MORUS

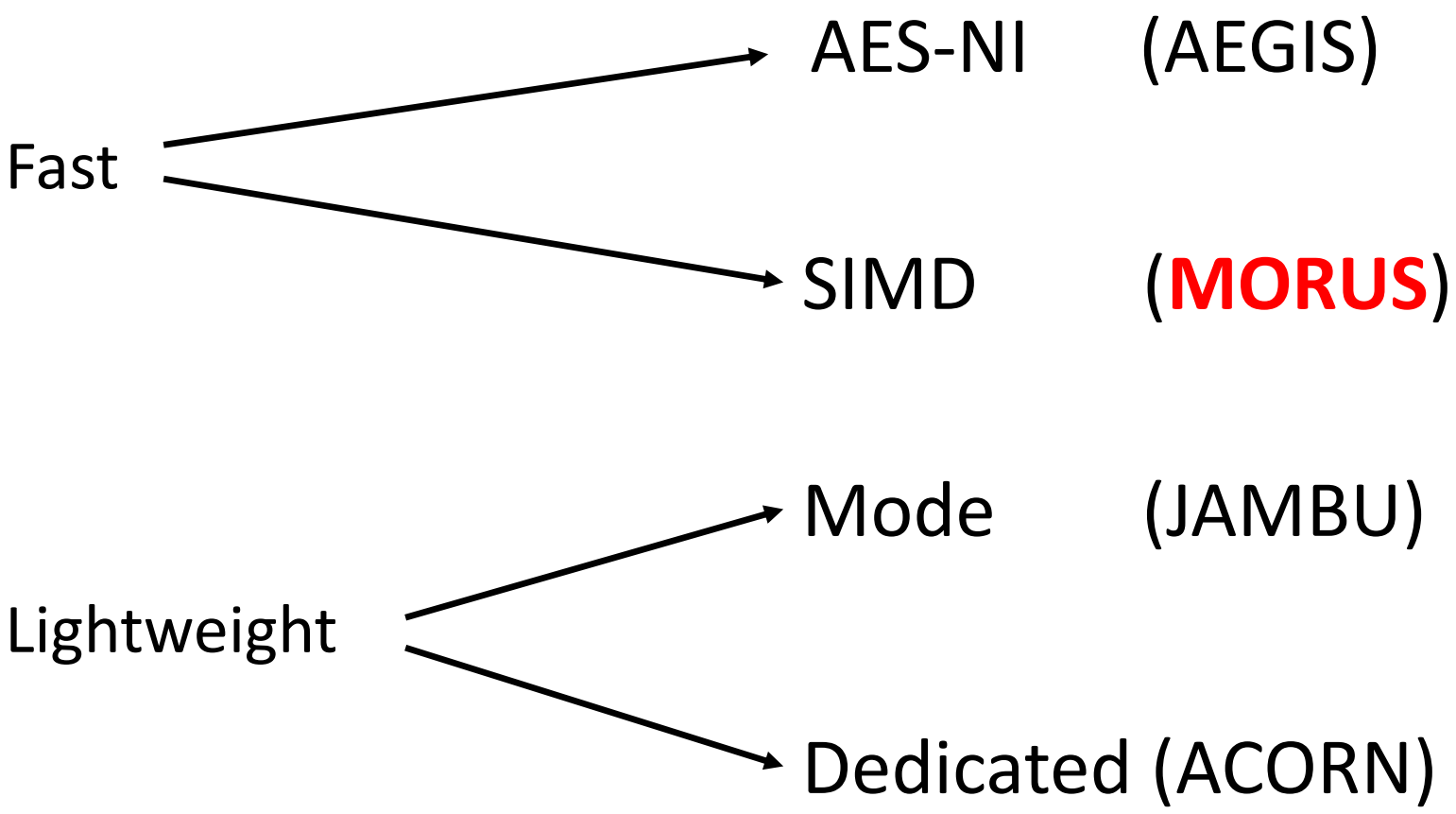
A Fast Authenticated Cipher

Hongjun Wu **Tao Huang**

Nanyang Technological University

MORUS

Different Design Approaches:



MORUS: Main features

- Fast
  - MORUS-1280 is **0.69 clock cycles/byte** on Haswell
  - **The only CAESAR candidate** which is not based on AES-NI, but faster than AES-GCM on Haswell
  - **Likely the fastest** CAESAR candidate on the processors with SIMD (SSE2, AVX2) instructions, but no AES-NI
- Nonce-based

Design software-efficient ciphers

Two general methods for designing software efficient ciphers

- Method 1:
  - reduce the number of computations in the design
- Method 2:
  - use operations that can be computed fast on CPUs

Design software-efficient ciphers

- Method 1:
  - reduce the number of computations in the design

- How to design a cipher using Method 1?
  - Method 1a: Proper security margin (should not be too large)
    (the designers should/can analyze the security of the ciphers)
  - Method 1b: Typically stream cipher requires much less operations than block cipher (anyway, block cipher more robust than stream cipher)
  - Method 1c: Efficient design
    Example: how to achieve high security with less operations ….

Design software-efficient ciphers

- Method 2:
  - use operations that can be computed fast on CPUs

- Some efficient operations on CPUs:
  - SIMD (single instruction multiple data)
    - SSE2: 128-bit registers (**available on many CPUs**)
    - AVX2: 256-bit registers (available on the latest Intel Haswell CPUs)
  - AES-NI (AES new instruction set)
    - The design of AEGIS

Design software-efficient ciphers

- Design efficient ciphers using SIMD instructions
  - Salsa (stream cipher using 128-bit SSE2 instructions, 2005)
  - Blake, JH (hash functions using 128-bit SSE2 instructions, 2008)
  - MORUS, NORX (authenticated ciphers using 256-bit AVX2 instructions, 2014)

MORUS: Design

- MORUS is a fast software cipher
  - Encryption: stream cipher
  - Authentication: almost for free
  - Use SIMD instructions

MORUS: Design

- MORUS-1280-128: 1280-bit state, 128-bit key
- MORUS-1280-256: 1280-bit state, 256-bit key
- MORUS-640-128: 640-bit state, 128-bit key

- Tag: 128-bit

- MORUS-640 benefits from 128-bit SIMD instructions
- MORUS-1280 benefits from 128/256-bit SIMD instructions

MORUS: Design

- MORUS-1280 (128-bit/256-bit key):

  The cipher state consists of five 256-bit words

  XOR, AND, SHIFT operations are used

- In each step,

  5 rounds are used to update the state, and

  256-bit keystream word is generated

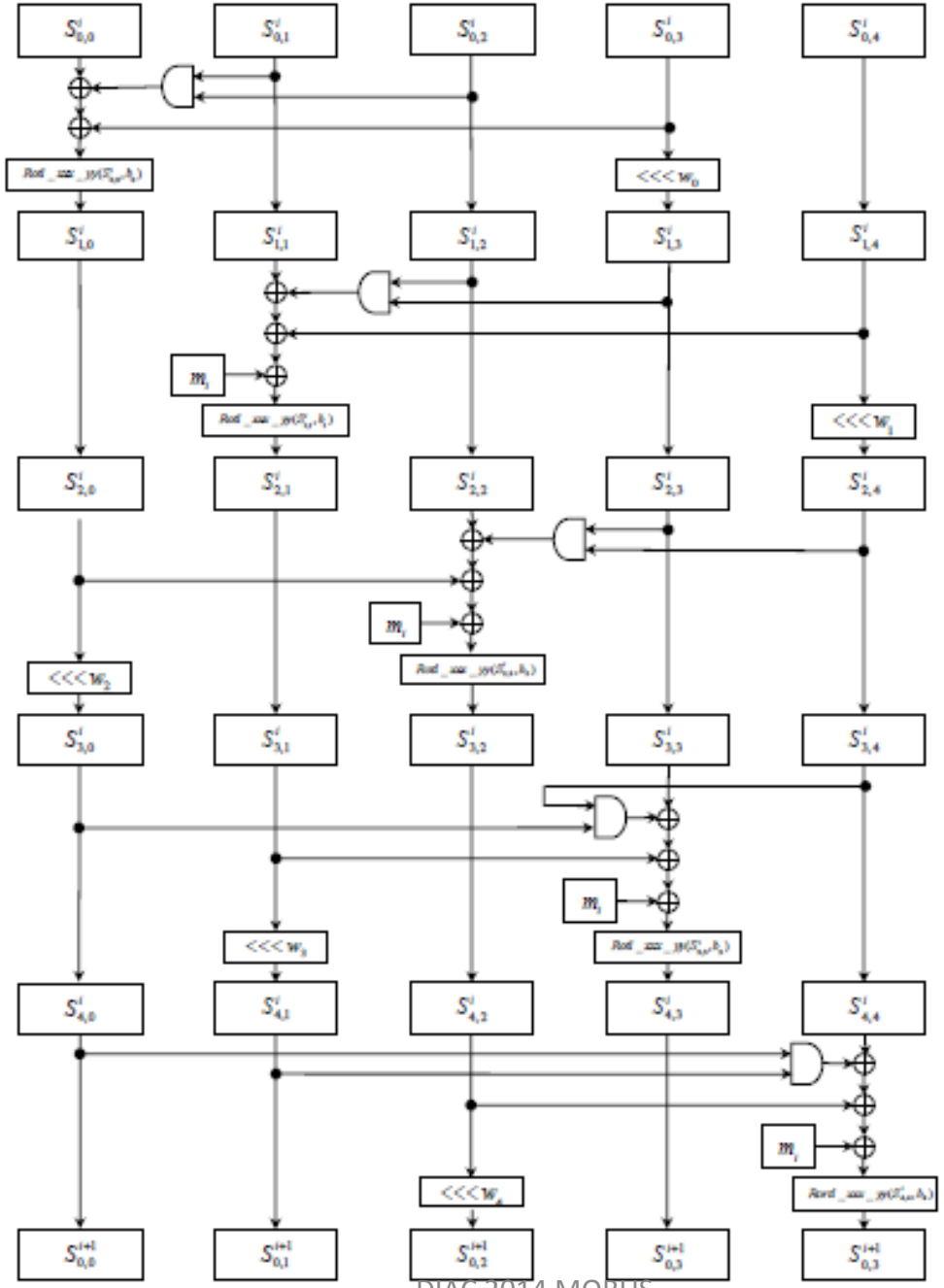
MORUS: Design

- MORUS-640 (128-bit key):

  The cipher state consists of five 128-bit words
- Each step consists of 5 rounds, and

  128-bit keystream word is generated

The state update of MORUS in one step: 5 rounds



MORUS: Design

- Initialization
  - 16 steps
  - key XORed to the state at the end of the initialization

- Finalization
  - 8 steps
  - Part of secret state and length (ad, message) are used to update the state in finalization
  - Generate 128-bit tag from the state

MORUS: Security

- We analyzed differentials involving the low weight input differences
  - The probability of state collision is much less than 2^{-128} (it is tremendously difficult to eliminate the difference in the state)
- The high weight input differences likely lead to even lower probability of state collision

MORUS: Performance

Speed on Haswell

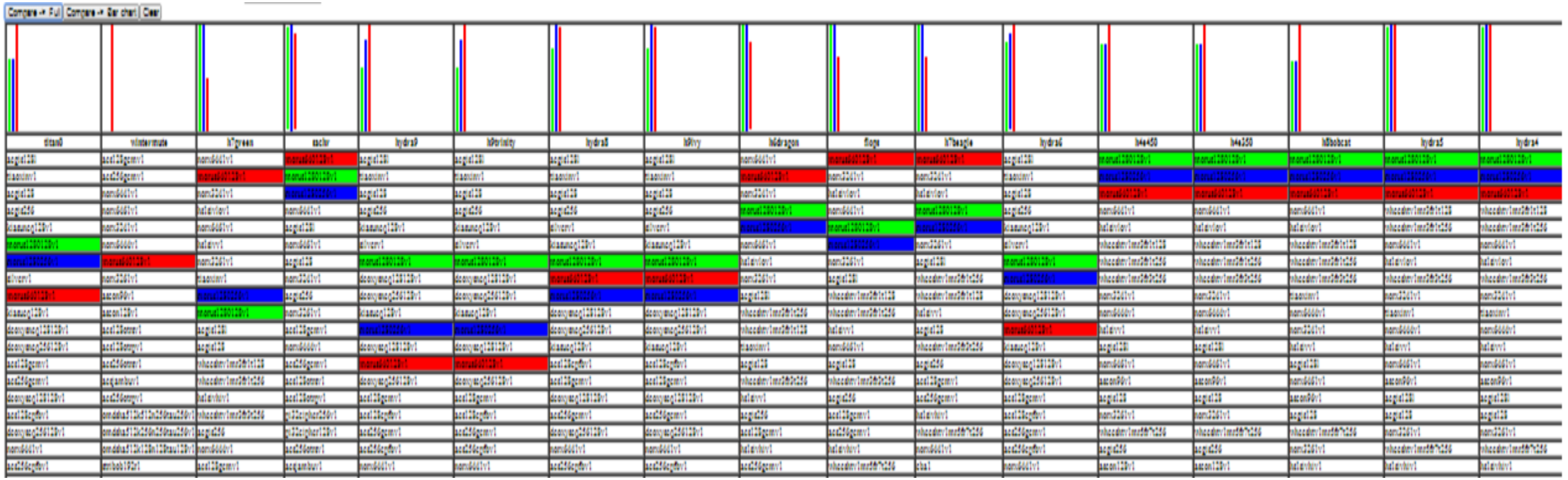
	16B	64B	512B	1024B	4096B	16384B
MORUS-640(EA)	28	7.72	1.95	1.58	1.18	1.11
MORUS-640(DV)	28	7.99	1.97	1.56	1.23	1.16
MORUS-1280(EA)	33.9	8.28	1.59	1.12	0.78	0.69
MORUS-1280(DV)	35.8	8.46	1.63	1.13	0.80	0.69

MORUS-640 is slower since it uses only 128-bit SIMD

AES-128-GCM: 1.03

MORUS: Performance

- MORUS is likely the fastest on the platforms with SIMD but no AES-NI
  - Reason 1: MORUS benefits from SIMD
  - Reason 2: We carefully removed the redundant operations in the cipher



MORUS: Performance

- MORUS is expected to be very fast on hardware
  - Critical path is very short in each step (8XOR, 3AND)
  - 128-bit (256-bit) keystream is generated for MORUS-640 (MORUS-1280)

Conclusion

- MORUS benefits from SIMD
- Likely the fastest candidate on platforms with SIMD but no AES-NI