, CRD, ILL, CPS

4. Results and Discussions

The results of the assessment for the method suggested have been contrasted against the most popular caching techniques currently being used, for example leave Copy Everywhere (LCE), Leave Copy Down (LCD), Cache less for more (CL4M) and Probability Caching (ProbCache) and random (choice). The results of simulations using the above strategies for caching, using the suggested method for various metrics of performance are summarized.

Table 2: Achieved cache hit rates of the caching scheme proposed at (a) =0.6

Strategy	Simulation Run	Cache Size					
		0.006	0.011	0.02	0.03	0.04	0.05
Proposed	1	0.024	0.02	0.031	0.054	0.075	0.084
	2	0.036	0.06	0.041	0.08	0.064	0.095
	3	0.032	0.033	0.054	0.041	0.024	0.095
	4	0.024	0.055	0.045	0.098	0.041	0.091
	Average	0.034	0.039	0.055	0.084	0.087	0.081

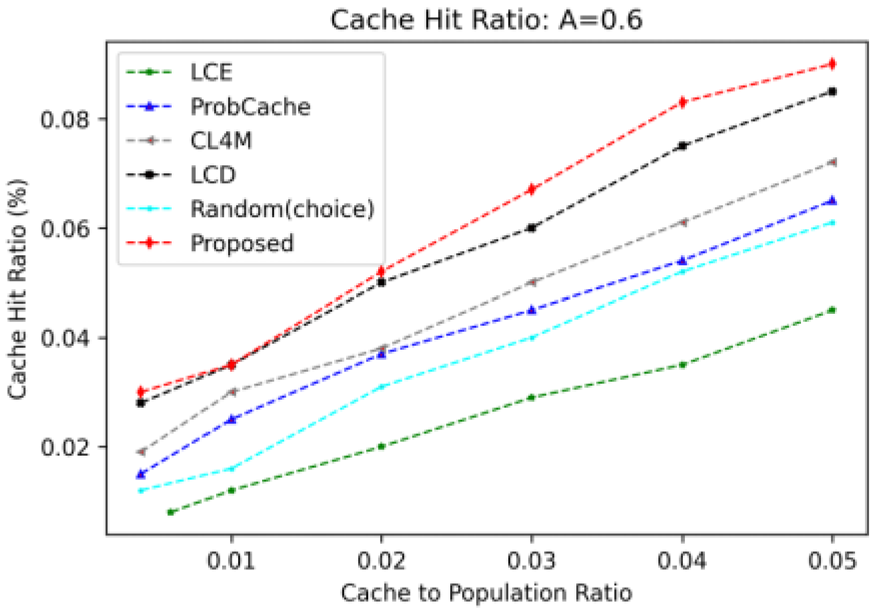
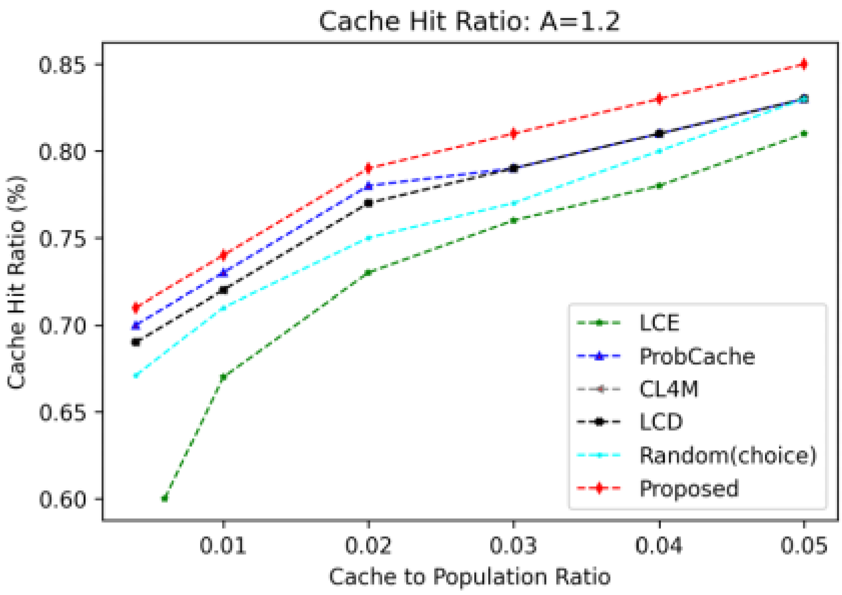


Figure 4: Influence of cache size on CHR for α =0.6

For cache sizes of 1% and 5%, respectively, the CHR performance ranges from 2% to 81% and almost 7% to 85%. Content caching is possible at the network's edges because to the layered network design, which nearly always includes cache routers and supports D2D communication between end user devices. This is one of the crucial characteristics for the suggested strategy's improved CHR performance. Utilising near route caching at ICN network layers provides caching close to the delivery path in addition to D2D communication capability, which boosts CHR.

Figure 5: Influence of cache size on CHR for α =1.2



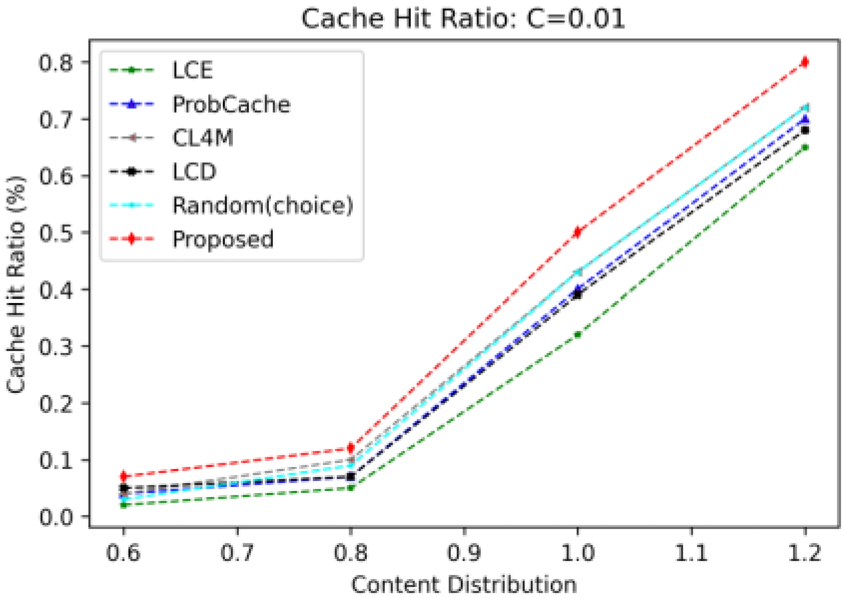


Figure 6: Influence of content distribution (α) on CHR for cache size =1%

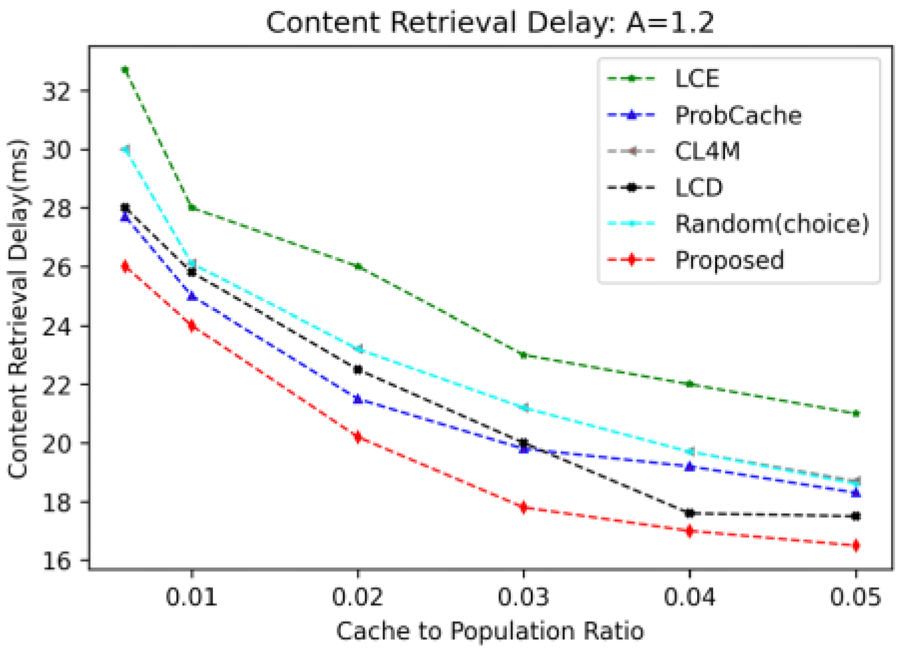


Figure 7: Influence of cache size on CRD for α =1.2

The research revealed that the strategy suggested did a better job by 9% than the next-best LCD for the same price, with an average of 492.3 bytes in the suggested approach as well as 542.5 Bytes on LCD in all situations tested. Reactive caching, which shifts the traffic load for requests out of peak hours, could be the reason for this. The suggested system also caches the material on the end user devices, which reduces link load once again.

5. Conclusion and Future Scope

The chapter begins with an overview of the research along with a list of potential possibilities for future research into ICN caching. The transformation from host-centric communications to the use of content-centric communication to distribute content was made possible thanks to ICN. Highly advised for various IoT applications because of its inherent capabilities by the receiver-driven communication based on content names as well as the ubiquitous in-network caching feature. This thesis makes a leap in the direction of next-generation wireless communication making use of ICN caching within networks in conjunction with other IoT applications. This thesis contributed to the development of a new caching strategy to each smart city that is based on ICN and vehicles since need for caching for different IoT applications are different.

The paper outlines four main characteristics of the design aspects of traditional ICN cache systems, by meticulously looking at the latest technology. The possibility of an ICN edge caching method has been proposed for efficiently controlling large multimedia delivery in smart cities based on careful analysis of these four properties of caching. The proposed system allows data caching for devices that are used by the end user and also on ICN network nodes, which will help in enhancing edge caching. The method proposed relies on the capabilities of a node like forwarding or routing and peer cache composition production of content, as well as the characteristics of tier creation in the network's structure. This means that the method proposed can be used to divide the entire ICN edge network into separate layers. peer caches are created on the user's bottom layer enables efficient caching as well as D2D communication.

Future Work

Other characteristics, like different types of content as well as cache capacities and locations of the nodes could be considered in future research on the caching systems that are being evaluated by smart cities to separate the network's architecture into various levels and tiers. In addition, many of studies could be carried out using a real-world distribution of content generation and request importance to produce more helpful insights for the next study in this field.

6. References

1. Atzori, L., A. Iera, and G. Morabito. "The internet of things: A survey," Computer Networks, vol. 54, no. 15, pp. 2787-2805." (2010).
2. Singh, Dhananjay, Gaurav Tripathi, and Antonio J. Jara. "A survey of Internet-ofThings: Future vision, architecture, challenges and services." In 2014 IEEE world forum on Internet of Things (WF-IoT), pp. 287-292. IEEE, 2014.
3. Zheng, Jun, and Abbas Jamalipour. Wireless sensor networks: a networking perspective. John Wiley & Sons, 2009.
4. Li, Jing, Chong Shen, and Kae Hsiang Kwong. "A 6LoWPAN Routing Optimization Mechanism for WMSN." International Scholarly Research Notices 2013 (2013).
5. Amadeo, Marica, Claudia Campolo, Jose Quevedo, Daniel Corujo, AntonellaMolinaro, Antonio Iera, Rui L. Aguiar, and Athanasios V. Vasilakos. "Informationcentric networking for the internet of things: challenges and opportunities." IEEE Network 30, no. 2 (2016): 92-100.
6. Zhang, Lixia, Deborah Estrin, Jeffrey Burke, Van Jacobson, James D. Thornton, Diana K. Smetters, Beichuan Zhang, Gene Tsudik, Dan Massey, and Christos Papadopoulos. "Named data networking (ndn) project." Relatório Técnico NDN-0001, Xerox Palo Alto Research Center-PARC 157 (2010): 158.
7. Xylomenos, George, Christopher N. Ververidis, Vasilios A. Siris, Nikos Fotiou,Christos Tsilopoulos, Xenofon

Vasilakos, Konstantinos V. Katsaros, and George C. Polyzos. "A survey of information-centric networking research." IEEE communications surveys & tutorials 16, no. 2 (2013): 1024-1049.

8. Mars, Dorra, Sonia Mettali Gammar, Abdelkader Lahmadi, and Leila Azouz Saidane."Using information centric networking in internet of things: a survey." Wireless Personal Communications 105, no. 1 (2019): 87-103.
9. Yu, Keping, Suyong Eum, Toshihiko Kurita, Qiaozhi Hua, Takuro Sato, Hidenori Nakazato, Tohru Asami, and Ved P. Kafle. "Information-centric networking: Research and standardization status." IEEE access 7 (2019): 126164-126176.
10. Hussaini, Muktar, Shahrudin A. Nor, Amran Ahmad, Inusa Sani Maijama'a, Adamu Isah, and Abdullahi Aminu. "Mobility Support and Operation of Information Centric Networking Approach." International Journal of Computer Network & Information Security 10, no. 10 (2018).
11. Arshad, Sobia, Muhammad Awais Azam, Mubashir Husain Rehmani, and Jonathan Loo. "Recent advances in information-centric networking-based Internet of Things (ICN-IoT)." IEEE Internet of Things Journal 6, no. 2 (2018): 2128-2158.
12. Abdullahi, Ibrahim, Suki Arif, and Suhaidi Hassan. "Survey on caching approaches in information centric networking." Journal of Network and Computer Applications 56 (2015): 48-59.
13. Wang, Cong, Chen Chen, Qingqi Pei, and Licheng Wang. "IDDS: An ICN based Data Dissemination Scheme for Vehicular Networks." In ICC 2020-2020 IEE International Conference on Communications (ICC), pp. 1-7. IEEE, 2020.
14. Su, Zhou, Yilong Hui, and Qing Yang. "The next generation vehicular networks: Acontent-centric framework." IEEE Wireless Communications 24, no. 1 (2017): 60-66
15. Boukerche, Azzedine, Rodolfo WL Coutinho, and Antonio AF Loureiro."Information-centric cognitive radio networks for content distribution in smartcities." IEEE Network 33, no. 3 (2019): 146-151.
16. Shariat, Ali, Ali Tizghadam, and Alberto Leon-Garcia. "An ICN-based publishsubscribe platform to deliver UAV service in smart cities." In 2016 IEEE Conferenceon Computer Communications Workshops (INFOCOM WKSHPS), pp. 698-703.IEEE, 2016.
17. Chai, Wei Koong, Konstantinos V. Katsaros, Matthias Strobbe, Paolo Romano, ChangGe, Chris Develder, George Pavlou, and Ning Wang. "Enabling smart grid applications with ICN." In Proceedings of the 2nd ACM Conference on InformationCentric Networking, pp. 207-208. 2015.
18. Satyanarayanan, Mahadev. "The emergence of edge computing." Computer 50, no. 1(2017): 30-39.
19. Yu, Wei, Fan Liang, Xiaofei He, William Grant Hatcher, Chao Lu, Jie Lin, and XinyuYang. "A survey on the edge computing for the Internet of Things." IEEE access 6 (2017): 6900-6919.
20. Zhang, Yin, Yujie Li, Ranran Wang, Jianmin Lu, Xiao Ma, and Meikang Qiu. "PSAC: Proactive sequence-aware content caching via deep learning at the network edge." IEEE Transactions on Network Science and Engineering 7, no. 4 (2020): 2145-2154.