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R. Barnes
B. Schneier
C. Jennings
T. Hardie
B. Trammell
C. Huitema
D. Borkmann

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Confidentiality in the Face of Pervasive Surveillance: A Threat Model and Problem Statement

Abstract

Since the initial revelations of pervasive surveillance in 2013, several classes of attacks on Internet communications have been discovered. In this document, we develop a threat model that describes these attacks on Internet confidentiality. We assume an attacker that is interested in undetected, indiscriminate eavesdropping. The threat model is based on published, verified attacks.

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1. Introduction

Starting in June 2013, documents released to the press by Edward Snowden have revealed several operations undertaken by intelligence agencies to exploit Internet communications for intelligence purposes. These attacks were largely based on protocol vulnerabilities that were already known to exist. The attacks were nonetheless striking in their pervasive nature, in terms of both the volume of Internet traffic targeted and the diversity of attack techniques employed.

To ensure that the Internet can be trusted by users, it is necessary for the Internet technical community to address the vulnerabilities exploited in these attacks [RFC7258]. The goal of this document is to describe more precisely the threats posed by these pervasive attacks, and based on those threats, lay out the problems that need to be solved in order to secure the Internet in the face of those threats.

The remainder of this document is structured as follows. In Section 3, we describe an idealized passive pervasive attacker, one which could completely undetectably compromise communications at Internet scale. In Section 4, we provide a brief summary of some attacks that have been disclosed, and use these to expand the assumed capabilities of our idealized attacker. Note that we do not attempt to describe all possible attacks, but focus on those that result in undetected eavesdropping. Section 5 describes a threat model based on these attacks, focusing on classes of attack that have not been a focus of Internet engineering to date.

2. Terminology

This document makes extensive use of standard security and privacy terminology; see [RFC4949] and [RFC6973]. Terms used from [RFC6973] include Eavesdropper, Observer, Initiator, Intermediary, Recipient, Attack (in a privacy context), Correlation, Fingerprint, Traffic Analysis, and Identifiability (and related terms). In addition, we use a few terms that are specific to the attacks discussed in this document. Note especially that "passive" and "active" below do not refer to the effort used to mount the attack; a "passive attack" is any attack that accesses a flow but does not modify it, while an "active attack" is any attack that modifies a flow. Some passive attacks involve active interception and modifications of devices, rather than simple access to the medium. The introduced terms are:

Pervasive Attack: An attack on Internet communications that makes use of access at a large number of points in the network, or otherwise provides the attacker with access to a large amount of Internet traffic; see [RFC7258].

Passive Pervasive Attack: An eavesdropping attack undertaken by a pervasive attacker, in which the packets in a traffic stream between two endpoints are intercepted, but in which the attacker does not modify the packets in the traffic stream between two endpoints, modify the treatment of packets in the traffic stream (e.g., delay, routing), or add or remove packets in the traffic stream. Passive pervasive attacks are undetectable from the endpoints. Equivalent to passive wiretapping as defined in [RFC4949]; we use an alternate term here since the methods employed are wider than those implied by the word "wiretapping", including the active compromise of intermediate systems.

Active Pervasive Attack: An attack that is undertaken by a pervasive attacker and, in addition to the elements of a passive pervasive attack, also includes modification, addition, or removal of packets in a traffic stream, or modification of treatment of packets in the traffic stream. Active pervasive attacks provide more capabilities to the attacker at the risk of possible detection at the endpoints. Equivalent to active wiretapping as defined in [RFC4949].

Observation: Information collected directly from communications by an eavesdropper or observer. For example, the knowledge that <alice@example.com> sent a message to <bob@example.com> via SMTP taken from the headers of an observed SMTP message would be an observation.

Inference: Information derived from analysis of information collected directly from communications by an eavesdropper or observer. For example, the knowledge that a given web page was accessed by a given IP address, by comparing the size in octets of measured network flow records to fingerprints derived from known sizes of linked resources on the web servers involved, would be an inference.

Collaborator: An entity that is a legitimate participant in a communication, and provides information about that communication to an attacker. Collaborators may either deliberately or unwittingly cooperate with the attacker, in the latter case because the attacker has subverted the collaborator through technical, social, or other means.

Key Exfiltration: The transmission of cryptographic keying material for an encrypted communication from a collaborator, deliberately or unwittingly, to an attacker.

Content Exfiltration: The transmission of the content of a communication from a collaborator, deliberately or unwittingly, to an attacker

3. An Idealized Passive Pervasive Attacker

In considering the threat posed by pervasive surveillance, we begin by defining an idealized passive pervasive attacker. While this attacker is less capable than those that we now know to have compromised the Internet from press reports, as elaborated in Section 4, it does set a lower bound on the capabilities of an attacker interested in indiscriminate passive surveillance while interested in remaining undetectable. We note that, prior to the Snowden revelations in 2013, the assumptions of attacker capability presented here would be considered on the border of paranoia outside the network security community.

Our idealized attacker is an indiscriminate eavesdropper that is on an Internet-attached computer network and:

- can observe every packet of all communications at any hop in any network path between an initiator and a recipient;
- can observe data at rest in any intermediate system between the endpoints controlled by the initiator and recipient; and
- can share information with other such attackers; but
- takes no other action with respect to these communications (i.e., blocking, modification, injection, etc.).

The techniques available to our ideal attacker are direct observation and inference. Direct observation involves taking information directly from eavesdropped communications, such as URLs identifying content or email addresses identifying individuals from application-layer headers. Inference, on the other hand, involves analyzing observed information to derive new information, such as searching for application or behavioral fingerprints in observed traffic to derive information about the observed individual. The use of encryption is generally sufficient to provide confidentiality by preventing direct observation of content, assuming of course, uncompromised encryption implementations and cryptographic keying material. However, encryption provides less complete protection against inference,

especially inferences based only on plaintext portions of communications, such as IP and TCP headers for TLS-protected traffic [RFC5246].

3.1. Information Subject to Direct Observation

Protocols that do not encrypt their payload make the entire content of the communication available to the idealized attacker along their path. Following the advice in [RFC3365], most such protocols have a secure variant that encrypts the payload for confidentiality, and these secure variants are seeing ever-wider deployment. A noteworthy exception is DNS [RFC1035], as DNSSEC [RFC4033] does not have confidentiality as a requirement.

This implies that, in the absence of changes to the protocol as presently under development in the IETF's DNS Private Exchange (DPRIVE) working group [DPRIVE], all DNS queries and answers generated by the activities of any protocol are available to the attacker.

When store-and-forward protocols are used (e.g., SMTP [RFC5321]), intermediaries leave this data subject to observation by an attacker that has compromised these intermediaries, unless the data is encrypted end-to-end by the application-layer protocol or the implementation uses an encrypted store for this data.

3.2. Information Useful for Inference

Inference is information extracted from later analysis of an observed or eavesdropped communication, and/or correlation of observed or eavesdropped information with information available from other sources. Indeed, most useful inference performed by the attacker falls under the rubric of correlation. The simplest example of this is the observation of DNS queries and answers from and to a source and correlating those with IP addresses with which that source communicates. This can give access to information otherwise not available from encrypted application payloads (e.g., the "Host:" HTTP/1.1 request header when HTTP is used with TLS).

Protocols that encrypt their payload using an application- or transport-layer encryption scheme (e.g., TLS) still expose all the information in their network- and transport-layer headers to the attacker, including source and destination addresses and ports. IPsec Encapsulating Security Payload (ESP) [RFC4303] further encrypts the transport-layer headers but still leaves IP address information unencrypted; in tunnel mode, these addresses correspond to the tunnel endpoints. Features of the security protocols themselves, e.g., the TLS session identifier, may leak information that can be used for

correlation and inference. While this information is much less semantically rich than the application payload, it can still be useful for inferring an individual's activities.

Inference can also leverage information obtained from sources other than direct traffic observation. Geolocation databases, for example, have been developed that map IP addresses to a location, in order to provide location-aware services such as targeted advertising. This location information is often of sufficient resolution that it can be used to draw further inferences toward identifying or profiling an individual.

Social media provide another source of more or less publicly accessible information. This information can be extremely semantically rich, including information about an individual's location, associations with other individuals and groups, and activities. Further, this information is generally contributed and curated voluntarily by the individuals themselves: it represents information that the individuals are not necessarily interested in protecting for privacy reasons. However, correlation of this social networking data with information available from direct observation of network traffic allows the creation of a much richer picture of an individual's activities than either alone.

We note with some alarm that there is little that can be done at protocol design time to limit such correlation by the attacker, and that the existence of such data sources in many cases greatly complicates the problem of protecting privacy by hardening protocols alone.

3.3. An Illustration of an Ideal Passive Pervasive Attack

To illustrate how capable the idealized attacker is even given its limitations, we explore the non-anonymity of encrypted IP traffic in this section. Here, we examine in detail some inference techniques for associating a set of addresses with an individual, in order to illustrate the difficulty of defending communications against our idealized attacker. Here, the basic problem is that information radiated even from protocols that have no obvious connection with personal data can be correlated with other information that can paint a very rich behavioral picture; it only takes one unprotected link in the chain to associate with an identity.

3.3.1. Analysis of IP Headers

Internet traffic can be monitored by tapping Internet links or by installing monitoring tools in Internet routers. Of course, a single link or a single router only provides access to a fraction of the

global Internet traffic. However, monitoring a number of high-capacity links or a set of routers placed at strategic locations provides access to a good sampling of Internet traffic.

Tools like the IP Flow Information Export (IPFIX) Protocol [RFC7011] allow administrators to acquire statistics about sequences of packets with some common properties that pass through a network device. The most common set of properties used in flow measurement is the "five-tuple" of source and destination addresses, protocol type, and source and destination ports. These statistics are commonly used for network engineering but could certainly be used for other purposes.

Let’s assume for a moment that IP addresses can be correlated to specific services or specific users. Analysis of the sequences of packets will quickly reveal which users use what services, and also which users engage in peer-to-peer connections with other users. Analysis of traffic variations over time can be used to detect increased activity by particular users or, in the case of peer-to-peer connections, increased activity within groups of users.

3.3.2. Correlation of IP Addresses to User Identities

The correlation of IP addresses with specific users can be done in various ways. For example, tools like reverse DNS lookup can be used to retrieve the DNS names of servers. Since the addresses of servers tend to be quite stable and since servers are relatively less numerous than users, an attacker could easily maintain its own copy of the DNS for well-known or popular servers to accelerate such lookups.

On the other hand, the reverse lookup of IP addresses of users is generally less informative. For example, a lookup of the address currently used by one author’s home network returns a name of the form "c-192-000-002-033.hsd1.wa.comcast.net". This particular type of reverse DNS lookup generally reveals only coarse-grained location or provider information, equivalent to that available from geolocation databases.

In many jurisdictions, Internet Service Providers (ISPs) are required to provide identification on a case-by-case basis of the "owner" of a specific IP address for law enforcement purposes. This is a reasonably expedient process for targeted investigations, but pervasive surveillance requires something more efficient. This provides an incentive for the attacker to secure the cooperation of the ISP in order to automate this correlation.

3.3.3. Monitoring Messaging Clients for IP Address Correlation

Even if the ISP does not cooperate, user identity can often be obtained via inference. POP3 [RFC1939] and IMAP [RFC3501] are used to retrieve mail from mail servers, while a variant of SMTP is used to submit messages through mail servers. IMAP connections originate from the client, and typically start with an authentication exchange in which the client proves its identity by answering a password challenge. The same holds for the SIP protocol [RFC3261] and many instant messaging services operating over the Internet using proprietary protocols.

The username is directly observable if any of these protocols operate in cleartext; the username can then be directly associated with the source address.

3.3.4. Retrieving IP Addresses from Mail Headers

SMTP [RFC5321] requires that each successive SMTP relay adds a "Received" header to the mail headers. The purpose of these headers is to enable audit of mail transmission, and perhaps to distinguish between regular mail and spam. Here is an extract from the headers of a message recently received from the perpass mailing list:

Received: from 192-000-002-044.zone13.example.org (HELO ?192.168.1.100?) (xxx.xxx.xxx.xxx) by lvps192-000-002-219.example.net with ESMTPSA (DHE-RSA-AES256-SHA encrypted, authenticated); 27 Oct 2013 21:47:14 +0100 Message-ID: <526D7BD2.7070908@example.org> Date: Sun, 27 Oct 2013 20:47:14 +0000 From: Some One <some.one@example.org>

This is the first "Received" header attached to the message by the first SMTP relay; for privacy reasons, the field values have been anonymized. We learn here that the message was submitted by "Some One" on October 27, from a host behind a NAT (192.168.1.100) [RFC1918] that used the IP address 192.0.2.44. The information remained in the message and is accessible by all recipients of the perpass mailing list, or indeed by any attacker that sees at least one copy of the message.

An attacker that can observe sufficient email traffic can regularly update the mapping between public IP addresses and individual email identities. Even if the SMTP traffic was encrypted on submission and relaying, the attacker can still receive a copy of public mailing lists like perpass.

3.3.5. Tracking Address Usage with Web Cookies

Many web sites only encrypt a small fraction of their transactions. A popular pattern is to use HTTPS for the login information, and then use a "cookie" to associate following cleartext transactions with the user's identity. Cookies are also used by various advertisement services to quickly identify the users and serve them with "personalized" advertisements. Such cookies are particularly useful if the advertisement services want to keep tracking the user across multiple sessions that may use different IP addresses.

As cookies are sent in cleartext, an attacker can build a database that associates cookies to IP addresses for non-HTTPS traffic. If the IP address is already identified, the cookie can be linked to the user identify. After that, if the same cookie appears on a new IP address, the new IP address can be immediately associated with the predetermined identity.

3.3.6. Graph-Based Approaches to Address Correlation

An attacker can track traffic from an IP address not yet associated with an individual to various public services (e.g., web sites, mail servers, game servers) and exploit patterns in the observed traffic to correlate this address with other addresses that show similar patterns. For example, any two addresses that show connections to the same IMAP or webmail services, the same set of favorite web sites, and game servers at similar times of day may be associated with the same individual. Correlated addresses can then be tied to an individual through one of the techniques above, walking the "network graph" to expand the set of attributable traffic.

3.3.7. Tracking of Link-Layer Identifiers

Moving back down the stack, technologies like Ethernet or Wi-Fi use MAC (Media Access Control) addresses to identify link-level destinations. MAC addresses assigned according to IEEE 802 standards are globally unique identifiers for the device. If the link is publicly accessible, an attacker can eavesdrop and perform tracking. For example, the attacker can track the wireless traffic at publicly accessible Wi-Fi networks. Simple devices can monitor the traffic and reveal which MAC addresses are present. Also, devices do not need to be connected to a network to expose link-layer identifiers. Active service discovery always discloses the MAC address of the user, and sometimes the Service Set Identifiers (SSIDs) of previously visited networks. For instance, certain techniques such as the use of "hidden SSIDs" require the mobile device to broadcast the network identifier together with the device identifier. This combination can further expose the user to inference attacks, as more information can

be derived from the combination of MAC address, SSID being probed, time, and current location. For example, a user actively probing for a semi-unique SSID on a flight out of a certain city can imply that the user is no longer at the physical location of the corresponding AP. Given that large-scale databases of the MAC addresses of wireless access points for geolocation purposes have been known to exist for some time, the attacker could easily build a database that maps link-layer identifiers and time with device or user identities, and use it to track the movement of devices and of their owners. On the other hand, if the network does not use some form of Wi-Fi encryption, or if the attacker can access the decrypted traffic, the analysis will also provide the correlation between link-layer identifiers such as MAC addresses and IP addresses. Additional monitoring using techniques exposed in the previous sections will reveal the correlation between MAC addresses, IP addresses, and user identity. For instance, similarly to the use of web cookies, MAC addresses provide identity information that can be used to associate a user to different IP addresses.

4. Reported Instances of Large-Scale Attacks

The situation in reality is more bleak than that suggested by an analysis of our idealized attacker. Through revelations of sensitive documents in several media outlets, the Internet community has been made aware of several intelligence activities conducted by US and UK national intelligence agencies, particularly the US National Security Agency (NSA) and the UK Government Communications Headquarters (GCHQ). These documents have revealed methods that these agencies use to attack Internet applications and obtain sensitive user information. There is little reason to suppose that only the US or UK governments are involved in these sorts of activities; the examples are just ones that were disclosed. We note that these reports are primarily useful as an illustration of the types of capabilities fielded by pervasive attackers as of the date of the Snowden leaks in 2013.

First, they confirm the deployment of large-scale passive collection of Internet traffic, which confirms the existence of pervasive passive attackers with at least the capabilities of our idealized attacker. For example, as described in [pass1], [pass2], [pass3], and [pass4]:

- NSA’s XKEYSCORE system accesses data from multiple access points and searches for "selectors" such as email addresses, at the scale of tens of terabytes of data per day.

- GCHQ’s Tempora system appears to have access to around 1,500 major cables passing through the UK.

- NSA's MUSCULAR program has tapped cables between data centers belonging to major service providers.

- Several programs appear to perform wide-scale collection of cookies in web traffic and location data from location-aware portable devices such as smartphones.

However, the capabilities described by these reports go beyond those of our idealized attacker. They include the compromise of cryptographic protocols, including decryption of TLS-protected Internet sessions [dec1] [dec2] [dec3]. For example, the NSA BULLRUN project worked to undermine encryption through multiple approaches, including covert modifications to cryptographic software on end systems.

Reported capabilities include the direct compromise of intermediate systems and arrangements with service providers for bulk data and metadata access [dir1] [dir2] [dir3], bypassing the need to capture traffic on the wire. For example, the NSA PRISM program provides the agency with access to many types of user data (e.g., email, chat, VoIP).

The reported capabilities also include elements of active pervasive attack, including:

- Insertion of devices as a man-in-the-middle of Internet transactions [TOR1] [TOR2]. For example, NSA's QUANTUM system appears to use several different techniques to hijack HTTP connections, ranging from DNS response injection to HTTP 302 redirects.

- Use of implants on end systems to undermine security and anonymity features [dec2] [TOR1] [TOR2]. For example, QUANTUM is used to direct users to a FOXACID server, which in turn delivers an implant to compromise browsers of Tor users.

- Use of implants on network elements from many major equipment providers, including Cisco, Juniper, Huawei, Dell, and HP, as provided by the NSA's Advanced Network Technology group [spiegel1].

- Use of botnet-scale collections of compromised hosts [spiegel2].

The scale of the compromise extends beyond the network to include subversion of the technical standards process itself. For example, there is suspicion that NSA modifications to the DUAL_EC_DRBG random number generator (RNG) were made to ensure that keys generated using that generator could be predicted by NSA. This RNG was made part of

NIST's SP 800-90A, for which NIST acknowledges the NSA's assistance. There have also been reports that the NSA paid RSA Security for a related contract with the result that the curve became the default in the RSA BSAFE product line.

We use the term "pervasive attack" [RFC7258] to collectively describe these operations. The term "pervasive" is used because the attacks are designed to indiscriminately gather as much data as possible and to apply selective analysis on targets after the fact. This means that all, or nearly all, Internet communications are targets for these attacks. To achieve this scale, the attacks are physically pervasive; they affect a large number of Internet communications. They are pervasive in content, consuming and exploiting any information revealed by the protocol. And they are pervasive in technology, exploiting many different vulnerabilities in many different protocols.

Again, it's important to note that, although the attacks mentioned above were executed by the NSA and GCHQ, there are many other organizations that can mount pervasive surveillance attacks. Because of the resources required to achieve pervasive scale, these attacks are most commonly undertaken by nation-state actors. For example, the Chinese Internet filtering system known as the "Great Firewall of China" uses several techniques that are similar to the QUANTUM program and that have a high degree of pervasiveness with regard to the Internet in China. Therefore, legal restrictions in any one jurisdiction on pervasive monitoring activities cannot eliminate the risk of pervasive attack to the Internet as a whole.

5. Threat Model

Given these disclosures, we must consider a broader threat model.

Pervasive surveillance aims to collect information across a large number of Internet communications, analyzing the collected communications to identify information of interest within individual communications, or inferring information from correlated communications. This analysis sometimes benefits from decryption of encrypted communications and deanonymization of anonymized communications. As a result, these attackers desire both access to the bulk of Internet traffic and to the keying material required to decrypt any traffic that has been encrypted. Even if keys are not available, note that the presence of a communication and the fact that it is encrypted may both be inputs to an analysis, even if the attacker cannot decrypt the communication.

The attacks listed above highlight new avenues both for access to traffic and for access to relevant encryption keys. They further indicate that the scale of surveillance is sufficient to provide a general capability to cross-correlate communications, a threat not previously thought to be relevant at the scale of the Internet.

5.1. Attacker Capabilities

Attack Class	Capability
Passive observation	Directly capture data in transit
Passive inference	Infer from reduced/encrypted data
Active	Manipulate / inject data in transit
Static key exfiltration	Obtain key material once / rarely
Dynamic key exfiltration	Obtain per-session key material
Content exfiltration	Access data at rest

Security analyses of Internet protocols commonly consider two classes of attacker: passive pervasive attackers, who can simply listen in on communications as they transit the network, and active pervasive attackers, who can modify or delete packets in addition to simply collecting them.

In the context of pervasive passive surveillance, these attacks take on an even greater significance. In the past, these attackers were often assumed to operate near the edge of the network, where attacks can be simpler. For example, in some LANs, it is simple for any node to engage in passive listening to other nodes' traffic or inject packets to accomplish active pervasive attacks. However, as we now know, both passive and active pervasive attacks are undertaken by pervasive attackers closer to the core of the network, greatly expanding the scope and capability of the attacker.

Eavesdropping and observation at a larger scale make passive inference attacks easier to carry out: a passive pervasive attacker with access to a large portion of the Internet can analyze collected traffic to create a much more detailed view of individual behavior than an attacker that collects at a single point. Even the usual claim that encryption defeats passive pervasive attackers is weakened, since a pervasive flow access attacker can infer relationships from correlations over large numbers of sessions, e.g.,

pairing encrypted sessions with unencrypted sessions from the same host, or performing traffic fingerprinting between known and unknown encrypted sessions. Reports on the NSA XKEYSCORE system would indicate it is an example of such an attacker.

An active pervasive attacker likewise has capabilities beyond those of a localized active attacker. Flow modification attacks are often limited by network topology, for example, by a requirement that the attacker be able to see a targeted session as well as inject packets into it. A pervasive flow modification attacker with access at multiple points within the core of the Internet is able to overcome these topological limitations and perform attacks over a much broader scope. Being positioned in the core of the network rather than the edge can also enable an active pervasive attacker to reroute targeted traffic, amplifying the ability to perform both eavesdropping and traffic injection. Active pervasive attackers can also benefit from passive pervasive collection to identify vulnerable hosts.

While not directly related to pervasiveness, attackers that are in a position to mount an active pervasive attack are also often in a position to subvert authentication, a traditional protection against such attacks. Authentication in the Internet is often achieved via trusted third-party authorities such as the Certificate Authorities (CAs) that provide web sites with authentication credentials. An attacker with sufficient resources may also be able to induce an authority to grant credentials for an identity of the attacker’s choosing. If the parties to a communication will trust multiple authorities to certify a specific identity, this attack may be mounted by suborning any one of the authorities (the proverbial "weakest link"). Subversion of authorities in this way can allow an active attack to succeed in spite of an authentication check.

Beyond these three classes (observation, inference, and active), reports on the BULLRUN effort to defeat encryption and the PRISM effort to obtain data from service providers suggest three more classes of attack:

- Static key exfiltration
- Dynamic key exfiltration
- Content exfiltration

These attacks all rely on a collaborator providing the attacker with some information, either keys or data. These attacks have not traditionally been considered in scope for the Security Considerations sections of IETF protocols, as they occur outside the protocol.

The term "key exfiltration" refers to the transfer of keying material for an encrypted communication from the collaborator to the attacker. By "static", we mean that the transfer of keys happens once or rarely and that the transferred key is typically long-lived. For example, this case would cover a web site operator that provides the private key corresponding to its HTTPS certificate to an intelligence agency.

"Dynamic" key exfiltration, by contrast, refers to attacks in which the collaborator delivers keying material to the attacker frequently, e.g., on a per-session basis. This does not necessarily imply frequent communications with the attacker; the transfer of keying material may be virtual. For example, if an endpoint were modified in such a way that the attacker could predict the state of its pseudorandom number generator, then the attacker would be able to derive per-session keys even without per-session communications.

Finally, content exfiltration is the attack in which the collaborator simply provides the attacker with the desired data or metadata. Unlike the key exfiltration cases, this attack does not require the attacker to capture the desired data as it flows through the network. The exfiltration is of data at rest, rather than data in transit. This increases the scope of data that the attacker can obtain, since the attacker can access historical data -- the attacker does not have to be listening at the time the communication happens.

Exfiltration attacks can be accomplished via attacks against one of the parties to a communication, i.e., by the attacker stealing the keys or content rather than the party providing them willingly. In these cases, the party may not be aware, at least at a human level, that they are collaborating. Rather, the subverted technical assets are "collaborating" with the attacker (by providing keys/content) without their owner’s knowledge or consent.

Any party that has access to encryption keys or unencrypted data can be a collaborator. While collaborators are typically the endpoints of a communication (with encryption securing the links), intermediaries in an unencrypted communication can also facilitate content exfiltration attacks as collaborators by providing the attacker access to those communications. For example, documents describing the NSA PRISM program claim that NSA is able to access user data directly from servers, where it is stored unencrypted. In these cases, the operator of the server would be a collaborator, if an unwitting one. By contrast, in the NSA MUSCULAR program, a set of collaborators enabled attackers to access the cables connecting data centers used by service providers such as Google and Yahoo. Because communications among these data centers were not encrypted, the collaboration by an intermediate entity allowed the NSA to collect unencrypted user data.

5.2. Attacker Costs

Attack Class	Cost / Risk to Attacker
Passive observation	Passive data access
Passive inference	Passive data access + processing
Active	Active data access + processing
Static key exfiltration	One-time interaction
Dynamic key exfiltration	Ongoing interaction / code change
Content exfiltration	Ongoing, bulk interaction

Each of the attack types discussed in the previous section entails certain costs and risks. These costs differ by attack and can be helpful in guiding response to pervasive attack.

Depending on the attack, the attacker may be exposed to several types of risk, ranging from simply losing access to arrest or prosecution. In order for any of these negative consequences to occur, however, the attacker must first be discovered and identified. So, the primary risk we focus on here is the risk of discovery and attribution.

A passive pervasive attack is the simplest to mount in some ways. The base requirement is that the attacker obtain physical access to a communications medium and extract communications from it. For example, the attacker might tap a fiber-optic cable, acquire a mirror port on a switch, or listen to a wireless signal. The need for these taps to have physical access or proximity to a link exposes the attacker to the risk that the taps will be discovered. For example, a fiber tap or mirror port might be discovered by network operators noticing increased attenuation in the fiber or a change in switch configuration. Of course, passive pervasive attacks may be accomplished with the cooperation of the network operator, in which case there is a risk that the attacker’s interactions with the network operator will be exposed.

In many ways, the costs and risks for an active pervasive attack are similar to those for a passive pervasive attack, with a few additions. An active attacker requires more robust network access than a passive attacker, since, for example, they will often need to transmit data as well as receive it. In the wireless example above,

the attacker would need to act as a transmitter as well as a receiver, greatly increasing the probability the attacker will be discovered (e.g., using direction-finding technology). Active attacks are also much more observable at higher layers of the network. For example, an active attacker that attempts to use a mis-issued certificate could be detected via Certificate Transparency [RFC6962].

In terms of raw implementation complexity, passive pervasive attacks require only enough processing to extract information from the network and store it. Active pervasive attacks, by contrast, often depend on winning race conditions to inject packets into active connections. So, active pervasive attacks in the core of the network require processing hardware that can operate at line speed (roughly 100 Gbps to 1 Tbps in the core) to identify opportunities for attack and insert attack traffic in high-volume traffic. Key exfiltration attacks rely on passive pervasive attack for access to encrypted data, with the collaborator providing keys to decrypt the data. So, the attacker undertakes the cost and risk of a passive pervasive attack, as well as additional risk of discovery via the interactions that the attacker has with the collaborator.

Some active attacks are more expensive than others. For example, active man-in-the-middle (MITM) attacks require access to one or more points on a communication's network path that allow visibility of the entire session and the ability to modify or drop legitimate packets in favor of the attacker's packets. A similar but weaker form of attack, called an active man-on-the-side (MOTS), requires access to only part of the session. In an active MOTS attack, the attacker need only be able to inject or modify traffic on the network element the attacker has access to. While this may not allow for full control of a communication session (as in an MITM attack), the attacker can perform a number of powerful attacks, including but not limited to: injecting packets that could terminate the session (e.g., TCP RST packets), sending a fake DNS reply to redirect ensuing TCP connections to an address of the attacker's choice (i.e., winning a "DNS response race"), and mounting an HTTP redirect attack by observing a TCP/HTTP connection to a target address and injecting a TCP data packet containing an HTTP redirect. For example, the system dubbed by researchers as China's "Great Cannon" [great-cannon] can operate in full MITM mode to accomplish very complex attacks that can modify content in transit, while the well-known Great Firewall of China is a MOTS system that focuses on blocking access to certain kinds of traffic and destinations via TCP RST packet injection.

In this sense, static exfiltration has a lower risk profile than dynamic. In the static case, the attacker need only interact with the collaborator a small number of times, possibly only once -- say,

to exchange a private key. In the dynamic case, the attacker must have continuing interactions with the collaborator. As noted above, these interactions may be real, such as in-person meetings, or virtual, such as software modifications that render keys available to the attacker. Both of these types of interactions introduce a risk that they will be discovered, e.g., by employees of the collaborator organization noticing suspicious meetings or suspicious code changes.

Content exfiltration has a similar risk profile to dynamic key exfiltration. In a content exfiltration attack, the attacker saves the cost and risk of conducting a passive pervasive attack. The risk of discovery through interactions with the collaborator, however, is still present, and may be higher. The content of a communication is obviously larger than the key used to encrypt it, often by several orders of magnitude. So, in the content exfiltration case, the interactions between the collaborator and the attacker need to be much higher bandwidth than in the key exfiltration cases, with a corresponding increase in the risk that this high-bandwidth channel will be discovered.

It should also be noted that in these latter three exfiltration cases, the collaborator also undertakes a risk that his collaboration with the attacker will be discovered. Thus, the attacker may have to incur additional cost in order to convince the collaborator to participate in the attack. Likewise, the scope of these attacks is limited to cases where the attacker can convince a collaborator to participate. If the attacker is a national government, for example, it may be able to compel participation within its borders, but have a much more difficult time recruiting foreign collaborators.

As noted above, the collaborator in an exfiltration attack can be unwitting; the attacker can steal keys or data to enable the attack. In some ways, the risks of this approach are similar to the case of an active collaborator. In the static case, the attacker needs to steal information from the collaborator once; in the dynamic case, the attacker needs continued presence inside the collaborators' systems. The main difference is that the risk in this case is of automated discovery (e.g., by intrusion detection systems) rather than discovery by humans.

6. Security Considerations

This document describes a threat model for pervasive surveillance attacks. Mitigations are to be given in a future document.

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Dave Thaler
Brian Trammell
Suzanne Woolf

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Authors' Addresses

Richard Barnes

Email: rlb@ipv.sx

Bruce Schneier

Email: schneier@schneier.com

Cullen Jennings

Email: fluffy@cisco.com

Ted Hardie

Email: ted.ietf@gmail.com

Brian Trammell

Email: ietf@trammell.ch

Christian Huitema

Email: huitema@huitema.net

Daniel Borkmann

Email: dborkman@iogearbox.net