EN-PreD: Early Notification-driven Pre-Declaration for Low-Latency Producer Mobility in 5G-ICN Edge Networks

Shintaro Konno
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
shintaro.konno@g.softbank.co.jp

Yushi Yamada
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
yushi.yamada@g.softbank.co.jp

Sho Isobe
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
sho.isobe02@g.softbank.co.jp

Hailong Zheng
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
hailong.zheng@g.softbank.co.jp

Cheanfei Shee
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
cheanfei.shee@g.softbank.co.jp

Nagare Kameno
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
nagare.kameno@g.softbank.co.jp

Shin Owada
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
shin.owada01@g.softbank.co.jp

Nobuyasu Seki
Data Infrastructure Strategy Division
SoftBank Corp.
Tokyo, Japan
nobuyasu.seki@g.softbank.co.jp

***Abstract*— In Information-Centric Networking, it is known that Producer Mobility causes delays in data retrieval by consumers. This delay occurs because the routing information is typically updated only after handover. We present EN-PreD, a control-plane mechanism that uses 5GC Early Notification via the Network Exposure Function to pre-declare ΔFIB (delta FIB, i.e., changes in the Forwarding Information Base) entries at target ICN routers in parallel with handover. On an AWS testbed (Free5GC, UERANSIM, Zenoh), EN-PreD reduces median service interruption by approximately 11%. EN-PreD strengthens Producer Mobility without dual connectivity or centralized anchors and fits cleanly into 5G-ICN integration.**

Keywords—Information-Centric Networking; Named Data Networking; Producer Mobility; Zenoh; 5G Core; MEC

I. Introduction

The fifth-generation mobile communication system (5G) and its evolution 5G-Advanced (5G-A) aim to support ultra-low-latency and massive-connectivity services such as smart mobility and smart cities [1][2]. These cyber–physical applications require sensor data from the physical space to be delivered to the cyber space, processed in real time, and fed back as control actions. To meet such latency requirements, it is essential to (i) collect geographically distributed data with low delay and (ii) deploy Multi-access Edge Computing (MEC) infrastructure for real-time, low-latency processing [3][4][5]. MEC places applications and data processing on edge servers close to IoT devices, but mobile devices such as vehicular sensors frequently change their serving edge server as they move (Fig. 1), requiring mobility management across handovers and increasing the burden on application developers and operators [5].

To mitigate this burden, a middleware that provides location transparency has been studied. Location transparency refers to

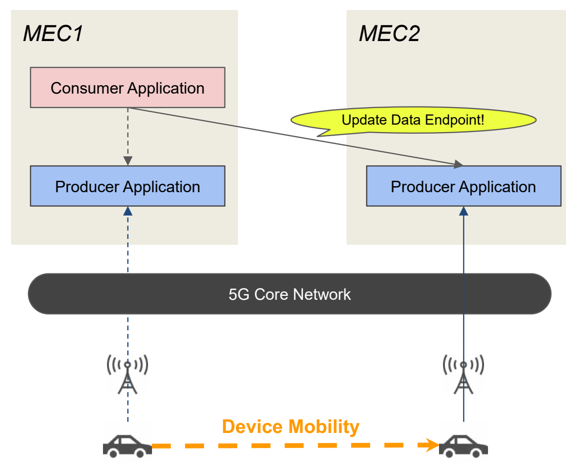

Fig. 1. Service continuity challenge in 5G-A MEC: mobile devices change their serving edge server as they move, requiring effective mobility

the ability to use data resources without awareness of their physical location. Information-Centric Networking (ICN) is a representative approach [6], allowing users to access data by names rather than addresses. Representative implementations include Content-Centric Networking (CCNx) and Named Data Networking (NDN) [6][7]. Zenoh [8][[9] inherits key concepts from ICN, particularly NDN, and provides a unified Query/Pub/Sub API for loosely coupled data sharing across devices, edges, and the cloud.

In this work, we adopt Zenoh as location-transparent middleware and propose an architecture for seamless data delivery between mobile devices and applications in a 5G-A MEC environment. Previous studies have reported that in NDN, data retrieval is interrupted until Forwarding Information Base (FIB) updates are completed during Producer Mobility [10]. The

FIB is the routing table in each NDN router, mapping data names to forwarding interfaces. In this work, we use ΔFIB to denote the set of new or updated FIB entries that must be propagated to relevant routers when a producer moves. Mobility support methods are generally categorized into proactive and reactive approaches. The former suffers from control overhead because of dual connectivity or centralized anchors, while the latter suffers from service interruption due to waiting for FIB convergence [11]. To overcome these issues, we design Early Notification-driven Pre-Declaration (EN-PreD), which leverages the 5GC's Early Notification to proactively propagate ΔFIB entries in parallel with handover processing.

The contributions of this work as follows: (i) an integrated Zenoh-5GC architecture for distributed MEC, (ii) EN-PreD which parallelizes ΔFIB updates with 5G handover by Early Notification (EN), and (iii) an AWS-based implementation and evaluation.

II. Related Work

Prior work on Producer Mobility can be categorized into reactive and proactive approaches. Reactive anchor-less schemes (e.g., MAP-Me [12]) update the FIB along the previous path, whereas proactive ones (e.g., PMLS [13]) prepare the next path via dual connectivity. A complementary line of work integrates 5GC control with ICN updates [14]. The main ideas and trade-offs are summarized in Table I.

However, these existing methods face significant limitations: reactive schemes risk update storms and path stretch, while proactive approaches require additional overhead or dual connectivity. Moreover, few studies fully exploit the standard capabilities of 5G-ICN integration. To address these challenges, we propose a new approach that leverages 5G standard capabilities to pre-declare ΔFIB entries in parallel with handover processing.

III. Proposed Method

This section presents our mechanism, EN-PreD, to shorten Producer Mobility interruption in ICN.

A. *Basic Idea*

In conventional Producer Mobility managements, FIB updates at ICN routers occur only after the completion of 5G handover, resulting in serial delays. The basic idea of EN-PreD is to leverage the EN provided by the 5GC to proactively disseminate ΔFIB entries to target ICN routers in parallel with the handover process. The service interruption time L in the conventional case is:

$$L = A + B \tag{1}$$

and with EN-PreD it becomes:

$$L = \max(A, R + B). \tag{2}$$

Here, A is the 5G handover time, B is the FIB propagation time, and R is the EN-PreD control time.

B. *Early Notification*

In 3GPP 5G System, Early Notification denotes a pre-change notice of user-plane path reconfiguration, typically a change of the Data Network Access Identifier (DNAI). It is defined by the DNAI change type enumeration: EARLY (pre-change), LATE (post-change), and EARLY_LATE (both) in TS 29.571 [15]. In EN-PreD, we treat EN as a proactive trigger to disseminate ΔFIB entries to target ICN routers in parallel with the handover process.

TABLE I. COMPARISON OF PRODUCER-MOBILITY APPROACHES

Approach	Representative	Key idea	Trade-off
Reactive (anchor-less)	MAP-Me [12]	Updates FIB along the previous path without anchors; data-plane triggers for fast reconnection	Transient path stretch; update storm risk on rapid moves
Proactive (dual connectivity)	PMLS [13]	Prepares the next path via dual connectivity to cut interruption	Extra radio/control overhead; DC availability required
5G–ICN control integration	5G–ICN Integration [14]	Coordinates cellular handover and ICN state via control-plane coupling	Requires 5GC hooks and function integration

C. *Mobility Management Function*

To realize EN-PreD, we introduce a new component called the Mobility Management Function (MMF). The MMF acts as an Application Function (AF) as defined by 3GPP, connecting to the Network Exposure Function (NEF) and subscribing to User Equipment (UE) mobility events.

D. *Processing Flow*

Fig. 2 illustrates the processing flow of EN-PreD, which consists of the following four steps:

1) Subscription Registration: The MMF registers with the NEF to subscribe to UE mobility events, allowing it to receive handover-related notifications from the 5GC.

2) Handover Preparation (Mobility Detection): The gNB (next generation NodeB) selects the target cell for handover based on measurement reports and policies. In parallel, a UE mobility event is generated via the NEF's Event Exposure API, triggering Pre-Declaration.

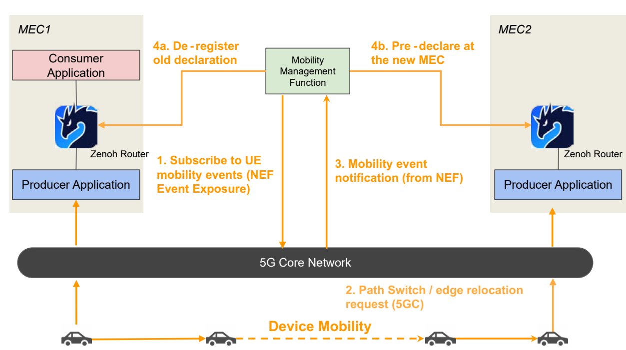

Fig. 2. EN-PreD processing flow: (1) mobility-event subscription, (2) handover preparation, (3) EN reception at the mobility function, (4) ΔFIB pre-declaration to target ICN routers.

3) EN Reception: The NEF sends an EN to the MMF, specifying the UE and its target cell for handover.

4) ∆ FIB Pre-Declaration (Routing Update): Upon receiving the EN, the MMF proactively propagates ∆FIB entries to the target ICN routers (4b) and at the same time, deregisters the old declaration at the previous MEC node (4a). This ensures that FIB updates are completed in parallel with the 5G handover process, reducing service interruptions.

IV. Evaluation

A. Experimental Environment

We evaluate on an AWS EC2 testbed using UERANSIM [16] and Free5GC [17] to emulate handover and EN. Zenoh serves as the ICN router to enable name-based delivery and apply ∆FIB pre-declaration (Fig. 3).

The main experimental settings are as follows:

－ Cloud: AWS EC2, all VMs in the same region(ap-northeast-1) and VPC

－ OS: Ubuntu Server 20.04

－ Instance types: t3a.xlarge for the 5GC and UE/gNB, t3a.medium for MEC nodes, AF/MMF, and the consumer

－ Software: Free5GC v3.4.0, UERANSIM v3.2.6, Zenoh v0.11.0

－ Network: no artificial delay or packet loss is injected

B. Evaluation Metric

The evaluation metric is the service-interruption time L: the duration from the start of handover until the Consumer can resume data retrieval. The model, the notation (A, B, R) and the expression L are defined in Section III-A; here, we report medians and interquartile ranges over 20 trials per scenario.

C. Experimental Procedure

We compare a baseline (without EN-PreD) vs. EN-PreD. The consumer issues Zenoh queries every five seconds; the UE hands over from MEC-1 to MEC-2. In the EN-PreD case, the 5GC sends an EN to the MMF, which pre-declares ∆FIB. We log timestamps to compute L (20 trials per scenario).

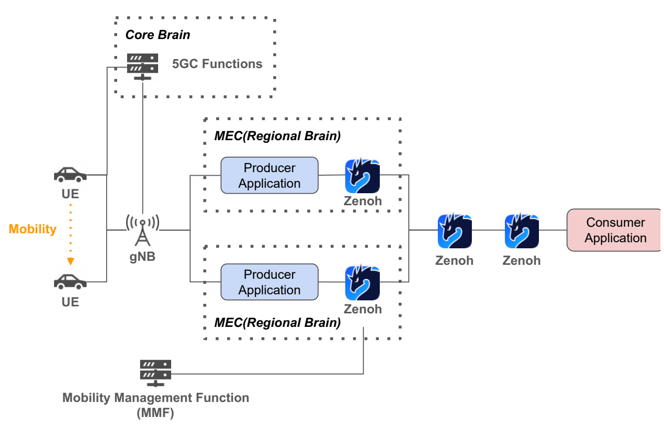

Fig.3 Experimental testbed constructed on AWS virtual machines. The UE and gNB were emulated using UERANSIM, and the 5GC was implemented with Free5GC. Zenoh was employed as the ICN router implementation. UE handover was triggered by varying Measurement Report values during the experiment to emulate mobility.

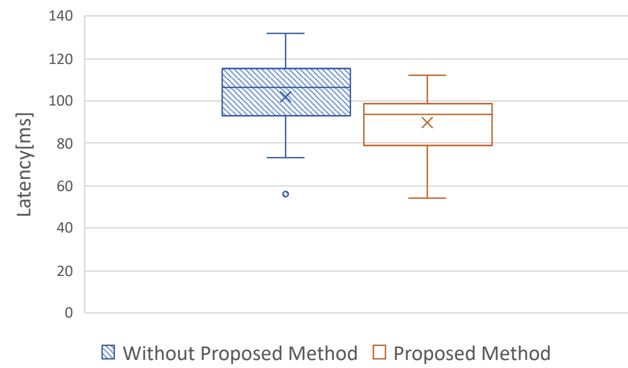

Fig.4 Service interruption (box plots) with/without EN-PreD (n=20): medians 106 ms vs. 93.5 ms; IQRs 93–114.5 ms vs. 83–98.25 ms.

D. Results

Fig. 4 shows the box plot results for the baseline and EN-PreD scenarios, illustrating the distribution of service interruption times measured during the handover experiments. Without EN-PreD, the median interruption was 106 ms with an IQR of 93–114.5 ms. With EN-PreD, the median was reduced to 93.5 ms with an IQR of 83–98.25 ms. Thus, EN-PreD achieved an 11% reduction (−12 ms), and the entire distribution shifted toward lower latency, indicating more stable performance. This confirms that EN-PreD can effectively mitigate handover-induced service interruption by exploiting EN-triggered ∆FIB pre-declaration in our testbed.

V. Discussion

EN-PreD parallelizes ∆FIB pre-declaration with the 5G handover, thereby shortening the interruption window. This approach allows the routing update process to proceed simultaneously with the handover procedure, eliminating the serial bottleneck present in conventional Producer Mobility management. As a result, EN-PreD achieved an approximately 11% reduction (−12 ms) in median service interruption time, as shown in Fig. 4.

This improvement demonstrates the benefit of integrating control-plane signaling (i.e., Early Notification) with data-plane reconfiguration in 5G-ICN edge environments. By proactively propagating ∆FIB entries during the handover, consumers can resume data retrieval with lower latency. Furthermore, because EN-PreD does not require dual connectivity or centralized anchors, it can be applied to distributed MEC scenarios without major changes to existing infrastructure.

Beyond this concrete prototype, EN-PreD highlights a more general design pattern in which fine-grained 5GC mobility events are used as triggers for adapting edge routing. In our implementation, EN notifications drive ∆FIB updates in a Zenoh-based ICN layer, but the same principle could be applied to other name-based or service-based routing schemes as long as they can consume information about the producer's new attachment point. This suggests that EN-PreD is not tightly coupled to a specific ICN realization and could serve as a reusable building block for broader 5G edge service continuity mechanisms.

VI. CONCLUSION AND FUTURE WORK

This paper proposed EN-PreD (Early Notification-driven Pre-Declaration) to reduce service interruption during Producer Mobility in 5G-Advanced MEC environments. EN-PreD leverages the Early Notification function of the 5GC to proactively disseminate ΔFIB entries to target ICN routers in parallel with the handover procedure. Evaluation on an AWS-based testbed using Free5GC, UERANSIM, and Zenoh demonstrated that EN-PreD reduced median service interruption time by about 11% (−12 ms). Overall, EN-PreD strengthens Producer Mobility support in 5G-ICN integration and contributes to highly reliable and low-latency mobile applications.

Our current evaluation, however, has clear limitations. The testbed involves a single UE and two MEC nodes in a relatively small ICN topology, and all links are confined to a single cloud region without additional background traffic. Therefore, the present results should be interpreted as a proof of concept rather than a comprehensive scalability study. As future work, we plan to evaluate EN-PreD's scalability and robustness in a larger-scale network with more realistic conditions, i.e., a network with more regional nodes, gNBs, and mobile UEs.

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