Application Concentrator: Application-Level Gateway for Enabling Interconnection of Multiple Closed Networks

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***Abstract*—In this paper, we propose a framework called *application concentrator*, which enables interconnection of multiple closed networks at an application level. Because of rapid development and deployment of advanced networking technologies, various social activities have been shifting onto a network, thus necessitating a technology for providing closed networks for real/virtual groups. In particular, interconnection of multiple closed networks is the key for realizing those social activities on a network. In this paper, we therefore propose an application-level gateway called *application concentrator*, which enables interconnection of multiple closed networks for various types of application protocols. In the application concentrator, interconnection of multiple closed networks is realized by multiplexing/demultiplexing the content of communications. For demonstrating effectiveness of the application concentrator, we design example implementations of the application concentrator for three typical applications such as Web, e-mail, and remote desktop.**

***Index Terms*—Application Concentrator, Application Gateway, Closed Network, VPN (Virtual Private Network), Interconnection, Multiplexing/ Demultiplexing**

1. Introduction

There have been rapid advances in networking technologies in recent years, and various social activities have been shifting onto a network [1]. One of the causes has been the fast development of information and networking technologies, which have lead to an explosive profusion of high-speed and low-cost information and networking technologies. For securely and safely realizing various social activities on a network, it is indispensable to provide closed networks, such as a VPN (Virtual Private Network), to each group and/or community.

One of the key technologies for closed networks is interconnection of multiple closed networks (i.e., *multiple association*) [2]. If network users can perform multiple association with multiple closed networks, it is possible to naturally migrate various social activities onto a network.

In the literature, various methods have been proposed for realizing multiple association with multiple closed networks [2]–[5]. However, for most of those methods, it is necessary to change operating systems and/or applications running on users' terminals.

We have proposed *Web concentrator* for realizing multiple association with multiple closed networks using the HTTP protocol [6]. The Web concentrator realizes multiple association at the application level without changing the existing HTTP protocol. Users can therefore perform multiple association with multiple closed networks using a standard Web browser. But multiple association with the Web concentrator is limited to the HTTP protocol. For shifting various social activities onto a network, support for non-HTTP applications is indispensable.

In this paper, by generalizing the concept of the Web concentrator proposed in [6], we propose a framework called *application concentrator*, which is an application-level gateway for enabling interconnection of multiple closed groups for various applications. The application concentrator is a versatile framework for realizing multiple association at the application level. The key idea of the application concentrator is to realize multiple association with multiple closed networks at the application level by *multiplexing and demultiplexing the content of communications at the application layer*. The noticeable feature of the application concentrator is its backward compatibility with existing operating systems and networking applications since it just uses the standard TCP/IP protocol.

For demonstrating effectiveness of the application concentrator, we design example implementations of the application concentrator for three typical applications such as Web, e-mail [7], and remote desktop [8]. Through those example implementations, we reveal that the application concentrator framework can be easily applied to wide range of networking applications. Note that the example implementation of the application concentrator for Web is almost identical to the Web concentrator proposed in [6]. In this paper, it is demonstrated that the Web concentrator can be systematically designed using the versatile framework of the application concentrator.

The remainder of this paper is organized as follows. In Section 2, existing techniques for multiple association are described. In Section 3, the overview of the application concentrator framework is explained, followed by discussion on its functions and characteristics. In Section 4, three example implementations of the application concentrator are designed. Finally, Section 5 concludes this paper and discusses further works.

2. Related Work

In what follows, existing techniques for realizing multiple association with multiple closed networks are briefly explained with their advantages and disadvantages.

Several standard networking protocols for building VPN (Virtual Private Network), such as IPsec [9] and MPLS-VPN [10], are designed for providing closed networks. Those protocols, however, generally assume association with a single closed network; i.e., multiple association with multiple closed networks is of the scope.

MAVPN (Multiply-Associated Virtual Private Network) architecture, which allows individual users to be associated with multiple networks (i.e., multiple association), has been proposed [2]. MAVPN realizes multiple association with multiple

closed networks by integrating existing networking technologies at three different network layers: the physical network level, the logical network level, and the user network level. Since MAVPN realizes multiple association at the network layer (e.g., layer 2 or 3 in the OSI reference model), it is necessary to change the operating system on every user's terminal.

In [3], a network architecture called MyNetSpace, which enables construction of end host groups, is proposed. MyNetSpace realizes multiple association with multiple closed networks by inserting a special header to IP packets for distinguishing source/destination groups. Also, similar to MAVPN, MyNetSpace realizes multiple association at the network layer. It is therefore necessary to change operating systems and applications on users' terminals.

Realizing multiple association at the network layer as in MAVPN and MyNetSpace might be a solution in some cases, but it cannot be a generic solution since change to operating systems and applications of users' terminals are mandatory. For generality and ease of deployment, realizing multiple association at the application layer, as in overlay networking technologies [11]–[14], is promising. In this paper, we therefore focus on an application-level approach rather than a network-level approach.

3. Application Concentrator

The overview of the application concentrator framework is explained, followed by discussion on its functions and characteristics. The application concentrator is a versatile framework, which is independent of a particular application or networking technology. First, definitions of terms used throughout this paper are explained.

A. Terminology

- Entity
  Entity is an endpoint of communication. Generally, a user or an application running on an end host corresponds to an entity. The application concentrator realizes multiple association at the application layer. Entity therefore may correspond to applications as well as users.
- Closed network
  A logically independent network composed of a single or multiple entities is called a *closed network*. Examples of closed networks include a VPN constructed using IPsec or MPLS-VPN, a VLAN constructed using 802.1Q [15], and an overlay network constructed using logical tunnels among over nodes.
- Multiple association
  Simultaneous access to multiple closed networks is called *multiple association*. In multiple association, multiple closed networks are interconnected so that an entity in a closed network can communicate with other entity in the same or different closed network.
- Identifier
  A name that uniquely identifies an entity is called an *entity identifiers*, and a name for a closed network is called a *closed network identifier*. Definitions of an entity identifier or closed network identifier should depend on the definition of a closed network and the underlying networking technology, respectively.

B. Overview

The application concentrator is a versatile framework for realizing multiple association at the application level. The key idea of the application concentrator is to realize multiple association with multiple closed networks at the application level by multiplexing and demultiplexing the content of communications at the application layer (see Figs. 1 and 2).

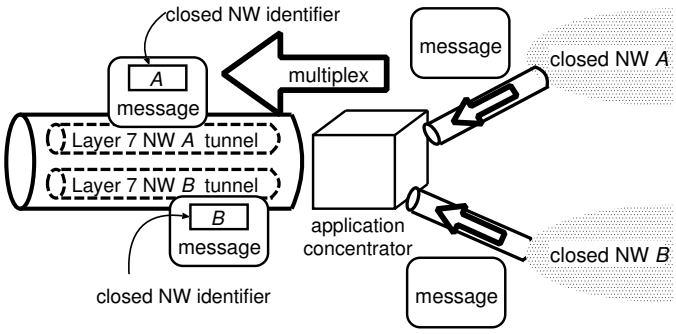

Fig. 1: Multiplexing the content of communications at the application layer

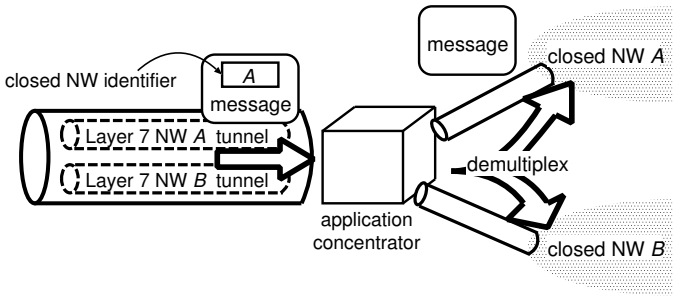

Fig. 2: Demultiplexing the content of communications at the application layer

The noticeable feature of the application concentrator is its backward compatibility with existing operating systems and networking applications since it just uses the standard TCP/IP protocol.

The application concentrator is based on the idea of *multiplexing and demultiplexing at the application layer*. If demultiplexing can be performed at the application layer, this effectively means that information can be transmitted from entities to multiple closed networks. Similarly, if multiplexing can be performed at the application layer, entities can receive information from multiple closed networks.

The multiplexing and demultiplexing of the content of communications at the application layer is realized by appending closed network identifiers to the content of communications at the application level. In this way, if entities append closed network identifiers to the content of communications they wish to transmit at the application layer, it becomes technically possible to transmit information to any closed networks. Also, with identification based on the closed network identifiers included in the content of transmissions received, it is conversely possible for entities to receive information from any closed networks.

However, it is not desirable for an entity to explicitly add or remove closed network identifiers. Hence, the application concentrator therefore provides an intuitive and natural interface for entities by utilizing the application-level protocol. It should be noted that the application concentrator realizes multiple association with multiple closed networks using an existing application, even when it does not support multiple association.

C. Architecture

The application concentrator is composed of three function blocks (i.e., multiplexer, demultiplexer, and protocol converter). Each of these blocks is explained as follows.

- Multiplexer
  In the application concentrator, the multiplexer inserts closed network identifiers into the content of communications for identifying destination closed networks. Thus, communications from multiple closed networks are multiplexed, and merged into a single communication. Note that the insertion of closed network identifiers is performed without changing the application protocol.
- Demultiplexer
  On the contrary, the demultiplexer analyzes the content of communications, and delivers it to multiple closed networks according to the analyzed closed networks identifier. The closed network identifiers inserted into the content of communications are removed, and the content of communications is sent to the corresponding closed network. Note that the removal of closed network identifiers is performed transparently so that usually invisible to entities.
- Protocol converter
  The protocol converter generates an intuitive and natural interface by tweaking the content of communications multiplexed by the multiplexer. Generation of an interface is dependent on the application protocol used for communications. Examples of interfaces generated by the protocol converted will be discussed in Section 4.

D. Functions

The functions provided by the application concentrator are explained from the viewpoint of users and network administrators.

- Users
  The application concentrator enables multiple association with multiple closed networks without changing operating systems and/or applications running on users' terminals. Thus, users can enjoy multiple association with multiple closed networks using as-is terminals and applications. Moreover, with the protocol converter in the application concentrator, users can intuitively access multiple closed networks.
- Network administrators
  Network administrators can easily deploy the application concentrator since it requires no change to users' terminals and/or existing networking infrastructure. Multiple association with multiple closed networks can be enabled simply by installing an application concentrator at the gateway of the network. This greatly saves administrative cost for operation and management of users' terminals and networking devices.

E. Characteristics

By multiplexing and demultiplexing the content of application layer communications, the application concentrator realizes multiple association with multiple closed networks at the application level. Since the application concentrator operates at the application layer, it is not necessary to change operating systems and/or applications running on users' terminals. The application concentrator therefore possesses advantages in terms of flexibility, functionality, ease of deployment, and efficiency. Each of these characteristics is briefly discussed by comparing with those of existing networking technologies.

- Flexibility
  Unlike MAVPN and MyNetSpace, the application concentrator can be deployed without changing operating systems or applications on users' terminals. Multiple association with multiple closed networks is therefore possible regardless of entities' computational and/or network environments.
- Functionality
  The core function of the application concentrator is the multiplexing and demultiplexing of the content of communications at the application layer. With the protocol converter, any function specific to a particular application protocol can be easily adopted. Examples of application-specific extensions will be discussed in Section 4.
- Ease of deployment
  The application concentrator only needs to be placed along the path between a user's terminal and an application server. Thus, the application concentrator is much easier to deploy than other techniques for multiple association at the network layer such as MAVPN and MyNetSpace. Moreover, the application concentrator can be shared by a large number of users.
- Efficiency
  The application concentrator performs multiplexing and demultiplexing of the content of communications at the application layer. Techniques for multiple association at the network layer such as MAVPN and MyNetSpace must process all packets, but the application concentrator must not; i.e., it just processes application-level session information. Thus, the processing overhead of multiplexing/demultiplexing of the application concentrator should be significantly lower than that of other network-level techniques.

4. Example Designs of Application Concentrator

For demonstrating effectiveness of the application concentrator, we design example implementations of the application concentrator for three typical applications such as Web, e-mail [7], and remote desktop [8]. Through those example implementations, we reveal that the application concentrator framework can be easily applied to wide range of networking applications.

Note that the example implementation of the application concentrator for Web is almost identical to the Web concentrator proposed in [6]. In this paper, it is demonstrated that the Web concentrator can be systematically designed using the versatile framework of the application concentrator.

A. Web concentrator

- Overview
  We have proposed *Web concentrator* for realizing multiple association with multiple closed networks using the HTTP protocol [6]. The Web concentrator realizes multiple association at the application level without changing the existing HTTP protocol (see Fig. 3). Users can therefore perform multiple association with multiple closed networks using a standard Web browser.
- Functions
  The Web concentrator implements a *virtual browser* as a user interface for multiple association (see Fig. 4). The virtual browser provides the functions of a tab browser virtually, in a standard Web browser. *Virtual tabs* are shown within the virtual tab browser, and each virtual tab is mapped to a different closed network. By viewing virtual tabs, it is possible for users to identify the closed networks associated with communications. By selecting virtual tabs, it is also possible for users to specify

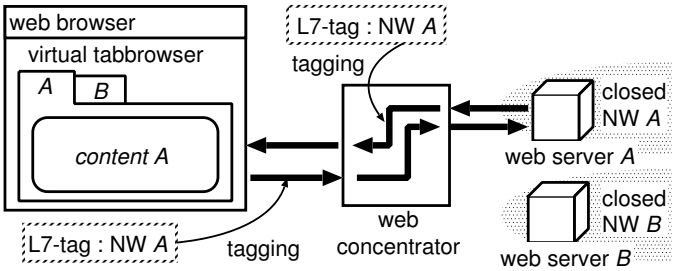

Fig. 3: Web concentrator

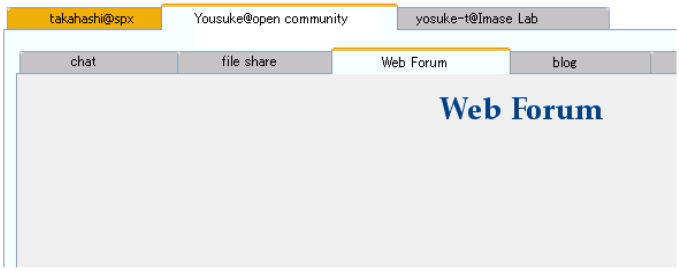

Fig. 4: Virtual tab browser that Web concentrator provides

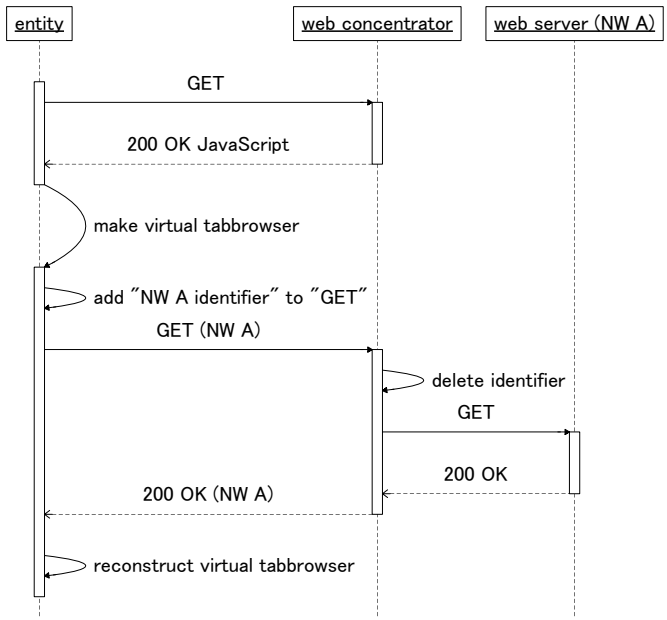

Fig. 5: Communications using the web concentrator

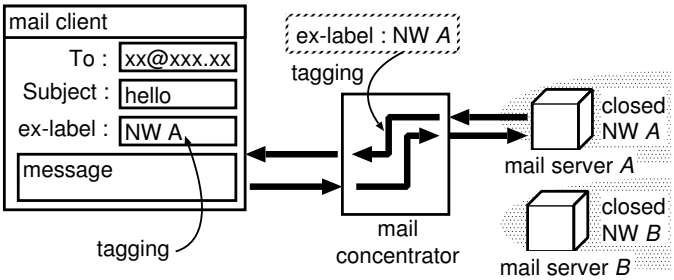

Fig. 6: Mail concentrator

the closed networks for communications. Using such interfaces, users can intuitively access multiple closed networks.
Furthermore, by utilizing the asynchronous communication functions within the web browser, users can switch over virtual tabs independently of communication to the Web concentrators. Users can therefore switch over closed networks without stress.

- Design
  The protocol converter of the Web concentrator sends Web pages containing the code which implements the virtual tab browser to the Web browser running on a user's terminal. This code is written in JavaScript [16], and by executing the JavaScript code, the Web browser implements the virtual tab browser. Also, the virtual tab browser uses JavaScript asynchronous communication functions implemented by the Web browser to refresh the information in the virtual tabs without reloading the Web page.
  Communications using the Web concentrator are conducted among entities, the Web concentrator, and Web server in the manner shown in Fig. 5. An entity first connects to the Web concentrator, and obtains a Web page containing the code for the virtual tab browser. GET requests sent to the Web browser are appended with a closed network identifier according to the virtual tab selected by the entity. By analyzing the content of HTTP communications, the Web concentrator identifies closed network identifiers, and forwards communications to the appropriate closed network. The Web concentrator sends the content of communications to entities as the content within virtual tabs.

B. *Mail concentrator*

A *mail concentrator* which realizes multiple association with multiple closed networks at the SMTP/POP protocol level was designed using the concepts of the application concentrator (see Fig. 6).

- Overview
  A mail concentrator is arranged on the path between a user terminal, an SMTP server, and a POP server. Users can exchange e-mails with entities in multiple closed networks via the mail concentrator. The mail concentrator can be utilized by the standard mail client running on a user's terminal.
- Functions
  Users may exchange e-mails with entities on multiple closed networks using a standard mail client. However, unlike a Web browser, changing the user interface of a mail client is difficult. Also, the user interfaces for sending and receiving e-mails are usually independent. It is therefore difficult to implement a protocol converter which provides a mail client with a natural user interface for multiple association.
  In the mail concentrator, an SMTP protocol extended header is therefore used for closed network identifiers. It is necessary for users to utilize the mail client and manually append the extended headers. However, since the functionality of some mail clients may be extended by installing plug-ins, it may be possible to implement a natural interface for multiple association using such plug-ins.

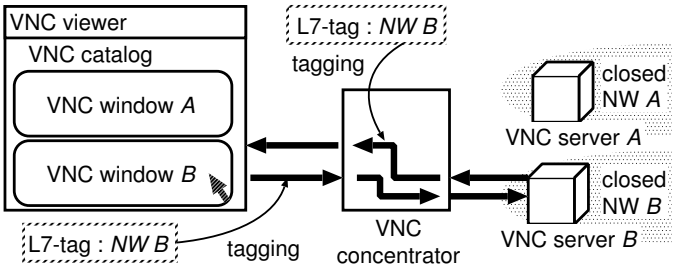

Fig. 7: VNC Concentrator

- Design
  The multiplexer within the mail concentrator redirects POP transmissions from multiple closed networks to the mail clients on users' terminals. During this process, the mail concentrator identifies the closed network at which a transmission originated, and appends a closed network identifier to the e-mail as an extended header.
  The demultiplexer within the mail concentrator redirects SMTP transmissions from the mail clients running on users' terminals to the target closed networks. During this process, the closed network identifier defined in the extended mail header is examined, and the target closed network is determined.

C. VNC Concentrator

A *VNC concentrator* which realizes multiple association with multiple closed networks at the RFB protocol level was designed using the concepts of the application concentrator.

- Overview
  The VNC concentrator enables RFB communications with multiple closed networks. Using the VNC concentrator, it is possible to communicate with entities on multiple closed networks using a standard VNC client. The VNC concentrator may be utilized by a standard VNC client running on a user's terminal.
- Functions
  The VNC concentrator provides a *VNC catalog* as a user interface for multiple association. Multiple *VNC windows* are located in the VNC catalog (see Fig. 7). The VNC windows are mapped to closed networks. The VNC windows also show screen thumbnails provided by the VNC servers on the closed networks. It is possible to simultaneously browse the thumbnails provided by the multiple VNC servers using the VNC catalog. Users may also designate target closed networks by selecting VNC windows in the VNC catalog. The VNC windows expand into the corresponding VNC client's full screen when they are selected by the user. This enables users to communicate with a target VNC server.
  The VNC concentrator is a mechanism which multiplexes and demultiplexes RFB communications at the application level (see Fig. 7). Users may conduct VNC communications among multiple closed networks using the VNC concentrator. Users may also utilize the *VNC catalog* interface for multiple association from a standard VNC client running on a terminal. The *VNC windows* in the VNC catalog are mapped to closed networks, and by selecting VNC windows, users can select target closed networks.
- Design
  The protocol converter of the VNC concentrator operates as described as follows. When a user accesses the VNC concentrator, the VNC concentrator sends the VNC catalog screen data to the VNC client. The VNC catalog is generated by the VNC concentrator, and the user interface composed of VNC windows is provided to the VNC client on the user's terminal. When a user selects a VNC window from the VNC catalog, the selected closed network identifier is sent to the VNC concentrator. The VNC concentrator selects the closed network which should be communicated with according to the closed network identifier sent by the VNC client. The VNC concentrator requests screen data from the VNC server of the closed network, and forwards the received screen data to the VNC client on the user's terminal.

5. Conclusions and Further Work

In this paper we proposed a framework called *application concentrator*, which was an application-level gateway for enabling interconnection of multiple closed groups for various applications. The application concentrator is a versatile framework for realizing multiple association at the application level. For demonstrating effectiveness of the application concentrator, we designed example implementations of the application concentrator for three typical applications such as Web, e-mail, and remote desktop.

Further work includes the construction of a prototype based on the methods proposed, and the evaluation of its efficacy in a practical operating environment.

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