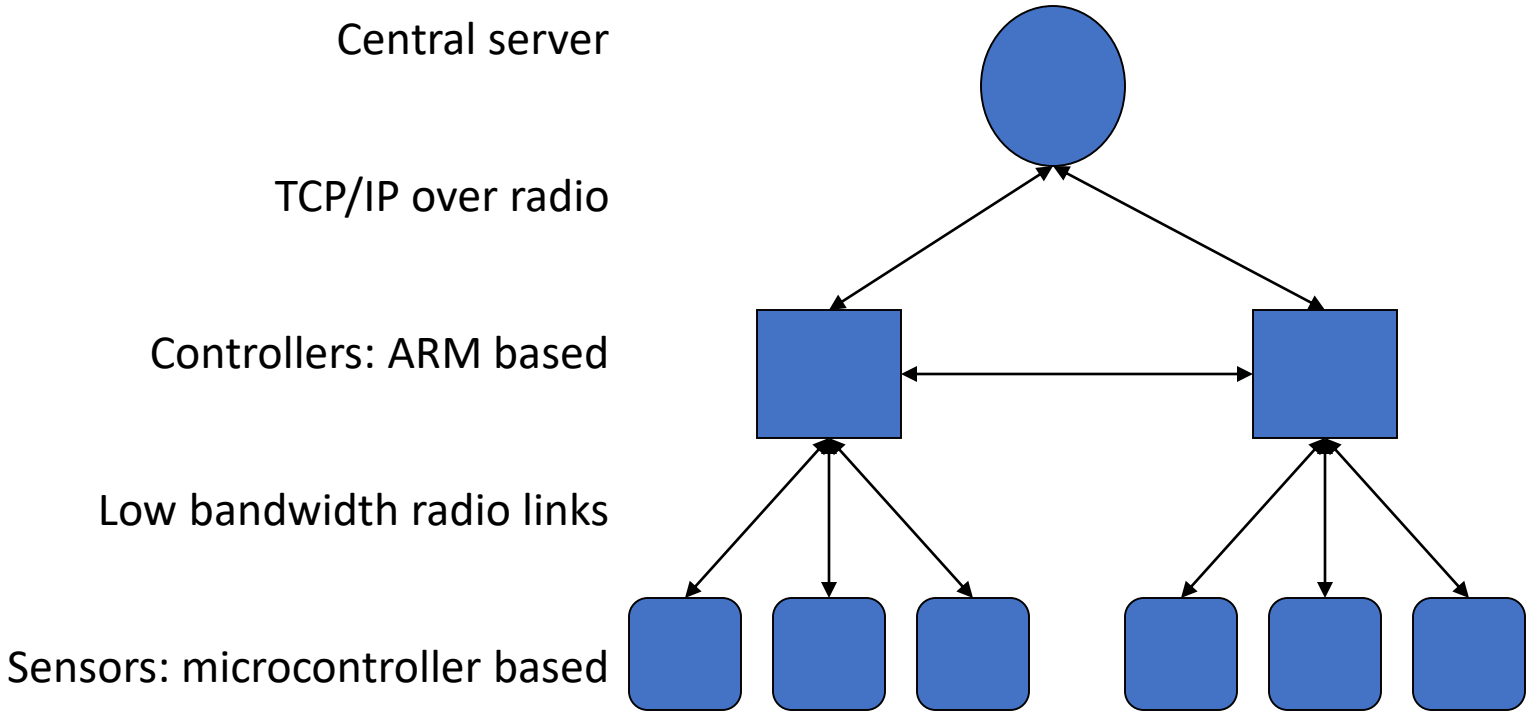
Real Time Operating Systems (RTOS)

EE5182 Microcontrollers and Embedded Systems

Based on content by Subhashis Banerjee, Indian Institute of Technology, Delhi & Akos Ledeczi, Vanderbilt University

Fire alarm system: An example



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Fire alarm system: An example

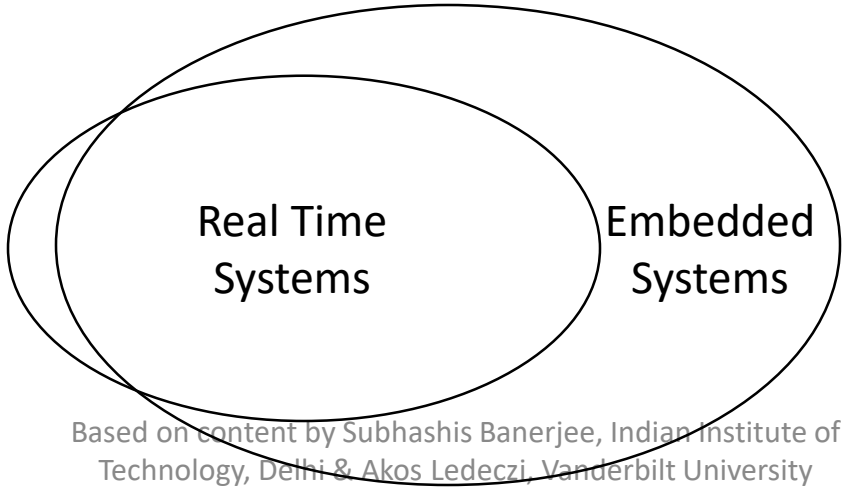
- Problem
  - Hundreds of sensors, each fitted with Low Range Wireless
    - Sensor information to be logged in a server & appropriate action initiated
- Possible Solution
  - Collaborative Action
    - Routing
      - Dynamic – Sensors/controllers may go down
      - Auto Configurable – No/easy human intervention.
      - Less Collision/Link Clogging
      - Less number of intermediate nodes – Fast Response Time
      - Secure

Real Time Systems

- A system is said to be Real Time if it is required to complete it's work and deliver it's services on time.
- Example – Flight Control System
  - All tasks in that system must execute on time.
- Non Example – PC system

Embedded vs. Real Time Systems

- Embedded system:
  - A computer system that performs a limited set of specific functions.
  - It often interacts with its environment.
- Real Time Systems:
  - Correctness of the system depends not only on the logical results, but also on the time in which the results are produced.



Examples?

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Examples

- Real Time Embedded:
  - Nuclear reactor control; Flight control; Basically any safety critical system
  - GPS; Mobile phone
- Real Time, but not Embedded:
  - Stock trading system
  - Skype
- Embedded, but not Real Time:
  - Home temperature control
  - Sprinkler system
  - Washing machine, refrigerator, etc.
  - Blood pressure meter

Characteristics of Real Time Systems

- Event-driven, reactive
- High cost of failure
- Concurrency/multiprogramming
- Stand-alone/continuous operation
- Reliability/fault-tolerance requirements
- Predictable behavior

What's Important in Real Time Systems

- Metrics for real-time systems differ from that for time-sharing systems.

	Time-Sharing Systems	Real-Time Systems
Capacity	High throughput	Schedulability
Responsiveness	Fast average response	Ensured worst-case response
Overload	Fairness	Stability

- schedulability is the ability of tasks to meet all hard deadlines
- latency is the worst-case system response time to events
- stability in overload means the system meets critical deadlines even if all deadlines cannot be met

Hard and Soft Real Time Systems (Qualitative Definition)

- Hard Real Time System
  - Failure to meet deadlines is fatal
  - example : Flight Control System
- Soft Real Time System
  - Late completion of jobs is undesirable but not fatal.
  - System performance degrades as more & more jobs miss deadlines
  - Online Databases

Hard and Soft Real Time Systems (Operational Definition)

- Hard Real Time System
  - Validation by provably correct procedures or extensive simulation that the system always meets the timings constraints
- Soft Real Time System
  - Demonstration of jobs meeting some statistical constraints suffices.
- Example – Multimedia System
  - 25 frames per second on an average

Role of an OS in Real Time Systems

- Standalone Applications
  - Often no OS involved
  - Micro controller based Embedded Systems
- Some Real Time Applications are huge & complex
  - Multiple threads
  - Complicated Synchronization Requirements
  - Filesystem / Network / Windowing support
  - OS primitives reduce the software design time
- Real Time Operating System (RTOS)

Features of RTOS

- Scheduling
- Resource Allocation
- Interrupt Handling
- Other issues like kernel size

Scheduling in RTOS

- More information about the tasks are known
  - No of tasks
  - Resource Requirements
  - Release Time
  - Execution time
  - Deadlines
- Being a more deterministic system better scheduling algorithms can be devised.

Scheduling Algorithms in RTOS

- Clock Driven Scheduling
- Weighted Round Robin Scheduling
- Priority Scheduling
  - (Greedy / List / Event Driven)

Scheduling Algorithms in RTOS (contd)

- Clock Driven
  - All parameters about jobs (release time/ execution time/deadline) known in advance.
  - Schedule can be computed offline or at some regular time instances.
  - Minimal runtime overhead.
  - Not suitable for many applications.

Scheduling Algorithms in RTOS (contd)

- Weighted Round Robin
  - Jobs scheduled in FIFO manner
  - Time quantum given to jobs is proportional to it’s weight
  - Example use : High speed switching network
    - QOS guarantee.
  - Not suitable for precedence constrained jobs.
    - Job A can run only after Job B. No point in giving time quantum to Job B before Job A.

Scheduling Algorithms in RTOS (contd)

- Priority Scheduling
  - (Greedy/List/Event Driven)
  - Processor never left idle when there are ready tasks
  - Processor allocated to processes according to priorities
  - Priorities
    - static - at design time
    - Dynamic - at runtime

Priority Scheduling

- Earliest Deadline First (EDF)
  - Process with earliest deadline given highest priority
- Least Slack Time First (LSF)
  - slack = relative deadline – execution left
- Rate Monotonic Scheduling (RMS)
  - For periodic tasks
  - Tasks priority inversely proportional to it’s period

Resource Allocation in RTOS

- Resource Allocation
  - The issues with scheduling applicable here.
  - Resources can be allocated in
    - Weighted Round Robin
    - Priority Based
- Some resources are non preemptible
  - Example : semaphores
- Priority Inversion if priority scheduling is used

Solutions to Priority Inversion

- Non Blocking Critical Section
  - Higher priority Thread may get blocked by unrelated low priority thread
- Priority Ceiling
  - Each resource has an assigned priority
  - Priority of thread is the highest of all priorities of the resources it's holding
- Priority Inheritance
  - The thread holding a resource inherits the priority of the thread blocked on that resource

Other RTOS issues

- Interrupt Latency should be very small
  - Kernel has to respond to real time events
  - Interrupts should be disabled for minimum possible time
- For embedded applications Kernel Size should be small
  - Should fit in ROM
- Sophisticated features can be removed
  - No Virtual Memory
  - No Protection

Linux for Real Time Applications

- Scheduling
  - Priority Driven Approach
    - Optimize average case response time
  - Interactive Processes Given Highest Priority
    - Aim to reduce response times of processes
  - Real Time Processes
    - Processes with high priority
    - No notion of deadlines
- Resource Allocation
  - No support for handling priority inversion

Interrupt Handling in Linux

- Interrupts are disabled in ISR/critical sections of the kernel
- No worst case bound on interrupt latency avaliable
  - eg: Disk Drivers may disable interrupt for few hundred milliseconds
- Not suitable for Real Time Applications
  - Interrupts may be missed

Other Problems with Linux

- Processes are non preemtible in Kernel Mode
  - System calls like fork take a lot of time
  - High priority thread might wait for a low priority thread to complete it's system call
- Processes are heavy weight
  - Context switch takes several hundred microseconds

Why Linux

- Coexistence of Real Time Applications with non Real Time Ones
  - Example http server
- Device Driver Base
- Stability

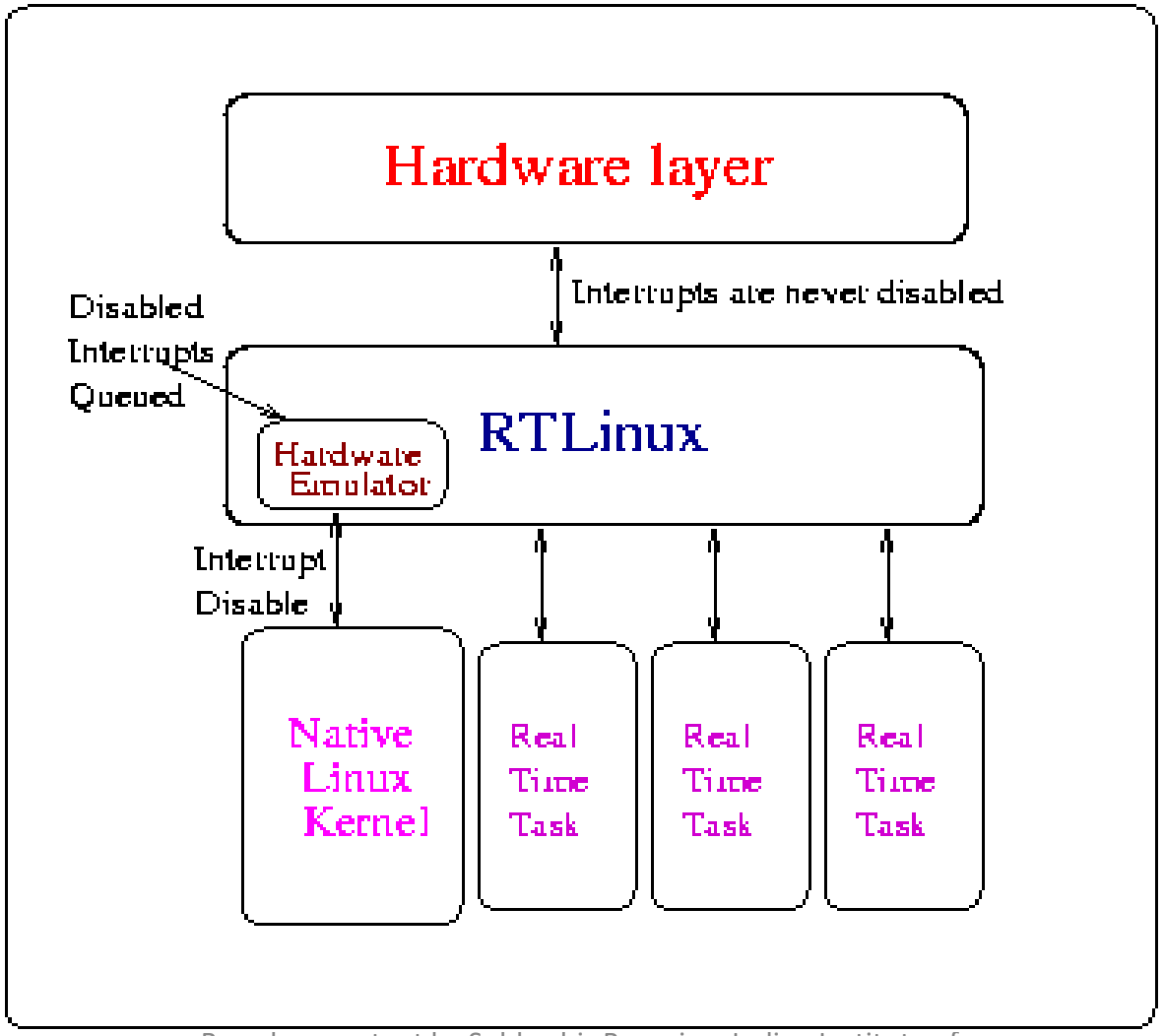
RTLinux

- Real Time Kernel at the lowest level
- Linux Kernel is a low priority thread
  - Executed only when no real time tasks
- Interrupts trapped by the Real Time Kernel and passed onto Linux Kernel
  - Software emulation to hardware interrupts
    - Interrupts are queued by RTLinux
    - Software emulation to disable_interrupt()

RTLinux (contd)

- Real Time Tasks
  - Statically allocate memory
  - No address space protection
- Non Real Time Tasks are developed in Linux
- Communication
  - Queues
  - Shared memory

RTLinux Framework



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Other RTOS's

- LynxOS
  - Microkernel Architecture
    - Kernel provides scheduling/interrupt handling
  - Additional features through Kernel Plug Ins(KPIs)
    - TCP/IP stack , Filesystem
    - KPI's are multithreaded
  - Memory Protection/ Demand Paging Optional
  - Development and Deployment on the same host
    - OS support for compilers/debuggers

Other RTOS's (contd)

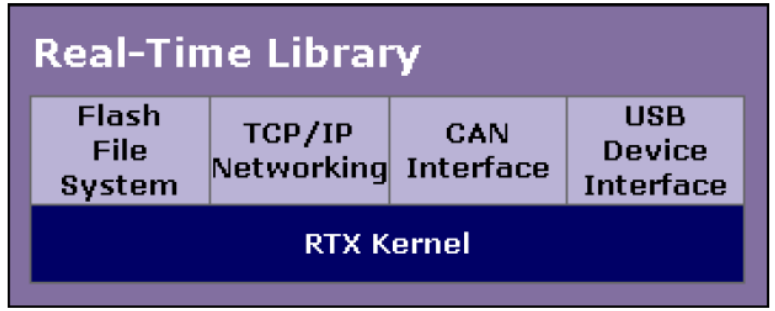
- VxWorks
  - Monolithic Architecture
  - Real Time Posix compliant
  - Cross development System
- pSOS
  - Object Oriented OS

RTX

- Royalty-free, deterministic, open source RTOS
- High-Speed real-time operation with low interrupt latency
- Flexible Scheduling: round-robin, pre-emptive, and collaborative
- Small footprint for resource constrained systems
- Compatible with ARM cores (from ARM7, ARM9 to Cortex-M processors) and software tools (Keil MDK-ARM)
- Support for multithreading and thread-safe operation
- Kernel aware debug support in Keil MDK-ARM
- Dialog-based setup using µVision Configuration Wizard

RTX Structure

- Keil Real-Time Library (RTL)
  - RTX Kernel
  - Flash file system
  - Networking
  - CAN interface
  - USB device interface



- RTX Kernel
  - Scheduler is the core of the RTX kernel
  - Supports for mutex, memory pool, mailbox, timing functions, events and semaphores