A Scalable Simulator for TinyOS Applications

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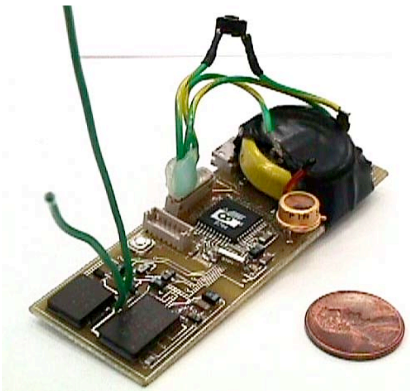
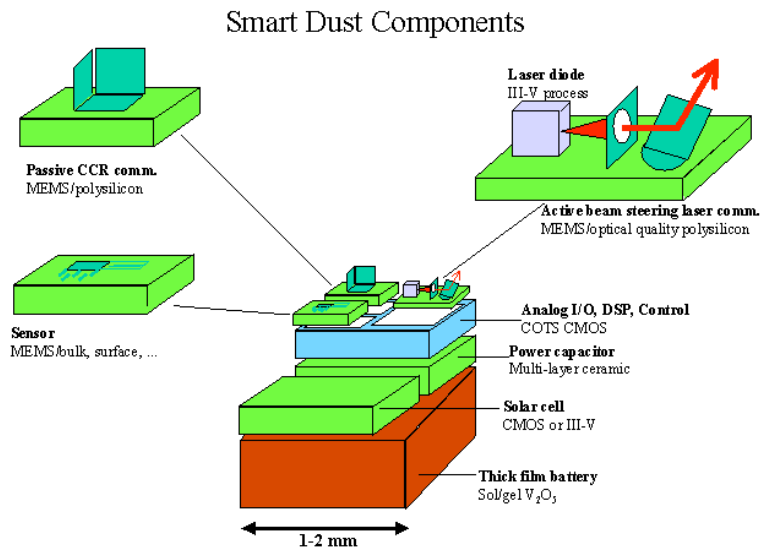
Motivation

The Smart Dust project

UC Berkeley

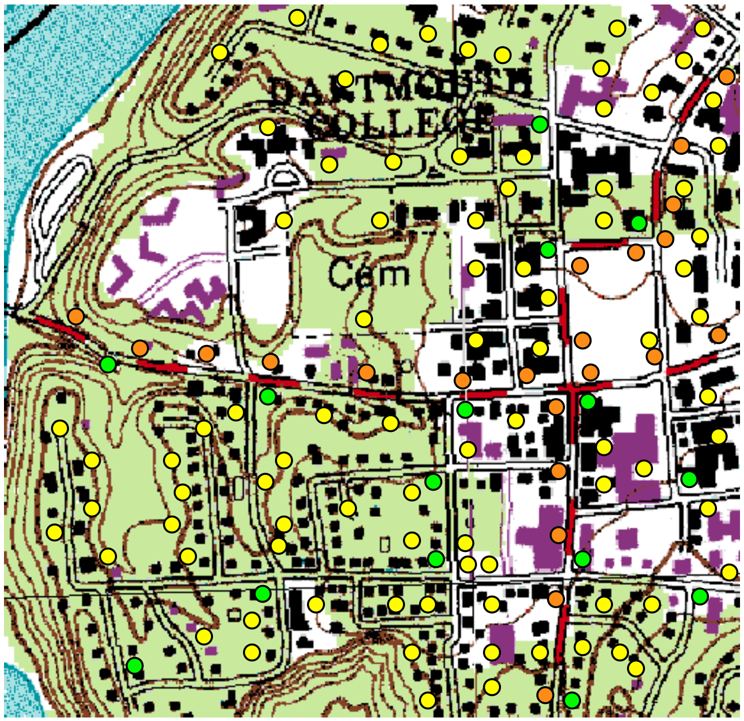


macro scale



micro scale

The need for simulation



- Chemical sensor
- Traffic sensor
- Monitor/sensor

Network features:
Massively parallel, large-scale, self-configurable, application diversity, wireless, dynamic, mobility, behavior dependent on environmental conditions.

Environment features: Diversity of independent and inter-dependent dynamic processes.

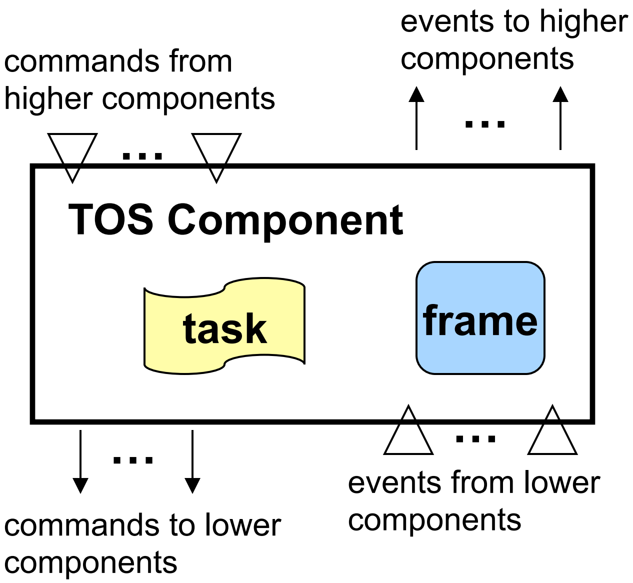
Difficulties: Development, testing, debugging, performance evaluation.

Wish list for a simulator

- Simulates:
  - The processes that drive the sensors in the motes
  - The programs that run on motes
  - The communication medium
- Supports:
  - Very large numbers of motes
  - Direct-execution of programs that run on motes
  - Different applications in the same environment
  - Accurate radio propagation model

TinyOS

The operating system on the mote platform.



Frames represent the internal state of the component and are statically allocated.

Events are analogous to signals or hardware interrupts. They may signal other events or call commands.

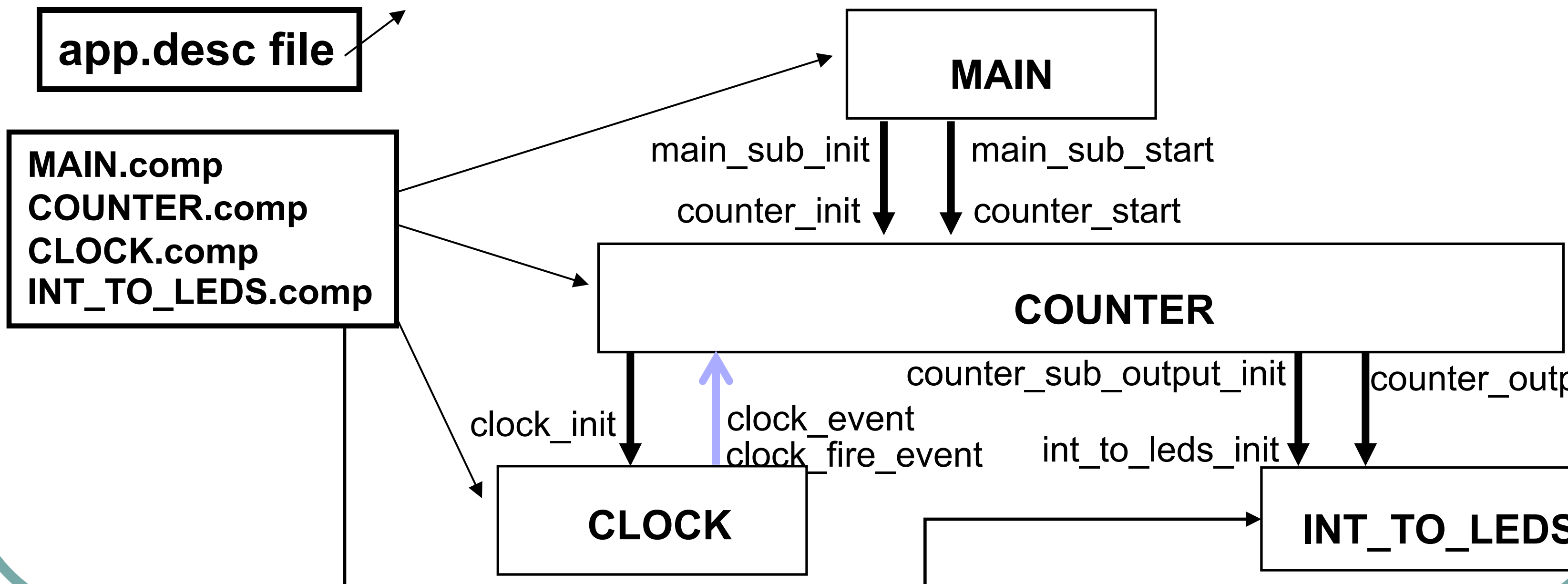
Commands can call other commands or post tasks.

Tasks may be interrupted by events, but not by other tasks. They may signal events and call commands.

Within a mote, tasks are scheduled in FIFO order.

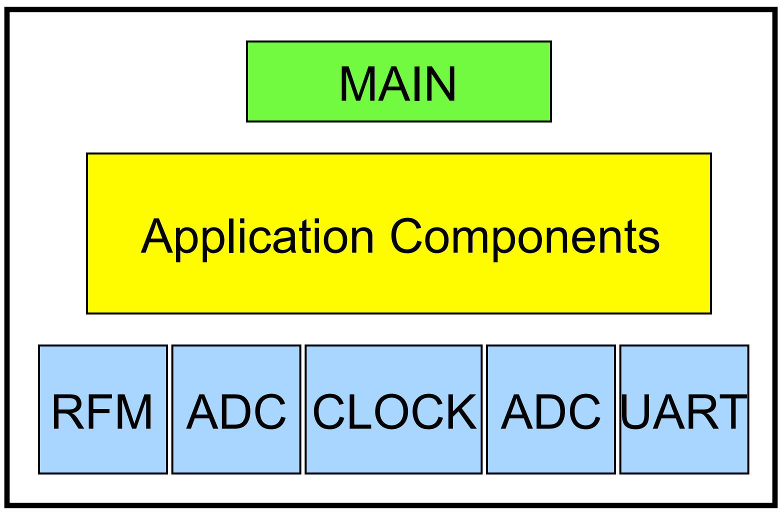
A TinyOS application description

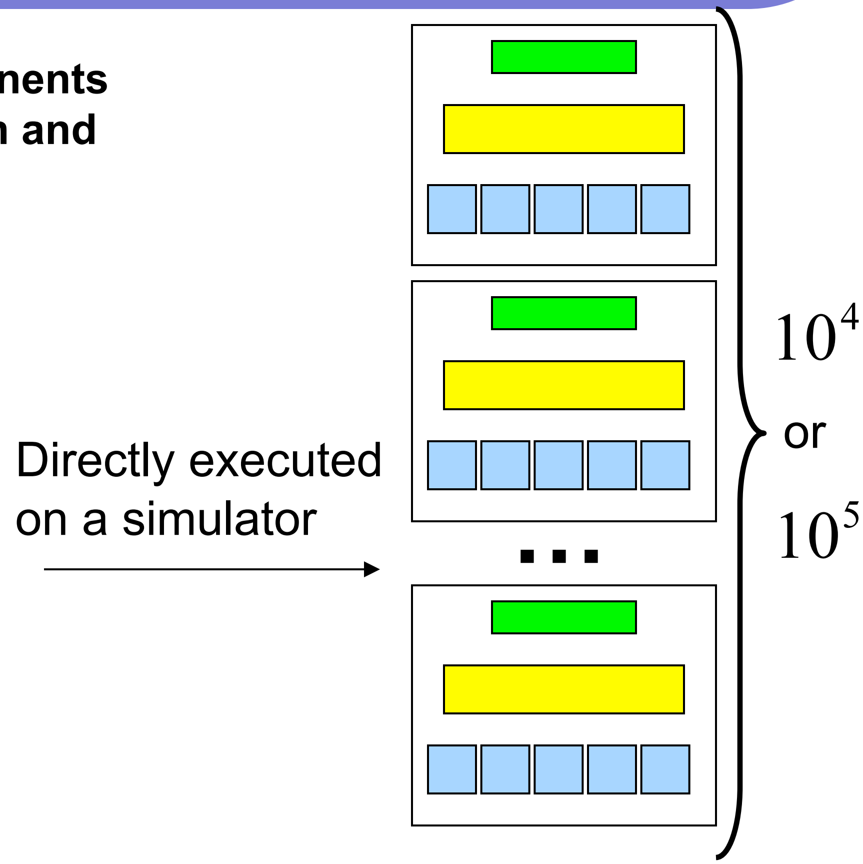
```
include modules{
MAIN;
COUNTER;
INT_TO_LEDS;
CLOCK;
};

MAIN:MAIN_SUB_INIT COUNTER:COUNTER_INIT
MAIN:MAIN_SUB_START COUNTER:COUNTER_START

COUNTER:COUNTER_CLOCK_EVENT CLOCK:CLOCK_FIRE_EVENT
COUNTER:COUNTER_SUB_CLOCK_INIT CLOCK:CLOCK_INIT

COUNTER:COUNTER_SUB_OUTPUT_INIT INT_TO_LEDS:INT_TO_LEDS_INIT
COUNTER:COUNTER_OUTPUT INT_TO_LEDS:INT_TO_LEDS_OUTPUT
```



Toward direct execution simulation

Application code for one mote: components are wired together through compilation and linking.





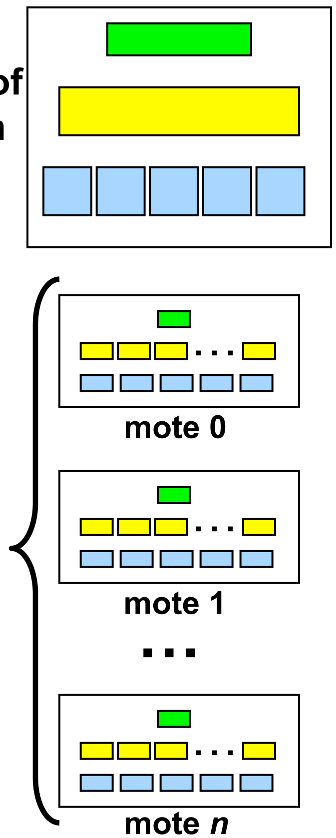
Unnecessary replication of the same code within the simulator.

Frames and local variables

Simulator's memory space:

One instance of the application code

Multiple instances of the component frames in the application



Frame declaration:

```
#define TOS_FRAME_TYPE mycomp_frame
TOS_FRAME_BEGIN(mycomp_frame) {
        int x;
}
TOS_FRAME_END(mycomp_frame);
```

Frame variable reference:

```
VAR(x)=0;
```

Frame declaration:

```
struct BLINK_frame : public TOSSF_Frame {
  char state;
};
```

Frame variable reference:

```
registerFrame("BLINK", new BLINK_frame, moteId);
BLINK_frame* TOSSFptr = (BLINK_frame*)
    getFrame("BLINK", moteId);
(TOSSFptr->state)=0;
```

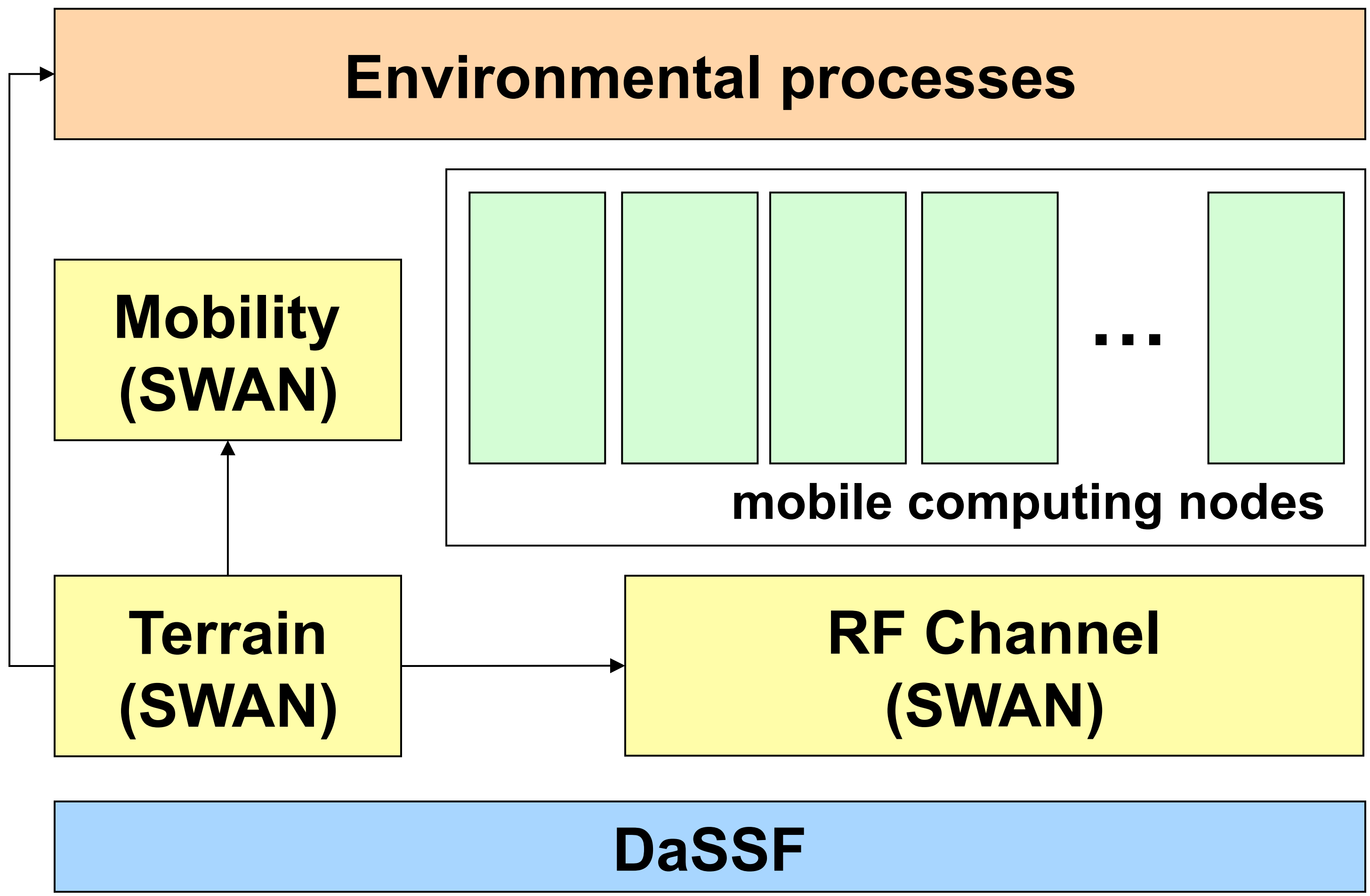
Application / Component linkage

To each application associate an object that maps the outbound wires of a component to the inbound wires of another. This object can be initialized at run time: applications can be defined at run time from a definition file or script.

```
char BLINK_INIT_COMMAND(long moteId) {
  registerFrame("BLINK", new BLINK_frame, moteId);
  BLINK_frame* TOSSFptr = (BLINK_frame*) getFrame("BLINK", moteId);

  (*TOSSFwiringMap("BLINK","BLINK_LEDr_off_COMMAND")) (moteId);
  (*TOSSFwiringMap("BLINK","BLINK_LEDy_off_COMMAND")) (moteId);
  (*TOSSFwiringMap("BLINK","BLINK_LEDg_off_COMMAND")) (moteId);
  (TOSSFptr->state)=0;
  (*TOSSFwiringMap("BLINK","BLINK_SUB_INIT_COMMAND")) (moteId,  tick1ps);
  return 1;
}
```

```
REGISTER_COMMAND("BLINK", BLINK_INIT_COMMAND);
REGISTER_COMMAND("BLINK", BLINK_LEDr_off_COMMAND);
REGISTER_COMMAND("BLINK", BLINK_LEDy_off_COMMAND);
REGISTER_COMMAND("BLINK", BLINK_LEDg_off_COMMAND);
```

The simulation substrate



A simple TOSSF model

```
MODEL [
  ARENA [
  MOBILITY [
    model "mobility.stationary"
    deployment "preset"
    seed 12345
    xdim 5000 ydim 5000  ]
  NETWORK [
     model "network.fixed-range"
     cutoff 200    ]
  ]

  MOTE [
    ID 1
    xpos 0 ypos 0
    battery 500
    _extends .APPLICATION_TYPES.BLINK
   ]
  …
]
```

```
APPLICATION_TYPES [
BLINK [
 components [
 session [name "LEDS" use "system.LEDS"]
 session [name "MAIN" use "core.MAIN"]
 session [name "CLOCK" use "core.CLOCK"]
 session [name "BLINK" use "app.BLINK"]
 ]
 wiring [
 map [MAIN MAIN_SUB_INIT
          BLINK BLINK_INIT]
 map [MAIN MAIN_SUB_START
         BLINK BLINK_START]
 map [BLINK BLINK_LEDy_on
          LEDS YELLOW_LED_ON]
 …
 ]
]
]
```

DML script describing the application and the simulation scenario

Limitations of TOSSF

- All interrupts are serviced after a task, command or event finishes executing.
- Commands and event handlers execute in zero simulation time units.
- No preemption.

Scalability

- The complete SWAN code occupies 1.5M bytes of memory.
- A workstation with 256M bytes memory can hold roughly 32,500 motes.
- The memory overhead associated with each application type definition is that of a wiring map definition.
- The processing overhead involves table lookups for every variable reference and every function call (command or event). The cost incurred is application dependent.
- The model can be broken up for parallel simulation in SWAN: we’ll be able to experiment with very large network.

Future work on TOSSF

- **Mote platforms got a lot more powerful: memory has increased from 8K to 128K. One can code up a single executable containing different applications to be deployed in all motes.**
- **A new generation of motes slated to be released soon will use different radio technology.**
- **With the release of TinyOS 1.0, applications are described in a different way in a dialect of C: nesC. All the source-to-source translation in TOSSF needs to be rethought.**
- **The nesC language is said to be a *transient* solution: a more powerful programming language are a work in progress.**