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Survey paper

In-band Network Telemetry: A Survey

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ABSTRACT

With the development of software-defined network and programmable data-plane technology, in-band network telemetry has emerged. In-band network telemetry technology collects hop-by-hop network status information through business packets to achieve end-to-end visualization of network services. In-band network telemetry uses the data plane to directly drive the network measurement process, subverting the research idea of traditional network measurement that treats network switching device as an intermediate black box. In-band network telemetry technology has the advantages of flexible programming, strong real-time, less noise and path-level network status perception, etc. It has become an emerging representative of network telemetry technology and has received extensive attention from academia and industry.

In this survey, we conduct a comprehensive investigation on the situation of in-band network telemetry technology. Firstly, we review the different development stages of network measurement and give a chronology. And we sort out the development history and research results of in-band network telemetry. Secondly, we introduce in detail several existing representative solutions of in-band network telemetry, including INT, IOAM, AM-PM and ANT, in terms of systems, implementation idea, technical features, standardization, and research results. Thirdly, we analyze several key technologies of the in-band network telemetry system, which runs through data generation, export, storage, and analysis. We summarize the advantages and disadvantages of the existing solutions. Moreover, we investigate the latest applications of in-band network telemetry from two aspects: performance measurement and function measurement. Furthermore, we highlight the technical opportunities brought by in-band network telemetry technology to network measurement and management, as well as several technical challenges and future research directions.

1. Introduction

Network measurement is the foundation of network management and control [1]. Since the Natural Science Foundation (NSF) of the United States began to fund Internet measurement in 1995, academia and industry have proposed and improved many measurement methods. As shown in Fig. 1, according to the development of measurement methods, we can divide network measurement into three research ideas: (1) traditional network measurement developed since 1995; (2) software-defined measurement that was produced and developed with software-defined networks (SDN) since 2008; (3) network telemetry with the rise of programmable data plane (PDP) technology since 2015.

1.1. Traditional network measurement

According to RFC 7799[2], traditional network measurement is divided into active, passive and hybrid network measurement.

The research idea of active network measurement is to deduce the overall performance status of the network by constructing, observing and analyzing the operation status of the probe packet on the network. Representative schemes are Ping [3] and Traceroute [4]. The forwarding path of the out-of-band probe constructed by the active measurement scheme may not be exactly the same as the service traffic flow, so the measurement results cannot accurately reflect the

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telemetry metadata, traffic, network scale, etc. The processing capacity of telemetry server may be the performance bottleneck of telemetry system. Therefore, when telemetry endpoint reports telemetry data, it should consider pre-compression, filtering and aggregation of the telemetry data to reduce the pressure on telemetry server.

The existing metadata field can only store some indispensable limited data. With the development of network automation, virtualization and convergence technology, in-band network telemetry should collect and provide more network data on demand. Therefore, future research needs to fully consider the flexibility and scalability of data field definition, aggregation, acquisition and filtering.

Since business packets may be lost due to various reasons, INT telemetry information will inevitably be lost. But the telemetry mechanism makes INT unable to detect the network packet loss. There is no feasible packet loss measurement solution for INT.[1] There are some high-performance packet loss measurement solutions, but none of them have been integrated into INT. It is worth noting that there is already scheme [133] using INT to measure packet loss rate, but it belongs to active measurement. In other words, the reason it can measure the packet loss rate is not because of INT, but because it constructs active network probes. Besides, it measures the packet loss rate of the probe instead of per-flow. Therefore, INT itself should support packet loss detection and localization.

5.5. Orchestration of telemetry tasks

Compared to traditional network measurement, in-band network telemetry task orchestration is more complicated [113]. The monitoring application only cares about the data itself, instead of how to obtain the data. Therefore, a telemetry task scheduling layer must be used to achieve efficient task distribution and data acquisition. In addition to upper-level monitoring applications and telemetry projects, the factors participating in the orchestration of in-band network telemetry tasks include real-time and changing network flows [114]. How to achieve high-quality network measurement at low cost according to the existing network status will be a key issue of in-band network telemetry that continue to be studied.

5.6. Telemetry security

The data plane programmability of in-band network telemetry may lead to potential software vulnerabilities, backdoors, viruses, and other security issues. Malicious INT and IOAM source nodes continuously construct telemetry packets to carry out malicious and illegal attacks, occupying network bandwidth, consuming node processing capabilities. These attacks may cause the exhaustion of available network resources. In-band network telemetry technology requires packet-level operations such as decapsulation, insertion, and encapsulation. These operations may threaten the confidentiality and security of user information. Therefore, in-band network telemetry systems need to have node authentication functions. Pan et al. [155] used vector homomorphic encryption to design a lightweight telemetry data encryption scheme. By hash-based signature encoding of the encrypted INT data, The telemetry server can verify the integrity of INT data, thus eliminating the threat of telemetry data security due to data tampering.

[1] The latest version of INT specification [61] has divided INT into three types: INT-XD, INT-MX and INT-MD. The first two draw on the ideas of iFIT [39] and IOAM [37], and export metadata hop by hop, so they can be directly used for loss measurement. This survey only discuss the third type of INT here.

6. Summary

In this survey, we researched in-band network telemetry from various aspects, i.e., development history, research situation, application and key technologies. Technical challenges and future research directions were also proposed.

Existing researches have documented that in-band network telemetry technology has important research value and broad application prospects. In-band network telemetry technology is in the ascendant, and there is still a lot of room for research and innovation, and it is worth continuing to explore in academia and industry.

CRediT authorship contribution statement

Lizhuang Tan: Conceptualization of this study, Writing - original draft. **Wei Su:** Project administration, Funding acquisition. **Wei Zhang:** Writing - review & editing. **Jianhui Lv:** Writing - original draft. **Zhenyi Zhang:** Data curation. **Jingying Miao:** Writing - original draft, Data curation. **Xiaoxi Liu:** Writing - original draft. **Na Li:** Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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