THE TCP AUTHENTICATION OPTION (TCP-AO)

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Engineering
Simplicity

Why do we need TCP security?

MOTIVATION

- What are we protecting?
  - Long-lived TCP sessions
  - Examples
    - Routing protocols (BGP, LDP)
    - Long-lived TCP sessions between other applications
- What are we protecting against?
  - Blind insertion attacks
  - Replay attacks

BLIND INSERTION ATTACK ON A BGP SESSION

- Router A maintains a BGP session with Router B
  - They exchange many routes over many hours
- Node C sends a few packets per second to Router B for many hours
  - IP source address: Router A (spoofed)
  - Payload: TCP
    - RST bit set
    - Destination ports: BGP (179)
    - Random sequence numbers
- B discards most packets, because their sequence numbers are invalid
- Sooner or later, C sends a packet with a valid sequence number
- BGP session resets

TCP MD5

LEGACY SOLUTION: TCP-MD5 [RFC 2385]

- Sending and receiving nodes are configured with a pre-shared key
- Sending node procedures
  - Calculate a Message Authentication Code (MAC) for each TCP segment
    - Use MD5 to calculate MAC
    - Calculate MAC over the TCP segment and the pre-shared key
  - Include an MD5 Signature Option in each segment
    - MD5 Signature Option includes MAC
- Receiving node procedures
  - Calculate a MAC for each received TCP segment
  - Discard the packet if the calculated MAC does not match the received MAC

TCP-MD5 IS DEPRECATED

- New requirements
  - Change pre-shared keys without resetting TCP session
  - Support multiple authentication algorithms
- Pre-shared key change
  - It is difficult to change TCP-MD5 pre-shared keys without resetting the TCP session
  - It is difficult to reset TCP sessions that support BGP
  - Therefore, TCP-MD5 pre-shared keys were rarely changed
- Authentication algorithm agility
  - MD5 has been replaced by stronger authentication algorithms
  - Even stronger authentication algorithms are expected in the future

- **Monday, June 5 2006 - NANOG 37**

  Ron Bonica - Authentication for TCP-based Routing and Management Protocols

- **June 2010**

  RFC5925 published

- **Tuesday, June 26 2018 - NANOG 73**

  Ignas Bagdonas - Lightning Talk: BGP Transport Security - Do You Care?

- **Monday, October 19 2020 - NANOG 80**

  Melchior Aelmans - It is time…to replace MD5

TCP Authentication Option

TCP-AO [RFC 5925] REPLACES TCP-MD5

- Supports
  - Pre-shared key change without resetting TCP session
  - Multiple authentication algorithms

TCP-AO CONCEPTS

- Master Key Tuple (MKT)
  - One or more MKTs are configured on each node
  - Used to derive traffic keys
- Traffic key
  - Used to generate a MAC for each TCP segment
- TCP-Authentication Option
  - Used to authenticate TCP segments
  - Contains a MAC, KeyID and RNextKeyID
    - KeyID identifies MKT and traffic key that were used to generate MAC
    - RNextKey identifies MKT and traffic key that the receiving node should use when generating a MAC for the next segment it sends

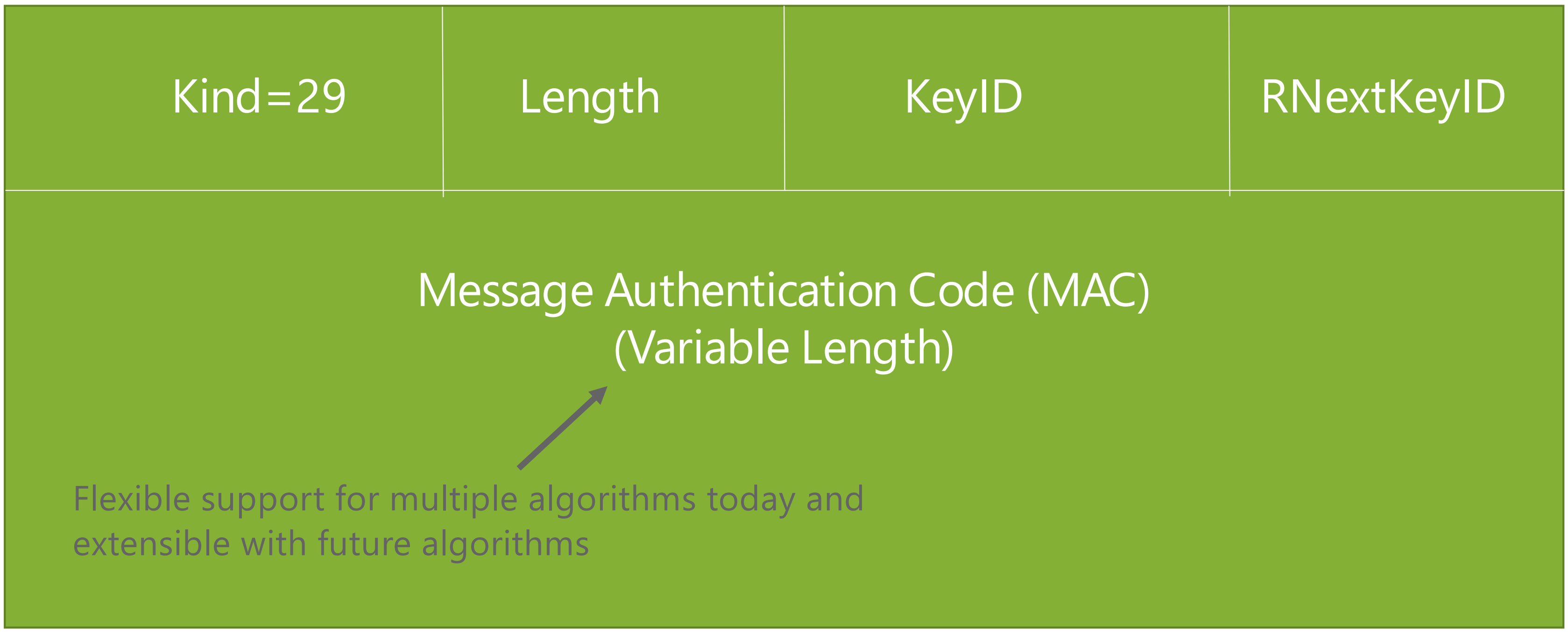
MKT CONTENTS

- A TCP connection identifier
  - Source address, destination address, source port, destination port
  - Wildcards allowed
- A TCP Options flag (determine which TCP options are covered by MAC)
- Identifiers
  - Sending: Used to generate KeyID on outbound segments
  - Receiving: Used to resolve KeyID on inbound segments
- An authentication algorithm
- Master key (i.e., keying material)
- A key derivation algorithm

TRAFFIC KEYS

- Four traffic keys are derived from each MKT
  - SEND_SYN
  - RECEIVE_SYN
  - SEND-OTHER
  - RECEIVE-OTHER

THE TCP AUTHENTICATION OPTION



PULLING IT ALL TOGETHER: KEYING

- Each node is each configured with one or more MKTs
- Each node derives four traffic keys from each MKT
- Each node independently determines which MKT is active
  - Method is beyond the scope of RFC 5925
  - Many implementations specify a start-time and an end-time for each MKT

PULLING IT ALL TOGETHER: AUTHENTICATION

- Sending node procedures
  - Calculate a Message Authentication Code (MAC) for each TCP segment
    - Use the appropriate authentication algorithm
    - Calculate MAC over the TCP segment and an active traffic key
  - Include a TCP-AO in each segment
    - MD5 Signature Option includes MAC, KeyID and RNextKeyID
- Receiving node procedures
  - Calculate a MAC for each received TCP segment
    - Use algorithm and traffic key associated with the received KeyID
  - Discard the packet if the calculated MAC does not match the received MAC

IMPLEMENTATION STATUS AND FURTHER READING

Implementation status:

- Nokia: SR OS 16.0.R15, 19.10.R7 and 20.5.R1 (interop tested with Juniper)
- Cisco: Stable since IOS XR 6.6.3 and 7.0.1
- Juniper Networks: 20.3R1
- Huawei: targeted for Q2 2021

Further information:

- Nokia & Juniper interoperability test: https://github.com/TCP-AO/Interoperability-testing
- Configuration examples: https://github.com/TCP-AO/Configuration-examples
- Routing Table Podcast starring Ron Bonica and Greg Hankins: https://anchor.fm/routing-table/episodes/The-TCP-Authentication-Option--why-do-we-need-it-and-will-it-replace-MD5----Greg-Hankins-Nokia-and-Ron-Bonica-Juniper-Networks-ekemrp

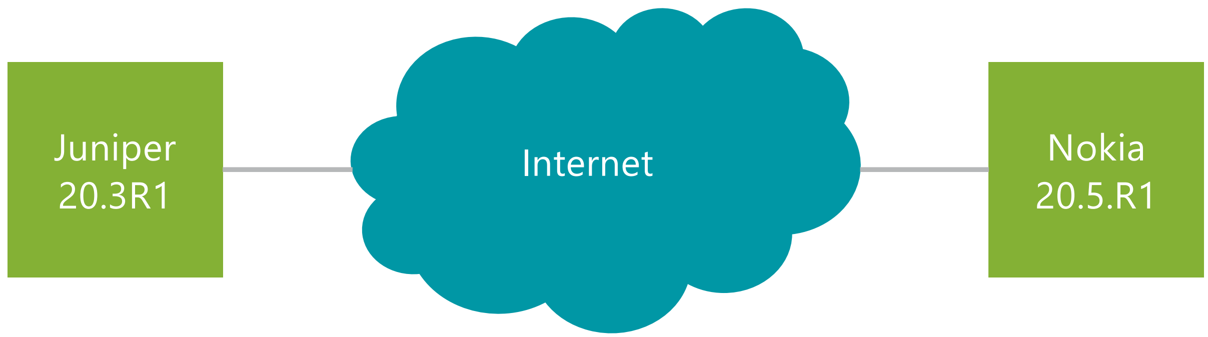
RELATIONSHIP WITH GTSM [RFC 5082]

- GTSM protects eBGP sessions
  - Sender sets TTL to 255
  - Receiver rejects packets containing eBGP if TTL is less than 254
- TCP-AO still needed to protect eBGP sessions from attackers that are one hop away
- TCP-AO still needed to protect iBGP sessions from internal attack

➢ Security best practices implement many layers of protection, don't rely on just one mechanism!

Interoperability testing

JUNIPER AND NOKIA INTEROP TEST RESULTS



- Successful interop test using TCP-AO for BGP finished in June 2020
- Established multihop IPv4 and IPv6 BGP sessions over the Internet
- No need to meet or bring routers for testing in person
- Tested with HMAC-SHA-1-96 and AES-128-CMAC-96 algorithms

LESSONS LEARNED #1 – SEND AND RECEIVE ARE CONFIGURED FROM THE ROUTER'S PERSPECTIVE

Juniper

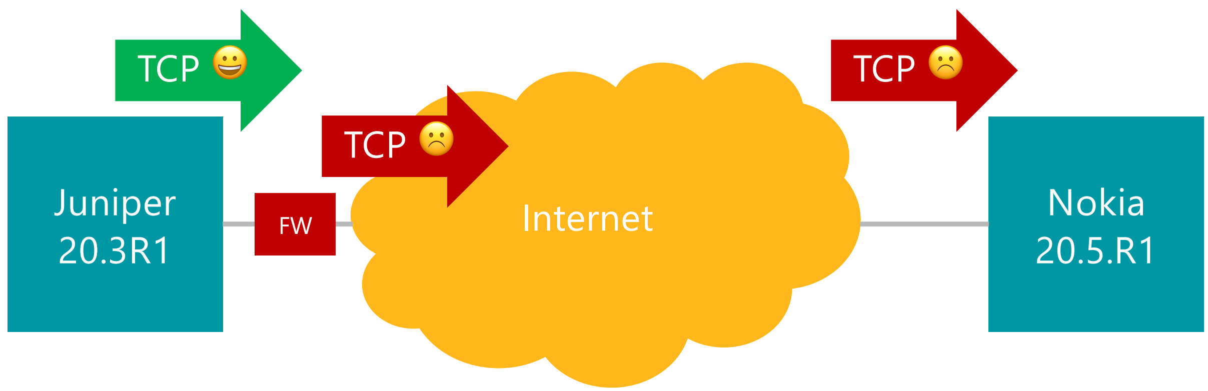
```
# show security authentication-key-chains
key-chain ao_aes_chain {
    key 0 {
        secret "$9$xk3NVYq.53/taZnCu1yrwYg4UHf5F/A0z3"; ##
SECRET-DATA
        start-time "2020-6-16.01:00:00 +0530";
        algorithm ao;
        ao-attribute {
            send-id 9;
            recv-id 2;
            tcp-ao-option enabled;
            cryptographic-algorithm aes-128-cmac-96;
        }
    }
}
```

Nokia

```
configure system security {
    keychain "interoptest-aes" {
        tcp-option-number {
            receive tcp-ao
            send tcp-ao
        }
        receive {
            entry 9 {
                authentication-key
"yzClLKIFsAVR91AobUXUT/ppPzL7bVxBrNNg" hash
                algorithm aes-128-cmac-96
                begin-time 2020-06-09T04:00:00.0Z
            }
        }
        send {
            entry 2 {
                authentication-key
"yzClLKIFsAVR91AobUXUT/ppPzL7bVxBrNNg" hash
                algorithm aes-128-cmac-96
                begin-time 2020-06-09T04:00:00.0Z
            }
        }
    }
```

- Send and receive IDs must match each other
- TCP-AO supports multiple algorithms, make sure you are using are the same one

LESSONS LEARNED #2 – FIREWALLS MAY CHANGE TCP HEADERS



- The TCP MSS option was modified by a firewall in the path between the routers
- This caused the MAC calculation to fail on the receiver and the BGP session would not come up
- The TCP-AO option worked as expected to protect against modified packets!

CALL TO ACTION

Operators:

- Think about how TCP-AO fits into your overall routing security strategy
- Router vendor implementations are available now, start looking at them
- Ask for TCP-AO in RFPs/RFIs if it's missing

Developers:

- There is no ecosystem of open source implementations and tools yet
- Need kernel implementations: Linux and *BSD
- Need support in tools: tcpdump, Wireshark, etc.
- Need features in routing implementations: BIRD, FRR, goBGP, OpenBGPD, etc.
- Juniper and Nokia can provide implementations for testing!


THANK YOU
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