MLA: MAC Layer Architecture

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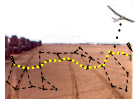
Challenges

- Power management is critical for wireless sensor networks
  - Limited energy source
  - Lifetime from months to years
- Gap between protocols and systems
  - Significant advance in power management protocols
  - Significant challenges to integrate them in real systems
  - Minimum support for power management in OS
- **Need unified architectures for flexible power management!**

Diversity of MAC Protocols

- Conflicting application requirements
  - Energy
  - Latency
  - Throughput
- Radio is a major consumer of energy
- Need different MACs to meet different requirements


Habitat Monitoring

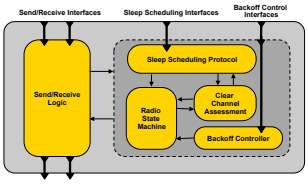

Tracking


Structural Health

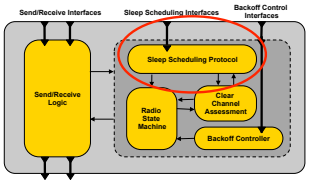

Health Care

Current Solution

- Design a new MAC protocol as a **monolithic stack**
  - S-MAC
  - BMAC
  - ZMAC
  - XMAC
  - WiseMAC
  - T-MAC
  - SCP
  - Funnel-MAC
  - Crankshaft
  - 802.15.4
  - DRAND
  - ……

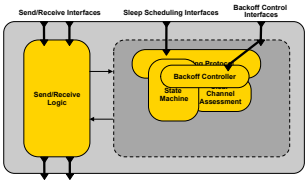


Problem with Current Solution



No separation between power management & core radio functionality

Problem with Current Solution



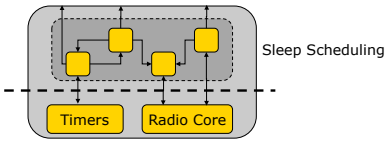
All features jumbled into one big monolithic implementation

Problem: Monolithic Radio Stack

- Hard to develop new MAC protocols
  - No clear separation of concerns
  - Need intimate knowledge of entire stack
- Hard to maintain multiple MAC stacks as OS evolves
- Protocols not reusable across radio/processor platforms

MLA: MAC Layer Architecture

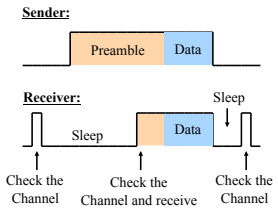
- Separation of sleep sleeping from radio core [IPSN'07]
- Components for sleep scheduling protocols [SenSys'07]
  - Reusable → ease development & maintenance of protocols
  - Platform independent → reduce porting effort



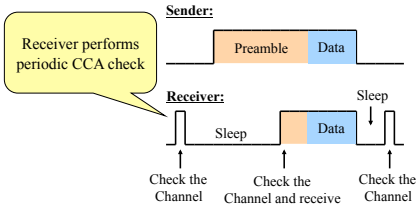
MLA: MAC Layer Architecture

- Components implement common features of MAC protocols
  - Hardware-independent: portable across platforms
  - Hardware-dependent: portable interfaces, platform specific implementations
- Simplifies porting to a new platform
  - Re-implement hardware-dependent components
    - Once per platform
  - Hardware independent components stay the same
- Support diverse MAC protocols
  - CSMA (contention-based), TDMA (scheduling-based), Hybrid
- Comparable efficiency to monolithic implementations

B-MAC: An Example Protocol



B-MAC



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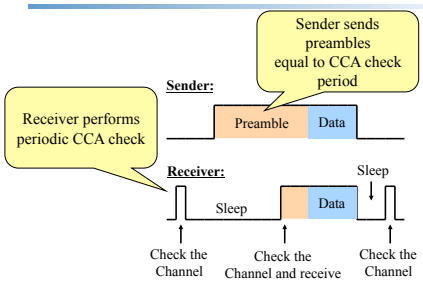

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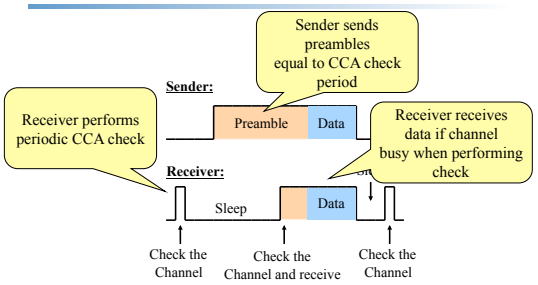
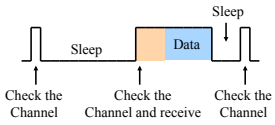


B-MAC: What Does It Need?

- Method of turning the radio on and off
- Method of checking the channel for radio activity (CCA)
- Periodic Timer to listen for radio activity
- A way of sending / receiving preambles
- A way of sending / receiving data



Breakdown of B-MAC

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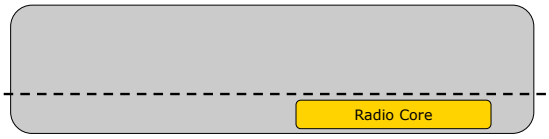

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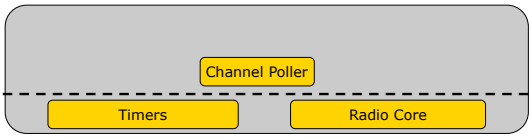
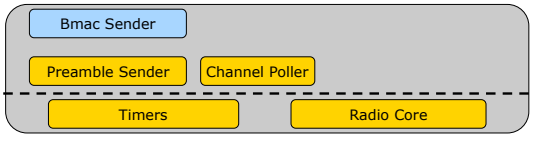


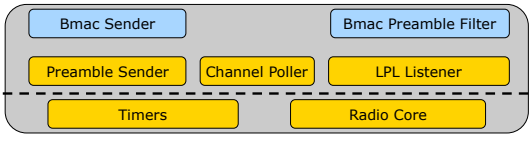
Breakdown of B-MAC

- What does it need?
  - Method of turning the radio on and off
  - Method of checking the channel for radio activity (CCA)
  - Periodic Timer to listen for radio activity
  - A way of sending preambles and data



Breakdown of B-MAC

- What does it need?
  - Method of turning the radio on and off
  - Method of checking the channel for radio activity (CCA)
  - Periodic Timer to listen for radio activity
  - A way of sending preambles and data
  - A way of receiving data and filtering out preambles



Component Library

CSMA Protocols

Hardware Independent	Hardware Dependent
Preamble Sender	**Radio Core**
LPL Listener	Local Time
Channel Poller	**Alarm**
Slot Handlers (TDMA/CSMA)	
Time Synchronization	
Low Level Dispatcher	
Asynchronous I/O Adapter	

Component Library

TDMA Protocols

Hardware Independent	Hardware Dependent
Preamble Sender	Radio Core
LPL Listener	**Local Time**
Channel Poller	**Alarm**
Slot Handlers (TDMA/ CSMA)	
Time Synchronization	
Low Level Dispatcher	
Asynchronous I/O Adapter	

Component Library

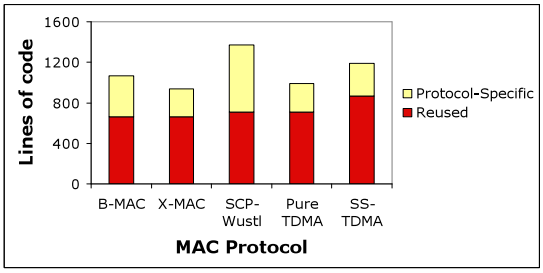
Hybrid Protocols

Hardware Independent	Hardware Dependent
Preamble Sender	**Radio Core**
LPL Listener	**Local Time**
Channel Poller	**Alarm**
Slot Handlers (TDMA/ CSMA)	
Time Synchronization	
Low Level Dispatcher	
Asynchronous I/O Adapter	

Evaluation

- All evaluations performed on TelosB motes in TinyOS 2.0.1
- Implemented 5 MAC protocols
  - B-MAC, X-MAC, SCP-Wustl, Pure TDMA, SS-TDMA
- Measure
  - Reusability of components among protocols
  - Memory footprint compared to monolithic implementations
  - Throughput
  - Latency
  - Energy Consumption

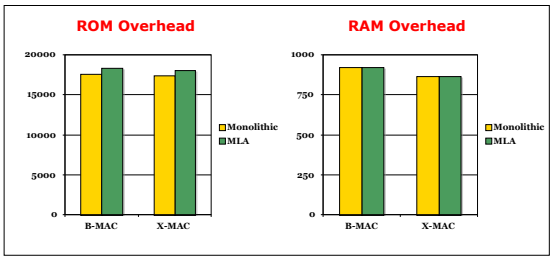
Code Reuse



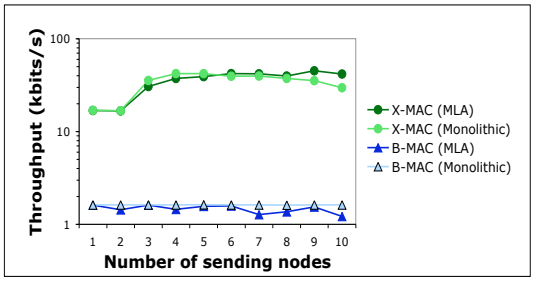
Reusability of Components

	B-MAC	X-MAC	SCP-Wustl	Pure-TDMA	SS-TDMA
Channel Poller	○	○	○		
LPL Listener	○	○	○		
Preamble Sender	○	○	○		
Time Synchronization			○	○	○
TDMA Slot Handler				○	○
CSMA Slot Handler					○
Low Level Dispatcher				○	○
Async I/O Adapter	○	○	○	○	○
Alarm	○	○	○	○	○
Local Time			○	○	○
Radio Core	○	○	○	○	○
Other Components	**3**	**3**	**4**	**2**	**2**
Reused Components	**6**	**6**	**8**	**7**	**8**

Memory Footprint (TelosB)



Throughput



MLA: Summary

- Component-based, low-power MAC architecture
  - Increases flexibility
  - Simplifies development
  - Reduces porting effort
- Provides evidence contrary to the existing philosophy that radio stacks must be monolithic to be efficient
  - Bridge the gap between algorithms/protocols and systems.
- Code: tinyos-2.x-contrib/wustl/upma

Solve the Real Problems

- Hard to develop new MAC protocols?
  - RI-MAC (SenSys'08) built on top of MLA
  - More built on MLA
- Hard to maintain multiple MAC stacks as OS evolves?
  - Upgrading MLA for TinyOS 2.0.1->2.0.2->2.1 took several hours
  - Multiple MAC protocols survived upgrade without any change!
- Protocols not reusable across radio/processor platforms?
  - Supports both Telos and MicaZ
- TinyOS 2.1 version available from TinyOS "contrib" CVS

References

- K. Klues, G. Hackmann, O. Chipara and C. Lu, A Component-Based Architecture for Power-Efficient Media Access Control in Wireless Sensor Networks, SenSys'07.
- K. Klues, G. Xing and C. Lu, Link Layer Support for Unified Radio Power Management in Wireless Sensor Networks, IPSN'07.