A Blueprint for Civil GPS Navigation Message Authentication

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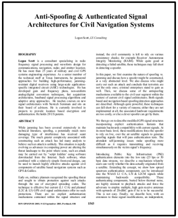
May 6, 2014

NMA is Gaining Traction

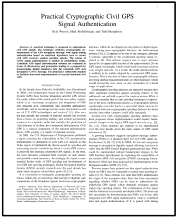
Scott, 2003



Anti-Spoofing & Authenticated Signal Architectures for Civil Navigation Systems

Logan Scott, *LS Consulting*

Wesson et al., 2012



Practical Cryptographic Civil GPS Signal Authentication

Kyle Wesson, Mark Rothlisberger, and Todd Humphreys

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2014

GPS L2C

Galileo OS

Tradeoff: Overhead vs. Authentication Frequency

- Would you like authentication every 36 seconds?

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uses 100% of available CNAV message slots

Tradeoff: Overhead vs. Authentication Frequency

- Would you like authentication every 36 seconds?

  uses 100% of available CNAV message slots

- What if NMA was restricted to 2% of the CNAV data rate?

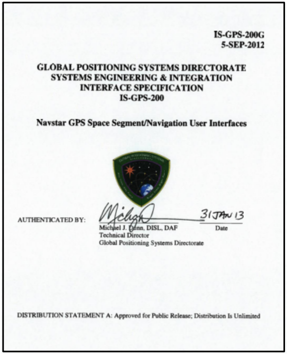
  is it still useful?

case study: 1 message every 9 minutes

Outline

- Introduction to NMA
- Two schools of thought: ECDSA or TESLA?
- Fitting NMA data into CNAV

IS-GPS-200


IS-GPS-200G
5-SEP-2012

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AUTHENTICATED BY: Michael J. Dunn, DISL, DAF, Technical Director, Global Positioning Systems Directorate — 31 JAN 13 (Date)

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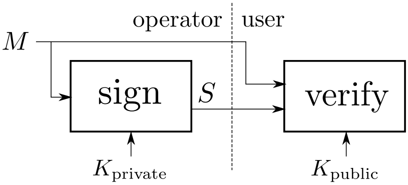
What is GNSS NMA?

Technique to add cryptographic authentication to GNSS navigation data stream [1, 2, 3, 4, 5]

1. GNSS operator signs a section of navigation data M
2. digital signature S is broadcast in navigation data stream
3. users verify (M, S)



Anti-Spoofing with NMA

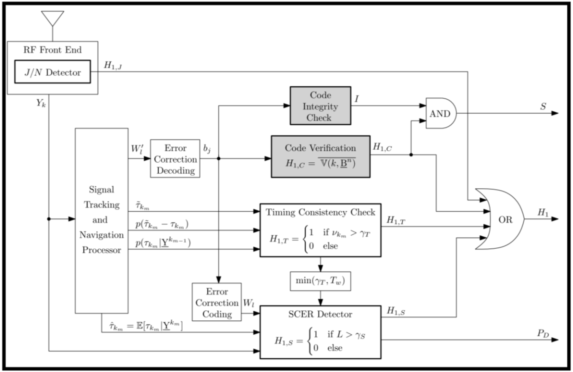
NMA is an attractive anti-spoofing measure:

- minimal burden on a low-cost receiver
- backward compatible
- provides **data authentication**
- enables **signal authentication**

Signal Authentication with NMA

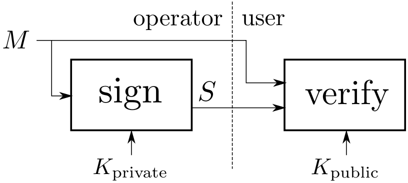
Signal authentication technique developed in [4] and [5]

- ensures underlying GNSS signal is authentic, not just navigation data
- requires μs-level time offset $\delta t_{\text{RX}} < \gamma$



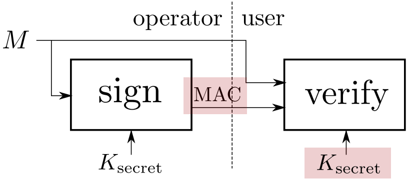
NMA Requires Asymmetric Cryptography

Public-key authentication



- S is a *digital signature*
- users only have public key $\rightarrow$ cannot sign messages

Symmetric-key authentication



- MAC is a *message authentication code*
- users have secret key $\rightarrow$ can sign messages
- length(MAC) < length(S)

What is the required bit strength?

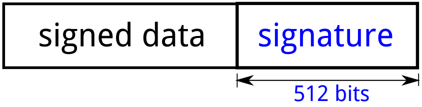
NIST-recommended security level for authentication [6]

b_s	secure until
112	2030
128	> 2030

assume equivalent symmetric-key bit strength b_s = 128 bits

Elliptic Curve Digital Signature Algorithm (ECDSA)

- Standardized public-key authentication scheme
- Assuming P-256 ($b_s = 128$), digital signature is 512 bits



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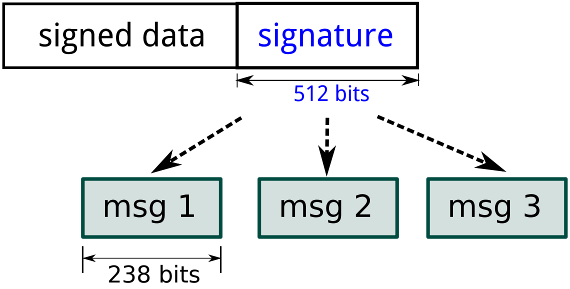


$T_{\text{ba}} \approx$ 27 minutes

Timed Efficient Stream Loss-Tolerant Authentication

public key — root key

$$K_0 \xleftarrow[h(\cdot)]{} K_1 \xleftarrow[h(\cdot)]{} \cdots \xleftarrow[h(\cdot)]{} K_{N-1} \xleftarrow[h(\cdot)]{} K_N$$

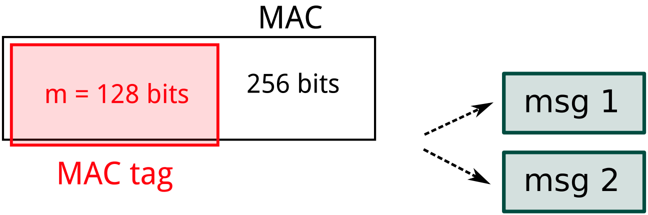
TESLA protocol [7]

- Generate one-way chain of keys
- Broadcast message authentication code MAC (M_i, K_i)
- After delay, broadcast K_i as plaintext
- Receiver checks both MAC and $h^k(K_i) = K_{i-k}$

Note: variant of TESLA where each key is only used for one MAC

TESLA Truncation

- Generate MAC by applying hash function to (M, K_i)
- Truncate MAC to m left-most bits, yielding **MAC tag** [8]



128+m = 256 bits per authentication

$T_{\text{ba}} \approx 18$ minutes

Assume P-256 and 1 NMA-dedicated CNAV message per 9 minutes.

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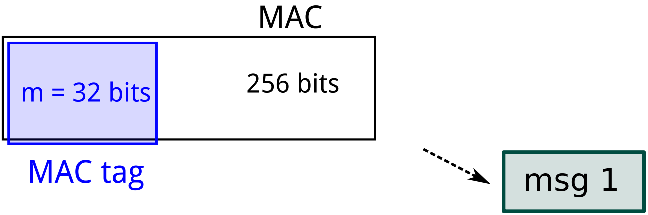


$128{+}m =$ 160 bits per authentication

$T_{\text{ba}} \approx$ 9 minutes

Assume P-256 and 1 NMA-dedicated CNAV message per 9 minutes.

TESLA Truncation

What is the effect of decreasing m?

Key recovery

- discover a future element of the key chain, or an alternate key that, once the one-way function is applied, matches a previously-disclosed key
- 2^{128} complexity
- decreasing m does not aid attack

MAC tag forgery

TESLA Truncation

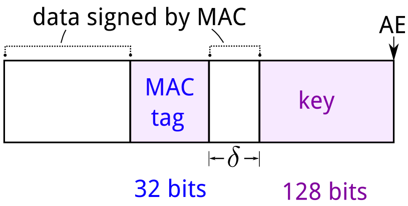
What is the effect of decreasing m?

Key recovery

MAC tag forgery

- forge message or MAC tag without knowing if the MAC tag will pass the victim receiver's verification test
- MAC tags appear random to attacker $\rightarrow$ probability of successfully forging a specific MAC tag is 2^{-m}
- **Ex:** $m = 32$, forgery attempt every 144 seconds for 10 years $\rightarrow$ 1 in 2,000 success rate
- NIST recommends $m \geq 32$ [9]

TESLA Format



- delay δ is critical: key is secret before the delay, but public afterward
- security condition $|\delta t_{\text{RX}}| < \delta$ must hold
- **Ex:** $\delta = 880$ ms

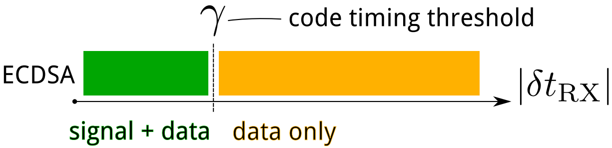
TESLA or ECDSA?

TESLA advantages

- **Lower overhead:** for fixed $b_s = 128$ bits, reduce overhead for one authentication from 512 bits to 160 bits

TESLA disadvantages

- Not standardized
- **Requires approximate time**, $|\delta t_{\text{RX}}| < \delta$



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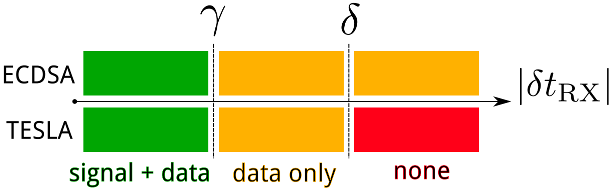


Goal: low overhead without ignoring users in the red box

Hybrid NMA

- auth. spaced equally in time (T_{ba}), but vary in *type*
- k consecutive TESLA type
- followed by one ECDSA type

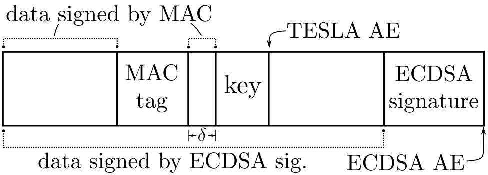


Figure: $k = 1$ hybrid NMA data stream

- only 1 of $(k+1)$ authentications is ECDSA type $\rightarrow$ **low overhead**
- all data signed by ECDSA $\rightarrow$ **cryptographic data authentication** $\forall \delta t_{\text{RX}}$

Three Ways To Transmit NMA Data in CNAV

Data for $(k+1)$ authentications split into

- $238N_{\text{arb}}$ bits in new NMA messages
- $149N_{\text{clk}}$ bits in new clock+NMA messages
- N_e bits exploited from other messages

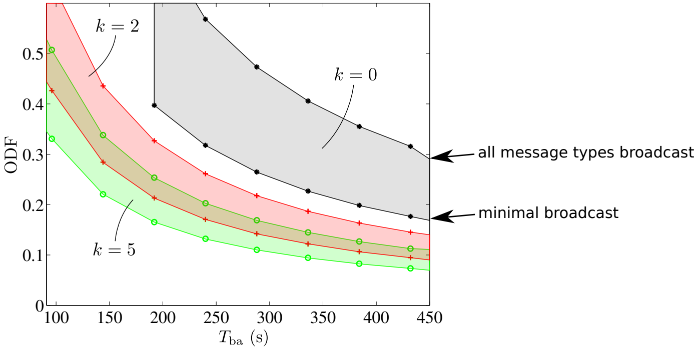
Select $(N_{\text{arb}}, N_{\text{clk}}, N_e)$ to minimize *open data fraction*

$$\text{ODF} = \frac{149N_{\text{clk}} + 238N_{\text{arb}}}{149O_{\text{clk}} + 238O_{\text{arb}}}$$

where $O_{\text{arb}}, O_{\text{clk}}$ are the number of open slots.

Cost Versus Performance

Example result when $N_e = 0$



Example Message Definition

- Choose $k = 5 \quad \rightarrow \quad$ 1 in 6 authentications is ECDSA type
- Choose $N_{\text{clk}} = N_e = 0$

MT	bits	contents
NMA-1	1-32	MAC tag
	38-88	$S_i,\ i \in 1, \ldots, 5$
	89-110	salt
	111-238	TESLA key
NMA-2	1-232	S_6
	233-238	salt

Example Message Definition

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Conclusions

More efficient NMA without significant security compromises

- TESLA MAC truncation to $m = 32$
- hybrid NMA with all data signed by ECDSA
- optimal $(N_{\text{arb}}, N_{\text{clk}}, N_e)$ w.r.t. ODF cost metric

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Case study

- 2% of CNAV data rate
- ODF = 6% - 9%

$T_{\text{ba}} \approx$ 9 minutes

Questions?

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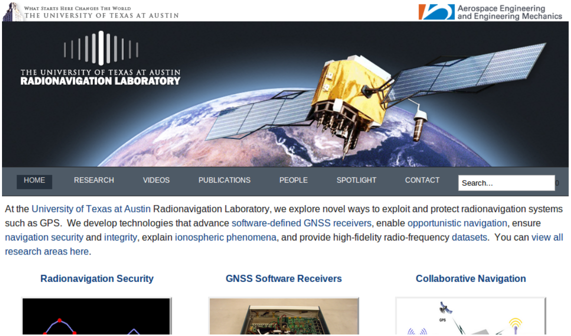

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[13] NIST, "Recommendation for key management—Part I: General (revision 3)," SP 800-57, National Institute of Standards and Technology, July 2012.

GPS L2 CNAV Specification

CNAV message broadcast intervals [10]

MT	*Contents*	*Minimal*	*Maximal*	*Unallocated*
10	Ephemeris 1	48 sec.	48 sec.	3 bits
11	Ephemeris 2	48 sec.	48 sec.	7 bits
3*	Clock	48 sec.	48 sec.	up to 149 bits
30	Clock, ISC/IONO	288 sec.	288 sec.	12 bits
33	Clock, UTC	288 sec.	288 sec.	51 bits
35	Clock, GGTO	N/A	288 sec.	81 bits
32	Clock, EOP	N/A	30 min.	N/A
37	Clock, Midi Alm.	N/A	32 per 120 min.	N/A
31	Clock, Red. Alm.	N/A	20 min.	N/A
12	Reduced Alm.	N/A	4 per 20 min.	N/A
13	Diff. Corrections	N/A	30 min.	N/A
14	Diff. Corrections	N/A	30 min.	N/A

MT-10	MT-11	clock	arbitrary

ECDSA Curve Selection

ECDSA curves with $b_s = 128$

		curve: *random*	curve: *Koblitz*
field	*binary*	B-283	K-283
field	*prime*	P-256[a]	secp256k1

[a] Also brainpoolP256r1 and brainpoolP256t1 from ECC Brainpool [11][12]

Assume prime field $\rightarrow$ 512-bit signature

Key Distribution

- PKC contains ECDSA and TESLA public keys, period of validity, etc.
- Maximum key period is 1-3 years [13]
- Easily distributed to users with a secure side channel
- Standalone receivers use over-the-air re-keying
    - Initial key inserted by manufacturer
    - Broadcast PKCs are verified via NMA using current key