Mobility Support in the Internet Using Identifiers

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ABSTRACT

To support mobility in the Internet is becoming an urgent need in the near future. So far a large number of solutions are proposed providing various methods, but there still exist many open questions on how to add the new feature of mobility into the Internet architecture. In this paper we pay attention to the approaches with a new identifier namespace introduced. We give an overview to such schemes followed by a qualitative comparison, to find out that they differ in many aspects in achieving various design goals. We then focus on core mobility mechanisms of the proposals and abstract their common elements to form an overlay network called ION. By preliminary analyze on ION, we argue that a particular key point towards better identifier-based mobility support is to balance the tradeoff between mapping dynamics and routing path stretch in the overlay. Though lack of detailed modeling and data support (which is in our future work), we consider the viewpoint in this paper to be useful in designing of new identifier-based mobility methods.

Categories and Subject Descriptors

C.2.1 [Computer-Communication Networks]: Network Architecture and Design

General Terms

Design

Keywords

Identifier, mobility, routing, overlay

1. INTRODUCTION

Mobility is becoming one of the key demands in the future Internet. Mobile data is growing exponentially with the increasing use of handheld devices and popularization of a wireless environment. Different from the cellular network, the Internet was not created to support mobility, so adjustments need to be made to the Internet architecture to provide mobility functions. However, due to the fundamental differences between the two networks, it is unsuitable to copy the cellular mobility model to the Internet. Besides, mobile users of the Internet may not only roam between network attachment points, but also from one ISP or even one device to another at any time. We prefer to access the Internet through ISPs with high performance and low cost and devices which are convenient. When switching among multiple ISPs and devices, we become mobile in the global Internet, which goes beyond the concepts of the mobility in cellular network. Therefore, there still exist many difficulties and open questions regarding how to support global mobility in the Internet.

Many mechanisms have been proposed to support mobility in the Internet. From one point of view, they can be classified into two categories, i.e. routing-based solutions and mapping-based solutions [1]. Routing-based solutions keep IP addresses of the mobile (hosts, devices, users or other entities) unchanged when they roam in the Internet. Therefore, to maintain the reachability of the mobile, such solutions require dynamic routing. While mapping-based solutions solve this problem by assigning each mobile an identifier which is relatively permanent and storing mappings from identifiers to locators (normally IP addresses) somewhere in the network. Correspondent ends are able to reach the mobile by resolving its identifiers to network addresses. When the mobile roams, correspondent ends can still reach it using the identifier as soon as the mappings are updated.

Relying on routing-based solutions alone is considered not suitable in solving the mobility problem in the global Internet, as these solutions require to informing the whole network when movement takes place and may not scale well in large networks [2]. Thus, a mapping-based method or some combination of the two should be considered when designing new mobility solutions (we call identifier-based mobility solutions). As a result, an unavoidable task brought by supporting mobility in the global Internet is the introduction of an identifier[1] namespace. However, identifiers not only benefit mobility, but also facilitate other features such as host/site multi-homing, traversal of middle-boxes, security, content retrieval and so on. Therefore, most proposals that employ identifiers to support mobility also try to settle other problems simultaneously. In this paper, we first give an overview to the current identifier-based mobility solutions to find that, in achieving different design goals, these solutions vary in many aspects from the definition and structure to the maintenance and resolution of identifiers. For this reason, it becomes quite difficult to analyze and compare these proposals with a unified method.

Therefore, in the following sections we focus only on the core mobility mechanisms of these proposals. We regard identifier-based mobility proposals as providing mobility function in an overlay network above the network layer, which we call ION (Identifier Overlay Network). We show that various identifier-based solutions can be regarded as distinct instances of ION differ in topology construction and routing mode. Then we further discuss the mobility management based on ION and consider handling mapping dynamics as a particular key task of identifier-based mobility solutions. However, reducing mapping dynamics

[1] "Identifier" here refers to some name of a network entity (normally hosts) that is topology-free, which means that the relationship between the name and the entity remains relatively stable, even if the entity moves from one point of attachment to another in the network.

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in ION may lead to a path stretch between two communication ends. We show how current proposals take different ways to make tradeoffs between mapping dynamics and path stretch.

The contribution of this paper is two-fold. First, it provides an overall review of current identifier-based mobility proposals with comparisons from multiple aspects. Second, it abstracts the core mobility mechanisms of various proposals, and puts forth a new viewpoint with preliminary analysis, which may help on further research and designing of identifier-based mobility methods.

In the following of this paper we first give an overview to the current identifier-based mobility proposals and make comparisons on several aspects in Section II and III. Then, in Section IV, we propose the general definition of ION and its instantiations in different situations. Based on ION, we make further discussions on mobility handling in Section V. Finally, we summarize the paper and discuss future work in Section VI.

2. OVERVIEW OF CURRENT SOLUTIONS

As is mentioned above, identifier-based mobility solutions diverse in multiple aspects and, thus, can be categorized differently according to various classification criteria. Since one of the key points to support mobility is to resolve identifiers to locations of the mobile, we choose to sort the solutions by their resolution methods.

2.1 Resolution on End-nodes

Several proposals perform resolution of identifiers on end-nodes, which means both ends are aware of each other's identifiers and related location (IP addresses) exactly. As shown in Figure 1(a), in such solutions, the initiator of communication usually obtains the mapping from correspondent's identifier to its current IP addresses from a global infrastructure that maintains the mappings. After connections are established, data flows directly between both ends without the participation of the mapping system.

ILNP (Identifier Locator Network Protocol) [3] is an experimental protocol that aims to provide multi-homing and mobility support by splitting IPv6 address space into an identifier part and a locator part. The first 64bits of IPv6 address remains to be used for routing in the network, while the last 64bits are used to uniquely identify the host. ILNP makes changes the transport layer of hosts to ensure that the connection state in that layer only contains the identifier part of the entire IPv6 address (with port number). ILNP utilizes DNS to store the mapping by introducing new resource records. Before data transmission, ILNP nodes request DNS to get correspondents' locators using their identifiers.

TCP Migrate [4] and NBS (Name-based Sockets) [5] both use Domain Names as the identifier of hosts and, thus, again rely on DNS to store the mapping. TCP Migrate makes modifications to TCP and introduces a Migrate option to allow on-going TCP connections migrated from one IP address to another. Meanwhile NBS provides a set of new APIs to applications and call existing sockets to establish and manage TCP or UDP connections.

HIP (Host Identity Protocol) [6] inserts a Host Identity Layer into the protocol stack between the transport and network layer. A new namespace called Host Identity (HI) is introduced as the identifier of hosts. HI is represented by the public part of a public-private key pair. HIP use HI together with a port number to uniquely identify a transport layer session and IP addresses to deliver data

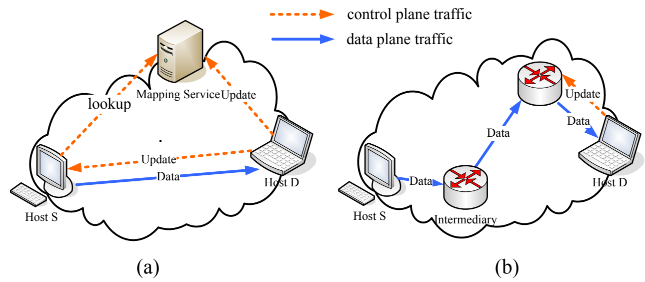

Figure 1. Overview of solutions that resolve identifiers (a) on end-nodes, and (b) with intermediaries

packets. Different from the previous solutions, though mappings from HI to IP addresses are stored in DNS, additional rendezvous points are introduced to assist the resolution. The initiator sends DNS request and fetch correspondent's HI and related rendezvous point. Then, the first data packet goes by the rendezvous point to reach the correspondent. After the initiator receives a data reply from the correspondent, following data stream will travel directly between both ends.

Serval [7] is a proposal which focuses on services run on multi-homed and mobile servers in the Internet. Serval proposes a Service Access Layer that map from ServiceID to locations. Service Routers are deployed to maintain the mappings together with hosts. Similarly to HIP, Serval also performs "late binding", which means Serval delivers the first packet of a connection using ServiceID via Service Routers to reach the destination and, then, retrieve the address of the target service.

In all the approaches above, mapping updates are transferred directly from the mobile to correspondent ends immediately when mobility occurs. Therefore, once the connection is set up, mobility can be handled by end hosts without any assistance from some third parties, except for the scenario that both ends are mobile. To cope with the situation that both ends move simultaneously and prepare for incoming connections form new hosts, these solutions also require the mobile to update the mapping in the mapping system after movement.

2.2 Resolution with Intermediaries

Many proposals introduce intermediaries into the resolution and forwarding process of identifiers. Normally, in such solutions, one or both communication ends are not aware of the exact locations of its correspondent. Instead, they only get the location of some nodes which can be regarded as the relay of the correspondent in the whole process of data transmission, as shown in Figure 1(b). In this way, intermediary-nodes are responsible for keeping the exact location of the mobile and to perform redirections when packets arrive.

Mobile IP [8][9] can be regarded as using Home Addresses as identifiers for the mobile. Correspondent hosts are only aware of the Home Addresses of the mobile, while real locations are hidden from them. Home Agents, which can be considered as intermediaries between the mobile and their correspondents, take care of the mobile by maintaining their Care-of Addresses and redirecting packets. After movement, the mobile needs to contact Home Agents for mapping update. Mobile IP extensions deploy additional intermediaries. Proxy Mobile IPv6 [10] introduces Mobile Access Gateway and Local Mobility Anchor to free the mobile from mobility management. Hierarchical Mobile IPv6 [11] use Mobility Anchor Point for performance improvement.

ROAM (Robust Overlay Architecture for Mobility) [12] is a pure mobility proposal built on top of I3 (Internet Indirection Infrastructure) [13]. In I3, data receivers are able to freely choose indirection points. The chosen indirection point is represented by an identifier, which is also the identity of the receiver. Data sender delivers packets to the indirection point and the latter redirects packets to the receiver. Thus in mobility scenario, data receivers are responsible for updating their locations to the indirection points. ROAM utilize the features of I3 and make several function and performance enhancements for mobility support.

LISP (Locator Identifier Separation Protocol) Mobile Node [14] and NID (Node Identity Interworking Architecture) [15] use more intermediaries to participate in the resolution procedure of identifiers. Both proposals separate the edge networks from the core to make a hierarchical network topology (2-layer hierarchy in LISP, and more layers in NID). Hosts stay in the edge network and are assigned with permanent identifiers. Border routers between the layers are responsible for resolving identifiers and forwarding packets, first, up to the top of the hierarchy (the core) and, then, down to the edge to reach the destination host.

2.3 Hybrid Solutions

Other proposals enable both types of resolution methods. SIP (Session Initiation Protocol) [16] is a mobility solution originally used for multimedia. Typically, SIP acts like an application-layer version of HIP: Users register themselves with current IP addresses in their SIP Servers, and the SIP Servers redirect the INVITE message to help the establishment of connections between both ends. When mobility happens, the mobile sends a RE-INVITE message to its correspondent for mapping updates. SIP also allows a scheme similar to mobile IP for faster hand-off in mid-call mobility, in which SIP Proxies behaves like Home Agents and redirects packets for the mobile.

FARA [17] and MobilityFirst [18] can be considered as clean-slate designs that highlight mobility support using identifiers. FARA defines an abstract network model which separates E2E communication between mobile entities from the underlying forwarding mechanism. M-FARA, which is an instantiation of FARA for mobility, associate each mobile with an M-agent that acts as an intermediary. Packets can be redirected by M-agent, or bypass M-agent and go directly to the destination. MobilityFirst assigns GUIDs (Globally Unique Identifier) to network attached objects and deploys GNRS (Global Name Resolution Service) for dynamic ID-to-address binding. MobilityFirst allow any router on the way from source to destination to resolve GUID to addresses.

3. COMPARISONS

3.1 Definition

Though all the solutions introduce new identifiers to name network entities, they vary in the exact definition of identifiers. Mobile IP and LISP use IP addresses as identifiers, thus they have the limitation of defining identifiers as names of nodes in the network layer. Most solutions use identifiers to name end-points, which is relatively flexible. Such identifiers can be names of one or multiple devices, or certain processes on the device. Other solutions focus on new requirements in the Internet, and choose to name mobile services [7], data [19][20] or even context [18] in the network.

We cannot say which definition of identifier is better in providing mobility function, as different definitions facilitate mobility support in different levels, and meet various design requirements. It is possible that one type of identifier alone is inadequate in satisfying diverse requirements in future Internet, and multiple identifiers may coexist.

3.2 Structure

Proposals using flat identifiers, such as HIP and NID, normally make them hash of the public key of a key pair, and become self-authenticating ones to provide security enhancements. Since such identifiers have cryptographic meaning, hosts are able to prove ownership to their identifiers, and realize other security features relying on cryptography. Without self-authenticating identifiers, other mechanisms are needed to ensure the validity of identifiers.

Using hierarchical identifiers may have convenience in realizing the resolution. Domain Names may be the most commonly used hierarchical identifiers as the DNS is already providing similar services to that needed by mapping systems. Other mechanisms using IP addresses as identifiers also benefit from the aggregatable feature and the existing routing infrastructure in the network layer for resolving identifiers. In comparison, flat identifiers may require additional protocols to maintain their mappings to IP addresses. The solutions from [15] and [21] suggest resolving flat identifiers using DHT or similar mechanisms, while [6] introduces rendezvous points to store the mappings distributedly.

3.3 Resolution

The solutions perform resolution on end-nodes may have lower end-to-end delay than the one with intermediaries. Since the source host knows exactly the IP address of the destination, data traffic from the source travels directly to the destination without any delay from above the network layer. While if additional boxes are deployed in the middle, data traffic have to pass the intermediaries on the way to its destination and redirected by them, which may cause stretch of the data path.

Intermediaries may reduce the mapping overhead in global scope. On one hand, intermediaries can share the responsibility for maintaining the global mapping records, which may reduce the overhead of a centralized mapping system. On the other hand, with intermediaries enabled, it becomes not necessary that mapping updates from the mobile travel through the Internet to reach all of its correspondences, which decreases the overhead brought by plenty of updates sent from the frequently-moving mobile. Besides, intermediaries can keep privacy for the mobile to some extent. Mobile users who do not want to expose locations can choose intermediaries as their delegates, which achieves similar features to NAT.

3.4 Implementation

Support to mobility can be implemented in different layers on end hosts. Mobile IP, HIP and LISP choose to provide mobility support below the transport layer. Such practices need to make modifications to the protocol stack of hosts, while keeping the APIs to applications unchanged. Thus all applications, no matter stale or newly designed, can benefit from it.

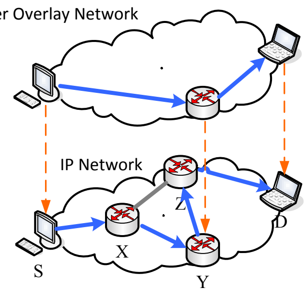

Figure 2. ION over IP network

Solutions like TCP Migrate implement mobility support in the transport layer by modifying existing protocols (normally TCP) or introducing new protocols (SCTP [22][23], MPTCP [24] and their extensions). To the applications, these methods can choose to either become transparent, or provide new interfaces. Another highlight of changing transport layer is to provide the function of multi-path transport due to the potential improvement in the handoff process when the mobile is multi-homed.

NBS inserts a new layer above the transport layer. It gives applications new socket interfaces, and call existing interfaces of TCP, UDP or SCTP for data delivery. In this way, mobility is hidden from the applications, and no changes to TCP/IP are needed, but applications require re-designed to adapt new socket functions, which means stale application cannot make use of it to realize mobility support.

Application-layer proposals may be the easiest ones to be implemented and get deployed because they demand no host-change or network-change. However, one application cannot unify the market, and the same functions need to be repeated in each application that provides mobility support. Also, without cross-layer interactions, programs in the application layer may not know enough information in the layers below to make good decisions. Further, implementations in application layer may get poorer performance than that in the protocol stack.

4. IDENTIFIER OVERLAY NETWORKS

In this section, we abstract the common elements in various identifier-based mobility solutions to form an overlay network called ION. We first define the general concept of ION and, then, describe different types of ION instances to show that the mobility mechanisms in previous proposals can be regarded as different ways of designing topology and routing in ION.

4.1 General Definition

For any proposals that introduce an identifier namespace above the IP address space, the resolution from identifiers to IP addresses is a level of indirection above the network layer. In other words, the resolving of identifiers can be considered as overlay routing over the IP address space. Figure 2 shows the scenario that there exist multiple hops (X, Y and Z) in the IP network between node S and D, but only one of them is an identifier-aware intermediary. Thus, S, D and Y form an overlay network, or say ION, above the IP network.

In the control plane, ION nodes keep mapping tables (namely routing tables in the overlay) locally from identifiers to IP addresses. The overlay routing information in ION is propagated via some overlay routing protocol. In the data plane, when receiving data packets, ION nodes lookup in the local mapping table to get the IP address of its next-hop in the overlay and forward the packet via IP network.

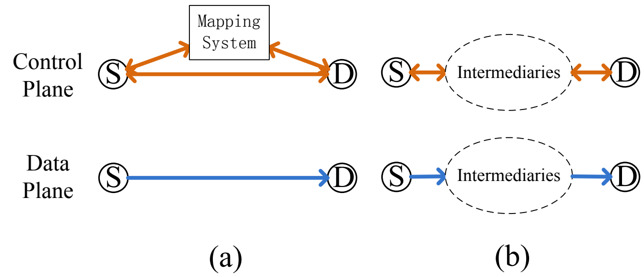

Figure 2. ION of (a) end-nodes resolution method and (b) intermediary resolution method

ION can also be used to describe identifier-based mobility solutions. Normally there are two types of ION nodes. The *end-nodes* are hosts with identifiers, which only act as the source and destination of data flow and are likely to be mobile. The *intermediary-nodes* are identifier-aware middle-boxes, which act as relays between end-nodes and are relatively at stable locations.

In mobility scenario, mobile nodes change their locations, which makes some of the mappings on ION nodes become stale. Thus they rely on ION to disseminate new mappings within the overlay network for reachability. Mapping updates are always originated from the mobile nodes and propagated within ION. Similar to IP routing convergence, in ION, it also takes some time before all the nodes that hold stale mapping finish updating.

4.2 ION Instantiations

Similar to other overlay networks, the topology and routing of ION can be flexibly defined according to different requirements. If a node s in ION stores some identifier ID_d of node d and related location IP_i, there exists a logical link between s and the node i located at IP_i, and normally, i is the next-hop on the route from s towards d. Even if IP_i changes, the link between s and i still exists as long as s is informed of the new value of IP_i.

4.2.1 ION without intermediary-nodes

ION of solutions in Section 2.1 only contains end-nodes. We assume node s have a correspondent node d. Since s keeps direct mappings from ID_d to IP_d, we can say that s maintains a logical link to its correspondent node d in the overlay network, as shown in Figure 2(a).

In the data plane, packets travel directly from s to d and vice versa without interruption from any other node in the overlay. In the control plane, ION first needs a mechanism for bootstrap, i.e. to establish logical links from s to d. Thus node s has to obtain mapping information of node d. Most solutions rely on a global mapping system and choose a centralized way (normally DNS) to achieve the procedure. Node s queries the mapping system (early binding) or sends the first packet via the mapping system (late binding) to retrieve the mapping information of node d. After link establishment, links are maintained in an end-to-end way by sending mapping updates directly from d to s.

4.2.2 ION with intermediary-nodes

ION of solutions in Section 2.2 deploys intermediary-nodes between end-nodes in the topology. Node s never stores the exact

IP address IP_d of its correspondent node d but keeps an indirect mapping from ID_d to IP_i, which is the address of an intermediary-node. Instead, the intermediary-node is responsible for maintaining mappings from ID_d to IP_d. A simplified topology of such schemes is shown in Figure 2(b), in which all intermediary-nodes are gathered together to form an intermediary infrastructure.

In the data plane, packets go through the intermediary infrastructure and are redirected towards the destination. For bootstrap in the control plane, ION also needs a global mapping system. Most solutions choose to co-locate the mapping system with the intermediary infrastructure and run a distributed protocol (such as DHT in [12][21]) for mapping maintenance. The link establishment from s towards d is realized using late binding. After bootstrap, mobile end-nodes update mappings to related intermediary-nodes when necessary. Mapping updates may be further propagated inside the intermediary infrastructure (as in [25]) or not (as in [9]) according to specific protocol design, and normally ION shields end-nodes from receiving updates in such solutions.

5. MOBILITY HANDLING IN ION

ION provides a new viewpoint from which we can research into the mobility functions of identifier-based solutions. In this section, we further discuss the handling of mobility in ION. We argue that the key task of handling mobility in identifier-based solutions to be balancing the trade-off between mapping dynamics and routing path stretch.

5.1 Location and Handoff Management

In analogy to mobility management in cellular networks which consists of location and handoff management, mobility handling in ION can also be discussed from two aspects. "Location management" in ION refers to maintaining mappings from identifiers to locations globally and setting up logical links from source towards destination when initiating connections. While "handoff management" in ION means handling mapping changes caused by node mobility during data transmission.

According to the analysis in Section 4.2, location management in ION is mainly achieved by a global mapping system, no matter using early or late binding. The introducing of a mapping system into the Internet architecture is not a particular research point in mobility-related solutions, but has already been widely studied in many areas. Therefore we do not further discuss the issue in this mobility-centric paper.

For handoff management in ION, we consider its main task as handling mapping dynamics. Mappings dynamics means changes to mappings on ION nodes due to mobility. To maintain the existing connections on the mobile node, mapping dynamics need to be propagated within the overlay network. Such dynamics may be relatively frequent and have large impact on ION performance. To the overlay network, mapping dynamics requires a large number of mapping updates and propagation of such messages may bring a heavy overhead in the control plane. Also, delay in dissemination of mapping dynamics may make mapping entries in ION nodes become stale, thus results in packet losses. Therefore, we regard it as a particular issue in identifier-based mobility solutions and an important research point that need further analysis.

5.2 Tradeoff between Dynamics and Stretch

One way to reduce mapping dynamics is to localize the mapping updates by deploying mobility agents (similar to Home Agent in Mobile IP). In ION, it is represented by the introduction of intermediary-nodes for mobile end-nodes. In this way, a large number of mapping updates only take place between the mobile and its mobility agent, which will normally benefits in both lowering control overhead and keeping mappings up-to-date. However, this may result in a path stretch in the data plane, as data needs to travel to the mobility agent first and, then, be redirected towards the destination.

In [26], the authors discussed a fundamental tradeoff between routing table size and routing path stretch in a static network and explained its reason as loss of topological information. It is a similar case in ION with intermediary-nodes, where a node is not aware of the exact location of its destination, thus may not be able to forward data in the optimal path. If we treat paths in the IP network as shortest ones, we can define routing path stretch in ION as the ratio of the actual path-length between two end-nodes in ION to the length in the IP network. The more stable the mappings hold in nodes, the larger the path stretch may become, because, if the next-hop of a node is relatively fixed in IP network, it is more likely to be located away from the optimal path towards the destination.

5.3 Handling Mapping Dynamics

Current solutions take different ways to make tradeoffs between the two factors. Solutions in Section 2.1 introduce no path stretch, because they choose to introduce mapping dynamics into the entire network. Thus, end-nodes have the enough knowledge of their correspondents and are able to forward data packets in the optimal path. However, control overhead brought by such solutions is relatively high, and the freshness of mappings may not be well ensured when the distance between two end-nodes in IP network is quite large.

Solutions in Section 2.2 choose to localize the mapping updates caused by end-nodes and, in this way, overhead in the control plane will drop since the most mapping updates are only propagated to limited nodes in the overlay. There may exist path stretch in such solutions, according to the location of intermediary-nodes. When the intermediary-node is on the optimal path between both ends, the path stretch will be 1.0, but, most of the time it may not be the case, if we assume that the intermediary-node is in a fixed location while the end-nodes are free to move in a large scope. However, when the locations of intermediaries are not fixed, path stretch may be kept relatively low, with the cost of generating more mapping dynamics. Besides, mapping freshness will also decrease along with the increase of distance between end-nodes and intermediaries.

In conclusion, both types of solutions have their advantages and drawbacks in handling mapping dynamics. In the future Internet, it is a possible scenario that multiple identifier-based solutions that provide diverse mobility support coexist, enabling the flexibility of users in the network to select suitable services according to different preferences, applications, context, etc.

6. CONCLUSION AND FUTURE WORK

In this paper we pay attention to the mobility solutions in the Internet which introduce a new identifier namespace. First we give an overview by sorting them according to different resolution methods, and make comparisons qualitatively from various respects. Then we propose a different viewpoint to research the identifier-based mobility solutions in an overlay network called ION. We study a particular issue in ION to point out that there exists a tradeoff between mapping dynamics and routing path stretch, and argue that a key point to mobility handling is to balance the tradeoff.

In future work, we are planning on detailed modeling on ION to further research into the tradeoff between mapping dynamics and path stretch. Also, we need data collected from simulation and experiments in real network environment to support our arguments. Based on the research results, we are going to make improvement to existing identifier-based solutions or design new mobility methods.

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