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Performance Comparison of Cache Based Routing in Information Centric IoT Networks

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ABSTRACT

In-network caching within the distributed computing is one of the most promising aspects of Information-Centric Networking (ICN) in comparison with traditional centralized server based data retrieval. With ICN, it can ensure that required data is readily available within the intermediate IoT routers, even when the original producer is not reachable. However, in Internet of Things (IoT), where the storage capacity is often severely limited, IoT nodes cannot simply cache any and all the content that will receive to the intermediate caching device(routers). Hence, it is very significant to know which content has to cache and how long the content has to be in the intermediate caching device. Moreover, cache-based routing plays a predominant role in reducing the end-to-end delay with enhanced network throughput by efficiently discovering the shortest-path from the intermediate caching devices in ICN-IoT networks. In this paper, comparison of different cache based routing protocols for ICN-IoT networks is discussed in terms of ICN caching and cache replacement strategies along with the performance metrics suitable for evaluating in an IoT context.

Key words: Caching, ICN networks, IoT Networks, ICN-IoT networks.

1. INTRODUCTION

Internet of Things (IoT), which will be a trend of future networks, has recently started to explore extensively in both industry and academia [1-2]. Huge number of constrained IoT devices generate tremendous amount of measurement, monitoring, and automation data with a large number of end-users across the world to run the applications that consume these IoT data. Even though each of the IoT device's traffic is commonly regarded as low rate, the aggregate load from multiple IoT devices on the core networks is expected to be very large[3]. Hence, it is important to reduce the traffic flow, lower the communication latency, and reduce the data communication overheads for network operators. Moreover, in most of the IoT applications, end users who request the constrained data from IoT networks are likely to be similar. For example, the data generated for traffic conditions by Transportation Department will be requested by government departments, search engines, traffic websites, and millions of other application users to predict the traffic conditions within specific location [4-5]. Another example can be air quality data, which will be published by different air condition monitoring stations to serve the requests from entire city. Very similar to Internet traffic, a large percentage of IoT network traffic is redundant i.e., multiple users request much of the same content from the IoT networks.

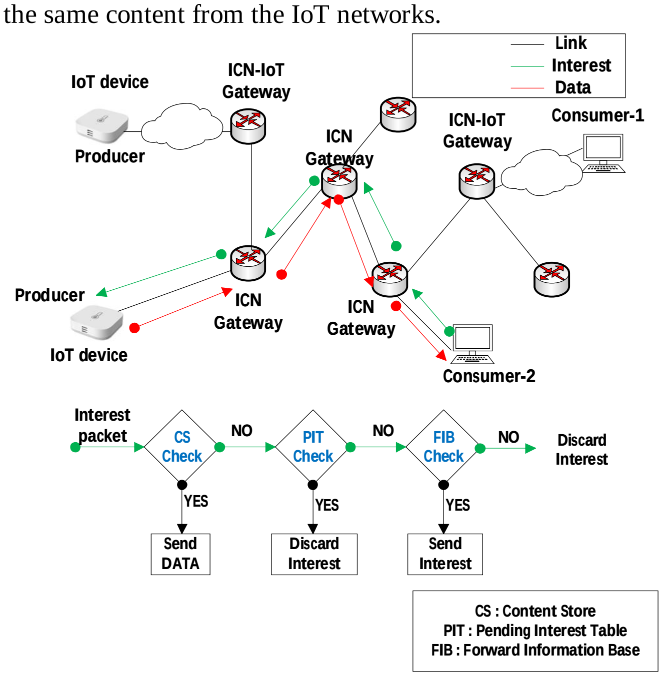


Figure 1: Operation of ICN-IoT Networks.

Although some of the IoT data are un-cacheable at the intermediate networking devices due to its real-time operations (multimedia IoT applications), it is necessary and natural to exploit the caching technology to minimize the redundancy that was caused by delivering the similar content over the IoT network. Network caching refers to the concept of storing the frequently accessed data in a location close to the requester, thereby data storage is distributed and it can be retrieved much faster than conventional data retrieval techniques (traditional data access in Internet). Cache based data retrieval technique is extensively studied and used in the Internet [6]. Currently, data accessing can be done in two ways:

1) Edge node caching (Content Delivery Network(CDN))—the application data contents are cached within the edge servers that are close to the user at the edge of the network.

2) In-network caching (Information Centric Network(ICN))—the application data contents are cached in the IoT routers of the core network, i.e., caching is considered as a basic network functionality in intermediate routers.

Researchers start to explore the IoT caching problem in the two caching mechanisms in recent years.

1) Edge Caching for IoT: On one hand, many recent works discuss the caching issues of edge computing [7] or 5G mobile communication for IoT perspective. On the other hand, some traditional CDN providers also design specific solutions for IoT, such as Akamais over the air (OTA) solution [10] and Microsoft Azure CDN [11]. In addition, the ubiquitous caching idea is also considered in 4G/5G network to decrease the backhaul traffic by using the cache in serving gateway (S-GW), packet data network gateway (P-GW) and mobility management entity (MME).

2) In-Network Caching for IoT: The first study on caching the IoT data in Internet content routers is explained in [8]. Later, [9-11] design the caching strategies for IoT which exploit the ICN architecture. With both edge caching and in-network caching, designing an efficient content caching should provide the solutions for: which content should be cached, where and when within the network. In-network caching in the IoT environment is extremely important due to its fast dissemination of content with multiple devices in a cost-efficient way. IoT applications may contain solicitude content based on specific properties such as critical/emergency content, monitoring, event traffic and query-based traffic.

2. RELATED WORKS

Information-Centric Networking [7], which is a promising paradigm for the future Internet is being proposed to overcome the various issues and challenges in the traditional host-centric centralized data retrieval model. The intention of the ICN is to integrate all the network functionalities around the content name instead of using host address. This section starts with related works of ICN and IoT with the focus of in-network caching. ICN for IoT: Leveraging ICN as a forwarding plane for the IoT environment is strongly recommended. This is because the re-design from connectivity towards content oriented paradigm makes ICN as one of the best candidates for IoT. It is noteworthy that the application pattern of IoT network follows content-oriented fashion where sensors and actuators do not need to communicate with a specific thing. In other words, constrained network applications are more interested in the offered data regardless of its geographical location. In addition, ICN supports seamless mobility management, in-network caching, and content-based security which is more appropriate and suitable for IoT environment. [8] mainly focus on smart home deployment by proposing the ICN framework based on the usage of hierarchical names with the support of push and pull traffic with multiparty forwarding strategy to allow data retrieval from multi-producers. In [9], healthcare applications were being proposed with a distributed ICN architecture that deals with communication models, publish-subscribe, and mobility issues. [10] discuss about Intelligent Transportation System from smart cities perspective to provide a secure and a reliable communication on the top of ICN model. In-network Caching in ICN-IoT Networks: The content names are independent from the original provider location which states that each data packet is self-consistent. ICN-IoT networks can provide in-network caching feature with the possibility that each intermediate node, in the communication path, can cache the content and serve it for future requests. Therefore, the overall network performance will be improved by facilitating content retrieval, and reduce the communication delay. However, deciding what content should be cached and on which device require ICN to involves different metrics such as content popularity, freshness, as well as device properties. In [12], ubiquitous in-network ICN caching is focused to improve the adaptive video streaming where the use of bit-rates and content size for best cache utilization is being suggested. Furthermore, they propose a rate-selective caching scheme which maximizes the overall throughput and improves the QoS. [13] proposed an entropy-based proactive strategy to measure the node mobility prediction using Markov-based predictors. The proposed caching method fetches the content and cache it in the network then locates the best node to retrieve the content that may reduce the latency of retrieving predictable content requests. Furthermore, it will decrease the server load and cache redundancy to handle the mobility hand-overs. In [14], ICN cache placement from ISP perspective is being proposed with a cost-aware greedy algorithm to minimize the overall costs or maximize the hit-ratio with the consideration of content placement and its size. The authors in [15] define the cost of Internet Service Providers (ISP's) content retrieval by the cost associated with the external bandwidth needed to retrieve the requested contents. IoT devices and its network traffic have different characteristics in comparison with the traditional Internet connectivity for content popularity, freshness, nodes energy level, distance from original content producer and data consumers. Hence, it is significant to consider the above characteristics while designing a caching placement scheme for ICN-IoT networks. [16] mainly focus on the content freshness metric and a novel scheme called freshness-based caching scheme is being proposed. This scheme focus of adding the Content Freshness Value in Cache Store table. Subsequently, it keeps checking the requested content from a consumer with the freshness value before serving that request. In [16], ICN caching from IoT perspective is being proposed and recommend due to the nature of IoT devices and application data. The caching strategies in ICN-IoT cannot be applied in a similar way to multimedia data. Hence, [17] consider different metrics (e.g., data property and popularity) to decide whether an IoT content should cache or not at the intermediate IoT routers. Different metrics are used in the study such as content lifetime, time range of incoming requests, and hop distance from the content source to requesters/Consumers. A distributed probabilistic caching strategy called as pCASTING has been proposed in [18] with the consideration of multi-hop wireless IoT system. In pCASTING, data freshness parameter is considered along with the node characteristics (i.e., energy level and storage capabilities) in a distributed caching probability without the need for any additional signaling information. This strategy aims to increase the energy usage with low content retrieval delays in comparison with other NDN caching schemes. [19] propose a simple greedy caching algorithm in order to determine which content should be cached in the ICN-IoT network. The caching scheme is mainly based on the content popularity metrics with the calculation of the total number of incoming requests for the content and the relative popularity of each content chunk. In [20], the cooperative caching scheme and power-saving in low-power IoT environment is proposed. A Cooperative Caching Side-Protocol aims to maximize the sleeping cycles, minimize the nodes energy consumption and increase the content availability. The most commonly used caching strategies are: Leave Copy Everywhere (LCE), Leave Copy Down (LCD), Edge Caching (EC) and Consumer Cache (CC). LCE consists of keeping a copy of the content in all the intermediate IoT nodes along the content delivery path. [21] propose a method to determine whether a received IoT data item should be cached according to the items lifetime, the rate and time range of incoming requests and router hop distances to the data source. [22] proposes a multi-attribute caching decision algorithm in IoT networks based on content-centric network (CCN) by considering the content store size, hop count and key temporal properties by the consideration of data freshness and the node energy level.

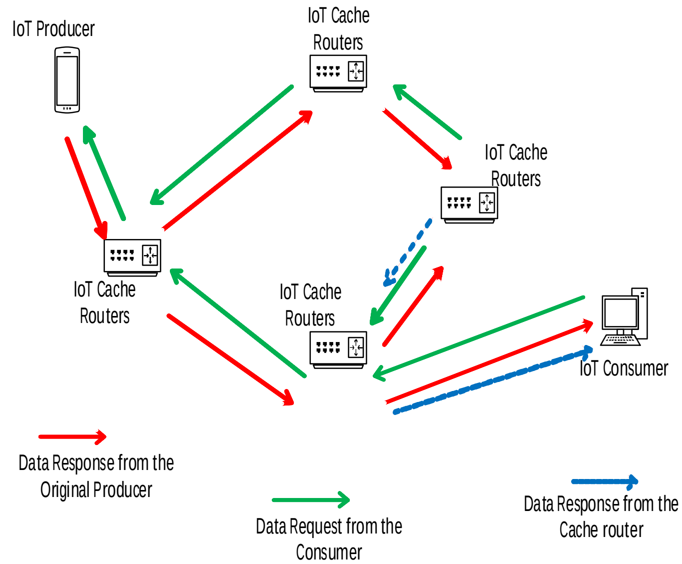


Figure 2: Caching in ICN-IoT Networks

[23] proposes a collaborative caching strategy for ICN-wireless sensor networks (WSNs) by allocating and shifting the cache tasks according to nodes' ability, location, and importance so as to adapt for the resource-constrained IoT environment. However, these techniques do not consider the heterogeneity in IoT and the popularity features of IoT data and make them perform poorly in the complicated IoT environment.

3. PERFORMANCE OVERVIEW OF CACHE BASED ROUTING PROTOCOLS

The current internet architecture is designed to forward all the requests of same content toward original producer which increases the network load, data retrieval delay and most importantly bandwidth consumption. In addition, the current Internet architecture lacks the support of data dissemination and fast retrieval of the user content. Due to these technical issues, the need for in-network caching is being raised. To deal effectively with the shortcomings of the current Internet architecture, Content Delivery Networks (CDNs) was proposed. By employing CDNs, caching is deployed as an overlay patch at the application layer (Web-caching) of the current Internet architecture. But, CDNs are costly to implement and do not utilize the network resources in a better efficient way in case of dynamic flash crowds. Hence, in the design of the future Internet architecture caching is added as an essential feature to enhance the performance of the network in terms of retrieval delay. In ICN-IoT based architectures, caching is implemented at the network layer that directly operates on named information. Existing ICN architectures like DONA, NDN, SAIL, and MF primarily support on-path caching whereas PURSUIT, COMET, and CONVERGENCE support both on-path and off-path caching [21]. In ICN-based IoT networks, in-network caching is highly required and recommended to disseminate the information quickly toward the edge devices in a cost-efficient way. Some of the IoT applications need a fresh content of data along with some specific timing requirements. In addition, most of the IoT contents are ephemeral in nature which needs to be replaced with the newer versions. For instance, the temperature value of a room needs to be monitored and updated very frequently. Furthermore, as IoT nodes are highly heterogeneous, which may differ in the processing resources (i.e., constraint-oriented and powerful nodes) and IoT networks are a mixture of wired and wireless technologies. In ICN-IoT, caching at the intermediate devices or IoT routers offers many benefits. Since the receiver is dissociated from the original data producer, therefore by caching the contents at the distributed locations, data security will be improved and the scalability of IoT network increases. Energy efficiency/Energy consumption of the constraint-oriented IoT devices can be improved and the node mobility can be handled in efficient ways [24]. Resiliency and lifetime of the ICN-IoT networks can be improved by employing the efficient caching mechanisms [25]. Even though caching offers many benefits, it also puts some restrictions and complications on the design of caching strategies for an environment like IoT [26]. To design ICN-IoT based caching, caching strategies must count for some properties of content to cache and IoT node that intends to cache it. Content properties at the intermediate IoT nodes can include popularity, freshness, ephemerality, timing and specific producer. In addition, it is significant to consider the caching node properties like node battery (power level), the distance of a node from the producer (or/and consumer) and remaining memory.

On the basis of above observations, caching placement strategies can be divided into three categories.

1) Content-based caching (CBC): These kind of strategies decide what type of data content has to be stored on the basis of content properties.

2) Content and node-based caching (CNBC): These kind of strategies decide whether an IoT node should cache the data content or not depending on both the content properties and node resources (like battery life, storage availability).

3) Alternative caching schemes: Algorithms that include the distance of a IoT node from producer or position/role in the ICN-IoT network in caching decision lies in this category. ICN based caching node architecture and cache coherency are also discussed in this category. A detailed overview of ICN-based caching techniques for IoT networks is presented in Fig.1.

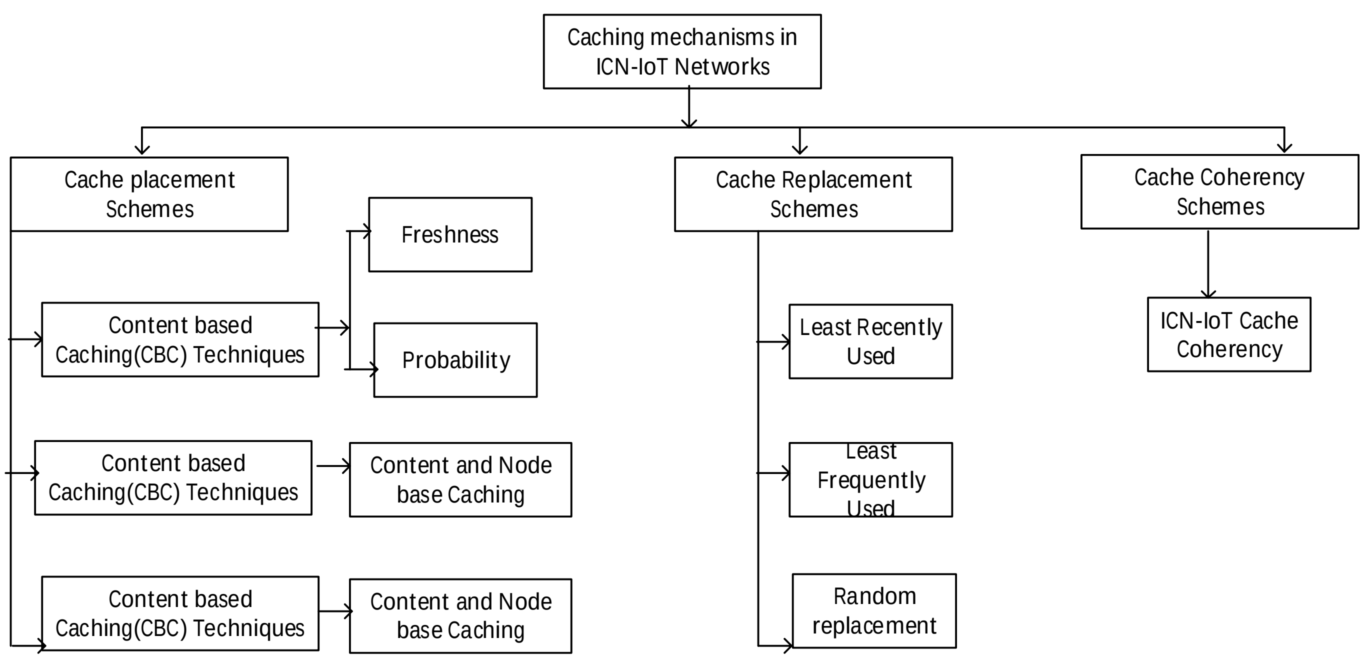
A caching strategy is further divided into the following three phases.

1) Content placement into the cache node: In this phase, cache space is allocated to IoT data contents on the basis of content or node. Content placement that comes under this scheme include cache each and everything (CEE) or universal caching and probabilistic caching.

2) Content replacement from the cache node: In this phase, when the cache at IoT node becomes full and there is no space vacant for next upcoming content then it will be dynamically decided to replace the already existing content. Content replacement schemes include Least Recently Used (LRU) and Least Frequently Used (LFU).

3) Cache coherency of contents in the cache node: In this phase, the validity of contents that reside in the cache is checked. The existing work shown in Table.1 depicts the caching based ICN-IoT design.

Table-1 shows the existing works that was categorized into three caching strategy



In this manuscript, Content Based Caching (CBC) placement scheme is compared in terms of Architecture, placement category scheme, parameters evaluated and simulator. [22] use LRU (Least Recently Used) as a cache replacement strategy, CCN as a network architecture and ndnSIM for CCN and NS3 as a network simulator. Parameters evaluated in this work is bandwidth consumption and energy consumption. [23] use LRU (Least Recently Used) as a cache replacement strategy, CCN as a network architecture and ndnSIM for CCN and NS3 as a network simulator. Parameters evaluated in this manuscript is cache hit ratio and average number of hops. [11] use LRU Random (Least Recently Used) as a cache replacement strategy, NDN (Name Data Networking) as a network architecture and ndnSIM for NDN and NS3 as a network simulator. Parameters evaluated in this manuscript is cache hit ratio, retrieval delay and interest re-transmissions. [12] use dynamic probability as a cache replacement strategy, CCN (Content Centric Networking) as a network architecture and RIOT operating system as a network simulator. Parameters evaluated in this manuscript is cache hit ratio, retrieval delay, interest re-transmissions, number of packets sent with respect to interest and data packets.

Content and Node Based Caching (CNBC) placement scheme is compared in terms of placement subcategory, replacement scheme, performance metrics and simulator. [14] uses LRU as a cache replacement scheme, NDN architecture and ndnSIM for NDN-N3 as a network simulator. Cache Hit Rat\io(CHR), network lifetime and retrieval delay was calculated and compared with the existing works. [15] uses LRU random as a cache replacement scheme, NDN architecture and matlab for analytical model as a network simulator. Cost Saving Ratio, network lifetime and hop distance ratio was calculated and compared with the existing works. Alternate caching schemes for ICN-IoT is compared in terms of placement subcategory, replacement scheme, performance metrics and simulator. [16] uses Infrastructure Based Caching, LRU as a cache replacement strategy, ICN architecture and MATLAB analytical modeling as a network simulator. Performance metrics evaluated in this work is percentage of validity, response latency, hop reduction ratio and server hit reduction ratio. In alternative caching schemes, the state-of-the-art research provides a comprehensive overview of caching schemes which do not focus on a specific method (For example: content or node-based caching) but introduces a caching schemes for IoT from other perspectives. In these, ICN-based caching methods for IoT is designed in-terms of overlay caching and cache coherency schemes. This is because they provide a caching network architecture on the existing Internet and cache coherency mechanism for ICN-IoT. Content Based Caching schemes compute the properties for every data content which include freshness and popularity of the data content. Researchers put more focus on exploring the content freshness of the data while popularity has been explored in a few existing CBC approaches. Hence, ICN-based content popularity caching strategies for the ICN-IoT networks needs truly an urgent attention from the research community. On the other side, it is important to consider both the node and content properties while making the cache decision at the intermediate IoT routers. On this side, a few extra efforts have been made to combine the features in cache placement strategies. For caching mechanism, authors categorize it into two strategies namely CBC and CNBC. CNBC strategies include data content properties along with the IoT node characteristics like node battery timings, Content size, node geographical position, and caching module designing in the IoT node and network type. As we know that IoT nodes are assumed to have the low processing power, memory, and battery. But, the current literature on content caching is missing the consideration of characteristics of the IoT low power and low memory constraints in ICN-IoT applications with mobile devices. In addition, existing caching strategies lacks in the push traffic type consideration for the ICN-IoT network. During the comparison to decide about the optimal caching schemes in ICN-based IoT networks, Content and Node Based Caching is better than Content Based Caching alone with respect to throughput, but apparently it requires more network resources to compute about caching decision at the intermediate ICN-IoT routers. Since constrained batteries are in being used in IOT nodes, ICN-based energy efficient caching schemes for IoT networks should also needed to explore further by the research community.

Besides both Content Based Caching and Content Node Based Caching, authors categorize the rest of the ICN-based caching schemes for IoT networks into alternative caching strategies. This can include the application specific caching node architecture which seems like disaster management application, cache coherency protocol and overlay caching mechanism. The third category can be decided irrespective of both the node and content properties at the intermediate ICN-IoT routers. The existing research survey strongly conveys that Content Based Caching has been explored to some more extent than the Content Node Based Caching. This can be because CBC protocols directly deal with the content properties like content freshness and node popularity. Since every IoT application demands the content generation with different properties, for example, real-time traffic demand highly fresh contents whereas flash crowds may need more popular contents. This results that CBC schemes are more easy to explore for the IoT application scenarios. On the other hand, Content Node Base Caching schemes are little bit challenging to implement as ICN-based IoT node and network architecture are still under research and exploration phase. In the cache replacement methodologies, mostly Least Recently Used schemes has been implemented in a common node due to its better results whereas Least Frequently Used scheme has been considered for edge nodes. Further, random replacement scheme is easy and simple to implement than LFU and LRU because it ensures high data diversity. Until now, there is only one cache coherency protocol for ICN based IoT [21] networks. Hence, ICN-based coherent protocols are highly required for IoT networks to provide content validation in IoT applications. In our extensive survey of ICN-IoT caching Schemes, the authors understand that ICN caching provides better IoT network performance and improves data delivery. Based on the existing cache placement and replacement strategies, authors think that research needs to explore more towards CNBC caching schemes for ICN-IoT constraint-oriented nodes while accommodating both the transient and ephemeral contents.

4. CONCLUSION

Based on the extensive literature survey on cache placement and replacement mechanisms, authors discussed and presented various caching mechanisms in paradigms of IoT and ICN networks. Subsequently, requirements and challenges to build a reliable and interoperable communication network architecture for ICN and IoT networks is being discussed. Throughout this manuscript, author also discussed about the ICN caching methods and its suitable features to different ICN projects for the future Internet design. ICN-IoT applications are briefly discussed in terms of their characteristics along with corresponding feasibility for IoT in terms of naming schemes, caching mechanisms, security, and mobility support.

Mapping of constrained IoT communication network architecture to the requirements of existing ICN NDN architecture is discussed. Furthermore, authors discussed ICN-based solutions for the IoT networks to present the applicability of ICN for IoT networks in terms of naming, caching, security, and mobility. At the end, authors present identified research gaps which needs extra attention by research community to build ICN-based network architecture for IoT I being discussed.

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REFERENCES

1. J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, **"Internet of Things (IoT): A vision, architectural elements, and future directions**," *Future Generation Computer Systems.*, vol. 29, no. 7, pp. 1645–1660, 2013.
2. H. Ma, L. Liu, A. Zhou, and D. Zhao, "**On networking of Internet of Things: Explorations and challenges**," *IEEE Internet Things.*, vol. 3, no. 4, pp. 441–452, Aug. 2016.
3. Ahmad K. Al Hwaitat , Mais Haj Qasem, "**A Survey on Li Fi Technology and Internet of Things (IOT)**", *International Journal of Advanced Trends in Computer Science and Engineering*, Vol.9.No.1, Feb-2020
4. G. Paschos, E. Bastug, I. Land, G. Caire, and M. Debbah, "**Wireless caching: Technical misconceptions and business barriers**" *IEEE Communication Magazine*, vol. 54, no. 8, pp. 16–22, Aug. 2016.
5. G. Pallis and A. Vakali, "**Insight and perspectives for content delivery networks,**" *ACM Communications,* vol. 49, no. 1, pp. 101–106, 2006.
6. J. Choi, J. Han, E. Cho, T. Kwon, and Y. Choi, "**A survey on content oriented networking for efficient content delivery**," *IEEE Communication Magazine.*, vol. 49, no. 3, pp. 121–127, Mar. 2011.
7. B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher, and B. Ohlman, "**A survey of information-centric networking,**" *IEEE Communication Magazine.*, vol. 50, no. 7, pp. 26–36, Jul. 2012.
8. S. Wang, X. Zhang, Y. Zhang, L. Wang, J. Yang, and W. Wang, "**A survey on mobile edge networks: Convergence of computing, caching and communications,**" *IEEE Access*, vol. 5, pp. 6757–6779, 2017.
9. E. K. Markakis, K. Karras, A. Sideris, G. Alexiou, and E. Pallis, "**Computing, caching, and communication at the edge: The cornerstone for building a versatile 5G ecosystem,**" *IEEE Communication Magazine.*, vol. 55, no. 11, pp. 152–157, Nov. 2017.
10. X. Wang, M. Chen, T. Taleb, A. Ksentini, and V. C. M. Leung, "**Cache in the air: Exploiting content caching and delivery techniques for 5G systems,**" *IEEE Communication Magazine.*, vol. 52, no. 2, pp. 131–139, Feb. 2014.
11. J. Quevedo, D. Corujo, and R. Aguiar, "**Consumer driven information freshness approach for content centric networking,**" in *Proc. IEEE Conference Computer Communications Workshops (INFOCOM WKSHPS)*, Toronto, ON, Canada, Apr. 2014, pp. 482–487.
12. J. Quevedo, D. Corujo, and R. Aguiar, "**A case for ICN usage in IoT environments,**" *in Proc. IEEE Glob. Commun. Conf.*, Austin, TX, USA, Dec. 2014, pp. 2770–2775.
13. M. A. M. Hail, M. Amadeo, A. Molinaro, and S. Fischer, "**On the performance of caching and forwarding in information-centric networking for the IoT,**" in *Proc. Wired/Wireless Internet Commun.*, Jan. 2015, pp. 313–326, doi: 10.1007/978-3-319-22572-2_23
14. E. Baccelli, C. Mehlis, O. Hahm, T. C. Schmidt, and M. Wählisch, **"Information centric networking in the IoT: Experiments with NDN in the wild,"** *in Proc. 1st Int. Conf. Inf. Centric Netw.*, 2014, pp. 77–86.[Online]. Available: http://dx.doi.org/10.1145/2660129.2660144

15. W. Shang, Q. Ding, A. Mariantoni, J. Burke, and L. Zhang, "**Securing building management systems using named data networking,**" *IEEE Networks*., vol. 28, no. 3, pp. 50–56, May/Jun. 2014.
16. S. Li, Y. Zhang, D. Raychaudhuri, and R. Ravindran, "**A comparative study of mobilityfirst and NDN based ICN-IoT architectures,**" *in Proc. Conf. 10th Int. Heterogeneous Netw. Qual. Rel. Security Robustness (QShine)*, Aug. 2014, pp. 158–163.
17. V. Sourlas, L. Tassiulas, I. Psaras, and G. Pavlou, "**Information resilience through user-assisted caching in disruptive content-centric networks,**" *in Proc. IFIP Netw. Conf. (IFIP Netw.)*, May 2015, pp. 1–9.
18. M. A. Hail, M. Amadeo, A. Molinaro, and S. Fischer, "**Caching in named data networking for the wireless Internet of Things,**" *in Proc. Int. Conf. Recent Adv. Internet Things (RIoT), Singapore*, Apr. 2015, pp. 1–6.
19. S. Vural et al., "**In-network caching of Internet-of-Things data,**" *in Proc. IEEE Int. Conf. Commun. (ICC), Sydney, NSW, Australia*, Jun. 2014, pp. 3185–3190.
20. M. Meddeb, A. Dhraief, A. Belghith, T. Monteil, and K. Drira, "**Cache coherence in machine-to-machine information centric networks**," *in Proc. IEEE 40th Conf. Local Comput. Netw. (LCN)*, Oct. 2015, pp. 430–433.
21. M. Amadeo, C. Campolo, and A. Molinaro, **"Information-centric networking for connected vehicles: A survey and future perspectives**," ***IEEE Commun. Mag.*, vol. 54, no. 2, pp. 98–104, Feb. 2016.**
22. **E. G. AbdAllah, H. S. Hassanein, and M. Zulkernine, "A survey of security attacks in information-centric networking,**" *IEEE Commun. Surveys Tuts.*, vol. 17, no. 3, pp. 1441–1454, 3rd Quart., 2015.
23. M. Zhang, H. Luo, and H. Zhang, "**A survey of caching mechanisms in information-centric networking,**" *IEEE Commun. Surveys Tuts.*, vol. 17, no. 3, pp. 1473–1499, 3rd Quart., 2015.
24. C. Fang, F. R. Yu, T. Huang, J. Liu, and Y. Liu, "**A survey of energyefficient caching in information-centric networking,**" *IEEE Commun. Mag.*, vol. 52, no. 11, pp. 122–129, Nov. 2014.
25. M. F. Bari, S. R. Chowdhury, R. Ahmed, R. Boutaba, and B. Mathieu, "**A survey of naming and routing in information-centric networks,**" *IEEE Commun. Mag.*, vol. 50, no. 12, pp. 44–53, Dec. 2012.
26. M. Amadeo et al., "**Information-centric networking for the Internet of Things: Challenges and opportunities,**" *IEEE Networks.*, vol. 30, no. 2, pp. 92–100, Mar./Apr. 2016.