Biometric Passports

Security and Privacy

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What is a biometric passport?

- A passport with an embedded chip containing biometric data
- Also known as an e-passport or digital passport
- Standardised by the International Civil Aviation Organisation (ICAO) as Document 9303 [1]
- Identified by this symbol:

What data does it contain?

All biometric passports contain a chip with the following data:

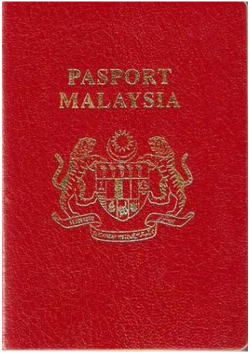
- A copy of the information printed on the passport
- A digital photo of the passport holder
- Digital signatures from the issuing country

Issuing countries may optionally include additional data:

- Fingerprints
- Iris scans
- Additional personal information (e.g. address)
- Additional document information (e.g. observations)

A Brief History

- 1968: Development begins
- 1980: Machine-readable passport first standardised
- 1988: Work begins on biometric systems
- 1998: First biometric passport issued by Malaysia [2]
- 2006: Biometric passport standardised



How is the data used? [3]

When the passport is scanned:

1. The machine-readable zone (MRZ) is read

```
P<GBRHENDERSON<<WILLIAM<EDWARD<HASWELL<<<<<<
0123456789GBR0409061M231011<<<<<<<<<<<<<<<02
```

2. The scanner and chip derive keys to establish a secure channel
3. The scanner reads the chip and verifies the digital signatures
4. The photo (and possibly other biometrics) are compared to the passport holder
   - by an e-gate using facial recognition
   - or by a human officer
5. The system checks the holder against watchlists
6. The holder is allowed into the country (or not)

Live Demo

- Reading the passport chip with an NFC-enabled phone
- Written in TypeScript (big mistake)

Basic Access Control (BAC)

- The data in the passport chip cannot be accessed without first establishing a secure channel
- One way of doing this is with Basic Access Control (BAC)
- We will call the scanner the interface device (IFD) and the chip the integrated circuit (IC)

- The hash function **H** is SHA-1
- The encryption function **E** is Triple-DES
- The MAC function **M** is ISO 9797-1 MAC algorithm 3

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Step 0: Document Access Key Calculation

$$P = \text{passport number}$$
$$D = \text{date of birth}$$
$$E = \text{date of expiry}$$

$$\text{MRZ} = P \,\|\, D \,\|\, E$$
$$K_{\text{seed}} = \mathbf{H}(\text{MRZ})_{0,\ldots,15}$$
$$\mathbf{KDF}(K, c) = \mathbf{H}(K \,\|\, c)_{0,\ldots,15}$$
$$K_{\text{Enc}} = \mathbf{KDF}(K_{\text{seed}}, 1)$$
$$K_{\text{Mac}} = \mathbf{KDF}(K_{\text{seed}}, 2)$$

$\|$ denotes concatenation

$X_{a,\ldots,b}$ denotes the bytes a to b of X

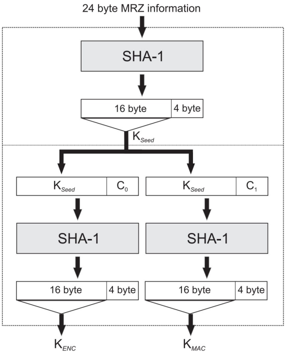

Figure 1: BAC key derivation [4]

Step 1: Basic Access Control

Inspection System (IFD)		**Passport (IC)**
		$\mathrm{RND_{IC}} \in \{0,1\}^{64}$
	$\xleftarrow{\mathrm{RND_{IC}}}$	
$\mathrm{RND_{IFD}}, K_{\mathrm{IFD}} \in \{0,1\}^{64}$		
$X \leftarrow \mathrm{RND_{IFD}} \parallel \mathrm{RND_{IC}} \parallel K_{\mathrm{IFD}}$		
$E_{\mathrm{IFD}} \leftarrow \mathbf{E}_{K_{\mathrm{Enc}}}(X)$		
$M_{\mathrm{IFD}} \leftarrow \mathbf{M}_{K_{\mathrm{Mac}}}(E_{\mathrm{IFD}})$		
	$\xrightarrow{E_{\mathrm{IFD}} \parallel M_{\mathrm{IFD}}}$	
		Decrypt and verify $E_{\mathrm{IFD}} \parallel M_{\mathrm{IFD}}$
		$K_{\mathrm{IC}} \in \{0,1\}^{128}$
		$Y \leftarrow \mathrm{RND_{IC}} \parallel \mathrm{RND_{IFD}} \parallel K_{\mathrm{IC}}$
		$E_{\mathrm{IC}} \leftarrow \mathbf{E}_{K_{\mathrm{Enc}}}(Y)$
		$M_{\mathrm{IC}} \leftarrow \mathbf{M}_{K_{\mathrm{Mac}}}(E_{\mathrm{IC}})$
		$\mathrm{KS_{Seed}} = K_{\mathrm{IFD}} \oplus K_{\mathrm{IC}}$
	$\xleftarrow{E_{\mathrm{IC}} \parallel M_{\mathrm{IC}}}$	
Decrypt and verify $E_{\mathrm{IC}} \parallel M_{\mathrm{IC}}$		
$\mathrm{KS_{Seed}} = K_{\mathrm{IFD}} \oplus K_{\mathrm{IC}}$		

Step 2: Session Key Derivation

Once the shared secret $\mathsf{KS}_{\mathsf{Seed}} = K_{\mathsf{IFD}} \oplus K_{\mathsf{IC}}$ is established:

$$\mathsf{KS}_{\mathsf{Enc}} = \mathbf{KDF}(\mathsf{KS}_{\mathsf{Seed}}, 1)$$
$$\mathsf{KS}_{\mathsf{Mac}} = \mathbf{KDF}(\mathsf{KS}_{\mathsf{Seed}}, 2)$$

The send sequence counter (SSC) is further initialised:

$$\mathsf{SSC} = (\mathsf{RND}_{\mathsf{IC}})_{4,\ldots,7} \parallel (\mathsf{RND}_{\mathsf{IFD}})_{4,\ldots,7}$$

Step 3: Secure Messaging

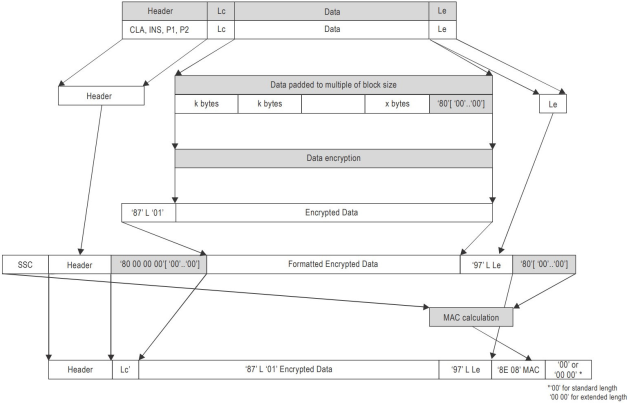

Figure 2: SM command APDU structure [1]

Passive Authentication

With Secure Messaging enabled, the IFD can read the holder's data from the IC and verify its authenticity and integrity using Passive Authentication.

- Each issuing country has a Country Signing Certificate Authority (CSCA) which issues certificates for national Document Signers (DS)
- CSCA certificates must be acquired from a trustworthy source (e.g. ICAO PKD)
- The Document Security Object (SO_D) contains digital signatures over hashes of the data in the passport, as well as the DS certificate
- The inspection system builds and validates a certificate chain from a Trust Anchor to the DS certificate
- The inspection system finally verifies the digital signatures in SO_D

Attacks

- **E-Passport: Cracking Basic Access Control Keys**, Liu et al. (2007)
  Due to the low entropy of the MRZ, the BAC keys can be cracked in a matter of seconds using specialised hardware.
- **A Traceability Attack Against e-Passports**, Chothia et al. (2010)
  By measuring the time taken for the IC to respond, the movements of an individual passport can be traced.
- **ePassport: Side Channel in the Basic Access Control**, Sportiello et al. (2014)
  Further timing analysis can be used to recover the MRZ without eavesdropping.

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E-Passport: Cracking Basic Access Control Keys [4]

- Eavesdrop $\mathrm{RND}_{\mathrm{IC}}$, $E_{\mathrm{IFD}} \parallel M_{\mathrm{IFD}}$, $E_{\mathrm{IC}} \parallel M_{\mathrm{IC}}$ and the entire subsequent communication C
- Run a key search on the MRZ information to match the most significant eight bytes of E_{IC}.
- C can then be decrypted.

This becomes feasible if the MRZ has low entropy, due to:

- Passport numbers that are sequential, structured, include a checksum, or are otherwise predictable
- Passport expiry dates having a small range
- An attacker being able to narrow down the date of birth

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E-Passport: Cracking Basic Access Control Keys [4]

- At the time, a lot of passports had these issues!
- **Germany**: 4 digits for local authority (of which there are 295), remaining 5 digits sequential
- **Netherlands**: Begins with fixed character "N", ends with a check digit, remaining 7 digits sequential

The authors demonstrated that, with just a photo of the passport holder and some knowledge about the dependency between passport numbers and expiry dates, the keys for a German passport could be cracked in ≈ 22 seconds and a Dutch passport in ≈ 10.3 seconds.

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A Traceability Attack Against e-Passports [5]

- Eavesdrop $E_{\mathrm{IFD}} \| M_{\mathrm{IFD}}$ during a legitimate BAC exchange
- Initiate a BAC exchange with the IC and send it random data
- Initiate a BAC exchange with the IC and send it the recorded message
- Compare the time taken for the IC to respond

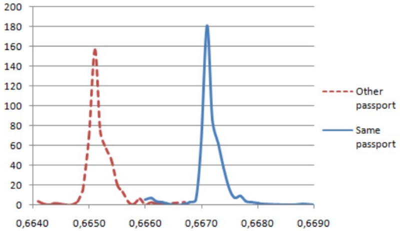

Figure 3: Sampled response times (British passport) [5]

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A Traceability Attack Against e-Passports [5]

- IC checks the MAC before comparing nonces
- If the MAC is invalid (i.e. K_{Mac} is wrong), the IC will not compare nonces, and the response time will be shorter
- Could be used to, for example, build a bomb that detonates in the presence of a specific person [6]
- All 10 passports from 6 countries that the authors tested were vulnerable
- The French passport was even worse: it went against the spec and explicitly gave a different error code!

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ePassport: Side Channel in the Basic Access Control [7]

- Set a generic E_{IFD} and a random M_{IFD}.
- Vary the ith byte of M_{IFD} and measure the time taken for the IC to respond.
- The value that causes the longest mean response time is the correct value of the ith byte.
- Work through the bytes to find the valid MAC for E_{IFD}.
- Use specialised hardware to crack the MRZ.

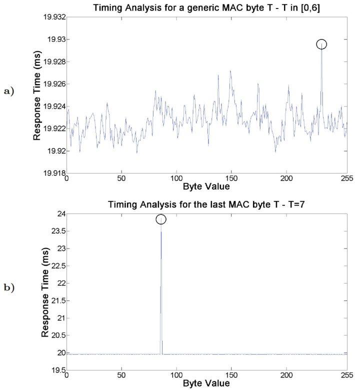

Figure 4: Timing analysis [7]

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ePassport: Side Channel in the Basic Access Control [7]

- Requires an interaction of $\approx$ 85 hours with the IC
- The authors suggest that this could be achieved by performing the attack from malware on the target's phone:
  - Phone and passport are kept in the same pocket or bag
  - Malware uses the phone's NFC reader to communicate with the passport
  - Once the keys are cracked, the malware can extract further data from the passport and send it to the attacker
  - Alternatively the passport could be used remotely through a relay attack

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Mitigations

- Ensure that the IC does not leak information through the timing of its responses
- Improve the entropy of the MRZ (e.g. by using a random passport number)
- Shield the chip so it can only be read if the passport is open
  - The US passport has a thin metal mesh in the cover [8]
- What to do about the fundamentally insecure DES encryption?

Password Authenticated Connection Establishment (PACE)

- PACE is an alternative to BAC that uses asymmetric cryptography
- Generates strong session keys independent of the strength of the password (in this case, the MRZ)
- Based on Diffie-Hellman key exchange
- Further communication is encrypted using AES
- See ICAO Doc 9303 Part 11, Section 4.4 [1]

Cryptographic Weaknesses

- EU passports since 2014 have been required to use PACE [9]
- Until 2018 it was still required to support BAC [1]
- PACE prevents eavesdropping but if BAC is still supported, the MRZ can still be cracked

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LDS2 Applications

- In 2021, the ICAO introduced Logical Data Structure 2 (LDS2), which allows for additional data to be stored
- This includes travel history, visa records, and additional biometric data

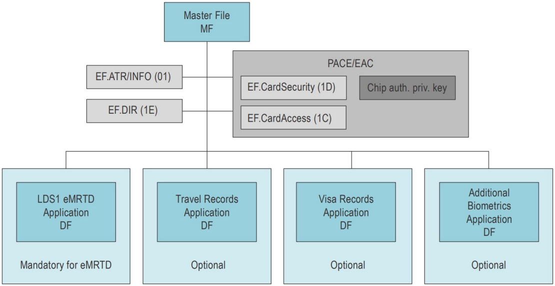

Figure 5: Applications for LDS1 and LDS2 [1]

Mandatory recording of travel history

- Up to the issuing country whether to enable this feature
- If enabled, it is mandatory for all countries to record the holder's travel history
- Currently, countries that don't want visitors stigmatised can issue visas and record entries and exits on separate documents

Tag	Tag	Content	Mandatory /OPTIONAL	Format	Example
'5F44'		Embarkation/Debarkation State (copy for SEARCH RECORD)	M	F (3) A	USA
'73'		Entry / Exit Travel Record (signed info)			
	'5F44'	Embarkation/Debarkation State	M	F (3) A	USA
	'5F4C'	Visa approvals, refusals, and revocations	O	V (50) A,N,S,U	Free-form text
	'5F45'	Travel date (Date of entry/exit)	M	F (8) N	20120814 (yyyymmdd)
	'5F4B'	Inspection authority	M	V (10) A,N,S	CBP
	'5F46'	Inspection location (Port of Entry/Exit)	M	V (10) A,N,S	SFO
	'5F4A'	Inspector reference	M	V (20) A,N,S	SFO00001234
	'5F4D'	Result of inspection	O	V (50) A,N,S,U	Free-form text
	'5F49'	Mode of travel	O	F (1) A	A (Air), S (Sea), L (Land)
	'5F48'	Duration of stay (days)	O	V (2) B	'00FF' (255 days)
	'5F4E'	Conditions holder is required to observe while in the issuing State	O	V(50) A,N,S,U	Free-form text
'5F37'		Authenticity token (Signature)	M	V (140) B	'5F' '37' Len {Signature}
'5F38'		Reference (record number) to LDS2-TS Signer certificate in Certificates Store	M	F (1) B	'01' …'FE'

Figure 6: Entry/Exit Record [1]

Irremovable messages

- Countries can add irremovable messages to the passport
- For example, a country could mark a person as “suspicious” with no reason given and no way to remove it
- This would make it difficult for the holder to travel [10]

Conclusion

- Biometric passports allow for much faster border control without compromising security
- Most of the security issues are fixed and just need time to be rolled out
- The privacy issues are just getting started...

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