

## SURVEY

# Named Data Networking: A Survey on Routing Strategies

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This work was supported in part by the Information Centric Network (ICN) and Network Communication Technology Research Groups, Faculty of Information Science and Technology, and Universiti Kebangsaan Malaysia, through the Fundamental Research Grant Scheme under Grant FRGS/1/2019/ICT03/UKM/02/1.

**ABSTRACT** As the Internet grows in popularity, data become an increasingly crucial component. People now care more about the data than the data location. Named data network (NDN) takes this concept and pairs it with the idea of making data a core component rather than host addresses. As data traffic increases exponentially, NDN offers three main advantages over current Transmission Control Protocol and Internet Protocol-based networks. These advantages are in-network caching, smooth mobility, and robust content dissemination. NDN-related challenges are open for investigation as NDN becomes more invaluable. Routing in NDN is another essential domain that needs to be addressed, and several approaches are presented to address routing concerns in NDN. In this study, we discuss and highlight NDN and its routing strategies comprehensively. In addition, this research compares important routing paradigms to emphasize the breadth of routing research in NDN. Moreover, we investigate the routing attributes of NDN and expose the latest literature on this critical topic. Finally, this study provides useful insights into the emerging areas of guidance in NDN to assist future studies in addressing challenges and open research issues.

**INDEX TERMS** Named data network (NDN), open research issues in NDN, routing in NDN.

## I. INTRODUCTION

The Internet is a global broadcasting platform, a tool for information transmission, and a collaborative resource. In addition to and without regard to location geography, the Internet reflects cooperation between people and their computers. The Internet is characterized as one of the most effective technology for continuous investment, commitment to research, and development of information infrastructure. Starting with early packet switching research, the government, business, and academia have worked together to develop and demonstrate this innovative new technology.

The Internet usage has grown tremendously throughout the years, making data one of the most critical components.

The associate editor coordinating the review of this manuscript and approving it for publication was Guangjie Han<sup>1</sup>.

Internet users are very keen on the data, ignoring the data location. An information-centric network (ICN) customizes this idea and makes data an integral component instead of host addresses [1]. Several studies show that from 2014 to 2016, YouTube usage more than tripled. In 2017, users submitted 400 hours of new videos every minute of every day and viewed 4,146,600 videos per minute [2]. This change reflects the limit of the current Internet architecture and opens a new horizon for the Internetworking world. Evidently, the next-generation Internet will be all about speed, data rate, and heavy data. As discussed above, ICN architecture is here as a solution, and ICN-based projects promise faster data communication than its rival Internet Protocol (IP) architecture and other network approaches because of its in-network caching capability [3], [4]. However, the current world requires enhanced bandwidth as end-user application

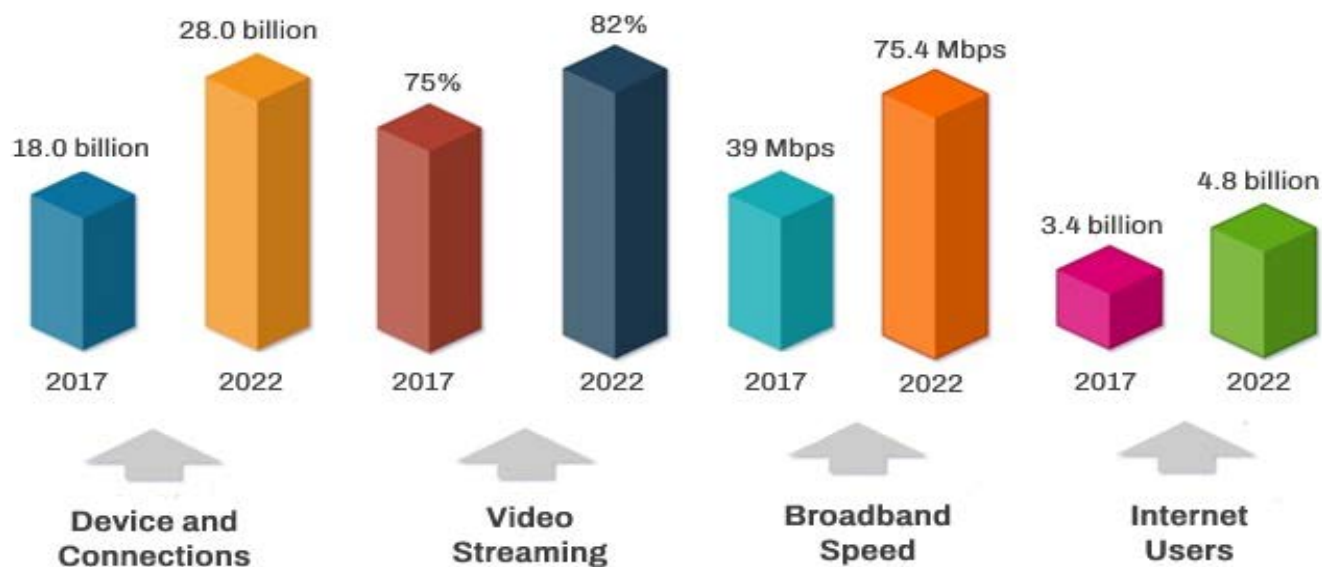


FIGURE 1. Cisco's VNI global IP traffic forecast [7].

and service load is increasing every day. People leave televisions and switch their interests toward the Internet. They use their cell phones through which they can easily find world news and be entertained with a single touch.

In relation to entertainment, American media service provider Netflix has seen a decline in its DVD section. In 2018, Netflix's DVD rental service had 2.73 million subscribers in the United States, a decline from 11.17 million in 2011 [5]. The Netflix online streaming content in 2007 offered no more than 1,000 movies and television shows, only 1% compared with its more than 100,000 DVD titles. As Netflix's popularity grew, so did the amount of films accessible for streaming, which peaked at 12,000 movies and episodes in June 2009 [6]. In 2018, Netflix had over 148 million streaming subscribers worldwide. Cisco's virtual network index (VNI) also estimates that video traffic in 2022 will increase up to 82% of the total traffic compared with 73% in 2017 [7], as shown in Fig. 1.

As previously said, the new Internet paradigms are critical in the current scenario, particularly in the event of a pandemic, when high data rates are required for numerous medical applications and other uses [8], [9], [10]. Named data network (NDN) plays a pivotal role in this regard. ICN is a broad study direction in network design that focuses on content, information, and data. NDN is a type of architecture that falls under the ICN umbrella. Substantial work is currently being done in the field of NDN, making it a better candidate for the future generation Internet. Researchers have looked into different aspects of NDN, such as IoT [11], [12], [13], [14], [15], producer mobility [12], [16], vehicular networks [17], [18], 5G networking [19], [20], [21], network security [21], [22], [23], [24], and caching [18], [24], [25], [26], [27]. Moreover, the traditional routing plane of the IP-based networks has been changed from using host address to using content name, known as name-based routing. Furthermore, in-network caching and replication are used during

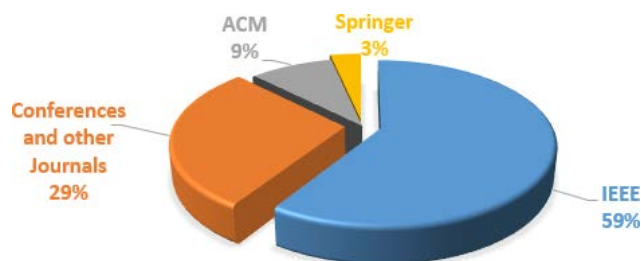


FIGURE 2. Articles from different resources.

communication to allow fast data retrieval [28]. NDN design providing name-based routing [29] is another vital domain that requires attention of researchers.

**A. METHODOLOGY**

The narrative review method is employed in this study as the primary purpose of narrative reviews is to provide readers an ample background to understand the topic of research and highlight the importance of new knowledge. We use several research databases such as IEEE, ACM, Springer, and Elsevier. Basing on the general "Information Centric Networking" keyword, we select various papers on ICN and remove duplicates. In addition, the specific keywords used in the collected IEEE, ACM, Springer, and Elsevier databases are "Routing in Named Data Network," "Geographical routing in NDN," and "Link State Routing in NDN." We first rate most papers from 2011 to 2021. We also select 52% of the total papers from the IEEE database. Another domination is from various conferences and journals: 25%, 8%, 3% from ACM, Springer, and other conferences and journals, respectively. This study is qualitative and conducts a narrative investigation. Qualitative research assists researchers to reach comprehensive data in their natural setting; considering the interpretative nature of the study, it gives researchers a prospect to for data interpretation. Fig. 2 presents the distribution of articles from different resources.



FIGURE 3. Organization of the article.

Recently, no research has discussed extensively the latest routing and forwarding strategies. A few review papers focus on this theme [25], [30], [31], [32], [33], [28], [34], [35], [36], [37], [38], and they review articles that address a wide range of routing and forwarding-related topics, including forwarding with IoT, vehicular network, route caching, energy conservation strategies, and wireless network applications. Yet, none of the current review studies suggest a universal and consistent taxonomy of the important characteristics of routing and forwarding in NDN. As a result, this research provides in-depth information on the subject. This research looks at the broad domain of routing and forwarding in NDN, and it will pave the way for current researchers.

## B. CONTRIBUTION

Bari *et al.* [39] explored naming and routing in relation to ICN, but they also did not provide a detailed analysis of routing in ICN. In this study, NDN and its routing techniques are thoroughly examined. Existing routing techniques in NDN in terms of geographical routing (GR), link state routing (LSR), and distance vector routing (DVR) are discussed in detail as well as the timeline of NDN routing, performance analysis of NDN routing, open issues, and challenges in NDN routing. In addition, the comparison of important routing paradigms exemplifies the study topics on NDN's broad routing. Moreover, the routing attributes of NDN are investigated, and the latest literature on this topic is discussed. Finally, this research offers valuable insights into NDN's expanding areas of guidance, which will aid future studies in addressing challenges and open research questions. The major contributions of our work are as follows:

1. A detailed discussion of NDN's history and routing procedures
2. A thorough examination of present routing methods
3. A comprehensive discourse of open research issues and problems in NDN routing techniques

## C. STRUCTURE

The remainder of this paper is structured as follows: Section I outlines the background and methodology employed in this study. Section II describes NDN, its qualities, characteristics, and functionality. Section III discusses the most recent routing and forwarding strategies, as well as their drawbacks and benefits. Section IV delves into the most up-to-date routing strategies in the field of NDN. Section V examines open research challenges in NDN routing and forwarding, which open new avenues for future researchers. Finally, Section VI draw the conclusion. Fig. 3 illustrates the summary and organization of this article.

## II. BACKGROUND OF NDN

NDN is a state-of-the-art technology that can effectively solve many problems caused by conventional Internet architecture [40]. NDN is an ICN application that focuses on information rather than location [41] NDN naturally solves many IP architecture problems, such as routing loop and consumer mobility [42].

The major advantage of NDN is in-network caching from the network content store (CS). Along with CS, NDN routers contain two other data structures called pending interest table (PIT) and forward information base (FIB) [42] PIT is responsible for storing unsatisfied interests and interfaces from

which interests are received. FIB is responsible for providing the list of providers of matching data [43].

If content is not found in the NDN router CS, then producers must access the NDN routing time, similar to its counterpart IP architecture. NDN accesses cached data near consumers, thereby increasing packet delivery performance and decreasing dependence on specific content sources that may fail due to faults or attacks as in conventional IP infrastructure. However, if data are not found cached, then consumers must approach producers to obtain their desired data.

IP routers do not cache data once they are sent [44], whereas NDN routers use the in-network caching ability for this purpose. For static files, NDN attains nearly optimal data transfer. Dynamic data can also be cached in situations such as teleconferencing or packet retransmission after losing packets [45]. The access time of desired content is quite similar to that in IP architecture.

Similar to other ICN approaches, NDN uses public-key cryptography to ensure security [46]. Everything over NDNs is known as an entity, and each entity in NDN has the same name with the cryptographic key. After obtaining an NDN certificate, each name becomes an identity [47]. Apart from digital keys, NDN uses two other approaches for content security, namely, trust policy and NDN certificate. As far as trust policy is concerned, identity reliability is determined by the application. Moreover, producers establish data packet names, and consumers only accept these data packets that contain proper name formats. In the NDN certificate approach, interest packets are used to fetch NDN certificate data packets that support public key information [48].

Table shows the existing NDN survey and review papers. Additionally, vehicular named data networking (VNDN), which is made conceivable by the characteristics of NDN, is another crucial topic in NDN. It offers a potential remedy to the problems with traditional Transmission Control Protocol and Internet Protocol (TCP/IP)-based and even IP-based Internet of Vehicles (IoV). As the content is removed from its originating location, using in-network caching in VNDN is beneficial to increase data availability and boost bandwidth efficiency in data transmission. With the widespread use of IoV and the rising need for content sharing, more academics attempt to integrate NDN into IoV [25]. The majority of current research published between 2016 and 2021 is focused on VNDN, although there some reviews are about security, mobility assistance, and congestion control in NDN.

### III. ROUTING IN NDN

In NDN, forwarding is the act of taking packets, looking at their destination address, consulting the forwarding table, and delivering them in the direction decided by the table, whereas routing is the process of constructing the forwarding table. Names are used to route and forward NDN packets. As a result, unlike the IP design, NDN does not experience address-related difficulties. First, unlike IP, there is no address exhaustion problem because NDN's namespace is

unbounded. Second, there is no network address translation (NAT) traversal issue because the routing scheme does not require public or private addresses [57]. In this study, routing in NDN is divided into three distinct techniques, i.e., GR [58], LSR [59], and DVR. GR normally consists of two modes: greedy mode and perimeter mode. In greedy mode, packets are routed to the neighbor with the shortest distance to the destination. In perimeter routing, if a node does not have a neighbor who is closer to the destination than the right-hand rule, packets are sent to the neighbor [60]. In contrast to GR, the LSR method searches directly for the shortest or best global path. LSR must count and select from all available information on the route to the destination. As a result, in LSR, each node must deliver the data required to map all possible network paths. [59], [61].

Another classification for NDN routing is proactive and reactive routing. The nodes in proactive routing [62], [63], [64], [65] communicate their network state and save data generated by themselves to the network. Each node uses the network information it receives to determine routes to the network's data sources beforehand and then updates the FIB. When a network node receives an interest packet from a consumer requesting data, the node sends the packet to a next-hop node via the FIB routes. By contrast, reactive protocols [66], [67], [68], [69], [70], [71], [72] based on-demand routing algorithms create a route to a specific destination only when a node initiates a route discovery process. Once a route is formed, it is maintained by the node until the destination is no longer reachable. The requesting and intermediate nodes do not have a routing table in reactive routing (i.e., FIB in NDN) [73].

Fig. 4 demonstrates the NDN routing paradigm, from Nodes A to C, utilizing the Name Link State Routing Protocol (NLSR), in which every node sends link state advertisements (LSAs) at regular intervals, which include adjacency and name LSAs. The former contains all the functioning links of a router, each linked with adjoining link cost and a router's name. It is generated at router startup. Whenever the state of the router changes, it contains all of the name prefixes registered locally with NLSR as well as those entered by connected end hosts [74].

Nodes D and E show the GR in NDN as nearly all vehicular applications are concerned in location associated information; therefore, many GR protocols are available [75], [76], [77] and in the context of NDN [60], [78], [79], [80]. Interest and data packets in GR forwarding techniques incorporate the destination's geographical location (either a content producer or the location of an area of interest).

Intermediary nodes can utilize this information to figure out how to forward a packet based on its location. Consumer location information is included in interest packets to ease the GR of relevant data packets back to the consumer. The data packets created in response to the interest packets include this location information. Each vehicle keeps track of its present neighbors in a table. Every node transmits a beacon message on a regular basis. To distinguish itself from other messages,

**TABLE 1.** Existing NDN review and survey areas.

Year	Reference	Area of Concern and Scope	Contribution
2016	[49]	Comprehensive survey on NDN	The article comprehensively discusses architecture and various schemes in NDN as well as NDN applications with open challenges.
2016	[50]	Congestion control in NDN	In this article, techniques to improve congestion and detect interest rate shaping in NDN are discussed.
2016	[51]	Mobility support in NDN	In this survey, mobility support in NDN is discussed in the context of mobile producers and consumers.
2018	[52]	Forwarding in NDN	In this paper, various forwarding techniques are compared, and issues, challenges, and future research directions are discussed.
2018	[53]	Interest flooding attack in NDN	This article discusses the DDoS attack and interest flooding attack in NDN, which attempt to overflow the NDN router's PIT, causing the router's performance to drop rapidly.
2018	[54]	VNDN challenges and support in NDN	In this article, the advantages and disadvantages of ICN to vehicles everywhere are discussed. Existing solution and applications of vehicle to everywhere are also investigated.
2018	[47]	Security support in NDN	This article addresses security related issues such as data authenticity, availability, confidentiality, and bootstrapping.
2020	[28]	Vehicular ad hoc networking in NDN	Vehicular area network (VANET) is discussed in terms of NDN-based naming, routing and forwarding, security, caching, and mobility methods. Existing standards, solutions, and simulation tools used in NDN-based VANETs, as well as open challenges and issues, are also examined.
2020	[25]	Caching in VNDN	VNDN's existing cache selection and replacement techniques are compared for their applicability. In addition, issues encountered during cache design are thoroughly examined in light of VNDN's unique properties.
2020	[35]	Energy conservation strategies in NDN	This article examines past researchers' congestion control solutions for NDN in general to determine what characteristics a congestion control solution should have for NDN-based MANETs. In addition to these studies, this paper proposes a set of criteria for congestion control solutions that should be implemented in an NDN-based MANET.
2021	[55]	Data dissemination schemes in V NDN	A new fine-grained nomenclature for these methods is established, and recently suggested V-NDN data transmission protocols are fully assessed. After that, a qualitative comparison of the solutions under consideration is presented based on a range of parameters. In this domain, a single performance evaluation metric is also proposed. Finally, issues and challenges in V-NDN data transmission are discussed as well as future-oriented solutions.
2021	[56]	Bloom filter implementation in NDN	The role of bloom filter in implementing NDN is discussed in depth in this article. The paper also goes through bloom filter and the NDN architecture's core components, including packet, CS, PIT, and FIB.

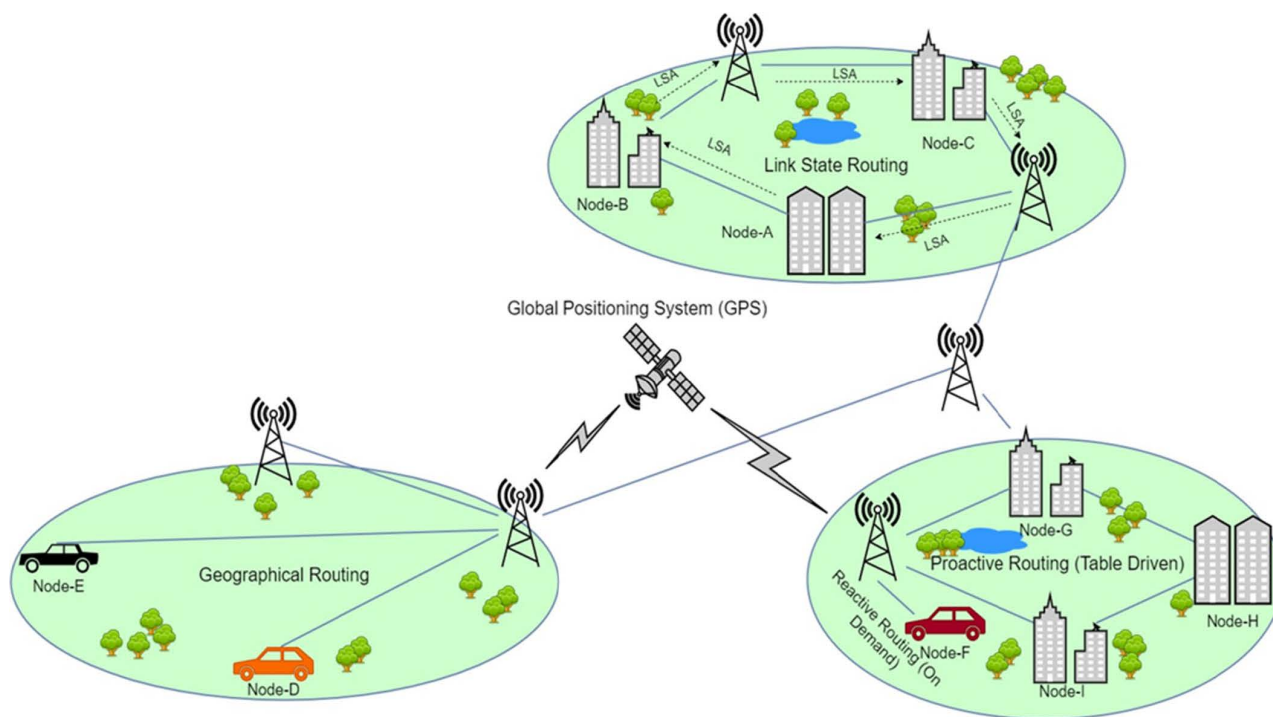


FIGURE 4. NDN routing paradigm.

a beacon message’s name includes the prefix “/hello”. This information is recorded in the surrounding tables of other nodes within the communication scope. Based on the items in a nearby table, a node can choose the best neighbor as the forwarder. A node can also use beacon messages to detect whether it is on a road or at an intersection [60].

Furthermore, Nodes G, H, I, and F show the proactive and reactive routing scenarios [81], [82], [83], [84]. In proactive routing in NDN, routers need a forwarding table. FIB is employed for name prefixes, which indicates the relationship between a name prefix and an interface. This name prefix has a face (or a neighbor identification) to the content. FIB is not used at all in reactive routing systems; the only PIT is used to forward data packets. Proactive routing can enable FIB to respond to current network topologies, but it comes at the cost of routing control message exchange. Reactive routing, on the contrary, has no routing overhead but does have interest packet transfer overhead.

Fig. 4 depicts the ad hoc nature of NDN routing [85], [86], [87]. A content producer site has a stable network where producers and intermediary routers are positioned in fixed locations as a typical ad hoc network installed in a community area, such as shopping malls. Consumers are mobile nodes who move around frequently in this case Node I as shown in Fig. 4. As a result, a hybrid approach that combines proactive and reactive routing is considered beneficial [88].

NDN is created for wired network topologies, but it may also be used in wireless multihop ad hoc network topologies. Nodes in wireless ad hoc networks move around more than in wired networks.

#### IV. EXISTING ROUTING TECHNEQUES IN NDN

NDN is a hot topic these days as many researchers are developing new and novel techniques for NDN [89]. In this article, we collect latest research from different perspectives and distribute it into three classifications as shown in Fig. 5. In addition, II presents the characteristic of NDN routing, and Fig. 6 illustrates the analysis of routing strategies in NDN. Between 2015 and 2021, the majority of research is conducted in the context of LSR, followed by DVR, ad hoc, and GR. In addition, the greedy method in GR is preferred to the perimeter approach in terms of ad hoc routing. Proactive routing is studied more by researchers than reactive routing, as shown in Table 2 and Fig. 6.

Moreover, Fig. 7 shows the timeline of routing techniques in NDN. Table 3 indicates the performance analysis of NDN routing. In terms of the framework of current routing paradigms, they are available; nevertheless, the speed of convergence for each routing solution may differ. For example, the GR speed of convergence is sluggish due to the potential of routing loops. Proactive routing, like ad hoc routing, has a slow convergence speed, but reactive routing is fast. DVR comes in second, closely followed by LSR. In terms of resource use, GR and LSR require more resources than DVR and ad hoc routing, which have restricted resources. All methods of routing are complex to implement and maintain.

##### A. GR IN NDN

GR is a method of routing that uses geographic coordinates. It is generally recommended for wireless networks and is based on the idea that rather than using the network address,



FIGURE 5. NDN routing selection.

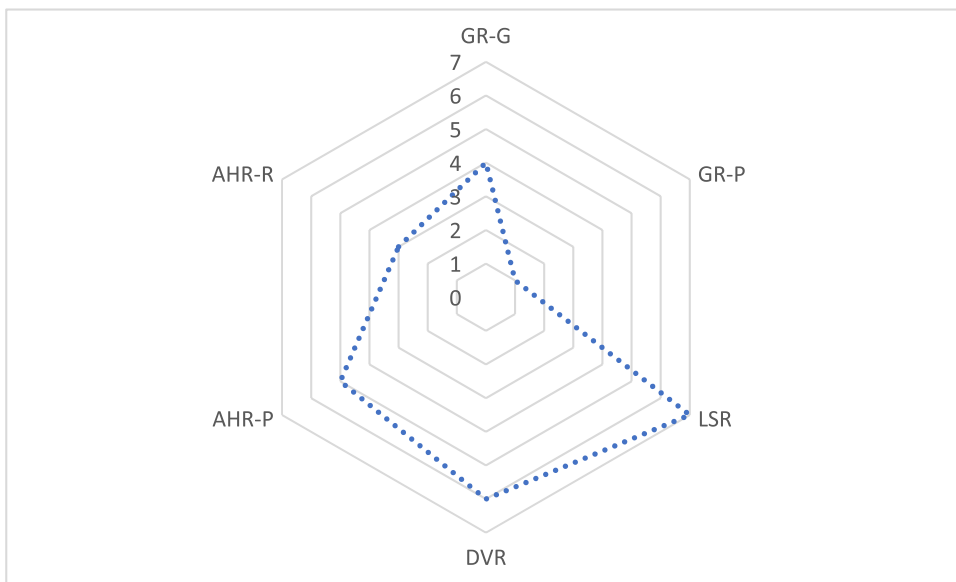


FIGURE 6. Routing strategy analysis trend.

the source sends a message to the destination’s geographic location. GR demands each node’s ability to determine its own position as well as the source’s information of the destination’s location.

In NDN, VNDN is yet another geographical route user. Aldhalan *et al.* [102] explained the GR approach for dealing with VNDN. With the help of the proposed method, problems connected to the floods of interest, delivery, and data forwarding are solved. However, this method does not support multiple forwarding paths in NDN.

In VNDN, Aldhalan *et al.* used a delay-tolerant network in conjunction with NDN to mitigate the flooding issue of interest and the disruption problem. In another research, Ryu *et al.* [90] proposed a mechanism for location-based IoT. This mechanism employs NDN to support anonymous GR.

This routing/forwarding mechanism’s main aim is to allow users to acquire location-dependent data without leaking the locations of the user. Yet, the suggested mechanism’s scalability is limited by a few aspects, including the placement of routers such that the router and geographical topology are not too far apart. Second, if a big number of IoT devices are deployed, the size of the anonymity set grows significantly [90].

Furthermore, Eirini *et al.* [91] discussed routing protocol in the context of VNDN for selecting the best directional antenna for unicasting a message, allowing cars outside of the message’s spreading region to do other things. When content is not obtained after a certain amount of time, each vehicle executes route discovery to nodes that store content. As a result, pathways are rearranged as needed to accommodate

TABLE 2. Routing in NDN.

Reference	Year	Geographical Routing		Link State Routing	Distance Vector Routing	Ad Hoc Routing	
		Greedy	Perimeter			Proactive	Reactive
[93]	2015	×	×	✓	×	×	×
[90]	2016	×	✓	×	×	✓	×
[106]	2016	×	×	×	✓	×	×
[109]	2017	×	×	×	✓	×	✓
[74]	2018	×	×	✓	×	×	×
[96]	2018	×	×	✓	✓	×	×
[91]	2019	✓	×	×	×	✓	×
[92]	2019	✓	×	×	×	×	✓
[98]	2019	×	×	✓	×	✓	×
[99]	2019	×	×	✓	✓	×	✓
[104]	2019	×	×	×	✓	×	×
[107]	2019	✓	×	×	✓	✓	×
[102]	2021	✓	×	×	✓	×	✓
[65]	2021	×	×	✓	×	✓	×
<b>Percentage</b>		17%	7%	24%	21%	17%	14%

new automobiles. However, this research does not include any infrastructure; hence, installation of directional antennas on vehicles are needed. Yang *et al.* [92] presented content-based hyperbolic routing (HR) named “Pop-Hype.” This research presents a greedy method, which surpasses others in terms of hop count and packet loss. The hyperbolic coordinates are pre-calculated, and the network’s dynamic change is not taken into account. Moreover, the popularity of content is supposed to be constant.

**B. LSR**

The core idea behind LSR is that each node builds a map of the network’s connection in the form of a graph, indicating which nodes are connected to which others. The next best rational path from each node to every potential destination in the network is then calculated separately by each node. Each node’s routing table is made up of a collection of the best pathways.

Hemmati *et al.* [93] developed a new technique to name-based LSR for ICN, and they suggested a named-based solution with the article titled “A New Approach to Name-Based Link-State Routing for Information-Centric Networks.” In this study, multiple routes to name prefixes can be established by routers without requiring each router to be aware of all prefix instantiations. When a name prefix is duplicated at numerous sites in the network, link state for information-centric

routing (LSCR) is demonstrated to avoid permanent routing loops and perform better than typical LSR methods. In another research, Lan Wang *et al.* [74] revised the already available NSLR protocol [94] to make it more reliable in terms of naming, advertisement, and propagation.

Wan *et al.* replaced CCNSync with ChronoSync in the improved design [95]. CCNSync is packaged with CCNx’s Repo, and all the data collected by CCNSync are saved in the Repo and cannot be erased. Running NLSR for a while results in a memory problem. ChronoSync, on the contrary, just alerts NLSR of new data names, which NLSR then uses to fetch the data. Another significant design change is to advertise every router’s name prefixes in a single LSA. As a result, fewer messages are needed to collect the name prefix information.

Ghasemi *et al.* [96] introduced a new technique in which, similar to LSR protocols, it collects network topology and calculates the shortest paths to producers. It also gets many alternative paths from adjoining routers, similar to DVR protocols. Furthermore, because each routing update is tagged at the network’s entrance point, internal routers use the same border router for the same name prefix, which improves the hit percentage of cached data. Multipath forwarding and in-network caching (MUCA) can be used for many content producers, according to this study, although it is not evaluated. As a result, new researchers can examine this [96].



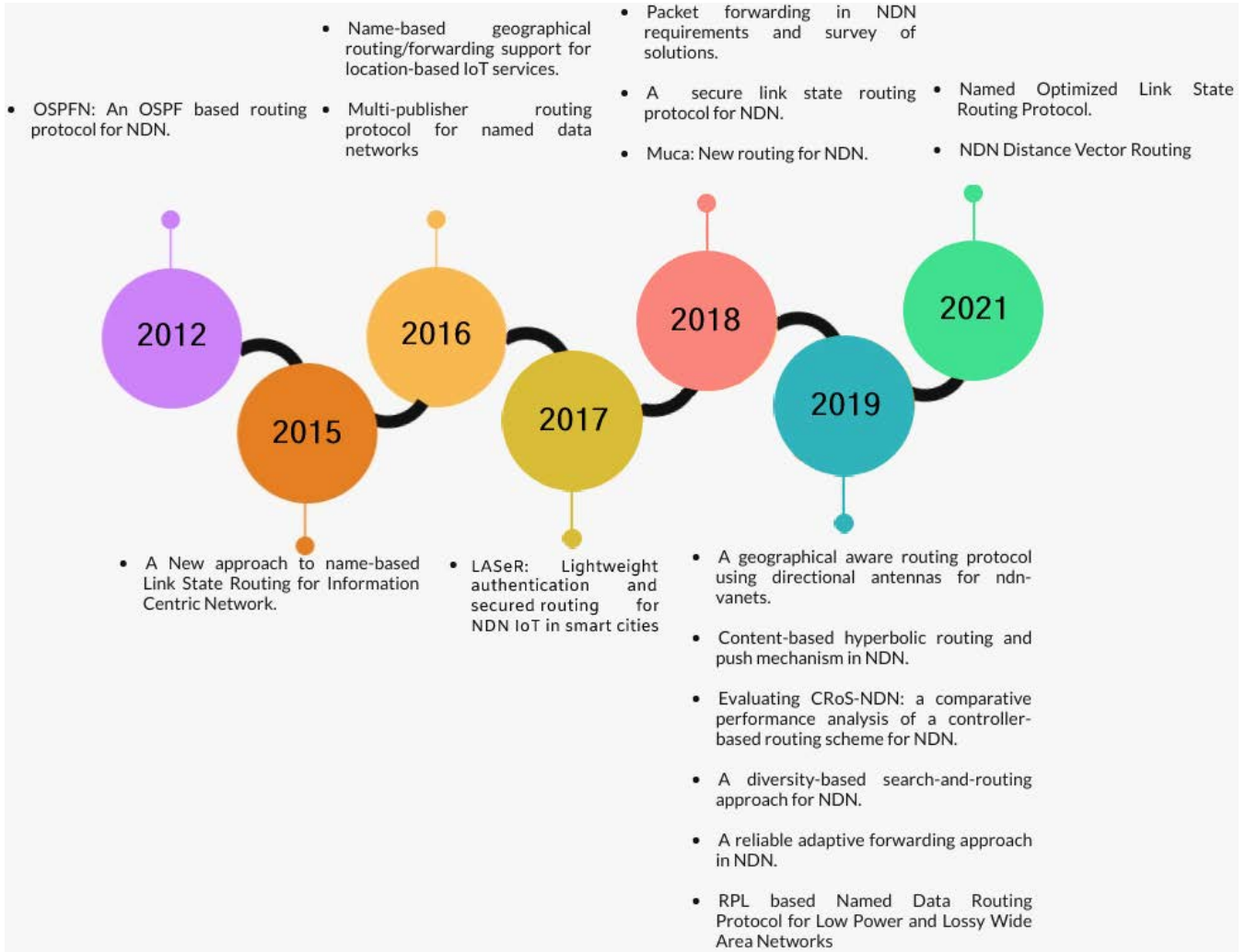


FIGURE 7. Timeline of routing techniques in NDN.

TABLE 3. Performance analysis of NDN routing.

Performance Characteristic	Reference	Geographical Routing	Link State Routing	Distance Vector Routing	Ad Hoc Routing
Framework/Topology	[94, 102, 110, 111]	Yes	Yes	Yes	Yes
Analysis Type	[94, 102, 110, 111]	Simulation	Emulation	Simulation	Simulation
Scalability (Size of network)	[112,113,114]	Small	Large	Large	Small
Speed of convergence	[104, 115,116,117]	Slow (possibility of routing loop)	Fast	Very Fast	Slow (Proactive), Fast (Reactive)
Resource usage	[61, 102, 118, 119]	High	High	Medium	Limited
Implementation and Maintenance	[32, 100, 104, 113]	Complex	Complex	Complex	Complex

In another research, Xian Gao *et al.* [65] presented the improvement of the already proposed routing technique [97] named as “Named Optimized Link State Routing Protocol” (NOLSR), which is a proactive routing protocol based on the link-state algorithm. This protocol introduces a novel neighbor discovery that provides unidirectional link detection. NOLSR affects performance in small-scale networks. However, as the size of the network grows, the quantity of NOLSR packets decreases.

In another paper, Torres *et al.* [98] presented CRoS-NDN, which uses the same interest and data packets to preserve NDN properties. CRoS-NDN improves content mobility and provides speedy content recovery from copies that do not belong to the consumer-producer path because it separates identification from location without triggering FIB size explosion or presuming prefix aggregation. It offers characteristics similar to content distribution networks in NDN and enhances the routing efficiency. However, researchers used their own implementation of the routing protocols listed in this study for comparison because they are unoptimized and lack critical functionality. According to the findings, the performance of this protocol implementation is unaffected.

Another research “A diversity-based search-and-routing approach for named-data networking (DIVER)” was proposed by Bastos *et al.* [99]. DIVER looks for volatile replicas, with traditional end-to-end routing acts as a backup to ensure content reachability if the requested replica is already evicted from the router CS. However, the experiment is only conducted with one producer and one content. DIVER behavior in scenarios with multiple producers, numerous contents, and chunks of varying sizes, as well as across multiple topologies, has yet to be determined. Only shortest path first NDN (OSPFN) is another routing approach [100] that uses opaque LSAs [101] to make name prefixes public while maintaining backward compatibility. It accepts name prefix advertisements from a variety of sources. However, OSPFN only delivers one optimum path to each destination.

### C. DISTANCE VECTOR ROUTING PROTOCOL

In data networks, DVR protocol calculates the best route for data packets depending on distance. DVR protocols calculate the distance by counting the number of routers that a packet must pass through; one hop equals one router. Brito *et al.* [102] presented their work related to distance vector protocol. In this study, a routing protocol for NDN mobile ad hoc networks is discussed. The goal of NDN DVR (NDVR) is to communicate name prefix reachability information in the simplest possible way using distance-vector techniques. Neighbors are dynamically recognized, and routing adjustments are relayed as needed.

Furthermore, employing certain tactics when broadcasting protocol messages in a group of nodes, NDVR from the wireless shared medium and NDN opportunistic caching features to reduce protocol overhead. NDVR is solely compared in this

study to distributed dataset synchronization over disruptive networks (DDSN) [103], which is a synchronization technique rather than a routing system. As a result, there is yet to be a performance comparison with routing strategies.

Rezaeifar *et al.* [104] discussed the forwarding technique which uses the Enhanced Interior Gateway Routing Protocol (EIGRP) [105] metric and the NLSR protocol. NLSR employs only one parameter to rank each interface for a certain prefix, which is the cost of reaching a destination, whereas, the EIGRP metric includes numerous parameters. Rezaeifar *et al.* updated the EIGRP metric and used it in NDN to rank each interface in a router for each prefix. Yet, when compared with the traditional forwarding approach, the proposed forwarding technique tested the performance with the infusion of fake content into the network. The examination of performance in different attacking scenarios is needed.

In another research, Garcia Luna [106] presented a DVR protocol that solves the problem of forwarding an interest to multiple content providers. In the context of low-power and lossy wide-area networks, Dong L. *et al.* [107] proposed an IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) [108] based on NDN protocol (NRPL) for low power and lossy networks. In this study, the NRPL protocol allows content to be published both upstream and downstream. To be as efficient as possible, the content request might be processed in either storing or non-storing mode.

In another paper titled “LAsER: Lightweight authentication and secured routing for NDN IoT in smart cities,” Travis *et al.* [109] offered a reactive routing technique similar to RPL in relation to IoT. This technique is lightweight because of IoT. Network discovery and authentication, node authentication, and path advertisement are the three processes in onboarding and routing. According to simulation results, LAsER only uses broadcast for initial neighbor discovery, in contrast to reactive schemes. However, it is assumed that alternative methods, such as a link-state protocol, will be used to handle routing between anchors and gateways and is outside the purview of this study.

### V. NDN ROUTING CHALLENGES AND OPEN ISSUES

As research in NDN is progressing day by day, so are the challenges. In this section, routing challenges and open research issues are discussed. Table 4 summarizes open issues and challenges discussed in this section. The issue of interest flooding is a major barrier in every routing approach and that current researchers must address it. In terms of GR, geographical region disruption is a relatively common concern. Extreme levels of broadcast traffic also cause a broadcast storm in GR, which is another unsolved challenge for researchers interested in this area. In GR, content and source mobility is another issue that needs to be addressed because when a consumer, a producer, or both are in transit, routing becomes complicated. In NDN, there are many challenges with producer mobility that date back to the initial design of the network, such as long handoff latency, high handoff signaling costs, table size scalability issues, unnecessary

**TABLE 4.** Summary of challenges and open issues in NDN routing.

Issues	Reference	Geographical Routing	Link State Routing	Distance Vector Routing
Interest flooding	[90, 116, 123, 133]	✓	✓	✓
Disruption problem	[90]	✓	-	-
Broadcast storm problem	[125]	✓	-	-
Content source mobility	[126]	✓	-	-
Reverse path mechanism of NDN	[79]	✓	-	-
Routing scalability issue	[58, 59]	✓	✓	-
Identification issue of physical and logical interfaces	[131]	-	✓	-
Neighbor discovery	[130]	-	✓	-
Needless broadcast messages	[131]	-	✓	-
Congestion caused by duplicate copies	[133]	-	✓	-
Counting to infinity	[135]	-	-	✓
Routing loop	[135]	-	-	✓
Sending distance information to all prefix	[136]	-	-	✓
<b>Total Issues</b>		6	6	4

interest packet loss, and high bandwidth utilization costs [120]. Another challenge that arises as a result of mobility in GR is NDN's reverse path mechanism. As NDN uses reverse path to fulfill requests, this process causes issues in GR that must be addressed. Furthermore, due to geographical constraints, routing scalability is another challenge with GR.

LSR has a scalability issue with routing. The overhead of protocol-related messages, which are propagated via interest flooding, determines the scalability of an LSR protocol. [59]. Other challenges in LSR include neighbor discovery, needless broadcast messages, and congestion caused by duplicate copies because LSR protocols communicate network map information by broadcasting the state of each individual link in a form. When either side of a link senses that the link has died (or that a new link has become available), it sends out "flooding" link-state packets [121].

Measure issues in DVR include routing loops, counting to infinity, and delivering distance information to all prefixes. The vector routing protocol has a problem called count to infinity. This is because the nodes topology in the networking creates a routing loop [122]. The challenges and open issues in NDN distribution are depicted in Figure 8. NDN open issues and challenges are divided into three categories based on the routing techniques discussed in the above section.

#### A. CHALLENGES AND OPEN ISSUES IN GR IN NDN

GR in NDN is widely considered as VANET or mobile area network (MANET) because of its landscape boundaries. Currently, GR is coping up with many challenges and issues. One common routing issue in GR is the interest flooding problem [123]. A consumer who is interested in data sends out Interest packets, which include the content's name prefix as well as additional parameters. Interest packets are typically sent out via broadcast, which might result in network flooding. If an interest packet is received by a producer or an intermediate router with cached content, the corresponding data packet will be delivered to the consumer through the same path as the interest packet. This flooding strategy will lead to excessive redundancy, significant conflict, and collision, hence it is known as the broadcast storm problem [124]. In this issue, uncontrolled broadcasting of data and interest packets floods the network with duplicated packets. As broadcast is the simplest and most common method of information distribution in VNDN, broadcast storm problems are the most frequently mentioned research issues. Numerous studies cover broadcast storm mitigation in VNDN. In their most recent analysis, Ahed *et al.* [31] found that 8% of the NDN-based vehicular networks articles they examined address cache redundancy, reverse path partitioning, and other issues, whereas 31% of the publications cover the broadcast storm problem.

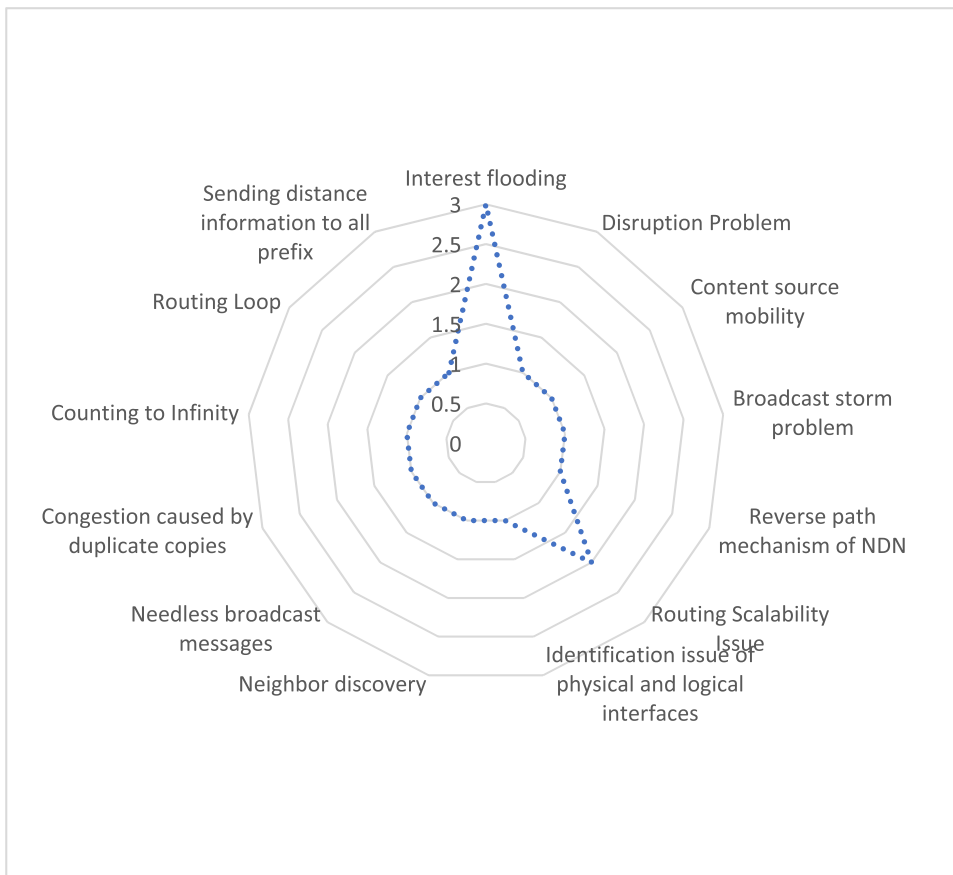


FIGURE 8. Challenges and issues tendency.

The majority of the articles surveyed aims to reduce the problem of broadcast storms by introducing a method to control the broadcast. It is important to note that the routing issue in NDN-based vehicular networks is related to both the network’s scenario and broadcasting.

In addition, unnecessary collisions and frequent contention difficulties occur frequently among neighboring nodes [125]. Data distribution interruption [79] is another issue that highlighted in VNDN because as VNDN node is mobile and continuously changes its position therefore, the reverse path mechanism is impractical in VNDN. Another important issue in GR is data source mobility in VNDN as discussed by Duarte *et al.* [126]. In this study, a content sharing technique is presented that does not require any infrastructure and relies on in-network caching and content replication to provide content sharing within a geographical region.

Moreover, GR is more suitable for VANET or MANET because it avoids the complexity and latency of maintaining routing tables in favor of using nodes’ geographic positions, which can be determined by Global Positioning System devices on moving vehicles [127].

**B. CHALLENGES AND OPEN ISSUES IN LSR IN NDN**

There are three methods involved in designing a LSR protocol. The first is method is called weight computation: where

the network-management system uses a periodic and centralized optimization to calculate a set of link weights. The second method is traffic splitting, which involves each router deciding traffic splitting ratios among its outgoing links for each destination based on link weights. The third method is packet forwarding, in which each router chooses an outbound connection to send a packet which depends solely on its destination prefix to achieve the required traffic splitting. The popularity of LSR is mostly due to its simplicity of management [128].

In the latest research, Wibowo *et al.* [59] showed that LSR is on average 24% more efficient than GR in terms of data transmission in NDN, traditional routing methods based on LSR and DVR strategies may be utilized without modification [129]. This is accomplished by a single basic change: the NDN router publishes name prefixes rather than IP prefixes. The routing protocol sends these notifications across the network, allowing each router to establish its own FIB. The aforementioned method is implemented by NLSR, NDN-based LSR, which greatly aids in understanding and implementing NDN ideas into routing. NSLR is one of the most widely used NDN LSR protocols, and it uses HR to address the scalability issue. However, the performance of NSLR with HR is currently under investigation. Lehman *et al.* conducted one such investigation [58].

They presented a forwarding approach named “Adaptive Smoothed RTT-based Forwarding” to improve HR’s sub-optimal path selection. Their experiment shows that HR provides a more scalable routing method with low influence on routing path optimality. NLSR will grow over time to incorporate neighbor discovery and eventually become a full-fledged NDN inter-domain routing protocol [130]. Another issue that arises with NLSR is that it requires techniques to identify accessible physical and logical interfaces when it first starts up; other programs have the same problem, which influences work on autoconfiguration [131]. Furthermore, NLSR naively retrieves routing updates using sync [131], with no idea which neighbors could hold the data, resulting in needless broadcast messages. On multi-homed devices, this problem may influence other applications; fixing it can enhance sync usability and performance. Choi *et al.* [132] presented another technique as a dual-connectivity strategy that can be stated as a soft handover to remove the previous NDN face after the NLSR distributes updated location information about the producer’s contents throughout the NDN. Another issue with LSR for NDN is avoiding congestion caused by duplicate copies of content in the network. Dash *et al.* [133] showed with a simulation that their approach can decrease the flooding problem up to 30% while retaining the hit ratio. Wibowo *et al.* [112] discussed the scalability issue in NDN routing in terms of routing and forwarding.

To conclude, LSR performs better in terms of throughput, packet delivery, and end-to-end delay for IoT in NDN [134].

### C. CHALLENGES AND OPEN ISSUES IN DVR IN NDN

In distance vector or path vector routing, routers inform their peers of the cost of the completely routing path to each destination. When a router receives a data routing announcement, it calculates the path cost by adding the link cost to the received path cost [102]. When employed in content-centric networks, DVR faces several problems, including the inherent difficulty of counting to infinity and routing loops [135]. In addition, each router must track and send location information for all prefix copies and destination nodes in the network, adding to the complexity [136]. Although, because of adaptive forwarding, the DVR protocol works quite well under NDN [137]. Furthermore, Garcia *et al.* [136] present a method that uses distance-based content routing named distance-based content routing (DCR). DCR is proven to be loop-free at all instances, and it can converge on the shortest paths to the closest content copies. Research suggests that DVR with an ad-hoc setup works better in MANET [138].

### VI. CONCLUSION

NDN and its routing strategies in terms of GR, LSR, DVR, and ad hoc routing are discussed in this paper. We explain existing NDN routing techniques in detail, including their timing and characteristics. We also highlight several obstacles and open research concerns in various study domains, including GR, LSR, and DVR. NDN is an ongoing approach,

and many studies call for further investigations to prove that NDN is the best replacement for its rival TCP/IP. This paper attempts to deeply scrutinize the existing routing mechanisms related to NDN. In addition, we discuss research challenges that may prove valuable in comprehending NDN routing. Future works in this area should focus on shortcomings in different NDN routing schemes so that readers can draw ideas to create a de-facto routing architecture for NDN that can address utmost limitations in current NDN routing approaches. LSR and GR in NDN, as discussed in this article, are research topics that require more attention from researchers, followed by DVR.

### ACKNOWLEDGMENT

The authors are grateful for the resources provided by the ICN and Network Communication Technology (NCT) Research Groups, FTSM, and UKM for this study.

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