A look at the PGP keyserver data

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The PGP Ecosystem

- The OpenPGP standard (RFC 4880)
- Software packages (Original PGP, GnuPG, endtoend, ...)
- Key servers (today mostly sks)
- When I say PGP I mean the "PGP ecosystem" (software, standards etc.), not the PGP software product itself

Should we care?

- 'Why is GPG "damn near unusable"?' (31C3)
- "In the 1990s, I was excited about the future, and I dreamed of a world where everyone would install GPG. Now I'm still excited about the future, but I dream of a world where I can uninstall it." (Moxie Marlinspike)
- "Please throw some money to the GPG guy. Even though PGP sucks, it's the best we've got." (Matthew Green)

PGP problems

- Crypto is outdated, some of that is not fixable within the current model (Forward secrecy)
- PGP is and has always been "damn near unusable"
- Lots of backwards compatibility cruft, complex format, limited software options (no library)
- No subject encryption
- Two competing mail formats (PGP/MIME and PGP/Inline) each with its own advantages and disadvantages
- The trust model (web-of-trust, key signing) is incomprehensible for everyone outside the geek cosmos

Is PGP here to stay?

- Google and Yahoo work on PGP-based solutions (endtoend)
- Nothing currently seeks to replace it in the E-Mail space
- Systems like Textsecure and Pond are technically superior, but they're not built to replace E-Mail

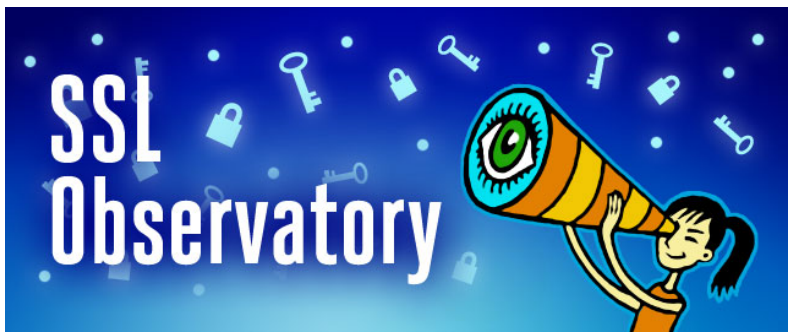
Conclusion

- I hate PGP, but I still try to make it better
- Fuzzing GnuPG found various vulnerabilities (CVE-2014-9087, CVE-2015-1606, CVE-2015-1607)
- Made proposal for subject encryption (a variant of it developed by Daniel Kahn Gillmor may land in Enigmail)
- I looked at the keyserver data to find crypto attacks (this talk)

The Idea

- PGP key servers store all keys ever sent to them on an add only basis
- You can't delete keys from key servers, you can just revoke them
- This leads to all kinds of potential problems (keyservers can be flooded with bogus data, privacy issues, ...)
- Crypto researchers perspective: Great, lots of data to investigate.

Inspiration



- EFF SSL Observatory (2010)
- Mining Your Ps and Qs (Nadia Heninger et al, 2012)

Look at keyserver data

- Large scale analysis of Internet wide scans for TLS certificate found crypto vulnerabilities
- For PGP we don't have to scan the Internet - we can get the data from the keyservers
- Let's put the crypto values in a database and analyze it

Parser challenges

- Lack of software: There is no low-level library to parse PGP key data
- pgpdump: Command line tool, doesn't give us all the data we want
- I wrote my own parser in python (warning: I'm not a good coder, the code looks horrible, but it works)
- keyr (abbr for key parser) will take keyserver data and output MySQL statements

Database challenges

- Large database (84 GB), careful adjustments of parameters (e. g. indexes)
- Used MyISAM, MySQL 5.6 and tcmalloc (improved memory allocator from Google)
- Increased values for max_allowed_packet, key_buffer_size, wait_timeout, interactive_timeout
- (Warning: My MySQL knowledge is limited)

How does it work?

- Download keyserver dump, unpack if neccessary
- Create database and tables from keyr-tables.sql
- Run keyr on keyserver dump files, pipe output to MySQL

How does it look like?

id	keyid	keyid_short	keyid_master	rsa_n	rsa_e	rsa_bits	ver	sub	errors	file
1	681d3a753b6c249e	3b6c249e	681d3a753b6c249e	cc2fd9d011aa7e6	010001	4096	4	0		sks-dump-0000.pgp
2	e8a53b713ba1a13e	3ba1a13e	681d3a753b6c249e	b1caa684b085e6	010001	4096	4	1		sks-dump-0000.pgp
3	ce040c74f9a3f1dd	f9a3f1dd	ce040c74f9a3f1dd	bc4e17ab58a7c3	010001	1024	3	0		sks-dump-0000.pgp
4	c56c3caa9995bde7	9995bde7	c56c3caa9995bde7	ce5c68d84db34e	010001	2048	4	0		sks-dump-0000.pgp
5	8f38a91bb2f768b8	b2f768b8	c56c3caa9995bde7	dc9bda82490608	010001	2048	4	1		sks-dump-0000.pgp
6	bdab86311ea5de89	1ea5de89	bdab86311ea5de89	b77f13820f56011	11	1024	3	0		sks-dump-0000.pgp
7	5964884db64c74f1	b64c74f1	5964884db64c74f1	add498a0b7f80f7	010001	2048	4	0		sks-dump-0000.pgp
8	db6bf5d7096c9858	096c9858	5964884db64c74f1	dd32e94f23a421	010001	2048	4	1		sks-dump-0000.pgp
9	de0f188a5da5e3c9	5da5e3c9	de0f188a5da5e3c9	d6ac00d92b89c1	11	1024	2	0		sks-dump-0000.pgp
10	6ebee4263f9061ab	3f9061ab	6ebee4263f9061ab	a350484702343d	11	2048	3	0		sks-dump-0000.pgp
11	34455afcd61e9601	d61e9601	34455afcd61e9601	9853b6de08ed10	11	1024	3	0		sks-dump-0000.pgp
12	3f321e334428ae5f	4428ae5f	3f321e334428ae5f	f8f450594a5ab28	010001	2048	4	0		sks-dump-0000.pgp
13	a7d48cd9ba57e19c	ba57e19c	a7d48cd9ba57e19c	fc1fa7c3dc8ed6f4	010001	2048	4	0		sks-dump-0000.pgp
14	49c2abee3a1582b8	3a1582b8	a7d48cd9ba57e19c	cdfb03c755d820e	010001	2048	4	1		sks-dump-0000.pgp
15	54119a80a8e5fe8e	a8e5fe8e	54119a80a8e5fe8e	a64f2f32414f362	010001	2048	4	0		sks-dump-0000.pgp
16	2d6cf76a9e2d1897	9e2d1897	54119a80a8e5fe8e	94f38167e0c622	010001	2048	4	1		sks-dump-0000.pgp

What data?

- Keys and signatures splittet into their hex encoded crypto values
- Hashes for signatures
- Rememer: Crypto keys and signatures are just numbers
- Ignored: User ID strings etc. - everything that's not crypto/math

Attack idea: RSA

- RSA public key: Modulus N (product of primes p, q) and exponent e
- If we know p and q we can break the key
- If due to a bad random number generator two RSA keys share one factor of N (p*q1, p*q2) we can efficiently break the keys by calculating the greatest common divisor (GCD)
- Same attack as Heninger et al and Lenstra et al (2012)

Batch GCD

- We can replicate the attack with the code from Nadia Heninger, but no new insights
- Leads to two valid looking breakable keys, reason unknown
- Various obviously broken keys (small factors, no user ids etc.) - the key servers are full of invalid data, likely due to data transmission errors

DSA is common

- GnuPG by default created primary DSA keys with 1024 bit for a long time
- 1024 bit is considered bad, it can be broken by attackers with a large budget
- I don't have millions of euros and no degree in advanced number theroy
- But: DSA has a weakness when it comes to random numbers

DSA duplicate k

- When creating a DSA signature one has to create a temporary, random and unique value k
- If two signatures where created with the same k it leads to the same r, so we can easily find these signatures
- If due to bad random numbers we have two different signatures with a shared k/r value we can break the private key
- This is a real problem: Attack on Playstation 3 and Bitcoin stealing

Lots of DSA keys and signatures

- We have lots of DSA keys and signatures - if there ever was a PGP DSA implementation with a flawed random number generator we will probably find it
- A look at the code of original PGP and GnuPG shows that the developers knew of this problem and did a lot of things to prevent it from happening

Give me duplicate r's

- Let MySQL do the work:
- SELECT a.keyid, a.dsa_r, a.dsa_s, b.dsa_s, a.hash, b.hash, c.dsa_p, c.dsa_q, c.dsa_g, c.dsa_y FROM sigs_dsa a JOIN sigs_dsa b JOIN keys_dsa c ON a.dsa_r = b.dsa_r AND a.dsa_s ¡¿ b.dsa_s AND a.keyid = c.keyid GROUP BY a.dsa_r;
- We get around 350 duplicates, but most don't lead to working keys - again lots of invalid data
- One key fails
- Checking ECDSA (same vuln) gives no results

The broken key

- The key belongs to a developer of the company PrimeFactors
- Answer from PrimeFactors: Test keys created during development.
- "our shipping product versions use the Blum-Blum-Shub generator which does not suffer from the problem you mention."
- This doesn't completely make sense.
- Request for NDA prevented further analysis.

What could be done next?

- We only checked the signatures on the key severs - mailing list archives could be scanned for DSA signatures on mails (non-trivial)
- Other crypto attacks that work on large scale data sets? Ideas welcome.

Thanks

Thanks! Questions?
Code and background paper will be released:
`https://github.com/hannob/pgpecosystem/`