Name Data Networking Forwarding Strategy: A Survey

A Study based on Name Data Networking Forwarding Techniques

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Abstract— **Named Data Networking (NDN) is an information centric Internet architecture where packets carry data names rather than source or destination addresses. By leveraging named-data instead of named-hosts. Our motivation is the architectural mis-match of today's Internet architecture and its usage. As current internet have mostly used in web browsing, users exploit blog platforms, social networks and peer-to-peer systems to upload their own-generated content e.g. messages, photos, prerecorded or live video and to download or share popular files e.g., music, games, videos**

As the traditional TCP/IP protocol and their routing strategy needs end to end connectivity. But in the future network where the wireless technology growing fast along with increment in data traffic mostly users work on mobile nodes. Hence we need some architecture which does not need the setup and maintenance of stable paths between end-node. Which also scalable and handle mobility related issues.

In this paper we describe an initial design of NDN's forwarding plane and then presented a comparative study of various forwarding strategies for wireless ad-hoc network.

Keywords—Information-Centric Networking, Wireless ad hoc networks, Multihop communications, IEEE 802.11, Forwarding, FIB,PIT,CS

I. Introduction

An IP network packet delivery is done in two stages:

- *Routing plane*

  During this stage of packet delivery routing information is exchanged among the routers and the best routes are selected to create a forwarding table. Hence this stage is stateful and adaptive.

- *Data plane*

  In the next stage the FIB is followed strictly by the routers to forward the packet and thus this part is stateless and non-adaptive. In conclusion, in IP network routing is smart and forwarding is dumb.

Unlike an IP networking, Named Data Networking is based on interest/data packets having data names that uniquely identifies them instead of packets having the source and destination addresses. A data name is bound to a packet by a cryptographic signature.

The consumer or end host sends a packet to the network requesting some data. These packets are known as interest packets. The NDN routers maintain a datagram state for every interest packet they receive. If the contents of cache of a router matches the request, then the data is sent to the consumer in a packet called the data packet else the interest packet is forwarded to the next hop towards the data producer.

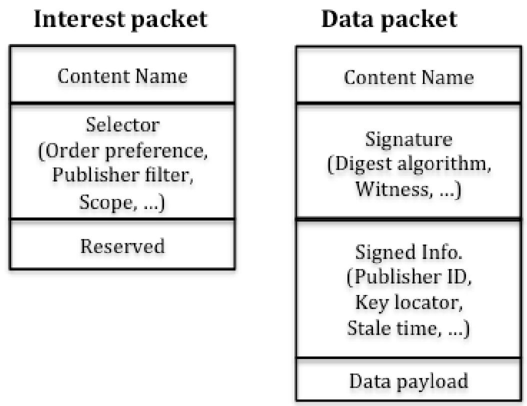

Fig. 1 Interest and Data Packet in NDN.

The data packet always uses the same path the interest packet had taken. The form of forwarding strategies used by a network is determined by its architecture design. In Table-1 we representing a Comparison between Name Data Networking protocol and TCP/IP Protocol.

Our main goal in this paper is to describe different NDN's forwarding mechanisms and identify its main advantages as well as the design tradeoffs. We first outline the design of an adaptive forwarding mechanism for NDN, illustrate its benefits using a few case studies, then identify key open research issues.

NDN	TCP/IP
Content Centric	Address Centric
Elimination of DNS	Can't Function without DNS
Not Host Centric	Host Centric
Multipoint to Multipoint	Point to Point
Stateful Data Plane	Stateless Data Plane
Adaptive Forwarding	Non Adaptive Data Forwarding by Routers
3 Entities Maintained CS,PIT,FIB	1 Entity Maintained FIB
FIB Stores Multiple	FIB Stores Only Next
Hop, Performance Information	Status, Hop Information
Existing Routing Propagation based on Name Prefix	Existing Routing Propagation based on IP Prefix
Security is Provided to Content Itself Not	End to End Channel is Secured like SSL
Interest Initiated Model	Client Server Model for Interaction
Information Distribution	Information Sharing
Optimization of Bandwidth, Congestion Reduction, Improved throughput	No Optimization of Bandwidth, Often Congestion Occurs

TABLE 1. Comparison between Name Data Networking protocol and TCP/IP Protocol.

II. BACKGROUND

In this section, we review the functionality shown in Fig.1 and design principles of various data structures mentioned in Fig.3 that a NDN router maintains.

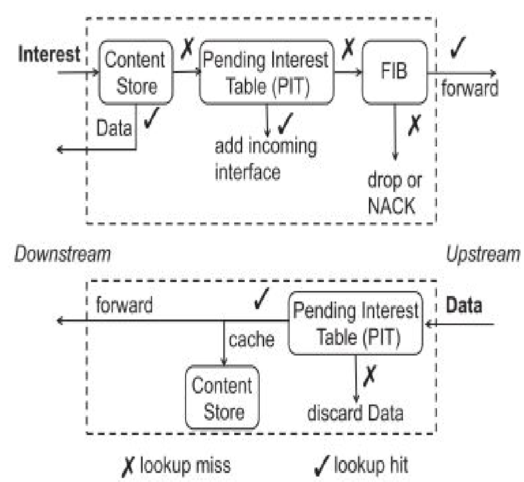

Fig. 2 Interest and Data Packet Flow in NDN.

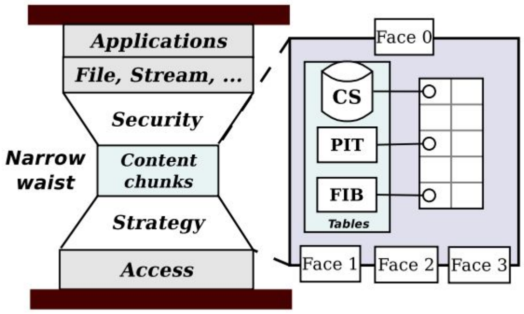

Fig. 3 NDN Hourglass.

A. Content Store

The content store of an NDN router contains data packets that has passed through it before. If the data requested by the interest packet is already present in the cache then instead of forwarding the packet along the path to find a data producer, data from the cache itself is sent back to the consumer.

B. Pending Interest Table

The Pending Interest Table provides two major functions in the NDN architecture first is Interest packet aggregation and other is Data packet multicast. Each incoming Interest name is looked up in the PIT. The Interest packet will be forwarded only if its name is not found in the PIT. The PIT keeps track of which face has requested what content, and each PIT entry stores a list of its Interest incoming faces. When a Data packet arrives, the PIT is queried to fetch all the outgoing faces, and then the Data packet is delivered. The contents of an entry for every name in PIT includes:

- Incoming interfaces for all the incoming interest packets for that particular name.
- A list of all nonces seen for that name. Every interest packet also contain a nonce. These nonces are used to detect looping packets in network.
- All outgoing interfaces that the interest packets associated with that name, have been forwarded to.
- For every incoming interface, the longest interface lifetime
- For every outgoing interfaces, time when the forwarding through that interface was done.

C. Forwarding Table

Forwarding table (FIB) maintains a ranked list of multiple interfaces that could be chosen to forward a particular interest packet. It also contains information from both routing and data plane for adaptive forwarding decisions.

Every FIB entry contain:

- Routing information which contains a list of all policy compliant interfaces with their routing preferences for a given name prefix.
- Forwarding Performance Information – The method used for recording status of an interface could be a simple colouring scheme
  - Green – interface is working.
  - Yellow - interface may or may not work.
  - Red – interface is not working.
- Interface ranking which is based on routing preference, forwarding performance and forwarding policy.
- Rate limit – The rate limit allows the router to limit the number of interest packets that are being forwarded in the event of heavy traffic in the network. Since there is one-to-one balance between interest and data packets in NDN, this results in effective congestion control.

III. Forwarding and Applications

Forwarding strategy must decide

- On which face interest packet should be sent. It can be

  <i>best performing face

  <ii>subset of possible faces

  <iii>all available faces

  The choice depends on face cost which is determined by face rank which in turn is determined by previous measurement of forwarding strategy.

- How to react when data packet is not received on time

  <i> Drop the Interest packet.

  <ii> Retransmit the packet on the same or a different face(s).

  <iii> Reply with a special NACK packet to the previous hop.

- Downstream faces

  <i>Which of the downstream faces working.

  <ii>How well does that face working.

- Type of forwarding strategy

○ *Adaptive Forwarding*

Records the performance of the faces to improve future decisions.

○ *Static Forwarding*

Relies exclusively on the decisions made by the routing protocol. Need to modify routing protocol to remove the face from FIB or to find lower cost face.

IV. NDN Forwarding a in ad hoc network

The forwarding operation is stateful and adaptive.All proposed techniques have in common "consumer aided" data delivery.

A. Aware Forwarding

This type of forwarding results in flooding. Although they result in collision, high overhead and redundancy, they have improved packet delivery performance.

The basic idea is that a node defers the packet of a random delay and drops it if the same packet is overheard on the radio channel. During the defer time a node overhears the channel: if the same Data is transmitted by other nodes for a number of times say Ct, then the node aborts Data forwarding.

Interest and Data transmissions are deferred in order to limit the collision probability and packet overhearing are leveraged in order to control Interest packet redundancy.

A blind controlled flooding does not always guarantee that

- The best nodes are selected to forward packets
- Overhearing avoids packet collisions.

Advantages:

- Blind forwarding can be regarded as a baseline implementation of NDN broadcasting in wireless networks.
- On top of it more sophisticated and aware forwarding strategies can be deployed.

Disadvantages :

- This method does not completely avoid packet collisions.
- Have hidden terminal problem.
- The packets propagation in the network cannot be completely controlled
- Potential forwarders could collide if they use the same defer time.

Note: We can overcome the hidden terminal problem by using RTS and CTS signals but that would increase the overhead.

B. Aware Forwarding

Next-hop awareness :

The consumer broadcasts the Interest to its one hop neighbors. The farthest node in each quadrant of its surrounding space is then selected as a relay node.

Two additional packets (ACK, CMD) are exchanged between the sender (and intermediate forwarders) and its neighbors, hop-by-hop.

Advantages:

- Interest Packet collision would be reduced.
- Simple implementation as compared to other aware forwarding strategies.

Disadvantages:

- This could further increase the overhead.
- Not very efficient aware strategy as compared to other aware forwarding strategies

Neighborhood-Aware Interest Forwarding (NAIF) scheme:

Eligibility of a relay node is decided by -

<i.> Its data retrieval rate for a given name prefix

<ii>Its distance to the consumer.

.If node is not eligible then the incoming Interest is discarded locally.
Advantages:

- Reduces packet collisions
- Reduces data redundancy

Disadvantages:

- Overhead of relay node selection.
- Not very efficient aware strategy as compared to other aware forwarding strategies

BlooGO:

The intermediate node determines if forwarding a packet or not by comparing the neighborhood of the sender and the receiver.

Adavantages:

- Less no. of nodes included in data delivery.

- Save network resources.
- Optimize Bandwidth utilization.

Disadvantage:

- High complexity.
- High overhead.
- Required knowledge of neighbouring nodes.

Provider awareness:

In case the consumer discovers more than one content source, it can select the best performing provider based on a criteria.

A three-way handshake is proposed in Listen First Broadcast Later (LFBL). An additional data structure is kept by nodes, the Provider table .The objective is to forward Interests towards the selected provider and to route Data over the shortest identified path.

Advantages :

- The channel load is kept under control
- Reducing download time and energy consumption is reduced.
- The multi-home advantage of fetching the content from different nodes is not reduced.
- A node storing the content can reply with Data if it realizes that it is closer to the consumer than the selected provider.
- Controlled packet redundancy.
- Reduces no. of packet collisions.

Disadvantages:

- Additional data structure Provider Table required.
- Additional REQ and REP packets between consumer and providers increases overhead.
- Complex design.

C. E-CHANET

Overview:

Interest forwarding over IEEE 802.11 networks is improved by using information from Content Provider Table and extra data from Interest and Data packets piggybacking. These information allows to do a distance check to decide whether or not to forward the interest packet.

Data forwarding is done in a way similar to adaptive forwarding in NDN but with an additional distance check done by PIT lookup.

The building blocks of E-CHANET includes functions such as-

1. Routing and forwarding function

Define mechanism for content retrieval that minimize download completion time and control scalability by coping with broadcast storm and channel unreliability.

2. Mobility handler

Cope with delay or disruption period due to mobility by consumer driven handover and producer driven handover procedures.

3. Transport functions

When data packet is lost, interest packet is retransmitted to ensure reliable data transfer. Interest rate control that adapt packet transmission rate and guarantee high utilization of available bandwidth is applied.

Naming assumption: Content divided in several packets each packet has content packet identifier. Each node has nodeID as MAC address of node which is unique & location independent.

E-CHANET Routing and Forwarding Function and the Mobility Handler have a twofold purpose

- Reduce no. of nodes involved in forwarding process
- Take advantage of content sharing by multiple hopes to cope with mobility.

Packet forwarding consider counter-based suppression mechanism where priority is given to data packet. If a potential forwarder overhears the same packet transmitted by another node during its defer time, then it aborts its own transmission.

Interest packet and data packet are piggybacked with “light-weight-path” information. Extra data structure content provider table is required. In Fig.4 we are showing a mapping between E-CHANET architecture over generic CCN model.

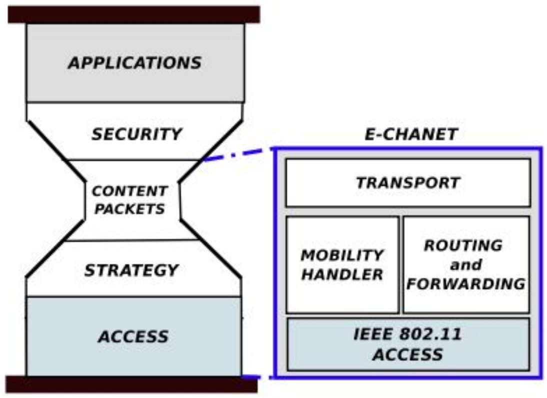

Fig. 4 Mapping the E-CHANET architecture over generic CCN model.

Advantages:

- Coping with channel unreliability.
- Coping with delays suffered by dynamic network topologies.
- Broadcast storm mitigation.
- Packet suppression mechanisms handles Scalability.
- Controlled Interest rate helps in handling congestion.
- Energy efficient behaviour
- Support mobile behaviour at a large extent using mobility handler..

Disadvantages:

- Complex design.
- Additional data structures required.
- Hidden terminal problem can't be overcome completely.
- Handover and computation overhead.
- Piggybacking increases the extra data overhead.

V. Adaptive Forwarding in NDN

A. Design

New interest packet

New PIT entry is created and the packet is forwarded to highest ranking green interface. If no such interface exists, the highest ranking yellow interface is used.

Retransmitted Interest packet

The newcomer matches a PIT entry but its nonce is not is nonce list. If received after the exploration timer expires, then it will be forwarded like a new interest packet.

Interest NACK

Router starts a timer based on RTT after forwarding an interest packet. A data packet may not be able to reach the router before the timer expires. In another scenario, data may not be found along a certain path. In this case, the interest packet stays in PIT until its lifetime expires (dangling state).In both of the above cases, a NACK is returned to the previous router along the incoming path so as not to block other interest packets for the same data. The router receiving the NACK will send the interest packet to the next highest ranking available green interface if available otherwise it will also send a NACK further back along the path.The router uses an exploration timer to limit the number of alternative paths probed.

Interface Probing

Yellow interfaces are proactively probed to discover better paths.This is done by sending a copy of an interest packet to it. The overhead caused is controlled by limiting the probing frequency.

B. Advantages

Benefits of adaptive forwarding in NDN is demonstrated in three problem scenarios.

Link Failure

IP networks depend on lengthy process of periodic keep-alive messages to detect link failures while the NDN observes two way flow of packets.

If an interface fails or RTT timer expires then the router explores alternative paths. If no such path is available then interest NACK is returned. This leads to downstream routers to search other paths. The NDN routers use both routing information and data plane feedback for forwarding decision.

Congestion

Due to interest NACK and alternative paths exploration, the traffic in NDN is split into multiple paths resulting in better performance. When lot of NACKs are received then the router can change its rate limit dynamically to control traffic congestion.

Thus, instead of reacting to congestion after it occurs, NDN adjusts the number of interest packets sent before excess data packets are pulled in network. Hence a hop-by-hop adaptive congestion control mechanism is applied.

Prefix Hijack
In this type of attack, the hijacker hijacks a victim's prefix name and drops the interest packets going to it or returns bogus data packets.

If a router sees a yellow interface with a higher rank than the current green interface, it sends copies of interest packets through the yellow interface. Because of the hijacker, the yellow interface too will not return any data packets.

Moreover, other routers with their paths going through the hijacker' router will realise that their packets have stopped coming too.

Hence current interface will be labelled yellow and better paths would be searched for identifying bogus data packets, signature verification is done over randomly selected data packets.

C. *Disadvantages*

Forwarding state
Per-packet datagram state of NDN is significantly costly in terms of router storage and in packet processing overhead.

Reducing the size of PIT and efficient lookup and operations on PIT are also issues that remains.

Forwarding Strategies
Discovering a working path for a new interest packet, efficient use of multiple paths and methods to do interface probing properly are few of the research issues that are still unresolved.

VI. Conclusion

We have presented various NDN forwarding strategies used in different scenarios and studied their mechanisms and characteristics. A controlled flooding gives better results than a simple blind forwarding strategy. The blind scheme depends only on packet overhearing and set timers to support multihop forwarding while counteracting the Broadcast storm. This problem can be reduced by controlled flooding but not completely erased. Hence, a provider-aware forwarding strategy has been designed to improve the data delivery efficiency. This method carries provider information in Interest/Data packets and stores them in the routers. Provider-aware forwarding strategy is better than the blind forwarding scheme in efficiency. This is done by reducing the number of packets in the network. However, in the case of specific application scenarios and requirements, a simple blind scheme could be a better solution than provider-aware strategy.

NDN's adaptive forwarding mechanism shows high performance and resilience in comparison to above strategies and can provide excellent performance in handling various problem scenarios such as prefix hijacks, link failures and congestion. Though implementing this mechanism requires dealing with many open issues in terms of both technical feasibility and economical viability. In multihop wireless environment E-CHANET outperforms the simple adaptive forwarding mechanism by decreasing the number of routers forwarding interest and data packets in the network.

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