Remote Incremental Adaptation of Sensor Network Applications

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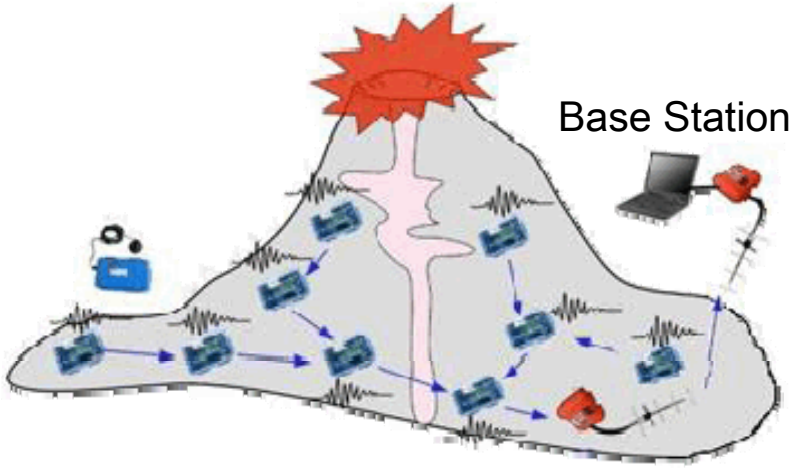
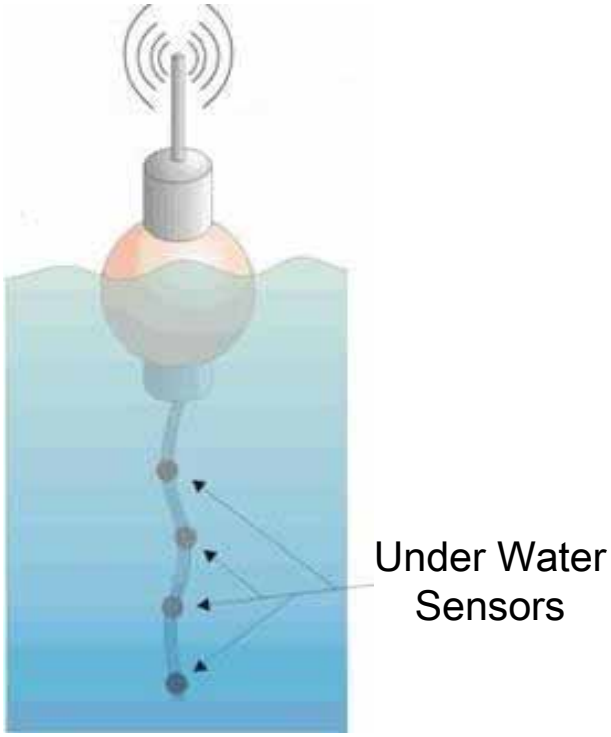
Distributed Systems

RWTH AACHEN UNIVERSITY

Motivation

- **WSN require uninterrupted operation indefinitely**
- **Customizing the system to the environment**
  - Feature upgrades
  - Retasking of the System
- **Post-deployment software updates are common**
  - Bug Removal





Sources of Images: http://www.eecs.harvard.edu/~mdw/proj/volcano/

Motivation – contd.

- **State of the art**
  - Image replacement
  - Virtual machines
  - Dynamic OS's

  Disadvantages:

  Energy wastage, Restricted reconfigurability, Clean slate approaches

  - TinyOS – A framework to generate application specific OS
    - Component based architecture
    - Select app components, statically analyze and optimize
    - Supports only full binary upgrades

- **Goals**

  Energy Efficient, Fully configurable, Integrated and Transparent, Fulfilling usual Embedded System Constraints

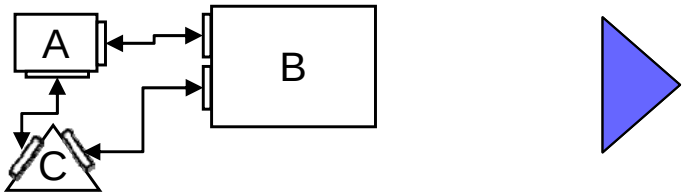
Outline

- Motivation
- **Strategy**
- **Architecture**
  - Overview
  - Components
  - Update Procedure
- **Evaluation**
  - Transfer cost
  - Update cost
- **Conclusion & Future Work**

TinyOS as a base

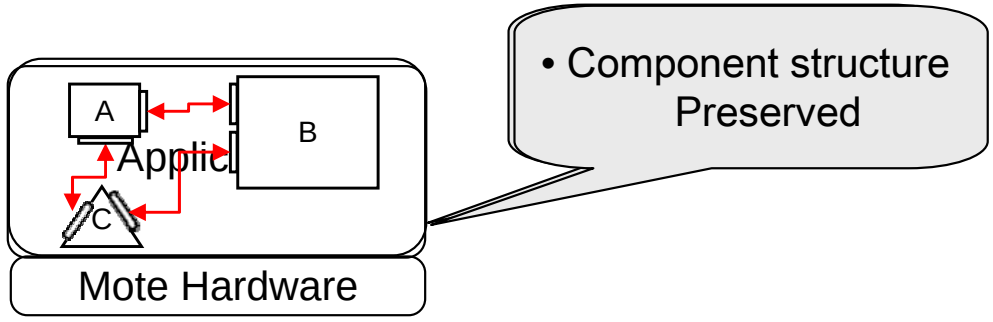
- Seasoned code repository
- Wide user base
- Runtime wiring

Mote Reconfiguration



Appropriate Components wired together

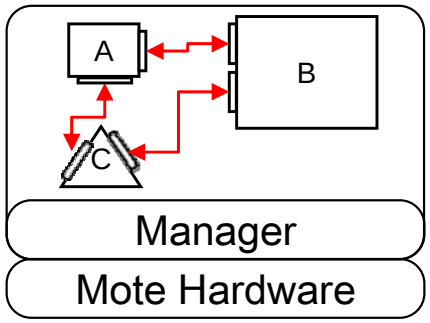
Compiled + Linked + Loaded



Mote reconfigured with a new Monolithic Binary

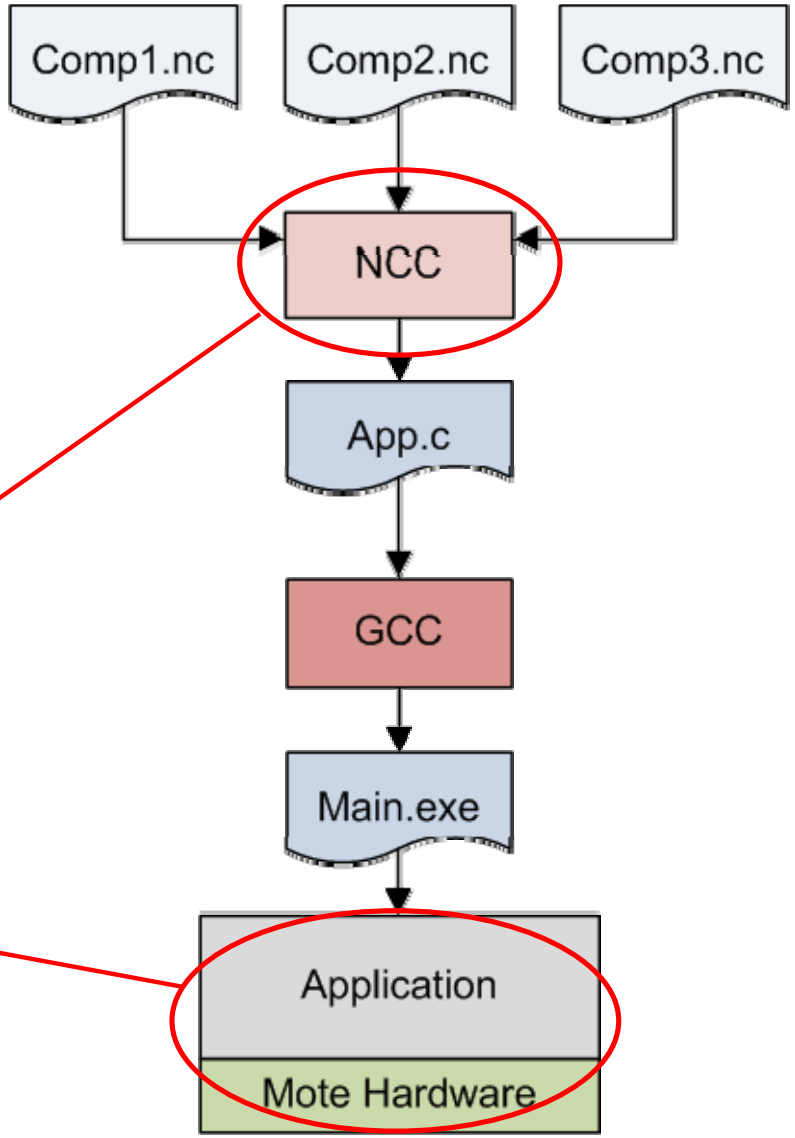
Architecture – Overview

Runtime Wiring



Required

- Isolate individual nesC components
- A runtime Manager/Linker

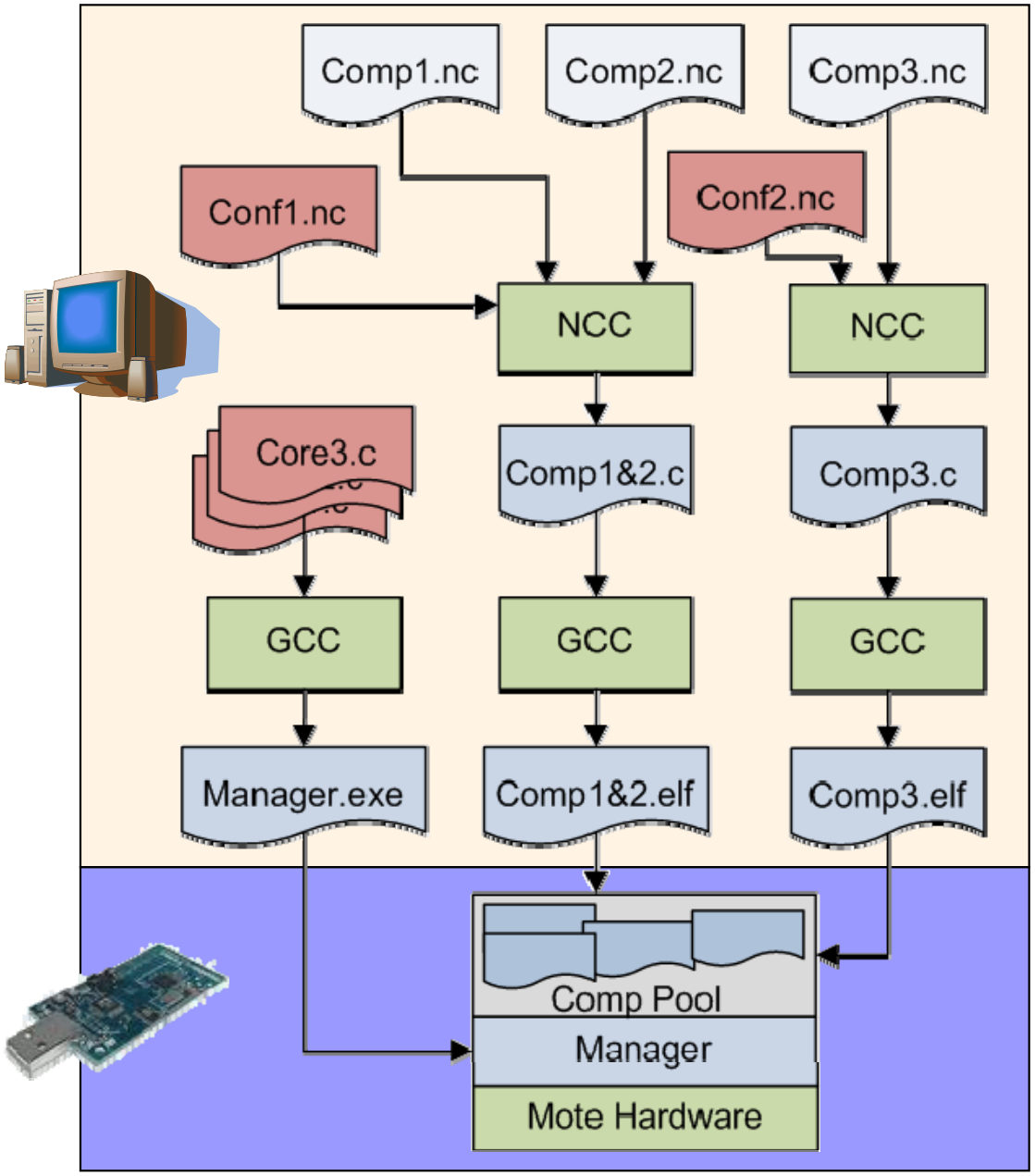


Traditional TinyOS Mote Reconfiguration Process needs modifications

Architecture – Overview contd.

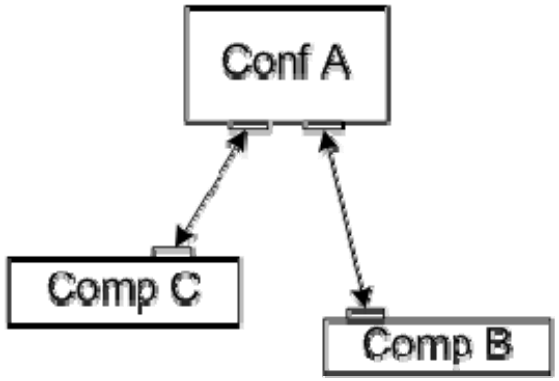
Main Components

- Host
  - Configuration Generator
- Mote
  - Manager (TinyMan)
    - Linker
    - Memory Manager
    - Interrupt Router
    - File System Controller
    - Global Symbol Table

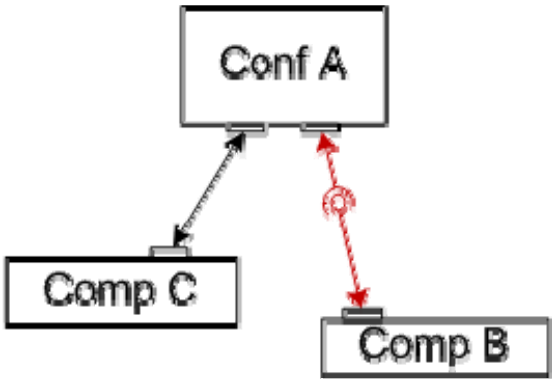


Configuration Generator

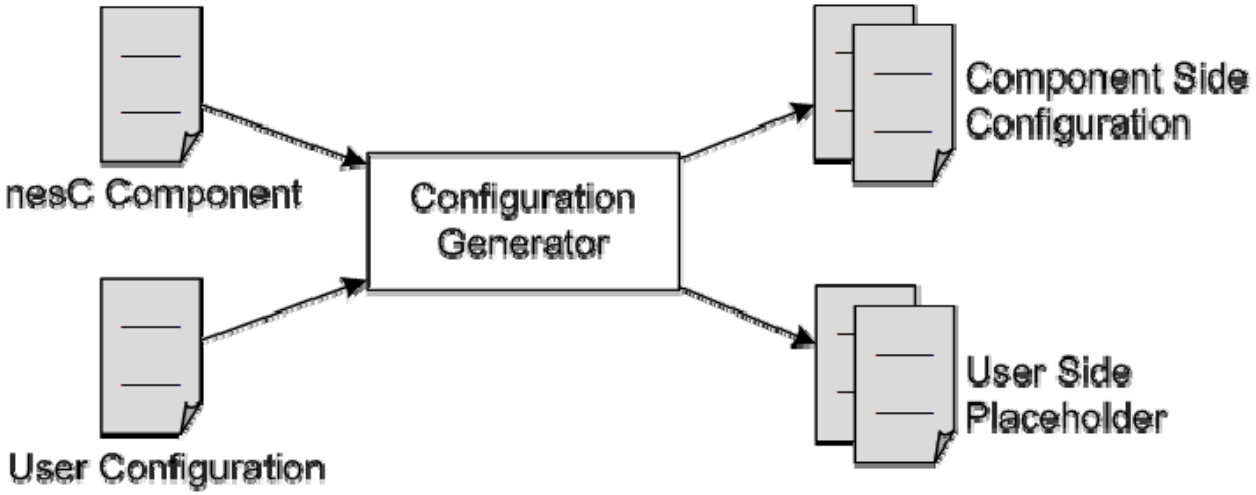
- Disambiguates NCC's operation



A Normal TinyOS app



Separately compiled TinyOS app

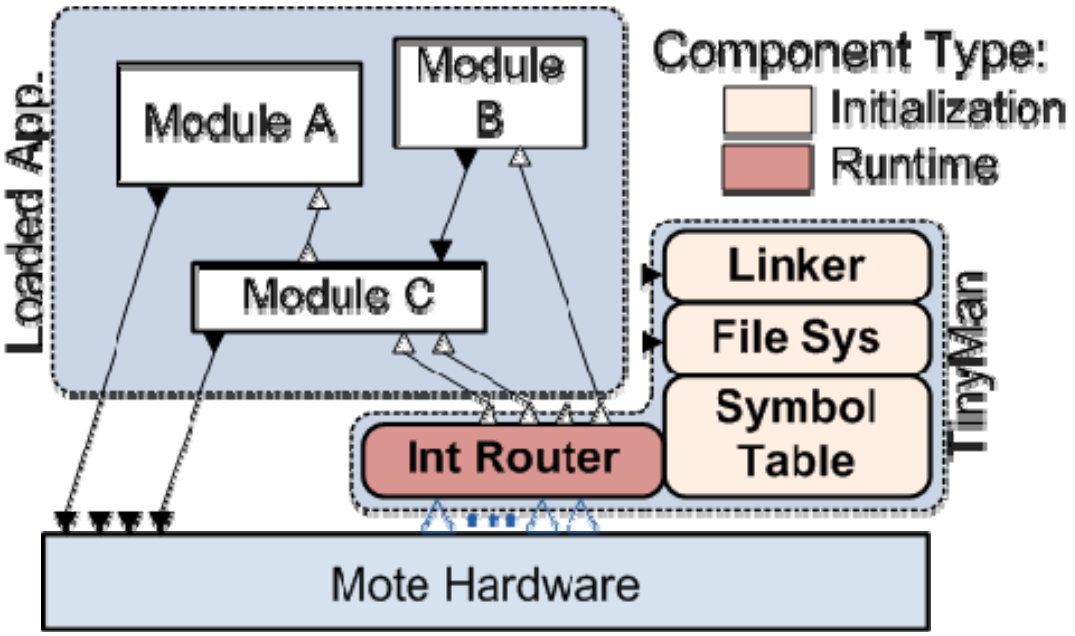


Architecture – Mote

TinyMan

- Linker
  - Memory Manager: Manages allocation of internal flash
  - Loader: loads the linked Objects into program memory
- Interrupt Router

  Reroutes interrupts to the functions registered as ISRs

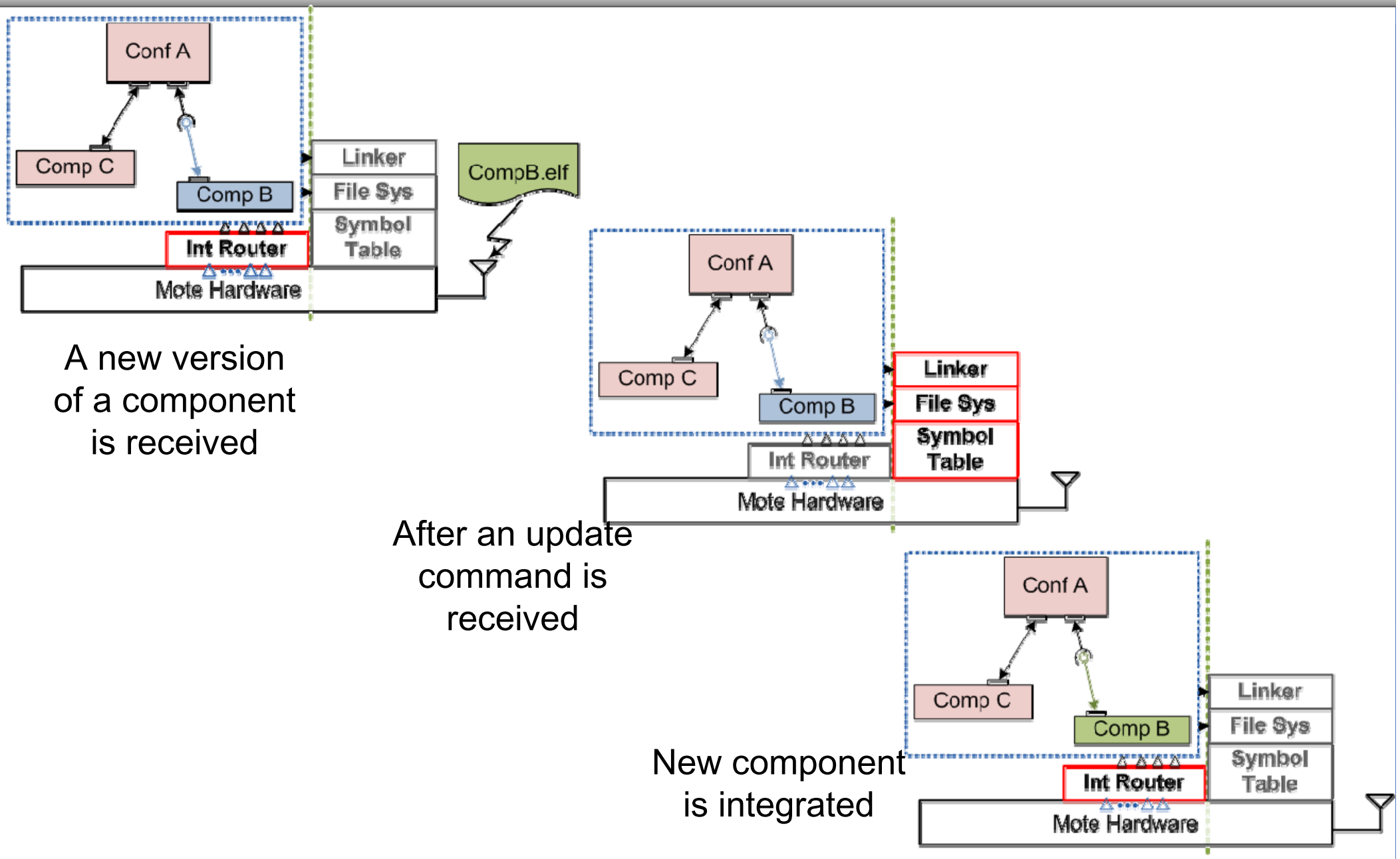


- File System

  Manages storage and retrieval of ELF objects to and from non-volatile storage.
- Symbol Table

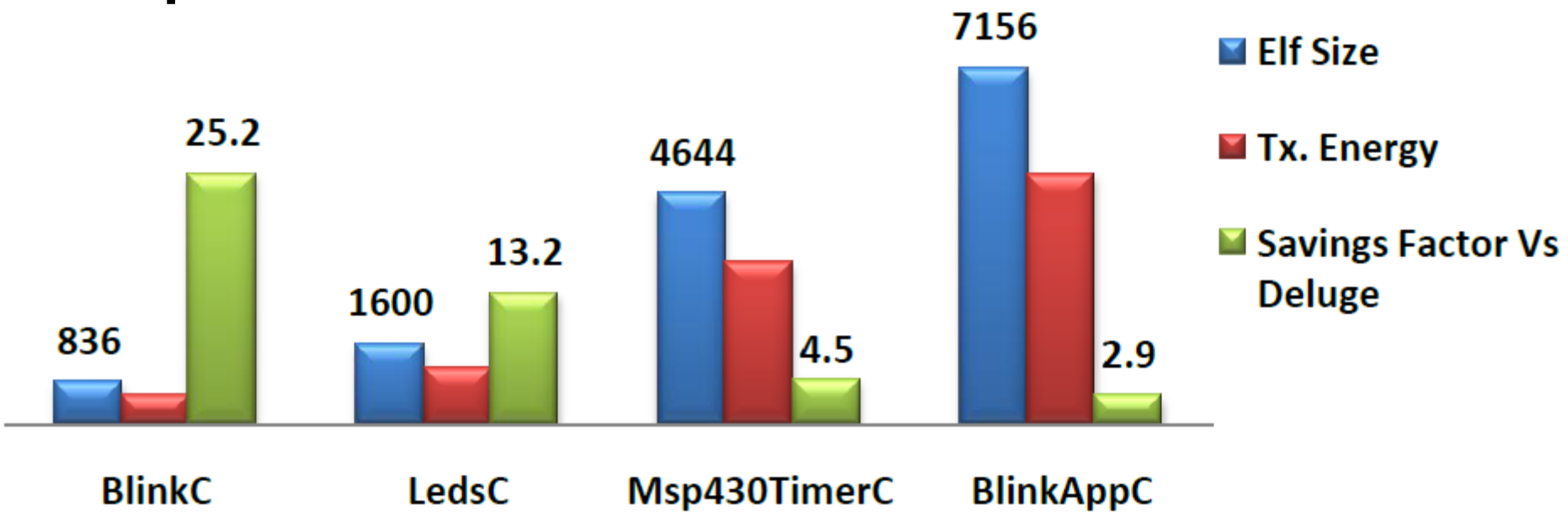
  Manages list of available symbols for cross linking support

Architecture – Update Procedure



Evaluation – Update Cost

- **Update Cost in terms of Energy Include**
  - Multihop communication cost
  - Cost of processing a received update
- **Multihop Communication Cost**



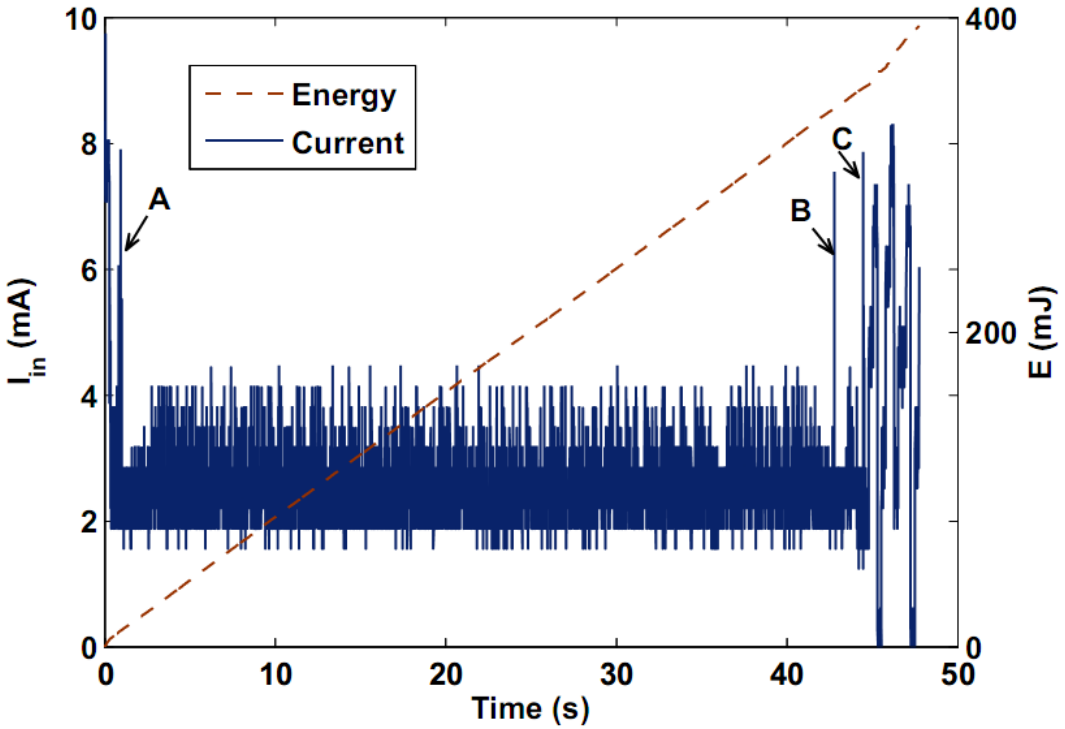
  - Transfer cost proportional to the size of object

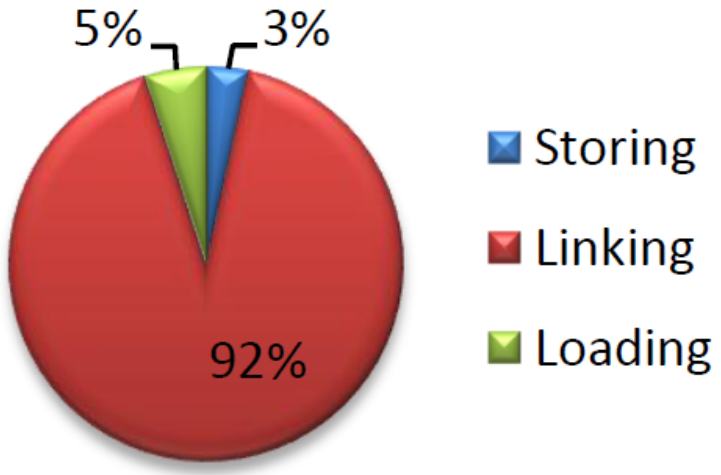
Moderate energy consumption for transfer

* Blink with Deluge = 21132 bytes

Evaluation – Update Cost contd.

- **Update Processing Cost**
  - Linking consumes most energy
    - Exponentially proportional number of string comparison operations
  - Does not depend on size of update





Linking: prime candidate for optimization

Future Work & Conclusion

Conclusion

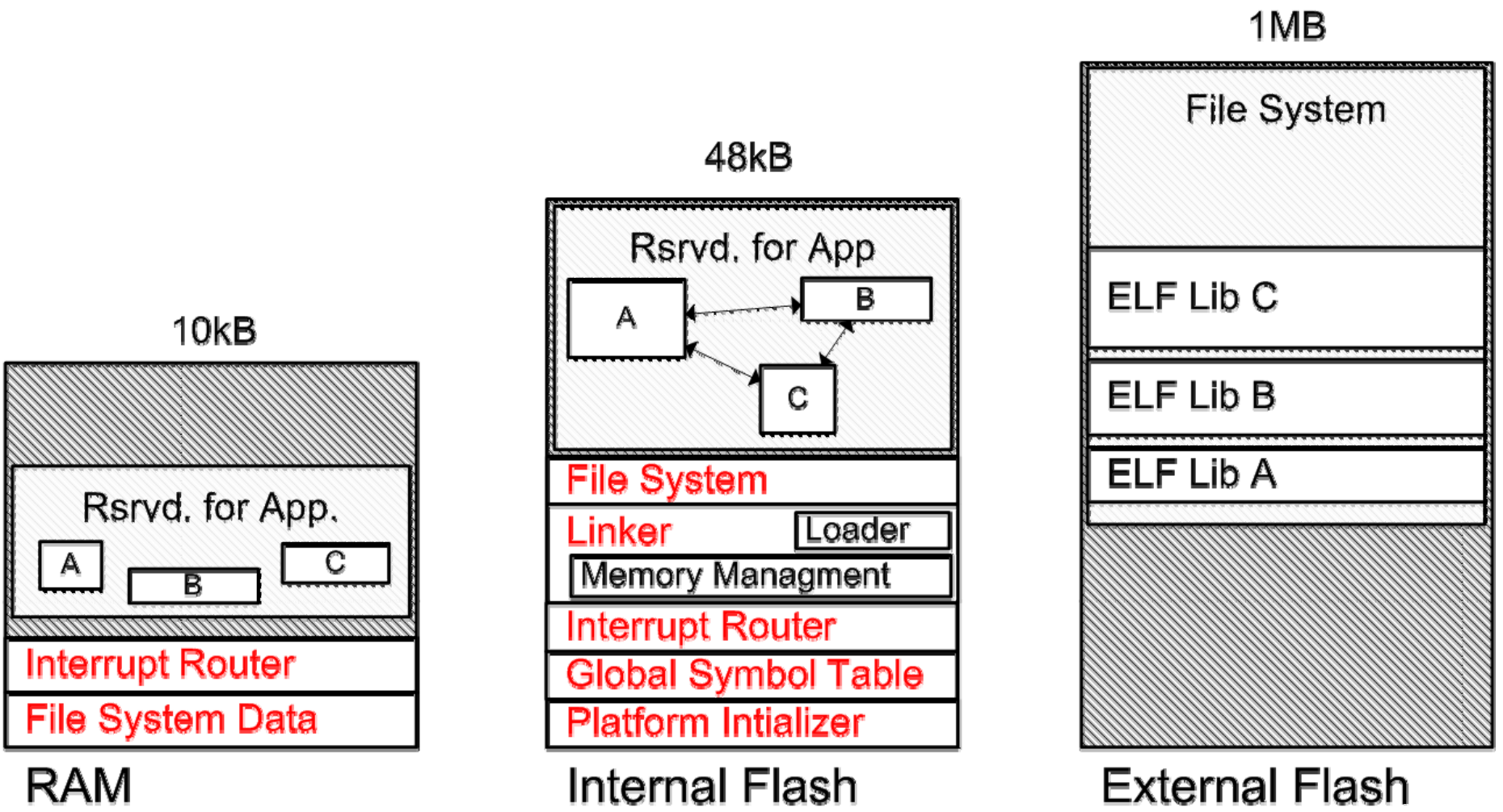
- Sensor network applications reconfigured
  - Remotely, Incrementally, With selectable granularity
- Transparent operation – user friendly
- Reasonable Memory footprint
- Almost zero performance overhead

Future Work

- Automating the Configuration Generator
- ELF format optimization
  - Size Reduction due to 16 bit addressing is 8%
- Wiring compatibility checks
- Versioning scheme

Thank you
Questions ?

Sys Internals

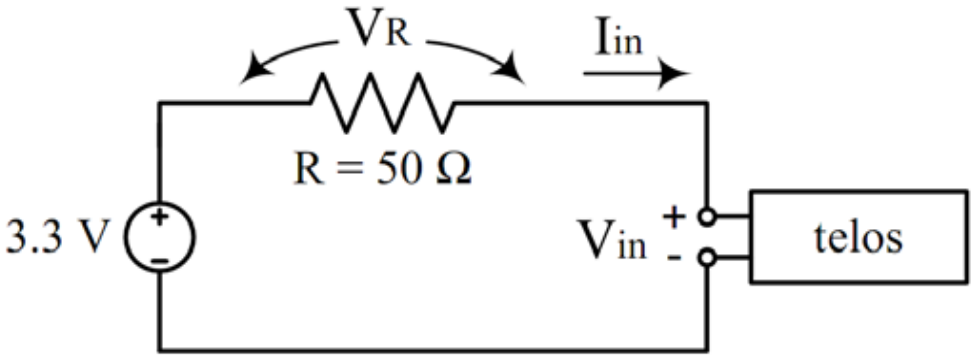


Related Work

Category	Solution	Update Mechanism	Pros /Cons
Image Replacement	Xnp	New Binary Image	+ No linking Required + Relatively transparent operation + No Execution Overhead - Large communication overhead
	Deluge		
Virtual Machine	Maté	New Script	+ small communication overhead - Coarse configuration granularity - Large execution overhead
Dynamic Operating System	Impala	New Application	- Fixed kernel + App side API
	Contiki	New ELF File	- Independent from TinyOS - Multiple ELFs not supported
	SOS	New PIC Module	- PIC modules
	FlexCup	New Module	- Not compatible with new nesC features
	FiGaRo	New Module	- Clean slate approach, A new C API used

Evaluation

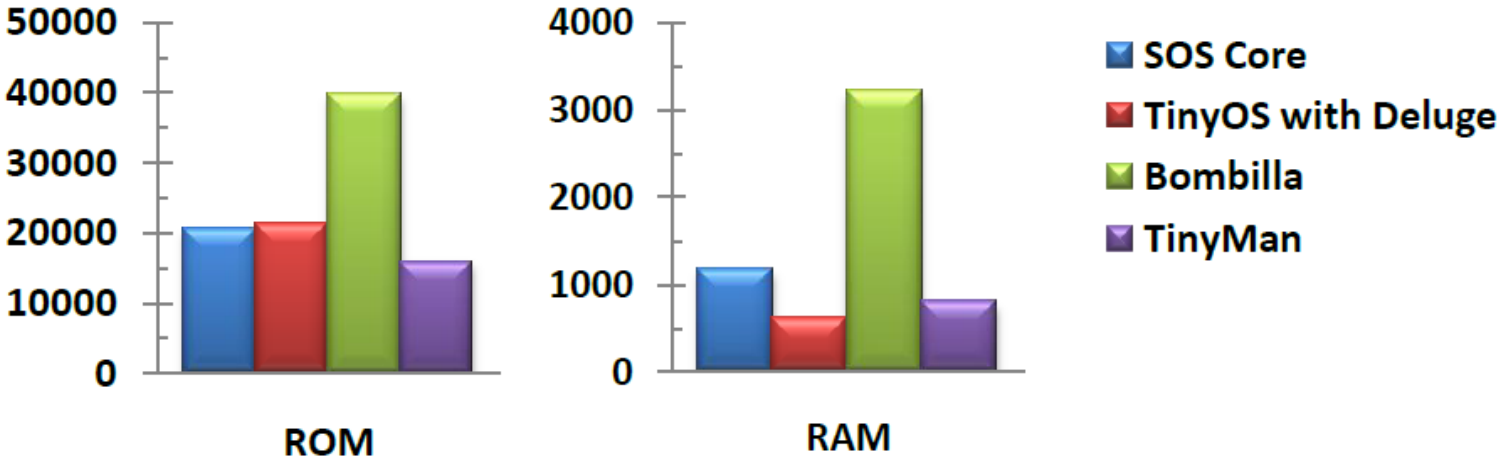
- **Evaluation Criteria**
  - Update Cost
  - ELF format suitability
  - Memory Footprint
  - Performance Overhead



- **Setup**
  - Platform used: telos rev B
  - Applications Used
    - FFT Calculator: A processor intensive application with no IO
    - Blink: An IO intensive application, Uses Timers
    - Radio ping: Application to analyze Multihop Transfer Costs

Memory, Performance

- **Memory Footprint - On telosB**
  - 7.7 % of RAM, 32 % of total program memory, 1.4% of total non-volatile storage

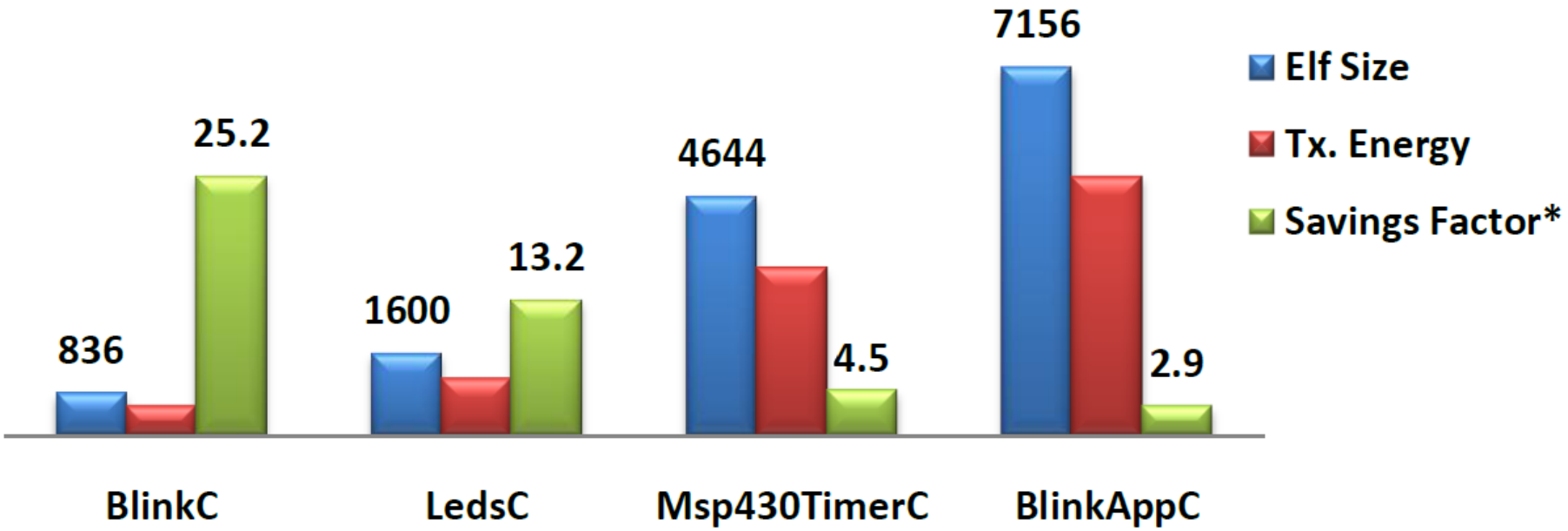


System Name	Flash ROM (bytes)	RAM (bytes)
SOS Core	20464	1163
TinyOS with Deluge	21132	597
Bombilla Virtual Machine	39746	3196
TinyMan	**15826**	**792**

- **Performance Overhead**
  - A worst case delay of 23 cycles in interrupt processing

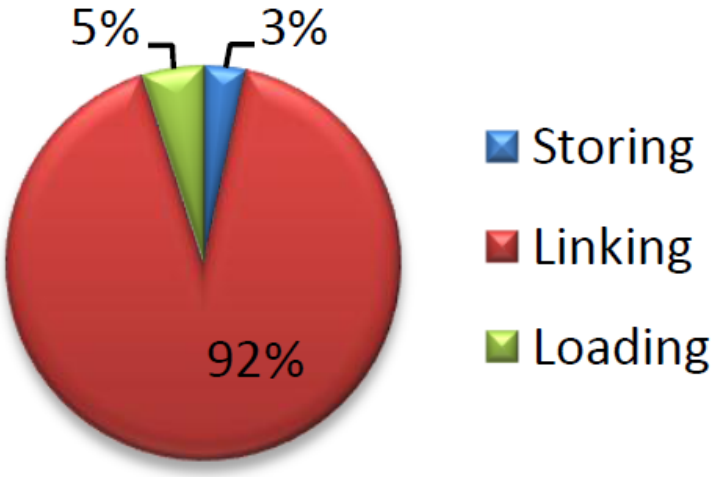
Multihop Communication Cost

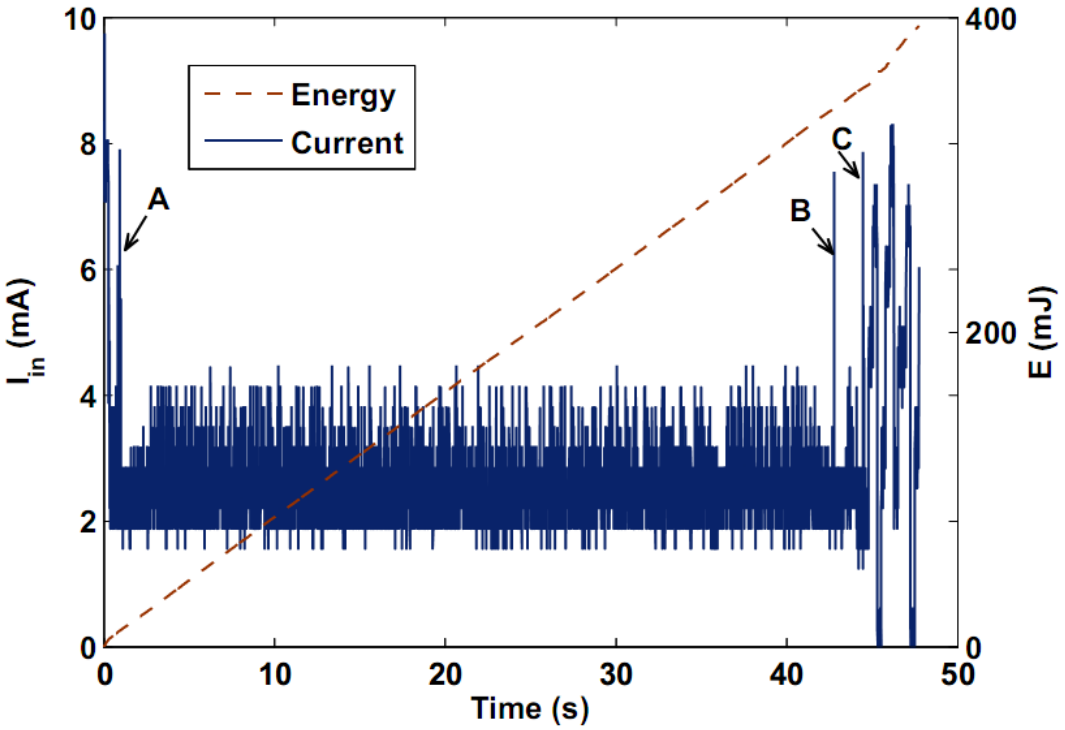
App.	Components	ELF Size	Tx. Energy (mJ)	Saving Factor (Vs. Deluge)
Blink	BlinkC	836	58.77	25.2
	LedsC	1600	112.48	13.2
	Msp430TimerC	4644	326.47	4.5
	BlinkAppC	7156	503.06	2.9
	Total		**1000.78**	--



Update Processing Cost

Application	Steps	Size (B)	Time (s)	Energy Consumed (mJ)
Blink	Storing	14236	0.9	11.4
	Linking	14236	43.2	305.1
	Loading	4756	1.5	16.7
	Total		**45.6**	**333.2**

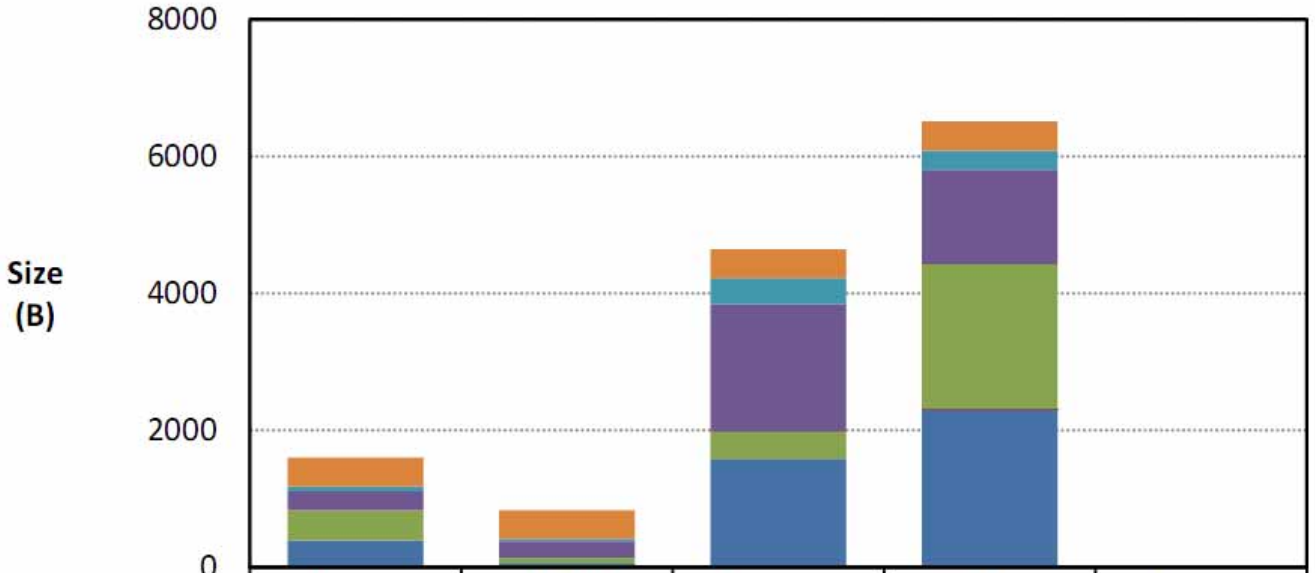




Detailed Memory Footprint

Component		Flash ROM (bytes)	RAM (bytes)
File System		5630	228
Platform Initializer		454	0
Linker	Linker Main	368	4
	Memory Management	344	84
	Loader	2460	24
Interrupt Router		1092	30
Global Symbol Table		1028	74
Node Runtime		390	0
Hardware Drivers	UART	102	259
	Flash Write	158	4
	SPI	54	0
	Ex Flash	726	0
Library Reference		3020	85
Total		**15826**	**792**

ELF Sections Detail



	LedsC	BlinkC	TimerC	BlinkAppC	Average
Misc.	422	424	423	425	23%
String Table	72	34	383	281	5%
Symbol Table	272	240	1856	1376	27%
Relocations	444	84	396	2112	20%
Data	0	0	0	2	0%
Code	390	54	1586	2312	25%
Total	1600	836	4644	6508	