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IP and ICN Networking in D2D_IoT Communications: A Comparative Study

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Abstract

Device-to-device Internet of Things (D2D_IoT) communications are promising and futuristic communications that contribute to reducing pressure on the network. Recently, the research community proposed information-centric networks (ICN) to achieve D2D_IoT communications. This paper will provide a qualitative comparison between Internet Protocol (IP) and ICN networks. The paper will compare naming, messaging, routing, caching, and security. ICN is more suitable for the D2D_IoT due to its compatibility with its design and the requirements of IoT applications, making it a promising solution for IoT networks.

Article Info

Keywords:
D2D, IoT, communication, IP, ICN , ICN architecture

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1. INTRODUCTION

According to expectations, by 2025, the number of objects connected to the IoT will increase three times more than in 2019. More than 75 billion objects will be connected to the IoT. There will be 5.3 billion Internet users worldwide, with an average of 3.6 Internet-connected devices per capita [1], [2]. This expansion and increased number of devices led to a significant increase in the amount of data. Therefore, D2D communication has become an inevitable necessity. Devices decide to communicate directly without transmitting data to the upper layers, thus reducing pressure on the network [3]. Recently, IP-based technologies such as IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) and Low-power wide area networks (LPWA) have been developed to suit the requirements of connecting IoT devices. However, recent research indicates that ICNs provide direct support for the functions and requirements of IoT applications, especially D2D communications. The main features offered by ICNs, such as naming, forwarding, security, and caching, make them promising networks for IoT [4], [5]. This paper illustrates a theoretical comparison between IP networks and ICNs. The rest of the paper is summarised in Fig. (1) and organized as follows: Section 2 outlines an overview of D2D communications and its challenges. Section 3 explains the principles of ICN with different architectures. Section 4 compares ICN and IP regarding messages, naming, routing and forwarding, caching, and security—finally, Section 5 deals with conclusions.

2. D2D_IOT COMMUNICATION

As the number of connected devices and subscribers increases, there is a growing need to reduce access time and increase data rates. D2D_IoT is being developed as an emerging and future technology [6]. The D2D_IoT communication architecture is divided into three layers: the D2D_IoT devices layer, the management layer, and the D2D_IoT application layer, as shown in Fig. (2) [7]. The first layer consists of D2D_IoT devices that communicate with each other via D2D_IoT links. Then, data is collected and sent to the management layer, which consists of either wired or wireless networks. This layer sends data to service providers. Service providers deliver applications to customers and manage them.

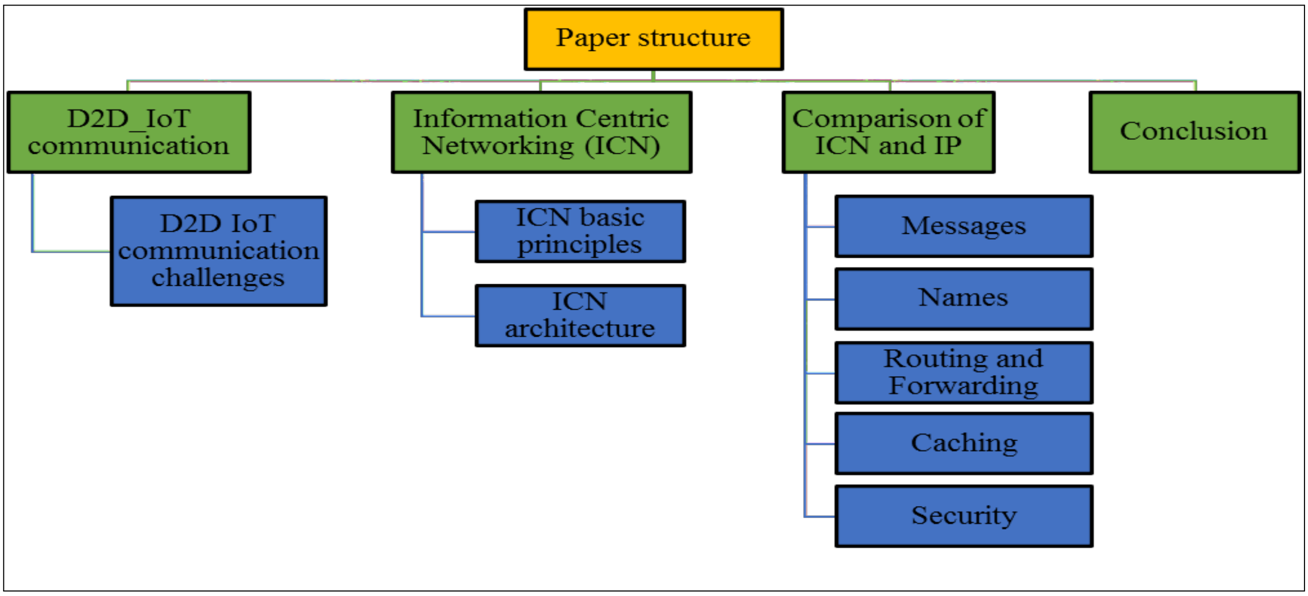

Figure 1. Paper structure

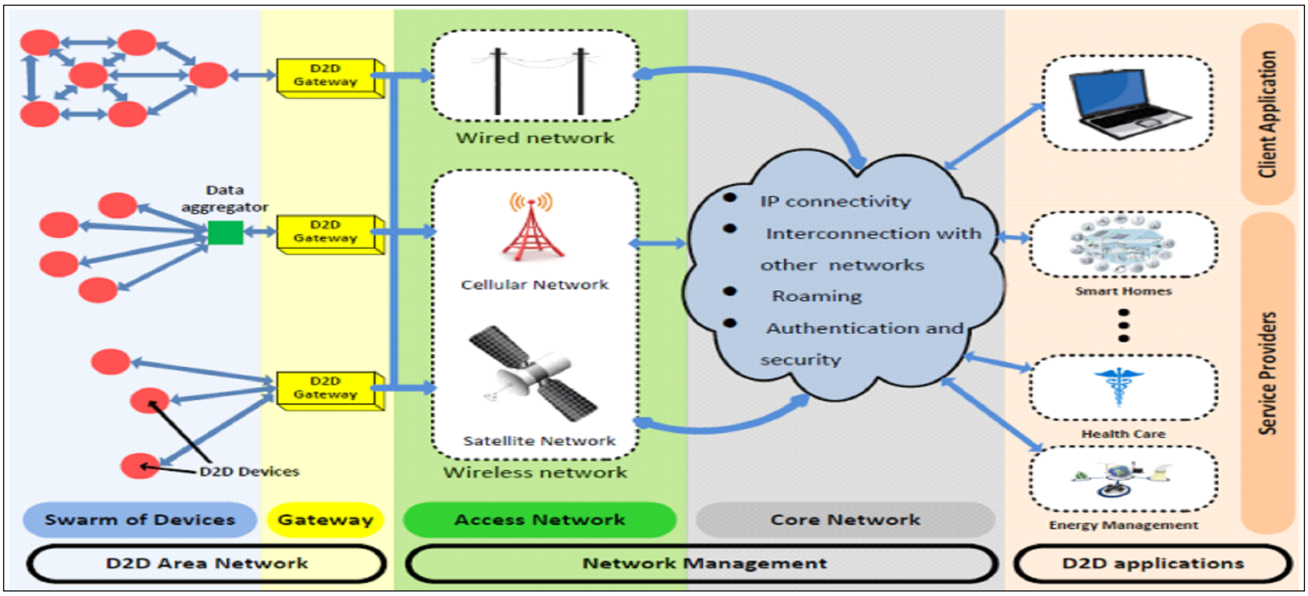

Figure 2. D2D_IoT communication architecture [7]

2.1. D2D_IoT COMMUNICATIONS CHALLENGES

There are many challenges facing D2D_IoT communications, and some of these challenges include the following [3], [8]–[10]: **Security and privacy**. D2D_IoT communications must ensure secure and reliable data exchange, free from hardware complexity and power consumption. **Device discovery**, as devices must be able to discover each other to establish direct communications. This communication can be distributed or centralized. D2D_IoT communications must ensure reduced network interference and fast delivery. Simultaneous with the high mobility of devices and different applications. Also, resources must be well managed to minimize interference in a single network. **Communication mode.** Choosing the appropriate communication mode from the challenges of D2D_IoT communications. These modes are the specialized mode where the sender and receiver communicate directly. Alternatively, cellular mode, where devices communicate via the base station. Reuse mode, where the resources available with the cellular connection are reused.

3. INFORMATION-CENTRIC NETWORKING (ICN)

As mentioned earlier, ICN networks enhance communication, as data is accessed by name instead of address. This is particularly true due to the increasing number of Internet users and the expanding range of its applications. ICN is the natural evolution of networks since IP was not

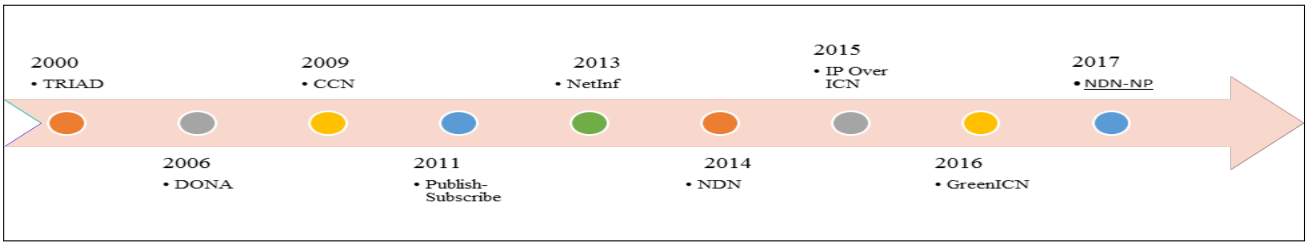

Figure 3. ICN Architecture

initially directed to accommodate new technologies such as cloud computing, IoT, social networking, and big data. This section will explain the basic principle of ICN work, the different architectures, and their differences.

3.1. ICN basic principles

In ICN, when a user needs data, it sends an interest packet to the network with the name of the requested content embedded within it. Based on this name, the packet is forwarded to the node containing the requested data, which then sends the data to the consumer [11]. Through content caching, it is possible to eliminate content source throttling, reduce the load on a data product, and thus improve the overall network performance. Each intermediate router in the network caches a copy of the data; when this router receives an interest packet, it sends the content from its cache rather than forwarding it to the requested data producer. This enhances data availability while reducing network traffic and minimizing data delivery latency. As mentioned earlier, routers forward messages of interest and send the required data to the consumer. To achieve this, they build a reverse path that contains the status information that the router maintains. Since routing in ICN is based on content name, unique and site-independent mechanisms for data naming have been proposed. These mechanisms may be based on hierarchical or flat naming.

3.2. ICN architecture

The Internet Protocol Version 6 (IPv6) design predates the web, and although it provides more addresses, it does not help with the content problem. Therefore, many researchers proposed new content-based architecture, starting with the Translating Relaying Internet Architecture integrating Active Directories (TRIAD) project in 2000 [12]. These architectures underwent major changes, and many different architectures were proposed [13]. In this part, the researchers will review some of these proposed architectures. Figure (3) summarizes these architectures.

3.2.1. TRIAD Architecture

The TRIAD architecture was proposed in 2000 and has revolutionized data delivery over the Internet [12]. TRIAD enhances content routing and caching by explicitly adding a content layer over the IPv4 infrastructure. It is compatible with traditional network Internet protocols such as Internet Protocol Version 4 (IPv4), Transmission Control Protocol (TCP), and domain name system (DNS). The client uniquely defined names present in the network, and to speed up the delivery of content to the customer, TRIAD caches data near the requests data from the content layer based on the consumer. The naming schemes in TRIAD are hierarchical and Domain Name System (DNS) based, but in this architecture, no mechanism is integrated to provide security.

3.2.2. Data-Oriented Network Architecture (DONA)

In 2006, researchers at the University of California proposed DONA, which improves TRIAD architecture and provides security in the network architecture [14]. DONA is redefining the naming scheme in the TCP/IP network for a content-centric environment. It uses a flat naming system, making names available to customers via trustworthy mechanisms such as private connections and search engines.

3.2.3. Content-Centric Network (CCN) Architecture

Jacobson proposed the CCN architecture in 2009 [15]. CCN builds on the principles of TCP/IP and makes it powerful, simple, and scalable. CCN is expected to replace IP and also can be deployed as an overlay on IP networks. Strategy and security are new layers that have been included in this architecture. These layers achieve an easy heterogeneous connection and enhance the security of the contents. CCN uses two types of packets: interest and data. The client specifies the name of the content, and then a packet of interest is generated. These packets are broadcasted via links available in the network. If the node contains the data, it responds to the interest packets by sending the required data. Otherwise, it forwards the interest packets to the next nodes until they reach the data source. CCN uses hierarchical naming and keeps the reverse path for the data to be used in the future instead of forwarding it back to the source. CCN uses the Least Frequently Used (LFU) or Least Recently Used (LRU) algorithms to find space for the most recently used data, while IP uses the Most Recently Used (MRU) algorithm to replace the most frequently used addresses.

3.2.4. Publish-Subscribe Architecture

The publish-subscribe architecture was proposed by Nikos Fotiou et al. in 2011 [16]. The resource publishes the information in this architecture, and the client arranges the content according to its needs. This architecture links relevant information and the principle of need (subscription) for information and availability (dissemination)—organizing and accessing information hierarchically and more generally than naming in the DONA architecture. The publishing-subscribe architecture's naming scheme consists of a scope identifier and a rendezvous identifier. A scope identifier groups related contents, and a rendezvous identifier is a unique identifier within a single group.

3.2.5. Network of Information (NetInf) architecture

In 2013, researchers proposed a NetInf [17]. NetInf has focused on deployment in different heterogeneous networks, such as the traditional backbone network and data centers. This architecture is based on flat naming and needs more routing based on name resolution or aggregation. It uses routing hints for object retrieval over the legacy IPv4 network.

3.2.6. Named Data Networking (NDN) architecture

In 2014, Zhang Lixia and others developed the NDN architecture [18], which improved the CCN architecture and completely replaced the IP architecture with a content-driven architecture. The NDN architecture uses hierarchical naming, and content is distributed in a distributed environment that provides load balancing. This architecture also supports in-network caching and multipath forwarding. Similar to the CCN architecture, the NDN architecture contains two types of packets: interest packets and data packets. NDN architecture has more detailed fields in these two packets, such as the meta-information fields for packet age and content type. The customer creates an interest pack with the name of the requested data. Routers forward interest packets to a data location that may be a data producer or a caching. Then the data is returned to the customer with the required content. The data bears a signature from the actual product to ensure its validity and reliability.

3.2.7. IP Over ICN

In 2015, Dirk Trossen et al. proposed enabling individual customers to improve their services in IP networks by exploiting all ICN key benefits to improve the performance of IP networks [19]. In IP networks, information is exchanged between points based on their addresses; in this architecture, these addresses are replaced by the names of the required data that express the content. The proposed architecture is based on the network attachment point (NAP), which connects the IP and ICN networks.

3.2.8. GreenICN architecture

The researchers [20] introduced an environmentally friendly ICN architecture with an energy-saving security system and efficient cache management. The researchers applied GreenICN in a video delivery scenario and a potential natural disaster scenario.

3.2.9. Named Data Networking Next Phase (NDN-NP) architecture

Jacobson et al. developed the next phase of the NDN architecture [21]. This NDN-NP architecture has been deployed and evaluated in four environments: mobile health, building automation management systems, data science applications, and multimedia real-time conferencing tools. NDN-NP has made progress in developing protocols to support security and content-based data validation. NDN-NP has made progress in forwarding and congestion control.

3.2.10. Modern ICN Architecture

Then came the various ICN architectures that seek to spread ICN in the real world through experimentation on a global scale, such as ICN-2020 [22], which is concerned with video delivery, social networking, cloud services, and Internet of Things features. Researchers have developed an information-centered wireless sensor architecture. The client requests information in this network instead of establishing end-to-end communication [23].

4. COMPARISON OF ICN AND IP

By 2025, IoT is expected to connect 75 billion heterogeneous objects, raising the challenges facing IP networks that rely on data addresses and locations and are not designed to handle data content [1]. As mentioned, ICN changes how networks work by relying on content regardless of location, which most IoT applications need, especially D2D_IoT applications, where communication centers around information. In the previous part reviewed many different architectures for ICN networks. In this part, researchers will compare IP and NDN networks because NDN is the architecture in which content-based networks completely replace IP networks. In the future, this will likely happen when communication will be based on content instead of titles.

4.1. The main differences between ICN and IP

The main difference between the ICN architecture and the IP architecture lies in the focus of the first on the data (what) and the focus of the other on the location (where). As mentioned, this study will focus on the structure of NDN, and resarchers will use the term ICN to express it in the rest of the paper. In recent years, there have been many changes and developments in ICNs, especially in

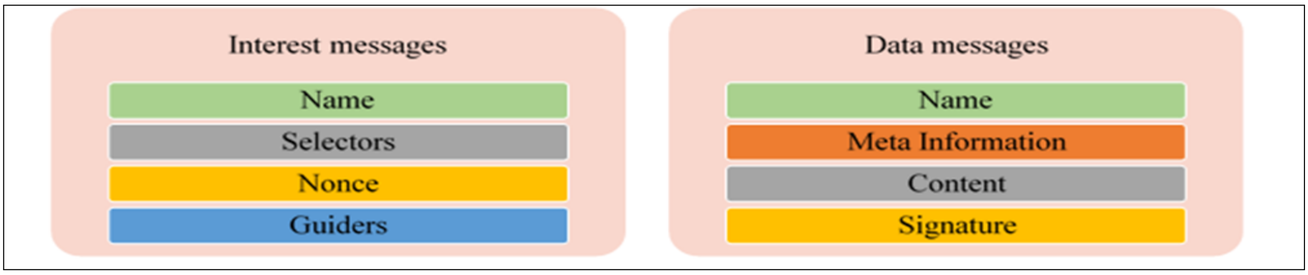

Figure 4. Messages types in ICNs

routing and naming methods, regardless of the architecture. Therefore, the term ICN used here stands for NDN with recent developments.

4.1.1. Messages

There is no distinction between IP message types; all packets are forwarded similarly. Unlike that, ICN has two types of messages, namely interest messages and data messages. Figure (4) shows these messages. Consumers send an interest message to request data and then receive a data message that matches the interest message [18].

- Interest message, which contains the name of the content used to search for data and direct it to a cache or data producer. Selectors that specify the details of the request, filters, if any, any additional restrictions on the requested content, and so on. Nonce is a random number generated by the consumer to detect duplicate interests. It may contain a fourth field, the guide, expressing the age of interest or the range.
- The data message contains four fields the name of the data, the content, and a signature by the producer to ensure the reliability of the content, as well as a field containing identifying information such as the type of content.

Some ICN applications may provide extra fields in these messages. ICN contains two types of nodes according to their role. The producer's role is the nodes that produce new data. The consumer's role is the nodes that request data within the network. The producer's node may assume a consumer role if it requests data from others [24]. The roles of the producer and consumer are defined during only one data exchange.

4.1.2. Names

In ICNs, objects are named uniquely, and hierarchical naming, such as that used in URLs, is usually used to name web content. As mentioned earlier, the naming is independent of the location, and the components of the names are human-friendly. In IP networks, the connection endpoints are named and are the source and destination IP addresses. The correct name and address are searched to process the requested data, whereas in ICN, the consumer requests the data directly. In both cases, the name requested by the consumer is analyzed and translated. In IP, the translation occurs between the content name and its address. In ICN, the translation is done between the name of the content and the names of the ICN known in the network because publishing is done on a large scale [24].

One of the differences in naming is that the size of IP addresses is usually fixed and has limited space. IPv4 addresses consume 4 bytes, while IPv6 addresses consume 16 bytes, unlike the unlimited and variable naming space in ICN, which eliminates the problem of potential address space depletion, especially with the huge increase in IoT devices. The data namespace in an ICN depends on the naming scheme used and the applications. However, controlling the routing table with different name sizes is an important challenge in ICN. Moreover, when mobility handling is used, the data names in the ICN remain the same, so the connection is not disconnected, as in IP, which requires changing addresses, which causes disconnection in some cases [25]. In the ICN name, the different levels are separated by a forward slash. The authors of [26], [27] used that the naming be composed of four components, namely: The first component contains the public domain name and is set by the consumer. The second component is optional and used to send additional information about some services or applications. The third component contains the application's name. The last component contains additional information about specific events, such as adding timestamps to the packet of interest or device identification (ID). Figure (5) shows these components with an example.

4.1.3. Routing

In each ICN node, there are three data structures for forwarding and processing: Content Store (CS), Pending Interest Table (PIT), and Forwarding Information Base (FIB) [5], [28]. Received data is cached in CS, which helps speed up the delivery of future requests for this data. When a new interest message is received, the requested data is first looked up in CS. If it exists, it is forwarded directly to the consumer, unlike the cache in IP routers, where the data cannot be reused after being forwarded. PIT contains all the interests the router has

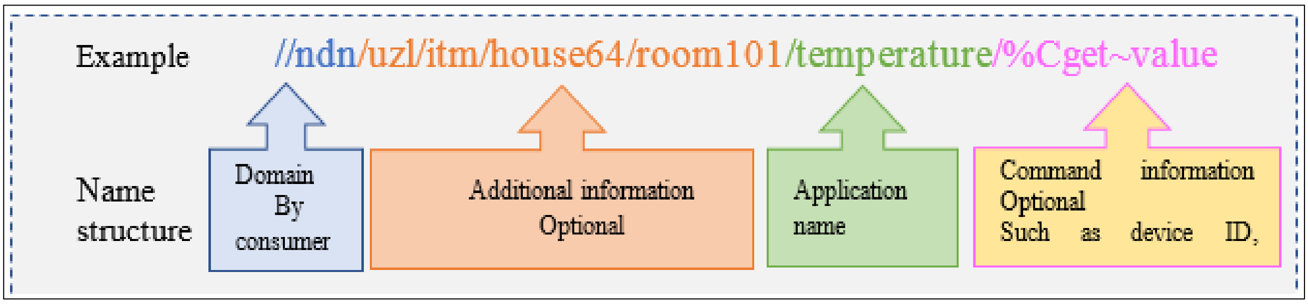

Figure 5. ICN Name Structure

sent but has yet to satisfy. On every attention the PIT receives, the name of the requested data is recorded with the outgoing and incoming interfaces. This information is used to track incoming interfaces and thus return the requested data packets to the consumer. The PIT contains the name of the data with the nonces of that name, the list of incoming interfaces from which interests for that name were received, and the list of outgoing interfaces to which the interests were redirected. Figure (6) shows the PIT structure. FIB stores a data name prefix to forward packets of interest toward requested data sources. The FIB is populated using a name-based routing protocol. The function of FIB in ICN is similar to that of an IP router, except that the IP router depends on the prefixes of the IP address, while the FIB depends on the prefixes of the data name. • **Routing Process**

On receiving an interest packet, the ICN router first checks the CS for matching data; if the data already exists, it returns it to the interface from which it came. Otherwise, the ICN router will look into the PIT if it has previously received any interest in the specified content. It registers the incoming interface for that interest in the PIT entry, forwards the data message to all interfaces from which the interest packet came in the PIT entry, and stores the data. In CS, it removes the PIT entry. If PIT has not previously received interest for this content, a new entry for the interest message will be entered with the incoming interface to PIT. Then, based on the forwarding strategy and the information in the FIB, the message of interest is forwarded to another node that may be the data producer. If the router receives an interest message for the same data from different nodes, it only forwards the data from the data producer to the first node, and the rest of the nodes get the data from it. If the router receives a data message, it checks the data name in the PIT entry. If the name of the data is found in a PIT entry, the data is stored in the CS and forwarded to the incoming interfaces that requested it and were previously registered in the PIT. Otherwise, the data is deleted because it is no longer required or was not required at all [29]. Each interest message and data stored in the CS has an associated lifetime, and these messages or data are removed when the lifetime expires. Figure (7) describes the routing process in ICNs; red shows interest messages, while green shows data messages. As noted above, ICN uses stateful redirection, the data message always follows the path of the interest message in the opposite direction back to the consumer. While IP uses stateless forwarding, the request and response message routing paths are not necessarily the same. Moreover, a stateful routing scheme allows interest aggregation for the same data. The second interest message for the same data will not result in a redirect to the data source, but rather, the data will be obtained from the intermediate node [28]. That is, the data will be sent from the data producer only once to different consumers. The more nodes are interested in the same data at the same time, the less bandwidth is used and, therefore, a more efficient network compared to IP. It is also noted that if the nodes contain divergent paths to the product or the interest time of consumers of the same data is different. The use of interest aggregation has a small effect on network efficiency.

4.1.4. Caching

In ICN, the consumer does not need to connect to the data producer whenever he wants to obtain it; interest can be satisfied with the intermediate nodes in the network, where each node acts as a store for content in addition to transmitting data. ICN uses cache as a compact structure. The consumer can obtain the content from its nearest network node; thus, reduced latency, response speed to subsequent requests, and traffic reduction improve network performance [30]. Caching does two processes: content placement (positioning) and replacement. The positioning process determines which nodes will be cached and what content will be stored. The replacement process removes previous content and allows for storing newly arrived content. The replacement process uses traditional approaches such as LFU, LRU, random replacement (RR), and First in, first out (FIFO). However, the traditional methods could be more practical in dealing with the unknown dynamic changes in the popularity of the content. So, more recently it has turned to managing cached resources using the tools of artificial intelligence (AI), machine learning (ML), and deep learning (DL) to improve performance. Intelligent methods use several strategies for caching. For example, deter-

Figure 6. PIT Structure

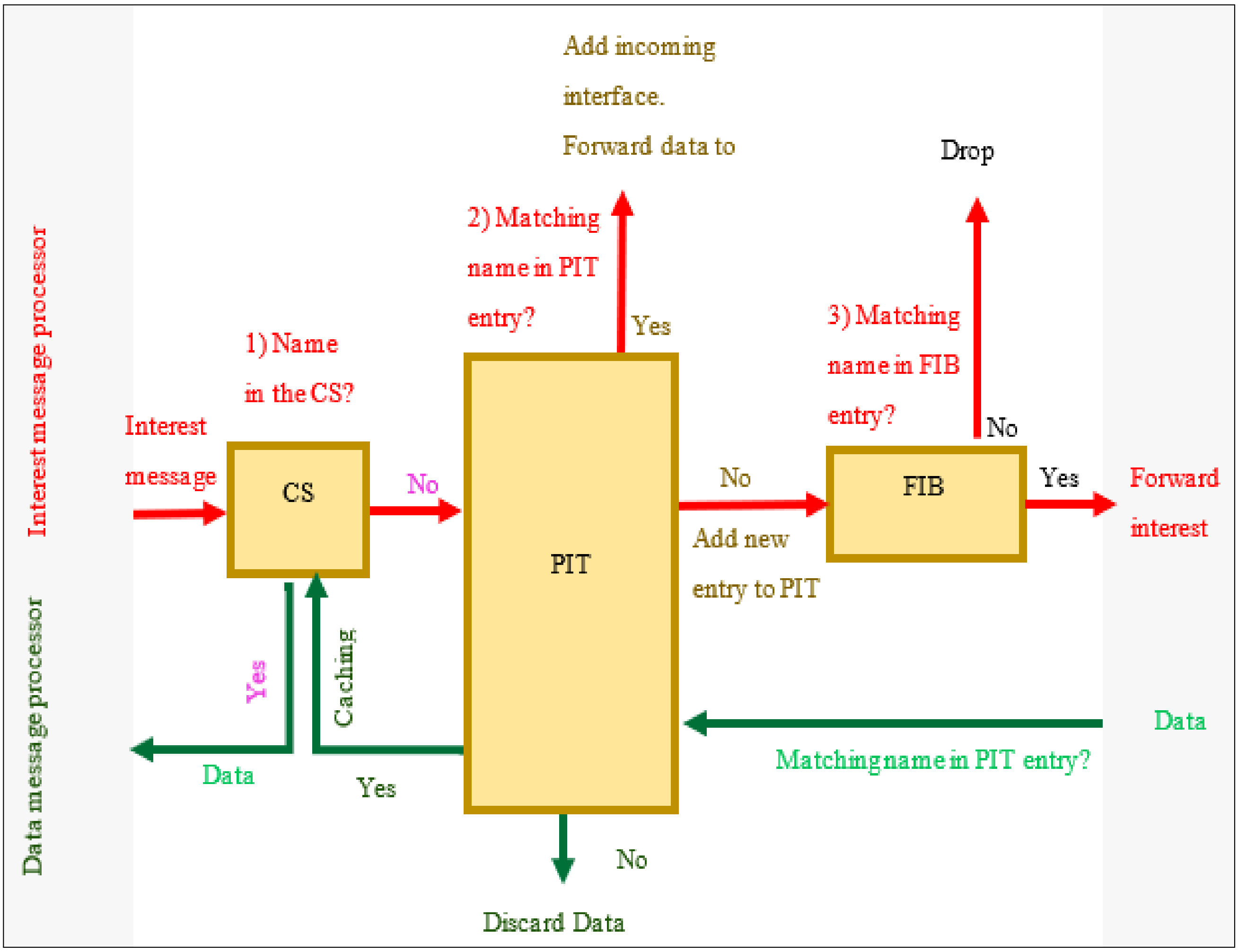

Figure 7. Routing process in ICNs

mining the popularity of content through the frequency of access to it, a mechanism for predicting consumer preferences, and proactive caching with observance of the user's geographical location and movements [31]. In ICN, the caching is at the network layer, while in IP, the caching is at the application layer. Messages in IP refer to the source, and destination addresses do not refer to data. Therefore, it is not easy to distinguish repeated requests for the same data in the network layer. This is done in the higher layers that distinguish this data and is often the application layer. IP routers contain a cache, but IP routers cannot reuse the data after forwarding it. As mentioned, they do not distinguish the data in the network layer, unlike the cache in ICN that can redirect the same data to more than one consumer because it distinguishes the data from its names [5].

4.1.5. Security

The ICN architecture provides security naturally. Security is a basic building block at the waist, as shown in Fig. (8) [5]. Security in ICN relies on securing application data rather than the entire communication channel. Unlike the IP network, which provides weak protection, security depends on securing communication channels. This is achieved by securing the channel between the source and the destination and using encryption. The overhead, complexity of operations across layers, and complexity of managing connections make the security model used in IP unsuitable for IoT architectures. In ICN, security is more user-centric and content-based. Instead of securing communication channels between the source and destination, data is signed by data producers and verified by consumers. Content-based security leverages signed data caching, which is unavailable on IP networks. This

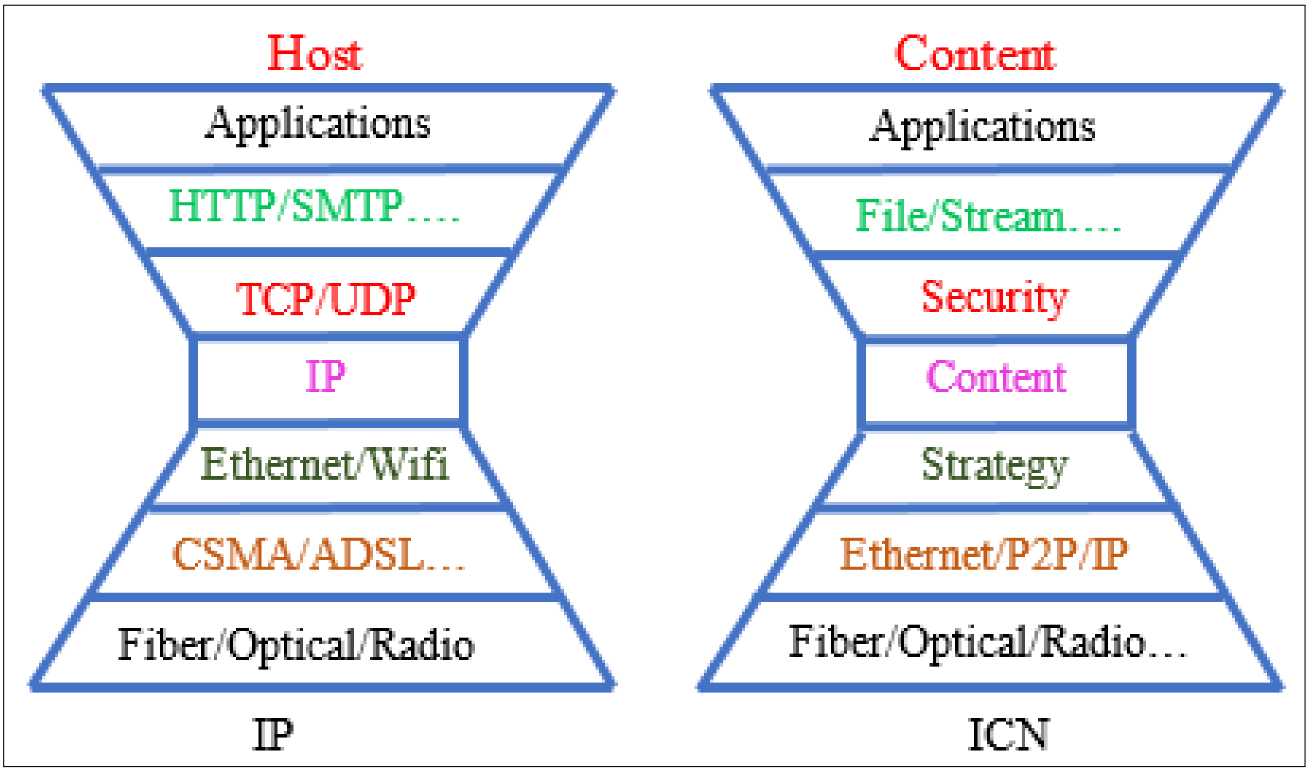

Figure 8. ICN and IP stack

allows for integrity verification, confidentiality, and access control locally at the network layer without additional overhead and services to a third part [5]. In IP, the destination address can know the data consumers, and the packet's content can be known by examining the payload or the header. In ICN, it is also possible to know the data using smart polling schemes, but it is not possible to know who requested the data. Data encryption can be used so that it is not visible to everyone.

4.1.6. Mobility

ICNs inherently support consumer mobility, because they rely on content distributed in the ICN network cache. Any source close to the consumer can be used. While in the IP mobility is supported by mobile IP protocol. Locating and accessing the location-based end provider is one of the major difficulties faced in navigating IP networks [5]. Table 1 summarizes a comparison between ICN and IP. Resarchers note from Table 1 that ICN is a promising network that is more suitable for IoT applications, especially D2D communication because it focuses on content retrieval, not the host [32], [33]. IoT applications require flexible network architectures that handle the huge traffic many connected objects generate. There is no limitation on the number of connected devices because it depends on data names, not addresses [26]. ICN also overcomes the challenges of D2D communication, including mobility and security [3]. ICN networks depend on naming data and thus provide flexibility for dynamic mobility, so communication is not interrupted due to changing addresses, as happens in IP networks. ICN offers security solutions without any complexity or increased energy consumption. Both data delivery and latency are improved.

5. CONCLUSION

This paper presented a qualitative comparative study between IP and ICN, their benefits and suitability for D2D IoT communications. The paper reviewed the communication challenges of D2D. It also explains the different architectures of ICN networks. First, in this paper, researchers compared message types in IP and ICN. There is no distinction between types of messages in IP networks, while a distinction is made between two types of messages in ICN: interest and data messages. In terms of naming, ICN networks focus on what the data is and not where it is located. Thus, access to it is faster, especially with new technologies such as IoT and cloud computing that generate huge amounts of data. For forwarding, IP uses stateless forwarding, while ICN uses stateful forwarding. Caching is done in the application layer in IP, while ICN is in the network layer. A comparison was also made between security, as it requires an additional layer in IP to achieve it and securing communication channels. In contrast, the data itself is essentially secured in the ICN. Comparing ICN and IP for IoT is still unexplored, and there is no fair comparison to show which performs better according to pre-defined metrics and scenarios. However, understanding how ICN performs compared to IP is very important, as ICN will play a dominant role as a promising IoT network.

Table 1 Differences between ICN and IP

Comparisons elements	IP	ICN
Messages	Messages are not differentiated	It contains two types of messages: interest messages and data messages
Naming	Where (data)	What (data)
	IP address	Data name
	The length of IP addresses is fixed and limited.	The naming space is variable, eliminating the problem of address space exhaustion.
	Mobility may require a change of address, which may result in disconnection.	Disconnection does not occur when mobility because the data names do not change.
Routing and Forwarding	IP uses stateless forwarding.	ICN uses stateful forwarding. Interest aggregates for the same data. Less bandwidth. Network efficiency.
Caching	Caching in the application layer.	Caching at the network layer.
	Data cannot be reused after forwarding.	It is easy to forward the same data from intermediate nodes. Improved performance (response speed, reduces latency - traffic - power consumption)
Security	Additional overhead for security	A basic building block in architecture
	Securing the communication channel	Content-based security
	Securing data at the application layer	Data is secured locally at the network layer.
	Data and content consumers can be known	Data consumers cannot be known, and content can be known
Mobility	Mobility is supported by mobile IP protocol.	It relies on distributed content and navigation is smooth.

REFERENCES

[1] Statista, *Iot devices installed base worldwide 2015-2025 | statista.* [Online]. Available: https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/.

[2] Cisco, *Cisco annual internet report - cisco annual internet report (2018–2023) white paper - cisco.* [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html.

[3] M. A. Areqi, A. T. Zahary, and M. N. Ali, "State-of-the-art device-to-device communication solutions," *IEEE Access*, vol. 11, no. May, pp. 46 734–46 764, 2023. DOI: 10.1109/ACCESS.2023.3275915.

[4] M. Alareqi, F. Al-Wesabi, A. Zahary, and M. Ali, "A survey of internet of things services provision by telecom operators," *EAI Endorsed Trans. on Internet Things*, vol. 4, no. 14, p. 155 571, 2018. DOI: 10.4108/eai.13-7-2018.155571.

[5] A. Djama, "Tcp / ip and icn networking technologies for the internet of things: A comparative study," in *2019 International Conference on Networking and Advanced Systems (ICNAS)*, IEEE, 2019, pp. 1–6.

[6] P. Gandotra, R. Kumar Jha, and S. Jain, "A survey on device-to-device (d2d) communication: Architecture and security issues," *J. Netw. Comput. Appl.*, vol. 78, pp. 9–29, 2017. DOI: 10.1016/j.jnca.2016.11.002.

[7] R. Alkurd, R. M. Shubair, and I. Abualhaol, "Survey on device-to-device communications: Challenges and design issues," in *2014 IEEE 12th International New Circuits and Systems Conference (NEWCAS)*, 2014, pp. 361–364. DOI: 10.1109/NEWCAS.2014.6934057.

[8] P. Pawar and A. Trivedi, "Device-to-device communication based iot system: Benefits and challenges," *IETE Tech. Rev. (Institution Electron. Telecommun. Eng. India)*, vol. 36, no. 4, pp. 362–374, 2019. DOI: 10.1080/02564602.2018.1476191.

[9] T. For and R. Scholar, "D2d communication in internet of things: Conventional communication protocols, challenges and open issues," 2019, pp. 1279–1284.

[10] M. e. a. Waqas, "A comprehensive survey on mobility-aware d2d communications: Principles, practice and challenges," *IEEE Commun. Surv. Tutorials*, vol. 22, no. 3, pp. 1863–1886, 2020. DOI: 10.1109/COMST.2019.2923708.

[11] N. Dutta, H. Kumar, D. Sarma, R. Jadeja, and K. Delvadia, *Information Centric Networks (ICN)*. Springer International Publishing, 2021.

[12] D. R. Cheriton and M. Gritter, "Triad: A new next-generation internet architecture," 2000. [Online]. Available: http://www-Dsg.Stanford.Edu/Triad/.

[13] D. Buitenkamp, "A survey of information-centric networking approaches," *Wust-Jain*, pp. 1–19, 2019.

[14] T. e. a. Koponen, "A data-oriented (and beyond) network architecture," in *ACM SIGCOMM 2007: Conference on Computer Communications*, 2007, pp. 181–192. DOI: 10.1145/1282380.1282402.

[15] V. Jacobson, D. K. Smetters, N. H. Briggs, J. D. Thornton, M. F. Plass, and R. L. Braynard, "Networking named data," in *5th International Conference on Emerging Networking Experiments and Technologies*, New York, 2009, pp. 1–12.

[16] N. Fotiou, D. Trossen, and G. C. Polyzos, "Illustrating a publish-subscribe internet architecture," *Telecommun Syst*, vol. 51, no. 4, pp. 233–245, 2012. DOI: 10.1007/s11235-011-9432-5.

[17] C. Dannewitz, D. Kutscher, B. Ohlman, S. Farrell, B. Ahlgren, and H. Karl, "Network of information (netinf)-an information-centric networking architecture," *Comput. Commun*, vol. 36, no. 7, pp. 721–735, 2013. DOI: 10.1016/j.comcom.2013.01.009.

[23] X. S. Shen, *Encyclopedia of Wireless Networks*. Springer Nature Switzerland, 2020. DOI: 10.1007/978-3-319-78262-1.

[24] F. B. Drijver, *Assessment of benefits and drawbacks of icn for iot applications*, 2018.

[25] A. Principles and T. N. D. N. Architecture, *Named data networking: Motivation & details*, National Science Foundation (NSF). [Online]. Available: https://named-data.net/project/archoverview/.

[26] M. A. Hail, "Iot-ndn: An iot architecture via named data netwoking (ndn)," in *Proceedings - 2019 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology, IAICT 2019*, 2019, pp. 74–80. DOI: 10.1109/ICIAICT.2019.8784859.

[18] L. e. a. Zhang, "Named data networking," *Comput. Commun. Rev.*, vol. 44, no. 3, pp. 66–73, 2014. DOI: 10.1145/2656877.2656887.

[19] D. Trossen, M. J. Reed, M. Georgiades, N. Fotiou, and G. Xylomenos, "Ip over icn - the better ip? an unusual take on information-centric networking," *Arxiv preprint*, pp. 1–5, 2015.

[20] A. Tagami and M. Arumaithurai, "Greenicn project: Architecture and applications of green information centric networking," *IEICE Trans. on Commun.*, vol. E99B, no. 12, pp. 2470–2476, 2016. DOI: 10.1587/transcom.2016CNI0001.

[21] V. Jacobson, J. Burke, L. Zhang, *et al.*, "Named data networking next phase (ndn-np) project may 2015-april 2016 annual report," *Named Data Netw. (NDN)*, 2016.

[22] "Icn2020: Advancing icn towards real-world deployment through research, innovative applications, and global scale experimentation," 2020. [Online]. Available: http://www.icn2020.org/.

[27] M. Hail, I. Pösse, and S. Fischer, "Integration of fiware and iot based named data networking (iot-ndn)," in *11th International Conference on Sensor Networks*, 2022, pp. 184–190. DOI: 10.5220/0010936200003118.

[28] A. Kerrouche, *Routing named data in information-centric networks abdelali kerrouche to cite this version: Hal id: Tel-01784432*, 2018.

[29] H. Zafar, Z. H. Abbas, G. Abbas, F. Muhammad, M. Tufail, and S. Kim, "An effective fairness scheme for named data networking," *Electron. (Switzerland)*, vol. 9, no. 5, pp. 1–15, 2020. DOI: 10.3390/electronics9050749.

[30] O. Serhane, K. Yahyaoui, B. Nour, and H. Moungla, "A survey of icn content naming and in-network caching in 5g and beyond networks," *IEEE Internet Things J*, vol. 8, no. 6, pp. 4081–4104, 2021. DOI: 10.1109/JIOT.2020.3022243.

[31] R. M. Negara and N. Rachmana Syambas, "Caching and machine learning integration methods on named data network: A survey," in *Proceeding of 14th International Conference on Telecommunication Systems, Services, and Applications, TSSA 2020*, 2020. DOI: 10.1109/TSSA51342.2020.9310811.

[32] B. Nour, H. Ibn-Khedher, H. Moungla, *et al.*, "Internet of things mobility over information-centric/named-data networking," *IEEE Internet Comput.*, vol. 24, no. 1, pp. 14–24, 2019.

[33] B. Nour, H. Moungla, and A. Rayes, "Editorial: Information-centric network enabler communication for internet of things," *Future Gener. Comput. Syst.*, vol. 114, pp. 629–630, 2021. DOI: 10.1016/j.future.2020.08.042.