Operating Systems: Internals and Design Principles

Chapter 13
Embedded Operating Systems

Eighth Edition
By William Stallings

Embedded System

- Refers to the use of electronics and software within a product that is designed to perform a dedicated function
  - in many cases, embedded systems are part of a larger system or product
  - antilock braking system in a car would be an example

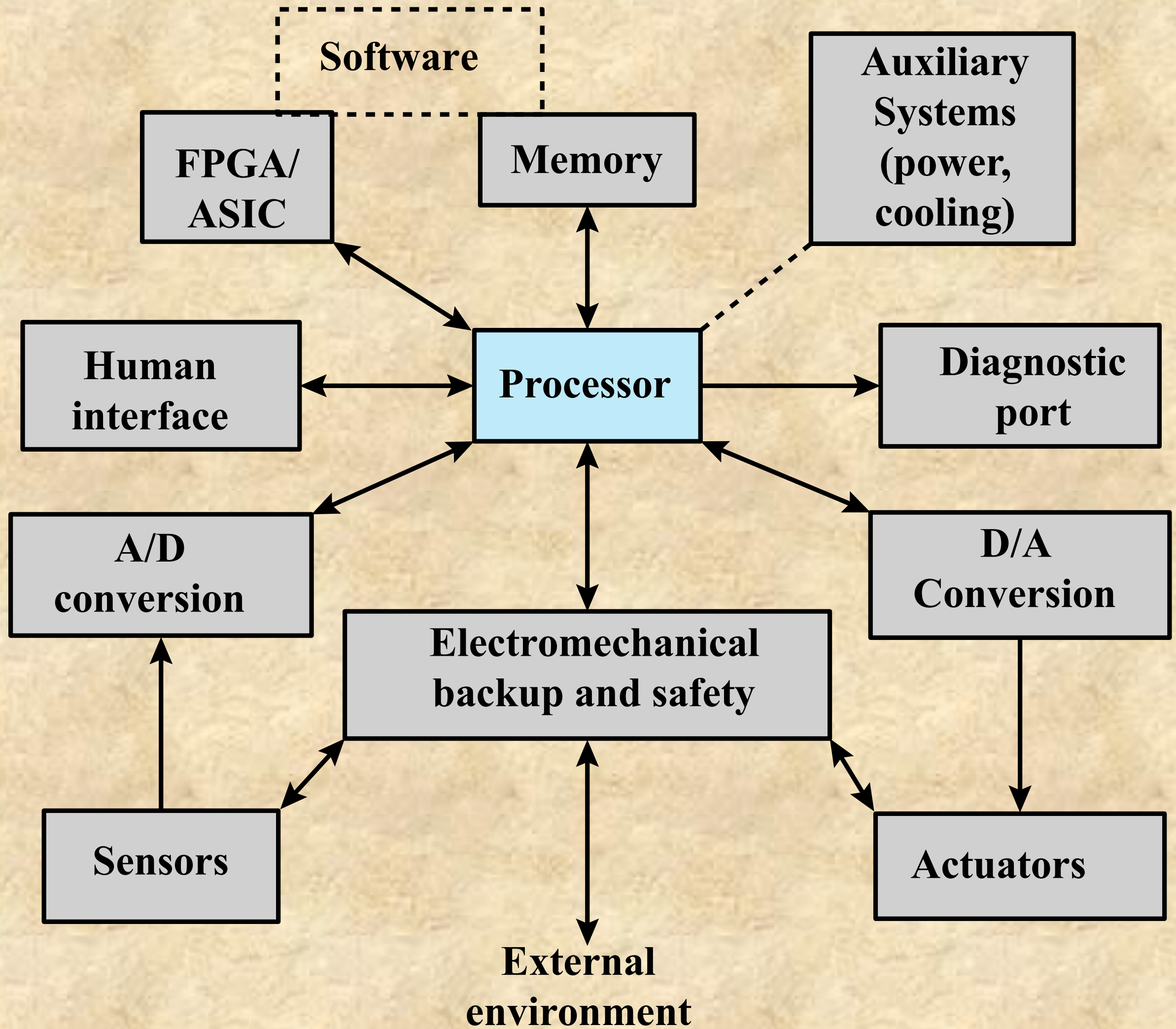


Figure 13.1 Possible Organization of an Embedded System

Characteristics of Embedded OS

- Real-time operation
- Reactive operation
- Configurability
- I/O device flexibility
- Streamlined protection mechanisms
- Direct use of interrupts

Developing an Embedded OS

Two general approaches:

- take an existing OS and adapt it for the embedded application
- design and implement an OS intended solely for embedded use

Adapting an Existing OS

- An existing commercial OS can be used for an embedded system by adding:
  - real time capability
  - streamlining operation
  - adding necessary functionality

Advantage:

- familiar interface

Disadvantage:

- not optimized for real-time and embedded applications

Purpose-Built Embedded OS

- Typical characteristics include:
  - fast and lightweight process or thread switch
  - scheduling policy is real time and dispatcher module is part of scheduler
  - small size
  - responds to external interrupts quickly
  - minimizes intervals during which interrupts are disabled
  - provides fixed or variable-sized partitions for memory management
  - provides special sequential files that can accumulate data at a fast rate

Two examples are:

- eCos
- TinyOS

Timing Constraints

To deal with timing constraints, the kernel:

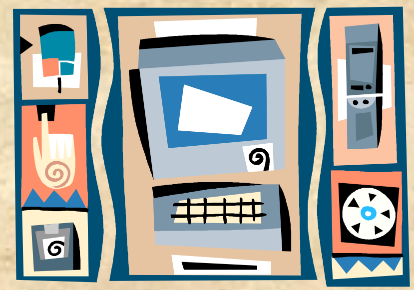
- provides bounded execution time for primitives
- maintains a real-time clock
- provides for special alarms and timeouts
- supports real-time queuing disciplines
- provides primitives to delay processing by a fixed amount of time and to suspend/resume execution

Embedded Linux

- A version of Linux running in an embedded system
- Embedded devices typically require support for a specific set of devices, periphrals, and protocols, depending on the hardware that is present in a given device and the intended purpose of that device
- An embedded Linux distribution is a version of Linux to be customized for the size and hardware constraints of embedded devices
  - includes software packages that support a variety of services and applications on those devices
  - an embedded Linux kernel will be far smaller than an ordinary Linux kernel

Cross Compiler

- A key differentiator between desktop/server and embedded Linux distributions is that desktop and server software is typically compiled on the platform where it will execute
- Embedded Linux distributions are usually compiled on one platform but are intended to be executed on another
  - the software used for this purpose is referred to as a cross-compiler



Embedded Linux File Systems

- File system must be as small as possible
- Commonly used examples:
  - cramfs
    - a simple read-only file system that is designed to minimize size by maximizing the efficient use of underlying storage
    - files are compressed in units that match the Linux page size
  - squashfs
    - a compressed, read-only file system that was designed for use on low memory or limited storage size environments
  - jffs2
    - a log-based file system that is designed for use on NOR and NAND flash devices with special attention to flash-oriented issues such as wear-leveling
  - ubifs
    - provides better performance on larger flash devices and also supports write caching to provide additional performance inprovements
  - yaffs2
    - provides a fast and robust file system for large flash devices

Advantages of Embedded Linux

- Advantages of using Linux as the basis for an embedded OS include the following:
  - vendor independence
    - the platform provider is not dependent on a particular vendor to provide needed features and meet deadlines for deployment
  - varied hardware support
    - Linux support for a wide range of processor architectures and peripheral devices makes it suitable for virtually any embedded system
  - low cost
    - the use of Linux minimizes cost for development and training
  - open source
    - the use of Linux provides all of the advantages of open source software

Android

- Focus of Android lies in the vertical integration of the Linux kernel and the Android user-space components
- Many embedded Linux developers do not consider Android to be an instance of embedded Linux
  - from the point of view of these developers, a classic embedded device has a fixed function, frozen at the factory

Android

- an embedded OS based on a Linux kernel
- more of a platform OS that can support a variety of applications that vary from one platform to the next
- a vertically integrated system, including some Android specific modification to the Linux kernel

TinyOS

- Streamlines to a very minimal OS for embedded systems
- Core OS requires 400 bytes of code and data memory combined
- Not a real-time OS
- There is no kernel
- There are no processes
- OS doesn't have a memory allocation system
- Interrupt and exception handling is dependent on the peripheral
- It is completely nonblocking, so there are few explicit synchronization primitives
- Has become a popular approach to implementing wireless sensor network software

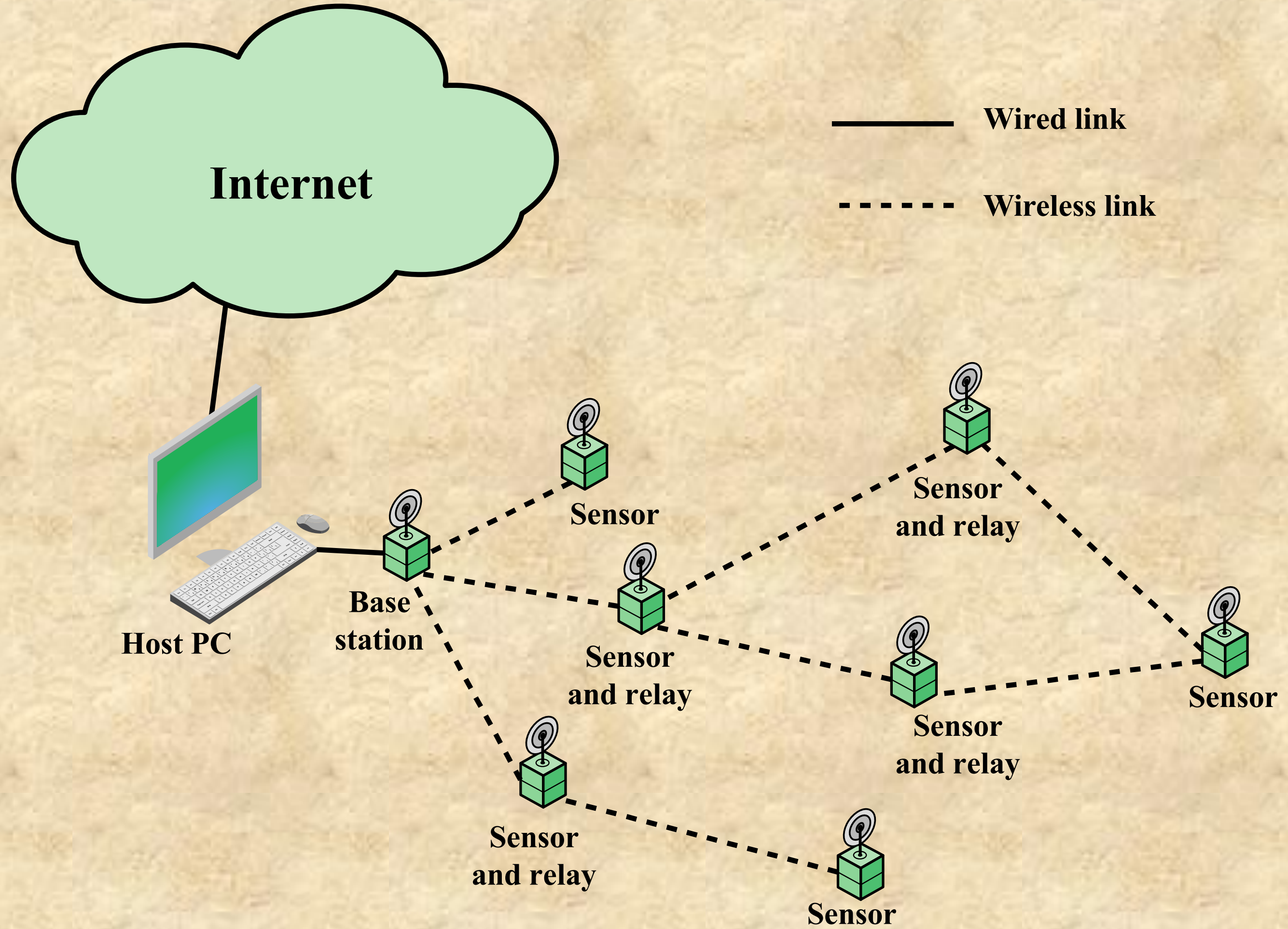


Figure 13.2 Typical Wireless Sensor Network Topology

TinyOS Goals

- With the tiny distributed sensor application in mind, the following goals were set for TinyOS:

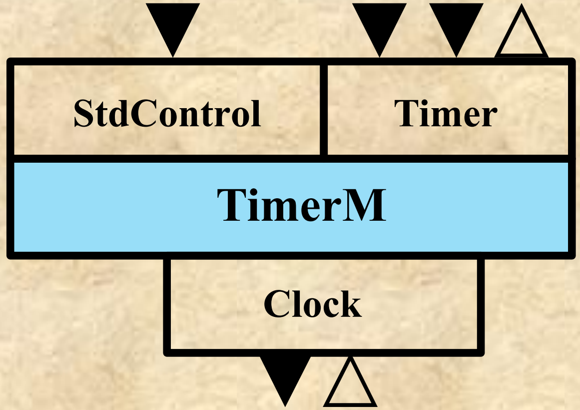
  - allow high concurrency
  - operate with limited resources
  - adapt to hardware evolution
  - support a wide range of applications
  - support a diverse set of platforms
  - be robust

TinyOS Components

- Embedded software systems built with TinyOS consist of a set of modules (called components), each of which performs a simple task and which interface with each other and with hardware in limited and well-defined ways
- The only other software module is the scheduler
- Because there is no kernel there is no actual OS
- The application area of interest is the wireless sensor network (WSN)

Examples of standardized components include:

- single-hop networking
- ad-hoc routing
- power management
- timers
- nonvolatile storage control



(a) TimerM component

```
module TimerM {
   provides {
      interface StdControl;
      interface Timer;
   }
   uses interface Clock as Clk;
} ...
```

Components -- Tasks

- A software component implements one or more tasks
- Each ***task*** in a component is similar to a thread in an ordinary OS
- Within a component tasks are atomic
  - once a task has started it runs to completion

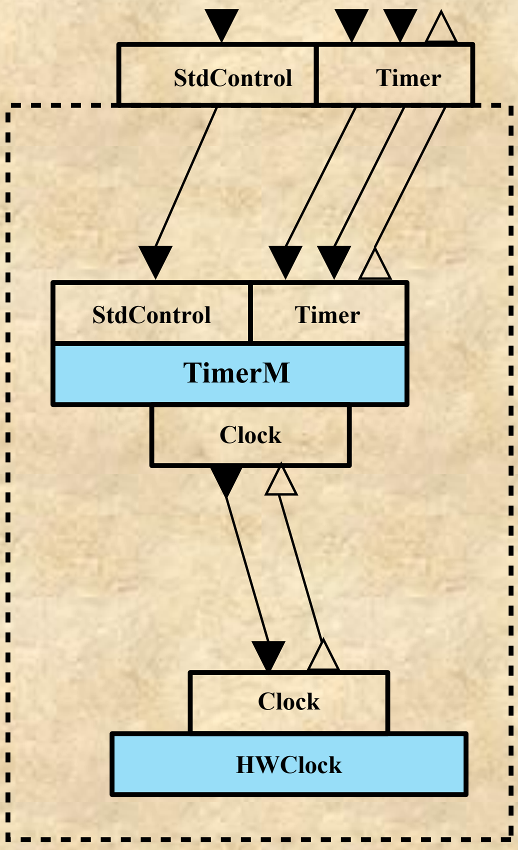
A task cannot:	A task can:
• be preempted by another task in the same component and there is no time slicing • block or spin wait	• perform computations • call lower-level components (commands) • signal higher-level events • schedule other tasks

Components -- Commands

- A ***command*** is a nonblocking request
  - a task that issues a command does not block or spin wait for a reply from the lower-level component
- Is typically a request for the lower-level component to perform some service
- The effect on the component that receives the command is specific to the command given and the task required to satisfy the command
- A command cannot preempt the currently running task
- A command does not cause a preemption in the called component and does not cause blocking in the calling component

Components -- Events

- ***Events*** in TinyOS may be tied either directly or indirectly to hardware events
- Lowest-level software components interface directly to hardware interrupts
  - may be external interrupts, timer events, or counter events
- An event handler in a lowest-level component may handle the interrupt itself or may propagate event messages up through the component hierarchy
- A command can post a task that will signal an event in the future
  - in this case there is no tie of any kind to a hardware event



(b) TimerC configuration

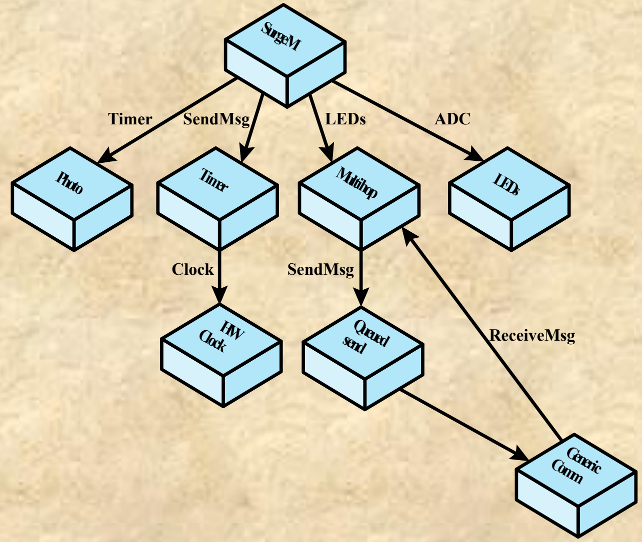
```
configuration TimerC {
   provides {
      interface StdControl;
      interface Timer;
   }
}

implementation {
   components TimerM, HWClock;
   StdControl = TimerM.StdControl;
   Timer = TimerM.Timer;
   TimerM.Clk -> HWClock.Clock;
}
```

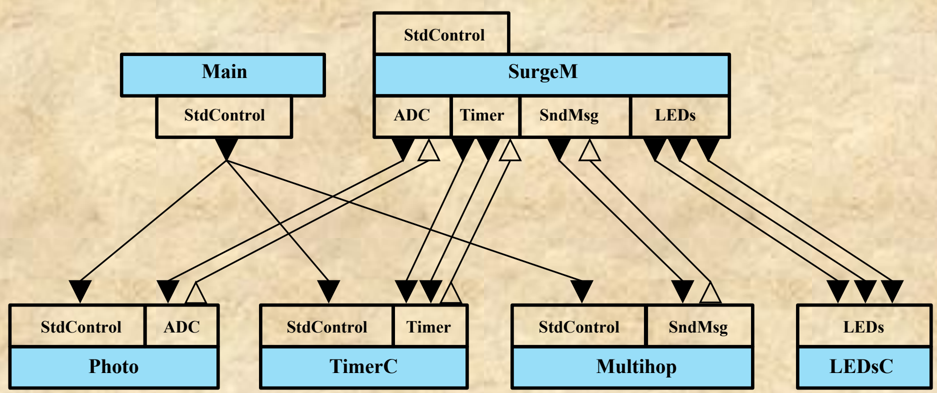
Figure 13.3 Example Component and Configuration

TinyOS Scheduler

- Operates across all components
- Only one task executes at a time
- The scheduler is a separate component
  - it is the one portion of TinyOS that must be present in any system
- Default scheduler is a simple FIFO queue
- Scheduler is power aware
  - puts processor to sleep when there is no task in the queue



(a) Simplified view of the Surge Application



(b) Top-level Surge Configuration

LED = light-emitting diode
ADC = analog-to-digital converter

Figure 13.4 Example TinyOS Application

TinyOS Resource Interface

- TinyOS provides a simple but powerful set of conventions for dealing with resources

Dedicated

- a resource that a subsystem needs exclusive access to at all times
- no sharing policy is needed
- examples include interrupts and counters

Virtualized

- every client of a virtualized resource interacts with it as if it were a dedicated resource
- an example is a clock or timer

Shared

- abstraction that provides access to a dedicated resource through an arbiter component
- arbiter determines which client has access to the resource at which time

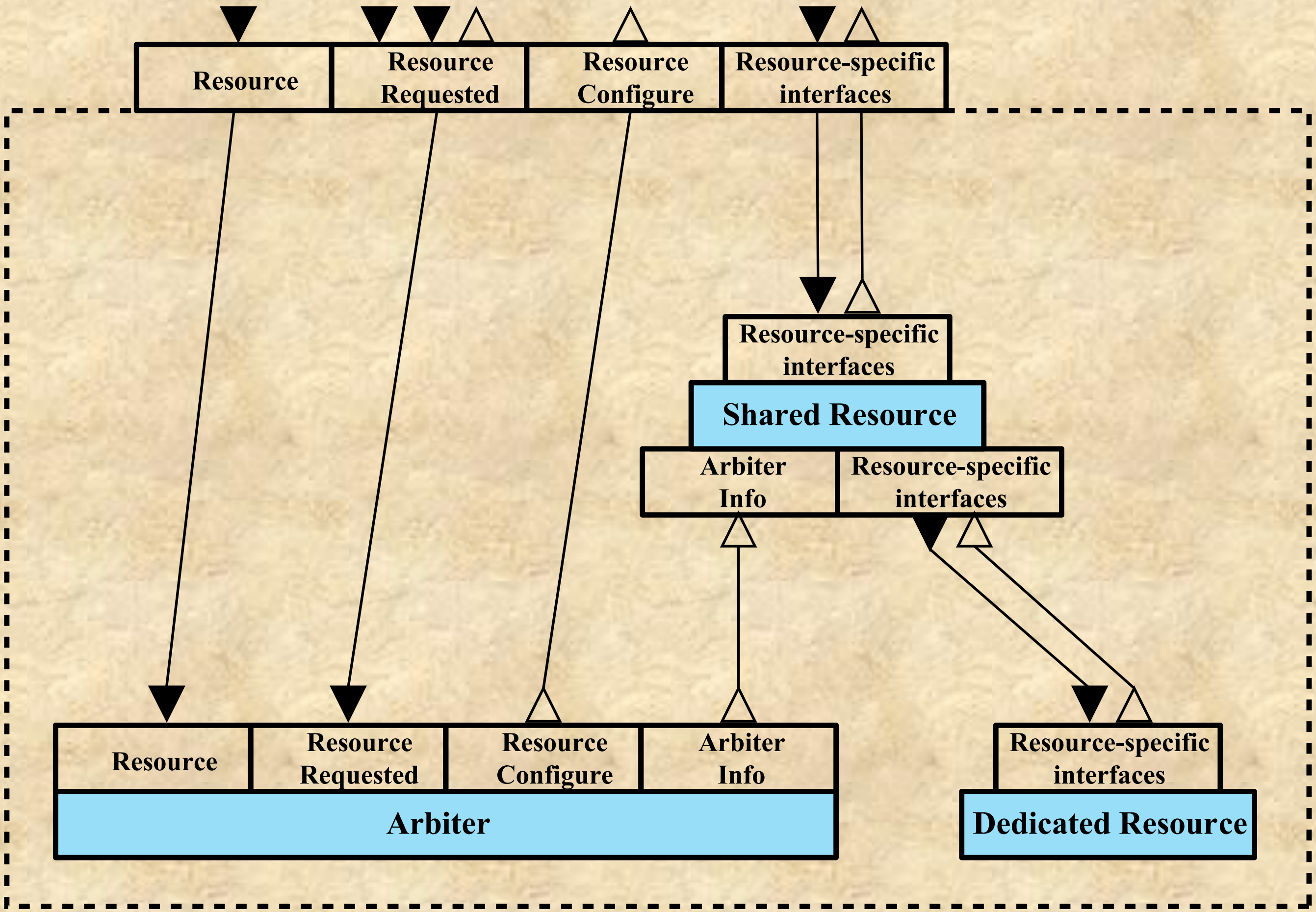


Figure 13.5 Shared Resource Configuration

Summary

- Embedded systems
- Characteristics of embedded operating systems
  - Adapting an existing commercial operating system
  - Purpose-built embedded operating system
- Embedded Linux
  - Kernel size
  - Compilation
  - Embedded Linux file systems
  - Advantages of embedded Linux
  - Android
- TinyOS
  - Wireless sensor networks
  - TinyOS goals
  - TinyOS components
  - TinyOS scheduler
  - TinyOS resource interface