

Better end-to-end visibility leads better networks

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Abstract

Visibility inside a network must be required for the future internet, though the design process is in progress. The previous works for the visibility have been focused on the network operator. Further, the disclosure policy is controlled by the operator. In this study, we present a concept to provide the visibility from an end-system using in-band cross-layer approach, which respects the policies, not only operators but also the end-system.

1 Introduction

With diversification of network technologies, we have encountered many difficulties due to the lack of visibility inside a network deriving from the end-to-end principle as the followings. In mobile networks, the situations of the mobile system, such as the system location, access bandwidth, corruption losses, and associated base station change continuously. In fixed networks, the difference between the lower and upper limits of bandwidth increases exponentially. The abovementioned factors must be considered for achieving high performance and for enhancing the convenience in network system.

Further, it is necessary for network systems beyond the end-to-end principle to provide visibility inside the network. In the case of QoS provisioning, such as Intserv and MPLS, visibility enables an end system to inspect whether or not a provisioned path satisfies the QoS commitment. A number of new network services and architectures that the network changes own behavior taking into consideration of the situation or the content of a message have been proposed, and some of them are realized, such as intelligent message routing [1]. Without any visibility inside these upcoming architectures, an end system cannot understand what was, is, or will be, happen on the network because the network is working under intelligent man-

ners compared to a dumb network.

In studies on congestion control, the several approaches that an end system utilizes inside network information for TCP congestion control have been presented as PTP, ETEN, SIRENS [10, 6, 7]. Hereafter, the above approaches are collectively called, “Explicit Network information Collection Along Path (ENCAP)” In ENCAP approaches, an end-system acquires inside information using an in-band cross-layer approach. ENCAP can handle any type of information on a network, although it was originally designed for congestion control. In this study, we utilize ENCAP as a generic information collection tool: this improves the visibility inside a network when the network is viewed from an end system. However, the current ENCAP approach discloses all the information along the path. In order to deploy ENCAP as a generic network visibility framework, we have to also provide a privacy-preserving function together. On the other hand, most of previous approach to improve the visibility is required a server to collect information from network device. In general, an end-system cannot access the collected information because the visibility is not for an end-system but for a network operator. Even in few approaches for an end-system, the server is also required, and the disclosure policy is managed by the operator.

Clark *et al.* showed a great picture of a future network architecture known as knowledge plane [2]. The goal of the knowledge plane is that a network can assemble, reassemble, diagnose, and heal itself using AI and cognitive technique. To utilize ENCAP for generic information collection is a step toward the knowledge plane. Because a scalable network information gathering mechanism is the key technology for *sensor* component in the knowledge plane. Note that the knowledge plane also requires *actuator* component to change network behavior according the information gathered by *sensor*. Clark *et al.* have also pointed out that privacy and competition issues will come up after a scalable information gathering mechanism in the

knowledge plane.

In this paper, we present a new concept to provide visibility inside a network path with respecting disclosure policies among the end-systems and networks. In Section 2, we firstly discuss how the visibility inside a network contributes to the enhancement of a network system. We present related works in Section 3. In Section 4, we present the ENCAP approach, and discuss the issue of privacy. In Section 5, we present our concept of privacy-preserving mechanisms. Finally, we conclude this paper in the last section.

2 Visibility inside a network

A network router maintains information that is required for routing, such as routing tables, access control lists, and link utilization. In addition, a router stores information required for the network operation, e.g., a calendar clock, time zone, temperature, location, operator's contact detail, and charging information of a circuit. Such information can be accessed only by the network operators. However, if the information is disclosed to an end-system, the network provides improved end-to-end visibility inside a network.

More types of information can be provided by a router by using auxiliary devices or its interfaces, such as environmental sensors and GPS. The cost of the auxiliary system is negligible as compared with an expensive ISP router. Further, since the router, as part of an ISP infrastructure, is maintained with a higher quality operation as compared to almost all end systems, the information obtained from the network is expected to be of a better quality.

End-to-end visibility would lead to the following benefits in end-systems, in addition to operation and management. (1) An enhanced congestion control considering the explicit path condition is realized. (2) A P2P sharing application can select a better peer set to achieve a high throughput. (3) If a VoD service offers video streams at different rates, the server can offer the optimal rate according to the bandwidth conditions of the path. (4) If the region in which the service of a VoD movie is offered is restricted by contract, the server respects this contract by using the path of the router location in addition to the declaration from the receiver. (5) A laptop PC can acquire correct information on daylight savings times and time zones from the uplink router. Note that part of the above features are already offered by the existing protocols, e.g., timezone and location can be acquired by DHCP and HELD, respectively.

Although SNMP has been well deployed on network devices, a network infrastructure device usually rejects SNMP queries from an unknown end system.

Because frequent SNMP queries degrades the device performance since the SNMP service is implemented on the management plane. A network device status and configuration can be changed with an SNMP operation. The system must take care of the action to change something on the device with the management plane.

However, the function to change a device status and configuration is beyond our scope, since our goal is just to collect information. Thus, a new information collection mechanism can be implemented with a different design not to involve the management plane.

3 Related Work

Most of tools and studies to provide visibility inside a network have been focused on operation and management. Our goal of visibility is also to enhance functionalities of an end-system with enriching network information.

`traceroute` is mostly used diagnostic tools for obtaining end-to-end IP reachability information inside a network. Network management and monitoring system, such as HP OpenView and MRTG, collects the information of devices with polling and receiving trap mainly using SNMP. Only limited information and access are enabled on the system from an end-system. Since the system usually serves single administrative domain only, it is far to enable end-to-end visibility.

Active network has been presented as an architecture beyond the end-to-end network with programmable router system. In studies on active network research, the same concept as ENCAP has been presented as an application of active network for network operation and management [9]. Active network system has not been realized yet, since there are still open issues, such as security and scalability.

In congestion control studies, number of proposals that the network more concerns with congestion control than ENCAP-type protocols are presented as XCP and TCP Quick Start [4, 8]. The proposals require a resource management component on the router in addition to the ENCAP-like visibility features. A mechanism to protect the resource management from bogus request is required to realize the proposals.

X-Trace enables reconstruction of action inside a networked system [3]. All actions relating datagram are traced by each system component, and they are collected into a server. X-trace was designed as a comprehensive diagnosis framework, and it requires a data collection server for each administrative domain.

The concept of cross-layer visibility in IP network as a service has been presented [5]. This study is also focused on not for an end-system but for an operator.

4 ENCAP and its privacy issue

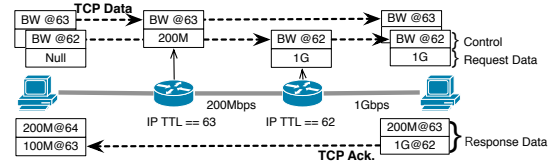
ENCAP is an in-band feedback approach that involves routers, and it is designed as a thin layer between the network layer and the transport layer. In the ENCAP protocols (Fig. 1), a sender host sends an information request encapsulating into a usual packet, such as TCP data. When a router receives an ENCAP request packet, the router inserts or overwrites appropriate information into the ENCAP header, if required. A receiver sends back the collected information onto the feedback packet as TCP Ack. In the case of PTP, with increase in the packet size, all the router data along the path are stacked into a single packet. In SIRENS, since the data of only a specific hop router is collected by one packet, N packets are required to collect all the information along the path: N corresponds to the number of router hops between the sender and the receiver. Thus, ENCAP cannot provide any information without cooperation between the sender and the receiver. Moreover, ENCAP only provides information on restricted routers that are located on the packet path between the sender and the receiver.

ENCAP provides a scalable network information collection infrastructure. Because, ENCAP just requires small storage both only on sender and receiver, and ENCAP does not include any risk of state explosion on router. This scalability enables that an end-system continuously records the information even at “normal” condition. In some cases of network trouble, it is difficult to identify what is different, because of lacking the information of “normal” condition. It is a significant helpful to identify a trouble, if an end user can report the trouble with the information both at “normal” and “trouble”.

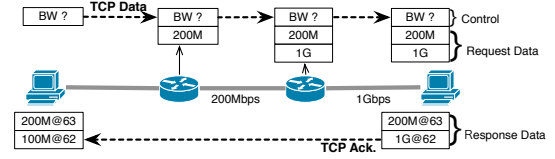
In the ENCAP studies conducted to enhance TCP performance, an end-system collects the network path conditions, such as bottleneck bandwidth, queue capacity of an interface, and corruption loss. The TCP behavior is optimized by adjusting the congestion window size or redundancy level of FEC according to the conditions.

As mentioned above, the original ENCAP proposals focused on congestion control only. Information relevant to congestion was regarded as not containing any privacy-sensitive information. However, if we apply ENCAP to all types of data, we have to consider the issue of privacy.

Let us assume that a TCP connection in which ENCAP is available is established between Alice and Bob. However, Alice and Bob prefer not to reveal their respective locations to others, before they both agree to disclose their locations to each other. If Alice would



(a) SIRENS: a packet collects only one hop's information.



(b) PTP: only one packet collects information along the entire path.

Figure 1. Overview of ENCAP protocols, (a) SIRENS, (b) PTP.

like to know the geographical location of the WiFi router on her own uplink, Alice sends ENCAP location requests by using the TCP connection. Bob gathers the location information of all the routers along the connection path. Bob sends back the location data to Alice. Thus, Alice knows the location of her uplink router. However, if all the ENCAP data are encapsulated with plain text, Bob can determine Alice's location immediately, when the ENCAP packet is received by Bob. If all the ENCAP data are encrypted in order to prevent Bob from accessing the data, Bob cannot determine the type of information that is being retrieved by Alice.

5 Preserving privacy with ENCAP

Although we have considered many risks and threat models related to ENCAP, we cannot present all of them here due to limited space. Further, we cannot enumerate the requirements for privacy preservation. Therefore, we present our concept for managing ENCAP information while respecting the privacy policy of the sender, receiver, and network. Further, we discuss a threat model for ENCAP protocols.

In order to implement the disclosure policy of the network, the network operator just applies the policy, such as whether the information on the router can be disclosed to everybody by an ENCAP request, or not. Different policies depending on the network operator are acceptable, though the information of the path is not a complete.

ENCAP requires three fields *control*, *request data*, and response data. The *control* field is used to specify

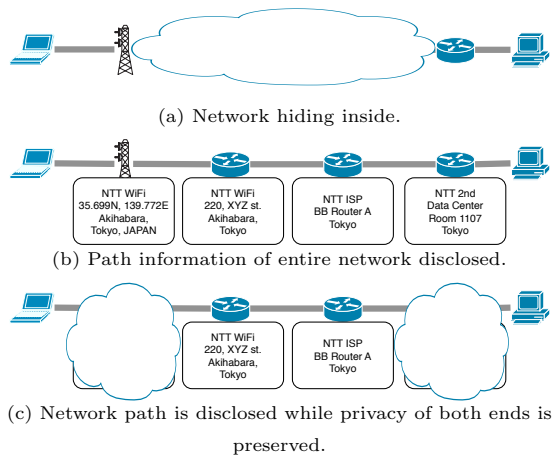
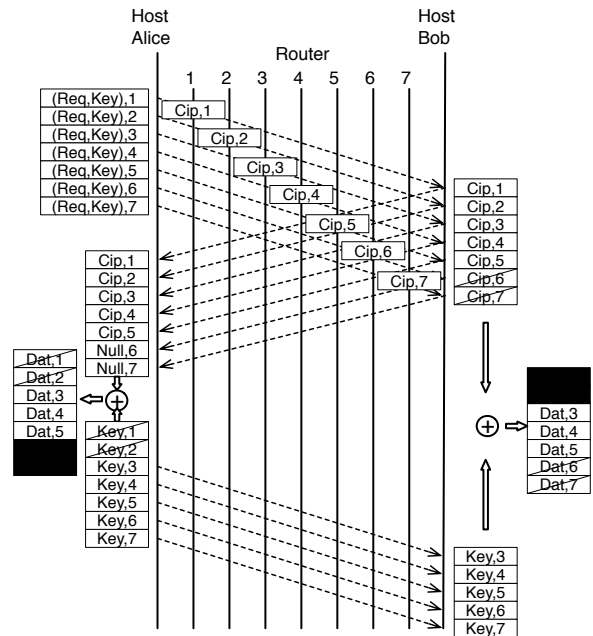


Figure 2. Privacy preserving model with EN-CAP

the requested data for the use of a receiver and routers. The *request data* is updated by a router, which delivers the requisite information to a receiver. The *response data* carries back the collected data from a receiver to a sender. The *control* field should not be encrypted because every ENCAP router has to refer to it. Further, the *control* field should not be modified by an intermediate router. This is because Bob should be able to determine the type of information that is being retrieved by Alice just by observing the control field. Bob stops sending the corresponding *request data*, when he decides not to disclose it. Therefore, the *control* field requires an end-to-end integrity protection mechanism, such as HMAC. The *response data* field does not require any new security mechanism because the *response data* does not involve any router action. It is sufficient for the *response data* to apply a deployed end-to-end security scheme, such as TLS.

In contrast to the abovementioned security scheme, which is aimed at sharing information between end-to-end systems, some contents of the *request data* field should be kept confidential from a receiver.

Our concept for preserving privacy is a simple: router information is selectively disclosed by designating whether or not a specific hop-count router information is disclosed. A selective disclosure mechanism can be realized as follows (Fig. 3): Alice generates a one-time encryption keys, and encapsulates the encryption keys into the ENCAP request packet. The number of keys corresponds to the *request data* field number. The router updates the *request data* field with the encrypted data and removes the used one-time key from the packet. If Bob can disclose the information type specified with the *control* field, he sends back the re-

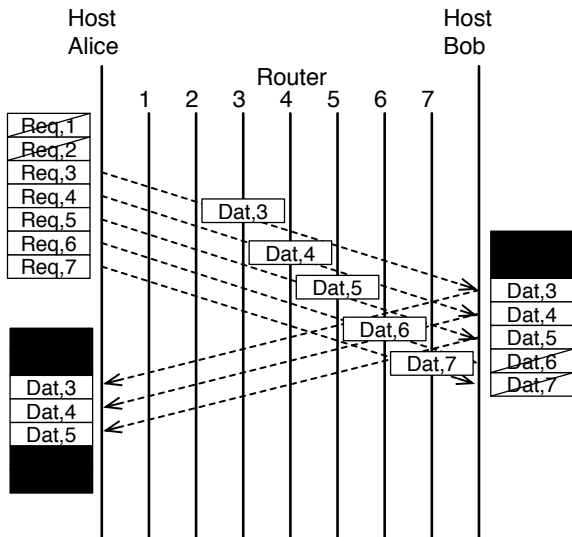


In the above example, both Alice and Bob prefer not to reveal the information up to second nearest routers from own host. Bob does not send back the ciphered text corresponding router 6 and 7 to Alice. Alice does not send Bob the decryption keys for the router 1 and 2. As the result, Alice knows the information from the router 1 to 5, and Bob knows from 3 to 7.

Figure 3. Privacy preserving on EN-CAP: using encryption.

ceived *request data* encrypted by Alice's key. Even if the privacy policy of Bob does not allow disclosure of specific information type, he can decide that the information on the router far from his system is of less concern regard to his privacy. In this case, Bob selectively sends back the encrypted request data following his policy. Alice confirms the location with the ENCAP responses sent back by Bob. If Alice decides to disclose the location to Bob, Alice transmits the corresponding encryption keys to Bob. In the above scheme, we quietly use a symmetric encryption algorithm for the request data field. It assumes that Bob cannot capture ENCAP request packets before the key being removed by a router. If Bob can get an encryption key used by the router along the path, he can obtain the information before Alice. If the risk cannot be acceptable, we have to use asymmetric encryption with higher processing cost.

If no encryption mechanism can be used on the ENCAP router, a selective disclosure can be realized with



In the above example, both Alice and Bob prefer not to reveal the information up to second nearest routers from own host. Alice does not send the request for the router 1 and 2. Bob does not send back the data at the router 6 and 7. As the result, Alice knows the information from the router 3 to 5, and Bob knows from 3 to 7. If Alice would like to know the router 1 and 2, Alice requests Bob to make the reverse action.

Figure 4. Privacy preserving on ENCAP:without encryption.

a selective ENCAP information request. It is required in the ENCAP protocol that the ENCAP requester can designate hop count to collect information at the specific section in the path (Fig. 4). Alice requests Bob to send ENCAP requests in order to collect the location information on the router near Alice. Bob sends ENCAP request packets by adjusting the hop count in order to designate the routers near to Alice. Alice knows the router locations around her by receiving the ENCAP request packets without revealing the location information on Bob side.

One threat model for the ENCAP system is that an end system can report a bogus network topology behind the actual end point by crafting the ENCAP response data. ENCAP essentially includes this risk by a phantom network topology, and this type of threat cannot be prevented. However, the risk is not significant and it is manageable. That is because, an end system cannot tamper with the real network information collected by the ENCAP packet sent from itself. In congestion control, even if an end system pretends under better conditions than the real net-

work, the transport stack optimizes itself considering the worst condition instead of the better one, such as bandwidth bottleneck. In content distribution with regional restriction, content leaks to outside can be detected from the router locations of the path. If a malicious user in Japan attempts to procure videos licensed in USA by forging his own location and network, the location of the user access managed by ISP is still included in the router locations on the path.

6 Conclusion

In this paper, we have provided the rough sketch of a protocol used for preserving privacy by using ENCAP. We recognize that there may be many problems and glitches in this protocol. However, we believe that better visibility inside the Internet can lead to significant advantages in network applications and end systems, and the ENCAP approach can be used to enhance the visibility.

From the view point of the knowledge plane, our visibility mechanism is a step to realize *sensor* component supporting privacy. However, at the knowledge plane, network infrastructure, that is router, changes own behavior according to the situation. Therefore, in order to provide complete *sensor* set for the knowledge plane, we have to develop a scalable visibility mechanism viewed from intermediate-node as well as from the end-system proposed by this paper.

In addition to the privacy issue discussed in this paper, we would like to address the next question: What is the extent and type of visibility is required for Future Internet to take off ?

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