Workload Characterization of Elliptic Curve Cryptography and other Network Security Algorithms for Constrained Environments

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Need for Security?

- Wireless devices: PDAs, multimedia cell phones, tablet PCs ...
  - Public channel = need for cryptography
  - Limited processing power, memory, power

Class	Function
Public-key	Key exchange, user authentication, digital signature
Symmetric-key	Confidentiality
Hash	Integrity

Algorithm Set

Class	Typical key size	Examples
Public-key	1024 – 2048 bits (non-elliptic curve)	**Diffie-Hellman**, ElGamal, DSA
	163 – 233 bits (elliptic curve)	
Symmetric-key	128 – 256 bits	DES, AES
Hash	N/A	SHA, MD5

- Diffie-Hellman is representative of other elliptic-curve algorithms.

Diffie-Hellman on Elliptic Curves

- E is an elliptic curve, P = (x,y) is a point on E.

Alice		**Bob**
Choose a.		Choose b.
$P \times a$		$P \times b$
$(P \times b) \times a$		$(P \times a) \times b$

Based on elliptic-curve discrete logarithm problem

Point Multiplication

- $P \times a$ is point multiplication. The result is **another point** on the elliptic curve.
- Computed by a double-and-add chain
  - No easy way to compute any arbitrary multiple of P.
- <u>Example</u>: if $a = 13$, then:

$$P \times 13 = [(2 \times P + P) \times 2 \times 2] + P$$

Point Doubling and Addition

P = (x,y) P × 2 = (x_f,y_f)	P = (x_1,y_1), Q = (x_2,y_2) P + Q = (x_3,y_3)
$\theta = x + \frac{y}{x}$ $x_f = \theta^2 + \theta + a$ $y_f = x^2 + (\theta + 1)x_f$	$\theta = \frac{y_2 + y_1}{x_2 + x_1}$ $x_3 = \theta^2 + \theta + x_1 + x_2 + a$ $y_3 = \theta(x_1 + x_3) + x_3 + y_1$
4 addition, 2 multiplication, 2 squaring, 1 inversion	9 addition, 2 multiplication, 1 squaring, 1 inversion

Binary Fields

- Coordinates of P=(x,y) come from a field.
- Fastest implementations are on binary fields.
  - Field elements = binary polynomials
- <u>Example</u>:

$$P = (x+1, x^2+1) = (0011,0101)_2$$

ECC and Polynomial Operations

Point doubling	Point addition
4 addition, 2 multiplication, 2 squaring, 1 inversion	9 addition, 2 multiplication, 1 squaring, 1 inversion

Addition	Multiplication	Squaring	Inversion
XOR	Shift-and-add Table-lookup Polynomial multiplier	Self-multiplication Table-lookup New instructions	Extended Euclidean Almost Inverse

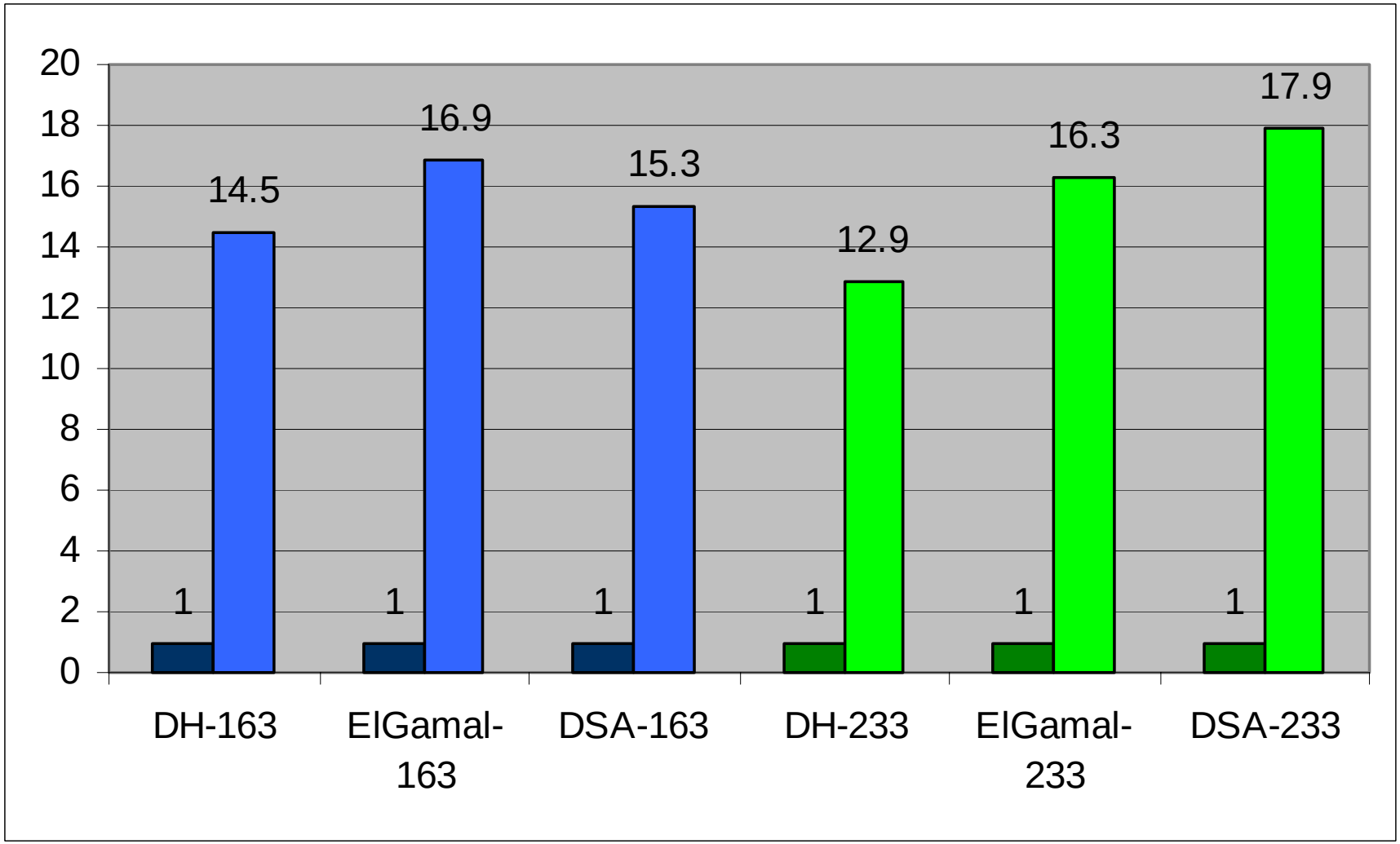
Orange: basic

Green: optimized

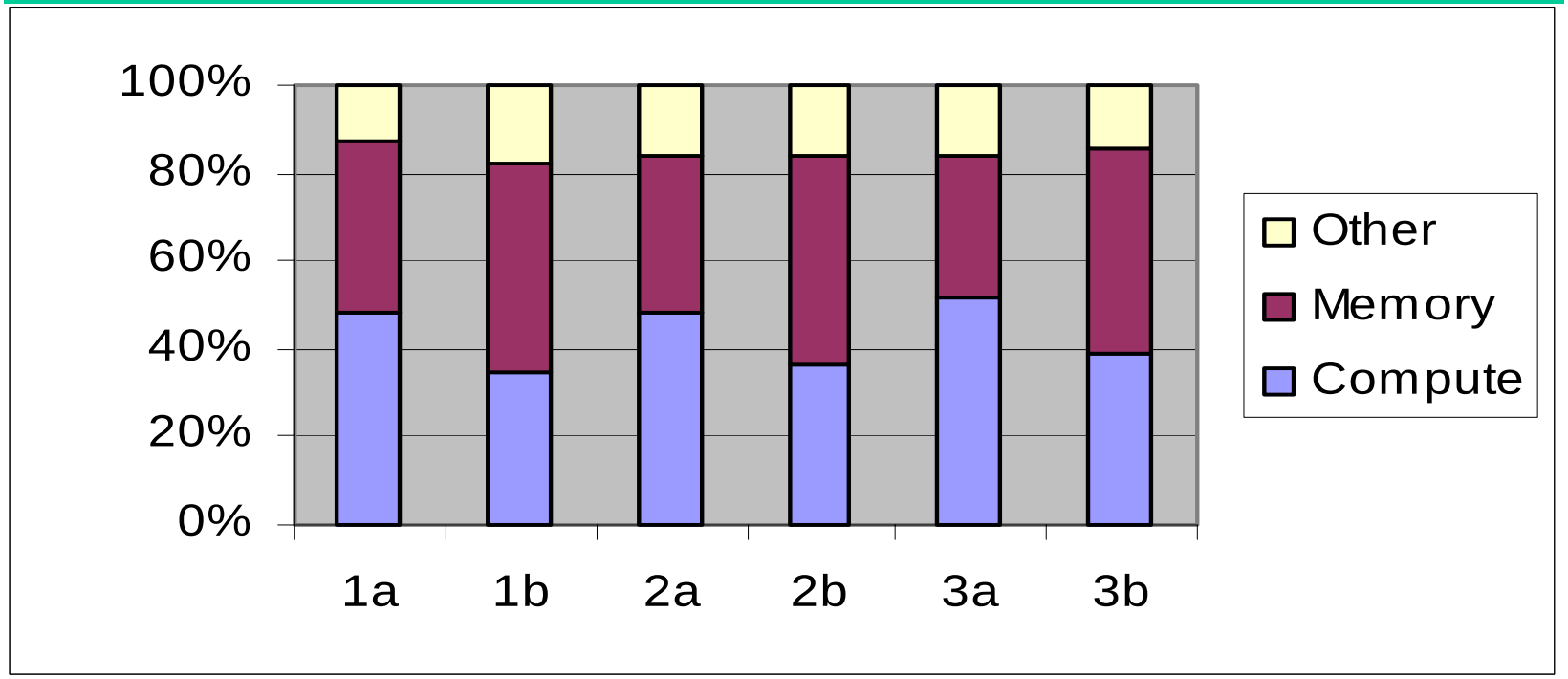
Methodology

- Algorithms coded and optimized in assembly
- 64-bit basic RISC architecture
- Simulated using two algorithm sets: basic and optimized
- 163-bit and 233-bit keys
- Diffie-Hellman, ElGamal, DSA
- AES and SHA (for completeness)

Speedup From Optimized Algorithms



Instruction Distribution



1a. EC-DHKE basic (1.0)

1b. EC-DHKE optimized (14.5)

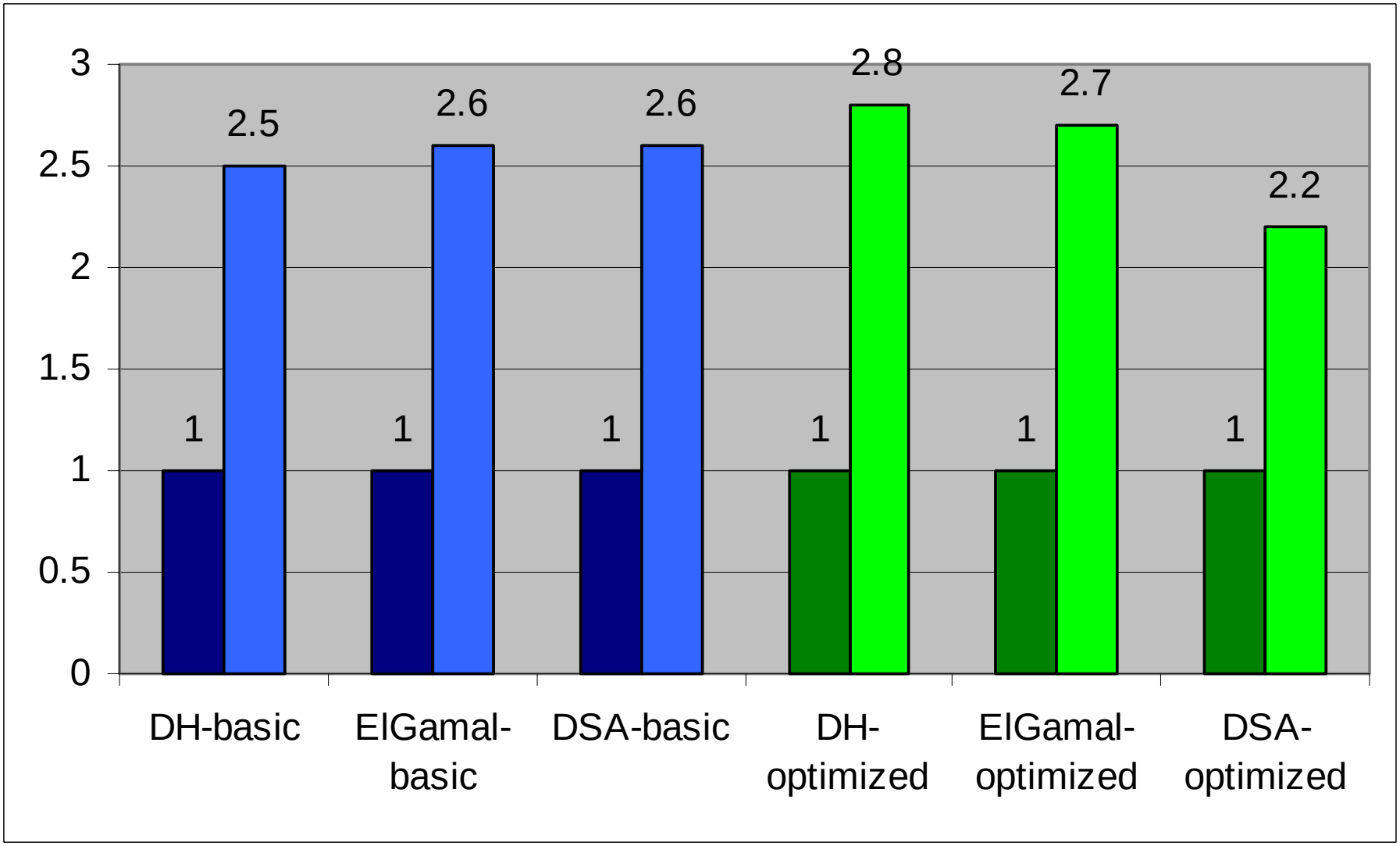
2a. EC-ElGamal basic (1.0)

2b. EC-ElGamal optimized (16.9)

3a. EC-DSA basic (1.0)

3b. EC-DSA optimized (15.3)

Pathlength Increase: From 163-bit to 233-bit keys



Observations

1. Algorithmic enhancements provide 15× speedup.
   - Mainly by reducing arithmetic operations (up to 30×)
2. Memory instructions are as frequent as compute instructions.
   - Reasons: Function call overhead, long data types
   - Further speedups possible based on memory optimizations (?)
3. Longer keys result in disproportionately large slowdowns.
   - Complexity of ECC operations
4. DH and ElGamal have similar distributions.
   - DSA is different; includes SHA as hash algorithm.
5. Optimized algorithms use little extra memory (<1kB).
6. A separate multiplier is not needed.

Summary

1. Selection of algorithms suitable for constrained environments:
   - Elliptic-curve versions of DH, ElGamal, and DSA; AES and SHA
2. Description of operations needed; focus on elliptic-curve and polynomial operations
3. Instruction frequencies
4. Sufficiency of a simple RISC processor

Future Work

- Expand algorithm set
  - Include block ciphers, other signature and hash algorithms
- Expand arithmetic operations to
  - Integers (prime fields)
  - Different representation of polynomials (different bases)
  - Different coordinate systems (e.g. projective)