Silver and AESCPFB

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23,24-8-14

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- CPFB only requires the encryption module of AES, Silver requires both the encryption and decryption modules.
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- They both use the nonce and master key to derive session keys.

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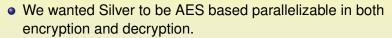
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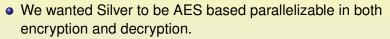
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- We chose the 1st,5th and 9th round keys to take advantage of the AES 4 round property.
- The change to the rounds is a simple xor with a counter, but the counter is key and nonce dependent.
- key and nonce of 128 bits each.

$Encrypt(P, roundkeys, \kappa, IC)$

• Split P into 128 bit blocks, last block partial if necesary (no pad).

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$Encrypt(P, roundkeys, \kappa, IC)$

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• For $i \leftarrow 1$...last complete block

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- $temprkeys_i = roundkeys_i$, $(i \neq 1, 5, 9)$
- temprkeys_i = roundkeys_i \oplus (κ + counter), (i = 1, 5, 9)

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- For $i \leftarrow 1$...last complete block
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- For $i \leftarrow 1$...last complete block
 - counter \leftarrow counter + *IC*
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- $\kappa = \text{AES}_{key}(npub), counter \leftarrow \{0\}^{128}$
- $IC \leftarrow AESroundkey_9(\kappa)OR([1]_{64} || [1]_{64})$
- For $i \leftarrow 1$...last complete block
 - counter ← counter + IC
 - $temprkeys_i = roundkeys_i$, $(i \neq 1, 5, 9)$
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 - $XT \leftarrow XT \oplus P_i$

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• Return (*C*, *XT*)

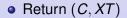
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If there is a last incomplete block of ℓ bytes: Encrypt with, basically, counter mode:



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If there is a last incomplete block of ℓ bytes:

Encrypt with, basically, counter mode:

•
$$bP = \left[\frac{|P|}{8}\right]_{64}$$

- $counter \leftarrow counter + IC$
- tmp = encrypt (bP||bP) with roundkeys associated to the counter.
- Split *tmp* in bytes *tmp*₁||*tmp*₂||...||*tmp*₁₆
- $C_s = P_s \oplus (tmp_1||...||tmp_\ell)$

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- Split *tmp* in bytes *tmp*₁||*tmp*₂||...||*tmp*₁₆
- $C_s = P_s \oplus (tmp_1||...||tmp_\ell)$
- to authenticate:
- $B = P_s ||tmp_{\ell+1}||...||tmp_{15}|| [\ell]_8$
- $counter \leftarrow counter + IC$
- XT ← XT ⊕ (encryption of B with AES using roundkeys associated to the new counter)
- Return (C, XT)

ProcessAD(A, roundkeys, κ, IC)

• Split *A* in 128 bits blocks, padding with bytes 1,0,...,0 if necessary (but only if necesary).

$ProcessAD(A, roundkeys, \kappa, IC)$

Silver

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- If the last block is complete, use the counter that would go there, else, use counter 0.
- Xor all the ciphertexts to form an AD tag AT.

• Obtain *AT*, *XT* as above.

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- Final tag *T* is the encryption of *AT* ⊕ *XT* with AES and roundkeys given by:

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- Final tag T is the encryption of $AT \oplus XT$ with AES and roundkeys given by:
 - roundkeys changed by using counter $g \leftarrow \left(\left\lceil \frac{|A|}{8} \right\rceil_{e_4} || \left\lceil \frac{|P|}{8} \right\rceil_{e_4} \right)$

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Silver

- Obtain AT, XT as above.
- Final tag T is the encryption of $AT \oplus XT$ with AES and roundkeys given by:
 - roundkeys changed by using counter $g \leftarrow \left(\begin{bmatrix} |A| \\ 8 \end{bmatrix}_{e_4} || \begin{bmatrix} |P| \\ 8 \end{bmatrix}_{e_4} \right)$
 - and changing the order of the roundkeys using the permutation (2, 3, 4, 6, 7, 8, 10, 0)(9, 1, 5)

Tag

- Obtain AT, XT as above.
- Final tag T is the encryption of $AT \oplus XT$ with AES and roundkeys given by:
 - roundkeys changed by using counter $g \leftarrow \left(\left[\frac{|A|}{8} \right]_{c_4} || \left[\frac{|P|}{8} \right]_{c_4} \right)$
 - and changing the order of the roundkeys using the permutation (2, 3, 4, 6, 7, 8, 10, 0)(9, 1, 5)

Decryption and Verification are the obvious ones.



 In addition to the tweak on each block, Silver changes the key expansion of AES so that the nonce also influences the round keys:

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Silver and AESCPFB

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• roundkey_i = AESroundkey_i(key), $i \leftarrow 1,9$

Some of these details have as objective blocking some attacks. For example:

 We use a mix of the expanded keys of key and κ instead of only the expanded keys of κ to prevent a key collision attack.

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- The order of the round keys for the tag is different to ensure that that call to the encryption function is not used elsewhere.
- Several measures ensure that an attempted forgery must be done with equal lengths texts.
- The masking of the ciphertext in the construction of *XT* is there to give some protection in the case that the nonce is repeated by mistake.

In cycles per byte (cpb) on Haswell Silver runs at:

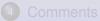
- With AESNI instructions
 - encrypts at:
 - 0,73 cpb for long messages
 - 1 cpb for 1536 bytes
 - 10,8 cpb for 44 bytes.
 - decrypts at:
 - 0,81 cpb for long messages
 - 1,2cpb for 1536 bytes
 - 9,6 cpb for 44 bytes.
- Without AESNI the numbers are:
 - 11,45/12,9 cpb for long messages,
 - 11,85/13,59 for 1536 bytes
 - 30,4/28,2 cpb for 44 bytes.

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CPFB (Counter/Plaintext Feedback) combines CTR y PFB. CTR provides security.

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- Public message number must be a nonce between 8 and 15 bytes.
- Key can be 128 or 256 bits.
- Message is split into 96-bit blocks, each one concatenated with a 32 bit counter.

• Initially two keys κ_0, κ_1 are generated from the nonce and key, in maner similar to Silver, but with a counter added.



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- κ₀ is used as encryption key to process the AD, κ₁ to process the message
- If the message is long, it may be necessary to generate more.
- κ₀ is also used as a mask in the message processing, to prevent a key collision attack, and in the process of the tag.

$\text{Encrypt}(M, \kappa_1, \kappa_0)$

 Split message into 96-bit blocks, with last block incomplete if necessary. (no pad)

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- Split message into 96-bit blocks, with last block incomplete if necessary. (no pad)
- stream $\leftarrow AES_{\kappa_1}(\{0\}^{128}), \quad counter \leftarrow 0$

● For *i* ← 1...*n*

- $C_i \leftarrow M_i \oplus \text{MSB}_{96}(stream)$
- counter \leftarrow counter + 1
- stream $\leftarrow AES_{\kappa_1}([counter]_{32})$

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- stream $\leftarrow AES_{\kappa_1}$ ($M_i || [counter]_{32}$)

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$\text{Encrypt}(M, \kappa_1, \kappa_0)$

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 - $C_i \leftarrow M_i \oplus \text{MSB}_{96}(stream)$
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 - stream $\leftarrow AES_{\kappa_1}((M_i || [counter]_{32}))$
 - *X* ← *X* ⊕ stream

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• Return (C, X)

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 - *X* ← *X* ⊕ stream
- If there is a final partial block M_{n+1}^* of length *r*:

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- If there is a final partial block M_{n+1}^* of length *r*:
 - $C_{n+1}^* \leftarrow M_{n+1}^* \oplus \text{MSB}_r(\text{stream})$

• Return (C, X)

$\text{Encrypt}(M, \kappa_1, \kappa_0)$

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- If there is a final partial block M_{n+1}^* of length *r*:
 - $C_{n+1}^* \leftarrow M_{n+1}^* \oplus \text{MSB}_r(stream)$
 - counter \leftarrow counter + 1
 - stream $\leftarrow \text{AES}_{\kappa_1}((M^*_{n+1}||\{0\}^{96-r}||[counter]_{32}) \oplus \kappa_0)$
 - $X \leftarrow X \oplus stream$
- Return (*C*, *X*)

ProcessAD(AD, κ_0)

- Pad AD with zeroes and split into 96 bit blocks.
- $X \leftarrow \{0\}^{128}$, counter $\leftarrow 0$
- For *i* ← 1…*n*
 - counter \leftarrow counter + 1
 - $X \leftarrow X \oplus AES_{\kappa_0}(AD_i || [counter]_{32})$
- Return X

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EncryptAndAuthenticate(AD, M, npub, key)

- $(\kappa_0, \kappa_1) \leftarrow \text{GenerateKeys}(npub, key)$
- $X_{AD} \leftarrow \text{ProcessAD}(AD, \kappa_0)$
- $(C, X_M) \leftarrow \text{Encrypt}(M, \kappa_1, \kappa_0)$

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EncryptAndAuthenticate(*AD*, *M*, *npub*, *key*)

- $(\kappa_0, \kappa_1) \leftarrow \text{GenerateKeys}(npub, key)$
- $X_{AD} \leftarrow \text{ProcessAD}(AD, \kappa_0)$
- $(C, X_M) \leftarrow \text{Encrypt}(M, \kappa_1, \kappa_0)$
- $T \leftarrow \operatorname{AES}_{\kappa_0}(X_{AD} \oplus X_M)$ • Poture (C, T)
- Return (*C*, *T*)

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EncryptAndAuthenticate(AD, M, npub, key)

- $(\kappa_0, \kappa_1) \leftarrow \text{GenerateKeys}(npub, key)$
- $mlen \leftarrow |M|/8$, $adlen \leftarrow |AD|/8$
- $X_{AD} \leftarrow \mathsf{ProcessAD}(AD, \kappa_0)$
- $(C, X_M) \leftarrow \text{Encrypt}(M, \kappa_1, \kappa_0)$
- $T \leftarrow \operatorname{AES}_{\kappa_0}(X_{AD} \oplus X_M)$
- Return (*C*, *T*)

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- $mlen \leftarrow |M|/8$, $adlen \leftarrow |AD|/8$
- $X_{AD} \leftarrow \text{ProcessAD}(AD, \kappa_0)$
- $(C, X_M) \leftarrow \text{Encrypt}(M, \kappa_1, \kappa_0)$
- $L \leftarrow AES_{\kappa_0}([mlen]_{64} || [adlen]_{32} || \{0\}^{32})$
- $T \leftarrow \operatorname{AES}_{\kappa_0}(X_{AD} \oplus X_M)$
- Return (*C*, *T*)

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- $X_{AD} \leftarrow \text{ProcessAD}(AD, \kappa_0)$
- $(C, X_M) \leftarrow \text{Encrypt}(M, \kappa_1, \kappa_0)$
- $L \leftarrow AES_{\kappa_0}([mlen]_{64} || [adlen]_{32} || \{0\}^{32})$
- $T \leftarrow \operatorname{AES}_{\kappa_0}(X_{AD} \oplus X_M \oplus L)$
- Return (*C*, *T*)

EncryptAndAuthenticate(*AD*, *M*, *npub*, *key*)

- $(\kappa_0, \kappa_1) \leftarrow \text{GenerateKeys}(npub, key)$
- $mlen \leftarrow |M|/8$, $adlen \leftarrow |AD|/8$
- $X_{AD} \leftarrow \text{ProcessAD}(AD, \kappa_0)$
- $(C, X_M) \leftarrow \text{Encrypt}(M, \kappa_1, \kappa_0)$
- $L \leftarrow AES_{\kappa_0}([mlen]_{64} || [adlen]_{32} || \{0\}^{32})$
- $T \leftarrow \operatorname{AES}_{\kappa_0}(X_{AD} \oplus X_M \oplus L)$
- Return (C, T)

Decryption and verification are the obvious ones.

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- Silver is not only faster than AESGCM, it is in fact competitive even with OCB and it appears to be among the group of the fastest CAESAR candidates.

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- Both are reasonably fast.
- Silver is not only faster than AESGCM, it is in fact competitive even with OCB and it appears to be among the group of the fastest CAESAR candidates.
- They both benefit from whatever improvement in speed, area, energy consumption, etc, to AES.

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- As of the moment of this writing there are no attacks against either.

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Silver and AESCPFB

Thanks! Gracias! Merci! Kiitos! Danke!

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