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Caching and Data Routing In Information Centric Networking (ICN): The Future Internet Perspective

Alcardo Alex Barakabitze, Tan Xiaoheng
College of Communication Engineering,
Chongqing University-China

Abstract—Information Centric Networking (ICN) is becoming an important direction of the future internet architecture research. Different ICN architectures like PSIRP, NetInf, PURSUIT, CCN, DONA, and NDN have been proposed with the aim of moving from the current host-to-host communication model to a content-centric communication model. Caching and data routing are among the most significant properties of ICN features which improves network efficiency and content distribution performance by satisfying user requests with cached content. New characteristics of ICN caching include the Internet to be transparent to applications, ubiquitous in-network caching (caching contents in routers in a granularity based-level different from the current Internet architecture which cache contents in file-level. This paper describes in-depth, the concepts of caching and data routing in ICN by providing a comprehensive survey of a number of cache decision and data routing policies in ICN. The paper provides also the caching and data routing mechanisms in the Named Data Networking (NDN) which is the promising ICN design for the future Internet architecture. In general, by modelling the in-network caching and data routing which will be based on more efficient cache decision and routing schemes, it will have more practical significance in ICN designs for the future Internet architecture.

Keywords—ICN, In-network Caching, Data routing, Cache Decision policies, Internet

I. INTRODUCTION

The Internet which plays a central role in work and business, education, social life, entertainment e.t.c was developed and deployed in the early 1960s and 1970s mainly based on the host–to-host communication model.[1].Since its deployment, the Internet has experienced a tremendous growth in the traffic(data flow) with the Cisco's Visual Networking Index (VNI) global forecast report showing that, the IP traffic will grow 3-fold with a Compound Annual Growth Rate(CAGR) of 21% from 2013-2018 and reaching 131.6 Exabytes per month in 2018 compared to 51.2 Exabytes per month in 2013[2].The Internet traffic also is anticipated to grow 2.8-fold with a CAGR of 23% reaching 102.2 Exabytes/month in 2018 compared to 36.4 Exabytes/month in 2013[2].The VNI report also indicates that, Globally, the IP Video traffic will grow 3-fold with an anticipated CAGR of 25% from 2013-2018 reaching 103.8 Exabytes per month in 2018 compared to 33.6 Exabytes per month in 2013;the Internet Video traffic will grow 4-fold with CAGR of 30% reaching 76.6 Exabytes per month in 2018 compared to 20.8 Exabytes per month in 2013[2].This traffic growth is mainly attributed by different forms of videos like TV, Video on Demand(VoD) and P2P which is expected to exceed 91 percent of global consumer traffic by 2018[2].

The majority of Internet interactions today are related to content based-access from the following Internet-based content technologies:-

- P2P Overlays such as BitTorrent, eMule, live streaming.
- Media aggregators (e.g. YouTube, GoogleVideo)
- Over-the-top video (e.g. Hulu, iPlayer)
- Content Delivery Networks (e.g. Akamai, Limelight)
- Social Networks (e.g. Facebook, MySpace)
- Photo sharing sites (e.g. Picasa, Flickr) etc.

These Internet-based technologies results into increased demand of traffic by consumers/users who are interested in the contents without caring of where the contents are located.According to Borst et.al[3], the increasing demand of traffic generated by receiver-driven digital video content retrieval mode like time-shift TV and high Definition VoD will continue to grow in the coming years. A number of content caching and different application layer solutions like the Content Distribution Network (CDN), Peer-to-Peer (P2P) networking systems, mobile video and cloud computing have been deployed [1] due to the increasing demand of massively distribution and replication of resources on the Internet [4].However, these applications which has been deployed on the current Internet architecture to cater for the needs of the increasingly demand of user generated contents have many limitations as shown in figure 1.

The content caching solutions like CDN and web caching proposed in the traditional internet architecture are characterized by inefficiencies due to the fact that they are deployed to an infrastructure which is built on top of a host-to-host communication model. The network caching solutions have been developed and deployed from web caching to Content Delivery Networks (CDN) and ISP transparent caching (see figure 1) mainly because of the rapid growth in internet traffic which is driven by user's content requirements.

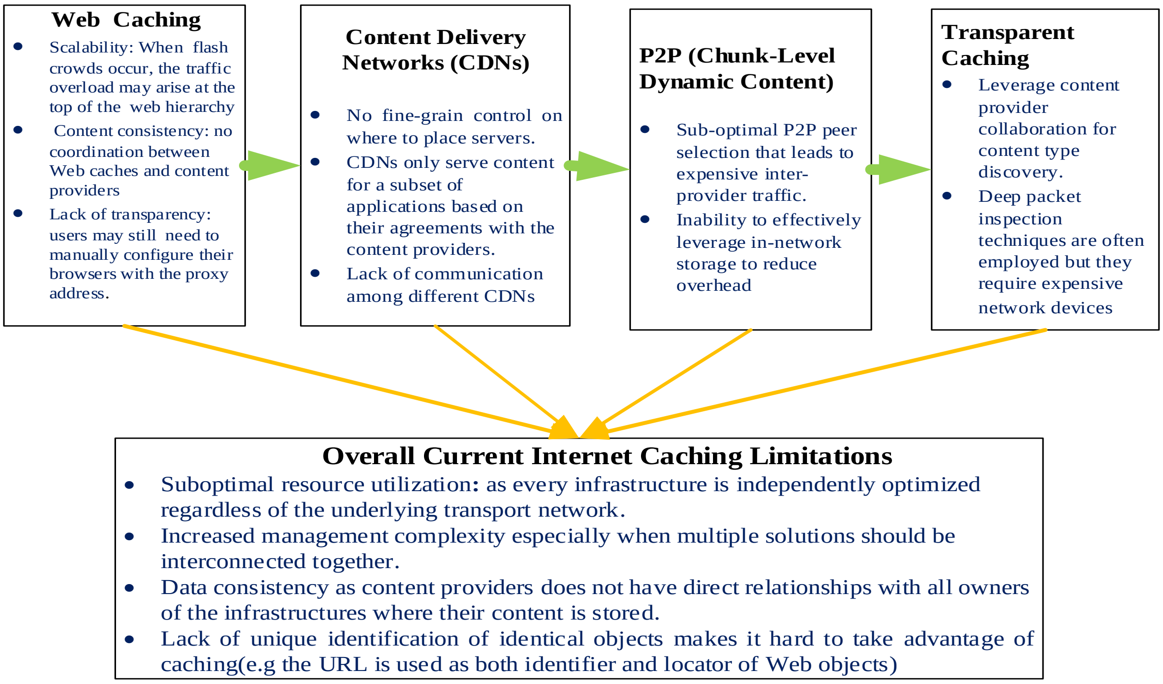

Figure 1: The current Internet content caching limitations

In order to overcome these limitations and cope with the future Internet usage, a number of innovative Internet infrastructures to shift from the current host-to-host communication model to a receiver-driven content retrieval model have been proposed [23][24]. These innovative network design for the future Internet architecture is called Information Centric Networking (ICN) and among the proposed ICN designs includes the Data Oriented Networking Architecture (DONA)[5],Content Centric Networking(CCN) now renamed to the Named Data Networking(NDN)[6][7][8]; PSIRP/PURSUIT[9][10][11][12][13];AWARD[14];COAST[84];ALICANTE[85];ENVISION[86],CONVERGENCE[15];NetInf[16][17];SAIL Project [18]; COMET[19][20][21][22]; MobilityFirst[23] and ANR Connect[25].For more survey papers concerning this ICN designs for the future Internet architecture, readers can refer to [16][17][28][29][30][37][38]. The concept of ICN has taken recognition in the current Information-Centric Networking Research Group (ICNRG) (https://irtf.org/icnrg) which aims to integrate the above ongoing ICN research projects and come up with solutions which will be relevant for evolving the future Internet requirements at large [26]. The Internet today is mainly used by a number of applications which are used for distributing and manipulating named information in steady of host-to-host communication between end users. Users of the Internet are interested in accessing contents irrespective of its location on the Internet. ICN therefore leverage and emerge as possible solutions in order to overcome the current problems of increasing traffic volume which cannot be handled by the current Internet architecture which was designed for host-to-host communication model.ICN introduces uniquely named data content which are independent from locations ,storage, applications and even the means by which data contents are transported on the Internet. In ICN, names are decoupled from host addresses and therefore completely removing the role of an IP addresses which play both as an identifier and as a locator in the current Internet architecture [27].The overall advantages of ICN is to have an improved network efficiency, better scalability and cost-efficient content distribution in terms of users' bandwidth demand [4], persistent and unique content naming, objects authentications for improving network security, provide mobility and multi-homing,better robustness and disruption tolerance in challenging communication scenarios[26] and the in-network caching(a mechanism for storing contents in routers or network nodes).

The rest of this paper is organized as follows: Section II provides key features of ICN designs; section III explores the caching and data routing in ICN; section IV describes in-depth the CCN/NDN architecture focusing on caching and data routing and finally, section V concludes the paper.

II. FEATURES OF ICN DESIGN FOR THE FUTURE INTERNET ARCHITECTURE

The key features or characteristics of all ICN design paradigms for the future Internet architecture are:-

A. Naming:

This is one of the characteristics of ICN of which the content unit is called the Named Data Objects (NDO).The NDO can represent any real world object and can be anything like web pages, video content, pictures or a file etc[28].According to Choi et al[29],different ICN architectures for the future Internet have different naming schemes which can be hierarchical or flat naming scheme[28].

B. Name resolution and data routing:

The name resolution is a mechanism that enables a consumer or a content subscriber to find NDO by using a name [30].This mechanism provides a means of mapping a name and content locator and forward the requested data to the source. In some ICN design like CONVERGENCE and NetInf [28], the name resolution is done by a Name Resolution System (NRS) which provides translations when mapping a name and a source locator. After the source of the content according the requested name has been found, the data routing process then constructs a path for transferring the data from the source to the user/client who requested the content.

C. Caching:

This is among an important and integral part in ICN design which require all network nodes or routers to have storage capabilities. This capability of storing NDO within the network nodes or routers is called In-network caching [30]. Among the benefits of caching in ICN includes increased performance of content delivery to end users by reducing response time of NDO requests; improved network performance and alleviating server loads [27].According to Pavlou [31], based on granularity levels, caching in ICN can be categorized into 3 levels namely: the ***object level*** which is a complete NDO; a ***chunk level*** which represent a part of NDO and a ***packet level*** which is represents some bytes of NDO. Caching can take place on the path when the request content traverse from the source to the client/subscriber which is called on-path caching or it can take place on network nodes different from the path that the request took from the client/subscriber to the source which is termed as off- path caching [28].Caching in CCN/NDN ICN design will be explored more in section IV in this paper.

D. Mobility:

Mobility is a very challenging issue in the current Internet architecture since hosts have to be reachable all the time and maintain a seamless connectivity between end points using TCP sessions [32].Since a large number of traffic are now attributed to mobile devices [2][33], when a mobile host changes its physical location, is also required to change its name and therefore creating problems[34]. The global routing challenge is another constraint which limits mobile hosts in the current Internet architecture. Although there are solutions like ***tunneling*** and ***re-binding*** of the what (the name) to the where (the address)[32] to overcome these mobility problems, still, the solutions are characterized by being slow, unreliable and costly. ICN designs provide solutions to overcome the mobility issues existing in the current Internet architecture by focusing on routing of content objects using their names rather than end hosts[34].In this manner, the change of a node's physical location does not need the change of its related network information like the routing state information. In addition to that, the content in ICN is an addressable entity and is itself the underlying routing target and not a host as in the current Internet architecture. Furthermore, the content in ICN is the one that is secured independently and not a communication channel and the publisher or subscriber interface is used and not a socket. Among the benefits of ICN in supporting host mobility includes: host multihoming, network address consistency, removal of connection-oriented sessions, scoping of content and location and resilience through replication [34].

E. Security:

This feature is co-related to naming in all ICN designs [35].The security concern in the current Internet architecture puts emphasis on authenticating the end points that is, the sender and receiver and protecting the connection between them using cryptographic methods and protocols such as Secure Sockets Layer (SSL), Transport Layer Security (TLS), Pretty Good Privacy (PGP) and the Internet Protocol Security(IPSec)(developed by the Internet Task force(IETF)) which provides security and authentication at the IP layer by transforming data using encryption[30][36].A user needs to trust in the content requested that it comes from the secured network. In this regard, when a copy of the requested object leaves from the server/host, its authentication becomes a problem which allows Denial of Service (DoS) attacks that can cause the intended content to be unavailable [39].ICN approach overcome the security limitations in the current Internet today by authenticating Information Objects (IO) themselves rather than the transport session and end points. Furthermore, the content authentication in ICN is to protect the alteration and eavesdropping different from the traditional Internet today [39].However, through replication of contents, ICN enables availability of contents in the network and totally reducing server load contents. According to Ahlgren et.al [4], five technical security aspects in ICN have been proposed as shown in figure 2.

Figure 2: Five ICN technical Security goals.

III. CACHING AND DATA ROUTING IN ICN

A. Caching

This is one of the important and hot research topics in ICN designs. Caching in ICN is to set improve the utilization of network resources and increase availability of data by overcoming the limitations of the traditional caching systems as shown in figure 1.There are two categories of caching in ICN namely:

- ***Caching at the network edge***-means that pushing all the applications, data and network services away from centralized nodes to the network extremity (e.g. using dedicated servers on an ISP network, user nodes like in P2P networks).Caching at the network edge ensures network load balancing and improve network resource management [40].
- ***In-network caching/Caching at the core network-*** means that, caching contents within the transport network. Every network router has capabilities to cache data such that other requests can be satisfied by nearby routers which have already cached the data. This is in conjunction also with the Name resolution Service (NRS) used in ICN proposals like CONVERGENCE, MobilityFirst, and NetInf [28]. Through in-network caching, the network efficiency is improved as well as increasing content distribution performance by satisfying user requests with cached content rather than retrieving contents from remote sources [41].This is also called ***user-assisted in-network caching*** where by user is enabled to download a content from a nearby user who has already downloaded the content.

ICN caching comes with new caching features for the future Internet architecture which includes:

Cache to be transparent to applications: transparency is enabled through content names which are self-certifiable, unified and are in a consistent manner [5][17][24][38][42][35].Transparency in ICN caching is also enabled through cache decision routing policies which are done at these unified named content therefore making the network to be aware of the content names and simplifying indeed the security checking of contents [43].

Cache ubiquity: means that the apparent existences of cached contents everywhere at the same time since routers or network nodes are equipped with storage capabilities. This is enabled in ICN due to the fact that, the points of caching contents are not fixed like in the current traditional Internet architecture which rely on linear or hierarchical tree structure. The caching network topology in ICN relies on hierarchical trees or arbitrary graphs which make it to exhibit high dynamics of contents availability and ubiquity of in-network caches [43].

Caching contents based on granularity-level: Three granularity based-levels have been defined for caching contents depending on every ICN architectural designs [30].These granularity based-levels are ***object level*** (involving caching a complete NDO)[20], ***chunk level*** (caching part of NDO)[44] and ***packet level*** (caching some bytes of NDO)[45].A chunk is the basic data unit in ICN to which caching and security like encryption and signature functions are applied [44].Therefore, all caching operations are applied on these granularity levels which is different from the traditional caching mechanisms which is performed on the file-based system as the basic unit of abstraction [46].

ICN provides capabilities to routers or network nodes to store contents that traverse through them when the request is returning back to the client. Every router will be able to cache data that flow through it and hence the term *in-network caching.* When the client issues a request looking for certain content in the network, the first router to receive the request checks first in its local cache if it has such content, if the request is found, then the router forwards the data to the client and drop out the request containing the message. In case that the router has no such content in its local cache then it forward the interest message to the next-hop towards the source/server/publisher containing the data. Consider the in-network diagram shown in figure 3.

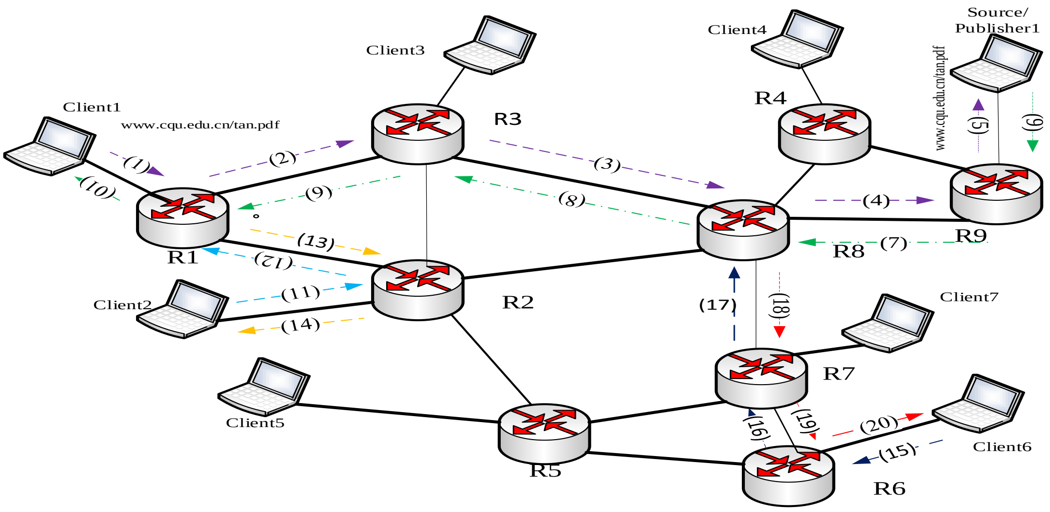

Figure 3:In-network cache in ICN

Suppose client 1 issue a request which has been published by publisher 1.The request message from client1 pass through R1,R3,R8 and R9 up to the publisher1 as shown by arrows (1-5).The content www.cqu.edu.cn/tan.pdf on the way back to client 1 will traverse routers R9,R8,R3 and R1 where each router traversed will remain with the copy of the *www.cqu.edu.cn/tan.pdf* in their local caches such that subsequent requests from other clients can be satisfied by these network nodes. When client 2 issues an interest message requesting the same data which has been requested by client 1, then, the data can be retrieved from Router R8 or R1 following the route path as shown in arrows (11-14) in which case router R2 also will cache the content. Request of the same message from client 6 can be satisfied by R8 following the route path as shown in arrows (15-20).

In-network caching improves network performance by reducing request latency, utilizing network resources more efficiently and making data availability more significantly [47].In this case, the same content can be requested by many clients who are geographically close to each other and within a short period of time. One of the drawbacks of in-network caching is the data redundancy which is resulted from caching the same data in every router. Therefore, the major problems to address in the in-network scenario are related to the selection where to caches contents in the network [39] in order to improve the network performance. The Leave Copy Everywhere (LCE) policy has been proposed which is to leave a copy of the content along the delivery route path from the source/publisher back to the client. With every router caching the contents it will result into data redundancy which can degrade the performance of the network and underutilize some of the network resources. The question to ask is: which network routers can be enabled to cache contents so that the network performance can be improved significantly and utilize resources more efficiently? Authors in [43] argue that, reducing cache redundancy and improving cache diversity need simple and effective coordination between cache nodes. In fact, two different approaches have been proposed to address the problem of allocation and selection of cache which are the *coordinated* and *uncoordinated* approaches [48].In the coordinated approach, network routers are required to exchange information in order to have a good estimation of where to cache the content and avoid storing too many contents of the same content. The coordinated approach is also categorized into explicit and implicit coordination schemes.

- **Explicit cache coordination schemes.**

With explicit scheme requiring prerequisite information like cache network topology, state of each cache and object's access pattern to be used as inputs during calculation of the placement position of each object in the network [43]. Explicit cache coordination scheme are also divided into three categories namely:-*Global Cache Coordination (GCC), Path Cache Coordination (PCC)* and *Neighborhood Cache Coordination* (NCC) schemes. With GCC, coordination involving all cache nodes in the network which is a mechanism done also in CDN[49][50].In PCC, the network nodes along the delivery path from the source/publisher back to the requesting client are involved in the coordination mechanism. Examples of PCC schemes is the coordinated en-route web caching (CERWC) [51][52].With NCC, neighbor nodes(e.g., directly connected nodes, two or three hops connected nodes) in the network are involved in during coordination mechanism. Example of NCC is the Cooperative In-Network Caching (CINC) [53] and the Breadcrumbs coordination mechanism which was proposed by Rosensweig and Kurose[54].However, the explicit cache coordination schemes impose the complexity issues in ICN due to their computational overhead incurred while nodes are exchanging network information in order to make the final decision on where to locate the content in the network caches[43].With a network topology in arbitrary trees structure,ICN needs simple and efficient cache decision policies which cannot impose such computational overhead in the network.

- ***In implicit cache coordination* schemes:**

A network node does not need to know the state information of other network nodes and in some cases very little information is only needed to be exchanged between network nodes in order to make the final decision on where to cache the object [43].A number of implicit cache coordination algorithms or decision policies have been proposed in the literature targeting to efficiently allocate and manage contents in ICN network caches [55]-[68]. These cache decision policies which decide where to put caches in order to utilize network resources more efficiently are shown in table 1 along with description of every policy.

Chai et.al [27] proposes the Betweenness centrality-based caching scheme which enables only selected nodes in the content delivery path to cache the content. This scheme requires that, all network nodes lying along a high number of content delivery paths (those with high *betweenness centrality)* are likely to get a cache hit. In this case, nodes in the core network have probability of caching contents since they are connected to many others different from nodes in the edge network which are scattered at a widely spaced interval. By exploiting the topology features of the network, the betweenness centrality policy spread the contents towards the user very fast therefore increasing user's contents cache hit rate [27].

B. Data routing:

In ICN, the storage management and request routing for contents are integrated together with the transport layer as shown in figure 4.ICN provides a receiver-driven transport layer which enables the receiver to drive the transfer of contents through searching based on granularity level (i.e. chunks/packets/object levels). An item in ICN is uniquely identified globally through the content name which acts like the Uniform Resource Identifier (URI)[39]. The content name allows a client to access direct the content, without caring its location in the network. The content request is therefore routed independently to the best source available (arrow 1-3) and the source respond to serve the request through a given network metric values and routing mechanisms agreed between the user and the content provider (arrows 4-6).

Table 1: A number of cache decision policies for ICN

Caching Policy	**Descriptions**
Leave Copy Everywhere[43]	• This policy leave a copy of a content to each node that it traverse along the delivery route-path from the source to the client(It is the default cache coordination policy proposed in most ICN architectures)
Leave Copy Down (LCD)[55][56]	• This policy was proposed for overlay cache networks such that when cache hit occurs it cause contents to be copied one hop closer to the user or to the next hop down the cache hierarchy.
Move Copy Down(MCD)[55][56]	• When cache hit occur to a network node, this policy move the copy of the requested content from the cache to its underlying cache and deletes the content from the hit node
Content Gradually Tend to Important Node (CGTIN)[57]	• This cache decision strategy push more popular contents to more important network nodes and extend the survival time of these more popular contents. CGTIN is suitable for any network topology.
Copy with Probability (Prob)[55]	• In this caching strategy, the requested content is copied with a certain probability p at every network node along the delivery route path from source to the client. When the probability p=1,this policy becomes similar to LCE(i.e, copy the content in each network node)
Probabilistic Cache (ProbCache)[58]	• This is an algorithm that approximates the capability of a path to cache contents based on path lengths and multiplexes contents accordingly. Contents should be cached closer to their destination with higher probability in order to leave caching space at the core of the network for shorter content flows. This policy utilize network resources efficiently, reduce cache redundancy and therefore reducing the network traffic redundancy.
Least Unified Value-Path(LUV-P)[59]	• In this caching policy, all routers along the delivery path will implicitly coordinate and cooperate whether to cache the content and each content to be cached will be assigned a Least Unified Value(LUV) with router's distance from the content provider in order to reflect its relative importance. In addition, during every content retrieval process, routers along the delivery path cache contents with different probability such that, routers near the content provider(upstream routers) will have higher probability to cache the content than routers near to the customer(downstream routers).However, contents that are not cached by upstream routers will be cached by downstream routers using accumulation of probabilities.
Intra-AS Cooperative Caching[60]	• This caching policy allows nearby routers to eliminate redundancy of their cached contents and collaboratively serve each other's requests which results into improved utilization of the limited network cache resources. This scheme improves the network caching performance and reduces the traffic load on the AS gateway links which is a good scenario to ISP
Hop-based Probability Caching(HPC)[61]	• On returning the content back to the client/requester, every router will cache data with the probability determined by the number of hops between the content source/publisher and the router itself. The HPC policy push contents to the network edge and avoid unpopular contents to be cached in the network.HPC is more better than Probcache in terms of archiving higher caching efficiency.
Age-Based Cooperative Caching(ABC)[62]	• The ABC policy adaptively pushes content objects to the network edge by using dynamically changing ages that control the lifetime of the content replicas in the router. The age of the content object is decided along the routing path and no signaling messages between routers or extensive computational overhead. In fact, ABC spreads popular contents to the network edge and at the same time eliminate unnecessary content replication in the middle of the network.
Intra-Domain Cooperative Caching(IDCC)[63]	• The IDCC policy uses probabilistic caching based on inlet traffic speed, and conducts intra-domain advertisements for popular contents. Routers cooperate in a distributed way and store a proper number of hierarchical cached replicas. With IDCC, cache redundancies are reduced and the router load constraint is satisfied, making popular contents to stay within the local AS. In addition, contents can stay for a long time in the cache and cache utilization ratio is improved significantly.
Progressive Caching Policy(PCP)[64]	• This scheme propose to avoid caching unpopular content in access routers and bring popular contents to end-users(clients) in a progressive manner. However,PCP is likely to resemble to the LCD policy by selecting the immediate downstream routers of the cache hit point as the primary citizen and a place for replicating the data packet. This scheme was proposed for CCN/NDN architecture.
Chunk caching Location and Searching(CLS)[65]	• The CLS scheme require the presence of at most one copy of a chunk to be cached on the path between a server and a leaf router. This copy is taken down one level towards the leaf router by a request or pushed up one level towards the server by the cache eviction. Hence, it is possible to store more diverse contents in the whole CCN and improve the network performance. In order to reduce the server workload and file download time, a caching trail of chunk is created to direct the following request where to find the chunk.
WAVE[66]	• WAVE adjusts the number of chunks cached at each node based on the content's popularity such that a content router explicitly sets the cache indication mark (i.e., in CCN's data packet), which makes its direct downstream content router cache this chunk. Once the chunk is cached, the cache indication mark is cleared. This mechanism is similar to LCD policy(the chunk is pushed one hop towards the requester every time).However, different from LCD, WAVE counts the access frequency of a given file.
DEMOTE[67]	• In DEMOTE, the content can be pushed back to one upstream level by following the cache hierarchy for caching such that objects cached closer to the network edge often have higher access frequencies than objects cached upstream in the cache hierarchy. In addition, the DEMOTE operation transfers data ejected from the client to the disk array and therefore archiving exclusive caching.
Least Benefit(LB)[68]	• In LB, the distance factor besides frequency is taken into account such that network nodes need to know the **HopGain** in order to cache some contents locally. The *HopGain* is the field in the content packet that indicates the current hop count it has traversed from the resident node of this copy of the content. By using HopGain field, every intermediate node could know the hop reduction for any content object it has encountered if caching it locally. Network nodes record the hop reduction (also referred to as distance) for every content object cached. When a hit happens, the current overall benefit of the hit content object would be increased by the current hop reduction. When a replacement is needed, the content object with least benefit will be evicted out.

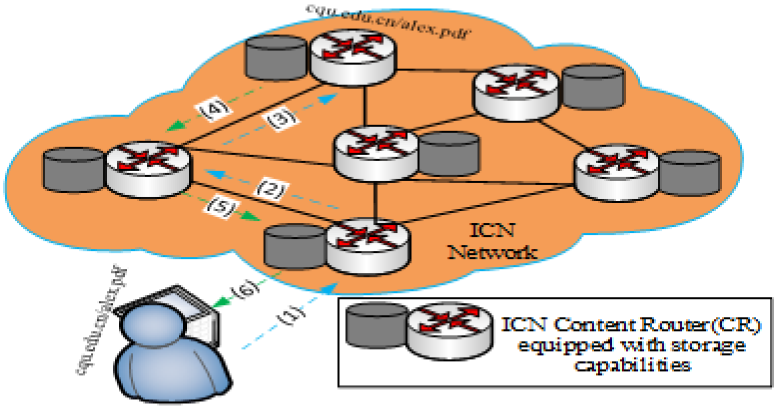

Figure 4: Content delivery in ICN

By directly accessing the content item in ICN using its name, enables the fine-grained resource control such that the storage allocation and bandwidth is optimized [39].The request routing in ICN is directly integrated as a native feature within a network through a name-based routing mechanisms. The Name-based routing in ICN stay attached together with the network topology which provides high reactivity in the presence of network sudden changes (i.e in traffic demands or content popularity) such that request routing information is properly reorganized. Carofiglio et.al [39] highlights that, the most significant technical challenge for the future internet architecture is the design of name-based routing protocols which will also replace the host addresses with the content names in ICN. In this regard, many research works have been devoted to the design by proposing different name-based routing schemes/protocols for ICN. The first name-based routing scheme was proposed in [69] called the Directed Diffusion (DD).All requests/interests for named content in DD are flooded throughout the network and any data that is found to match with the request is sent back to the client/subscriber. Authors in [70], presents the Disruption REsilient Content Transport (DIRECT) which provides named-based content routing for ad hoc networks that exploits in-network storage and disseminate named contents in a hop-by-hop manner subject to connectivity disruption. The Name-Based Routing Protocol (NBRP) which is an extension of the Boarder Gateway Protocol (BGP) is also among the early schemes to be developed for the named based routing of contents. NBRP advertize name prefixes among content routers in the network and in order to avoid permanent loops in the network, the path information among these contents routers is used [71]. Carzaniga et al [72], proposes the Combined Broadcast and Content Based (CBCB) for named content networking. In CBCB, the requests are sent between consumers and producers of content over the tree(s) that are established in the network during the content routing process. The name-based inter-domain routing scheme has been proposed in [73] which integrate the policy based name routing between adjacent networks with hierarchical interconnection overlays for scalable global connectivity.

A Two-Layer Intra-domain Routing Protocol (TLIRP) for NDN architecture has been proposed by Dai et.al [74].TLIRP consists of two layers which are: the **Topology Maintaining (TM) layer** and a **Prefix Announcing (PA) layer**. The TM layer is responsible for network node/link failure handling, shortest path calculations and topology discovering. The TM layer is similar to the link state information exchange functionality in OSPF such that each content router in NDN sends the Link State Advertisements(LSAs) to other content routers where every LSA is then flooded throughout the routing domain. The LSAs collected by content routers then forms the protocol's link which enables all routers to be aware of their link state databases [74].The PA layer is responsible to provide contents using two methods namely: the active publishing and passive serving methods which are compromised together by a popularity-based active publishing policy .In [75],the Potential Based Routing (PBR) scheme was proposed as a secondary best-effort routing mechanism which enable to boost the availability of content copies in ICN architectures. The term "*secondary best-effort routing*" means that, the routing algorithm forwards a user request to the source of the content based on a locator based forwarding like that used in [17] in order to guarantee the request delivery to the client/subscriber. Authors in [76] propose an Intra-domain Cache Aware Routing Scheme (ICARS) which performs computation of routes/paths that have a possible minimum transportation cost based on content demands and the network caching capabilities. Furthermore, the Scalable Multi-level Virtual Distributed Hash Table (SMVDHT) has been proposed in [77] which provides routing scalability and performs name resolution. In order to archive routing scalability, the SMVDHT utilizes a combination of multilevel virtual DHTs and name aggregation. This scheme exploits also the underlying inter and intra-domain IP routing protocols so as to build MVDHT for performing name resolution. Moreover, authors in [78] proposed the Name-Based Routing Protocol (NBRP) called the *αRoute* for ICN which utilizes bandwidth more efficiently and offers a guaranteed content lookup as well as providing a scalable routing table size. In fact, the *αRoute* is a name based DHT and among the advantages of this routing scheme is that, routing is done on content names and no bottleneck network node can occur which is different from the hierarchical routing mechanisms done in the traditional Internet architecture[78].In additional to that, recently Garcia-Luna-Aceves [79] from the PARC (Palo Alto Research Center) has proposed the first name-based content routing approach for ICNs called the Distance-based Content Routing (DCR) which is solely based on distance information. Routers in ICN are enabled by the DCR protocol in maintaining multiple loop- free routes towards the nearest instances of *any, some, or all* instances of the same NDO or name prefix in an ICN. After maintaining multiple loop free routes, then the trees for delivering contents are established.DCR does not need content routers in ICN to establish over-lays, to know the topology of the network, using complete paths to content replicas, or to know about all network nodes that have replicas of named content [79].On one hand, many ICN projects that are devoted in building the future Internet architecture like the PURSUIT and SAIL, their modalities in addressing content routing schemes are based on DHT which runs in overlays over the physical infrastructure to accomplish name-based routing[79].On the hand, other ICN projects like NDN, COMET and CONET[80] build their modalities for routing contents based on the original CCN routing approaches such as the OSPF for Named-data(OSPFN)[81] and the Named-data Link State Routing (NLSR)[82] Protocols. Interested readers can refer to [83] which provide a comprehensive survey of naming and name-based routing protocols for the proposed ICN architectures. The next section provides a brief description of the NDN architecture focusing on caching and data routing mechanisms.

IV. NAMED DATA NETWORKING (NDN)

The NDN has been developed from the Content Centric Networking (CCN) architecture [30].The CCN-ICN design for the future Internet architecture was first presented in the Google Tech Talk in 2006[87] by Jacobson before his first paper being published in 2009[6].The NDN[8] is among the four National Science Foundation for the Future Internet Architecture (NSF-FIA) projects which is funded by the US Government with the goal of designing the future Internet architectures [28][83].The NDN architecture is set to replace the traditional Internet Protocol(IP) infrastructure with the data oriented communication infrastructure of which the emphasis is put on the content itself rather than on its location on the Internet[8][74].

NDN employ a hierarchical naming scheme consisting of multiple components which can be a length of any string arranged in hierarchical structure [28][83].NDN names are similar to the traditional Universal Resource Locator(URL) though is not necessarily and these names can be human-readable or not. Example of an NDN name is ***/cqu.edu.cn./cec/project.pdf*;** in this case, a request for a NDO can match with any information in the requested name found in the nodes of a NDN network [28].For example, a request of /***cqu.edu.cn./cec/project.pdf*** can be matched with a NDO of ***/cqu.edu.cn./cec/NDN-ICN/project.pdf*.** Figure 5 below shows the hierarchical naming scheme in NDN.

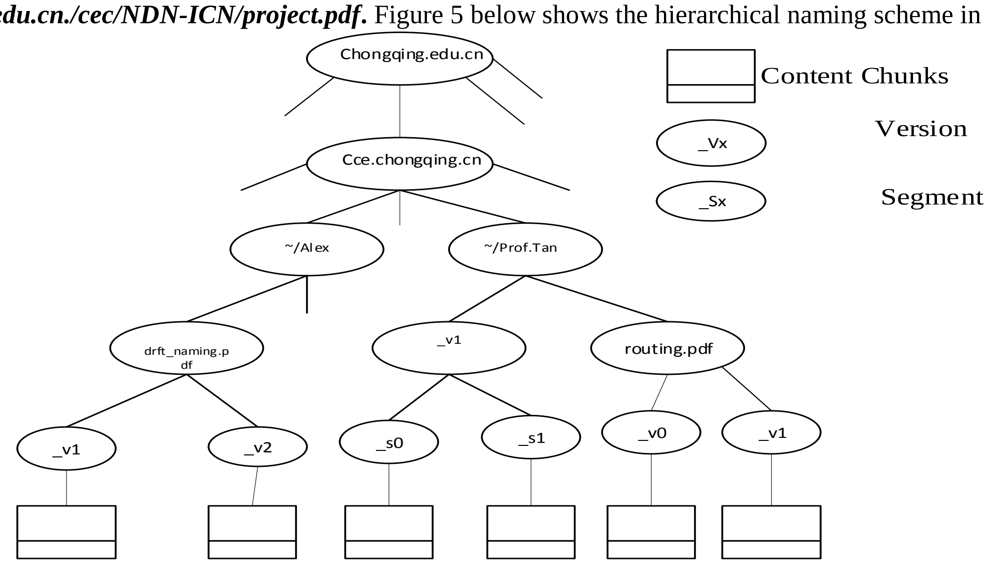

Figure 5: The naming scheme in NDN

In NDN, names may also consists of information such as segments and version numbers and every name in NDN contain a SHA256 digest which helps for resolving contents ambiguities[83].In order for NDN to provide content integrity and its authenticity, name to content mappings are digitally signed and delivered with the content.

A. Name Resolution and Data Routing in NDN.

There are exists an INTEREST packet and a DATA packet in NDN design [28][38][83].A client sends an INTEREST packet in order to request for a NDO which includes the name for a specific NDO cached in the Content Router(CR) of a NDN network. The source responds to client request using a DATA packet. According to Zhang et.al [7], every node or CR in NDN have three tables for forwarding, routing packet and caching data [30].These tables are:

a) The Forwarding Information Base (FIB)
b) Pending Interest Table (PIT).
c) Content Store (CS).

The Forwarding Information Base is mainly responsible to forward information object names to the output interface(s) which are used to direct the incoming INTEREST messages towards the data sources that have cached the requested NDO(see figure 6). The name- based routing protocol in NDN is the one that generates the FIB [30].The PIT is responsible to collect and keep track of all incoming interface(s) of the INTEREST packet such that, when the NDO is found in the CR, on the way back to the client, the DATA packet can be delivered to the client using the reverse path. The CS is responsible for caching all NDO that traverse through the CR in such a way that other client's request can be easily retrieved from these CR which is another advantage of NDN CR to have caching capabilities of contents. Figure 6 shows the named-based routing mechanism in NDN architecture.

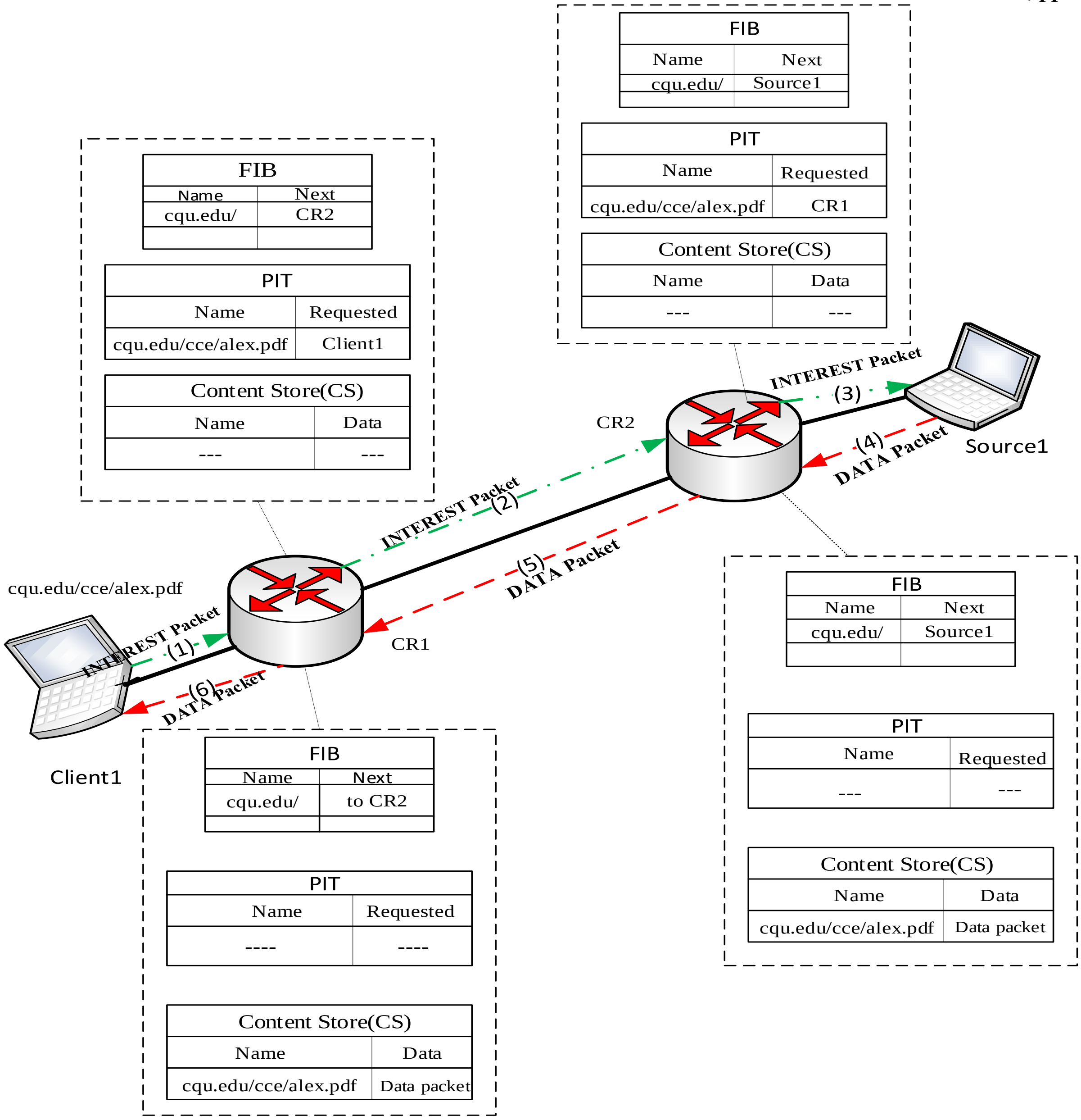

Figure 6: Name-based routing mechanism in NDN architecture.

When an INTEREST packet from the client reaches at the CR, the CR checks all the three tables it maintain in the order of CS, PIT and FIB [74].The CR checks in the CS if there is any cached NDO according to client's request using the requested prefix, if the there is a match, then the DATA packet which have both the name and content is sent back to the client through the incoming interface. After sending back the DATA packet in the reverse route the INTEREST packet is then discarded [28].If the INTEREST packet does not match with any prefix in the CS, then the PIT is checked if there is any request of the same data that have been made by other clients. When the INTEREST packet is found, then the PIT appends the interface of the arriving INTEREST packet to its interface list of the matched PIT and the INTEREST packet is dropped [30]. If no any INTEREST packet is found, a PIT keep records of this INTEREST packet in the list of arriving interfaces which did not have any match. In this case, the CR then forwards the INTEREST packet by consulting the FIB. The INTEREST packet is routed hop-by-hop up to the source which generates the DATA packet and route back to the client in the reverse path using information and recorded data routes in the PIT [30].

As shown in figure 6, client 1 issues an INTEREST packet for name cqu.edu/cce/alex.pdf to CR1 which has no such data in its CS and therefore records the interface from client1 in its PIT. CR1 then forwards this INTEREST packet to CR2 which also has no any data match with the incoming interest. CR2 forward again the INTEREST to the Source1 which cache the client's INTEREST and then send back the DATA packet which contain the requested name and the content to client1 in a hop-by-hop scenario. According to Jacobson et.al [6], NDN populate the FIBs by using the distributed routing protocols like OSPF where by CRs make advertisements of requested INTEREST packet name prefixes instead of using IP address ranges [28]. For example in figure 6, CR1 and CR2 advertise the INTEREST packet name prefix ***cqu.edu/*** to inform the network that it can provide information objects whose prefix is ***cqu.edu/***.

The INTEREST packet processing scenario in NDN from the client to CS, PIT and FIB to the original source of content is shown in figure 7.

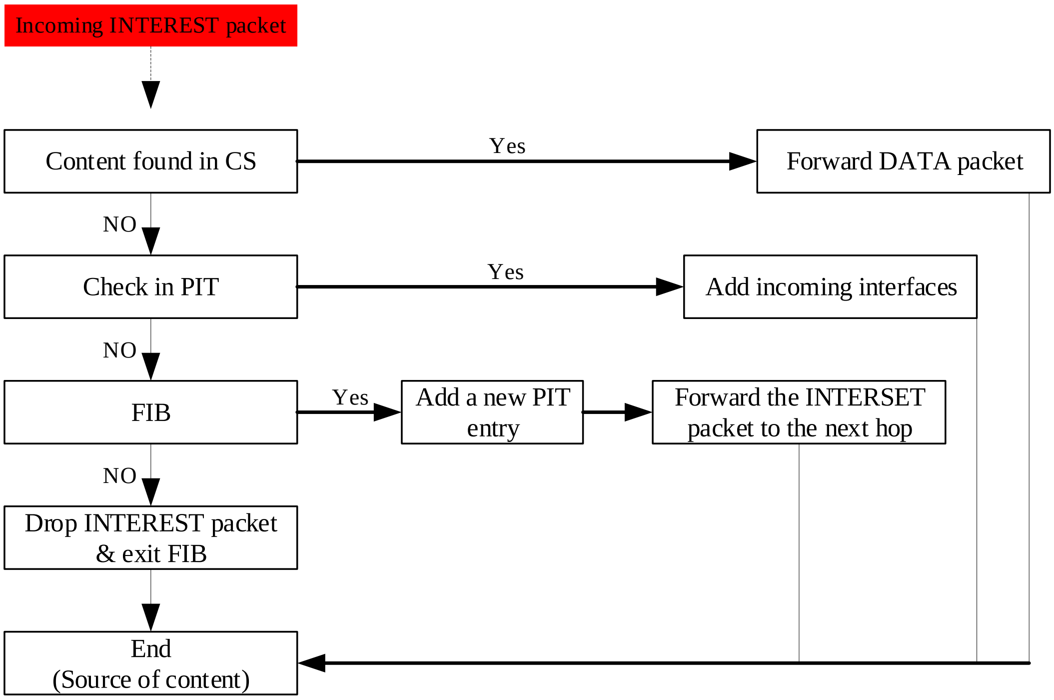

Figure 8: INTEREST packet mechanism in NDN

B. Caching in NDN.

NDN can support both ***on-path*** and ***off-path*** caching[28].On-path caching in NDN requires that, whenever a CR receives an INTEREST message then, it should first check in its CS if the requested content exists before forwarding the request to the source in a hop-by-hop manner. If the router reside on the delivery path, the it have to store all the information objects carried in the DATA message such that all subsequent requests from other clients will be served from that cache instead of going to the origin source.NDN support ***off-path*** caching when an INTEREST is forwarded to any source that may have the requested contents (i.e, the INTEREST packet can be directed to the CDN server instead of forwarding to the origin publisher) the responsible strategy layer can direct the INTEREST to a CDN

However, this caching mechanism is not transparent to NDN as it requires populating the FIBs with pointers to such content copies, which in turn requires the name prefixes of these copies to be advertised by the CDN server through the routing protocol used [28].

V. CONCLUSION

This paper has attempted to provide in-depth survey of ICN architectural design for the future Internet regarding to caching and data routing. The paper has provided the caching limitations in the current Internet architecture which motivates the shifting from host-to-host communication model to the content centric communication model. The paper has presented the promising features of ICN design for the new Internet architecture which are naming, name resolution and data routing, caching, mobility and security. In due course of these features for the proposed ICN designs in the Internet research community, the paper has mainly focused in caching and resource allocation policies (table 1) as well as data routing by giving in-depth survey of a number of cache and data routing policies from recent ICN researches. At last, we have shown and explained in more detail how caching and data routing is achieved in NDN which is a promising design for the future Internet architecture.

ICN is a promising candidate and a hot research field that has drawn attention to the Internet research community due to its potential for addressing the current problems of the Internet. There is a high need therefore, for doing further research and quantitative studies for evaluating the potential and significant benefits brought by this new Internet architectural paradigm. In general, by modelling the in-network caching and data routing which will be based on more efficient cache decision and routing schemes, it will have more practical significance in ICN designs for the future Internet architecture.

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