Towards a Low Power Virtual Machine for Wireless Sensor Network Motes

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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 functions 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

- Program
- Data
- Processor
- Accelerator
- Peripheral
- RF
- I2C, UART
- Data Bus
- Program Bus
- Peripheral Bus
**Optimization Target (1) Synchronization**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Cycles</th>
<th>Time (µs)</th>
</tr>
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<tbody>
<tr>
<td>Lock</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>Unlock</td>
<td>39</td>
<td>10</td>
</tr>
<tr>
<td>Check Runnability</td>
<td>929</td>
<td>232</td>
</tr>
<tr>
<td>Run</td>
<td>1077</td>
<td>269</td>
</tr>
<tr>
<td>Resume</td>
<td>2038</td>
<td>510</td>
</tr>
<tr>
<td>Analysis</td>
<td>15158</td>
<td>3790</td>
</tr>
</tbody>
</table>

(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: \texttt{pushc6 + add \rightarrow 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
  - * \texttt{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

```java
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. \texttt{add})
  – Some instructions are mandatory for stack-based architecture (e.g. \texttt{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?