UNA: A New Internet Architecture for User-level Multi-homing and Mobility

You Wang[1]
wangyou@netarchlab.tsinghua.edu.cn

Jun Bi[1]
Junbi@tsinghua.edu.cn

Chenghui Peng[2]
pch@huawei.com

Hongyu Hu[1]
huhongyu@cernet.edu.cn

[1] Tsinghua University
Network Research Center,
Tsinghua University, Beijing
100084, China

[2] Future Internet Work Team
Huawei Technologies Co., Ltd,
Shanghai
200040, China

ABSTRACT
Host multi-homing and mobility in the Internet have become a trend due to the widespread wireless services and broad access methods. Meanwhile, with more and more devices join in the Internet, it will be common that one user has multiple devices on-line. So users will also desire to be multi-homed and mobile across not only addresses but also devices. To provide such support, we present a new network architecture called UNA (User-centric Network Architecture) to achieve user-oriented communications. UNA will make communications completely independent of data delivery, which offers the basis of both network and user level multi-homing and mobility. We first show the general design of UNA including the introduction of new namespaces. Then UNA-I is presented as an illustration to complete the architecture with mapping, resolution and indirection schemes. At last we describe the instantiation of UNA under LTE framework with some security enhancements. However our work is far from complete and in this paper we focus on expressing the new idea.

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

General Terms
Design

Keywords
Internet architecture, identifier, multi-homing, mobility

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1. INTRODUCTION
1.1 Background
Along with the development of new access technologies to the Internet and the popularization of wireless environment, more and more devices are becoming multi-homed and mobile, which makes the topology of the network dynamic. Approach for device multi-homing and mobility across point of attachments in the network layer has become a pressing need.

Meanwhile, with the rapid growing of Internet users and mobile devices, it is becoming increasingly popular that one user can have multiple devices on-line, such as handheld phones, laptops, in-car devices, household appliances and so on. As a result, users will desire to be multi-homed and mobile across different devices. For example, Bob may prefer to use his desktop computer in the office, smart phone when outside and in-car-telephone when driving. It will provide much convenience if Alice can contact Bob by simply using his name, no matter which device he is currently using. Also Bob may want to switch on-going video call from smart phone to the digital TV when back home, which also demands device-independent communication.

More generally, it is a foreseeable need that communications in the future Internet should be completely independent of the process of data delivery. The end-points of communications will become mobile across the network addresses they are using, or the devices they reside in, or any other kind of communication substrates. The current Internet architecture is lack of such support.

The idea of ID/Locator split is used in many proposals to address the multi-homing and mobility problem. It is well known that the IP address has overloaded the semantics of both node identifier and network locator. In fact, IP addresses are names of point of attachments in the network and therefore it is a topology-dependent namespace. But it is also borrowed by the transport layer to identify the communication end-points, and it makes multi-homing and mobility difficult to achieve. ID/Locator split separates the semantics of node identifier from IP address by introducing a new namespace which is topology-independent to name the node. However, most ID/Locator split schemes focus on the network-layer problems, without considering user-level requirements.

1.2 User-centric Network Architecture

Data transmission in today's Internet is based on addresses or devices. But with more and more users access the Internet through all kinds of mobile devices, current communication mode is becoming somewhat a obstacle to the imformation sharing between users. To contact one person, we need to maintain the relationships between the person and a large number of ways to reach him/her. From the user's point of view, what they really care about are the other users, not the devices or addresses they reside in.

Here we propose a new network architecture called UNA (User-centric Network Architecture) as shown in Figure 1. Unlike most of the existing proposals which highlight the hosts or other entities in the network layer, we start from a different perspective by introducing a new namespace which is user-centric. In our proposal, the end-points of communications are users themselves, instead of addresses or devices in current Internet. One user may have multiple devices and addresses, but the fact is hidden by the "User Layer" and invisible to the applications above.

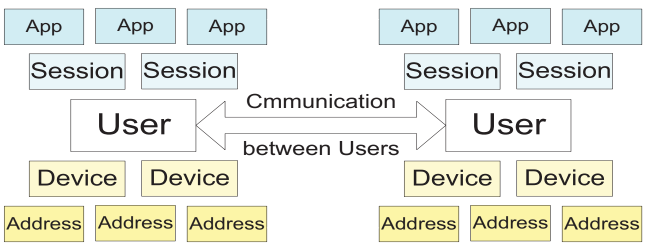

Figure 1. User-centric Network Architecture

UNA separates user identity from locations, thus it can not only solve network-level problems like traditional ID/Locator split methods, but also meet the user-level requirements such as multi-homing and mobility across devices. Also, the new namespace will facilitate applications because they do not have to maintain a large number of names and addresses any longer, but use names of the user directly to identify the communication correspondent. Further on, the user-centric architecture provides the basis of users' ubiquitous access and information sharing in the near future.

1.3 Scope and Limitations

UNA is designed to provide user-centric services, while in this paper we mainly focus on the following issues:

- Network layer multi-homing and mobility. Sessions should never break when devices change the point of attachments to the network.
- User-level multi-homing. User is able to manage his devices to make himself multi-homed. And network should be able to select one from the devices according to his preference to start communication.
- User-level mobility. Users should be able to switch ongoing communications among his devices freely while keeping session survivability.

We do not go deep into application-layer issues here. In the Internet today, pre-condition of communication is that users have a common application, which barriers ubiquitous communication and information sharing between Internet users. But in this paper, we will neither specify a particular application for inter-user communications, nor design methods for inter-working between different applications. UNA will not impose restrictions on the evolution of application layer, but be compatible with them. The integration of UNA and suitable applications, such as software design, will be left for future work.

The rest of the paper is structured as follows. First we summarize the related work in Section 2. Then we present general design of UNA in Section 3 and a particular architecture called UNA-I in Section 4, with some discussions of user-level multi-homing and mobility. We show one instantiation of UNA in Section 5 under LTE framework. Finally we make conclusions and discuss the future work in Section 6.

2. RELATED WORK

A large number of schemes are proposed to address the problems of multi-homing and mobility. TCP-R [5] and TCP-migrate [6] are mobility extensions to TCP. They allow an existing TCP connection to migrate from one IP address to another by exchanging redirection messages between hosts. Shim6 [7] and SCTP [8] aims to support IP multi-homing. To manage multiple IP addresses in one host, shim6 inserts a sub layer into the network layer, while SCTP designs a new transport-layer protocol. These mechanisms emphasize sessions in the transport layer and employ an end-to-end way, which is different from our work.

MobileIP [1][2] is designed to enhance the mobility of Internet Protocol by introducing new network entities to redirect traffic. LISP [10] separates edge from core network to solve the problem of routing table exploration due to multi-homing. Our work is similar to them in terms of the adoption of indirection, which will be discussed later in Sections 4.2.

Other methods such as HIP [9] and ILNP [11] bring new namespaces into the protocol stack to separate the semantics of identity from IP addresses. HIP introduces a new namespace called HI (Host Identity), which is independent of the IP addresses, to identify hosts in the network. Transport layer uses HI to set up connections which will also become location-independent. All the schemes above may solve problems in the network layer, but they do not consider user-related requiements, which is highlighted in this paper.

MobileMe, which is presented by Apple, pays attention to the problems arise from the fact of multi-device. It provides a easy way to keep the devices owned by a single user in sync including iPhone, iPad, Mac and so on, by using exsisting protocols to identify the devices in the DNS. Though MobileMe offers user-oriented services implicitly, only data synchronization between devices is supported at present.

There are approaches which design user-oriented architectures such as MPA [12], Universal Inbox [13], IPMoA [14], etc. They are proposed to achieve ubiquitous network access for users, such as providing data type transformation to integrate services across device-heterogeneity and user preference profiles to customizable redirection of incoming traffic, etc. These approaches can be regarded as application-layer solutions. It's difficult for protocols in the application layer to get enough network information when solving multi-homing and mobility problems, and they are less effective than the protocols operating in the lower layers in terms of handoff delay and signaling overhead and so on. While our work seldom involves the application layer and aims to solve the problems in the network layer by inserting a new namespace into the protocol stack.

3. GENERAL DESIGN OF UNA

In this section we describe the general design of UNA by firstly introducing a new layer and corresponding namespace. Then we discuss the interworking between layers in the new protocol stack, and show how user-centric communication is achieved with the support of user-level multi-homing and mobility.

3.1 Protocol Stack and Namespaces

We insert a new layer called User Identity Layer into the TCP/IP protocol stack as shown in Figure 2, between the application layer and transport layer. The User Identity Layer is able to set up sessions identified by user names between communication ends. The new layer uses UID (User Identifier) namespace, which refers to some person on the Internet, or some entity that provides data or services. UID must be globally unique and delivery-independent. In this way, the end-to-end sessions will never be coupled with the namespaces in the lower layers, which separates communications thoroughly from the data delivery process.

UID provides a unified namespace which can be used by the applications to identify the correspondent node. It will benifit upper layers because applications no longer need to manage addresses or other names in the network layer. Users only need to know the name of the other users to start communications. Addresses, devices or other entities that related to the delivery process are invisible to them.

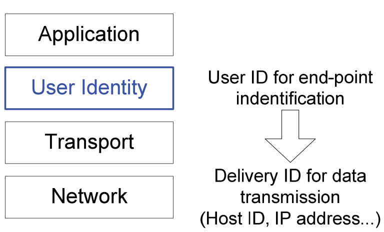

Figure 2. The User Identity layer

Accordingly, we use DID (Delivery Identifier) to identify a logical point of attachment (which can be a network address or a physical or logical device) in data delivery. DIDs can be IP addresses or host identifiers or any other namespaces which is delivery-dependent. The de-coupling of UID and DID spaces makes communications in the network survive when they change point of attachments in data delivering, which provides the basis for end-points' multi-homing and mobility.

There are different ways to implement the User Identity Layer. One is to develop a "session layer" above the transport layer and provides new interfaces to the applications above. In this method, the new layer will maintain sessions between end-users and invoke transport-layer connections for data delivering. Or we can modify the current transport layer to integrate with the UID namespace and keep the interfaces to applications unchanged. We will not discuss the detail of implementations in this paper.

3.2 User-centric Communication

With the new layer enabled, user-centric communications can be achieved. As shown in Figure 3, Bob accesses the Internet through his handheld phone and laptop simultaneously, and both devices are registered with Bob's ID. Alice is a friend of Bob on the social networking site and wants to share a video with Bob. After receiving the request from Alice, the applications simply sends out the message with both sides' UID, and then the message will be routed in the network according to Bob's ID and other information such as service type, Bob's preferences, context of the network, etc.

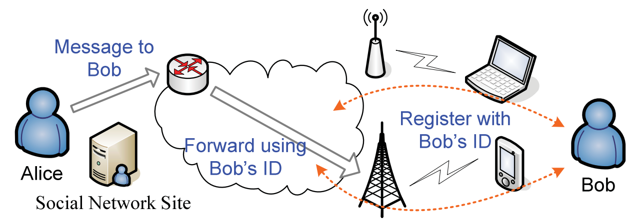

Figure 3. User-centric communications

The network is able to forward packets according to user's preferences. For instance, Bob in Figure 2 can configure his preferences into the network such as "Forward *Bob's Voice Calls* to *Handheld Phone* during *some time period*", "Forward *Bob's Instant message* to *Laptop* if it comes from *Alice*" and so on. Details of preference configuration rules are out of the scope of this paper. With this method, user-level multi-homing across devices can be realized. Meanwhile, the network can perform traffic redirections when users switch from one device to another. Since both devices are registered with the same UID, on-going sessions will never break when redirection is carried out, which achieves user-level mobility.

As long as the end-point identification and data delivery are separated, the technology used in the routing system will not interfere with the above layer. Any kind of forwarding method can be used here from traditional IP routing to name-based routing [17][18]. Delivery mechanisms will not be specified here for general design of UNA, while a particular scheme will be discussed in the next section for UNA's instantiation.

4. UNA-INDIRECTION

In this section, we show one particular architecture derived from UNA, called UNA-I (UNA-Indirection). UNA-I mainly defines the delivery mechanisms unspecified in the general design of UNA, using a mapping, resolution and indirection scheme. Solutions for both device and user-level multi-homing and mobility under UNA-I are discussed later in this section.

4.1 Mapping, Resolution and Indirection

We use a mapping and resolution way in UNA-I for data delivery. In this way, network will maintain the relationships between UIDs and DIDs, and resolve UID to certain DIDs before data transmission. We introduce a new resolution infrastructure called UMS (User Mapping System) to store the mappings from UIDs to DIDs. UMS can provide centralized service similarly to DNS, or distributed service in which case each mapping server is responsible for part of the UID space. With UMS enabled in the network, users can request UMS to get the correspondent's DID in communications. Data packets sent from users will also contain both sides' DID in the header, and these packets will be delivered according to the destination's logical point of attachment in the network and finally reach the correspondent user.

Moreover, to facilitate multi-homing and mobility, we adopt the idea of indirection, which is well instantiated in MobileIP. MobileIP assumes an indirection point called Home Agent between end-hosts. Hosts in MobileIP are identified by their home IP addresses, thus all the traffic directed to Mobile Node are intercepted by HA, which then performs redirection according to MN's current location. Likewise, LISP uses Ingress/Egress Tunnel Routers to link edge and core network. Hosts in edge networks communicate directly using identifiers. When packets travel across the core, ITR/ETR will redirect them by encapsulation. Similar discussions include [15]] and [16] in which indirections are considered part of life to the Internet.

Vary from MobileIP and LISP which redirect traffic for hosts, we introduce UIA (User Indirection Agent) for user-level indirections. Users are able to select different UIAs for preferences, and change them due to multi-homing or roaming. Mapping from users to corresponding UIAs will also be maintained in UMS. Meanwhile, UIAs must keep the actual DID of each user it serves, and redirect the traffic again according to user's current locations.

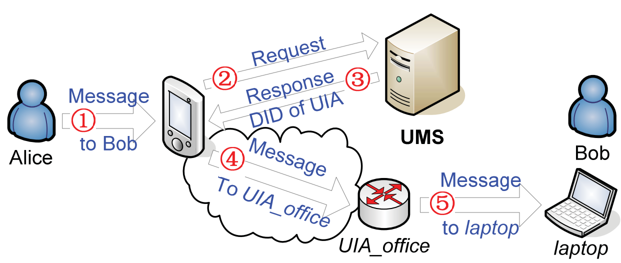

Figure 4. Mapping, resolution and indirection in UNA

As shown in Figure 4, Bob choose *UIA_office* as his laptop's indirection agent by making configurations in UMS such as "Redirect *Bob's Messages* to *UIA_office* during *work time*". When Alice wants to post an instant message to Bob, she looks up Bob's ID in the UMS with some extra information such as *Message* (service type), *Alice* (source user), etc., to obtain a DID of the destination which is actually the location of Bob's UIA. Next the message will be forwarded to *UIA_office* and again be redirected to Bob according to his current device or address.

Mappings in UMS are potential exposures to user's privacy containing their location, preferences and other information. Users who need privacy protections can also employ UIAs to maintain a part of the mappings instead of UMS. In this way, UIA acts as a service proxy of the user and provide privacy and security enhancements as discussed in [12].

4.2 Device Multi-homing and Mobility

Device multi-homing in UNA-I refers to the scenario that one device appears at multiple locations in the network topology simultaneously. It can be achieved through different ways. If DID refers to identity of devices, multi-homing is not within the scope of our work and should be supported at the lower levels. When DID refers to locations of devices, we can map a certain EID to multiple DIDs for multi-homing. E.g. Bob's laptop accesses the Internet through both Ethernet and WLAN, UMS will maintain the mappings from Bob's ID to both *DID_Ethernet* and *DID_WLAN*. Also, map from one UID to multiple UIAs is another way to do multi-homing for devices.

Device mobility in UNA-I refers to the scenario that devices roaming among access points in the network topology. UIA can smoothen the process of handover by indirection. As shown in Figure 4, when Bob moves around in the office, *UIA_office* will redirect incoming data traffic without notifying communication correspondents of the changing of locations.

Mobility in large scope may cause too much latency and overhead due to triangle routing, while in UNA-I this can be solved by switching between UIAs. Switching costs includes mapping update in both UMS and correspondents. [3] and [4] show similar methods and discuss related problems.

4.3 User Multi-homing and Mobility

User multi-homing in UNA-I refers to the scenario that one user can be accessed through multiple devices at the same time. As shown in Section 4.1, UMS maps from one user to different devices or locations, or to different UIAs for mobility reason, to achieve user-level multi-homing.

User mobility in UNA-I refers to the scenario that users switch between their devices in communications. The simplest case is that both devices are under the same UIA, therefore handover will be localized, and only require update to the particular UIA. In other cases, updates to both UMS and correspondents are needed.

Communication switching between devices needs support in the application layer. New applications are required to implement such user-level mobility. However, related details are not described in this paper and will be left for future work.

5. UNA under LTE Framework

In this section we integrate UNA with LTE framework and discuss more details of UNA design based on Section 4, including specification of namespaces, description of communication process, and some discussion to security enhancements, to make UNA not just a concept, and wish to implement a prototype and perform experiments.

The 3rd Generation Partnership Project (3GPP) standard is developing SAE/LTE architecture for the next generation mobile communication system. We choose to build UNA on LTE framework because currently mobile communication networks have a much more prominent demand for user-level multi-homing and mobility compared to the Internet, as well as it can provide mobility basis and thus facilitate deployment.

5.1 Architecture Overview

We use IMSI (International Mobile Subscriber Identity) as DID to identify devices in the network, and select one device from all the devices owned by a single user as his main-device. Main-device's IMSI will serve as the user's UID.

UMS maintain mappings from M-IMSI (Main-device IMSI, which is also the identity of the user) to S-IMSI (Sub-device IMSI, which is the identity of other devices of the user), or to IP addresses, as discussed in Section 4.1. Communication sessions are set up with (src M-IMSI, dst M-IMSI) even if users are using their sub-devices, hence M-IMSI should be pre-configured into all the sub-devices.

User's UMS will be co-located with the HSS (Home Subscriber Server) of his main-device, and the functions of UIA will be deployed at SGW (Serving gateway). We illustrate the architecture overview in Figure 5: Bob has a handheld phone *IMSI_hand* in 3GPP network and a laptop *IMSI_laptop* in non-3GPP network using IP access, and he selects *IMSI_hand* as his main device. In this way, Bob will be identified as *IMSI_hand* and the HSS of the phone will become his UMS. Also, he chooses *UIA_hand* as his redirection agent for voice calls, which is co-located with the SGW of his phone.

A common communication process can be described as follows:

- Alice in the 3GPP network wants to call Bob and sends her request to the MME/SGW;
- MME/SGW get Bob's HSS from his M-IMSI, and send to it a mapping request;
- HSS returns *UIA_hand* to the MME/SGW and the latter forwards data traffic to the corresponding gateway;
- Traffic arrives at the gateway are redirected to Bob's handheld phone.

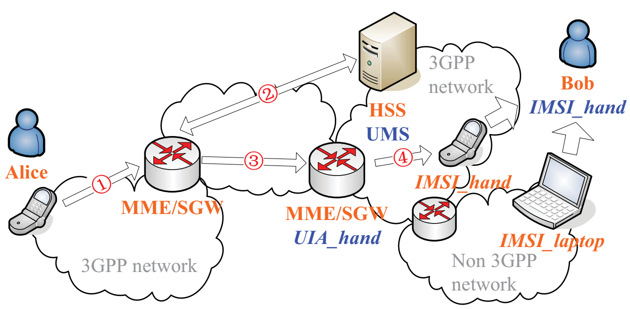

Figure 5. Overview of UNA under LTE framework

5.2 Security Enhancements

LTE has its security framework, and based on it we can make some security enhancements to the current UNA architecture.

In the data plane, data transmission must be secured. LTE architecture accomplishes device authentication by using EPS-AKA protocol, and generates multiple keys to protect user traffic. The integration of UNA and LTE will not influence the authentication process and therefore the security of data transmission can be enhanced.

In the control plane, the mapping from a given UID to its target must be correct, and only the owner of an UID may update the corresponding mappings in the UMS. A user may start mapping update from any device of his own to the HSS, and the security of such process can be achieved by existing mechanisms in mobile communication networks. We will describe it in two cases, as shown in figure 6.

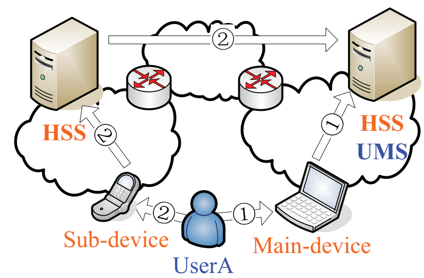

Figure 6. Security enhancements in control plane

- User starts mapping update from his main-device. The procedure is accomplished between the main-device and his UMS (which is just the HSS of the main-device). Such communications can be encrypted by the shared key between the USIM of the main-device and HSS.
- User starts mapping update from one of his sub-devices. If the sub-device and his main-device belong to the same HSS, the procedure is similar to the former case, or else the procedure is accomplished among the sub-device, its HSS and HSS of the user. The sub-device first sends update request to its HSS using the key between them, and the request is forwarded to user's HSS in a secure way.

6. CONCLUSION AND FUTURE WORK

In this paper, we focused on the users in the Internet and proposed a network architecture called UNA. Communications in UNA is completely independent of the delivery, to meet the requirements of user-level multi-homing and mobility. We show the general design of UNA by introducing a UID namespace and describing the interworking between layers in the new protocol stack. We use a mapping and resolution way and adopt the idea of indirection in designing UNA-Indirection and discuss details of both network-level and user-level multi-homing and mobility. In addition, an instantiation of UNA is presented with some security enhancements based on LTE framework for future implementation, experiments and deployment.

However our work has just begun and we still have a lot of work to do. Future work will cover the following contents: the first is detailing of the systems and protocols discussed mainly in Section 4, including the construction of UMS and mapping rules, design and optimization of signaling in resolution, updating and other control plane operations. Then application-layer issues should be considered such as software design, etc. Prototype implementation and experimental analysis are also urgent needs in our work. And we should study the deployment strategies in LTE if possible.

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