Review of Name Resolution and Data Routing for Information Centric Networking

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Abstract- Information Centric Networking (ICN) a future Internet, presents a new paradigm by shifting the current network to the modern network protocols. Its goal, to improve the traditional network operations by enabling ICN packet routing and forwarding based on names. This shift will bring advantages, but at the same time, it is leading to a big challenge on routing approaches to implement ICN nodes. Routing approaches must use special techniques to publish messages to all the network nodes. Flooding approach is an easy and stateless, however, results in control overhead, depending on the network size. Moreover, designing, implementing, and evaluating routing approaches with higher capacity is really a key challenge in the overall ICN research area, because the state of ICN brings a significant cost; both in packet processing and router storage. Many approaches were proposed in the literatures over these years for the efficient control of forwarding on the network. This paper provides a classification and review of the routing mechanisms that are proposed on six ICN architectures. A summary in tabular form and a comparative study of these six architectures is also given in the paper as well as few open research challenges are highlighted.

Index Terms— Future Internet Architectures, nformation-Centric Networking, Routing, Content naming, Data routing, Name resolution.

I INTRODUCTION

The Internet has evolved and changed the way we work and live. End users of the Internet have been confronted with a bewildering range of media, services and applications of technological innovation concerning media formats, wireless networks, terminal types and capabilities. The originality of the Internet was designed to be an End-to-End (E2E) connection substrate for the delivery of the contents [1][2]. All the later enhancements developed for improving its architecture revolved about the discussion model that contains connections between equipment using the IP protocol. The existing architecture of the Internet is now rapidly evolving interconnection of many networks, representing simple carriers providing basic packet delivery services without guarantees, therefore they make their utmost effort to attempt deliver to receivers anything that senders wish to send while only using IP addresses to identify endpoint for data forwarding and unwarily considering what's being delivered [3].

In addition to that, the current Internet content delivery today suffers from heterogeneity problems because its evolution and deployment to the current Internet architecture has been triggered by the market needs rather than the coherent Internet architectural plan. Hence, these reasons have driven the shift from the current Internet architecture to a new architectural plan of the future Internet called Information Centric Networking (ICN).

Information-Centric Networking (ICN) (Data Oriented Networking, Content-Based Networking or Content Centric Networking/Named Data Networking) paradigm is an alternative for the future of the Internet which concentrates on naming data rather than named hosts (IP address) for the communication model [4]. ICN has the potential to find a solution to several problems of the current Internet architectures, including inefficient resource utilization, Distributed Denial of Service (DDoS) attacks, inadequate security [5] as well as mobility, scalability, routing protocol and economics [6]. These problems are related to the original model of the Internet in the 1960s, where the Internet traffic speed was very slow with a limited number of trusted users.

The routing protocol specifies the communication between routers, which disseminates information which enables them for selecting routes between any two nodes in a computer network. Routing algorithms decide the particular selection of route [2]. Every router has one prior knowledge only of the networks attached to it in direct connection. Routing protocol shares this piece of information first with the immediate neighbors and after that in the whole network. In this way, routers get knowledge regarding the network topology [7]. The routing approach represents the core for any ICN architecture. Therefore, the main aim of ICN routing protocol systems is for locating one or more copies of content that is distributed in the network [8]. The projects of ICN have suggested different solutions for routing such as name resolution and data routing.

ICN routers have two major roles that must be achieved when there are a request for a specific Named Data Object (NDO). The first one is to find a node (e.g. contents server) that stores a copy of the NDO, and forward the request to that node. The second is to find a path from that node back to the requester over which the NDO can be delivered. One way to do this is through name resolution, which means to get one or more lower-layer locators for the name of NDO. These locators can be used to retrieve the object. An alternative way is to directly route the request to that node based on the NDO's name. This is often referred as name-based routing. In name-based routing scheme name resolution step is often omitted [9].

Although very good survey papers exist for research on ICN can be found in [10][11][12][13], due to their broad coverage they treat ICN architectures and related research efforts either incompletely. The main goal of this survey is to focus on routing in ICN architectures and describe routing approaches of six representative ICN architectures. Furthermore, this work provides a critical analysis as well as present their concepts and drawbacks of the main unresolved research challenges on routing in ICN that require further attention by the community. Finally, highlight the main challenges related to this issue.

The rest of this article is organized as follows. Section II provides a brief description of data routing and name resolution in ICN architectures. A comparative analysis of different concepts of routing in the ICN architecture presented in Section III. Section IV outlines the main challenges that remain unresolved for researchers interested on routing in ICN, and finally a brief concludes are provided in Section V.

II CLASSIFICATION ICN ROUTING ARCHITECTURES

ICN architectures based on routing approaches can be classified into two different approaches: Name Resolution and Name-Based Routing. These two approaches are handled by the routing of the NOD packet from its location-independent identifier in ICN [10][14]. Fig 1illustrates the routing in ICN according to the approach.

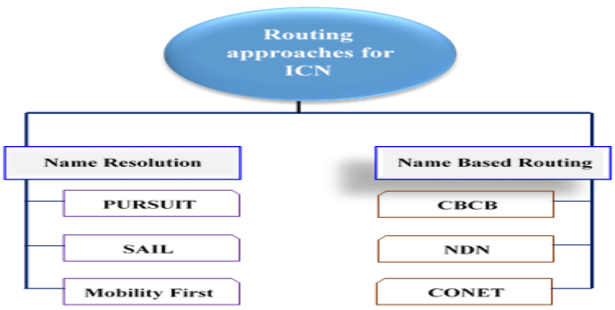

Fig 1: Routing Approaches in ICN Architectures

The name resolution process consists of two steps: the first step resolved the content name to a single or a set of locators, while in the second step, the request message is routed to one of these locators using topology based shortest path routing (e.g., ISIS, OSPF). This approach can guarantee finding NODs node. Failures in name resolution system may cause that many indices to be unreachable even though the content is there. On the other hand, the name based routing approach, forwarding the request by a direct route based on the identifier/name alone and some sort of state information is setup along the way so that requester. NDO request forwarded by Content Routers (CR), CR locally decidesthat is the next hop of the NDO request will be based on NDO name. In this approach, there is no guarantee to find NODs. However, this approach provides a high expectation of discovering the content, which is usually proportional to the number of visits nodes.

1- ICN Routing Using Name Resolution Approach

This section introduces and discusses some representative information-centric architectures, alongside their routing management by using name resolution approach include PURSUIT [13][15], Scalable and Adaptive Internet Solutions (SAIL) [13][16], and Mobilityfirst [17].

- **PURSUIT**

PURSUIT architecture consists rendezvous function, topology management function and forwarding function, each function separate from the other functions. As shows in Fig 2, when the function of rendezvous matches a subscription to a publication, it directs the function of topology management to create a route from the publisher to the subscriber. This route is finally used by the forwarding function to perform the actual transfer of data. Name resolution is handled by the rendezvous function, which is done by a collection of Rendezvous Nodes (RNs), the Rendezvous Network (RENE), implemented as a hierarchical DHT. If the publisher want to publish some information, he needs to export a publish message for its local RN to advertise an information object.

The NR will then route it to the other RN in corresponding scope ID. On the other hand, the subscriber need to send subscribe message for this information object to its local RN, the subscribe message will routing by the DHT to the exact RN. Topology Manager (TM) node will be directed by NR to create a route to connect the publisher with the subscriber to deliver the data. The TM sends that route by a START PUBLISH message to the publisher to use it to send the information object by a set of Forwarding Nodes (FNs). The TM nodes in PURSUIT jointly implement the topology management function by executing a distributed routing protocol to discover the network topology.

- **SAIL**

The architecture and design of the future Internet (4WARD) project and its continuation Scalable and Adaptive Internet Solutions (SAIL) are investigating designs for the future Internet and ways to facilitate a smooth transition from the current Internet. Name resolution and data routing in SAIL can be coupled or decoupled, and even hybrid operation is possible. In case of the decoupled, NRS is used to map object names to locators that can be used to reach the corresponding information object, such as IP addresses. The NRS is some form of DHT, either a multilevel DHT or a hierarchical SkipNet. In the multilevel DHT solution, each authority maintains its own local NRS to handle the resolution of the part ***L***, while a global NRS handles the resolution of the part ***A***.

A publisher makes an information object available by forwarding a PUBLISH command message with its locator to the local NRS, which stores the ***L*** to locator mapping. The local NRS aggregates all the parts ***L*** for the same authority ***A*** into a Bloom filter, and sends a PUBLISH message to the global NRS. The global NRS stores the mapping between the authority ***A*** plus the Bloom filter and the local NRS, replacing any previous such mapping. When the subscriber Interest in any information object, it can send a GET message toward its local NRS which consults the global NRS in order to return a locator for the object.

Finally, the subscriber sends a GET message to the publisher, using the returned locator, and the publisher responds with the information object in a Data packet in the coupled case, a routing protocol is used to advertise object names and populate the routing tables of Content Routers (CRs), as in NDN. A subscriber sends a GET message to its local CR, which propagates it hop-by-hop towards the publisher or a cache.

- **Mobility First**

All connections in Mobility First architecture start with GUIDs that may be translated to network addresses in one/ more step(s) by using a Global Name Resolution Service (GNRS). When the publishers wants to make the contents available, they asks for the naming service for the GUID in order to register it with its network addresses in the GNRS. Afterwards, GUIDs are mapped through hashing into a number of GNRS server addresses that may be contacted through the use of regular routing. Whenever subscribers are asked to receive data, it is sent a GET packet that includes the GUID from the requested object, together with its own GUID of that response to its intermediate node. It is only able to route based on actual network addresses e.g. IP addresses). Therefore, it requests the GNRS to obtain a mapping between destinations GUID one/more network address(s).

The GNRS reply to the number of network addresses (maybe optionally, it will also send the source route, an incomplete source route or intermediate network addresses). Intermediate nodes choose one of these network addresses, adding it GET packet, then it forwards using routing tables inside the intermediate nodes. The GET packet consists of both the destination GUID and also the destination network address. All intermediate nodes on the route can be checked at the GNRS to get an updated list of network addresses towards the destination GUID. In case there is mobility the GET packet can't be delivered to the publishers. They send its answer to the subscribers' GUID, using the same process. The resulting name resolution processes and data routing are hybrid between IP routing and name-based routing.

The routing performs dependent of network addresses, with the GNRS only used for mapping GUIDs to network addresses. To low dynamic services, MobilityFirst router can transform every GUID into a network address once, as like DNS, and function according to network addresses only require ignoring the GUID. Getting additional dynamic services, GUID may be translated many times; the first router asks the GNRS for the network addresses bound to certain GUID and makes forwarding decisions according to the response from the GNRS.

2- ICN Routing Using Name Based Routing Approach

This section introduces and discusses some representative information-centric architectures, alongside their routing management. There are many architectures under this approach include Combined Broadcast and Content-Based (CBCB) [18], Named Data Networking (NDN) [19][20], Content Centric Inter-Networking (CONET) [21].

- **CBCB**

Information regarding routing table is given by the protocol Combined Broadcast and Combined Based (CBCB). This is characterized by a layer based on content that is deployed on a layer of broadcast. This layer of broadcast treats every message as broadcast messages, whereas the layer based on contents dynamically prunes paths of distribution thereby shaping the way in which the messages are retransmitted. The layer of broadcast ensures that every message flow from the sending node to the receiver node through the most possible short path and loop free path. This layer can get implemented using the loop free topology mechanisms such as the per source trees, spanning trees and various other diffusion mechanisms.

Routing information gets propagated by CBCB in two ways; one is by sending Receiver Advertisements (RA) and the second by Sender Requests (SR). RA is periodically issued by the nodes and whenever they change, the change happens to their predicates also. The RA carries new predicates and propagates information to every potential content and provider nodes, thereby creating the needed routing state for proper message distribution towards the nodes that receives. When an RA gets received in a specific interface, content router checks on whether the address that is advertised is being covered by the interface predicate that receives. If this is true, RA is sends to flow by RA as well as the announced filter that belongs to RA emitter-centered tree. The last stage involves updating routing table by adding the filters logically in the RA to the receiving interface's predicate.

SR's are used by routers for gathering information regarding the existing receivers, thereby allowing them for updating their routing tables. On receiving the SR, nodes responds with an Updated Reply (UR). UR contains every predicate of its interface. SR reception implies its immediate forwarding thought every available interfaces inside the resource oriented tree. Apart from this, nodes just respond only with an SR to the node of origin after they receive UR from every interface that belongs to the source oriented tree or after one expired timer.

- **NDN**

NDN architecture used two types of packets which are Interest packet and Data packet. Consumers are sending out

Interest packet to request data object that arrives in Data packet form, the two types of packet carrying the name of the requested/transferred data object. Every NDN node includes three databases: Content Store(CS), Forwarding Information Base(FIB), and Pending Interest Table(PIT). The FIB is equivalent to the routing table in the conventional IP networks that keep the IP addresses of the directly connected nodes and their related interface to forward the coming packets accordingly. The NDN FIB differs from the one of the IP network is that the IP address prefix is changed with "content name" prefix while in NDN the interface is changed with "face (s)".

CS is the content cache. As mentioned before, in NDN, it is not important to know the location of content. It may be initially located at a single server (i. e., contentpublisher), but later and during the transmission into thenetwork, it keeps being stored in the cache of each node passed by. After being cached, any further request for thesame content Interest will be forwarded from the nearest nodethat already cached it as a reply to the end user or endpointrequest.

PIT is cache table for Interest packet. The node sends the Interest packet that requests a content by forwarding to connect node. It designs to keep tracks of propagated Interest in order that they came back to Data by following these tracks for the consumers. Furthermore, PIT is preventing multiple incoming request packets to generate multiple packet forwarding. If the same Interest from many interfaces are received, only the first one pushed to PIT table, the other will be only added the interface entry number until the router received the Data [20][22].

The lookup and forwarding process for NDN packets is less complicated than in IP. On receiving the Interest packet; first, NDN router at lookup its CS for one entry associated with the requested content. If one such entry exists, it sends the appropriate Data packet back. If not, the router checks for any pending Interest in this contents PIT. As such, the receiving part of the Interest packet is added to the interface list for sending content in PIT and the Interest packet gets discarded. At PIT if there is no entry, router forwards packet as per the rules of its FIB thereby creating PIT record for the source interface.

In FIB, if there is no entry for a particular content, it worth is neglected since there is no forwarding interface is valid. Such kind of diffused routing intends to gradually find one node that can respond and send Data packet in the backward path signaled by PIT entries in every hop. Only one valid PIT entry result in Data packet forwarding with every other scenario resulting in packet disposal. Sources of Data are needed in order to register their intention to provide content via a register primitive. When NDN router is received Data packet, NDN router forwards Data packet over all the requesting faces for matching PIT entry and remove this entry from PIT. Subsequently, CS will be caching based on certain policy [22].

- **CONET**

CONET architecture proposes a new layer of CONET, which gives consumers able to access on the network names resources, instead of remote hosts. The CONET architecture intends to interconnect various CONET SubSystem (CSS) that can be of many forms: nodes that are straight away linked by a point to point link (such as PPP); or a layer-2/ layer-3 network (such as Ethernet); or IPv4/IPv6 networks; or an UDP/IP overlay link. This fundamental idea makes CONET architecture scalability for deploying over the point to point links, whole Internet or the IP Autonomous System.

CONET architecture is divided the network into two layers, which are CONET and under-CONET layers. Whereas CONET layer is handled contents as a first class citizen, while under-CONET layer simply links CSSs or nodes. CONET SubSystem deploys by number of CONET nodes and make use of an under-CONET mechanism for allowing data to flow among them. All nodes have a CSS address that are consistent with the traversed under the CONET technology (e.g. IPv4 or Ethernet MAC addresses). CONET nodes gain wanted content by the issuance of requests known interest CONET Information Unit (CIU), receiving named data CIU in response.

These data CIU carries chunks of contents and it can be forwards to the consumer, be caches for use in future as well. CONET nodes get their name after their CSS function; Accordingly End Node (EN) requests content that issues interest CIU, Serving Node (SN) store, provide and advertise content, Border Node (BN) linking various CSSs, forwarding data CIU and interests among them and acts as cache for data CIU, Internal Nodes (IN), which are optional and acts within a CSS for providing in-network caches and finally the optional name System Nodes, that are used in CSS name based routing mechanism. EN requests data via issuingan interest CIU for a specific NID, that is encapsulated in one carrier packet and forwarded as per CONET based routing.

This routing process singles out the CSS address of the node coming to it toward the best node that holds the requested data and suitable for it, thereby allowing the nodes to forwarding it properly. CONET nodes don't store the state of network information, from the other side it is append in the set of CSS addresses and EN CSS of the traversed interfaces in the packet that carries a path information control field, enabling data for flowing towards EN based on source routing.

III COMPARISON OF ICN ARCHITECTUR BASED ON ROUTING APPROACHES

There are many information-centric architectures that are put forward in the past few years. In this survey, analyzing, comparing, and contrasting the information-centric architectures listed in Table 1. The selected research architectures provide a reasonable coverage of the diverse research efforts toward routing request and response in ICN.

Table 1: Comparison of ICN Architecture

Architecture	Year	Original	Strategy	Main Points	Drawback
PURSUIT	Sep 2010 -Sep 2013	http://www.fp7-pursuit.eu/ (Europe)	Name resolution	DHT-based rendezvous network. Compares publications to subscriptions and then matching them. Routing Basic structural consists of four components; Rendezvous, Routing, Topology, and Forwarding. Supports two types of messages: SUBSCRIBER and PUBLISH. Supports DHT of data structure.	Scalability problems. Many false positives because long path. Higher control overhead depending on the network size. Single point of failure problem Inter-domain paths problem. Requires a large storage to store NDO mapping.
SAIL	Sep 2010 -Feb 2013	http://www.sail-project.eu (Europe)	Name resolution	Name resolution based on DHT returns content locator. Relies on a two level (local and global) DHT solution. It has two types of data structure tables: MDHT and Skip Net. Supports three types of messages: GET, DATA , PUBLISH.	Increasing overhead since routes grow larger. Single point of failure problem. Additional resolution steps.
MobilityFirst	2011	http://mobilityfirst.winlab.rutgers.ed (Europe)	Name resolution	Hash based global name resolution service which is mapping names to network addresses. Used repeatedly for late binding of addresses. Distributes the name resolution service by using a hashing scheme. Supports GET message and Data packet. Supports Hash based global name table.	Single point of failure problem. Slow to update the name resolutionsystems. Requires a large storage tostore NDO mapping.
CBCB	2004	http://www.inf.usi.ch/carzaniga/cbn/routing/index.html (Universitu of Colorado)	Name based routing	Using two routing protocols: broadcast routing and content based routing. Support two type of packets: Interest announced and Receiver advertisement. Support one type of data structure namely Content based forwarding table. Discover alternate routing paths due to broadcasting.	Required to broadcast for publish and subscribe messages on a large number of network domains. Routing tables want to handle about 108 routes, which is four orders of size larger than the biggest BGP routing table size. No guarantee of content discovery.
NDN	Sep 2010 - Aug 2013	http://www.named-data.net/ (United States of America)	Name based routing	Looking hop by hop for object. Supports two kinds of packets: Content and Interests. Supports three types of data structure tables: CS, PIT and FIB. Storing content closer to the network edge. Discourages the formation of loops.	Link failures. Prefix black holing. PIT overflow. Congestion because of the PIT table size. Adding more complexity to the process of route aggregation. Not guarantee the discovery of content. Content routers in NDN face serious scalability limitations at the inter-domain level.
CONET	2013		Name based routing	Flexible architecture. Using the name-based routing mechanism to update CONET. Have the ability to support the content replication and caching effectively. It also supports integration approach. Contains the tuple (network-identifier, mask, next-hop, and output-interface).	Having scalability issue due to the CONET routing-by-name mechanisms. Adding more complexity for implementing.

IV CHALLENGES OF ICN ROUTING

Even though ICN is quite a new topic for researchers, many solutions and propositions covering a wide range of various issues under this topic has been done so far. Anyhow, there are yet many challenges and solutions to be developed and deployment aspects that call for in-depth investigation. Routing is one of the main important research field. The section here, highlights some issues in routing mechanisms which is identifying a list of desirable properties for it.

- ***Ensure delivery***: ICN should be able to serve a very large number of entities. In Internet, the number of content objects is huge that lead the flow, congestion and error control functions can happen. Therefore, the routing mechanism should provide guarantees on delivery of any existing content in an efficient way with reducing delivery latency as well as ensure delivery of the message to interested nodes only.
- ***Discover the nearest copy***: ICN architectures must employ routing mechanisms for disseminating messages to every nodes. Flooding is a basic as well as a simple approach that can do this, but may result in increased in inter-domain traffic that will lead to high control overhead which is depended on the network size. In order that, ICN routers must have ability to route a content request to the nearest copy. This characteristic should ensure the inter-domain traffic reduction.
- ***Scalability***: ICN should be able to serve a very large number of entities. In internet, the number of content objects is huge and rapidly growing. According to Ghodsi *at el*, in [23], every ICN architectures need to be prepared for handling a minimum of 10^{12} objects, depending on the present size of the web and taking into account of an extremely conservative estimate. Scalability of ICN routing mechanisms is a main and more challenging for providing due to tow main characteristics for these types of network architectures which are the difficulty to aggregate names and the expected size of the routing table.
- ***Routing tables overflow***: ICN approaches routing tables are very dynamic. Thus, for all incoming request packets and matching data packet, hence a special process must be happening in these tables. These processes should to

be performed faster to avoid these tables may be overflowed which cause the delay and packet loss for these packets. Because ICN approaches routing tables receive and remove the packets exponentially. It is not easy to predict the tables are full. Due to the high speed packet arrive rate to it. If the table is overflowing, consumers' requests will be discarded from the routers, and based on this, consumers will experience an increasing retransmitting rate that will lead to a complete collapse of the whole network.

- ***Single point of failure***: all architectures that are used name resolution approach may be suffered the single point of failure, which can result in many of the NDO published and registered in that NRS to be unavailable. These occur when the many nodes in the network will by an available. Thus may affect the QoS of the network for many applications (such as media streaming, interactive real time applications, file download). As a result single point of failure is undesirable in any architectures with a goal of high availability or reliability.
- ***Security and filtering***: limited researches and studies have been done about the data security in ICN, especially in term of routing mechanisms. One of these challenges, malicious users can craft artificial requests with the purpose of filling the available tables on ICN routers. Thus, implementing a DDoS attack. This type of attack could possibly be implemented by distributing generating requests packets which include a valid destination prefix, but non existing resource names, in order that the routers correctly forward requests and keep a new entries inside the table. Nonetheless, replies never come back. Another issue of security in ICN architectures is the vulnerability of ICN to the cache pollution attacks. This type of attack includes sending random interests of content as a way to modify content's popularity. Thereby forcing ICN routers, for storing unpopular contents in their catches.

V CONCLUSION

This paper has attempted to provide a survey of six projects of ICN architectural design for the future Internet concerning data routing. The paper has mainly focused on the two data routing approaches, which are name resolution and name based routing. They are given in depth survey how each one of the six ICN architecture routing its data depending on the mentioned data routing approaches. Hence, a comparison between these architect's routing approaches by identifying the originality, strategy, description and drawback of each one is presented. In conclusion, specified data routing approaches will lead to be more efficient routing schemes, having more practical significance in ICN designs for the future Internet architecture. So our future work will be extended to cover more ICN architectures deeply.deeply.

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