Optimizing AES for Embedded Devices and Wireless Sensor Networks

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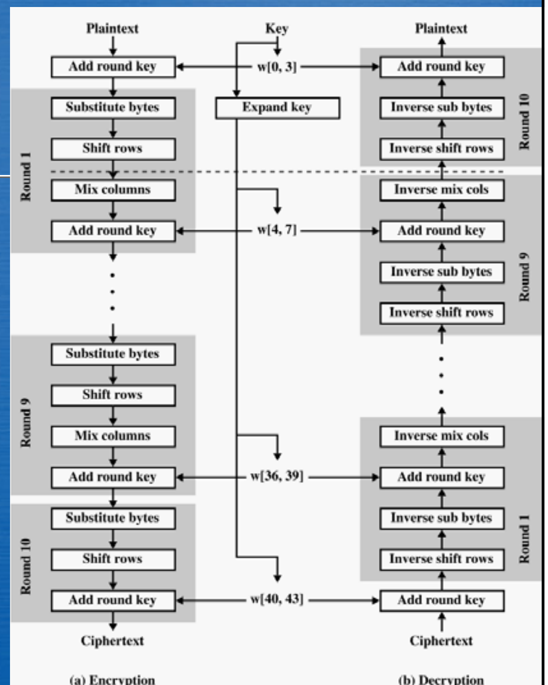
Goals

- Software-based AES-128 at Zigbee bitrate (250 kbps)
- Minimal code space (ROM) and memory usage (RAM)
- 16-bit, 8MHz microcontroller platform: MSP430
- Written in C for maximum portability

AES Review

- 10 rounds:
  - Substitute bytes
  - Shift rows
  - Mix Columns
  - Add round key
- Can pre-compute round keys or compute on-the-fly



AES Review - 2

- Encryption:
  - SubBytes: look-up table
  - ShiftRows: rotate bytes in each of 4 “rows”
  - MixColumns: matrix multiplication in GF(2^8)
  - AddRoundKey: XOR with round key
- Key Expansion:
  - SubWord: same as SubBytes, but operates on key
  - RotWord: cyclical byte-level shift

Brian Gladman's Reference

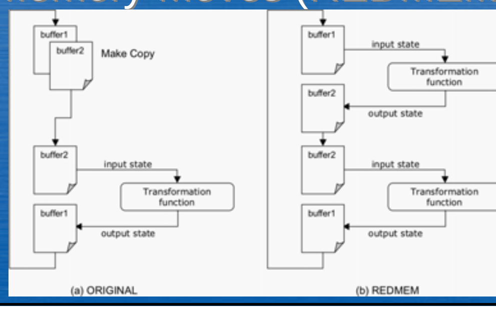
- Included with initial AES proposal
- "Low-resource"
  - All math reduced to XOR and Look-up Tables
  - Combines MixColumns with SubBytes
  - Combines MixColumns with ShiftRows
  - Tuning options:
    - HAVE_MEMCPY: uses built-in memcpy
    - HAVE_UINT32: allows 32-bit data types
    - VERSION_1: uses local buffers in functions instead of pointers

Optimization

- -O3 option to GCC
  - unpredictable effect on some manual optimizations
  - All compiler optimizations on
- Specialization (SPECIAL)
  - limit to only AES-128
- Varying Data Type Size (DATASZ)
  - Allows up to 64-bit variables for XOR operations
- Function Inlining (INLINE)
  - Reduce overhead and stack size

Optimization - 2

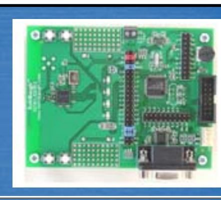
- Loop unrolling (UNROLL)
  - Common optimization to reduce loop index maintenance costs
- Reducing Memory Moves (REDMEM)



Optimization - 3

- Eliminate local buffers (LOCBUF)
  - Use pointers instead of copying
- Use of Global Key Schedule (GLOB)
  - Store round keys globally
- On-the-fly Key Generation (OTFK)
  - Recompute round keys as they are needed
- 16-bit Memory Writes in MixColumns
  - Change uint8_t buffers to uint16_t

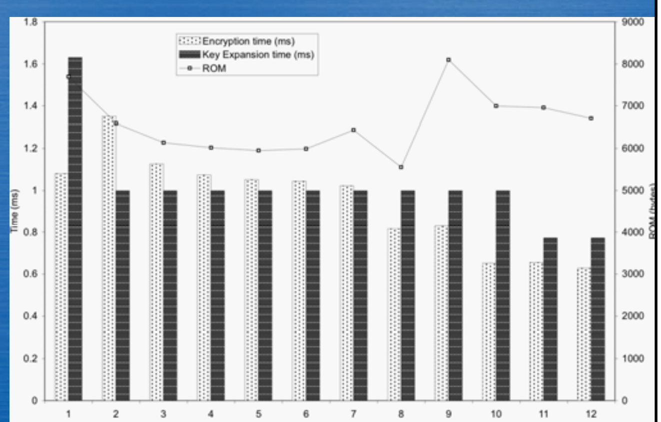
Experiment



- Softbaugh DZ1611 Zigbee Demo Board
- ROM (Code) Size
  - msp430-objdump
- RAM (Memory) Usage
  - msp430-gdb printing stack pointer
- Execution Time
  - Set I/O line on start, clear on end
  - Measure on oscilloscope

Results - Without -O3

- Version 12 is best:
  - SPECIAL
  - DATASZ(64)
  - INLINE
  - REDMEM
  - LOCBUF
  - GLOB



>> 200 Kbps

Results With -O3

- Version 12 is best:
  - SPECIAL
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  - REDMEM
  - LOCBUF
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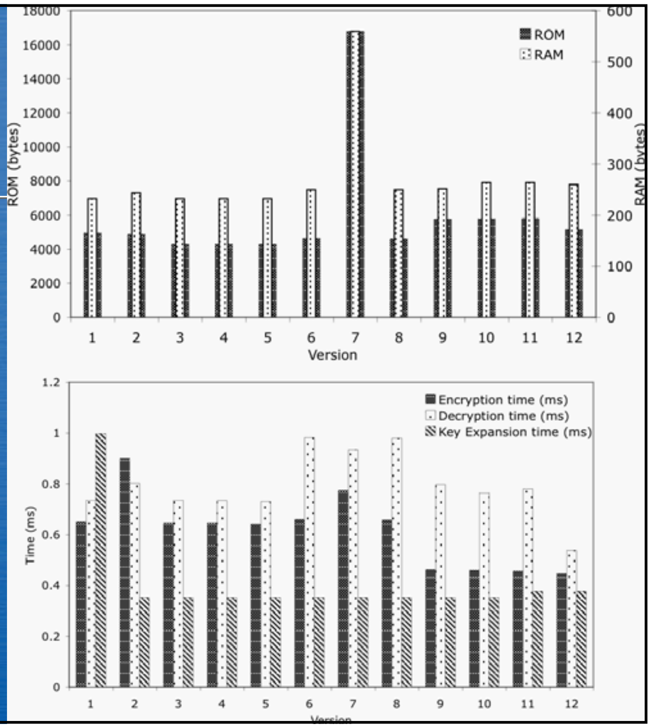
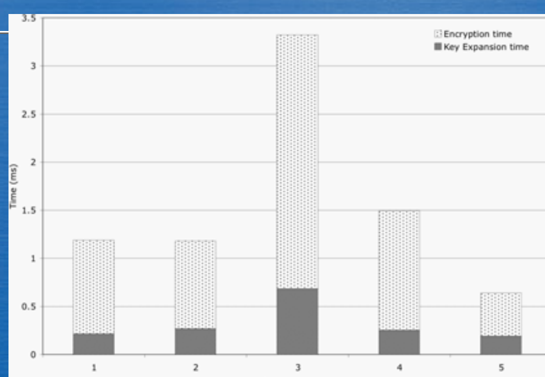
>> 286 Kbps!



Other Implementations

- Improved both speed and code size (RAM unknown)
- Note that our versions seem to have varied significantly from published numbers in some cases



Implementation	Reference paper	Measured ROM Usage	Published ROM Usage
1	[6]	5968 bytes	n/a
2	[12]	6780 bytes	12616 bytes
3	[14]	6848 bytes	3322 bytes
4	[10]	n/a	n/a
5	Our implementation	5160 bytes	n/a

Hardware AES

- As expected, performs much faster (579 kbps for standalone encryption)
- Complex, poorly documented for CC2420
- Offers standalone encryption, but not decryption
- "Stuck" with this chip: any future changes require change in hardware
- Used oscilloscope to time various operations:

Process	Time (μs)
Writing to the CC2420 RAM	94.40
Issuing the encrypt/decrypt command to the CC2420	6.40
Wait for encryption module to complete processing by requesting status byte	18.40
Read from the CC2420 RAM	102.40

Conclusion

- Catalogued ideal optimizations
- Measurement metrics
- Improvement over previous implementations

>> Final code runs at 286 Kbps with 5190 bytes ROM and 260 bytes RAM

Future Work

- Develop a full security suite in C for MSP430/CC2420 with AES-128 as core
- Perform similar optimizations for AES-256
- Deployment in safety and security applications at Purdue's Ross-Ade football stadium.