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Secure Telephone Identity Threat Model

Abstract

As the Internet and the telephone network have become increasingly interconnected and interdependent, attackers can impersonate or obscure calling party numbers when orchestrating bulk commercial calling schemes, hacking voicemail boxes, or even circumventing multi-factor authentication systems trusted by banks. This document analyzes threats in the resulting system, enumerating actors, reviewing the capabilities available to and used by attackers, and describing scenarios in which attacks are launched.

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1. Introduction and Scope

As is discussed in the STIR problem statement [RFC7340] (where "STIR" refers to the Secure Telephone Identity Revisited working group), the primary enabler of robocalling, vishing, swatting, and related attacks is the capability to impersonate a calling party number. The starkest examples of these attacks are cases where automated callees on the Public Switched Telephone Network (PSTN) rely on the calling number as a security measure, for example, to access a voicemail system. Robocallers use impersonation as a means of obscuring identity. While robocallers can, in the ordinary PSTN, block (that is, withhold) their calling number from presentation, callees are less likely to pick up calls from blocked identities; therefore, appearing to call from some number, any number, is preferable.

However, robocallers prefer not to call from a number that can trace back to the them, so they impersonate numbers that are not assigned to them.

The scope of impersonation in this threat model pertains solely to the rendering of a calling telephone number to a callee (human user or automaton) at the time of call setup. The primary attack vector is therefore one where the attacker contrives for the calling telephone number in signaling to be a chosen number. In this attack, the number is one that the attacker is not authorized to use (as a caller) but gives in order for that number to be consumed or rendered on the terminating side. The threat model assumes that this attack simply cannot be prevented: there is no way to stop the attacker from creating call setup messages that contain attacker-chosen calling telephone numbers. The solution space therefore focuses on ways that terminating or intermediary elements might differentiate authorized from unauthorized calling party numbers in order that policies, human or automatic, might act on that information.

Securing an authenticated calling party number at call setup time does not entail any assertions about the entity or entities that will send and receive media during the call itself. In call paths with intermediaries and gateways (as described below), there may be no way to provide any assurance in the signaling about participants in the media of a call. In those end-to-end IP environments where such assurance is possible, it is highly desirable. However, in the threat model described in this document, "impersonation" does not consider impersonating an authorized listener after a call has been established (e.g., as a third party attempting to eavesdrop on a conversation). Attackers that could impersonate an authorized listener require capabilities that robocallers and voicemail hackers are unlikely to possess, and historically, such attacks have not played a role in enabling robocalling or related problems.

In SIP, and even many traditional telephone protocols, call signaling can be renegotiated after the call has been established. Using various transfer mechanisms common in telephone systems, a callee can easily be connected to, or conferenced in with, telephone numbers other than the original calling number once a call has been established. These post-setup changes to the call are outside the scope of impersonation considered in this model: the motivating use cases of defeating robocalling, voicemail hacking, and swatting all rely on impersonation during the initial call setup. Furthermore, this threat model does not include in its scope the verification of the reached party’s telephone number back to the originator of the call. There is no assurance to the originator that they are reaching the correct number, nor any indication when call forwarding has taken place. This threat model is focused only on verifying the calling party number to the callee.

In much of the PSTN, there exists a supplemental service that translates calling party numbers into names, including the proper names of people and businesses, for rendering to the called user. These services (frequently marketed as part of 'Caller ID') provide a further attack surface for impersonation. The threat model described in this document addresses only the calling party number, even though presenting a forged calling party number may cause a chosen calling party name to be rendered to the user as well. Providing a verifiable calling party number therefore improves the security of calling party name systems, but this threat model does not consider attacks specific to names. Such attacks may be carried out against the databases consulted by the terminating side of a call to provide calling party names or by impersonators forging a particular calling party number in order to present a misleading name to the user.

2. Actors

2.1. Endpoints

There are two main categories of end-user terminals relevant to this discussion, a dumb device (such as a 'black phone') or a smart device:

- Dumb devices comprise a simple dial pad, handset, and ringer, optionally accompanied by a display that can render a limited number of characters. Typically, the display renders enough characters for a telephone number and an accompanying name, but sometimes fewer are rendered. Although users interface with these devices, the intelligence that drives them lives in the service provider network.

- Smart devices are general-purpose computers with some degree of programmability and with the capacity to access the Internet and to render text, audio, and/or images. This category includes smart phones, telephone applications on desktop and laptop computers, IP private branch exchanges, etc.

There is a further category of automated terminals without an end user. These include systems like voicemail services, which may provide a different set of services to a caller based solely on the calling party's number, for example, granting the (purported) mailbox owner access to a menu while giving other callers only the ability to leave a message. Though the capability of voicemail services varies widely, many today have Internet access and advanced application interfaces (to render ’visual voicemail’ [OMTP-VV], to automatically transcribe voicemail to email, etc.).

2.2. Intermediaries

The endpoints of a traditional telephone call connect through numerous intermediary devices in the network. The set of intermediary devices traversed during call setup between two endpoints is referred to as a call path. The length of the call path can vary considerably: it is possible in Voice over IP (VoIP) deployments for two endpoint entities to send traffic to one another directly, but, more commonly, several intermediaries exist in a VoIP call path. One or more gateways also may appear on a call path.

- Intermediaries forward call signaling to the next device in the path. These intermediaries may also modify the signaling in order to improve interoperability, to enable proper network-layer media connections, or to enforce operator policy. This threat model assumes there are no restrictions on the modifications to signaling that an intermediary can introduce (which is consistent with the observed behavior of such devices).

- A gateway is a subtype of intermediary that translates call signaling from one protocol into another. In the process, they tend to consume any signaling specific to the original protocol (elements like transaction-matching identifiers) and may need to transcode or otherwise alter identifiers as they are rendered in the destination protocol.

This threat model assumes that intermediaries and gateways can forward and retarget calls as necessary, which can result in a call terminating at a place the originator did not expect; this is a common condition in call routing. This observation is significant to the solution space because it limits the ability of the originator to anticipate what the telephone number of the respondent will be (for more on the "unanticipated respondent" problem, see [SIP-SECURITY]).

Furthermore, we assume that some intermediaries or gateways may, due to their capabilities or policies, discard calling party number information in whole or in part. Today, many IP-PSTN gateways simply ignore any information available about the caller in the IP leg of the call and allow the telephone number of the Primary Rate Interface (PRI) line used by the gateway to be sent as the calling party number for the PSTN leg of the call. For example, a call might also gateway to a multi-frequency network where only a limited number of digits of automatic numbering identification (ANI) data are signaled. Some protocols may render telephone numbers in a way that makes it impossible for a terminating side to parse or canonicalize a number. In these cases, providing authenticated calling number data may be impossible, but this is not indicative of an attack or other security failure.

2.3. Attackers

We assume that an attacker has the following capabilities:

- An attacker can create telephone calls at will, originating them either on the PSTN or over IP, and can supply an arbitrary calling party number.

- An attacker can capture and replay signaling previously observed by it.

- An attacker has access to the Internet and thus the ability to inject arbitrary traffic over the Internet, to access public directories, etc.

There are attack scenarios in which an attacker compromises intermediaries in the call path or captures credentials that allow the attacker to impersonate a caller. Those system-level attacks are not considered in this threat model, though secure design and operation of systems to prevent these sorts of attacks are necessary for envisioned countermeasures to work. To date, robocallers and other impersonators do not resort to compromising systems but rather exploit the intrinsic lack of secure identity in existing mechanisms; remedying this problem lies within the scope of this threat model.

This threat model also does not consider scenarios in which the operators of intermediaries or gateways are themselves adversaries who intentionally discard valid identity information (without a user requesting anonymity) or who send falsified identity; see Section 4.1.

3. Attacks

The uses of impersonation described in this section are broadly divided into two categories: those where an attack will not succeed unless the attacker impersonates a specific identity and those where an attacker impersonates an arbitrary identity in order to disguise its own. At a high level, impersonation encourages targets to answer attackers’ calls and makes identifying attackers more difficult. This section shows how concrete attacks based on those different techniques might be launched.

3.1. Voicemail Hacking via Impersonation

A voicemail service may allow users calling from their phones access to their voicemail boxes on the basis of the calling party number. If an attacker wants to access the voicemail of a particular target, the attacker may try to impersonate the calling party number using one of the scenarios described in Section 4.

This attack is closely related to attacks on similar automated systems, potentially including banks, airlines, calling-card services, conferencing providers, ISPs, and other businesses that fully or partly grant access to resources on the basis of the calling party number alone (rather than any shared secret or further identity check). It is analogous to an attack in which a human is encouraged to answer a phone or to divulge information once a call is in progress, by seeing a familiar calling party number.

The envisioned countermeasures for this attack involve the voicemail system treating calls that supply authenticated calling number data differently from other calls. In the absence of that identity information, for example, a voicemail service might enforce some other caller authentication policy (perhaps requiring a PIN for caller authentication). Asserted caller identity alone provides an authenticated basis for granting access to a voicemail box only when an identity is claimed legitimately; the absence of a verifiably legitimate calling identity here may not be evidence of malice, just of uncertainty or a limitation imposed by the set of intermediaries traversed for a specific call path.

If the voicemail service could learn ahead of time that it should expect authenticated calling number data from a particular number, that would enable the voicemail service to adopt stricter policies for handling a request without authentication data. Since users typically contact a voicemail service repeatedly, the service could, for example, remember which requests contain authenticated calling number data and require further authentication mechanisms when identity is absent. The deployment of such a feature would be facilitated in many environments by the fact that the voicemail service is often operated by an organization that would be in a position to enable or require authentication of calling party identity (for example, carriers or enterprises). Even if the voicemail service is decoupled from the number assignee, issuers of credentials or other authorities could provide a service that informs verifiers that they should expect identity in calls from particular numbers.

3.2. Unsolicited Commercial Calling from Impersonated Numbers

The unsolicited commercial calling, or ’robocalling’ for short, attack is similar to the voicemail attack except that the robocaller does not need to impersonate the particular number controlled by the target, merely some "plausible" number. A robocaller may impersonate a number that is not an assignable number (for example, in the United States, a number beginning with 0) or an unassigned number. This behavior is seen in the wild today. A robocaller may change numbers every time a new call is placed, e.g., selecting numbers randomly.

A closely related attack is sending unsolicited bulk commercial messages via text messaging services. These messages usually originate on the Internet, though they may ultimately reach endpoints over traditional telephone network protocols or the Internet. While most text messaging endpoints are mobile phones, broadband residential services are increasingly supporting text messaging as well. The originators of these messages typically impersonate a calling party number, in some cases, a "short code" specific to text messaging services.

The envisioned countermeasures to robocalling are similar to those in the voicemail example, but there are significant differences. One important potential countermeasure is simply to verify that the calling party number is in fact assignable and assigned. Unlike voicemail services, end users typically have never been contacted by the number used by a robocaller before. Thus, they can’t rely on past association to anticipate whether or not the calling party number should supply authenticated calling number data. If there were a service that could inform the terminating side that it should expect this data for calls or texts from that number, however, that would also help in the robocalling case.

When a human callee is to be alerted at call setup time, the time frame for executing any countermeasures is necessarily limited. Ideally, a user would not be alerted that a call has been received until any necessary identity checks have been performed. This could, however, result in inordinate post-dial delay from the perspective of legitimate callers. Cryptographic and network operations must be minimized for these countermeasures to be practical. For text messages, a delay for executing anti-impersonation countermeasures is much less likely to degrade perceptible service.

The eventual effect of these countermeasures would be to force robocallers to either (a) block their caller identity, in which case end users could opt not to receive such calls or messages, or (b) use authenticated calling numbers traceable to them, which would then allow for other forms of redress.

3.3. Telephony Denial-of-Service Attacks

In the case of telephony denial-of-service (TDoS) attacks, the attack relies on impersonation in order to obscure the origin of an attack that is intended to tie up telephone resources. By placing incessant telephone calls, an attacker renders a target number unreachable by legitimate callers. These attacks might target a business, an individual, or a public resource like emergency responders; the attacker may intend to extort the target. Attack calls may be placed from a single endpoint or from multiple endpoints under the control of the attacker, and the attacker may control endpoints in different administrative domains. Impersonation, in this case, allows the attack to evade policies that would block based on the originating number and furthermore prevents the victim from learning the perpetrator of the attack or even the originating service provider of the attacker.

As is the case with robocalling, the attacker typically does not have to impersonate a specific number in order to launch a denial-of-service attack. The number simply has to vary enough to prevent simple policies from blocking the attack calls. An attacker may, however, have a further intention to create the appearance that a particular party is to blame for an attack; in that case, the attacker might want to impersonate a secondary target in the attack.

The envisioned countermeasures are twofold. First, as with robocalling, ensuring that calling party numbers are assignable or assigned will help mitigate unsophisticated attacks. Second, if authenticated calling number data is supplied for legitimate calls, then Internet endpoints or intermediaries can make effective policy decisions in the middle of an attack by deprioritizing unsigned calls when congestion conditions exist; signed calls, if accepted, have the necessary accountability should it turn out they are malicious. This could extend to include, for example, an originating network observing a congestion condition for a destination number and perhaps dropping unsigned calls that are clearly part of a TDoS attack. As with robocalling, all of these countermeasures must execute in a timely manner to be effective.

There are certain flavors of TDoS attacks, including those against emergency responders, against which authenticated calling number data is unlikely to be a successful countermeasure. These entities are effectively obligated to attempt to respond to every call they receive, and the absence of authenticated calling number data in many cases will not remove that obligation.

4. Attack Scenarios

The examples that follow rely on Internet protocols including SIP [RFC3261] and WebRTC [RTCWEB-OVERVIEW].

Impersonation, IP-IP

An attacker with an IP phone sends a SIP request to an IP-enabled voicemail service. The attacker puts a chosen calling party number into the From header field value of the INVITE. When the INVITE reaches the endpoint terminal, the terminal renders the attacker’s chosen calling party number as the calling identity.

Impersonation, PSTN-PSTN

An attacker with a traditional Private Branch Exchange (PBX) (connected to the PSTN through ISDN) sends a Q.931 SETUP request [Q931] with a chosen calling party number, which a service provider inserts into the corresponding SS7 [Q764] calling party number (CgPN) field of a call setup message (Initial Address Message (IAM)). When the call setup message reaches the endpoint switch, the terminal renders the attacker’s chosen calling party number as the calling identity.

Impersonation, IP-PSTN

An attacker on the Internet uses a commercial WebRTC service to send a call to the PSTN with a chosen calling party number. The service contacts an Internet-to-PSTN gateway, which inserts the attacker’s chosen calling party number into the SS7 [Q764] call setup message (the CgPN field of an IAM). When the call setup message reaches the terminating telephone switch, the terminal renders the attacker’s chosen calling party number as the calling identity.

Impersonation, IP-PSTN-IP

An attacker with an IP phone sends a SIP request to the telephone number of a voicemail service, perhaps without even knowing that the voicemail service is IP-based. The attacker puts a chosen calling party number into the From header field value of the INVITE. The attacker’s INVITE reaches an Internet-to-PSTN gateway, which inserts the attacker’s chosen calling party number into the CgPN of an IAM. That IAM then traverses the PSTN until (perhaps after a call forwarding) it reaches another gateway, this time back to the IP realm, to an H.323 network. The PSTN-IP gateway takes the calling party number in the IAM CgPN field and puts it into the SETUP request. When the SETUP reaches the endpoint terminal, the terminal renders the attacker’s chosen calling party number as the calling identity.

4.1. Solution-Specific Attacks

Solution-specific attacks are outside the scope of this document, though two sorts of solutions are anticipated by the STIR problem statement: in-band and out-of-band solutions (see [RFC7340]). There are a few points that future work on solution-specific threats must acknowledge. The design of the credential system envisioned as a solution to these threats must, for example, limit the scope of the credentials issued to carriers or national authorities to those numbers that fall under their purview. This will impose limits on what (verifiable) assertions can be made by intermediaries.

Some of the attacks that should be considered in the future include the following:

- Attacks against in-band solutions
  - Replaying parts of messages used by the solution
  - Using a SIP REFER request to induce a party with access to credentials to place a call to a chosen number
  - Removing parts of messages used by the solution
- Attacks against out-of-band solutions
  - Provisioning false or malformed data reflecting a placed call into any datastores that are part of the out-of-band mechanism
  - Mining any datastores that are part of the out-of-band mechanism
- Attacks against either approach
  - Attack on any directories/services that report whether you should expect authenticated calling number data or not
  - Canonicalization attacks

5. Security Considerations

This document provides a threat model and is thus entirely about security.

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