NDN's Stateful Forwarding Plane Meeting Frequent Connectivity Changes of LEO Satellite Constellations

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ABSTRACT

As a data-centric network architecture, Named Data Networking (NDN) has a unique feature in its stateful forwarding plane, where Interest packets are routed towards data sources, leaving behind breadcrumb traces that steer requested data packets back to consumers. However, if one wishes to run NDN on LEO satellite networks (satnet), the frequent connectivity handovers in such an environment would disrupt the states of NDN's forwarding plane. In this poster, we first *graphically* illustrate several functions enabled by NDN's stateful forwarding plane, then describe the disruptions to this forwarding plane by frequent handovers due to fast LEO satellite movement, and explain the difference between the LEO satellite handover problem and today's mobile IP node handover. We argue that effective solutions to the above problems should be developed to enable NDN deployment over LEO satnets.

KEYWORDS

Named Data Networking, LEO satellite constellation

1 OVERVIEW

A distinctive characteristic of Low Earth Orbit (LEO) satellite networks is their frequent and dynamic changes in connectivity [4]. Assuming perfect routing that could adjust routing paths instantly according to the connectivity changes, packet delivery in IP networks would not be affected. In contrast, Named Data Networking (NDN) [1, 2, 5] employs a stateful forwarding plane, which has many advantages as we show in section 2, but is also susceptible to connectivity changes. [3]. This raises the question of whether NDN could successfully operate over LEO satellite networks.

In this poster, we use graphs to detail the step-by-step operation of an NDN network's Interest and Data packet forwarding process and explain the performance gains from NDN's stateful forwarding plane. These illustrations suggest that LEO satellite networks can benefit significantly from NDN's stateful forwarding, motivating new solution development for enabling NDN's stateful forwarding plane in the face of dynamic connectivity changes in LEO satnets.

2 NDN'S STATEFUL FORWARDING PLANE

In this section, we use graphs to illustrate, step-by-step, NDN's Interest and Data packet forwarding process, explain why NDN's forwarding plane is "stateful" and how data caching is built in, and the advantages of a stateful forwarding plane over IP's stateless forwarding plane.

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2.1 Stateful Forwarding Plane Enables Multicast Data Delivery

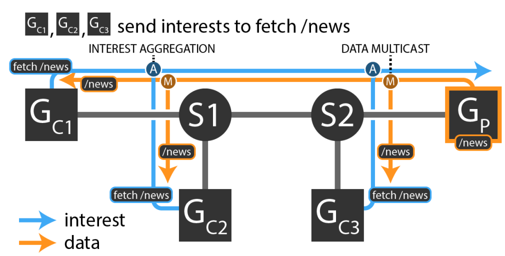

Figure 1: Three consumers fetching the same data

NDN automatically supports multicast data delivery via two mechanisms. First, when multiple consumers request the same data around the same time, their Interests are aggregated along the Interest forwarding path. Second, the returning Data are sent to every face that has a pending Interest for the Data, and cached at NDN routers. Thus, even when multiple consumers request the same data at slightly different time, later Interests can find the requested data from router caches, providing *asynchronous* multicast Delivery. Multicast data delivery enables LEO satnets to use finite network capacity to satisfy increasing user traffic demand.

2.2 In-network Caching Fast Loss Recovery

When lost packets need to be recovered, TCP/IP takes a full round-trip time (RTT) to fetch lost data from the original sender. In contrast, when NDN consumers resend Interests for missing data packets, these retransmitted Interests can find cached copies at the routers right before the lossy links. This speeds up loss recovery and utilizes network resources more efficiently. Satellite links are subject to various environmental factors and may have higher loss rate than terrestrial links. Thus, they can benefit more from NDN's fast loss recovery.

2.3 Stateful Forwarding Plane Enables Multipath Forwarding

It is a common perception that LEO satellites are likely to be evenly distributed on multiple orbital planes and connected as a grid topology. Such connectivity provides multiple paths to the same destination with similar latency, offering a great opportunity for multipath forwarding. The states maintained in each router's PIT enable NDN

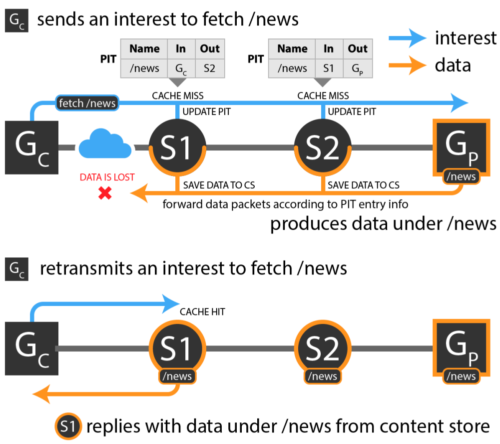

Figure 2: NDN fetching data under lossy link

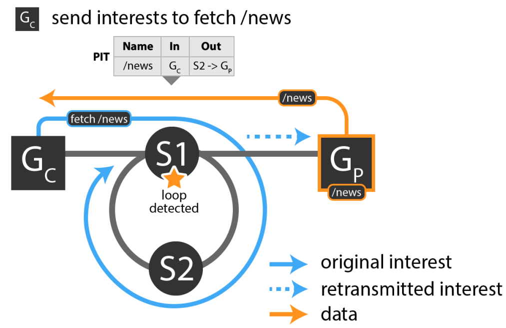

Figure 4: PIT allows loop detection Forwarding strategy allows in-network retransmission to alternative path

to explore all forwarding path options in a distributed and effective way. Each node can choose any path to forward Interests to. If a chosen path brings back Data, the data retrieval time can be measured and recorded. If a chosen path does not work, the corresponding PIT entry will time out, or a negative acknowledgment (NACK) packet be received. If a chosen path leads to a forwarding loop, the loop can be detected because the same Interest has arrived at the same node twice. Therefore, NDN's forwarding plane enables nodes to explore different choices, get feedback at the time scale of RTT to adjust their choices as needed, without any additional help. This can be a critical feature to exploit LEO satnet's rich connectivity and make packet forwarding more resilient to network failures.

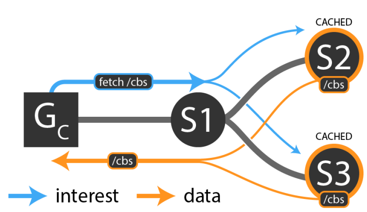

Figure 3: Multihomed to optimize the network bandwidth

3 HANDOVER PROBLEMS IN STATEFUL FORWARDING PLANE

Handover is a familiar concept associated with host mobility, e.g. a moving cellphone's connectivity switches from one basestation to another one. A stationary ground terminal also needs to periodically switch its connectivity from one satellite to another as LEO satellites move fast across the sky. However, different from cellular handovers, satellite handovers pose much greater challenges. This is because neighbor cellular basestations usually have direct terrestrial links with each other, a handover only changes the last hop to reah a moving cellphone. In LEO handover, the previously connected satellite of a ground terminal may *not directly* connect to the terminal's new "home", making it difficult to re-establish operational states between satellites.

More specifically, when a consumer establishes the connection to a new satellite, the previous satellite lost connection to the consumer. In figure 5, a data packet sent right before the handover follows the PIT breadcrumb to reach the satellite that is no longer connected. Consequently, all the data packets in transit, a round-trip time (RTT)'s worth, are lost. To mitigate this problem, the previous study proposes to retransmit all pending Interests with a forwarding hint to fetch the data from the disconnected satellite to achieve faster data retrieval and save network bandwidth [3]. Consumer handover does not affect routing because the path to the producer does not change.

On the other hand, when a producer handover occurs, only data traversing the final hop (from producer to its satellite) is lost as shown in figure 5. In addition, Interest packets will be rerouted toward the newly connected satellite according to the updated routing table.

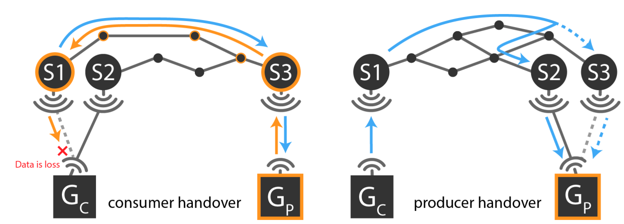

Figure 5: Data packets are always forwarded according to the PIT entries, potentially causing a disruption.

4 FUTURE WORK: MAKING NDN RUN OVER LEO

The benefits from NDN's stateful forwarding plane serve as a motivation to study NDN under LEO satellite networks and address the issues caused by dynamic connectivity changes. When connectivity changes, some network states will be outdated. As a result, the delivery of some packets may fail. Simple and effective solutions are needed in order to ensure minimal disruption to packet delivery.

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