Stream Ciphers

BMEVITMAV52

Information and Network Security

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Stream ciphers

- Comparison to block ciphers
  - Block ciphers process blocks (64 bits or more)
  - Stream ciphers work on smaller “blocks” usually 1 bit

  - Block ciphers have no memory
  - Stream ciphers need state information (memory) in addition to the key
    - block ciphers + memory (e.g. CFB)
      -> stream ciphers

One-time pad

- Vernam cipher
  - $c_i = p_i$ XOR k_i
- There exists a perfect cipher: one time pad
  - Vernam cipher
  - Key should be as long as the plaintext
  - Unconditionally secure (Shannon)
  - But, one-time pad is not feasible due to the long key

- Keystream generation
  - **The goal of the stream ciphers is to provide a long pseudorandom keystream based on a smaller key**
  - Computationally secure

Binary additive stream ciphers

- Synchronous stream ciphers, where the output function is the XOR operation
  - Just like Vernam cipher

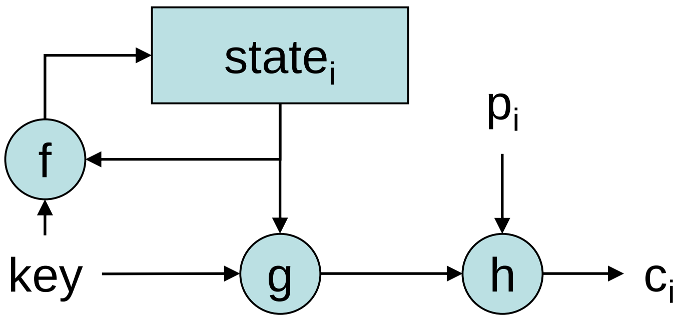
- Most of the stream ciphers are additive stream ciphers

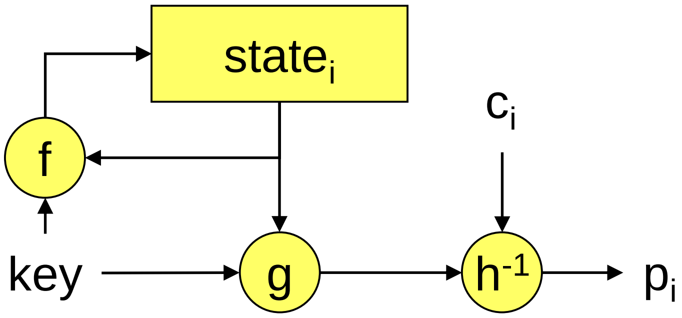
Synchronous stream ciphers

- Definition: keystream is generated independently of the plaintext and ciphertext
- Procedure:
  - $state_{i+1} = f(state_i, k)$ next state function
  - $z_i = g(state_i, k)$ keystream
  - $c_i = h(p_i, z_i)$ output function

Synchronous stream ciphers 2.

- Properties
  - Sender and receiver must be synchronized
    - Same key and same position
    - Lost synchronization fails decryption
    - Bit insertion/removal or replay attack are recognized
  - Bit errors produce bit errors
    - No error propagation
    - Ideal for lossy communication
    - Attackers know the result of the modifications
- -> OFB is a synchronous stream cipher



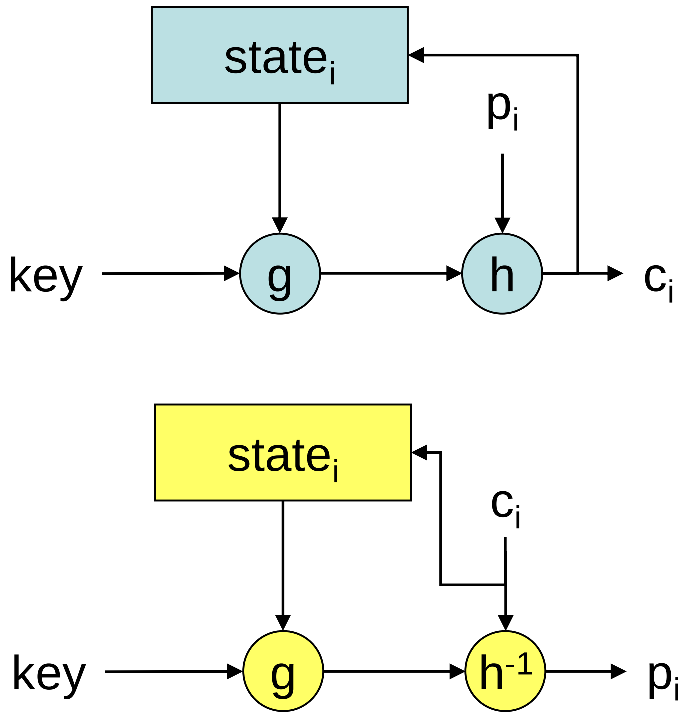


Asynchronous stream ciphers

- Self synchronizing stream ciphers
- Definition: keystream is generated from the key and a number of previous ciphertext bits
- Procedure
  - $state_i = (c_{i-1}, c_{i-2}, \ldots, c_{i-t})$
  - $z_i = g(state_i, k)$ keystream
  - $c_i = h(p_i, z_i)$ output function

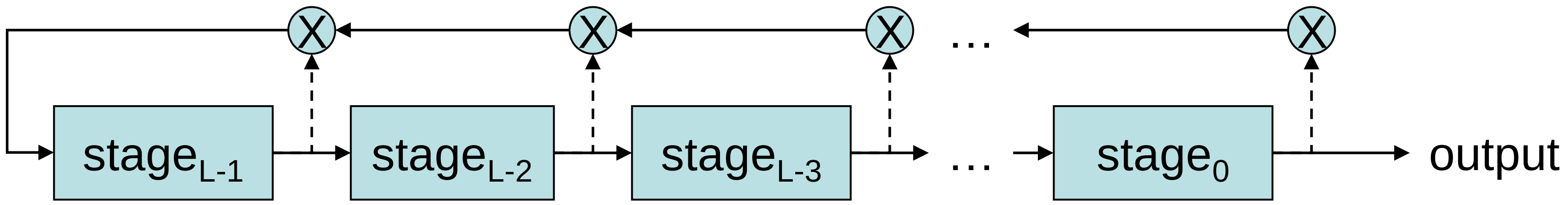
Asynchronous stream ciphers 2.

- Properties
  - Receiver is capable of recover after lost synchronization
    - Self synchronization after bit insertion/removal
    - Plaintext is unrecoverable during the synchronization
  - Bit errors produce more erroneous bits
    - Limited error propagation: up to t bits
    - Attackers can not be sure about the result of the modifications
  - Plaintext bits influence the rest of the ciphering
- -> CFB is an asynchronous stream cipher



Linear Feedback Shift Registers

- LFSR
  - Consists of L stages storing 1 bit information
  - A clock moves data through the stages -> shift
  - The last stage servers the output
  - The input of the first stage is a feedback, calculated as a modulo sum of a subset of the stages
- LFSR properties
  - Easy hardware implementation
  - Large period
  - Good statistical properties
  - Analysis through algebraic techniques

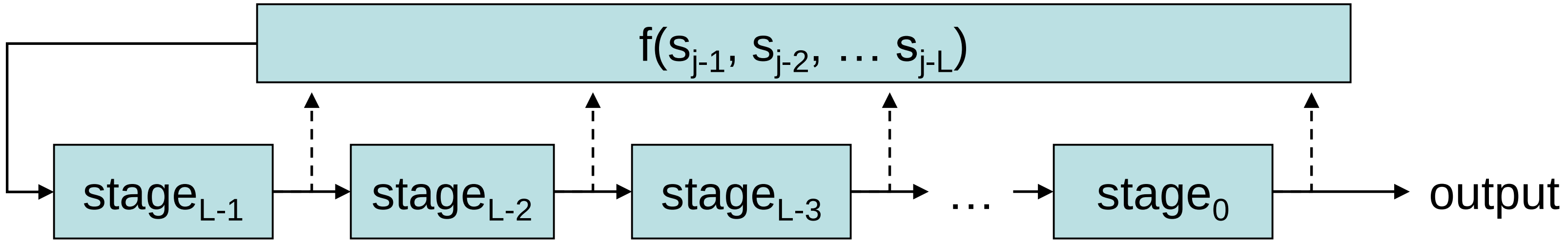


Maximum length LFSR

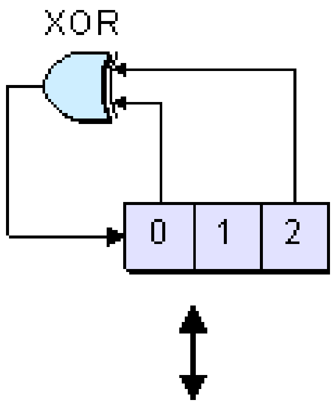
- LFSRs are periodic, since states are finite
  - Maximum length LFSR
    - Maximum length LFSR if it produces an output with period 2^{L-1}
  - Linear complexity
    - Linear complexity of s_n – denoted as $L(s_n)$ – is the shortest LFSR that produces a sequence having s_n as its first outputs

Nonlinear Feedback Shift Registers

- Feedback is any function of the stages
- No theory, how to create long periods!

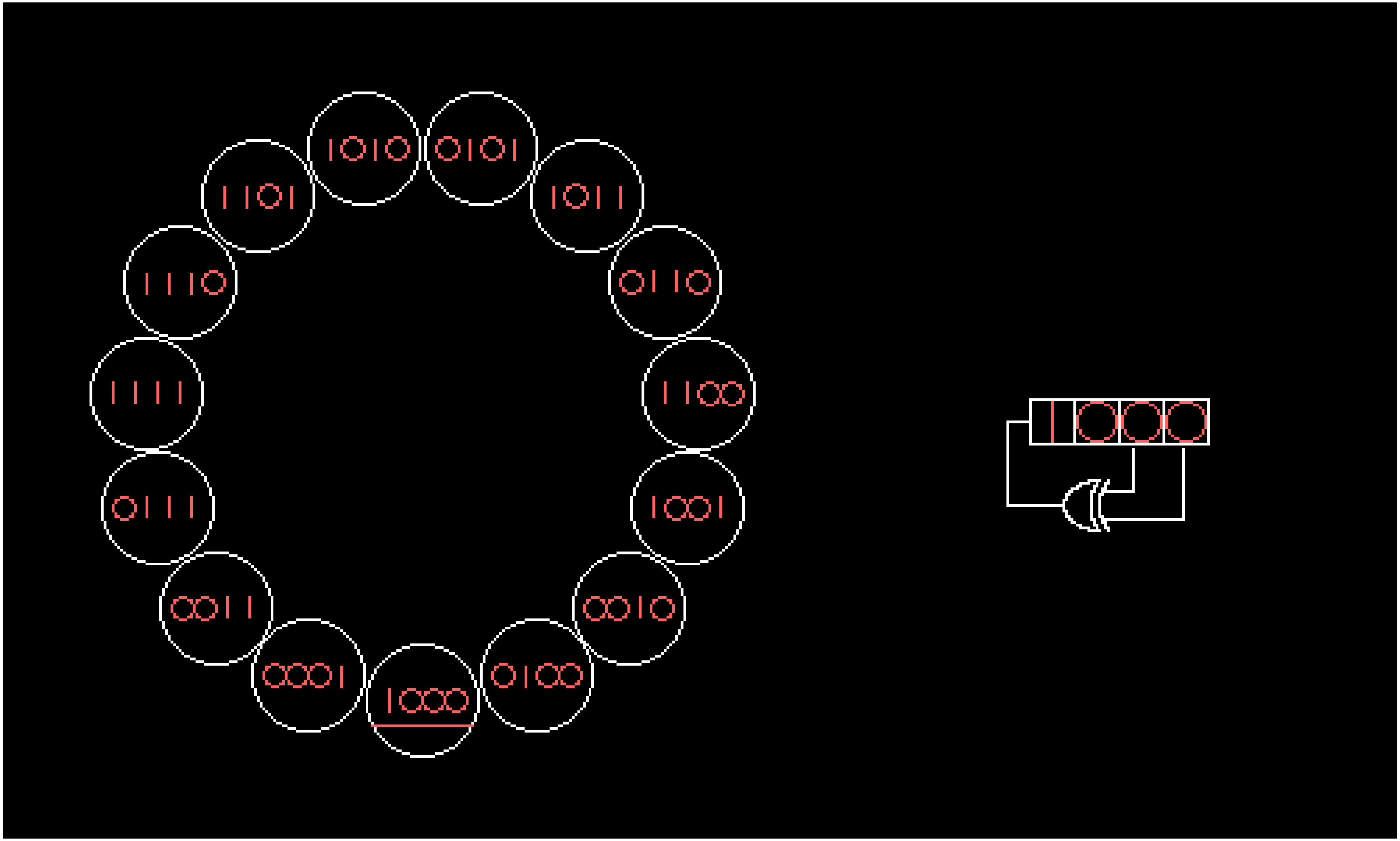


LFSR example



Clock	q0	q1	q2	
--	0	0	1	← Initial value
1	1	0	0	
2	1	1	0	
3	1	1	1	
4	0	1	1	
5	1	0	1	
6	0	1	0	
7	0	0	1	
8	1	0	0	
9	1	1	0	
:	:	:	:	

# of Bits	Length of Loop		Taps
2	3	*	[0,1]
3	7	*	[0,2]
4	15		[0,3]
5	31	*	[1,4]
6	63		[0,5]
7	127	*	[0,6]
8	255		[1,2,3,7]
9	511		[3,8]
10	1,023		[2,9]
11	2,047		[1,10]
12	4,095		[0,3,5,11]
13	8,191	*	[0,2,3,12]
14	16,383		[0,2,4,13]
15	32,767		[0,14]
16	65,535		[1,2,4,15]
17	131,071	*	[2,16]
18	262,143		[6,17]
19	524,287	*	[0,1,4,18]
20	1,048,575		[2,19]
21	2,097,151		[1,20]
22	4,194,303		[0,21]
23	8,388,607		[4,22]
24	16,777,215		[0,2,3,23]
25	33,554,431		[2,24]
26	67,108,863		[0,1,5,25]
27	134,217,727		[0,1,4,26]
28	268,435,455		[2,27]
29	536,870,911		[1,28]
30	1,073,741,823		[0,3,5,29]
31	2,147,483,647	*	[2,30]
32	4,294,967,295		[1,5,6,31]

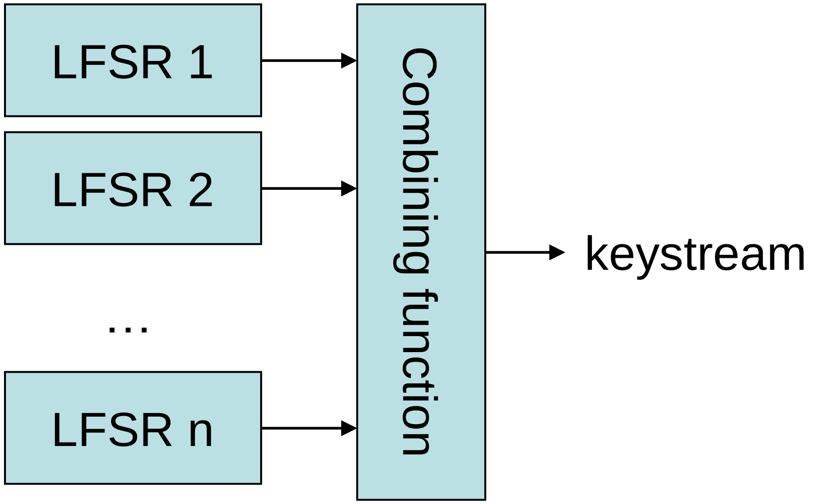

1010
0101
1101
1011
1110
0110
1111
1100
0111
1001
0011
0010
0001
1000
0100
1000

FSR based stream ciphers

- LFSR output is easily predictable
- To make the keystream secure:
  - Use nonlinear combination of LFSRs outputs
  - Use nonlinear filtering function on the LFSR output
  - Use LFSR output to clock more LFSRs
- Role of the key
  - Known LFSR connection: the key is the initial state of the LFSR(s)
  - Secret LFSR connection: the key is both the initial state of the LFSR(s) and the connection of the LFSRs
    - More security
    - More complex hardware

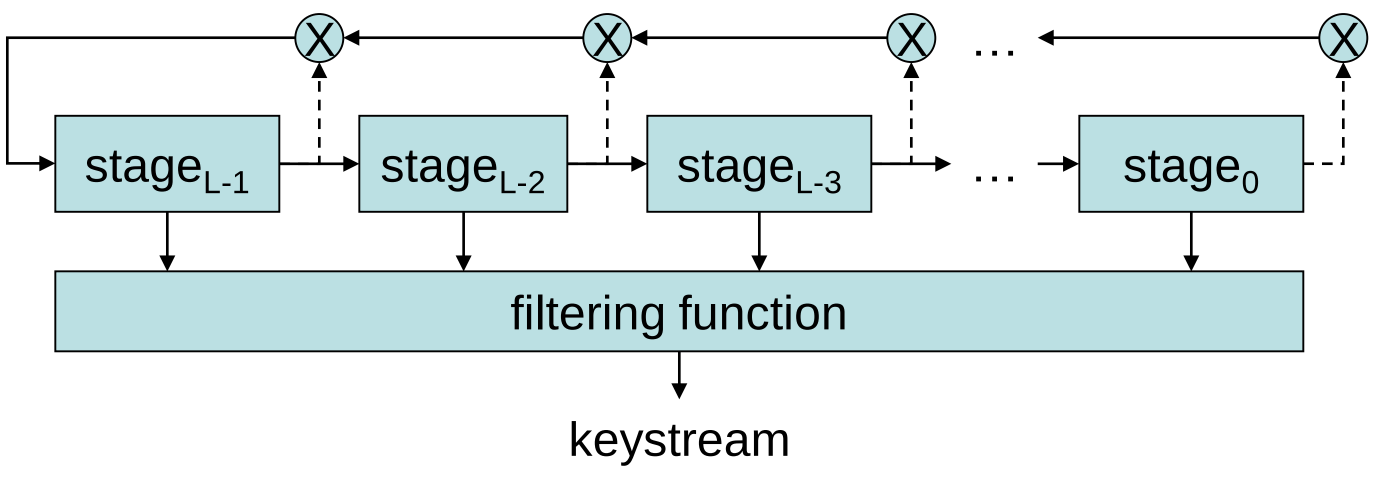
Nonlinear LFSR combinations

- Keystream is the nonlinear function of the LFSR outputs
  – Combining function



Nonlinear filtering function

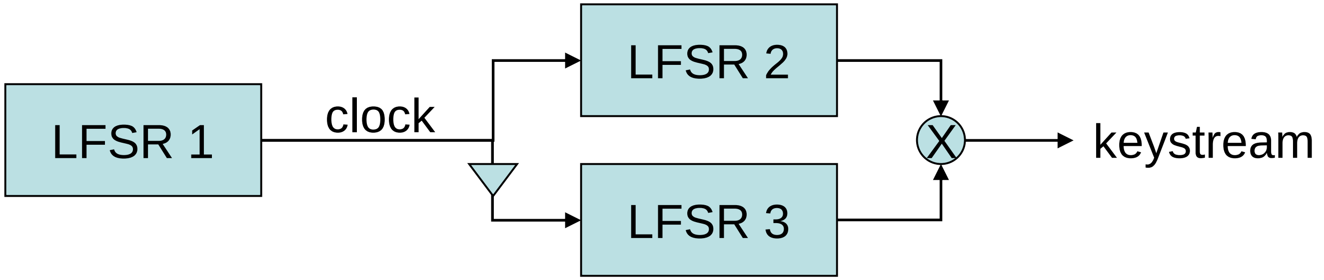
- Keystream is a nonlinear combination of the states
  - Filtering function



Clock-controlled generators

- Alternating step generator

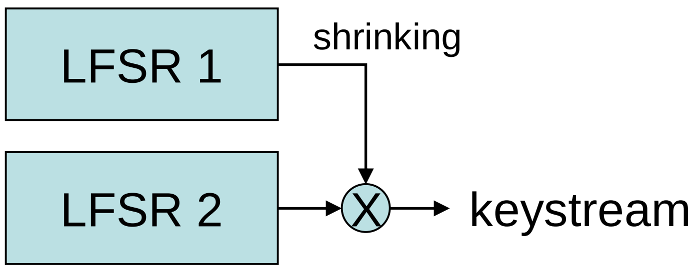
- Security
  - Maximum length LFSRs L_1, L_2, L_3
  - L_1, L_2 and L_3 pairwise relatively prime
  - $L_1 \approx L_2 \approx L_3 \approx l$
  - Best known attack: 2^l steps



Clock-controlled generators 2.

- Shrinking generator

- Security
  - Maximum length LFSRs: L_1, L_2
  - L_1 and L_2 are relatively prime
  - Output period: $(2^{L2-1})\cdot 2^{L1-1}$
  - $L_1 \approx L_2 \approx l$
  - Secret connections
  - Best known attack: 2^{2l} steps



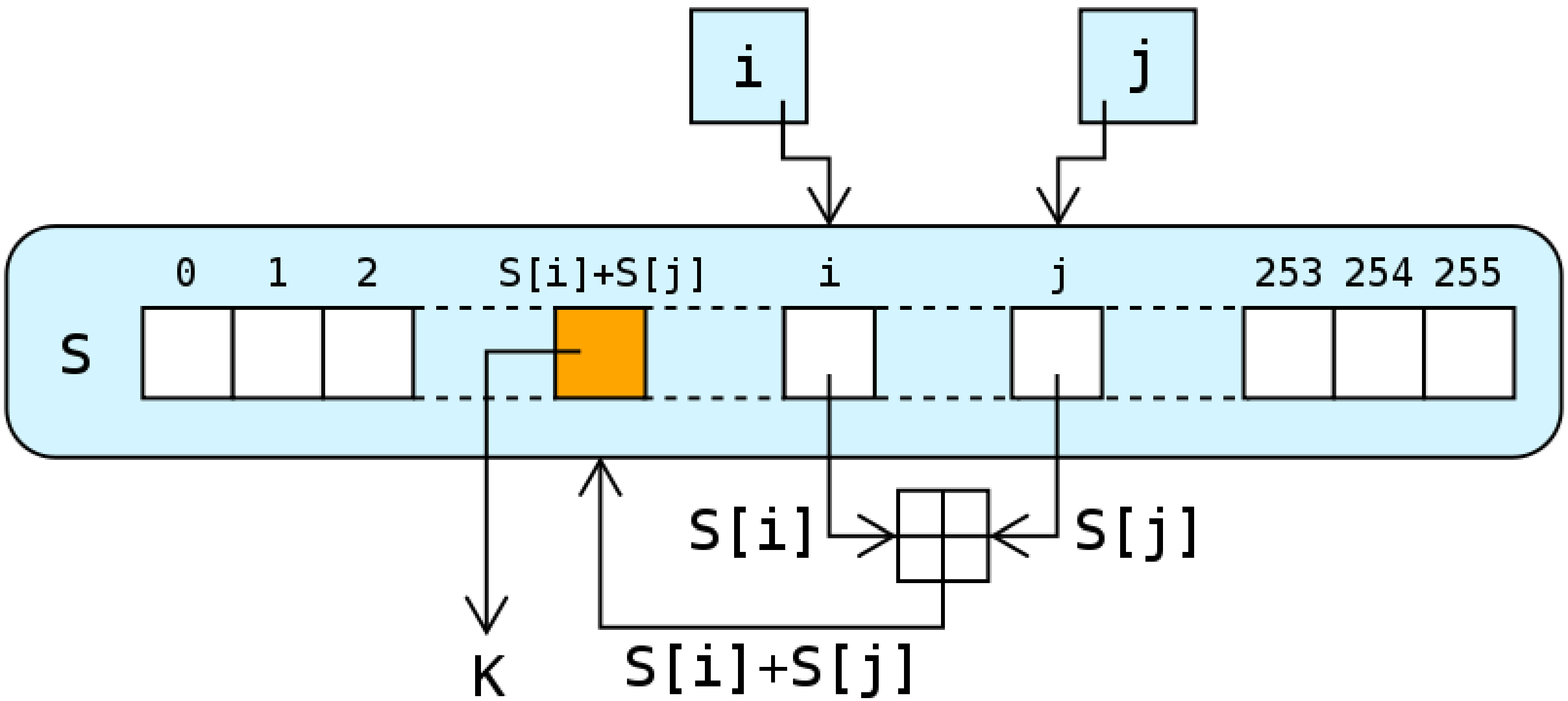
If shrinking = 0 then discard LFSR 2 output

Software stream ciphers

- FSR based ciphers are for hardware ciphers, but not good for software ciphers
- There is a need for a fast software cipher
  - SEAL – Software Optimized Encryption Algorithm
  - RC4 – Ron's Code 4
    - SSL, TLS, WEP, TKIP
  - Block ciphers with OFB, CFB modes of operation

RC4 cipher

- RC4 – Ron's Code 4



RC4 code

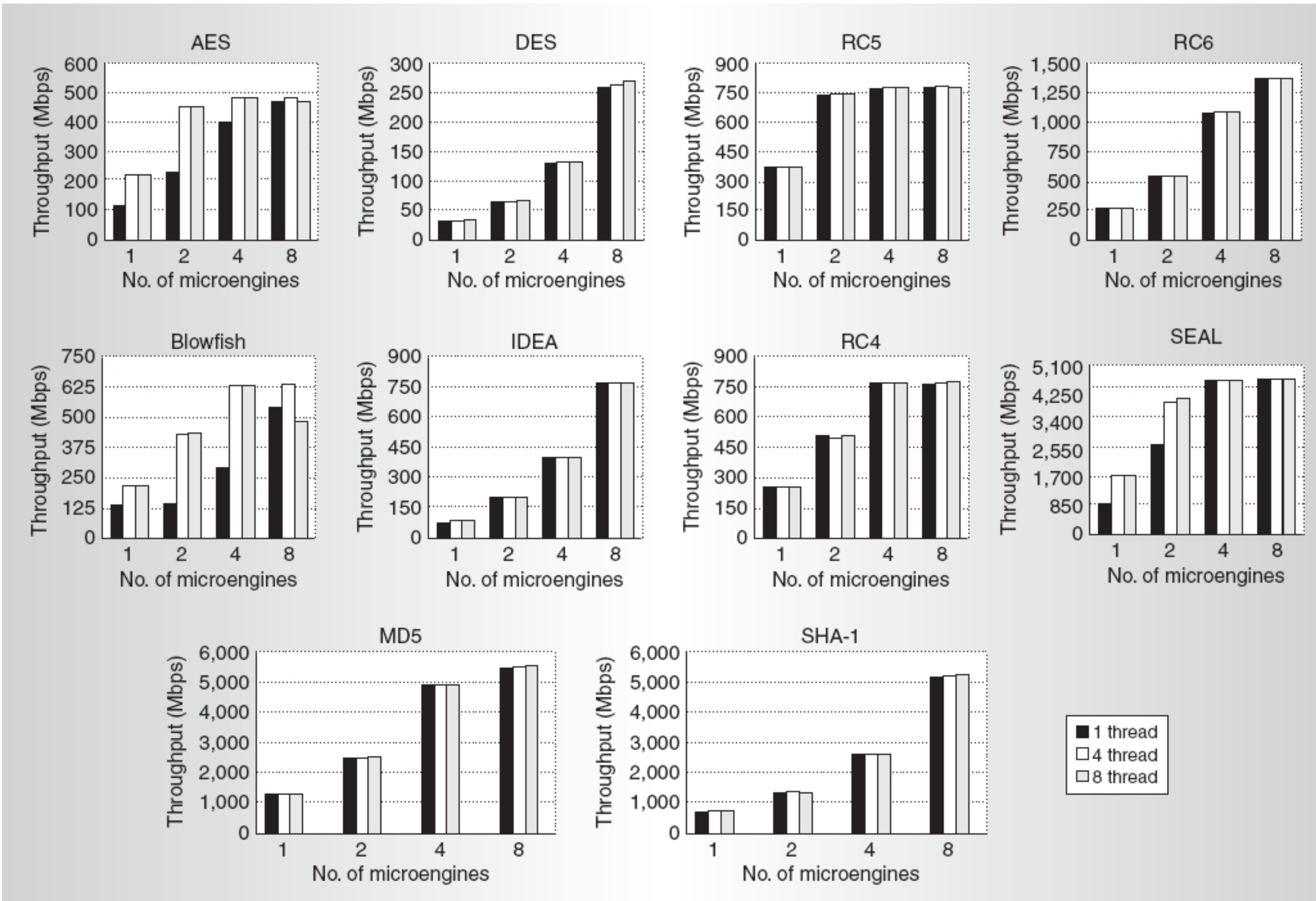
- Initialization

```
for i = 0 to 255:
  S_i = i
j = 0; for i = 0 to 255:
  j = (j + S_i + K_{i mod l}) mod 256
  swap S_i, S_j
```

- Keystream generation

```
i = (i + 1) mod 256
j = (j + S_i) mod 256
swap S_i, S_j
Out = S[(S_i + S_j) mod 256]
```

Speed of ciphers



Zhangxi Tan, Chuang Lin, Hao Yin and Bo Li: OPTIMIZATION AND BENCHMARK OF CRYPTOGRAPHIC ALGORITHMS ON NETWORK PROCESSORS

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