Towards a Low Power Virtual Machine for Wireless Sensor Network Motes

Hitoshi Oi

The University of Aizu

C. J. Bleakley

University College Dublin

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Wireless Sensor Network

- A network of tiny devices (motes) consisting of
  - a microcontroller (CPU)
  - wireless interface
  - battery
  - memory
  - sensors (e. g. temperature, sound)
- Possibly thousands of motes are deployed over a wide area and used for various applications such as habitat, environmental or traffic monitoring.
- Once deployed, reprogramming motes are difficult

Virtual Machine for WSNs

- Customized and uniform programming model
  - motes can be heterogeneous
  - choose instruction set and library for target applications
- Robust and Secure Platform that protect systems from malicious and buggy programs
- Concise program footprints
  - smaller memory size
  - shorter radio communication for program update over the network

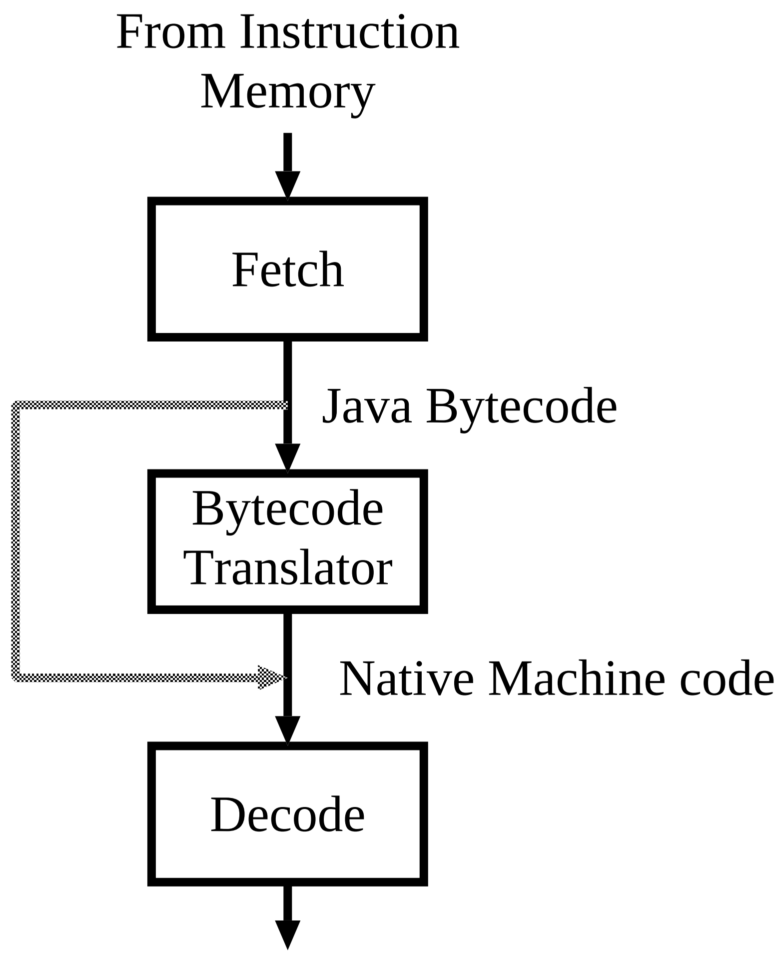
Execution Overheads of VMs

- Stack architecture on a register-based processor (redundant operations)
- Every few instructions executed as a TinyOS task (scheduling overhead)
- Polymorphic operands

These overheads make VM approach only suitable for applications frequently updated but infrequently executed.

Hardware Translation in Emb. JVM

- Mainly concerned with filling the gap between stack-based and register-based architectures.
- Small logic module translates Java Bytecodes into ARM instructions
- Translation is in on-the-fly single bytecode basis (no extra storage of translated code).



Virtual Machine WSNs

JVM

- Interactive system (response time)
- Relatively larger memory size
- Various and complex applications

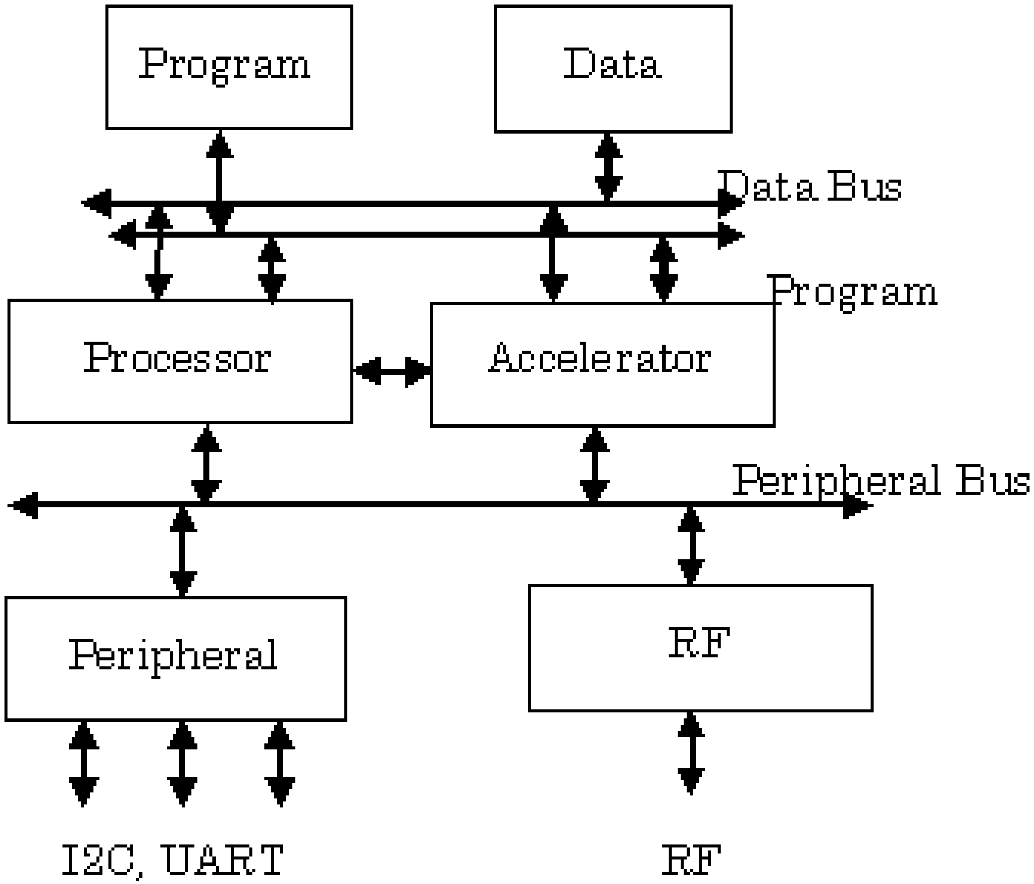
WSNVM

- Autonomous systems (power consumption)
- Smaller memory size
- Simple tasks (e.g. aggregation of sensor data)

Hardware Accelerator Approach

- Identify frequently executed functions in WSN (TinyOS) applications
- Investigate the feasibility of implementing these function by hardware modules (hardware accelerator)
- Execution of these functions by the simpler hardware modules should result in shorter running time and also lower power consumption.
- The hardware accelerator can also be used for reducing the execution overhead of VM execution.

WSN Node Architecture



Optimization Target (1) Synchronization

Operation	Cycles	Time (μs)
Lock	32	8
Unlock	39	10
Check Runnability	929	232
Run	1077	269
Resume	2038	510
Analysis	15158	3790

(From UCB//CSD-04-1343)

Check Runnability check if all resources available

Analysis extract resource usage in the capsule

Optimization Target (2) Stack Operation

Folding 'Simple' Instructions

- Example: `pushc6` + `add` → `addc6`
- Reduce the number of VM instructions to be executed effectively
- Reduce the task invocation overhead
  - Small number* of bytecodes are invoked as a task in Maté
  - * `MATE_CPU_QUANTUM` = 1 (ver. 1) or 5 (ver 2.19a)
- Should be done during the capsule analysis

Optimization Target (3) Polymorphic Operands

Some Instructions Take Multiple Operand Types

Example: `add`

`add Integer Integer` → `Integer` (Arithmetic Sum)

`add Message Integer` → Append `Integer` to Message

`add Message Message` → Message Concatenation

- Capsule analysis should disambiguate operand types
- Rewrite each `add` into type-specific `add` (such as `addII`, `addMI` or `addMM`)
- Eliminate instructions for type information retrieval and conditional branches

Polymorphic Operands Example: add

```
if ((arg1→type == MATE_TYPE_INTEGER)
  && (arg2→type == MATE_TYPE_INTEGER)) {
  call Stacks.pushValue(context, arg1→value.var
    + arg2→value.var);
}
else if (arg1→type == MATE_TYPE_BUFFER) {
  if (arg2→type ≠ MATE_TYPE_BUFFER) {
    call Buffer.append(context, arg1→buffer.var, arg2);
  }
  else {
    call Buffer.concatenate(context, arg2→buffer.var,
      arg1→buffer.var);
  }
}
```

Customizable Instruction Set (1)

- In Maté ver 2.19a, the instruction set is fully customizable.
- This is possible for Maté since it is implemented by software-only approach, but not an easy job for hardware assisted VMs.
- However, fully-customizable instruction set may not be necessary because:
  - Primitive arithmetic/logical instructions are needed for any applications (e.g. `add`)
  - Some instructions are mandatory for stack-based architecture (e.g. `push`)
  - Complex operations should be implemented as library functions rather than instructions

Customizable Instruction Set (2)

Our Approach

- Pre-refine commonly used instructions types
  (Foldable instructions are identified based on these types)
- Some parameters can be defined by users
  (such as # bits in constant or variable index field)
- Provide abundant library functions for the application target and let users select (for example) 256 out of them, so that users can invoke functions with a one-byte parameter.

Current and Future Work

- Identification of benchmark programs and usage model for WSN VMs
  - various application field of WSNs
  - VM approach for WSN is relatively new
  - Not only applications themselves but also program update frequency are important for the effectiveness of VM approach a
- Development of an analytical power consumption model for our WSN VM approach for initial evaluation of the approach.
- Development of a more detailed model and combining it with a TinyOS simulator (e.g. AVRORA).

Thank You !

Any Question ?