                              Path Signals
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Abstract

   This document discusses the nature of signals seen by on-path
   elements, contrasting implicit and explicit signals. For example,
   TCP's state mechanics uses a series of well-known messages that are
   exchanged in the clear. Because these are visible to network
   elements on the path between the two nodes setting up the transport
   connection, they are often used as signals by those network elements.
   In transports that do not exchange these messages in the clear, on-
   path network elements lack those signals. This document recommends
   that explicit signals be used by transports which encrypt their state
   mechanics. It also recommends that a signal be exposed to the path
   only when the signal's originator intends that it be used by the
   network elements on the path.

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Table of Contents

1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
document are to be interpreted as described in RFC 2119 [RFC2119].

2. Introduction

This document discusses the nature of signals seen by on-path
elements, contrasting implicit and explicit signals. For example,
TCP's state mechanics uses a series of well-known messages that are
exchanged in the clear. Because these are visible to network
elements on the path between the two nodes setting up the transport

connection, they are often used as signals by those network elements. In transports that do not exchange these messages in the clear, on-path network elements lack those signals. This document recommends that explicit signals be used by transports which encrypt their state mechanics. It also recommends that a signal be exposed to the path only when the signal's originator intends that it be used by the network elements on the path.

The interpretation of TCP [RFC0793] by on-path elements is an exmple of implicit signal usage. It uses cleartext handshake messages to establish, maintain, and close connections. While these are primarily intended to create state between two communicating nodes, these handshake messages are visible to network elements along the path between them. It is common for certain network elements to treat the exchanged messages as signals which relate to their own functions.

A firewall may, for example, create a rule that allows traffic from a specific host and port to enter its network when the connection was initiated by a host already within the network. It may subsequently remove that rule when the communication has ceased. In the context of TCP handshake, it sets up the pinhole rule on seeing the initial TCP SYN acknowledgement and then removes it upon seeing a RST or FIN & ACK exchange. Note that in this case it does nothing to re-write any portion of the TCP packet; it simply enables a return path that would otherwise have been blocked.

When a transport encrypts the fields it uses for state mechanics, these signals are no longer accessible to path elements. The behavior of path elements will then depend on which signal is not available, on the default behavior configured by the path element administrator, and by the security posture of the network as a whole.

3. Signals Type Inferred

The following list of signals which may be inferred from transport state messages includes those which may be exchanged during sessions establishment and those which derive from the ongoing flow.

Some of these signals are derived from the direct examination of packet trains, such as using a sequence number gap pattern to infer network reliability; others are derived from association, such as inferring network latency by timing a flow's packet inter-arrival times.

This list is not exhaustive, and it is not the full set of effects due to encrypting data and metadata in flight. Note as well that because these are derived from inference, they do not include any

path signals which would not be relevant to the end point state
machines; indeed, an inference-based system cannot send such signals.

3.1. Session Establishment

One of the most basic inferences made by examination of transport
state is that a packet will be part of an ongoing flow; that is, an
established session will continue until messages are received that
terminate it. Path elements may then make subsidiary inferences
related to the session.

3.1.1. Session Identity

Path elements that track session establishment will typically create
a session identity for the flow, commonly using a tuple of the
visible information in the packet headers. This is then used to
associate other information with the flow.

3.1.2. Routability and Consent

A second common inference that session establishment provides is that
the communicating pair of hosts can each reach each other and are
interested in continuing communication. The firewall example given
above is a consequence of the inference of consent; because the
internal host initiates the connection, it is presumed to consent to
return traffic. That, in turn justifies the pinhole.

Some other on-path elements (assume that a host which asked to
communicate with a remote address consents to establish incoming
communications from any other host (Endpoint-Independent Mapping/
Endpoint-Independent Filtering). This is, for example, the default
behavior in NAT64.

3.1.3. Flow Stability

Some on-path devices that are responsible for load-sharing or load-
balancing may be instructed to preserve the same path for a given
flow, rather than dispatching packets belonging to the some flow on
multiple paths as this may cause packets in the flow to be delivered
out of order..

3.1.4. Resource Requirements

An additional common inference is that network resources will be
required for the session. These may be requirements within the
network element itself, such as table entry space for a firewall or
NAT; they may also be communicated by the network element to other

systems. For networks which use resource reservations, this might
result in reservation of radio air time, energy, or network capacity.

3.2. Network Measurement

Some network elements will also observe transport messages to engage
in measurement of the paths which are used by flows on their network.
The list of measurements below is illustrative, not exhaustive.

3.2.1. Path Latency

There are several ways in which a network element may measure path
latency using transport messages, but two common ones are examining
exposed timestamps and associating sequence numbers with a local
timer. These measurements are necessarily limited to measuring only
the portion of the path between the system which assigned the
timestamp or sequence number and the network element.

3.2.2. Path Reliability and Consistency

A network element may also measure the reliability of a particular
path by examining sessions which expose sequence numbers;
retransmissions and gaps are then associated with the path segments
on which they might have occurred.

4. Options

The set of options below are alternatives which optimize very
different things. Though it comes to a preliminary conclusion, this
draft intends to foster a discussion of those tradeoffs and any
discussion of them must be understood as preliminary.

4.1. Do Not Restore These Signals

It is possible, of course, to do nothing. The transport messages
were not necessarily intended for consumption by on-path network
elements and encrypting them so they are not visible may be taken by
some as a benefit. Each network element would then treat packets
without these visible elements according to its own defaults. While
our experience of that is not extensive, one consequence has been
that state tables for flows of this type are generally not kept as
long as those for which sessions are identifiable. The result is
that heartbeat traffic must be maintained to keep any bindings (e.g.
NAT or firewall) from early expiry. When those bindings are not
kept, methods like QUIC's connection-id [QUIC] may be necessary to
allow load balancers or other systems to continue to maintain a
flow's path to the appropriate peer.

4.2. Replace These With Network Layer Signals

It would be possible to replace these implicit signals with explicit
signals at the network layer. Though IPv4 has relatively few
facilities for this, IPv6 hop-by-hop headers [RFC7045] might suit
this purpose. Further examination of the deployability of these
headers may be required.

4.3. Replace These With Per-Transport Signals

It is possible to replace these implicit signals with signals that
are tailored to specific transports, just as the initial signals are
derived primarily from TCP. There is a risk here that the first
transport which develops these will be reused for many purposes
outside its stated purpose, simply because it traverses NATs and
firewalls better than other traffic. If done with an explicit intent
to re-use the elements of the solution in other transports, the risk
of ossification might be slightly lower.

4.4. Create a Set of Signals Common to Multiple Transports

Several proposals use UDP [RFC0768] as a demux layer, onto which new
transport semantics are layered. For those transports, it may be
possible to build a common signalling mechanism and set of signals,
such as that proposed in "Transport-Independent Path Layer State
Management" [PLUS].

This may be taken as a variant of the re-use of common elements
mentioned in the section above, but it has a greater chance of
avoiding the ossification of the solution into the first moving
protocol.

5. Recommendation

Fundamentally, this paper recommends that implicit signals should be
replaced with explicit signals, but that a signal should be exposed
to the path only when the signal's originator intends that it be used
by the network elements on the path. For many flows, that may result
in signal being absent, but it allows them to be present when needed.

Discussion of the appropriate mechanism(s) for these signals is
continuing but, at minimum, any method should aim to adhere to these
basic principles:

o The portion of protocol signaling that is intended for end system
   state machines should be protected by confidentiality and
   integrity protection such that it is only available to those end
   systems.

   o Anything exposed to the path should be done with the intent that
      it be used by the network elements on the path. This information
      should be integrity protected.

   o Signals exposed to the path should be decoupled from signals that
      drive the protocol state machines in endpoints. This avoids
      creating opportunities for additional inference.

   o Intermediate path elements should not add visible signals which
      identify the user, origin node, or origin network [RFC8164].

6. IANA Considerations

   This document contains no requests for IANA.

7. Security Considerations

   Path-visible signals allow network elements along the path to act
   based on the signaled information, whether the signal is implicit or
   explicit. If the network element is controlled by an attacker, those
   actions can include dropping, delaying, or mishandling the
   constituent packets of a flow. It may also characterize the flow or
   attempt to fingerprint the communicating nodes based on the pattern
   of signals.

   Note that actions that do not benefit the flow or the network may be
   perceived as an attack even if they are conducted by a responsible
   network element. Designing a system that minimizes the ability to
   act on signals at all by removing as many signals as possible may
   reduce this possibility. This approach also comes with risks,
   principally that the actions will continue to take place on an
   arbitrary set of flows.

   Addition of visible signals to the path also increases the
   information available to an observer and may, when the information
   can be linked to a node or user, reduce the privacy of the user.

   When signals from end points to the path are independent from the
   signals used by endpoints to manage the flow's state mechanics, they
   may be falsified by an endpoint without affecting the peer's
   understanding of the flow's state. For encrypted flows, this
   divergence is not detectable by on-path devices.

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All errors are those of the editor.

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