Components of Named Data Networking

Anjali
Department of Computer Science and Applications,
Panjab University, Chandigarh 160014, India

Abstract—This paper introduces Named Data Networking (NDN) a.k.a Content Centric Networking (CCN) or Information Centric Networking (ICN) which is a new architecture for transferring information on Internet. This new paradigm changes the host-centric network architecture to data-centric network architecture. NDN focuses on what content the user wants i.e. named content rather than the position where it resides i.e. named hosts. In conventional architecture, IP Packets are used to find the information whereas in NDN Data/Interest Packets are used for same. NDN has various components i.e. Naming, Caching, Security, Routing and Forwarding etc. It uses hierarchical scheme for naming. In caching, IP handles same type of traffic conversely NDN caches heterogeneous type of traffic in one place which further improves content dissemination. Instead of securing the location/server where content resides, the security is embedded in the content itself. For Routing and Forwarding, data consumers sends Interest Packet, router checks the content store (CS); if not available then maintains the state of all pending interest in Pending Interest Table (PIT), which is used to guide the data packets back to the consumer. Then the request comes to Forwarding Information Base (FIB), through this request goes to multiple routes with the help of Named-Data Link State Routing Protocol (NLSR). The new architecture has several benefits over conventional IP Architecture like in-network caching, enhanced security, fast data retrieval process and less latency.

Keywords—Architecture, Caching, Comparison, Future Inter-net Architecture (FIA), Routing and Forwarding, Named Data Networking (NDN), Named Data Object (NDO)

I. INTRODUCTION

In 1960's and 70's when architecture of current Internet was developed, an example of successful communication was Telephony which was based on TCP/IP protocol (which is basically point to point conversation between two entities).This model established communication pipes between the hosts through which they could communicate to each other, means conventional architecture was designed to centre around com-munication between hosts in the network. IP-Based network has some limitations i.e. Security, Caching, Scalability, Two-step mapping overhead, Content Mobility.In order to satisfy these needs, some overlay network architecture takes initiative to improve users information access like peer to peer (P2P) system (Bit Torrent), Content Delivery Networks (CDN) but as traffic is increasing for content distribution, more efficient solutions are needed. Thus NDN has been proposed for the Future Internet Architecture (FIA). NDN is based on 'What' rather than 'Where' ; means Internet users will care more about what content they want rather than where the content resides (location independent). NDN is named content data ; and it has no idea of source and destination address. It changes the meaning of the network by delivering the packet based on the name rather than determining the destination address. NDN project aims to develop FIA that can capitalize on strengths and address weakness of the current host based network (point to point communication architecture) in order to naturally accommodate rising pattern of communication [1]. In the subsequent section, we will study about the Architecture and details of two different packets (Interest and Data/Content Packet) handled in NDN. After that the main components of NDN like Caching, Routing and Forwarding and Also the Comparisons between the IP and NDN will discuss; which will aid the reader to find out the fundamental differences between the two.

II. NDN OVERVIEW

NDN (a.k.a ICN/CCN) is an alternative to the Current IP model or Current Internet Architecture. The NDN includes 16 NSF (National Science Foundation) funded principal investi-gators at 12 campuses and growing interest from the industrial and academic research communities [2]. It is based on Named content and each content name is composed of one or more variable length components [3]. Hour Glass Architecture : Both NDN and IP Architecture have hour glass shape shown in Figure [1] but content chunks replaces IP at the network layer, which means packet can name object rather than addresses. The hour glass architecture centres on a universal network layer (IP) which implements the minimal functionality for global interconnectivity [1]. Two more advancement in the Architecture of NDN: Routing and Forwarding Strategy and Security. Every chunk of data is uniquely named so that Interest packet can be forwarded using multiple path, removing the IP single best path forwarding strategy. Security must be built in to the architecture; NDN provides security by signing all named data in the data packet whereas in Conventional architecture security is provided to the Location/server and not to the content.

III. ARCHITECTURE OF NDN

Communication in NDN works on Pull Model. In NDN, the communication is started by the receiver (consumer) through the interchange of two types of packet: Content/Data

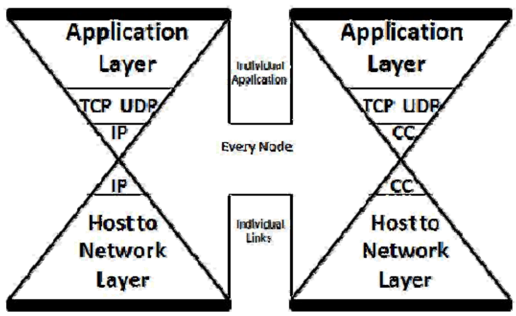

Fig. 1. Hour Glass Architecture

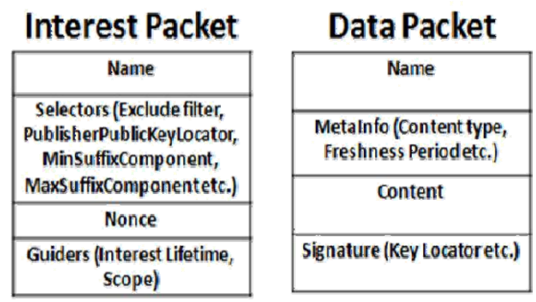

Fig. 2. Different Fields of Packet

Packet and Interest Packet. Both types of packet have name that can identify a piece of data [4]. A consumer puts the name i.e. Named data object (NDO) of the content in the Interest packet and sends it to the network [5]. Router sees the Interest Packet and forward in network. Once Interest Packet reaches the router that contains the NDO, then it will return content in Data packet that contains both the name, as well as signature too. A name can be human readable or a binary object. The signature attached to data object shows the name data integrity and authenticity for the security measures.

1) Detail Regarding Interest Packet and Data Packet :

Interest Packet: When a consumer wants some data then they send the name in the interest packet. Each interest packet has field name, selectors, nonce and Guiders/InterestLifetime. See Figure [2]

Name: NDN Name is a hierarchical name of variable length, which contains a sequence of name components. Selectors: It is an optional field which include Exclude filter (specify the component, when requested content come in Data Packet, the specified component exclude from the data packet), MinSuffixComponents(allows a data consumer to indicate the minimum number of component in the name), MaxSuffixComponents(allows a data consumer to indicate the maximum number of component in the name)[9], PublisherPublicKeyLocator (contain the hash of the producers public key for the requested content)[3]etc.

Nonce: It carries a randomly-generated 4-octet long byte-string[9]. The Name and Nonce combination should uniquely identify an Interest packet. For discarding the same data Nonce are useful.

InterestLifetime: It is also optional field which includes InterestLifetime (time for the life of interest packet) and scope (limit the number of hops an interest can propagate) type, Freshness period etc.

Content: Content field include the data. With each name there is some data associated.

Signature: Signature computed over the entire content packet and through the signature receiver assured that the data is correct. Security feature is directly related with this field. It includes key locator (the key needed to verify the Content Signature).

2) Detail Regarding Componenets of NDN:: See Figure [3]
Content Store (CS): Used for fast data retrieval and data caching.

Pending Interest Table (PIT): Store the information regarding the incoming interfaces of Interest Packet that are not satisfied yet [6]. It stores the information so that Data Packet can be delivered back to same path.

*Forwarding Information Base (FIB):*FIB is a table

Data Packet:When sources send content to the consumer, it sends the data in Data packet. Each Data packet has field Name, MetaInfo, Content and Signature[10].See Figure [2]

Name: Same as the name in the Interest Packet.

MetaInfo: MetaInfo contained the information like Content

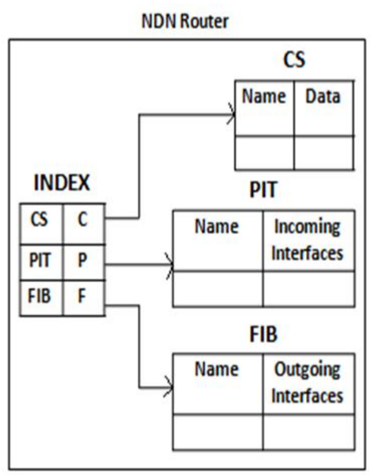

Fig. 3. Different Components in NDN Router

which consists of name prefixes and corresponding outgoing interfaces. Similarly in case of IP-Based Network, FIB also exists but in that IP address and next hop are specified.

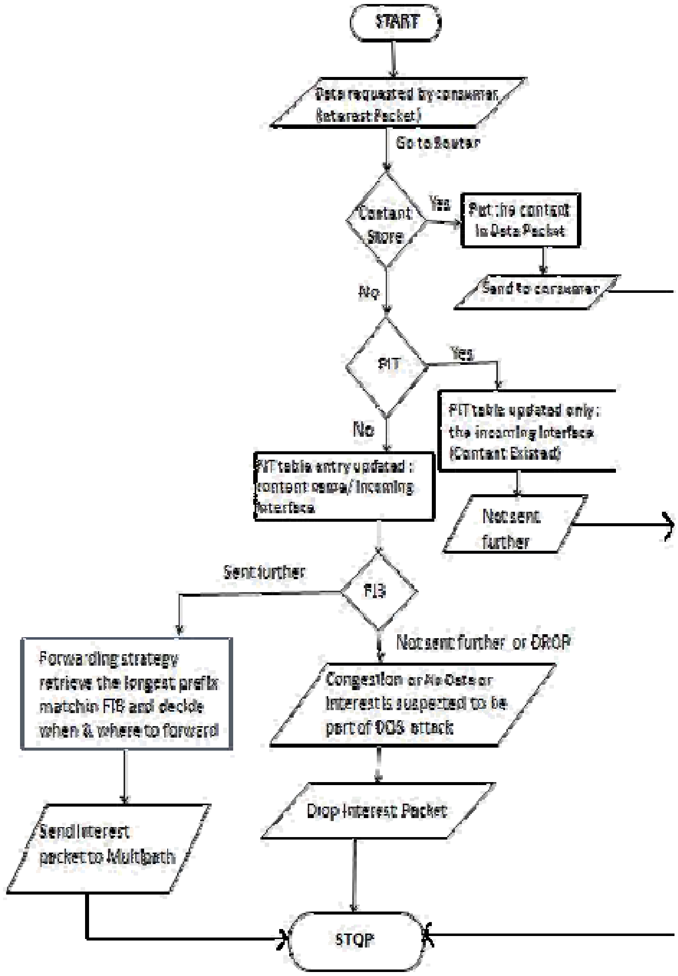

Fig. 4. Flowchart of Interest Packet

IV. WORKING OF PACKETS

1) Working of Interest Packet:: When the request is coming from the requester (consumer) the request coming in the Interest Packet, it goes to the router. NDN router first checks the Content Store (CS) [6] if the data is present in the Content Store then it inserts the content in the Data packet and sends it to the Table (PIT) .If the content is already requested by other consumer, then PIT table adds only the incoming interface in front of existing named content and request is not sent further because for this name content one request has already gone in the network. With reduction in network traffic performance is increases. If data is not found in the PIT table then add the new entry in the PIT table i.e. insert the new row (content name and incoming interface) in the table and send request to the Forwarding Information Base (FIB). When the request comes to FIB, then depending upon the network, it decides whether to send request further or not. If the network is congested at that time or interest is suspected to be the part of Denial of service (DoS)[2] then the router will not send the interest packet further ,i.e. it drops the interest packet. If the network is not congested at that time then it matches the name prefix with the longest name in the FIB table .On the basis of forwarding strategy, it is decided when and where to forward the request. It also sends the interest packet to multipath through which router suspect that the request can be fulfilled speedily.Figure [4] show the flowchart of the Interest Packet.

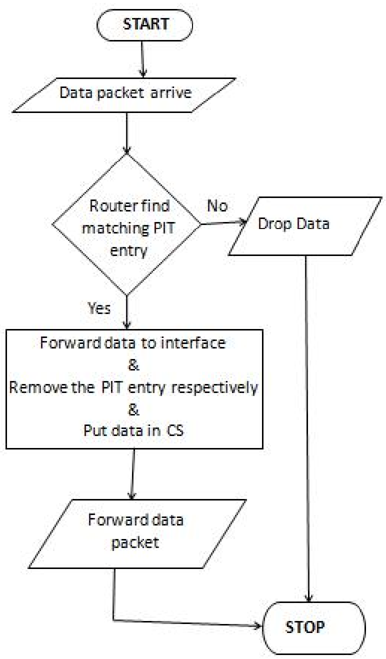

Fig. 5. Flowchart of Data Packet

2) Working of Data Packet:: The Data packet coming from one of the interfaces, router firstly finds the matching PIT entry with respect to named content. If the named content is not available in PIT table then the content is stored in content store and drop the data packet otherwise forward data to the incoming interfaces and remove the PIT entry respectively. Also save the data in the Content Store for increasing performance (response time less), so that if further the same request is coming from another requestor then there is no need to find the data from the producer.Figure [5] show the flowchart of the Data Packet.

The Interest Packet is forwarded hop by hop and Data Packet is also coming via the same path. There is more redundancy in NDN because it copies the content at each intermediate interface and for every request generated there is always one response. Overall NDN not only avoids network congestion and conflicts, it deals with content authenticity and integrity, get rid of dependence of end to end connection, Multihoming, mobility, flow balance/load balancing, security which improve performance and efficiency of larger scale content distribution.

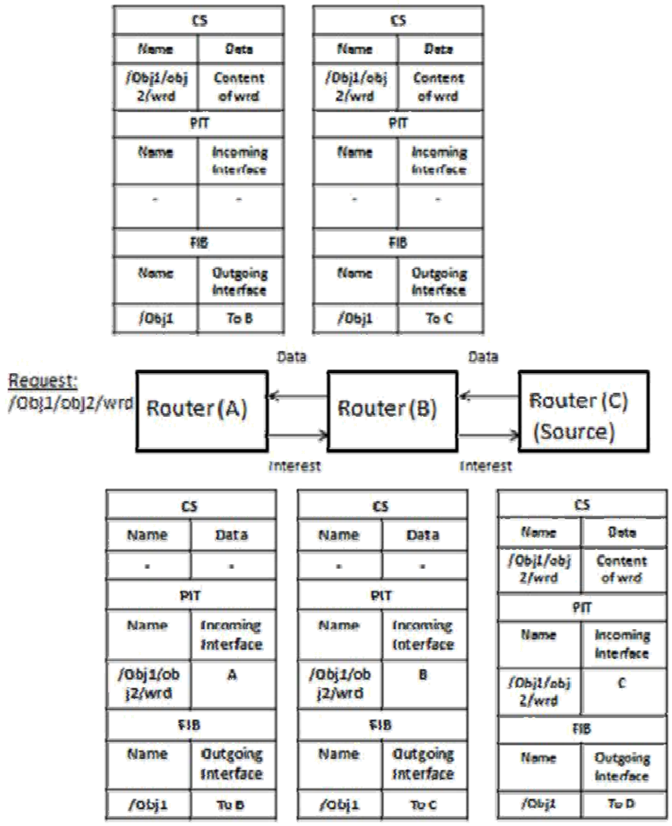

Fig. 6. Example of NDN Message Flow

3) Example of NDN Message Flow:: Suppose a consumer wants the data having name /obj1/obj2/wrd in Figure [6], it sends the Interest Packet having the name of the content to the Router A and router checks the Content Store. When the data is not available in CS then the entry(Name +Incoming Interface) are put in to the PIT and also searched for name in FIB (Name + Outgoing Interface) in which router finds the longest prefix match, then sent the request to next router B[7], same process is done by router B and then request is sent to Router C. When C checks its content store and data is available then it sends the Data Packet to the reverse path from where the packet is received with the help of PIT. When reverse path is followed by the Data Packet, then data saved at each intermediate router and PIT entry is removed. So the copy of data is saved at the router A and B also. When any requestor wants the same data then there is no need to go to C, the data is given directly from the Router A, so from this performance increases and also network traffic reduces [8].

V. NAMING SCHEME

Information/Data can be of any kind like video, image, webpage etc. Everything in the Internet have some name. NDN uses unique name to pull content irrespective of host entity (address). It uses hierarchical naming scheme and that are application specific and also allow routing to scale. It allow user to fetch and distribute content directly using their names. NDN names are non-transparent to network i.e. router doesnt know the meaning on the names but they know the boundary between the components in the name.NDN name is human readable (Figure [7]) and may contain several components arranged in hierarchy that is delimited by '/' where IP uses fixed length[11].Similar to the current Internet lookup, users in NDN will enter keywords with respect to some content they are looking for example: Figure [7] shows, if someone want to extract the content from Prof. Raj Jain , which belongs to the Washington University in St. Louis and want to extract the data about Computer Networks and the Internet and then this hierarchical name is used for this particular request. "cse:wustl:edu= jain=cse473 11=i 1cni", cse.wustl.edu is the globally routable name and = jain=cse473 11= is the organizational specified name and i 1cni is the segment of the name. In NDN architecture naming system is most important key component and still under active research area and the first open challenge is how to define and allocate the name, and, the second issue is that storing variable length name consumes high memory rather than IP addresses of fixed length.

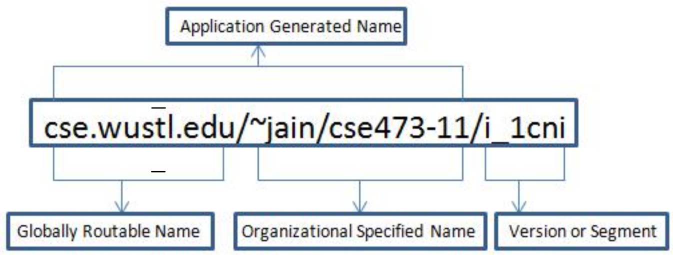

Fig. 7. Naming Scheme:Human readable content name

Example: If we have 6 components and each component have 5 character, then total memory consumed is 30 bytes which is more than IP address. So for resolving these issue, some researcher gives the solution for this: ”Name Component Encoding” (NCE) Scheme It is a code allocation mechanism developed to achieve memory efficient encoding for the name components and State Transistion Arrays used to accelerate the longest name prefix matching criteria.

VI. CACHING

To enhance the transmission efficiency of content dissemination, NDN offers caching mechanism. In conventional IP-Based network, caching concept is also used but when multiple replica of the similar object are located in different servers then multiple URLs will be used to access the content owned by different content providers. So in that it will treat them as different object. But in NDN, no concept of IP address is used, so this problem is being solved. When any Interest Packet is coming, the NDN router first analyses the Content Store [2]. If the data is present in the CS, then data will be sent back to the consumer. Here content store acts like a buffer memory.The in-network Caching concept is used.

Some new features of NDN caching are Transparency, Ubiquity and Fine Granularity: Firstly Transparency, Conventional cache system is designed for only a particular traffic class but NDN provides cache infrastructure which are shared by different traffic class. Each application manages the cache space independently. The name content i.e. NDO is unified and Persistent. On the basis of unified content name, NDN make its decision of routing and caching

.Secondly Ubiquity, in NDN cache is ubiquitous and the point where cache is done is no longer fixed. And lastly, Fine Granularity NDN technique is to divide large file into small self identifiable chunks. Instead of performing the caching to the large file, perform the cache on these units of chunks. First issue: there is neither experimental study nor analytical modelling of chunk level object popularity. By using, Caching and substituting at small level instead of large file with unified name, it is feasible to fetch distinct parts of same file from distinct nodes. This improves performance and maximizes space utilization.

Techniques for NDN Performance Optimization: Firstly, Caching Sharing Mechanism, distinct type of traffic shares the storage space of single cache node. If diverse type of traffic occurs then how to share limited resources efficiently?[12] Cache share mechanism can be fixed or dynamic. If we use fixed partition then two issues arise, first if distinct traffic class occur, then how to divide the space? Second, whether the similar partition ratio or distinct partition ratio should follow by each node, for different traffic the nodes can have changed partition ratio? For the former issue, dynamic feedback control theory used. For the latter, it is observed that VoD application requires less space than file sharing to achieve the hit ratio. Dynamic cache sharing: At particular time if the whole space of cache is not used by one traffic class, then any other traffic class can use it. Two strategies used: Priority based sharing and weighted fair sharing. In the first, it gives higher service priority to some applications. When any high priority object comes and wants some space in cache but there is no free space for that, then at that time the low priority objects from cache are abolished. If the traffic of high priority application enters at a constant rate, then it degrades the performance of low priority application. Weighted fair sharing increases space utilization. One traffic class share the cache space of other, if that space is not used at that instant. Secondly Policy for Cache Decision: it explains the object orientation in different cache nodes. In traditional web cache, it is possible to optimize object placement due to prior awareness of traffic requirement and network topology. NDN does not use the concept of permanent cache nodes. Also the traffic classes are distinct and line-rate operation occurs. One simplest approach is Leave Copy Everywhere (LCE) means at each intermediate node copy the object but this causes cache redundancy i.e. at multiple nodes similar object is copied. For increasing the value of cache system a) High Popularity contents are immediately pushed to the edge of the network, so that latency decreases and utilization of network resource increases. b) For reducing inter-domain traffic in the same ISP, we have to improve the entire network cache diversity; some schemes rather than LCE put the data in cache nodes. Move Copy Down (MCD): Remove the object from the hit node, where cache hit occurs and shift the object from the hit node to the straight downstream node and it reduces object redundancy. Leave Copy Down (LCD): This scheme only cache the object to direct downstream node, does not remove the object from the hit node. To pull the object down, several requests will do. Randomly Copy One (RCone): It copies the object at any one random node along the returning path, when cache hit occurs. Probabilistic Cache: with some probability the requested object copied at every node. Probability is inversely proportional to the distance from this node and the requestor node. Timing of Cache decision: The decision of cache need not to be taken only when a new object comes but also taken during cache replacement. Recent studies show that, the performance of simple random replacement algorithm and LRU are similar

VII. ROUTING AND FORWARDING

In the conventional IP architecture, the whole concept of routing and forwarding depend upon IP address. But in NDN, the packets are forwarded and routed on the basis of name rather than address. So the problem of address space exhaus-tion, scalable address management, mobility and NAT traversal are eliminated. In NDN, router exchange routing update with other routers and make FIB based upon receiving routing announcement. Router forwards the Interest Packet following the FIB. Routing security is an improvisation in NDN. First, data which is coming from the producer is all signed which shows that it prevents from intruder interception. Second, Prefix hijacking reduces with Multipath routing because router may identify the anomaly caused by prefix hijacking [2] and retrieve the data using other path. Third, its very difficult to forward a malicious data to a particular target because it talks only about data not the address of the host. In this the main issue is to make high-speed forwarding engine and scalable routing that can handle the traffic efficiently.

For the Scalable Routing, two main issues are a) how multipath Forwarding should be enabled to spread interest more efficiently? b) While allowing an unbounded name space in NDN, how bounding the amount of routing state (for scaling purpose)? So for solving the former issue, to prevent loops IP Router find the best way but NDN Router send an Interest Packet to multiple interfaces and cannot make loop, since the name plus nonce (randomly generated number) in the interest packet efficiently identify duplicated. Also Data packet does not loop because they take reverse path of Interest Packet. For the latter issue, extending existing routing protocol (OSPF, BGP) so that they also work on name prefixes (rather than IP) and multipath forwarding of interest[13]. For the Fast Forwarding Engine, the three mandatory requirements are: [14] a) Variable length, hierarchical name: NDN finds the longest matching name prefix (variable length) in the FIB.

IX. CONCLUSION

The recently proposed Named Data Networking (NDN) architecture highlights number of advantages in support of ”What” not ”Where” compared to the existing Internet infrastructure. It enhances the security feature. The data in the packet sent by the content provider is signed and this shows that the received data is correct. NDN removes the overhead of address and also increase the Performance with In-Network Caching mechanism. But instead of this, large number of open challenges in NDN are the following; Removing Redundancy in the router instead of using Leave Copy Everywhere (LCE) method for Caching; the methods used for hierarchical naming scheme; Size of cache and many more. So in the future, there is a need to work on these challenges and find justifiable solutions for these issues.

NAMED DATA NETWORKING(NDN)	CONVENTIONAL ARCHITECTURE(IP)
Future Internet Architecture	Current Internet Architecture
Data Centric Network Architecture	Host Centric network Architecture
"What"	"Where"
Router Content Cache	No Router Content Cache
Address Space and NAT Demolish	Address Space and NAT used
3 Entities Maintained	1 Entity Maintained
FIB, PIT, CS	FIB
FIB Stores multiple hop Status information	FIB Store only next hop Status information
New Routing Protocol NLSR based on name prefix	Existing Routing Protocols based on IP Address
Name prefixes are of variable length arranged in hierarchy delimited by '/'	IP address is of fixed length
Secure the data	Secure the container
In-network Caching and Cache shared infrastructure	No Concept of In-network Caching and Cache shared infrastructure
Optimization of bandwidth, congestion reduction with improved throughput	No Optimization of bandwidth, congestion often occur

Fig. 8. Comparison between NDN and IP

and sends the Interest to the next router. B) Fast update to prefix table: Prefix table (PIT, FIB. CS) must support quick insertion, deletion and modification when Interest/Data packet arrives. C) Very High Capacity: the capacity of content store should be high with respect to the size of packet. OSPFN is one of the Routing Protocol which works on name Prefix rather than IP address but it only find the single best path for forwarding. A new Protocol introduces Named-Data Link State Routing(NLSR) protocol which basically works on name Prefix as well as finding the multipath with the help of Dijkstras algorithm.With this Intradomain Routing Protocol, transmission efficiency of content dissemination increases.

VIII. COMPARISON BETWEEN IP AND NDN

Both architecture using hour glass shape for the architecture, but in the NDN IP is replaced by Content Chunks[15]. IP address is of fixed length (32bits in IPv4 and 128 bits in IPv6), but in NDN the Name prefixes used which are of variable length arranged in hierarchy delimited by '/'. NDN routers are able to reuse the data since they are identified by persistent name but IP router cannot reuse the data after forwarding them i.e. IP has stateless data plane and but NDN has stateful data plane. Figure 8, Differeniate these two Architectures.

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