Network Terminal-Supported NDN Mobility Management Mechanism Postprint

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Abstract

Named Data Networking (NDN), as a novel Internet architecture, aims to address the ever-increasing data traffic. Based on its consumer-driven content retrieval model, NDN naturally supports consumer mobility. However, producer mobility remains a challenging problem, requiring additional mechanisms to improve data availability during producer mobility. To address this issue, we propose a scalable mobility management mechanism to support producer mobility. This mechanism utilizes network terminals to establish temporary forwarding paths on the name-based NDN forwarding plane, and designs caching and retransmission mechanisms to support both delay-tolerant and delay-sensitive application data flows. Finally, a comprehensive simulation environment is established in ndnSIM to evaluate and compare the proposed scheme with existing solutions. Simulation results demonstrate that the mechanism can fully support producer mobility. At a speed of 30 m/s, the packet loss rate is only 3.0%, and the average transmission delay is 352.1 ms. Furthermore, the additional overhead required to support producer mobility is reduced by 49.18% compared to existing schemes.

Full Text

Preamble

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Mobility Management Mechanism Based on Network Terminal Supporting in Named Data Networking

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Abstract: Named Data Networking (NDN) represents a novel Internet architecture designed to address the exponential growth of data traffic. Thanks to its consumer-driven content retrieval model, NDN inherently supports consumer mobility. However, producer mobility remains a challenging issue that requires additional mechanisms to ensure data availability during producer movement. To address this challenge, we propose a scalable mobility management mechanism to support producer mobility. This mechanism leverages network terminals to establish temporary forwarding paths on NDN’ s name-based forwarding plane and designs a caching and retransmission mechanism to support both delay-tolerant and delay-sensitive application data flows. We implemented a comprehensive simulation environment in ndnSIM to evaluate and compare our proposed solution against existing approaches. Simulation results demonstrate that the mechanism fully supports producer mobility, achieving a packet loss rate of only 3.0% and an average transmission delay of 352.1 ms at a speed of 30 m/s. Moreover, the additional overhead required to support producer mobility is reduced by 49.18% compared to alternative schemes.

Keywords: named data networking; mobility; forwarding strategy; packet loss ratio; transmission delay

0 Introduction

With the rapid proliferation of mobile devices, mobile application traffic has surged dramatically. Mobile data demands for multimedia streams, audio, and video content continue to grow exponentially, making mobility a fundamental requirement for modern communication networks. Named Data Networking (NDN) emerges as a content-centric networking architecture where users focus on content itself rather than its location. NDN’ s stateless connection and identity-location separation features inherently facilitate user mobility. In NDN, mobility can be categorized into consumer mobility and producer mobility. While consumer mobility is naturally accommodated by NDN’ s receiver-driven model, enhancing producer mobility presents significant challenges due to the lack of separation between routing locators and content identifiers.

During movement, producers must dynamically update routing information to maintain consistency and continue receiving consumer requests. However, updating global routing information consumes substantial network resources and causes consumer requests to timeout and be lost when they cannot reach the producer’ s new location, resulting in prolonged communication interruptions.

Furthermore, under hierarchical naming mechanisms, many producers utilize specific prefixes, and frequent producer mobility undermines the prefix aggregation advantages of the Forwarding Information Base (FIB), leading to low aggregation and explosive growth in routing table entries. Therefore, a comprehensive solution is needed to address these challenges.

To enable normal communication between consumers and mobile producers in NDN, mobility management mechanisms must solve two key problems: dynamically tracking producer location and maintaining session continuity. Numerous techniques have been proposed to address producer mobility, which can be classified into five categories: routing-based methods rely on routing updates to forward consumer requests but face challenges in routing table scalability and convergence time; mapping-based approaches employ location-identity separation but are unsuitable for frequent producer mobility and delay-sensitive data flows; anchor-based methods forward Interest packets through local proxies but suffer from single-point failures, triangular routing, and reduced Content Store utilization due to packet encapsulation; proactive caching schemes push content to edge routers to mitigate mobility impact but may introduce high latency for real-time content; and Trace-based methods extend NDN' s stateful forwarding plane to establish reverse tracking between mobile producers and a fixed rendezvous server (RV), though they require assuming stable RV prefixes and consume significant signaling overhead to maintain temporary forwarding paths.

While existing schemes support producer mobility to some extent, they introduce additional problems. Some mechanisms exhibit high complexity that affects network scalability, while others violate NDN' s location independence principle. Moreover, many schemes cannot adequately support both delay-tolerant and delay-sensitive traffic simultaneously, and few address the issue of rapid retransmission after consumer request drops. Finally, the uncertainty of producer mobility status necessitates simplified communication between producers and anchors to minimize complexity. The design goal of mobility management mechanisms is to support producer mobility under various system constraints while minimizing overhead, reducing network latency and signaling consumption, and improving communication quality.

To address these issues, we propose NTMP (Network Terminal-based Mobility management Protocol), a mechanism that utilizes network terminals to establish effective forwarding paths on NDN' s content-name-based forwarding plane and designs the CRM-NT mechanism to support both delay-tolerant and delay-sensitive application data flows. NTMP incorporates a real-time handover notification mechanism that employs network terminals (NT) to dynamically track producers, reducing handover delay and overhead while minimizing anchor impact on performance. This notification mechanism extends the stateful forwarding plane by creating/updating temporary forwarding tables (TeFIB) in NDN routers to establish effective forwarding paths between the producer' s old and new locations and the network terminal. Finally, NTMP implements a caching and retransmission mechanism (CRM-NT) to cache consumer requests and en-

able rapid recovery from losses. Simulation results demonstrate that NTMP meets its predefined objectives and outperforms existing schemes across performance metrics including packet loss rate, handover delay, and retrieval time, fully supporting producer mobility.

1 NTMP Mobility Support Scheme

To enhance communication quality in mobile NDN environments, we designed NTMP, a network terminal (NT)-based mobility management mechanism. NTMP leverages network terminals to create effective forwarding paths on NDN' s name-based forwarding plane to maintain communication between consumers and mobile producers, and designs the CRM-NT mechanism to support both delay-tolerant and delay-sensitive application data flows. This section first describes NTMP' s forwarding process, then elaborates on the designed modules, and finally validates the scheme' s rationality and effectiveness.

1.1 NTMP Model and Basic Principles

Figure 1 illustrates NTMP' s analytical model. To enable normal communication between consumers and mobile producers, NTMP' s overall approach works as follows: before disconnecting from the network and after reconnecting, the producer sends mobility signaling containing its content name to the NT, which responds with corresponding Data packets. Network routers update their forwarding state based on the signaling exchange between the producer and NT to re-forward consumer requests. The forwarding process during producer mobility proceeds as follows:

Step 1: Before moving, the producer connects to the network via router R1 and then moves toward R2. Before disconnecting from R1, the producer sends a Mobility Interest (MI) packet to the NT. The MI contains a special marker "M" indicating the producer' s disconnecting state.

Step 2: Upon receiving the MI, R1 queries its FIB using the MI' s name prefix and forwards it to the NT according to the matched FIB entry.

Step 3: After receiving the MI, the NT enables caching functionality and replies with a Mobility Data (MD) packet. The MD contains marker "M" and includes the NT' s proprietary name prefix in its data segment.

Step 4: R1 recognizes marker "M" in the MD, establishes a temporary forwarding table (TeFIB), and forwards the MD downstream. NDN routers eventually forward it to the producer.

Step 5: During the producer' s disconnection period, consumer Interest packets forwarded along the original path to R1 are redirected to the NT based on its TeFIB. The NT records and caches these Interests.

Step 6: After reconnecting via R2, the producer immediately sends a Handover Interest (HI) packet containing special marker "H" to the NT. Marker "H" indicates the producer' s connecting state, and the HI requests the NT to release consumer Interests received during the producer' s disconnection.

Step 7: R2 receives the HI, queries its FIB using the HI' s name prefix, and forwards it to the NT.

Step 8: The NT recognizes marker "H" in the HI, releases the cached Interests, and replies with Handover Data (HD) containing marker "H" .

Step 9: R1 recognizes marker "H" in the HD, creates/updates its TeFIB, and forwards the HD to the producer. Additionally, R1 forwards consumer Interests by querying TeFIB/FIB.

Step 10: The producer receiving the HD indicates successful establishment of the temporary forwarding path. Upon receiving consumer Interests, the producer immediately sends Data packets.

Step 11: R2 receives Data packets, queries PIT entries, and forwards them downstream based on matching interface information, eventually returning them to the consumer.

Step 12: While the producer remains connected to R2, consumer Interests are forwarded via the newly established path to the producer' s new network location, and Data packets return along the same path.

1.2 NTMP Forwarding Algorithm Design

NTMP aims to minimize the impact of producer mobility by dynamically updating router forwarding states. NTMP designs a complete notification mechanism where mobile producers actively report their mobility status. NDN routers utilize this mechanism to create/update TeFIB entries for producer content. Additionally, a caching and retransmission mechanism is designed to provide complete producer mobility support.

1.2.1 Notification Message Format The producer' s notification mechanism employs special mobility Interest/Data packets: Mobility Interest (MI), Handover Interest (HI), and their corresponding Mobility Data (MD) and Handover Data (HD). As shown in Figure 2, the content name field contains the name of the data requested by consumers, including both /NT Prefix and /Routing Prefix. The /NT Prefix is the name prefix advertised by the NT in the routing plane, enabling producer mobility Interests to be forwarded to the NT. The /Routing Prefix is the mobile producer' s content prefix for which NDN routers establish temporary forwarding entries. The Tab field is an additional field indicating different mobility states, whose function is detailed below. The special Interest packet also includes a Signature Information name component containing information necessary to verify the producer' s signature (e.g., producer ID, public key address), enabling the NT to authenticate data origin and ensure the reliability of the /Routing Prefix.

An extra Tab field is added to the producer's notification message format. Based on the producer' s mobility state, this field is populated with either "M" or "H" markers. This field does not alter the content name or affect normal routing; it only triggers special operations at the NT and NDN routers:

- Upon receiving an Interest with marker "M", the NT records the producer's disconnecting state and the Interest's sequence number, triggers caching to store Interests requesting producer data, and replies with MD containing the NT' s proprietary name prefix to differentiate NTs.
- Upon receiving an Interest with marker "H", the NT records the producer' s connecting state and sequence number, replies with HD, extracts the producer' s content name from the HI, and queries whether it has cached Interests for that content name, releasing them if found.

NDN routers recognize special markers and create/update TeFIB entries by populating different interface information based on the marker type. Upon receiving Data with marker "M", routers extract the /Routing Prefix and the incoming interface of the MD to create TeFIB entries. Upon receiving Data with marker "H", routers use the incoming interface information of the corresponding HI (recorded in the PIT entry) and the /Routing Prefix to create TeFIB entries, as detailed in Section 1.2.2.

1.2.2 Creating/Updating Temporary Forwarding Table (TeFIB)

NDN routers create TeFIB by processing MD/HD packets returned from the NT. As shown in Figure 3, upon receiving a Data packet, the router first processes it normally by matching it against PIT entries and forwarding it downstream if a match exists. The router then searches for the Tab field in the Data. If a marker is found, the router extracts the producer' s content prefix /Routing Prefix and creates/updates the TeFIB entry with different interface information based on the marker type. For marker "M", the router establishes a TeFIB entry using the extracted /Routing Prefix and the incoming interface of the MD. For marker "H", the router establishes a TeFIB entry using the incoming interface of the HI, recorded in the PIT entry.

TeFIB coexists with normal FIB entries created by the routing plane but has higher priority and can be refreshed at any time. Each TeFIB entry includes a timer; when the timer expires, the entry is deleted, or it can be refreshed through updates. This prevents explosive growth of forwarding entries in TeFIB. The TeFIB creation/update process relies on authenticated Interest/Data exchanges between the mobile producer and NT—specifically, the notification messages MI, HI and authenticated Data packets MD, HD. The NT verifies the signature of these Interests using a signature key to confirm the producer' s identity, ensuring data authenticity and reliability. Algorithm 1 describes the TeFIB creation process in NTMP.

1.2.3 Caching and Retransmission Mechanism NTMP designs network terminals (NT) to dynamically track mobile producers. An NT consists of fixed nodes at the network edge that provide public interfaces to support producer mobility without affecting normal user node operations. User nodes can connect or disconnect freely without impacting host autonomy and can transfer services to other user nodes before disconnection.

1) Recording and Caching Mechanism: CRM-NT implements NT recording and caching functions. Through the mobile producer' s dynamic notification protocol, the NT records producer handover states and replies with corresponding Data packets. The NT provides data caching triggered by the producer' s notification protocol, enabling it to cache consumer Interests before the producer reconnects, preventing timeout drops. Specifically, upon receiving a notification packet MI with marker "M" , the NT: (1) records the producer' s disconnecting state, (2) extracts and announces the producer' s content name /Routing Prefix, (3) enables caching, and (4) replies with MD containing the NT' s proprietary name prefix. Upon receiving HI with marker "H" , the NT: (1) records the producer' s connecting state, (2) replies with HD, (3) extracts the producer' s content name, and (4) queries and releases cached Interests matching that name.

2) Marking and Retransmission Mechanism: CRM-NT introduces a special marker "C" for rapid Interest retransmission, added by the NT to cached consumer Interests. Following the design principle in Section 1.2.1, marker "C" is added to the Tab field of cached Interests, indicating NT cache release. When the NT receives a producer' s HI, it queries whether it has cached Interests for the content prefix in the HI. If found, it adds marker "C" when triggering the release mechanism. NDN routers processing Interests with marker "C" record the Interest' s incoming interface in the PIT and forward directly, as shown in Figure 4.

Marker "C" alters the Interest retrieval process in routers compared to normal processing. As shown in Figure 4, upon receiving an Interest, the router first queries the CS for matching data. If not found, it forwards downstream and queries the PIT. If a match exists in the PIT, the router adds the Interest' s incoming interface to the PIT entry' s interface list and checks for marker "C". If present, the router performs a longest prefix match in TeFIB/FIB and forwards accordingly. This controlled forwarding mechanism for cached Interests solves the problem of NT-cached Interests being dropped due to existing PIT entries. Algorithm 2 details the forwarding strategy for consumer requests in NTMP.

1.3 NTMP Mechanism Rationality Analysis

This section demonstrates that NTMP ensures effective and correct forwarding strategies. We first prove that NTMP creates a valid forwarding path to mobile producers, then prove that consumer requests ultimately reach the mobile producer.

Assume the NDN network is a graph G=(V, E) with V nodes and E links, where node nNT serves as the NT, node nMP as the mobile producer, any node nC as a consumer, and remaining nodes n V as routers. Let pNT be the routing prefix advertised by nNT in the routing plane, and pMP be the content prefix of mobile producer nMP. Let E=[p, n → h] represent a FIB entry at node n with name prefix p and next-hop h. For nodes m, n and prefix set p, let f(p, m → n) denote a forwarding path between m and n regarding p.

Definition 1: A valid forwarding path f(p, m → n) of length l (l>0) consists of a series of FIB forwarding entries [e_1, e_2, ···, e], where e =[p , n → h] for i=1,2,···,l.

Assume n V: f(pNT, n → nNT), and n V: f(pMP, n → nMP)=[e_1, e_2, ···, e]. The producer sends mobility signaling MI before disconnecting, and the NT replies with MD. After reconnecting, the producer sends HI, and the NT replies with HD.

Corollary 1: When the producer receives MD, f(pMP, nMP → nNT).
Proof: The producer' s MI reaches nNT along forwarding path f(pNT, nMP → nNT) of length l_1. Intermediate routers create TeFIB based on MD returned from nNT, so e =[p , n → h] f(pNT, nMP → nNT), we have t_1(l-i+1)=[pMP, n → h]. Therefore, f(pMP, nMP → nNT)=[t_1, t_2, ···, t $_1$].

Corollary 2: When the producer receives HD, f(pMP, nNT → nMP).
Proof: The producer' s HI reaches nNT along path f(pNT, nMP → nNT) of length l_2. Intermediate routers create TeFIB based on HD, so e =[p , n → h] f(pNT, nMP → nNT), we have t_2(l-i+1)=[pMP, h → n]. Therefore, f(pMP, nNT → nMP)=[t_1, t_2, ···, t $_2$].

Proposition 1: After the producer reconnects, n V: f(pMP, n → nMP).
Proof: Based on the assumption n V, f(pMP, n → nMP)=[e_1, e_2, ···, e], Corollary 1 (f(pMP, nMP → nNT)=[t_1, t_2, ···, t $_1$]), and Corollary 2 (f(pMP, nNT → nMP)=[t_1, t_2, ···, t $_2$]). e =[pMP, n → n] and t =[pMP, n → n] (e and t belong to FIB and TeFIB entries at node n respectively). Then f(pMP, nC → nMP)=[e_1, e_2, ···, e $_1$, t_1, t_2, ···, t $_1$]. After the producer reconnects, f(pMP, nNT → nMP)=[t_1, t_2, ···, t $_2$]. After reconnection, when the consumer sends requests, e =[pMP, n → n] and t =[pMP, n → n], then f(pMP, nC → nMP)=[e_1, e_2, ···, e $_1$, t_1, t_2, ···, t , t , t_2, ···, t $_2$] (where m≤l_1, n\$ \$1, and n=m+1).

2 Simulation and Performance Analysis

We implemented the complete NTMP mechanism in ndnSIM and conducted comprehensive simulations. This section describes the simulation setup and presents a thorough analysis of results.

2.1 Simulation Setup

As shown in Figure 5, the basic network topology for simulation consists of a 6$×$6 grid of nodes connected via point-to-point links with 100m spacing. Each routing node serves as both an access point and router, enabling user communication via wired links and receiving user packets via wireless links. Wired links are configured with 100 Mbps bandwidth and 10 ms delay. Wireless links employ IEEE 802.11n WiFi at 5 GHz with Minstrel rate adaptation and a log-distance propagation model with Rayleigh fading. Wireless access points have a 50m transmission range. Producers connect via AP nodes and switch between different access points. All nodes communicate using the NDN protocol. The consumer connects to node 6, the producer’ s initial location is node 1, the RV/mapping server connects to node 16, and the NT connects to node 1. Table 1 details the simulation parameters.

To evaluate NTMP performance, we designed a dynamic scenario simulating producer mobility following the random waypoint mobility model: producers move at constant speed for a fixed distance then randomly change direction. In simulations, producers move 200 meters before changing direction randomly. Producer speeds range from 3-30 m/s, with 200 simulation runs conducted for each speed setting. Simulation duration is 100 seconds, with consumers sending one Interest per second to retrieve producer data. We compared NTMP against RP and KITE schemes, where RP is an anchor-based approach and KITE is a classic Trace-based solution.

2.2 Performance Analysis

2.2.1 Packet Loss Rate Analysis Figure 6 shows average packet loss rates at different speeds with a consumer sending rate of 1 packet per second. NTMP’ s average packet loss rate gradually decreases and stabilizes around 3% across 3-30 m/s. KITE’ s loss rate remains stable around 20%, while RP’ s loss rate increases with speed. In NTMP, the NT enables caching service after producer disconnection to store consumer Interests. At low speeds, longer handover times cause cached Interests to expire and be dropped. At higher speeds, producers complete handover within the Interest lifetime, allowing cached Interests to be forwarded successfully, thus reducing loss rates. KITE and RP lack caching functionality and cannot update producer location promptly during handover, causing Interests to be forwarded to old locations and dropped. Consequently, NTMP achieves 14.24% and 25.81% lower packet loss rates compared to KITE and RP, respectively.

2.2.2 Transmission Delay Analysis Figure 7 presents average transmission delay results at different speeds. As speed increases from 3-30 m/s, NTMP’ s average delay decreases and stabilizes around 352.1 ms, while KITE’ s delay remains around 650 ms and RP’ s delay increases with speed. NTMP reduces average delay by 46.19% and 56.11% compared to KITE and RP, respectively. The CRM-NT mechanism reduces retransmissions through caching and redesigns forwarding rules for cached Interests to further reduce transmission delay. In KITE, Interests forwarded to the producer' s old location are dropped, requiring consumer retransmission. In RP, high-speed producers trigger frequent handovers requiring location updates to the mapping server, and consumers must request producer location information after Interest timeouts, causing information lag that increases with speed. Thus, NTMP maintains stable performance during high-speed mobility.

To further examine handover support, Figures 8 and 9 show consumer request response rates at 15 m/s and 30 m/s. During 100-second simulations, NTMP delivers more Data packets to consumers than KITE and RP. Magnified views reveal that NTMP restores normal communication fastest during single handovers, followed by KITE, with RP being slowest. These results confirm NTMP' s superior support for producer mobility.

2.2.3 Handover Overhead Analysis Figure 10 shows average handover overhead at different speeds. NTMP' s overhead increases gradually with speed, KITE' s remains stable around 100, and RP' s increases more sharply than NTMP. NTMP reduces overhead by 65.7% and 49.18% compared to KITE and RP, respectively. In NTMP, producers send only two mobility signaling messages per handover to create/update TeFIB, ensuring path validity without requiring maintenance signaling during connection, thus reducing overhead. Sequence numbers prevent stale updates, maintaining TeFIB freshness. In KITE, producers must periodically send mobility signaling to maintain the "trail" to the RV. In RP, both producers and consumers send signaling messages—producers update location during handover, and consumers query the mapping server before requesting content. Consequently, RP' s overhead always exceeds NTMP' s and increases with handover frequency.

2.2.4 Path Stretch Analysis Figure 11 shows average hop counts for consumer Interest forwarding in the 6$×$6 topology. NTMP' s hop count is nearly 15.6% lower than KITE' s, though RP achieves the lowest hop count because consumers obtain the producer' s latest location directly and forward along the shortest path. NTMP' s average hops range 7.68–8.51 versus KITE' s 9.29–10.62. NTMP introduces network terminal nodes at the edge, designing a handover notification mechanism that leverages terminal characteristics. When producers move near the network terminal, path stretch is lower than RV-based anchor schemes, demonstrating that anchor selection critically impacts path stretch. Both NTMP and KITE can use routing shortcuts under certain conditions to avoid worst-case path stretch. NTMP utilizes edge-located NTs to minimize path stretch impact in small-scale topologies, while in large-scale networks, mobile producers can select optimal NTs at different topological positions to reduce stretch.

Overall, simulation results show NTMP maintains stable performance as speed increases, making it suitable for frequent producer mobility. Compared to KITE and RP, NTMP significantly reduces packet loss, transmission delay, and handover overhead while optimizing path stretch.

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3 Conclusion

NDN represents a promising future Internet architecture, and researching producer mobility is crucial for its completeness. This paper analyzed challenges in NDN producer mobility and limitations of existing solutions, then proposed NTMP, a network terminal-based mobility management mechanism. NTMP replaces traditional servers with network terminal nodes and designs a handover notification mechanism for real-time producer tracking, improving handover notification efficiency, reducing TeFIB update frequency, and minimizing handover overhead. By creating temporary forwarding paths, NTMP reduces global routing updates and enhances mobile content availability. The CRM-NT mechanism improves cached Interest retrieval, reducing consumer Interest transmission delay. Simulation results demonstrate that NTMP fully supports producer mobility in wireless environments, achieving lower packet loss rates, reduced retrieval delay, minimized overhead, and improved path stretch metrics, outperforming comparison schemes across all performance indicators.

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