Poster Abstract: Using Meta-Code for Building Task-Specific WSNs

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ABSTRACT
High-level programming abstractions (i.e. "middleware") primarily aim at: abstraction from heterogeneity and hardware complexity, simplification of (re-)programming, specifying system behavior in a post-hoc fashion. So far in the Wireless Sensor Networks (WSNs) domain the focus has been put mainly on the first two tasks and the application level of the last one. The meta-code approach we propose offers mechanisms to support low-level programming (e.g. time-sync, routing schemes, etc) on pre-deployed networks still requiring minimal knowledge of network characteristics. Its sole task is to provide tools to finely tune existing infrastructures with an "assembler-level" granularity in order to create task-specific highly optimized configurations. The meta-code is being designed taking into account specific requirements of WSNs, namely limited computational resources and power consumption.

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1. INTRODUCTION
Middleware and novel programming paradigms normally come as a second front after corresponding low-level protocols within a certain domain have been designed, developed and evaluated. In case of WSNs those things started happening at the same time: Maté [1], Dynamic VM [2] and Contiki VM [3] (reprogramming), Agilla [4] (mobile agents), TinyDB [5] and SwissQM [6] (queries). This might be the reason why the solutions mentioned above lack a number of important features: changedeability, scalability, efficiency, etc.

By introducing the new approach called meta-code we try to fill the gap in which high-level programming abstractions can be used to build network architectures (full network stacks, or separate layers) in a post-deployment manner. Meta-code provides control (including version control), deployment and execution of a code without requiring any pre-configuration of the network. Meta-code can be used for building full network stacks from scratch, or to create a complementary layer to an existing one.

Our motivation behind creating the meta-code is to make feasible designing system-level protocols and deploying them over the existing network infrastructure. Eventually, it will allow us to build auto-configurable (can react to changes in topology, sensor attachments, etc) and self-documenting (can report changes) network systems. Another stimulus would be having a system which is able to take proactive actions (further operations are based on recognition and analysis of patterns from the past). More inspiration was taken from the works on mobile codes and chemical computing [7].

2. SYSTEM OVERVIEW
In the heart of the meta-code framework (see Figure 1) lies a stack-based extensible Virtual Machine (VM) which must be installed on each node.

![Figure 1: Meta-code framework](image)

VM (see Figure 2) is OS-independent and type-free, although it uses system calls to perform low-level operation (forward a packet, write a memory, etc). VM has a dynamically extensible Instruction Set Architecture (ISA). VM’s programs (meta-code) are delivered to a node and executed there in a form of capsules which can migrate from node to node. Capsule’s code is versioned. Capsules support split/merge operations; they are isolated from each other but can communicate via shared memory, though.

2.1 Meta-data Management
Meta-data layer is a fundamental part of the system which serves as an exchange media between various layers (VM, capsules) and a semantics holder for meta-code. Meta-data can hold any data types: network configuration (topology, faults, etc), software versioning, instruction set dictionary, user-defined structures. Instruction Set Dictionary (ISD) allows to dynamically change ISA by defining new or removing obsolete instructions. Possible version conflicts are managed through dictionary versioning. As a result code can be optimized (compressed) at a bit-level. Nodes exchange and
propagate this compressed code which allows to better utilize low-bandwidth wireless links.

2.2 Meta-code Execution

Meta-code can be used either for performing system-level tasks (track changes in the network, process on-demand requests, create reports for the upper layers, etc) or to develop user applications (e.g. data gathering). Dynamically extensible and configurable dictionary-based ISA used in the VM allows meta-code to change its behavior without changing the actual code resided on the node. This also makes possible code polymorphism when one instruction can be used to perform different actions (on different nodes and/or at different time points).

3. SHOW CASES

The following show cases are supposed to give some idea of how meta-code can be used. In the first example we show how to build a classical spanning tree using meta-code.

**Show Case 1: Building a spanning tree**

```plaintext
1: sys # SYSTEM segment
   AUTOUPDATE 1
   LIFETIME 10s
   ID 0x11
   .buf # DATA segment (allocated inside the capsule)
   ID 0x11 # 4-bit ID + 4-bit version number
   LIFETIME 10s
   AUTOUPDATE 1
   .code.init # CODE segment "init" (executed once)
   .bufc # DATA segment (allocated inside the capsule)

2: send ME,ALL # broadcast itself
   push BUFS[1] # check the distance
   mov BUFS[1],hops # (allocated from the node’s memory pool)
   inc hops
   jmp l2
   jmp l1
   mov BUFS[0],ME.ID # store ID and "hops" in the shared memory BUFS
   jmpeq ME.ID,l1
   push BUFS[0] # first we check the ID

3: show CASES different time points). to perform different actions (on different nodes and/or at the actual code resided on the node. This also makes possible applications (e.g. data gathering). Dynamically extensible and configurable dictionary-based ISA used in the VM allows meta-code to change its behavior without changing the actual code resided on the node. This also makes possible code polymorphism when one instruction can be used to perform different actions (on different nodes and/or at different time points).

The second show case demonstrates how to count the number of nodes in the network; the result is known at the top of the tree. The algorithm assumes that we already have an established tree topology in the network (see the example above). In addition, for this example we will have to change the spanning tree building capsule: instead of checking PACK.DST we check CAP.DST in order to receive and forward incoming capsules (not packets).

**Show Case 2: Count the nodes**

```plaintext
4: show CASES different time points). to perform different actions (on different nodes and/or at the actual code resided on the node. This also makes possible applications (e.g. data gathering). Dynamically extensible and configurable dictionary-based ISA used in the VM allows meta-code to change its behavior without changing the actual code resided on the node. This also makes possible code polymorphism when one instruction can be used to perform different actions (on different nodes and/or at different time points).

The last capsule is executed locally on the sink node $S$; it calculates all incoming "counting" capsules:

```plaintext
5: references

5. TinyDB. http://telegraph.cs.berkeley.edu/tinydb/.