Name-Based Routing for Information Centric Future Internet Architectures

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Abstract— **Information Centric Architecture has been proposed to overcome weaknesses of current Internet architecture. A number of research projects are exploring possible architectures for Future Internet (FI) based on Information Centric paradigm. There are number of challenges which needs to be addressed like Quality of Service provisioning, caching, scalability, trust management, security etc. Proposing an efficient and scalable routing solution for Information Centric Architecture is also a challenging research problem. The aim of this paper is to develop an understanding of the Information Centric Architectures and the problem of routing through a comparative analysis of existing solutions. We first outline the design challenges being faced by current Internet architecture which have motivated the need for new architecture for Internet followed by an overview of major Information Centric Architectures and name-based routing techniques proposed for them. We have classified the routing techniques for Information Centric Architectures into two main approaches i.e. distributed and centralized routing which either use DHT based or conventional IP like longest prefix matching solutions. Finally the paper outlines issues which need to be considered for finding the best solution for name-based routing.**

Keywords— **Future Internet, Name Based Routing, Information Centric Networks, Distributed Approaches, Centralized Approaches**

I. Introduction

The Internet architecture was developed in late 1960s [1]. It was started as a research project but it has become integral part of people's lives. Today, there are an estimated 2 billion users of the Internet worldwide and this number continues to grow [2]. However, its architecture could not keep pace with the phenomenal growth of users and technology. It is facing a number of challenges like scalability, support for mobile computing, Quality of Service etc. [3]. Most of the traffic on the Internet is caused by users retrieving contents and approximately ninety five percent of traffic being carried over the Internet is related to contents with an estimated annual traffic growth of thirty two percent from 2010 to 2015 [4]. Because of this design and usage inconsistency, the Internet architecture is also subject to a number of problems e.g. in-efficient mapping, poor resource utilization, complex usage and security. The problems which have motivated researchers to work on new architectures for Future Internet are briefly discussed below.

A. In-Efficient Mapping

Currently, the Internet uses IP addresses for routing packets between source and destination. Search engines like Google do the mapping between keywords and content URLs. The Domain Name System (DNS) is used for mapping a content URL to an IP address. This IP address is then used for routing packets. The mapping of a content URL to an IP address introduces delay and adversely effects performance when name cannot be resolved locally. In the last few years, DNS has also been one of the weakest points of the Internet as it has been exploited by hackers for launching DNS spoofing, DNS ID hacking and DNS cache poisoning attacks [5].

B. Security

Security issues of the Internet are well known. Security has been introduced into the current Internet architecture as an add-on module. Current security is based on the principle of securing links with encryption and trusting servers by using authentication. This has exposed the current Internet architecture to large number of security threats like virus, Trojans, phishing, DDOS attacks etc [6].

C. Mobility

Mobile nodes keep on changing their positions. In the current Internet architecture, a node is identified by its IP address. When a node changes its position, its IP address changes too, this makes reaching this node difficult. This is a well known problem and lot of research is being done to solve it, like Mobile IP, Internet Indirection Infrastructure etc. [7].

D. Quality of Service

The Quality of Service (QoS) refers to aspects related to ensuring reservation of resources like bandwidth, delay, throughput etc. QoS is especially important for new applications like VOIP, video on demand etc. The stateless nature of IP makes it very difficult to guarantee Quality of

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Service. Lot of research has been done to support prioritized traffic but this problem still remains unsolved [8].

E. Poor Resource Utilization

Currently, contents processed by routers are not being cached and because of that packets with the same contents are transferred by routers again and again [9]. This results in bandwidth waste, increased latency and congestion in networks.

F. Complex Network Configuration

Technologies like IP Version 6, NAT, CIDR, VPN, IPSec etc have been introduced to overcome security and scalability problems of the current Internet. They require complex manual configurations. Therefore there is a need to simplify network usage and reduce network set-up time [10].

In the last two decades a number of initiatives like caching, Content Delivery Networks (CDN), Peer-to-Peer (P2P) systems etc have been developed to improve user's access to contents. These solutions have been implemented as an overlay over the current Internet and suffer from problems such as the use of DNS for locating CDN servers, churn, node visibility, security, scalability etc. A new Information Centric Architectural design approach for Future Internet has been suggested in [11]. In the new architecture, data will be disseminated on the basis of content names instead of location. Contents will not be stored at a particular place and will be served by any device that hears a data request and possesses the requested data, thereby eliminating the need for mapping between content and location.

In this paper, we will explore the routing techniques suggested for Information Centric Architectures. Our aim is to review current routing protocols with an aim of pointing out issues that need improvement and further research. Section II gives a brief introduction of Information Centric Architecture. Section III explains name-based routing and concisely describes distributed and centralized routing algorithms. Section IV highlights issues which need to be considered for finding the optimum name-based routing solution and compares main routing approaches. Section V concludes the paper.

II. Information Centric Architectures

A new architecture for Future Internet has been proposed to address current shortcomings of the Internet and to provide better support for content distribution. Data-Oriented, Content Centric, Information-Centric, Content-Based, Named-Data etc are some of the terminologies used interchangeably for the new architecture. We will use the term Information Centric Networking (ICN) for this architecture. The essence of the new architecture lies in decoupling of information from location. It will support data caching at all nodes, for all contents and protocols. Information sources will advertise the availability of contents. The network will fulfill the request of user from a closely located copy, if available. It also adopts a content-oriented security model in which content will be signed by its original provider. Currently, a number of research projects in the USA and EU are exploring new ICN architectures [12]. These projects follow different ideas but share the same objectives and assumptions. The main projects on ICN are illustrated below.

A. TRIAD (Translating Relaying Internet Architecture integrating Active Directories)

The idea of using content name instead of location was first given by TRIAD project. They suggested the use of content routers with a name-based routing table that stores next hop routers or servers for each name. The name-based routing table is consulted for forwarding request towards content servers. Content servers use conventional IP for actual transfer of contents [13].

B. ROFL (Routing on Flat Labels)

ROFL was the first project to suggest a clean slate architecture for the Internet, separating content name and location. It proposed the use of Distributed Hash Tables and source routing for mapping content names to location [14].

C. DONA (Data Oriented Network Architecture)

DONA improved the TRIAD design by replacing content routers based name resolution with hierarchical Resolution Handlers based name resolution. Resolution Handlers combined the functions of caching and name resolution. It uses conventional IP for actual transfer of contents [15].

D. NDN (Name Data Networking)

The NDN (Name Data Networking) project suggested a new architecture for the Future Internet in which nodes will broadcast their request and the nearest node with a copy would respond. Each node will maintain a name-based Forwarding Information Base, Pending Interest Table and Content Store data structures to support name based routing. Longest prefix match will be applied on content names [16].

E. PSIRP (Publish/Subscribe Internet Routing Paradigm)

This project aimed to develop a new architecture based on the Publish-Subscribe model and Distributed Hash Tables [17]. The PSIRP architecture consists of publisher, subscriber and Rendezvous nodes. In the PSIRP architecture, information is published into the network by a publisher. Rendezvous nodes map subscription request from users to contents. A follow up project, PURSUIT, is further exploring and expanding work of the PSIRP project in several directions including wireless and optical transmission [18].

F. NetInf (Network of Information)

NetInf is based on the concept of Information Objects. Information objects are used to represent contents and are identified using a globally unique name. NetInf uses Name Resolution System (NRS) for matching content names to locations. NetInf is part of EU projects 4WARD and SAIL (Scalable and Adaptive Internet soLutions) [19].

III. Name Based Routing

Routing is the process of finding a path in a network. This process can be optimized by means of routing protocols which maintain mutually consistent information in every router of the network. Routing is categorized in many ways. Routing protocols in conventional wired networks generally use distance vector / path vector routing algorithms or link state routing algorithms. In both cases, all routers periodically broadcast some information, called routing advertisements, to their neighbours for maintaining consistent information.

Name-based routing for ICN is still an open research problem [20]. The purpose of name-based routing is to route packets on the basis of content names instead of IP addresses. The prior work on name-based routing can be classified into distributed and centralized approaches. These approaches can be further sub-divided into DHT or prefix-matching based, depending upon the method used for matching content name. The classification of name based routing approaches is given in Table 1.

In the centralized approach, global network state is maintained at a central controller. The goal is to push complexity to the central controller and make routers architecture simple. The routers consult the central controller for routing packets [21]. However, a central controller can become a single point of failure and can cause traffic bottlenecks and congestion in the network. It also suffers from inbuilt lag as a central controller has to be consulted for making routing decisions. In the distributed approach, nodes make decisions locally, without communicating with a central entity. Each node gathers all needed information, and bases its routing decisions on this information. However, each node will be required to maintain large state information for content based routing due to shifting of address space from one billion IPs to at least one trillion content names [22].

TABLE 1. CLASSIFICATION OF ROUTING PROTOCOLS

Distributed Approaches		Centralized Approaches	
Prefix Matching Based	**DHT Based**	**Prefix Matching Based**	**DHT Based**
INRP (TRIAD)	ROFL	COMET	PSIRP
DONA		CONET	NetInf
NDN		PBR (Potential Based Routing)	
Magnet			
SCAN (Scalable Content Routing)			

A. Distributed Approaches

1) Internet Name Resolution Protocol (TRIAD)

In TRIAD, a user request is mapped to a nearby content server without using Domain Name Server (DNS) [23]. The Internet Name Resolution Protocol (INRP) is used for forwarding requests on the basis of names and Name Based Routing Protocol (NBRP) is used for sharing name information between content routers. Content servers advertise their names to the content routers. Each content router maintains a set of name-to-next-hop mappings. NBRP distributes name reach-ability information among content routers in a manner similar to Border Gateway Protocol. A request for content is sent to local content router instead of a DNS server. The content router directs the packet along the path to the desired destination by including a source route. The destination then establishes a TCP/IP connection with the source

The use of IP for the actual transfer of contents makes it susceptible to the existing limitations of IP networking. It also suffers from scalability problems as all content routers in the network maintain name-to-next-hop mapping and share this information with each other using NBRP. This can work within a domain but will not scale well at global level due to large number of content names [24].

2) ROFL Routing Proposal

The ROFL routing proposal is based on a Distributed Hash Table (DHT) but it is not implemented as an overlay over the IP layer. All routers are assigned a unique ID along a circular namespace and are connected in a virtual overlay ring similar to Chord DHT. Messages from one node to the other are routed using the notion of successor and predecessor. It uses source routing and a source route is updated if intermediate routers are aware of a more efficient route. For inter-domain routing, a global routing ring is constructed by merging AS level routing rings [25].

In the ROFL routing proposal, router identifiers are chosen randomly. Information about a router's network location or its proximity to other routers cannot be deduced from its random identifier [26]. Randomness in node identifiers can lead to high end-to-end routing latency as it is possible that the physical route taken can contains many more hops than the shortest route. It also cannot efficiently handle routing of logically related content names, as the hash function destroys the locality awareness of the content name. It can also suffer from name collision if the labels used for identification of objects are not long.

3) DONA Routing Proposal

DONA uses the route-by-name paradigm for name resolution and routing. It uses a flat self-certifying label for identifying contents. It uses Resolution Handlers (RH) for resolving names to locations. RHs are arranged in a hierarchical tree. Content servers register their contents with a RH. Each RH maintains a forwarding table which provides information for the next hop for all available contents in the network. The RH share this information with their peers and parents in resolution system. A client request for information is handled by an RH. The RH either sends the client request to the next hop or to its parent if it cannot be resolved. Once contents have been located, then standard IP routing is used for transferring contents.

DONA is based on the underlying IP infrastructure which makes it susceptible to the existing limitations of IP networking. The fact that DONA uses non-aggregatable flat names will cause scalability problem at global level.

4) NDN Routing Proposal

The NDN forwarding model is similar to the IP router forwarding model but it applies longest prefix match on content names instead of IP address. It can therefore be used for implementing routing schemes that work with IP. The NDN project is working on extending the implementations of the OSPF (Intra-Domain) and BGP (Inter-Domain) routing protocols to support name prefixes for incremental deployment of NDN [27]. Eventually, the NDN project plans to develop a pure name based routing protocol for NDN [28].

NDN will suffer from scalability problems due to the Forwarding Information Base table's inability to store large numbers of content names [29] and due to unresolved content request entries, for un-popular contents, in Pending Interest table.

5) Magnet Routing Proposal

The Magnet routing proposal improves the content matching and content dissemination process by calculating a filtering gain and dissemination potential. Magnet routing is implemented using an overlay of mediation routers on top of the current Internet [30]. Each mediation router maintains a content dispatching table (CDT) which is similar to an IP router's FIB for dissemination and matching of requests.

The Magnet routing proposal relies on real time calculation of filtering gain and storage potential. Real time data processing is an extremely challenging problem due to dynamic and continuously changing values. Real time analysis is expensive in terms of computational power also. It requires development of efficient real time techniques and algorithms, as normal algorithms will not work at high frequency sampling rates.

6) Scalable Content Routing (SCAN) Proposal

Scalable Content Routing uses IP and content routing. SCAN content routers maintain Content Routing Tables (CRT) as well as the IP routing tables. When a request is received by a content router, then it first performs traditional IP routing. After performing the IP routing, it decides about initiating content routing (also called scanning) based on the router's load. Scanning is done to find out cached copies of a requested content in the close vicinity for fast content delivery.

SCAN is based on the underlying IP infrastructure which means that it will be susceptible to the existing limitations of IP. Generation of multiple scanning requests for required content by all content routers in the path to the destination server will have adverse effects on performance. Nodes waiting for contents will receive replies from multiple content routers and the original content server holding desired contents, which will result in wastage of bandwidth, increased latency and congestion in network [31].

B. Centralized Approaches

1) PSIRP Routing Proposal

PSIRP uses a two-phase resolve and retrieve routing model [32]. A subscriber sends a request to the Home Rendezvous Network (HRN). The HRN is responsible for finding suitable data transit and delivery paths in the network and denoting them by forwarding identifiers, which are implemented using a 256 bit Bloom filter [33]. If information is not available in the Local Rendezvous Network then the message is passed to a Rendezvous Interconnect (RI) for resolution. The RI subsystem is implemented using a DHT.

PSIRP suffers from the resource discovery overheads due to two-phase resolution. PSIRP uses RI, a global DHT network, for the requests which cannot be resolved locally. A global DHT approach requires total cooperation and trust among operators that run global dictionary nodes. In the global environment, there will be an issue of control due to the non co-operative nature of Autonomous Systems [34].

2) NetInf Routing Proposal

NetInf uses Name Resolution System (NRS) nodes for matching a content name with a location [35]. It supports name resolution based and name based routing. A Resolution Exchange subsystem and a Multilevel DHT (MDHT) are used for resolving information which is not available in a local NRS node [36]. The MDHT is used to implement recursive lookups. Name-based routing uses NRS and Late Locator Construction (LLC) for routing [37].

NetInf will suffer from the problems mentioned above for PSIRP and ROFL due to use of MDHT for name resolution. NetInf will also suffer from delays due to the two steps resolution process used for name based and name resolution based routing.

3) COMET Routing Proposal

COMET aims to provide a Quality of Service aware content distribution. It introduces a content mediation plane which consists of mediation routers. Mediation routers combine content resolution and access. A request for contents is handled by Awareness, Content Resolution and Content Delivery sub-operations. The awareness sub-operation is performed all the times to gather the current information about routing, server and network status. The content Resolution sub-operation consists of name resolution, path discovery and decision process to select the best server/path. The content delivery sub-operation is responsible for the delivery of the contents to the requestor [38].

COMET is likely to suffer from performance issues as making decisions on the basis of real time calculation of server and network status is an NP hard problem. It also requires a lot of management, configuration and coordination at the content mediation plane.

4) CONET Routing Proposal

CONET routing uses a two phase resolve and retrieve routing model if requests cannot be met by end nodes. End nodes maintain a limited forwarding table. If required information is not available in an end node, then the request is forwarded to NRS (Name Routing System) nodes which maintain a full routing table. Nodes forming part of NRS participate in content routing process using an approach proposed by DONA [39].

Limited resolution capabilities of end nodes will adversely affect performance. It will cause a content reach-ability problem as all the contents cannot be located. It will suffer from the resource discovery overheads due to two phase resolution.

5) Potential Based Routing Proposal

The Potential based architecture consist of Cache Aware Target idenTication (CATT) Nodes. It uses flat names for identifying contents. Each CATT Node is associated with a scalar value called potential field which is calculated on the basis of outgoing links, distance, traffic load etc. A request for contents is sent to a local CATT Node. If the local CATT Node does not have the requested contents then it forwards the request to one of its neighbouring CATT nodes. A request is forwarded in the direction which minimizes the potential value [40].

Guaranteeing an optimal operation in PBR is difficult due to the real time calculation of the potential. Environmental changes e.g. change of traffic load on a node etc. will directly affect routing convergence time. Use of flat names will cause scalability problem at a global level.

IV. COMPARISON OF MAIN APPROACHES

Some of the important issues which need to be considered for finding an optimum name based routing solution are discussed below:

A. Naming

Flat and hierarchical names are being used by ICN approaches for identification of contents. In a hierarchal naming scheme, name consists of multiple parts which follow a logical structure. The Internet uses hierarchal names to facilitate route aggregation. In a flat naming scheme, names do not have any structure. The two approaches have been compared on basis of scalability, backward compatibility, self-certifiability, and usability. Hierarchal names are more scalable, backward compatible and user-friendly. The major advantage offered by flat name is simplicity. There is a need to do further research to decide which naming scheme or combination of two should be adopted for use with ICN.

B. Name Resolution

Name resolution is the process of mapping content names to location. The two main name resolution systems being used by ICN approaches are one-step and two-step resolution systems. In two-step resolution systems, an external entity is queried for mapping content name to location. One-step or integrated resolution systems make decisions locally without consulting an external entity. It is the simpler approach but needs more processing and memory space. There is a need to carry out an in-depth analysis of both schemes for selection of an appropriate name resolution mechanism for ICN.

C. Caching

Caching is the process of storing copies of contents for subsequent satisfaction of requests. Caching reduces response time and data traffic, as request can be fulfilled locally. Caching can be classified as local and network based caching. In ICN, each node maintains its own cache whereas it is possible to use network based caching also i.e. using a single shared network cache. The performance of a caching system depends on the cache size, and the cache replacement and storage policies. The important research questions which need to be further investigated are:

- Should a local cache, a network cache or a combination of both schemes be adopted?
- Which contents should be cached and for how long?
- How to ensure that cached contents are up-to-date?

D. Scalability

In conventional TCP/IP networks, each router maintains state information for reaching different networks. However, each router in an ICN is required to store accessibility information for reaching millions of contents. ICN routers are also required to store copies of contents which will pass through them. This will require huge storage space and processing of millions of contents at each router. Shifting from one billion IPs to one trillion content names will create a scalability problem. The scalability issue can adversely affect performance, therefore there is a need to devise a scalable routing solution keeping in view the latest processor and memory available for the ICN routers.

E. Baseline Scenarios for Comparison

The comparison of major ICN approaches is given in a Table 2.

TABLE 2. COMPARISION OF ROUTING APPROACHES

	Naming	Name Resolution	Inter Domain	Scalability	Implementation
TRIAD	Hierarchal	One Step	Augmented BGP Based	Combines Name Suffix into Routing Aggregate	-
DONA	Flat	Two Step using RH	Hierarchal RH Based	RH keeps data state below or equal in AS	-
ROFL	Flat	One Step	Hierarchal DHT	Nodes may have to store Information for millions of nodes	-
NDN	Hierarchal	One Step	BGP Based	Difficult to achieve due to large number of entries in routing table	CCNx
PSIRP	Flat	Two Step using NRS	Global DHT Network	Nodes are stateless	Black Hawk
NetInf	Flat	Two Step using NRS	Multilevel DHT Based	Nodes are stateless	NetInf
COMET	Flat	One Step	Mediation Router Based	Difficult to achieve	-
CONET	Hierarchal	Two Step using NRS	Border Node Based	Proposed probabilistic caching to solve scalability problem	Lookup & Cache
Magnet	Flat	One Step	Mediation Routers Base	Filtering scheme ensures scalability	-
SCAN	Hierarchal	One Step	C-Routers Based	Bloom Filter is used to compress contents	-
PBR	Flat	One Step	CATT Node Based	Selective caching	-

The comparison shows that different ICN approaches use different naming, name resolution etc techniques. These solutions have not yet been compared with each other. It is impossible to carry out a meaningful comparison and performance evaluation of these approaches without defining a standard experimental setup and baseline scenarios. Therefore baseline scenarios for comparison of different ICN approaches need to be defined immediately.

V. CONCLUSION

In this paper, we have presented a survey of ICN name based routing approaches. We have discussed the problems of the current Internet which have motivated research for a new architecture. Main ICN approaches and main routing proposals suggested so far have been briefly described and compared. Naming, name resolution, caching, scalability and the need for baseline scenarios for a comparison of different ICN approaches have been identified as issues which need immediate resolution. Proposing an efficient and scalable routing solution for Information Centric Architectures still remains a challenging research problem.

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