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Keying and Authentication for Routing Protocols (KARP)
Overview, Threats, and Requirements

Abstract

Different routing protocols employ different mechanisms for securing protocol packets on the wire. While most already have some method for accomplishing cryptographic message authentication, in many cases the existing methods are dated, vulnerable to attack, and employ cryptographic algorithms that have been deprecated. The "Keying and Authentication for Routing Protocols" (KARP) effort aims to overhaul and improve these mechanisms. This document does not contain protocol specifications. Instead, it defines the areas where protocol specification work is needed. This document is a companion document to RFC 6518, "Keying and Authentication for Routing Protocols (KARP) Design Guidelines"; together they form the guidance and instruction KARP design teams will use to review and overhaul routing protocol transport security.

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1. Introduction

In March 2006, the Internet Architecture Board (IAB) held a workshop on the topic "Unwanted Internet Traffic". The report from that workshop is documented in [RFC4948]. Section 8.1 of that document states, "A simple risk analysis would suggest that an ideal attack target of minimal cost but maximal disruption is the core routing infrastructure". Section 8.2 calls for "[t]ightening the security of the core routing infrastructure". Four main steps were identified for that tightening:

- o Create secure mechanisms and practices for operating routers.
- o Clean up the Internet Routing Registry (IRR) repository, and secure both the database and the access to it, so that it can be used for routing verification.
- o Create specifications for cryptographic validation of routing message content.
- o Secure the routing protocols' packets on the wire

The first bullet is being addressed in the OPSEC working group. The second bullet should be addressed through liaisons with those running the IRR's globally. The third bullet is being addressed in other efforts within the IETF. For example, BGP message content validity is being addressed in the SIDR working group.

This document addresses the last item in the list above, securing the transmission of routing protocol packets on the wire. More precisely, it focuses on securing the transport systems employed by routing protocols, including any mechanisms built into the protocols themselves to authenticate packets. This effort is referred to as Keying and Authentication for Routing Protocols, or "KARP". KARP is concerned with issues and techniques for protecting the messages between directly communicating peers. This type of protection may overlap with, but is strongly distinct from, protection designed to ensure that routing information is properly authorized relative to the source of the information. Such assurances are provided by other mechanisms and are outside the scope of this document.

This document is one of two that together form the guidance and instructions for KARP design teams working to overhaul routing protocol transport security. The other document is the KARP Design Guide [RFC6518].

This document does not contain protocol specifications. Instead, its goal is to define the areas where protocol specification work is needed and to provide a set of requirements for KARP design teams to follow as they update a routing protocol's existing transport security (see Work Phase 1 in Section 4.1 of [RFC6518]).

This document has three main parts. The first part, found in Section 2, provides an overview of the KARP effort. The second part, in Section 3, lists the threats from "Generic Threats To Routing Protocols" [RFC4593] that are in scope for per-packet authentication for routing protocol transport systems. Therefore, this document does not contain a complete threat model; it simply points to the parts of the governing threat model that KARP design teams must address and explicitly states which parts are out of scope for KARP design teams. The third part, in Section 4, enumerates the requirements that routing protocol specifications must meet when addressing the threats related to KARP's Work Phase 1, the update to a routing protocol's existing transport security. ("Work Phase 2", a framework and usage of a Key Management Protocol (KMP), will be addressed in a future document[s]).

1.1. Terminology

This document uses the terminology "on the wire" to refer to the information used by routing protocols' transport systems. This term is widely used in RFCs, but is used in several different ways. In this document, it is used to refer both to information exchanged between routing protocol instances and to underlying protocols that may also need to be protected in specific circumstances. Individual protocol analysis documents will need to be more specific in their use of this phrase.

Additionally, within the scope of this document, the following words, when beginning with a capital letter, or spelled in all capital letters, hold the meanings described in this section. If the same word is used uncapitalized, then it is intended to have its common English definition.

Identifier

The type and value used by a peer of an authenticated message exchange to signify who it is to another peer. The Identifier is used by the receiver as an index into a table containing further information about the peer that is required to continue processing the message, for example a Security Association (SA) or keys.

Identity Authentication

Once the identity is verified, there must be a cryptographic proof of that identity, to ensure that the peer really is who it asserts to be. Proof of identity can be arranged among peers in a few ways, for example, symmetric and asymmetric pre-shared keys, or an asymmetric key contained in a certificate. Certificates can be used in ways that require no additional supporting systems external to the routers themselves. An example of this is using self-signed certificates and a flat file list of "approved thumbprints". The different identity verification mechanisms vary in ease of deployment, ease of ongoing management, startup effort, security strength, and consequences from loss of secrets from one part of the system to the rest of the system. For example, they differ in resistance to a security breach, and the effort required to recover in the event of such a breach. The point here is that there are options, many of which are quite simple to employ and deploy.

KDF (Key Derivation Function)

A KDF is a function in which an input key and other input data are used to generate keying material that can be employed by cryptographic algorithms. The key that is input to a KDF is called a key derivation key. KDFs can be used to generate one or more keys from (i) a random or pseudorandom seed value, or (ii) the result of the Diffie-Hellman exchange, or (iii) a non-uniform random source (e.g., from a non-deterministic random bit generator), or (iv) a pre-shared key that may or may not be memorable by a human.

KMP (Key Management Protocol)

KMP is a protocol that establishes a shared symmetric key between a pair (or among a group) of users. It determines how secret keys are made available to the users, and in some cases also determines how the secret keys are generated. In some routing protocols, the routing protocol derives the traffic keys from a master key. In this case, KMP is responsible for the master-key generation and for determining when the master key should be renewed. In other cases, there are only traffic keys (and no master key); in such a case, KMP is responsible for the traffic key generation and renewal mechanism.

KMP Function

Any KMP used in the general KARP solution framework.

Peer Key

Peer keys are keys that are used among peers as a basis for identifying one another. These keys may or may not be connection specific, depending on how they were established, and what forms

of identity and identity authentication mechanism are used in the system. A peer key generally would be provided by a KMP and would later be used to derive fresh traffic keys.

PSK (Pre-Shared Key)

A PSK is a key used to communicate with one or more peers in a secure configuration. It is always distributed out of band prior to a first connection.

Replayed Messages

Replayed messages are genuine messages that have been re-sent by an attacker. Messages may be replayed within a session (i.e., intra-session) or replayed from a different session (i.e., inter-session). For non-TCP-based protocols like OSPF [RFC2328] and IS-IS [RFC1195], two routers are said to have a session up if they are able to exchange protocol packets (i.e., the peers have an adjacency). Messages replayed during an adjacency are intra-session replays, while a message replayed between two peers who re-establish an adjacency after a reboot or loss of connectivity are inter-session replays.

Routing Protocol

This term refers to a Routing Protocol on which a KARP team is working to improve the security of its packets on the wire.

SA (Security Association)

An SA is a relationship established between two or more entities to enable them to protect the data they exchange. Examples of attributes that may be associated with an SA include Identifier, PSK, Traffic Key, cryptographic algorithms, and key lifetimes.

Threat Source

A threat source is a motivated, capable adversary.

Traffic Key

A Traffic Key is the key (or one of a set of keys) used for protecting the routing protocol traffic. A traffic key should not be a fixed value in a device configuration. A traffic key should be known only to the participants in a connection, so that a compromise of a stored key (possibly available to a terminated or turned employee) does not result in disclosure of traffic keys. If a server or other data store is stolen or compromised, the attackers gain no access to current traffic keys. They may gain access to key-derivation material, like a PSK, but not traffic keys currently in use.

Additional terminology specific to threats are listed and defined below in Section 3.

1.2. Requirements Language

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].

When used in lower case, these words convey their typical use in common language, and are not to be interpreted as described in RFC 2119.

2. KARP Effort Overview

2.1. KARP Scope

Three basic principles can be used to secure any piece of data as it is transmitted over the wire: confidentiality, authenticity, and integrity. The focus for the KARP working group will be message authentication and message integrity only. At this time, this work explicitly excludes confidentiality. Non-repudiation is also excluded as a goal at this time. Since the objective of most routing protocols is to broadly advertise the routing topology, routing protocol packets are commonly sent in the clear; confidentiality is not normally required for routing protocols. However, ensuring that routing peers are authentically identified and that no rogue peers or unauthenticated packets can compromise the stability of the routing environment are critical and thus in scope. Confidentiality and non-repudiation may be addressed in future work.

OSPF [RFC5709], IS-IS [RFC5310], LDP [RFC5036], and RIP [RFC2453] [RFC4822] already incorporate mechanisms for cryptographically authenticating and integrity checking the messages on the wire. Products and code that incorporate these mechanisms have been produced and have been optimized for these existing security mechanisms. Rather than turn away from these mechanisms, this document aims to enhance them, updating them to modern and more secure levels.

Therefore, the scope of KARP's roadmap of work includes:

- o Making use of existing routing protocol transport security mechanisms, where they have been specified, and enhancing or updating them as necessary for modern cryptographic best practices. [RFC6518], Section 4.1 labels this KARP's Work Phase 1.
- o Developing a framework for using automatic key management in order to ease deployment, lower cost of operation, and allow for rapid responses to security breaches. [RFC6518], Section 4.1 labels this KARP's Work Phase 2.

- o Specifying an automated key management protocol that may be combined with Routing Protocol mechanisms. [RFC6518], Section 4.1 labels this KARP's Work Phase 2.

Neither this document nor [RFC6518] contains protocol specifications. Instead, they define the areas in which protocol specification work is needed, and they set a direction, a set of requirements, and priorities for addressing that specification work.

There are a set of threats to routing protocols that are considered in scope for KARP, and a set considered out of scope. These are described in detail in Section 3.

2.2. Incremental Approach

This document serves as an agreement between the Routing Area and the Security Area about the priorities and work plan for incrementally delivering the work described in the KARP roadmap above. The principle of "crawl, walk, run" will be employed. Thus routing protocol authentication mechanisms may not go immediately from their current state to a state reflecting the best possible, most modern security practices. This point is important as there will be times when the best security possible will give way to security that is vastly improved over current security but that is admittedly not the best security possible, in order that incremental progress toward a more secure Internet may be achieved. As such, this document will call out places where agreement has been reached on such trade-offs.

Incremental steps will need to be taken for a few very practical reasons. First, there are a considerable number of deployed routing devices in operating networks that will not be able to run the most modern cryptographic mechanisms without significant and unacceptable performance penalties. The roadmap for any routing protocol MUST allow for incremental improvements on existing operational devices. Second, current routing protocol performance on deployed devices has been achieved over the last 20 years through extensive tuning of software and hardware elements, and is a constant focus for improvement by vendors and operators alike. The introduction of new security mechanisms affects this performance balance. The performance impact of any incremental security improvement will need to be weighed by the community and introduced in such a way that allows the vendor and operator community a path to adoption that upholds reasonable performance metrics. Therefore, certain specification elements may be introduced carrying the "SHOULD" guidance, with the intention that the same mechanism will carry a "MUST" in a future release of the specification. This approach gives the vendors and implementors the guidance they need to tune their software and hardware appropriately over time. Last, some security

mechanisms require the build-out of other operational support systems, which will take time.

An example where these three steps were at play in an incremental improvement roadmap was the improvement of BGP's [RFC4271] security via the TCP Authentication Option (TCP-AO) [RFC5925] effort. It would have been ideal, and would have reflected best common security practice, to have a fully specified key management protocol for negotiating the TCP-AO keying material, e.g., using certificates for peer authentication. However, in the spirit of incremental deployment, the IETF first addressed issues like cryptographic algorithm agility, replay attacks, and the resetting of TCP sessions in the base TCP-AO protocol, and then later began work to layer key management on top of these.

2.3. Goals

The goals and general guidance for the KARP work follow:

1. Provide authentication and integrity protection for messages on the wire for existing routing protocols.
2. Define a path to incrementally improve security of the routing infrastructure as explained in Section 2.2.
3. Ensure that the improved security solutions are deployable on current routing infrastructure. This requires consideration of the current state of processing power available on routers in the network today.
4. Operational deployability - A solution's acceptability also will be measured by how deployable the solution is by operator teams, with consideration for their deployment processes and infrastructures. Specifically, KARP design teams will try to make these solutions fit as well as possible into current operational practices and router deployment methodologies. Doing so will depend heavily on operator input during KARP design efforts. Hopefully, operator input will lead to a more deployable solution, which will, in turn, lead to more production deployments. Deployment of incrementally more secure routing infrastructure in the Internet is the final measure of success. We would like to see an increase in the number of respondents to surveys such as [ISR2008] to report deployment of the updated authentication and integrity mechanisms in their networks, as well as see a sharp rise in usage of these mechanisms across a greater percentage of their network's routers.

Interviews with operators show several points about routing security. First, according to [ISR2008], over 70% of operators have deployed transport connection protection via TCP MD5 [RFC3562] on their External Border Gateway Protocol (eBGP) sessions. Over 55% also deploy TCP MD5 on their Internal Border Gateway Protocol (iBGP) connections, and 50% make use of TCP MD5 offered on some other internal gateway protocol (IGP). The same survey states that "a considerable increase was observed over previous editions of the survey for use of TCP MD5 with external peers (eBGP), internal peers (iBGP) and MD5 extensions for IGPs." Though the data is not captured in the report, the authors believe anecdotally that of those who have deployed TCP MD5 somewhere in their network, only about 25-30% of the routers in their network are deployed with the authentication enabled. None report using IPsec [RFC4301] to protect the routing protocol, which was a decline from the few that reported doing so in the previous year's report. Anecdotal evidence from operators using MD5 shows that almost all report using one manually distributed key throughout the entire network. These same operators report that the single key has not been changed since it was originally installed, sometimes five or more years ago. When asked why, particularly for the case of protecting BGP sessions using TCP MD5, the following reasons were often given:

- A. Changing the keys triggers a TCP reset, and thus the links/adjacencies bounce, undermining Service Level Agreements (SLAs).
- B. For external peers, it is difficult to coordinate with the other organization, and in practice the coordination is very cumbersome and tedious to execute. Once the operator finds the correct contact at the other organization (not always so easy), the coordination function is serialized and performed on a per-peer or per-AS basis.
- C. Keys must be changed at precisely the same time, or at least within 60 seconds (as supported by two major vendors) in order to limit the duration of a connectivity outage. This is incredibly difficult to do, operationally, especially between different organizations.
- D. Key change is perceived as a relatively low priority compared to other operational issues.
- E. Staff levels are insufficient to implement the changes on a device-by-device basis.

- F. There are three use cases for operational peering at play: peers and interconnection with other operators, iBGP and other routing sessions within a single operator, and operator-to-customer devices. All three have very different properties, and all are reported as cumbersome to manage securely. One operator reported that the same key is used for all customer premise equipment (CPE). The same operator reported that if the customer mandated it, a unique key could be created, although the last time this occurred, it created such an operational headache that the administrators now usually tell customers that the option doesn't even exist, to avoid the difficulties. These customer-unique keys are never changed, unless the customer demands so. The main threat here is that a terminated employee from such an operator who had access to the one (or several) keys used for authentication in these environments could wage an attack. Alternatively, the operator could offer the keys to others who would wage the attack. In either case, the attacker could then bring down many of the adjacencies, thus destabilizing the routing system.
5. Whatever mechanisms KARP specifies need to be easier to deploy than the current methods and should provide obvious operational efficiency gains along with significantly better security. This combination of value may be enough to drive much broader adoption.
 6. Address the threats enumerated below in "Threats" (Section 3) for each routing protocol. Not all threats may be able to be addressed in the first specification update for any one protocol. Roadmaps will be defined so that both the Security Area and the Routing Area agree on how the threats will be addressed completely over time.
 7. Create a reusable architecture, framework, and guidelines for various IETF working groups that will address these security improvements for various Routing Protocols. The crux of the KARP work is to reuse the architecture, framework, and guidelines as much as possible across relevant Routing Protocols. For example, designers should aim to reuse the key management protocol that will be defined for BGP, which will establish keys for TCP-AO, for as many other routing protocols with similar characteristics and properties as possible.
 8. Bridge any gaps between the IETF Routing and Security Areas by recording agreements on work items, roadmaps, and guidance from the cognizant Area Directors and the Internet Architecture Board (IAB).

2.4. Non-Goals

The following goals are considered out of scope for this effort:

- o Confidentiality and non-repudiation of the packets on the wire. Once the goals of this roadmap are realized, work on confidentiality may be considered.
- o Non-repudiation of the packets on the wire.
- o Message content validity (routing database validity). This work is being addressed in other IETF efforts. For example, BGP message content validity is being addressed in the SIDR working group.

2.5. Audience

The audience for this document includes:

- o Routing Area working group chairs and participants - These people are charged with updating Routing Protocol specifications. Any and all cryptographic authentication work on these specifications will occur in Routing Area working groups, in close partnership with the Security Area. Co-advisors from the Security Area may often be named for these partnership efforts.
- o Security Area reviewers of Routing Area documents - These people are tasked by the Security Area Directors to perform reviews on routing protocol specifications as they pass through working group last call or IESG review. Their particular attention to the use of cryptographic authentication and newly specified security mechanisms for the routing protocols is appreciated. They also help to ensure that incremental security improvements are being made, in line with this roadmap.
- o Security Area engineers - These people partner with Routing Area authors/designers on the security mechanisms in routing protocol specifications. Some of these Security Area engineers will be assigned by the Security Area Directors, while others will be interested parties in the relevant working groups.
- o Operators - The operators are a key audience for this work, as the work is considered to have succeeded only if operators deploy the technology. It is anticipated that deployment will take place only if operators perceive that the improved security offered by the Routing Protocol updates warrants the complexity and cost of deployment and operation. Conversely, the work will be considered a failure if operators do not deploy it, either due to a lack of

perceived value or due to perceived operational complexity. As a result, the GROW and OPSEC working groups should be kept squarely in the loop as well.

3. Threats

This document uses the definition of "threat" from RFC 4949 [RFC4949]: "[a] potential for violation of security, which exists when there is an entity, circumstance, capability, action, or event that could cause harm."

This section defines the threats that are in scope for the KARP effort. It also lists those threats that are explicitly out of scope for the KARP effort. Threats are discussed assuming that no protection (i.e., message authentication and message integrity) has been applied to routing protocol messages.

This document leverages the model described in "Generic Threats to Routing Protocols" [RFC4593]. Specifically, the threats listed below were derived by reviewing [RFC4593], analyzing how the threats applied to the KARP problem space, and listing the threats that are applicable to the work for the KARP design team. This document categorizes [RFC4593] threats into those in scope and those out of scope for KARP. Each in-scope threat is discussed below, and its applicability to the KARP problem space is described. As such, the following text intentionally is not a comprehensive threat analysis. Rather, it describes the applicability of the existing threat analysis in [RFC4593] to KARP.

Note: terms from [RFC4593] appear capitalized below -- e.g. OUTSIDERS -- so as to make explicit the term's origin, and to enable rapid cross referencing to the source RFC.

For convenience, a terse definition of most [RFC4593] terms is offered here. Those interested in a more thorough description of routing protocol threat sources, motivations, consequences, and actions will want to read [RFC4593] before continuing here.

3.1. Threat Sources

3.1.1. OUTSIDERS

One of the threats that will be addressed in this roadmap is the situation in which the source is an OUTSIDER. An OUTSIDER attacker may reside anywhere in the Internet, may have the ability to send IP traffic to the router, may be able to observe the router's replies, and may even control the path for a legitimate peer's traffic. OUTSIDERS are not legitimate participants in the routing protocol.

The use of message authentication and integrity protection specifically aims to identify packets originating from OUTSIDERS.

KARP design teams will consider two specific use cases of OUTSIDERS: those on path, and those off path.

- o On Path - These attackers have control of a network resource or a tap that sits along the path between two routing peers. A "Man in the Middle" (MitM) is an on-path attacker. From this vantage point, the attacker can conduct either active or passive attacks. An active attack occurs when the attacker places packets on the network as part of the attack. One active MitM attack relevant to KARP, an active wiretapping attack, occurs when the attacker tampers with packets moving between two legitimate router peers in such a way that both peers think they are talking to each other directly, when in fact they are actually talking to the attacker. Protocols conforming to this roadmap will use cryptographic mechanisms to detect MitM attacks and reject packets from such attacks (i.e., discard them as being not authentic). Passive on-path attacks occur when the attacker silently gathers data and analyzes it to gain advantage. Passive activity by an on-path attacker may lead to an active attack.
- o Off Path - These attackers sit on some network outside of that over which the packets between two routing peers run. The source may be one or several hops away. Off-path attackers can launch active attacks, such as SPOOFING or denial-of-service (DoS) attacks, to name a few.

3.1.2. Unauthorized Key Holder

This threat source exists when an unauthorized entity somehow manages to gain access to keying material. Using this material, the attacker could send packets that pass the authenticity checks based on Message Authentication Codes (MACs). The resulting traffic might appear to come from router A and be destined for router B, and thus the attacker could impersonate an authorized peer. The attacker could then adversely affect network behavior by sending bogus messages that appear to be authentic. The attack source possessing the unauthorized keys could be on path, off path, or both.

The obvious mitigation for an unauthorized key holder is to change the keys currently in use by the legitimate routing peers. This mitigation can be either reactive or proactive. Reactive mitigation occurs when keys are changed only after one has discovered that the previous keys have fallen into the possession of unauthorized users. The reactive mitigation case is highlighted here in order to explain a common operational situation where new keying material will need to

be put in place with little or no advanced warning. In such a case, new keys must be able to be installed and put into use very quickly, and with little operational expense. Proactive mitigation occurs when an operator assumes that unauthorized possession will occur from time to time without being discovered, and the operator moves to new keying material in order to cut short an attacker's window of opportunity to use the stolen keys effectively.

KARP design teams can address this type of attack by creating specifications that make it practical for the operator to quickly change keys without disruption to the routing system and with minimal operational overhead. Operators can further mitigate threats from unauthorized key holders by regularly changing keys.

3.1.2.1. Terminated Employee

A terminated employee is an important example of an unauthorized key holder. Staff attrition is a reality in routing operations and is therefore a potential threat source. The threat source risk arises when a network operator who had been granted access to keys ceases to be an employee. If new keys are deployed immediately, the situation of a terminated employee can become an "unauthorized key holder, proactive" case, as described above, rather than an "unauthorized key holder, reactive mitigation" case. It behooves the operator to change the keys, to enforce the revocation of authorization of the old keys, in order to minimize the threat source's window of opportunity.

A terminated employee is a valid unauthorized key holder threat source for KARP, and designs should address the associated threats. For example, new keys must be able to be installed and made operational in the routing protocols very quickly, with zero impact to the routing system, and with little operational expense. The threat actions associated with a terminated employee also motivate the need to change the keys quickly, also with little operational expense.

3.1.3. BYZANTINE

According to [RFC4593], Section 3.1.1.2, BYZANTINE "attackers are faulty, misconfigured, or subverted routers; i.e., legitimate participants in the routing protocol", whose messages cause routing to malfunction.

[RFC4593] goes on to say that "[s]ome adversaries can subvert routers, or the management workstations used to control these routers. These Byzantine failures represent the most serious form of

attack capability in that they result in emission of bogus traffic by legitimate routers."

[RFC4593] explains that "[d]eliberate attacks are mimicked by failures that are random and unintentional. In particular, a Byzantine failure in a router may occur because the router is faulty in hardware or software or is misconfigured", and thus routing malfunctions unintentionally. Although not malicious, such occurrences still disrupt network operation.

Whether faulty, misconfigured, or subverted, Byzantine routers have an empowered position from which to provide believable yet bogus routing messages that are damaging to the network.

3.2. Threat Actions In Scope

The following THREAT ACTIONS are in scope for KARP:

- o SPOOFING - when an unauthorized device assumes the identity of an authorized one. Spoofing is special in that it can be used to carry out other threat actions that cause other threat consequences. SPOOFING can be used, for example, to inject malicious routing information that causes the disruption of network services. SPOOFING can also be used to cause a neighbor relationship to form that subsequently denies the formation of the relationship with a legitimate router.
- o DoS attacks
 - A. At the transport layer - This occurs when an attacker sends packets aimed at halting or preventing the underlying protocol over which the routing protocol runs. The attacker could use SPOOFING, FALSIFICATION, or INTERFERENCE (see below) to produce the DoS attack. For example, BGP running over Transport Layer Security (TLS) will still not solve the problem of an attacker being able to send a spoofed TCP FIN or TCP RST and causing the BGP session to go down. Since these attacks depend on spoofing, operators are encouraged to deploy proper authentication mechanisms to prevent them. Specification work should ensure that Routing Protocols can operate over transport subsystems in a fashion that is resilient to such DoS attacks.
 - B. Using the authentication mechanism - This includes an attacker causing INTERFERENCE, which inhibits exchanges of legitimate routers. The attack is often perpetrated by sending packets that confuse or overwhelm a security mechanism itself. An example is initiating an overwhelming load of spoofed routing

protocol packets that contain a MAC (i.e., INSERTING MESSAGES), so that the receiver spends substantial CPU resources on the processing cycles to check the MAC, only to discard the spoofed packet. Other types of INTERFERENCE include REPLAYING OUT-DATED PACKETS, CORRUPTING MESSAGES, and BREAKING SYNCHRONIZATION.

- o FALSIFICATION - An action whereby an attacker sends false routing information. This document targets only FALSIFICATION from OUTSIDERS that may occur from tampering with packets in flight or sending entirely false messages. FALSIFICATION from BYZANTINES (see Section 3.3) are not addressed by the KARP effort.
- o Brute-Force Attacks Against Password/Keys - This includes either online or offline attacks in which attempts are made repeatedly using different keys/passwords until a match is found. While it is impossible to make brute-force attacks on keys completely unsuccessful, proper design can make it much harder for such attacks to succeed. For example, current guidance for the security strength of an algorithm with a particular key length should be deemed acceptable for a period of 10 years. (Section 10 of [SP.800-131A] is one source for guidance.) Using per-session keys is another widely used method for reducing the number of brute-force attacks, as this would make it difficult to guess the keys.

3.3. Threat Actions Out of Scope

BYZANTINE sources -- be they faulty, misconfigured, or subverted -- are out of scope for this roadmap. KARP works to cryptographically ensure that received routing messages originated from authorized peers and that the message was not altered in transit. Formation of a bogus message by a valid and authorized peer falls outside the KARP scope. Any of the attacks described in Section 3.2 that may be levied by a BYZANTINE source are therefore also out of scope, e.g. FALSIFICATION from BYZANTINE sources or unauthorized message content by a legitimate authorized peer.

In addition, these other attack actions are out of scope for this work:

- o SNIFFING (passive wiretapping) - Passive observation of route message contents in flight. Data confidentiality, as achieved by data encryption, is the common mechanism for preventing SNIFFING. While useful, especially to prevent the gathering of data needed to perform an off-path packet injection attack, data encryption is out of scope for KARP.

- o INTERFERENCE due to:
 - A. NOT FORWARDING PACKETS - Cannot be prevented with cryptographic authentication. Note: If sequence numbers with sliding windows are used in the solution (as is done, for example, in Bidirectional Forwarding Detection (BFD) [RFC5880]), a receiver can at least detect the occurrence of this attack.
 - B. DELAYING MESSAGES - Cannot be prevented with cryptographic authentication. Note: Timestamps can be used to detect delays.
 - C. DENIAL OF RECEIPT (non-repudiation) - Cannot be prevented with cryptographic authentication.
 - D. UNAUTHORIZED MESSAGE CONTENT - Covered by the work of the IETF's SIDR working group (<http://www.ietf.org/html.charters/sidr-charter.html>).
 - E. DoS attacks not involving the routing protocol. For example, a flood of traffic that fills the link ahead of the router, so that the router is rendered unusable and unreachable by valid packets is NOT an attack that KARP will address. Many such examples could be contrived.
4. Requirements for KARP Work Phase 1: Update to a Routing Protocol's Existing Transport Security

Section 4.1 of the KARP Design Guide [RFC6518] describes two distinct work phases for the KARP effort. This section addresses requirements for the first work phase only, Work Phase 1, the update to a routing protocol's existing transport security. Work Phase 2, the framework and usage of a KMP, will be addressed in a future document(s).

The following list of requirements SHOULD be addressed by a KARP Work Phase 1 security update to any Routing Protocol (according to section 4.1 of the KARP Design Guide [RFC6518]document). IT IS RECOMMENDED that any Work Phase 1 security update to a Routing Protocol contain a section of the specification document that describes how each of the following requirements are met. It is further RECOMMENDED that justification be presented for any requirements that are NOT addressed.

1. Clear definitions of which elements of the transmitted data (frame, packet, segment, etc.) are protected by an authentication/integrity mechanism.

2. Strong cryptographic algorithms, as defined and accepted by the IETF security community, MUST be specified. The use of non-standard or unpublished algorithms MUST be avoided.
3. Algorithm agility for the cryptographic algorithms used in the authentication MUST be specified, and protocol specifications MUST be clear regarding how new algorithms are specified and used within the protocol. This requirement exists because research identifying weaknesses in cryptographic algorithms can cause the security community to reduce confidence in some algorithms. Breaking a cipher isn't a matter of if, but when it will occur. Having the ability to specify alternate algorithms (algorithm agility) within the protocol specification to support such an event is essential. Additionally, more than one algorithm MUST be specified. Mandating support for two algorithms (i.e., one mandatory to implement algorithm and one or more backup algorithms to guide transition) provides both redundancy, and a mechanism for enacting that redundancy.
4. Secure use of PSKs, offering both operational convenience and a baseline level of security, MUST be specified.
5. Routing Protocols (or the transport or network mechanism protecting routing protocols) SHOULD be able to detect and reject replayed intra-session and inter-session messages. Packets captured from one session MUST NOT be able to be resent and accepted during a later session (i.e., inter-session replay). Additionally, replay mechanisms MUST work correctly even in the presence of routing protocol packet prioritization by the router.

There is a specific case of replay attack combined with spoofing that must be addressed. Several routing protocols (e.g., OSPF [RFC2328], IS-IS [RFC1195], BFD [RFC5880], RIP [RFC2453], etc.), require all speakers to share the same authentication and message association key on a broadcast segment. It is important that an integrity check associated with a message fail if an attacker has replayed the message with a different origin.

6. A change of security parameters MUST force a change of session traffic keys. The specific security parameters for the various routing protocols will differ and will be defined by each protocol design team. Some examples may include master key, key lifetime, and cryptographic algorithm. If one of these configured parameters changes, then a new session traffic key MUST immediately be established using the updated parameters. The routing protocol security mechanisms MUST support this behavior.

7. Security mechanisms MUST specify a means to affect intra-session rekeying without disrupting a routing session. This should be accomplished without data loss, if possible. Keys may need to be changed periodically based on policy or when an administrator who had access to the keys leaves an organization. A rekeying mechanism enables the operators to execute the change without productivity loss.
8. Rekeying SHOULD be supported in such a way that it can occur during a session without the peer needing to use multiple keys to validate a given packet. The rare exception will occur if a routing protocol's design team can find no other way to rekey and still adhere to the other requirements in this section. The specification SHOULD include a key identifier, which allows receivers to choose the correct key (or determine that they are not in possession of the correct key).
9. New mechanisms MUST resist DoS attacks described as in scope in Section 3.2. Routers protect the control plane by implementing mechanisms to reject completely or rate-limit traffic not required at the control-plane level (i.e., unwanted traffic). Typically, line-rate packet-filtering capabilities look at information in the IP and transport (TCP or UDP) headers, but do not include higher-layer information. Therefore, the new mechanisms should neither hide nor encrypt the information carried in the IP and transport layers in control-plane packets.
10. Mandatory cryptographic algorithms and mechanisms MUST be specified for each routing protocol security mechanism. Further, the protocol specification MUST define default security mechanism settings for all implementations to use when no explicit configuration is provided. To understand the need for this requirement, consider the case where a routing protocol mandates three different cryptographic algorithms for a MAC operation. If company A implements algorithm 1 as the default for this protocol, while company B implements algorithm 2 as the default, then two operators who enable the security mechanism with no explicit configuration other than a PSK will experience a connection failure. It is not enough that each implementation implement the three mandatory algorithms; one default must further be specified in order to gain maximum out-of-the-box interoperability.
11. For backward-compatibility reasons, manual keying MUST be supported.
12. The specification MUST consider and allow for future use of a KMP.

13. The authentication mechanism in a Routing Protocol MUST be decoupled from the key management system used. The authentication protocol MUST include a specification for agreeing on keying material. This will accommodate both manual keying and the use of KMPs.
14. Convergence times of the Routing Protocols SHOULD NOT be materially affected. Changes in the convergence time will be immediately and independently verifiable by convergence performance test beds already in use (e.g. those maintained by router vendors, service providers, and researchers). An increase in convergence time in excess of 5% is likely to be considered to have materially affected convergence by network operators. A number of other factors can also change convergence over time (e.g., speed of processors used on individual routing peers, processing power increases due to Moore's law, and implementation specifics), and implementors will need to take into account the effect of an authentication mechanism on Routing Protocols. Protocol designers should consider the impact on convergence times as a function of both the total number of protocol packets that must be exchanged and the required computational processing of individual messages in the specification, understanding that the operator community's threshold for an increase in convergence times is very low, as stated above.
15. The changes to or addition of security mechanisms SHOULD NOT cause a refresh of route advertisements or cause additional route advertisements to be generated.
16. Router implementations provide prioritized treatment for certain protocol packets. For example, OSPF Hello and Acknowledgement packets are prioritized for processing above other OSPF packets. The security mechanism SHOULD NOT interfere with the ability to observe and enforce such prioritization. Any effect on such priority mechanisms MUST be explicitly documented and justified. Replay protection mechanisms provided by the routing protocols MUST work even if certain protocol packets are offered prioritized treatment.
17. The Routing Protocol MUST send minimal information regarding the authentication mechanisms and associated parameters in its protocol packets. This keeps the Routing Protocols as clean and focused as possible, and loads security negotiations into the KMP as much as possible. This also avoids exposing any security negotiation information unnecessarily to possible attackers on the path.

18. Routing Protocols that rely on the IP header (or information separate from routing protocol payload) to identify the neighbor that originated the packet MUST either protect the IP header or provide some other means to authenticate the neighbor. [RFC6039] describes some attacks that motivate this requirement.
19. Every new KARP-developed security mechanisms MUST support incremental deployment. It will not be feasible to deploy a new Routing Protocol authentication mechanism throughout a network instantaneously. Indeed, it may not actually be feasible to deploy such a mechanism to all routers in a large autonomous system (AS) in a bounded timeframe. Proposed solutions MUST support an incremental deployment method that benefits those who participate. Because of this, there are several requirements that any proposed KARP mechanism should consider.
 - A. The Routing Protocol security mechanism MUST enable each router to configure use of the security mechanism on a per-peer basis where the communication is peer to peer (unicast).
 - B. Every new KARP-developed security mechanism MUST provide backward compatibility with respect to message formatting, transmission, and processing of routing information carried through secure and non-secure security environments. Message formatting in a fully secured environment MAY be handled in a non-backward-compatible fashion, though care must be taken to ensure that routing protocol packets can traverse intermediate routers that don't support the new format.
 - C. In an environment where both secured and non-secured routers are interoperating, a mechanism MUST exist for secured systems to identify whether a peer intended the messages to be secured.
 - D. In an environment where secured service is in the process of being deployed, a mechanism MUST exist to support a transition free of service interruption (caused by the deployment per se).
20. The introduction of mechanisms to improve routing security may increase the processing performed by a router. Since most of the currently deployed routers do not have hardware to accelerate cryptographic operations, these operations could impose a significant processing burden under some circumstances. Thus, proposed solutions SHOULD be evaluated carefully with regard to the processing burden they may impose, since

deployment may be impeded if network operators perceive that a solution will impose a processing burden that either incurs substantial capital expense or threatens to degrade router performance.

21. New authentication and security mechanisms should not rely on systems external to the routing system (the equipment that is performing forwarding) in order for the routing system to be secure. In order to ensure the rapid initialization and/or return to service of failed nodes, it is important to reduce reliance on these external systems to the greatest extent possible. Proposed solutions SHOULD NOT require connections to external systems, beyond those directly involved in peering relationships, in order to return to full service. It is, however, acceptable for the proposed solutions to require post-initialization synchronization with external systems in order to fully synchronize security associations.

If authentication and security mechanisms rely on systems external to the routing system, then there MUST be one or more options available to avoid circular dependencies. It is not acceptable to have a routing protocol (e.g., unicast routing) depend upon correct operation of a security protocol that, in turn, depends upon correct operation of the same instance of that routing protocol (i.e., the unicast routing). However, it is acceptable to have operation of a routing protocol (e.g., multicast routing) depend upon operation of a security protocol, which depends upon an independent routing protocol (e.g., unicast routing). Similarly, it would be okay to have the operation of a routing protocol depend upon a security protocol, which in turn uses an out-of-band network to exchange information with remote systems.

5. Security Considerations

This document is mostly about security considerations for the KARP efforts, both threats and the requirements for addressing those threats. More detailed security considerations are provided in the Security Considerations section of the KARP Design Guide [RFC6518]document.

The use of a group key between a set of Routing Protocol peers has special security considerations. Possession of the group key itself is used for identity validation; no other identity check is used. Under these conditions, an attack exists when one peer masquerades as a neighbor by using the neighbor's source IP address. This type of attack has been well documented in the group-keying problem space, and it is non-trivial to solve. Solutions exist within the group-

keying realm, but they come with significant increases in complexity and computational intensity.

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