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Anchorless mobility through hICN
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Abstract

This document first discusses the use of locators and identifiers in mobility management architectures, and their implication on various anchorless properties. A new architecture is then proposed that is purely based on identifiers, and more specifically names as defined in Hybrid-ICN (hICN). The document then focuses on two main cases: the end-point sends data (data producer) or the end-point receives data (data consumer). These two cases are taken into account entirely to provide anchorless mobility management in hICN.

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1. Introduction

New usages of the network and the rapid growth of the Mobile Internet calls to reconsider the way we deploy and operate IP networks, where mobility is not built into the design, but rather added as an afterthought. Notable examples are IETF Mobile IP and its variants [RFC5944] and [RFC2275] 3GPP GTP-based architecture [TS29.274], both based on tunnelling and encapsulation.

One identified difficulty in proposing mobility models for IP lies in the semantic overloading of IP addresses which are both host identifiers, and locators used for routing. Starting with LISP, the identifier/locator split paradigm has shown promising results in virtue of its scalability properties with respect to routing tables entries, and the possibilities it offers in terms of mobility. Several solutions have been proposed around this concept, namely ILNP, ILSR, and ILA. One common facet of these proposals is to embrace the current trend of a clear separation between the control and data planes, which both allows for distribution of the control infrastructure, as well as anchorless operations in the data plane, including facilitated local breakout.

The counterpart of these architectures is an increased dependency on the control plane which is responsible for binding the identifiers used by the application at the edge to the locators used to forward the traffic in the network. Device mobility will typically induce a change of IP address, which makes performance of flows in progress dependent on interactions with those control elements which have to remain globally consistent.

In this document, we first propose to clarify protocol descriptions by adopting a new terminology of control-plane and data-plane anchors to characterize anchorless operations, and show their tight coupling with the use of locators and identifiers. This definition serves to position Loc/ID-split architectures with respect to the traditional use of tunnels, before advocating to push this step further and perform mobility management purely based on identifiers. We introduce a mobility approach based on Hybrid ICN (hICN) as described in [I-D.muscariello-intarea-hicn], for which we perform an in-depth analysis of mobility considerations. We show how this proposal can help addressing further challenges faced by networks today, such as multihoming and multipath, while preserving the simplicity and end-to-end design of the current Internet.

2. Locators, identifiers and anchorless mobility management

2.1. Terminology

The consideration of mobility in network design shares the challenges raised for routing for instance in [RFC6115], where the terminology for locators and identifiers is presented.

Because they are intrinsically bound to the topological location of a node, session established through locators require additional mechanisms to support mobility, including the presence of anchor points in the network. The notion of `_anchor_` and the resulting `_anchorless_` properties of mobility schemes are prone to different interpretation depending on the context. The following definitions attempt to reconcile those interpretations and propose a unifying terminology used throughout this document.

Anchor An anchor refers to a specialized node or service, possibly distributed, functionally required by a network architecture for forwarding or mobility. This is in contrast to decentralized architectures. Configuration of these anchors, including their location, will directly affect the overall scheme performance. We follow the classic distinction between control plane and user (or data, or forwarding) plane to distinguish control-plane anchors and user-plane anchors.

User-plane anchor A user-plane anchor is a node through which traffic is forced to pass. An example of such anchor is the indirection point in Mobile IP.

Control-plane anchor A control-plane anchor refers to a node that is not responsible for carrying traffic, but is needed for the operation of the forwarding and/or the mobility architecture. An example of such anchor is the resolution or mapping service of LISP. We remark that while not being on path, such anchors might affect the performance of the user-plane due to resolution delays or indirection (following a mapping cache miss for instance).

Anchorless This term qualifies approaches that do not involve any user-plane nor control-plane anchor. The challenge for such full anchorless approaches are exacerbated during mobility of both end points at the same time, as they cannot rely on any stable anchor point to preserve connectivity. Nor they can rely on routing mechanism that would be the source of overhead and instability.

2.2. Towards locator-independent network architectures

We distinguish network architectures based on their use of location independent identifiers (or names) and locators for forwarding.

Locator-based architectures

As mentioned earlier, IP architectures are typically operated based on locators corresponding to the IP addresses of the host interfaces in their respective network attachment, used also as session identifiers. This results in a complex mobility architecture built on top, involving traffic anchors and tunnels to preserve the identifier exposed to the transport layer: IP/IP or GRE tunnels in Mobile IP, and GTP tunnels in 3GPP architectures.

The limitations of locator-based schemes in terms of complexity, overhead and efficiency are well-recognized and led to other alternatives to be considered.

Locator-ID separation architectures

LISP [RFC6830] was the first proposal to distinguish between the usage of IP addresses as locators or identifiers by explicitly defining two namespaces, respectively used for endpoint identification and forwarding. A mapping service is further used to bind an identifiers to a given location, and updated after mobility. From there, several approaches have been defined, either host-based like SHIM6 [RFC5533] or HIP [RFC4423]), or network-based, like LISP [RFC6830], ILSR, ILNP [RFC6740] or ILA [I-D.herbert-intarea-ila] to cite a few.

An overview of these approaches and their use in mobility is presented in {I-D.bogineni-dmm-optimized-mobile-user-plane}}.

The main challenge consists in maintaining a (distributed) mapping service at scale, including the synchronization of local caches required for scalability and efficiency.

ID-based architectures

A third class of approaches exists that redefines IP communication principles (i.e. network and transport layers) around location-independent network identifiers of node/traffic. The interest of such architectures is highlighted in [I-D.vonhugo-5gangip-ip-issues] (referred to as ID-oriented Networking) for it removes the limitations introduced by locators and simplifies the management of mobility. The draft however question the possibility to realize such an architecture where node status and mobility would not affect routing table stability.

The work done around Information-Centric Networking (ICN) falls into such class of approaches that we refer to as purely ID-based, also known as name-based [I-D.irtf-icnrg-terminology], although as we will see, mobility management often departs from this principle.

2.3. Information-Centric Networking (ICN)

ICN is a new networking paradigm centering network communication around named data, rather than host location. Network operations are driven by location-independent data names, rather than location identifiers (IP addresses) to gracefully enable user-to-content communication.

Although there exist a few proposals, they share the same set of core principles, resulting in several advantages including a simplified mobility management [RFC7476]. For clarity, this section we focus on hICN [I-D.muscariello-intarea-hicn] an ICN implementation for IPv6.

2.4. Hybrid-ICN overview

Hybrid ICN (hICN) is an ICN architecture that defines integration of ICN semantics within IPv6. The goal of hICN is to ease ICN insertion in existing IP infrastructure by:

1. selective insertion of hICN capabilities in a few network nodes at the edge (no need for pervasive fully hICN network deployments);
2. guaranteed transparent interconnection with hICN-unaware IPv6 nodes, without using overlays;
3. minor modification to existing IP routers/endpoints;
4. re-use of existing IP control plane (e.g. for routing of IP prefixes carrying ID-semantics) along with performing mobility management and caching operations in forwarding plane;
5. fallback capability to traditional IP network/transport layer.

hICN architecture is described in [I-D.muscariello-intarea-hicn].

3. Hybrid-ICN Anchorless Mobility Management (hICN-AMM)

hICN, together with MAP-Me [I-D.irtf-icnrg-mapme], forms the basis for the mobility management architecture we describe in the rest of this document. Due to the pull based nature of hICN architecture, we distinguish consumer and producer nodes, for which mobility is handled differently

3.1. Consumer mobility in hICN

The consumer end-point is the logical communication termination that receives data. Due to the pull-based and connection-less properties of hICN communications, consumer mobility comes natively with ICN. It is indeed sufficient that the consumer reissues pending interests from the new point-of-attachment to continue the communication. Consumer mobility is anchorless by design, and managed without any impact on the transport session. It is however necessary to have an appropriate transport layer on top able to cope with eventual disruptions and path variations caused by the mobility event.

4. Producer mobility architectures

The producer end-point is the logical communication termination that sends data. Producer mobility is not natively supported by the architecture, rather handled in different ways according to the selected producer mobility management scheme, some of which diverge from the concept of pure ID-based architecture through their use of locators. Additional procedures have to be performed to maintain reachability as it moves in the network.

In fact, many schemes proposed for ICN are adaptations to the vast amount of work made in IP over the last two decades [RFC6301]. Surveys for the ICN family, resp. for CCN/NDN-specific solutions, are available in [SURVEYICN], respectively [SURVEY1] and [SURVEY2]. There has been however a recent trend towards anchorless mobility management, facilitated by ICN design principles, that has led to new proposals and an extension of previous classifications in [I-D.irtf-icnrg-mapme] and [MAPME] to the four following categories:

- * Resolution based solutions rely on dedicated rendez-vous nodes (similar to DNS) which map content names into routable location identifiers. To maintain this mapping updated, the producer signals every movement to the mapping system. Once the resolution is performed, packets can be correctly routed directly to the producer.
- * Anchor-based proposals are inspired by Mobile IP, and maintain a mapping at network-layer by using a stable home address advertised by a rendez-vous node, or anchor. This acts as a relay, forwarding through tunneling both interests to the producer, and data packets coming back.

- * _Tracing-based_ solutions allow the mobile node to create a hop-by-hop forwarding reverse path from its RV back to itself by propagating and keeping alive traces stored by all involved routers. Forwarding to the new location is enabled without tunneling.
- * _Anchorless_ approaches allow the mobile nodes to advertise their mobility to the network without requiring any specific node to act as a rendez-vous point.

4.1. Producer mobility in hICN

In an hICN network, regular routing protocols such as BGP, ISIS or OSPF can be used for propagating all prefix announcements and populate routers' FIBs. However, these protocols are not appropriate and should not be used to manage name prefix mobility, for scalability and consistency reasons.

The default mobility management for hICN is designed following the same principles and protocols as MAP-Me, an anchorless producer mobility management protocol initially proposed for ICN [I-D.irtf-icnrg-mapme] [MAPME]. It builds on an initial forwarding state bootstrapped by the routing protocol, and performs a lightweight path repair process as the producer moves. For simplicity, we refer to it as simply MAP-Me in the rest of the document.

In the rest of this section, we describe the specific realization of the protocol in an hICN context. Additional background and details are available in [I-D.irtf-icnrg-mapme] and [MAPME]. The solution is based on a path repair mechanism following mobility events, using dynamic FIB updates. Using data plane mechanisms for ensuring connectivity has been previously proposed in [DATAPLANE] to handle link failures, and has been proven more reactive than relying on typical control plane messaging.

5. Protocol description

5.1. Signalization messages; acknowledgements and retransmission

Signalization messages follow hICN design principles and use data plane packets for signalization. Signalization messages and acknowledgement are respectively Interest and Data packet (requests and replies) according to hICN terminology [I-D.muscariello-intarea-hicn]. Upon processing of those advertisements, the network will send an acknowledgement back to the producer using the name prefix as the source and the locator of the producer as the destination, plus the sequence number allowing the producer to match which update has been acknowledged.

Pending signalization interests that are not acknowledged are retransmitted after a given timeout.

5.2. Dynamic face creation and producer-triggered advertisements

The producer is responsible for mobility updates and should be hICN-enabled. It stores a sequence number incremented at each mobility event.

Faces in the producer are assumed synchronized with layer 2 adjacencies, upon joining a new point-of-attachment, a new face should be created. Face creation will trigger the increase of the sequence number, and per-prefix advertisement packets to be sent to the joined network.

Those advertisements should contain:

- * the name prefix as the destination address, plus a field indicating the associated prefix length;
- * the locator of the producer as the source address, that will serve for receiving acknowledgements;
- * a sequence number sequentially increased by the producer after each movement;
- * a security token (see Section 7.2).

Upon producer departures from a PoA, the corresponding face is destroyed. If this leads to the removal of the last next hop, then faces that were previously saved are restored in FIB to preserve the original forwarding tree and thus global connectivity.

5.3. Update protocol

Based on the information transmitted in the packet, and its local the network's local policy, the network might decide to update its forwarding state to reflect this change.

The update process consists in updating a few routers on the path between the new and a former point-of-attachment. More precisely, this is done in a purely anchorless fashion by sending a signalling message from the new location towards the name prefix itself. This packet will be forwarded based on the now-stale FIB entries, and will update forwarding entries to point to the ingress interfaces of each traversed router.

5.3.1. Illustration

{fig-mapme-update}} illustrates the situation of a P moving between access routers AR1 and AR2 while serving user requests:

1. A first interest towards the producer originates from remote. The producer answers with a Data packet.
2. Following this, the producer detaches from AR1 and moves to AR2.
3. As soon as it is attached to AR2, the producer sends an Interest Update towards its own prefix, which is forwarded from AR2 following the FIB towards AR1 (one of its former positions in the general case).
4. At each hop, the message fixes the FIB to point towards the ingress face, until the message cannot be further forwarded in AR1.
5. A subsequent message from remote will follow the updated FIB and correctly reach the producer's new location in AR2.

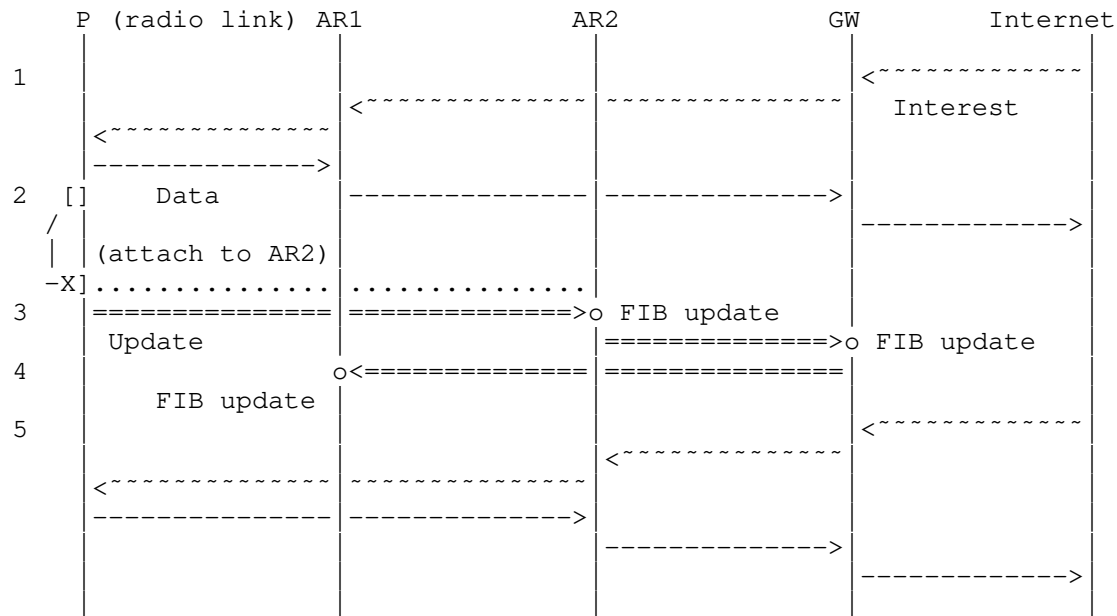


Figure 1: Signalization during producer mobility (MAP-Me)

Through this process, MAP-Me trades-off path optimality for a fast, lightweight and loop-free forwarding update. It has been shown in [MAPME] that stretch is bounded and typically kept low in scenarios of interest. This results from the fact that MAP-Me operations preserve the initial structure of the forwarding tree/DAG (direct acyclic graph), by only flipping its edges toward the new producer location.

MAP-Me does not perform a routing update. The protocol is complementary to the routing protocol in that it can run in between routing updates to handle producer mobility, at a faster timescale, and with a lower overhead. Routing updates can be performed at a lower-pace, to re-optimize routes once a node has relocated for instance.

5.3.2. Message content

The update messages should contain :

- * the name prefix as the destination address, plus a field indicating the associated prefix length;
- * the locator of the producer as the source address, that will serve for receiving acknowledgements;

- * a sequence number sequentially increased by the producer after each movement;
- * an optional security token.

5.3.3. Processing at network routers

At the reception of advertisement/update packets, each router performs a name-based Longest Prefix Match lookup in FIB to compare sequence number from the received packet and from FIB}. According to that comparison:

- * if the packet carries a higher sequence number, the existing next hops associated to the lower sequence number in FIB are used to forward it further and temporarily stored to avoid loss of such information before completion of the acknowledgement process.
- * If the packet carries the same sequence number as in the FIB, its originating face is added to the existing ones in FIB without additional packet processing or propagation. This may occur in presence of multiple forwarding paths.
- * If the packet carries a lower sequence number than the one in the FIB, FIB entry is not updated as it already stores 'fresher information'. To advertise the latest update through the path followed by the packet, this one is re-sent through the originating face after having updated its sequence number with the value stored in FIB.

5.4. Notifications and scoped discovery

The update protocol is responsible for reestablishing global connectivity with minimal changes to the FIBs. In order to further improve the reactivity of the scheme and better support QoS constraints of latency-sensitive traffic, we propose an additional mechanism named *Notifications*. It assumes hICN-enabled routers at the edge, and the existence of links between access routers, which are typically used for handover, and proposes to exploit them during mobility events, or to delay updates when possible.

5.4.1. Notification processing

Upon receiving a valid advertisement, the point-of-attachment will remember the presence of the producer, update its corresponding FIB entry but send no update. Previous next hops should be saved and restored upon face deletion so as to preserve the forwarding tree/DAG structure.

The rationale is that during mobility events, the producer will move access connected and neighbouring base stations. It will be then sufficient to make a scoped discovery around the last position known to forwarding to find the producer within a few hops.

5.4.2. Illustration

Figure 2 illustrate such as situation where an Interest is sent to the producer before it had the time to complete the update.

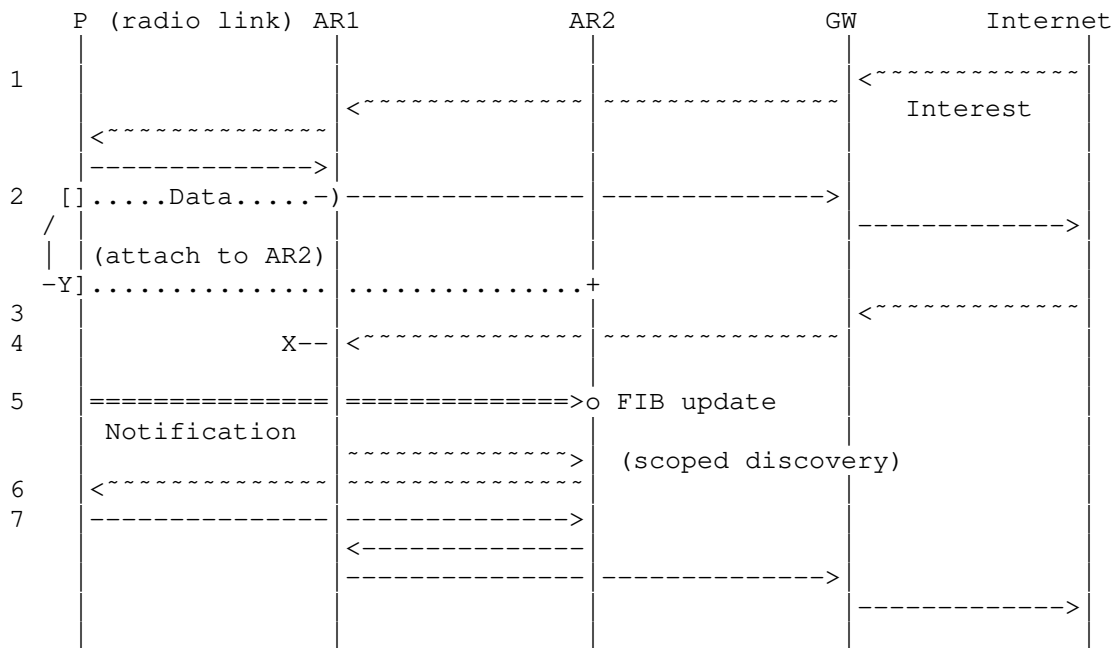


Figure 2: Scoped discovery during producer mobility

1. A first interest towards the producer originates from remote. The producer answers with a Data packet.
2. Following this, the producer detaches from AR1 and moves to AR2.
3. A subsequent message from remote arrives before the update could take place, and is thus forwarded to AR1.
4. AR1 has no valid face anymore towards the producer, and enters discovery mode by broadcasting the interest to neighbours.
5. In the meantime, we assume the notification reaches AR2.

6. Because the producer is attached to AR2, the producer can be directly reachable. Otherwise, AR2 would iterate the discovery to neighbours only if it had more recent information about the producer location than its predecessor (based on sequencing of regular Interests and Interest Updates).
7. The Data packet follows the reverse path to the consumer as usual.

6. Benefits

We now review the potential benefits of the general architecture we have presented using features from the hICN data plane for supporting consumer and producer mobility.

6.1. Overview

Native mobility : This mobility management process follows and exploits hICN design principles. It makes producer mobility native in the architecture by preserving all benefits of hICN even when consumers and/or producers are moving.

Anchorless mobility : Such approach belongs to the category of pure ID-based mobility management schemes whose objective is (i) to overcome the limitations of traditional locator-based solutions like Mobile IP (conf)using locators as identifiers and requiring tunnels, and (ii) to remove the need for a global mapping system as the one required by locator-identifier separation solutions. The result is a fully anchorless solution both in the data plane and in the control plane.

Local and decentralized mobility management : Mobility updates are handled locally and the routers that are affected are those on path between successive positions of the producer. In particular, remote endpoints are not affected by the event. Mobility is managed in a fully distributed manner and no third party is required. This does not prevent any centralized control (as discussed in [I-D.auge-dmm-hicn-mobility-deployment-options]), but makes the network robust to disconnectivity events.

The next section will discuss more in depth the following advantages

6.2. Simplicity, scalability, efficiency

As emerges from the points raised in the previous section, consumer mobility is transparently supported by an hICN network in virtue of the pull-based model and the way the forwarding path works. After moving, a consumer can just reissue pending interests once attached to the new access router at layer 2, without requiring any more information from L3 and above. This ensures a fast and simple handover, which can be further enhanced through additional mechanisms such as in-network caching. Consumer mobility is fully anchorless with hICN, and does not incur any signalization nor tunneling overhead.

This is particularly interesting considering that most mobile users are consumers only (e.g. linear video distribution, or large scale video conferencing where we typically have few presenters and most users are simply consumers).

Another aspect of using the unifying hICN architecture in replacement of the traditional tunnel-based mobile core is that it removes the need to maintain state for consumers and producers which are not mobile (eg. IoT sensors), or not currently moving.

6.3. Reduced latency through caching

While this is not strictly linked to mobility, we first illustrate the benefits of caching content close to the edge to reduce user latencies. This is particularly important for wireless networks such as WiFi or LTE which have non-negligible latencies especially during connection setup, or after an idle period. The characteristics of those radio networks are thus of interest for the performance of the mobility architecture as a whole.

The example in Figure 3 considers a mobile node that can move access two accesses linked to Access Routers (AR) AR1 and AR2, both connected to the Internet through a common gateway (GW). This same setup will be later used to illustrate the flow of packets during mobility events, eventually specializing AR into AP or eNB when it makes more sense.

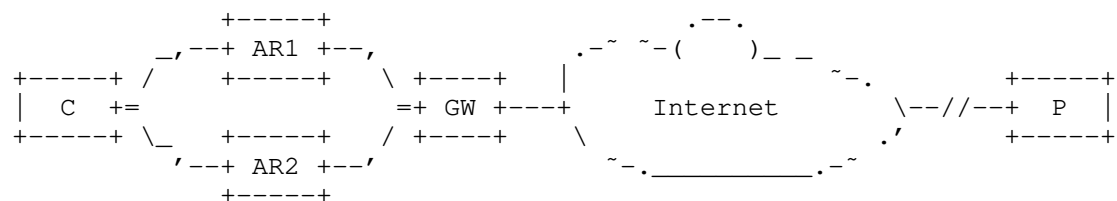
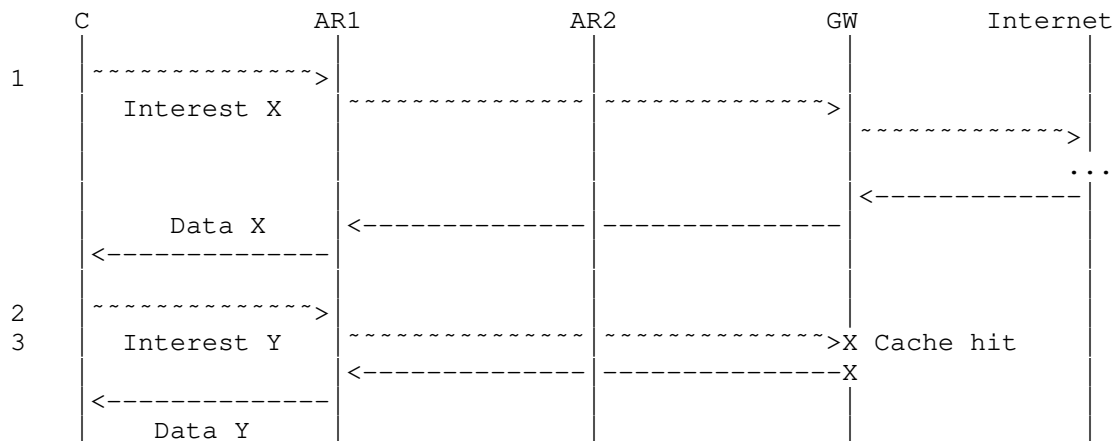


Figure 3: Simple topology with a multi-homed consumer

We represent in Figure 4 a simple data flow between the different entities involved in the communication between the mobile node M, and a remote producer available over the Internet.



LEGEND:

~~~~~>: Interest      <---- Data      =====> Signalization  
 ....-: L2 detach      .....+ L2 attach      X failure      o event

Figure 4: Reduced latency through caching

Numbers on the left refer to the following comments relative to the data flow:

1. The consumer issues a first interest towards name prefix X, which is transported up to the producer. A Data packet comes back following the reverse path and populating intermediate caches. Latency of the exchange can be seen by the distance between lines on the vertical axis.
2. The consumer now requests content B, which has previously been requested by another consumer located on the same gateway. Interest B thus hits the cache, refreshes the entry, and allows a lower round-trip latency to content both for consumer C and any subsequent request of the same content.



#### 6.4. Improved reliability through caching

Mobile networks might consist in unreliable access technologies, such as WiFi, responsible for packet losses. Figure 5 considers a similar scenario with a lossy channel (eg. WiFi) between the mobile and the first access router.

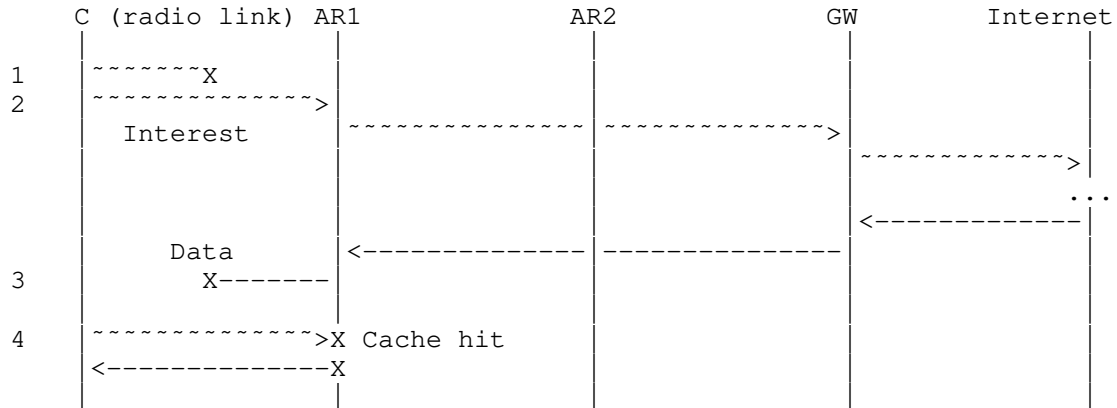


Figure 5: IU propagation example

1. The first issued interest is lost due to bad radio conditions.
2. Upon detection (either after a timeout, the consumer can just reissue the lost Interest).
3. This time the remote producer successfully replies but the Data packet is lost on the radio link.
4. Upon a similar detection, the consumer can reissue the lost Interest that will hit a locally stored copy at the router where the loss occurred (or again use a detection mechanism to retransmit the Data packet).

#### 6.5. Local mobility and recovery from common cache

The same mechanism can be used to recover from mobility losses after the consumer reconnects to the new network as the content will already be available in the cache at the junction router between the two accesses. This is particularly interesting in case of micro-mobility between access routers that are topologically close in the network.





Evaluations of the scheme have shown this scheme to preserve the performance of flows like mobile video distribution up to very high switching rates in the order of a second, not even considering optimization occurring from network support.

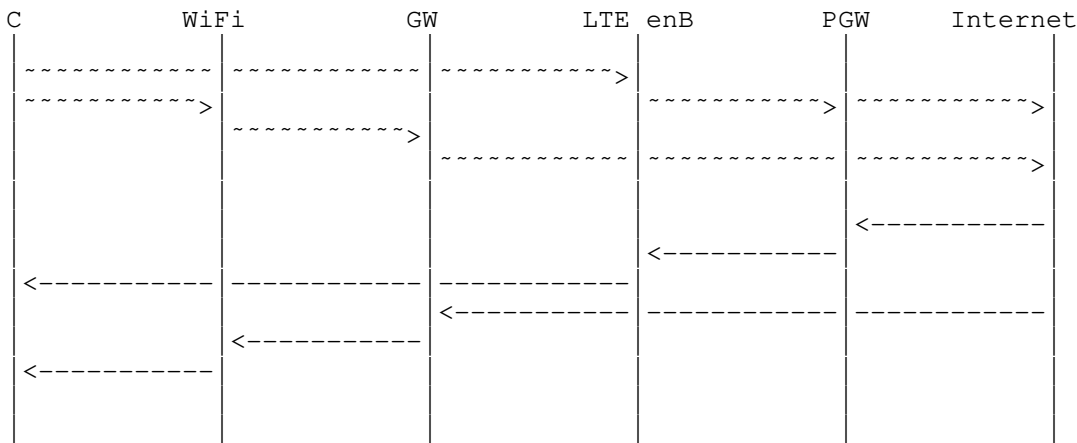
Mobility is handled transparently at the network layer with very fast handover times, due to the connection-less property of hICN. This makes it possible to offer reliable WiFi connectivity, besides its lossy nature as observed in previous use case and besides the frequency of mobility from one network access to the other.

#### 6.7. Bandwidth aggregation with consumer multihoming

Bandwidth aggregation can be realized dynamically through a congestion-aware load-balancing forwarding strategy at the client, with no a priori knowledge of paths. This is done similarly in the network by hICN forwarders, allowing a combination of multi-homing, multipath and multi-source data transfers. As all the paths are used at the same time, hICN offers the full network capacity to the users and tends to smooth fluctuations due to the radio channels.

Over an heterogeneous network access, hICN also offers a simple and cost-effective realization of heterogeneous channel bonding allowing an user to seamlessly roam across different radios or fixed lines (for increased reliability or reduced costs), or aggregate their bandwidth for high-throughput applications such as video streaming.

We illustrate a simplified data flows with one mobile consumer C alternating interests between a WiFi and LTE access points. The load balancing strategy would in that case optimize the split ratio between the two access to realize an optimal split. Note that in that case the relative distances on the vertical axis have not been respected here for readability.



Fine grained control from the application allows fully exploiting available bandwidth, resulting in an aggregated throughput equal to the sum of access throughputs, which is hard to achieve with existing solutions.

6.8. Traffic and signalization offload

As a natural consequence of its anchorless behavior, an hICN network can continue to operate in disconnected mode, for local mobility, even though no upstream entity is available.

In order to illustrate this, we slightly extend the previous topology in Figure 8 with an additional access network. To show that local mobility induces no traffic on upstream links, we further assume a failure on the link between the gateway (GW) and the Internet.

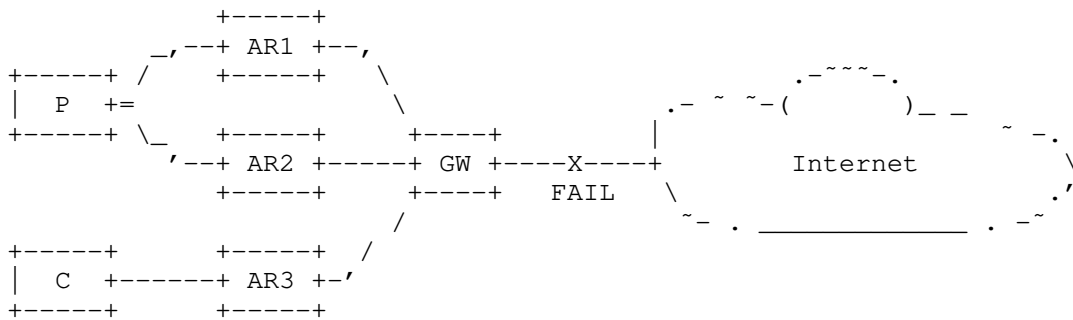


Figure 8: Access network disconnected from core



### 7.1. Interaction with non-hICN enabled routers

The realization of the architecture in a partial hICN deployment where some routers are not extended to support hICN mechanisms requires either to introduce additional functionalities or protocol support, or to reuse existing protocols achieving similar objectives (following hICN design).

One such example is the combination of ICMP redirect messages and Neighbour Discovery Proxies (NDProxy), that partially realizes the objectives of the update process:

- \* ICMP packets do not include sequence numbers however they can be transported as part of the payload; verification is deferred to the next hICN node which should send the packet backwards in case of verification failure to fix the incorrect path update.
- \* multipath is not supported in the pure-IP part of the network (which is the expected behaviour)

Identified concerns might be about the unexpected use of such protocols, the lack of available implementation for NDProxy, and security aspect related to redirect messages. The latter shares the fate of source routing, which has long been advocated against, and has recently gained popularity within the SPRING context. A proper security scheme is certainly the right way to address this problem, and we believe the set of benefits that we have listed are worth reconsidering such aspects.

### 7.2. Security considerations

As indicated in previous sections, signalization messages transmitted across trust boundaries must be secured. The choice of the solution will intimately depend on the selected protocols.

The use of ICMP packet might allow reusing existing security schemes such as AH headers [RFC4302], or SEND [RFC3971] (and its proxy extensions [RFC6496], [RFC5909]).

Alternatively, [SEC] has reviewed standard approaches from the literature and proposes a fast, lightweight and distributed approach that can be applied to MAP-Me and fits its design principles.

### 7.3. Discussion

Both consumer and producer mobility support multiple paths, however the support of mobility for a multihomed producer, is left for future updates of the present document.

Similarly, the proposed producer mobility solution is appropriate for the management of micro-mobility; its extension to multiple domains is out of scope.

## 8. IANA Considerations

This memo includes no request to IANA.

## 9. References

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