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Distributed Diagnostics Tool for Sensor Networks

Master's Thesis in the Master Degree Program, Network and Distributed Systems

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Department of Computer Science and Engineering
CHALMERSUNIVERSITYOFTECHNOLOGY
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Abstract

Sensor network plays more and more import role in modern industries, but debugging and diagnosis is always error-prone and time-consuming.This research aims to make up the debugging gap between simulation and testbed on sensor net.

'SUSE' is a set of tools that provide a variable level debugging and diag-nostics tools on both emulators and testbeds. Firstly, 'Snapshot collector' used to generate snapshots on test beds then collect them into a sink node. Secondly 'Up/Downloader' make helps on transferring data between emu-lators and test beds. 'Standard mask generator' creates variable masks from snapshots. Finally 'Evaluator' generates a report depends on comparison between masks that come from emulators and test beds.'SUSE' can fulfill the gap between simulations and testbeds, which also provides help on performing different tests and fault injection on testbeds. 'SUSE' is also a powerful idea that can be expanded to different platforms.

Key words: Sensor Networks, Debug, Diagnose,'SUSE', 'Snapshot Collector', 'Up/Downloader', 'Standard Mask Generator', 'Evaluator'.

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Glossary

Definitions

Contiki	Name of a micro-operating system.
Cooja	Name of a simulator inContiki.
Sink node	Node to receive checkpoint files from others.
Supplier node	Node to send checkpoint file to sink node.
VANET	Vehicle ad-hoc networks.
CFS	Coffee File System
Tmote Sky	Name ofa sensor model.

Chapter 1

Introduction

Recent work on sensor networks shows growing demands in debugging and diagnosis. They need innovative applications to enhance diagnostics performance and reduce the gap between simulator and test bed at the same time. The prospects of these applications depend on the ablility of recording instant snapshots from all nodes, and then transfer these snapshots between simulators, computers and test beds. We consider a solution that may create, transfer snapshots and then diagnose them. One of the options is the checkpoint function that provided by Contiki, which can freeze a node and dump all memory content into a checkpoint file (one snapshot).

The studied problem appears when sensor nodes can only rollback from where the snapshots were created, and there is no diagnosis method that can help developers from manually checking these snapshots, see Chapter 2. We propose an integrated model that supports data transmission between simulator and test bed; we also provide an efficient diagnosis method by evolving a variable mask, see Chapter 3. Let us illustrate the problem and challenges of performing diagnosis on sensor networks. Consider two neighboring nodes are working on an algorithm, they work well in the first cycle, and then one node starts to generate wrong data from the second cycle, but the strange thing is that this bug is never produced on simulator. In the past, there are three options for us to settle this dilemma: a regression test on another simulator, checks source code line by line or analyzes the output. Alghough we can fix the bug sooner or later, but apparently this is a very time comsuming process especially when we work on large numbers of nodes.

1.1 Related Work

A number of diagnosis methods have beens used for sensor networks, for example [1] consider diagnositic tracing for sensor networks,[2] studied fault management in sensor networks, [3] consider monitoring and diagnosis in sensor networks, [7] mention how to enabling efficient static verification, and [8, 9] look into the problem of fault diagnosis and the discovery of silent failure in sensor networks.Some of them have provided variable related diagnosis: for example, [1] shows a inter-procedural and intra-procedural tracing on the values of key variables, [10] studied a hybrid simulation and emulation on test bed of VANETs. These are more efficient methods than before but they still do not consider 'cross-border' diagnosis to fulfill the differences between simulator and test bed.

Osterlind et al. [5] purposed a solution for a 'cross-border' diagnostic method by transferring checkpoint files between simulator and test bed. This solution shows a new thinking. Observe that this diagnostic method can reproduce bugs on simulator after we found them in test bed. We can firstly dump all variables into a checkpoint file on testbed, and then send these checkpoing files to simulator; after rollback from these checkpoint files, we can restart the scenario that was originally running on test bed and trace the variables if any of them have triggered the bug on test bed. But this method still does not a complete solution. One of the reasons is that there are over 500 or 600 variables in one sensor node under normal circumstances, so manually validating all variables is a super time consuming task although we can transfer and rollback all variables from test bed to simulator through checkpoint files, just imagine what will happen if we have to debug a 10-sensor system.

We note that an efficient diagnosis can display suspect variables from all nodes and it should also work at least semi-automatically instead of fully manually checking. Comparing with existing literature, our solution provides at least two contributions: first of all, it provides a new kind of simulation that involves both simulator and test bed. When comparing to our solution, other existing method can only operate the simulation either on simulator or test bed, so they can not deal with the bugs only produced on test bed but never show themselves on simulator. Our advantage is obvious: we can reproduce the bugs on simulator just after we found them on test bed. What's more, we can carry on further diagnosis by observing the values of variables. On the other hand, our implementation provides a fast variable level diagnosis mechanism that can automatically diagnose the suspect variables with possible faulty values within tens of seconds; comparing with other existing methods, our solution can save a lot of time when diagnose on systems that involves large number of sensor nodes.

Chapter 2

Preliminaries

The system consists of a test bed and a simulator. In this case, the test bed consists of 3 sensor nodes and we use Cooja to work as the simulator. The tasks of test bed are running algorithms then create and collect checkpoint files; and the tasks of simulator is to perform diagnosis by generating masks and then find out suspect variables by comparing them. From section 2.1, we will introduce basic knowledges for test bed, Contiki, Cooja and checkpoint process. More information could be found on the website of Contiki.

2.1 Test Bed

We use three Tmote Sky sensor nodes to work as test bed in this case. Tmote Sky is a broadly used energy-saving wireless sensor, it also supports varies standard ADC interfaces or SPI/I2C interfaces. Tmote Sky use MSP430 series CPU and mostly commonly are F1161 and F5438; among them, F1161 has lowest energy consuming feather in MSP430 series but its computing performance is also much lower than F5438. MSP430 is able to make use of tool chains that are provided by TI, but those tool chains cannot support full features of this type of CPU. One advantage is that the Tmote sky sensor nodes supports both Contiki and TinyOS embedded operating system. It also supports extremely low power consumption and highly integrated antenna. Tmote Sky has become an eco-friendly device, which also broadly used in many areas. In this case, we use one Tmote Sky to works as sink node, which task is to receive checkpoint files from all others.

2.2 Contiki

Contiki was developed by SICS (Swedish Institute of Computer Science). Contiki has the advantage in supporting IP connections when comparing with TinyOS. Although Contiki is a lightweight embedded operating system, but it supports many enhanced features, such as multi-threading, build-in TCP/IP stack, file system and even a web browser, which is maybe the smallest in the world.

Contiki is an open-source embedded operating system, and it is easy to transplant to many sensor platforms. One of its advantages is it supports an embedded file system named Coffee File System (CFS), which use external flash as its storage media when comparing to other embedded systems. Observe that Coffee File System can help delivering update files by transferring them to nodes' external disk then trigger the update operation if we want to spread the new code base to large amount of sensors. But it also comes with one disadvantage: it cannot use either large-scale data structure or memory cache due to the limited memory size when comparing to file systems that are using on computers.

Protothread is another advanced feature that provided by Contiki. Protothread is a process controlling model, which is a lightweight threads mechanism and it can run without the support of per-process stacks. On the other hand, protothread does not have any complex state machines and full-featured multi-threading operations, so it can fulfill the limited hardware requirement on sensors. One disadvantage of protothread is the lack of support for local variables when we switch context between threads or thread blocks, since Contiki does not has any internal stacks to maintain variable states. Fortunately, we can define variables into a 'static' type to avoid this.

2.3 Cooja

Cooja is a simulator and it is also a component of Contiki. Cooja can simulate the operations of multiple sensors before we deploy them on test bed. It is a multi-layer simulation tool, which can perform simulation on all three levels. But it is also coming with a disadvantage: it cannot implement a simulation on all three layers in one node simultaneously; so if we want to perform the simulation on all levels in one scenario, we have to run it three times. This feature slightly reduces the practical value to some extent.

Cooja provides us flexible expanded capacity with multiple plugins and interfaces. Observe that plugins can be divided into five categories: mote plugin can initiate from the menu of one specific node instead of Cooja's menu. It provides functions that are directly related with nodes, such as read/write motes' memory, serial input/output and Contiki shell. Secondly, Contiki provides simulation plugins that can be activated throughout one or multiple simulations. It can be initiated from the Cooja's menu. Thridly, Cooja plugins are general plugins for all instances, and they do not depend on any senarios, such as the control panel, simulation visualizer and the timeline. Simulation Standard plugin is easy to confuse with simulation plugin, the only difference is that they can initiated by default together with simulation initiating, what's more, we can configure them by editing configuration in Cooja. Lastly, Cooja standard plugins can also automatically activated with simulation initiating simultaneously.

One advantage of Cooja is that we can develop plugins that we need, and then add them into plugin list before using them in a new session.

2.4 Checkpoint Process

Checkpoint process works in Tmote Sky nodes, which dumps all content from memory to a checkpoint file. This is a useful feature when we diagnose on simulator or test bed; we can rollback from them and let the nodes go backwards to previous states when we have created them.

Observe that there is one factor that might restrict the effect of checkpoint mechanism: checkpoint files can only rollback in same environments where we have created them.Contiki does not provide any tools that can transfer checkpoint files between simulator and test bed.But obviously it will be more powerful if we can.Other than that, although we can rollback from a checkpoint file, we have to manually check the variables when a bug occurs.

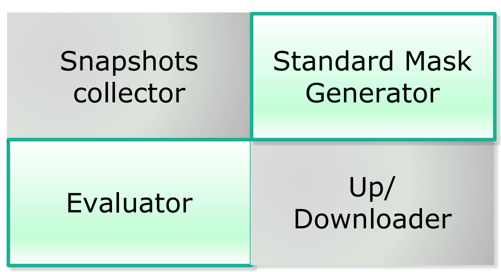
2.5 Task Definition

The problem of diagnosis on sensor networks is that we need a tool, which can enhance the efficiency of testing and debugging when we deploy our source code from simulator to test bed. This tool should provide the ability to make snapshots on nodes, transfer them between simulator and test bed, and then perform diagnosis on them.

Chapter 3

Design Strategies for Distributed Diagnostics Tool

We have addressed four problems in the design of diagnostics tool: collect checkpoint files to sink node; transfer checkpoint files between sink node and computer; generate standard masks; perform an automatically diagnosis and figure out all possible faulty variables. Before settling implementation details in Chapter 4, we organize all functions into four low coupling and high cohesion modules according to the problems that we have addresses, see figure 2.1.



Compositions for 'SUSE','S' is the first letter of 'Snapshots collector', 'U' is the first letter of 'Up/Down loader', 'S' is the first letter of 'Standard mask creator', 'E' is the first letter of 'Evaluator', that's why we call it: 'SUSE'.

Figure 3.1 *compositions of 'SUSE'*

‘*Snapshots collector*’ creates checkpoint files and collects them to sink node; ‘*Up/downloader*’ exchanges files between sensors (both in simulator and test bed) and computers. ‘*Standard mask creator*’ creates a standard mask, which works as a reference. And finally, ‘*Evaluator*’performs diagnosis by comparing target masks and a standard mask. We present the design details for different modules from section 3.1.

3.1 Snapshots Collector

This module creates and collects checkpoint files to sink node. Theoretically, ‘*Snapshots Collector*’ is consists of three main procedures: an algorithm that is going to be diagnosed, a process that creates checkpoint files and a data-collection process.

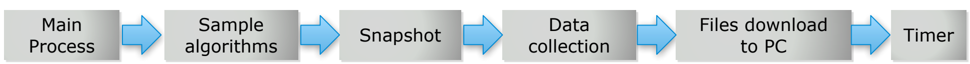


Figure 3.2*Snapshots collector*

Let us look into a typical workflow of ‘*Snapshots Collector*’, see figure 2.2. Given one algorithm that runs periodically on test bed, we say that this algorithm is the target for diagnosing. Observe that figure 2.2 shows only one cycle within a loop; the sample algorithm then follows by a checkpoint process, which saves all variables from memory to a checkpoint file.As soon as the checkpoint process is finished, we start a collect protocol in order to collect checkpoint files to sink node. This process includes a parent finding algorithm and a routing algorithm by default, and it costs about 30 seconds to discover the routing information before data transfer. After that, we pad data into radio packet and send them through a radio connection to sink node.In this case, one sink node has the capability to save 100 snapshots at the same time.Other than this, we setup a 20 seconds delay for file transfer from Cooja/test bed to computers.Observe that one of the advantages of ‘*Snapshots Collector*’is simpleto use: we simply replace the sample algorithm to another that we want to debug. In next section, we present standard mask creator that works as a reference in diagnosis.

3.2 Up/Downloader

Up/downloader exchanges checkpoint files between test beds and simulators. Cooja has provided a socket serverfor sending and receiving files, but we have to develop a client that works on computer. Considering test beds are connected to computer through a serial port, we develop a serial reader and writer for exchanging files between them.

Contiki does not provide any commands that directly write data to serial ports, but we have found a uart_writeb ()function in serial driver, which sends one byte to serial port at each time.According to receive data in nodes, let us look into a typical receiving workflow in Contiki,as soon as we send a byte to nodes, Contiki calls an input handler function and then sends the byte to a receiving buffer.So in this case,we redefine the input handler and redirect the incoming data flow when we receive files in nodes.

One important thing to also note is that the writing speed in nodes is much slower than reading, so we define a buffer and transfer files by blocks in order to enhance the writing performance.

3.3 Standard Mask Creator

This module creates standard masks to work as references in debugging. Observe that a standard mask indicates which variable is modified during checkpoint process and which isn't. This provides the ability to compare between a standard mask and target masks; the latter is a mask comes from test bed that needs to be diagnosed. Let us look into a distributed sensor neworks to find out what happens when we create checkpoints.When we trigger a checkpoint process on all nodes, they do not start at same time. There are two possible reasons that may explain this, one is we do not have any synchronize mechanism on nodes, and the other is that nodesmust react to interrupts or incoming packets before they start checkpointing. We can observe schematic diagram from figure 2.3.

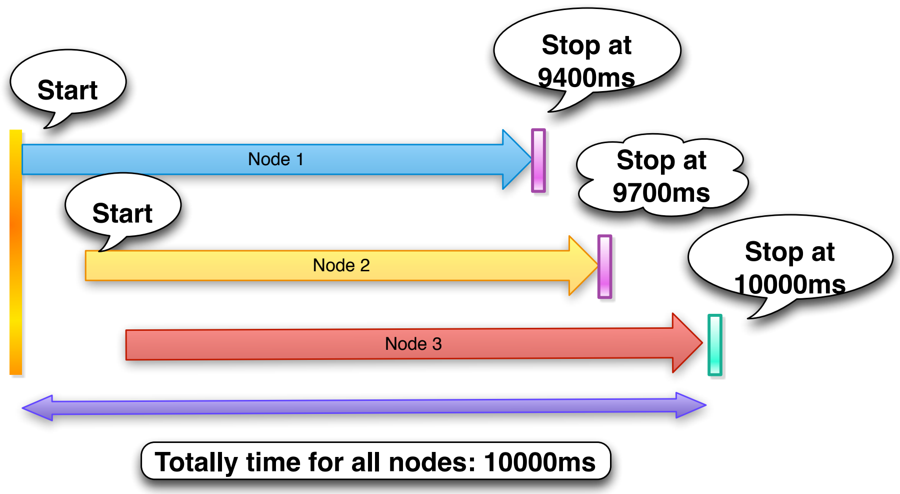
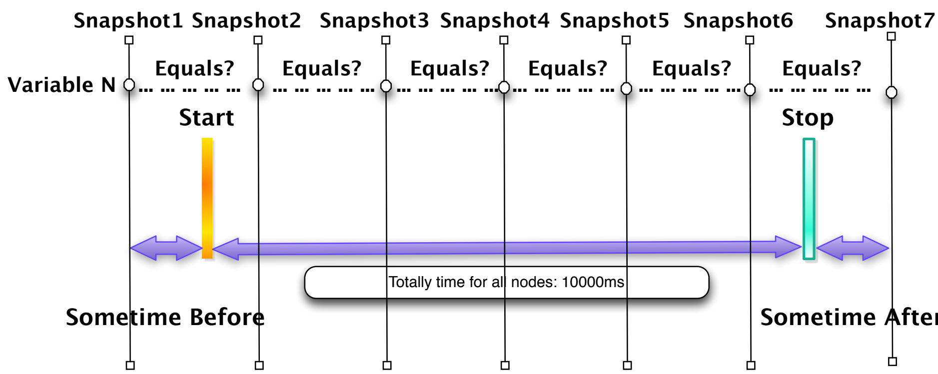


Figure 3.3*Checkpoint processesthat run on multiple nodes*

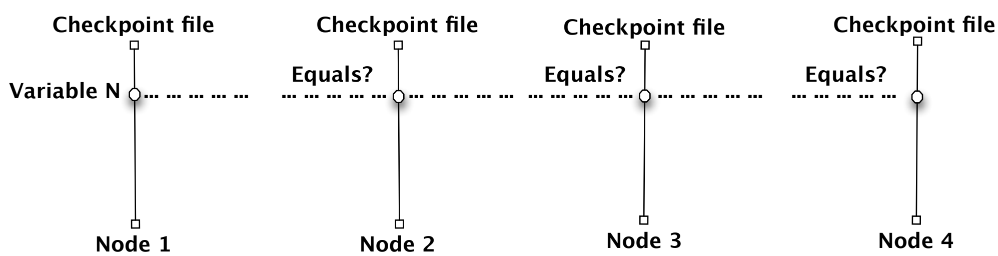
We have worked out a solution to combat the asynchronous problem during checkpoint process. Recall from the previous paragraphs that in order to find out which variable has been modified, we need to devide checkpoint process into several snapshots then compare between them. See figure 2.4-up, in this case, we cover all checkpoint process from all nodes by defining an earlier start time and a later end time on them.



First Step: Create One Mask in Cooja

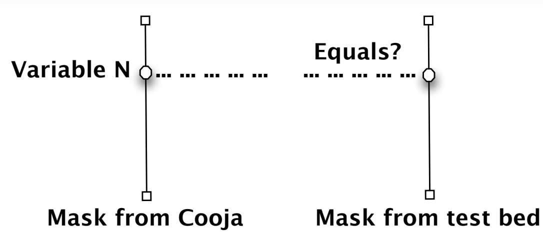
Data source: Given one node, define several breakpoints in checkpoint process and create snapshots from it. Then save all snapshots into database.

Operation: Compare each variable from the first snapshot to the last, keep their value if they equal to each other, modify to a special value if they don't.



Step 2: Create One Mask from Test bed

Data source: Given all nodes in test bed**,** create one checkpoint file in each.



Step 3: Create One Standard Mask

Operation: Import all checkpoint files into Cooja, then compare each variable from the first checkpoint file to the last, keep their value if they equal to each other, and modify to a special value if they don't.

Data source: One mask comes from Cooja and one comes from test bed.

Operation: Compare each variable between them, keep their value if they equal to each other, modify to a special value if they do not.

Figure 3.4 *Creation of a standard mask*

Figure 2.4-middle shows the creation of a mask from Cooja. It is not a standard mask unless we amend it by a mask that comes from test bed. We cannot interrupt nodes when they are running, but we can create mask from their checkpoint files, because a checkpoint file copys all variables from memory.In figure 2.4-down,we amend the Cooja mask in order to generate a standard mask.Next step, in section 3.4, we perform a diagnosis with the help of evaluator.

3.4 Evaluator

Evaluator performs comparison between different masks, and then generates a report to display all suspect variables, together with their physical addresses.

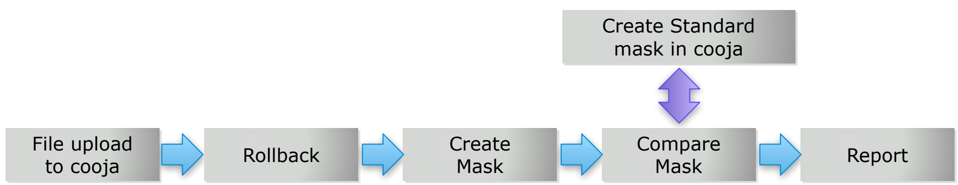


Figure 3.5*Working* flow of *evaluator*

This module is based on the ability to make comparison between different masks. Observe from figure 2.5 that we need to upload checkpoint files to Cooja in order to create debug mask. A debug mask is similar with test bed mask that has been mentioned in section 3.3, the only difference is, we use checkpoint files that come from a faulty test bedthat needs to be diagnosed.If there are any differences between a debug mask and standard mask, we save these suspect variables into final report together with their physical addresses.

Chapter 4

Implementation

This chapter delineates the challenges and techniques that related to the implementation of 'SUSE', such as: Contiki does not provide a bulk data transmission protocol between different sensors, so we have to find a method in order to collect checkpoint files to sink node. Other than this, we have to develop a tool to transfer different checkpoint files between sink and computer. We also have to find out how to define a standard mask and how to implement the fast diagnosis automatically.

4.1Platform and Achitecture

For all implementations and evaluations in this case, we use Contiki2.5 and Tmote sky to work as operating system and test bed; the latter is based on an MSP430 with 802.15.4 compatible CC2420 radio chip. Tmote sky provides a one-megabyte external flash storage memory (ST M25P80 40MHz) and two light sensors. Tmote sky also includes a 10k byte RAM and a 48k byte flash.

4.2Snapshots Collector

The data colleting protocol is initially designed for gathering data from sensors such as temperature, humidity or light, but it supports packet size up to 100 bytes. In this case, we collect files by selecting an appropriate packet size, transmission interval and retransmission time.

```
collect_open();                 // open collect channel
collect_find_sinknode();        // find sink node through a routing algorithm
memcpy(packet_buffer);          //read data from file then pad into rime packet
collect_send();           // send out packets through collect channel
packet_buffer_clear(); // clear the rime buffer and wait for new data
```

In this case, we tweak the performace of data collection by modifying time interval and retransmission time between each two packets. If we decrease these two settings, we enhance the data-collection performance but also increase the data loss rate at the same time. Next, we will describe the implementation of data collection on sink node and supplier nodes.

Implementation of sink node in data collection:

```
// Variables definition
collect_open ();                // define and open a new collect channel
if (node_id==1){                // judge whether it is the sink node by node id
collect_set_sink ();            // if this is sink, setup collect protocol by it
}
```

Sink node is chosen by node id, and then other nodes find sink node by a parent finding algorithm, which also works as a simple routing method. Next is the receiving method of sink node.

```
cfs_open ();                    // define a file for incoming checkpoint files
memcpy (packetbuf);             // receive packets and then copy to a buffer
cfs_write ();                   // save data from buffer to a file
cfs_close ();                   // close the file after each writing
```

We save data into different files since all received packets are distinguished by their rime addresses in headers. Sink node also transfers files with computer, see section 4.4 for more details on file up/download.

Implementation of supplier nodes in data collection:

```
collect_open ();              // define and open a new collect channel
if (node_id! =1)              // make checkpoint on other nodes instead of sink node
{
make snapshot;
}
collect_parent ();            // find sink node
setup etimer ();              // an event time for time interval between two packets
if (checkpoint file exists)   // if checkpoint file exists, goto next step
{
read file;                    //read from checkpoint files, read 64 bytes in each time
memcpy (packet_buffer);       // pad data into packet buffer
send out packet ();           // send packets to sink node
packet_buffer_clear ();       // clear packet buffer for next transimission
}
cfs_close ();                 // close checkpoint files
```

We divide checkpoint files into blocks for data collection, and we select 64 bytes as the block size when considering both rime buffer and collecting efficiency. We also clear the packet buffer after each sending and then wait for new data.One important thing to also note is that there is no synchronization mechanism for both senders and receiver. At the end of data collection, we setup a 20 seconds delay for file transfer from Cooja/test bed to computer.

4.3 Evaluator

Let us look into an evaluator to find out its implementation, we use database to save and excute large scale of data.In this case, each node creates500~600 varaibles in their snapshots, suppose each mask needs 20 snapshots from 2 sensors, then we have to deal with 20,000 to 24,000 variables. This is why we decided to use database instead of other options.

MySQL is an open-source, relational database manages system, which is relatively lightweight than others such as SQL server or ORACLE. MySQL also provide several client-end tools, take MySQL administrator as an example, it provides an integrated interface for database management. Other than that, it provides a MySQL query tool that can execute SQL query statements.All of these features help us to manage and execute data efficiently.In this case, we need to download a java connector that works as the bridge between MySQL and Cooja, after that, we define SQL statements and execute them.See section 4.5 for more details about mask creation.

4.4Up/Downloader

Recall from Chapter 3 that the writing speed of flash file system in MSP430 is much slower than RAM or ROM. And considering the potential writing latency between any two bytes, we decide to use a blocked transfer. So we define an internal buffer, which can receive bytes through UART then write to flash as a block.Then it is possible to transfer blocks in a much faster speed then wait for a short latency between each two.

```
FILE *fp = fopen (checkpoint file);       //open checkpoint file from hard disk
while (1) {
        for (bytes<64){                   // read 64 bytes from file
                sleep ();                 // define a short time interval
                write (serial ports);     // write data to serial port
}
usleep (longer interval);                 // a longer interval between each two 64 bytes
}
```

Cooja simulates sensor's serial ports into standard socket ports. Each mote that simulated in Cooja has been assigned a unique port number consists by "60000+node id". Then we call the uart_writeb (byte) function from motes in order to send bytes tothe socket client that runs on a computer.Checkpoint files are savedas byte files, the name format is designed as: Snapshot_hour-minute-second.bin. The file should always use a expansion name as '. bin', which is the default type for byte files in Ubuntu.

4.5 Standard Mask Creator Pseudocode

Create a mask from Cooja:

1 **SELECT** * **from snapshots table where VarName='first variable' and id not in (select min (id) from mask group by VarName having count (*)>1) limit 1**

//firstly find all records that with same variables' name, start from the first variable

2 **TRUNCATEtarget table** *//clear target table*

3 **SELECT* from snapshots table where VarName='first variable'** *//select first variable from table that evolve all snapshots*

4 **TRUNCATEtable temp table** *//clear temp table*

5 **SELECT* from snapshots where id=?** *//traverse all variables by selecting from first to last variable*

6 **INSERTinto temp table select * from mask where VarName=? order by desc**

//select data items into temp table, which has same variable name

7 **SHOWtable status of temp table** *//count the length of temp table, which is also the number of baches of data.*

8 **SELECTValue from temp table order by id asc limit 1** *// find the value of first variable when listing by ascending*

9 **SELECTValue from temp table order by id desc limit 1** *// find the value of first variable when listing by descending*

10 **INSERTignore into target table select * from temp table order by id asc limit 1**

//if they are same, then variables that come from all batches has same data value, then insert to the target table.

11 **UPDATEtemp table SET value= -99999 order by id asc limit 1** *//else, mark the value.*

12 **INSERTignore into target table select * from temp table order by id asc limit 1** *//insert the marked variable into target table.*

Create a standard mask:

1 **SHOW table status from mysql like 'test bed mask'** *// find table length of test bed mask to ensure the length of loop*

2 **SELECT * from test bed mask where VarName='first varaible'** *//traverse all variables in test bed mask from start to end.*

3 **TRUNCATE table temp table** *//clear temp table*

4 **SELECT * from test bed mask where id=?** *//select variables from first to end*

5 **INSERT into temp table select * from test bed mask where Varname=?**
//select variables into temp table from test bed mask

6 **INSERT ignore into temp table select * from Cooja mask where Varname=?**

//select variables into temp table from COOJA mask

7 **SELECT Value from temp table order by id asc limit 1** *// find the value of first variable when listing by ascending*

8 **SELECT Value from temp table order by id desc limit 1** *// find the value of first variable when listing by descending*

9 **INSERT ignore into standard mask select * from temp table order by id asc limit 1** *//if they equals with each other, then insert into final table.*

10 **UPDATE temp table SET value= special value order by id asc limit 1***//otherwise mark the variable with a special value*

11 **INSERT ignore into standard mask select * from temp table order by id asc limit 1**
//insert the marked variable into target table

4.6 Dictionary

Dictionary is a mapping between variables and their addresses. We build the mapping by retrieving data from Coojabecauseitalways createsanew mapping between memory elements and their addresses when it generates new nodes.

Generally speaking, we can build a dictionary in two steps: (1) Read variables names through the memory object, and (2) Traverse all variable names then retrieve their physical address through a ‘get address’ method in Cooja, then save them into database.Now if we found any problems during diagnosis on test bed, it is possible to knowtheir name through their physical addresses or vice versa.

4.7Diagnose

Diagnosis is a comparison between standard mask and a mask that needs to debug. If variables have same value, remains. Then if variables have different values, but one of their values has been marked that shows this variable can be ignored, then keep the original marks. Otherwise marks the variable to a special value. Finally we search in dictionary to find their physical addresses.

```
TRUNCATE table temp table                                          //clear temp report table
SHOW table status from mysql like data table                       //find length of masks
SELECT * from data table where VarName=first variable              //traverse variables from 1st to end.
TRUNCATEtemp table                                                 //clear temp table.
SELECT * from data table where id=?                                //start from first variable
INSERT into temp table select * from data table where Varname=?    //select data from debug mask
INSERT ignore into temp table select * from diagnose report where Varname=?
    //select data from standard mask
SELECT Value from temp table order by id asc limit 1               // find the value of first variable when listing by ascending
SELECT Value from temp table order by id desc limit 1              // find the value of first variable when listing by descending
INSERT ignore into tempreport select * from temptable order by id asc limit 1
    //select first value from temp table to temp report listing by ascending
INSERT ignore into tempreport select * from temptable order by id desc limit 1
    //select first value from temp table to temp report listing by descending
UPDATE temptable SET value= mark order by id asc limit 1           //mark abnormal variables
INSERT ignore into tempreport select * from temptable order by id asc limit 1
    //insert to temp report
TRUNCATE table reporttemp                                          //clear temp report
TRUNCATE table diagnose report                                     //clear report
INSERT reporttemp select * from tempreport INNER JOIN dictionary ON tempreport.VarName=dictionary.VariableName
    //select data from both temp report and dictionary
INSERT report SELECT id,SnapName,VariableName,Value,Addr FROM reporttemp where Value=-1234567
    //create report that evolves physical addresses
```

Chapter 5

Experiment and Evaluation

We will introduce the experiments and evaluation of 'SUSE' in this chapter. We test our design on a test bed that consists of 3 sensors, and we cover both micro and macro evaluations, then we observe resources consumption and overall characteristics. We can conclude from the evaluation that 'SUSE' can finish the diagnosis within 9 minutes on testbed and it occupies the RAM and ROM in a reasonable way. We will show and discuss more details from section 5.1.

5.1Design

5.1.1 Configuration

In this section we listboth hardware and software configurations in order to describe the running environment for all experiments in this chapter.

Items	**Information**
Sensors:	
Sensor model	Tmote sky MTM-CM5000MSP
CPU	MSP430
RAM	10K bytes
Flash	1024K bytes
Contiki Version	2.5
Computer:	
Operation system	UBUNTU 10.04
Compiling environment:	
GCC	3.8.3
JAVA	6

Table 5.1 *Configurations of experiments*

For all evaluations in this research we use three Tmote sky (MTM-CM5000MSP)sensors that connect to a laptop through anUSB hub. Thus we can upload source code to all sensors simultaneously instead of one by one. The Contiki that we are using is running on a UBUNTU 10.04 instead of an instant Contiki, one of the advantages is faster execution.

5.1.2Micro Evaluation

We firstly introduce our test planfor micro level benchmarkin this section.We measure performance in different part of 'SUSE'. These measurements includes time consumption, CPU usage and storage analysis. Micro evaluation helps us to determine the speed and effectiveness of 'SUSE'. It can also help us to locate the possible

bottleneck, which can possibly be improved. Take the time evaluation as an example,wemeasure how much time does 'SUSE' needs on:(1) checkpoint process,(2) data collection process and (3) file transferbetween sensors (both working in Cooja andtest bed)and computer. We finish the timeworkby calculating time difference between two watchpoints, whichhave been pre-defined in source code. Then we compare time usage between different parts of 'SUSE' and time usage between different numbers of sensor nodes in section 5.2.1.In section 5.2.2, we benchmark CPU consumption,whichis measuredby CPU cycles that can read from'MSP cycle watcher'inCooja. Another aspect that we have measured is storage consumption,which is especially useful before uploading code to test bed.In this case, we use 'size –A' command to benchmark storage usage, 'size –A' is a build-in command in 'MSP430-gcc' compiler, which analyzes memory consumption from compiled souce code, and then display information on the screen.

One of the disadvantages to micro evaluation is manual execution; we have to define watchpoints manually then copy data into aMicrosoft excel file for creating charts.So maybe we can improve it to an automatically test frame.One important thing to also note is that we did not benchmark power consumption in this research. Power consumption is one of the key features for sensors that working in natural environment, but ‘SUSE’ works in testing environment only, so power measurement did not take into consider now.

5.1.3Macro Evaluation

In this section, we describe test plan for macro evaluation. Weimplement a scenario on how to debug another algorithm with ‘SUSE’. This evaluation is more like a macroscopic acceptance test and we find out whether ‘SUSE’can fulfill our requirements, which has been described in previous chapters. In order to perform the macro evaluation, firsly we have to introduce a sample algorithm and this algorithm works as adebugging target. In this case, we develop a simplified Dijkstra’s algorithm, Dijkstra’s algorithm is a self-stabilize algorithm that firstly introduced in seminar paper of Edsger Dijkstra in 1974; this algorithm quickly becomes the important foundation of self-managing computer system and fault-tolerance computing system. One of the advantages is it does need any strong assumptions comparing to previous algorithms.

In this research, it works on a three-sensor system: one sink node and two working nodes that come into a stabilizedstate (one of them works as a deterministic leader). They use numbers to represent their states, and theyinitiate from two random states, then after several cycles of running, they come into a consistent state and keep this state in the following time.

To test the ‘SUSE’ further, we plan to find out two answers from macro evaluation: (1)whether ‘SUSE’ can successfully diagnose on other algorithms and (2)whether ‘SUSE’ affect other algorithms during the diagnosis.In order to answer the first question, we have to perform a complete test, then study and discuss the diagnose report andvalidate whether ‘SUSE’ can distinguish between a suspect variable and a correct variable but always changes its value. In order to answer the second question, we print sensor’s state on screen and check their correctness.One of the advantages to our macro evaluation is its practically, because we can check whether‘SUSE’ works in a real scenario, which is specially import for our research. But one of the disadvantages to our test is, we cannottest it in all possible contexts, thus we cannot ensure that ‘SUSE’ can diagnose all type of algorithms. To combat this, it is better to use it together with other debug tools, such as a semantic checker or a GDB debugger.

In this research, we cover both micro and macro evaluation, or in another words, both performance benchmark and acceptance test. One of the disadvantages in our design is, we do not evolve other testing techniques such as memory leak test, security validation or load test.Section 5.2 describes and discusses the micro evaluation, section 5.3describes the conclusion of macro evaluation.

5.2 Micro Evaluation

5.2.1 Time Consumption Analysis

In this case, we perform time benchmarkfor three processes: checkpoint process, data collection process and file transfer, because these processes are key functions in ‘SUSE’. Other than this, time usage varies when running ‘SUSE’ on different numbers of sensor nodes. We found that the best way to get accurate validations is to compare time consumption between different settings. There are many possible reasons for extra time consumption:an interfered radio connection,data collection between two sensors in a long physical distance, data loss during radio transimission, sender sendspackets in a much faster speed than receiver can handle or even any random unknown reasons. This is why we measure time usagefor ‘SUSE’; we have to state that although we are facing so many uncertainties, ‘SUSE’ can still execute in a reasonable time range.

For all micro-evaluation we directly use two build-in tools to perform benchmark in Cooja. One of them named ‘MSP code watcher’ and the other named ‘MSP cycle watcher’. ‘MSP code watcher’ is a plugin that inserts watchpoints in source code and then stop running on triggered watchpoints. This is especially useful on our timework; we measure any time difference after the definition of watchpoints. ‘MSP cycle watcher’ is a plugin that enable cycle counting of CPU, so when use it together with ‘MSP code watcher'; we have the capability to benchmark CPU usage between any two watchpoints. These two plugins make it possible to perform micro evaluation, taking advantage of its high accuracy.

In this research, we perform time benchmark in three steps: (1) first,we start 'MSP code watcher' andfind out the interesting part that we measure, then define watchpoints to mark them in source code. (2) Second, we start the simulation and save all timing information in an excel file when the simulation reaches pre-defined watchpoints. (3) Last, we finish the timework in excel and then generate charts. Next, we discuss time consumption for different process in section 5.2.1.1-5.2.1.3; then analyze the overall timing ratio in 5.2.1.4; finally we start a briefly discussion for time benchmark.

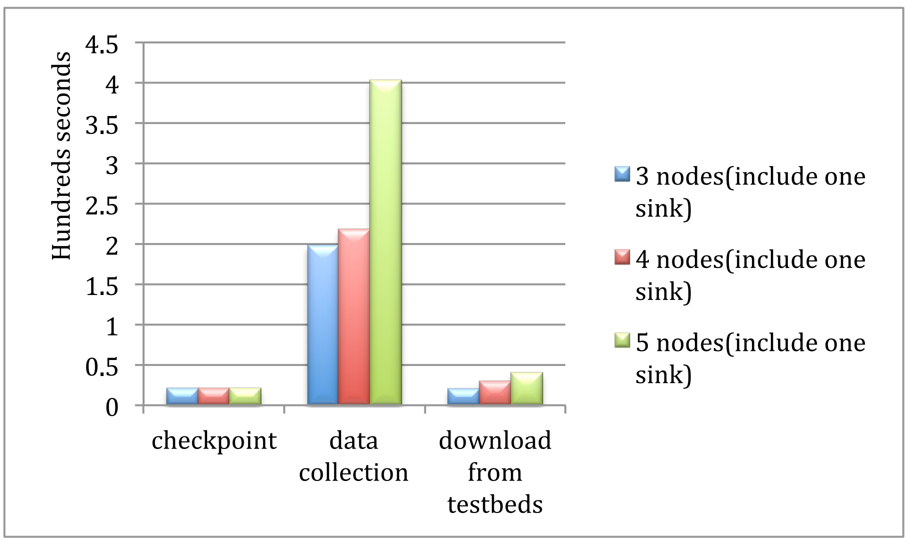


Figure5.2*Time consuming and the comparison between different numbers of nodes, it is obvious that time is positive correlation with numbers of nodes*

5.2.1.1Time Consumption for Checkpoint Process

In this section, we discuss time benchmark for checkpoint process. As mentioned before, when we make checkpoint files on several sensor nodes, they won't start/end at same time, because there isn't any synchronization between them, this is why we perform measurement on average time consumption.

We have compared the time benchmark between 3-5 nodes, and figure 8 clealy shows that checkpoint process does not vary much. One of the possible reasons is that they won't interfere by external aspects. We can read from the figure that, very little time difference between different numbers of sensors: only 0.301 seconds between 2 and 3

nodes, and 0.045 seconds different between 3 and 4 nodes.Comparing with the totally operating time of 'SUSE', time usage for checkpoint (with two nodes) is 4.4% when operate in Coojaand 2.1% when operate on test bed. In this case, this result is totally acceptable.

One important thing to also note is that the time usage for checkpoint process different between Coojaand test bedwhen we increase the numbers of nodes. Each sensor makes its own checkpoint on test bed and won't affect others, but in Cooja,all sensors share the same hardware resource. So imagine that if we run checkpoint process on 1000 sensor nodes in Cooja, they have to use much longer time than now. But when we compare time benchmark with data collection and file transfer, we find that those two processes are greatly affected by numbers of nodes.

5.2.1.2 Time Consumption for Data Collection

In this section, we discuss time usage for data collection process. We have already known that data collection is both a CPU-intensive and radio-intensive process. So we have to find out whether it can finish its job within a reasonable time range. We perform benchmark between different numbers of nodes, and then make a brief discuss on that.

We have clealy find out that data collection consumes a lot of time during diagnose, and time varies a lot when running on different numbers of nodes. As figure 8 shows, when we run data collection on three nodes, with one sink node and two supplier nodes, it uses198 seconds to finish all data transfer; the time increases to 218 seconds when we run the same process on 4 nodes; at last, data transfer time increases to 403 seconds for a 5-node. Thetime interval settingbetween each two packets is1 second in 3-sensor and 4-sensor system; senders canretransmit onceif theydo not receive anyacknowledgment from sink node. Thisdefinition isalmost the fastest settings for data collecting protocol. It is obvious that the time consumption increasealong with the increasing of nodes.Data shows the time interval should increase to at least 2 seconds in the 5-sensor system.

This result shows that the data collect protocol finishesits job within a reasonable time limit, but still not good enough. This is also one of the disadvantages when we decide to use this protocol. To combat this, we can implement a better data collect protocol in the future. But things are never absolute; an off-the-shelf option can save a large amount of time from developing and testing a new protocol.

5.2.1.3 Time Consumption for File Transfer

In this section, we discuss the benchmark result for file transfer. Firstly we need to know that checkpoint files have to be transported between sensors (running in Coojaor test bed) and computer in order to finish the diagnosis. File transfer means serial port operation or system bus operation, they are all time consuming jobs.

In this case we focus on pure transmit time only, and we decide to ignore other operations such as shell input.We can read from figure 8 thatfile transfer with Cooja does not waste too much time. One of the possible reasons is that, when we upload/download files between harddisks and simulator, most jobsaredone inside a computer system. Take this evaluation as an example, it only use 3 seconds to download single checkpoint file to hard disk from Cooja. And the uploading time is 14 seconds, which is little longer but still fast enough. However, it is little different when uploading to test bed, this operation costs at least 900 seconds to upload a singlefile. One of the explaination is that the continuous writing speed in Tmote sky is quite slow then reading speed. To combat this, we have implementa self-defined internal buffer to optimize the upload speed. The working procedure is: after we receive every 64 bytes in a relatively fast speed, then write them into flash file within a little longer time interval (500millisecond in this case). Finally, with the help of internal buffer, we have successfully decreased the uploading time from 900 seconds to 270 seconds.

It is possible to tweak the size of internal buffer according to the specific circumstances. Larger buffer can bring a faster transfer speed, but it consumes more memory spaces. So if we debug a tiny program, it issafe to increase the buffer size to 128 or even 256 bytes, but when we talk about normal situations,64 bytes is still anappropriate buffersize. One important thing to also note that upload to test bed is not commonly used in 'SUSE', because we actually create masks in Cooja instead of test bed.

5.2.1.4 Time Consumption Analysis

In this section, we discuss the overall statistics of time occupation in 'SUSE'. This analysis clearly tell us which part is consuming large amount of time, and also which part should be optimized if we decide to enhance system's performance.We separately discuss two situations: time statistics on Cooja and time statistics on test bed.

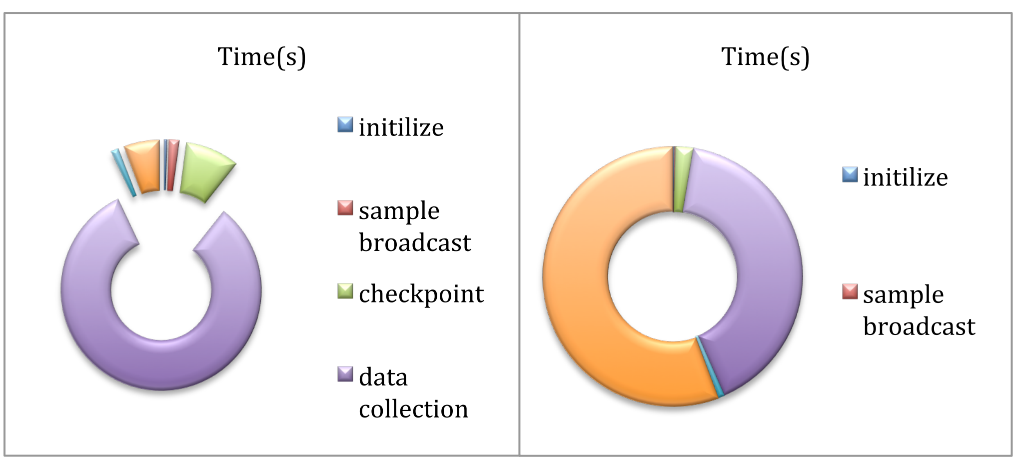


Figure 5.3*Time occupations on Cooja and Test bed, data collection and file transfer occupy the largest propotion of totally time consuming*

We read from the figure that most of the time is consumed by data collection process when we perform the simulation in Cooja; data collection occupies 82.2% of total execution time, while sample algorithm only cost 1.7%. We have calculated that the time usage of data collection is 50 times than sample algorithm and 9.5 times than checkpoint process.When we study the result ontest bed, we find that the time consumption for uploading files occupies even a larger proportion. Relatively, file upload use 54% of the totally execution time and data collection use about 39.8%.When we measure the overall time consumption, we find that it costs 240 seconds to execute 'SUSE' from beginning to the end on Cooja, and 497 seconds when running on test bed.

This evaluation clearly shows that, if we want to optimize the performance of 'SUSE', we should firstly consider about a new data collecting protocol, this is good idea to enhance the performance on both simulator and test bed. Secondly, it is obvious that we should speedup the file uploading speed to test bed, this is especially important when we run 'SUSE' on large numbers of nodes.

5.2.1.5 Discussion

In this evaluation, we have so far been unsuccessful in finding any resources that discuss the usage of time.Since 'SUSE' is an application for diagnose, despite any detailed benchmark, 5 minutes is still a good evaluation result for it. We can imagine that in the past, it is difficult to find a 'wrong' variable when a bug occurs, or even if we can, we have to consume a lot of time on it. But now, with the help of 'SUSE', we just use 5 minutes to find out all suspect variables from test bed. This is a tremendous progress when comparing to the past.

One important thing to also mention, performance is a balance between speed and stability. Firstly it is unrealistic to boost the performance infinitely, and then we do not want to lose any packet when weenhance the performance. So if there is any tweaking on time interval or transfer speed, it should follow by large amount of stability test.

5.2.2CPUConsumption

In this section, we perform measurements onCPU consumption of 'SUSE'.We benchmark CPU load on three processes: (1) only sample algorithm, (2) run sample algorithm and checkpoint process and (3) run all three processes including data collection.

CPU load is a key feature when we talk about execution efficiency and power saving.In this case, we evaluate the CPU load by counting CPU cycles.Each microinstruction costs one CPU cycle on Tmote Sky,so if a program leads a higher CPU cycling, it uses more time to finish the execution and it also consumes more electricity.

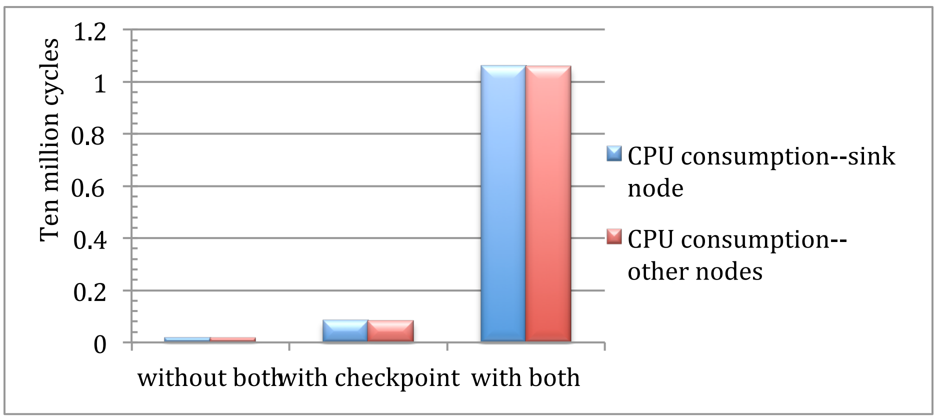


Figure 5.4*CPU consumptionsof sink node and supplier nodes, it is clear that data collection is a CPU-intensive process.*

In this case, we use both 'MSP cycle watcher' and 'MSP code watcher'to benchmark CPU counting in Cooja. Then we copy and save all data into an excel file.We read from figure 10 that it is does not consumea lot CPU cycling when we only run sample algorithm on test bed.Sink node uses 1.9227201(million) cycles to finish this algorithm and the other two nodes use 1.7050251(million) to finish their job.CPU counting becomes higher when we run both sample algorithm and checkpoint process. In this case, supplier nodesuse 8.2083616 (million) cycles to finish both porcesses, we can calculate that it is about 4.8 times when comparing to the previous benchmark.It is obvious that data collection process uses largest amount of CPU performance. Supplier nodes use 105.8424274 (million) cycles to finish all three processes, this data is almost 62times of sample algorithm. The situation is similar when we evaluate it on sink node, which uses106.060114 (million) cycles for all three processes.

5.2.2.1 Discussion

In this case, we find that CPU consumption differs a little between sink node and a supplier node, one of the possible reasons is they execute different part of source code. Take the sink node as an example, it does not run sample algorithms and checkpoint process but it receives data from both supplier nodes during data collection. On the other side, supplier nodes simply send out packets but they might need more CPU cycling during checkpoint process and parent finding. But generally speaking, both sink node and supplier nodes use similar CPU costage in all three comparisons. We also find out that sink node costs little more cycling during data collection, one of the possible reasons is supplier nodes operate CFS file (read operation) once in each loop, but sink node operates CFS file twice (write operation).Because of this, sink node consumes 12.77% cycles more than supplier nodes when we run sample algorithms only, and the ratio decrease to 2.6% when we running both sample algorithm and checkpoint process. When we compare the totally execution, we find that sink node costs only 0.2% more than supplier nodes.

We also found out that the CPU usage remains the same number when we run same processes.This is reasonable result because each instruction should use a fixed number of CPU cycles.On the other hand, this is also one of the advantages of our method, which means that we have retrieved data correctly from Cooja.

5.2.3Memory Consumption

In this section, we carry out the benchmark for memeory usage.We evaluate how much memory that has beenusedby ‘SUSE’ in both RAM and ROM. For Tmote sky nodes, variables are stored in RAM andsource codesaved in ROM. This evaluation is especially important to sensor network because memory efficiency is always a key feature to consider. In this case,we use a ‘size -A’ command to measure memory usage; ‘size -A’ is a build-in command from MSP430-gcc compiler and it can calculate memory occupation from compiled source file.

Other than this, we compare both RAM and ROM consumption from three aspects: (1) when we only run sample algorithm; (2) when we run both sample algorithm and checkpoint process; (3) when we run all three processes on test bed.

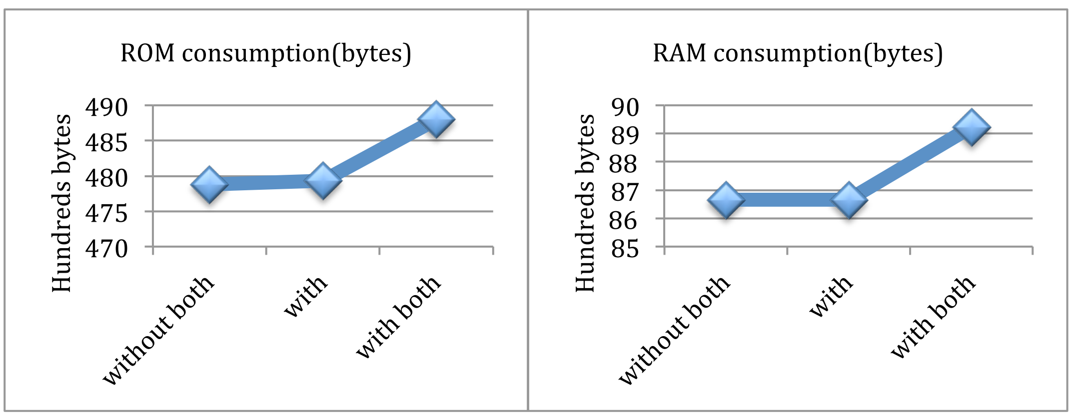


Figure 5.5ROM& RAM *consumption, obviously checkpoint process only use little memory space comparing with data collection process.*

For all memory evaluation we can directly use defaults make files in Contiki. We read from figure 11 thatsample algorithm costs minimal ROM and RAM,and checkpoint process occupiesonly 50 bytes in ROM and the same RAM occupation when comparing to sample algorithm. On the other hand, data collection process occupies 920 bytes in ROM and 258 bytes in RAM.

5.2.3.1 Discussion

Memory usages greatly affected by make file settings. In this case, we have used default make files, but it is possible to decrease memory occupation by resetting the make files in Contiki.Recall what we have mentioned in section 5.2.1.3, our self-defined internal buffer uses 64 bytes RAM space by default, so comparing to the 10k memory volume in Tmote sky, 'SUSE' uses 348 bytesaltogether in RAM, this is a positive result on memory benchmark.

5.2.4 Discussion for Micro Evaluation

Now we have finished in discussing micro evaluation for 'SUSE', and we have got positive results throughout this section.This is especially an important result for sensor network since hardware resources always restrictapplications that running on sensors. What's more, the purpose for us to design 'SUSE' is to provide support for diagnosing other algorithms, so resource efficiency becomes a more important feature to it.Another important thing to also note is that there is still a space to improve its performance.

We can develop a new data collecting protocol that can provide higher collecting efficiency. We can also enhance the serial port driver in Tmote sky, to let it receive data in a relatively faster speed.Next, in section 5.3,we discuss the result from macro evaluation.

5.3Macro Evaluation

In this section, we describe and discuss the result of macro evaluation of 'SUSE'. As we have mentioned in section 5.2, we firstly simulate a scenario for testing, we use two sensors to run Dijkstra's algorithm, and use another sensor to work as sink. 'SUSE' run on all 3 sensors to provide diagnose support. And suppose the scenario is working in such a situation: when two sensors are working on their Dijkstra's algorithm, suddenly one node can not receive anything from the other in the second cycle of running, so we decide to start ‘SUSE’ to diagnose it. We firstly insert the algorithm into ‘SUSE’, and suppose we have fixed all semantic bugs already, then we firstly create a Cooja mask, and then we upload the same source code to test bed. Suppose everything runs correctly and we gather two checkpoint files from sensors in first cycle of running. Next we can upload these files to Cooja and create a test bed mask, after this, we generate a standard mask. Then we run the Dijkstra’s algorithm again and download the checkpoint files that created in the second cycle of running. We upload the checkpoint files to Cooja again and perform diagnosis, when it finishes, we can get a report from database for further analysis.

First of all,we have to define two use cases for this evaluation:(1)‘SUSE’ should not modify the variables that in name of the sensor’s state, (2) these variables should not appear in final diagnose report. The reason for this definition is obvious: whenever ‘SUSE’ running, itshouldn’t modify any key variables in target program; then secondly, it should distinguish between a suspect variable and a correct variable but always changes its value, and finally display the result in report.We can use variable watcherto finish the first job,becauseit can provide any variable values during the simulation.We canperform thediagnosiswith improved simulation control panelto finish the second task.And at last, we read final report in database.We test the scenario for several times, in this case, we have defined two variables to work as sensors’ states: ‘node2state [1]’and ‘node3state [1]’ and weuse ‘variable watcher’ to validate them.We finally find out that ‘SUSE’ has not affected the Dijkstra’s algorithm because both nodes change their states correctly, and the states that read from sensors’ memory is also correct. Actually, because we designed ‘SUSE’ in a passive working pattern, so generally speaking, it only receives and dumps data instead of modify any. Then we check the final report in order to find more details. At last, we find that ‘SUSE’ distinguish suspect varaibles and correct variables correctly.Obviously,
none of ‘states variables’ appear in final report.We can also read the physical addresses of suspect varaiblesfrom report,which is quite important when debug on test bed.

id	SnapName	VariableName	Value	Address
216	Sky 1	announcements_list	-1234567	1774
226	Sky 1	broadcast	-1234567	1622
249	Sky 1	c	-1234567	177a
265	Sky 1	channel_list_list	-1234567	1ca0
289	Sky 1	ctimer_list_list	-1234567	21a0
291	Sky 1	cur_break	-1234567	142e
408	Sky 1	packetbuf	-1234567	8810
412	Sky 1	packetbufptr	-1234567	21ac
418	Sky 1	phase_list_list	-1234567	1148
427	Sky 1	process_list	-1234567	2046
501	Sky 1	shell_collect_conn	-1234567	3310
550	Sky 1	tc	-1234567	163a
560	Sky 1	uc	-1234567	2f7a

Figure 5.6*A sample report that lists all suspect varaiblesthat has been changed illegally, although these suspect varaiables do not mean the system must affected by bugs, but if there is one, it would be a good idea to check these suspect variables first.*

5.3.1 Discussion

In this evaluation, we have tested ‘SUSE’ in a simulated scenario to validate its function. Obviously it has successfully provided a variant-level debugging support for sensor network, both functionality and performance. The advantages of ‘SUSE’ are obvious: (1) ‘SUSE’ is an open-structure tool that composed by series elements, so it is easy to add new features to it, or use some of its functions separately for other purpose. What’s more, ‘SUSE’ is a powerful tool that has the capability todebug any algorithms that are running on test bed. The operation is also simple: just insert the target process in ‘SUSE’, then follows the same steps to get the final diagnose report. On the contrary, there are also some disadvantages that need pay attention to: first of all, checkpoint process affects broadcast process, although in this research we have avoided this problem by reset the rime stack, but this is still a problem because we do not know the exact reason for it. Secondly, 'SUSE' is a passive designed tool instead an active one, so most commonly scenario is: we have to run the programagain with the help of 'SUSE' after some errors have occurred, this is more or less a waste of time when comparing to active diagnose tool.

One important thing to also mention, if there are any suspect variables listed in final report, it does not mean that the program 'must' have a bug. On the contrary, if there is any bugs occurred in a program, most hopefully we can find valuable clues in diagnose report. So if we can combined using 'SUSE' with other diagnose tools, such as semantic checking tools, we can greatly improve the detect rate and decrease the false alarm rate at the same time.

6 Discussion

This work presents a diagnosis tool named ‘SUSE’, which provides an efficient and variable level diagnosis that works on both simulator and test bed. ‘SUSE’consists of four modules: ‘Snapshots collector’, ‘Up/Down loader’, ‘Standard mask creator’ and ‘Evaluator’.‘Snapshot collector’creates snapshots on sensor nodes then collect them to sink, up/down loader transfers filesbetween simulator, computer and test bed, ‘standard mask creator’ can generate standard mask that works as a reference in diagnosis, and finally ‘evaluator’ performs diagnosiswiththe help of standard mask.

Generally, there are two designing methods for diagnosis tools, one passive way and one active way. We say that a passive diagnosis tool won’t affect the running of sensor networks, because we do not need to run it when everything goes correct. That is the reason why a passive tool cannot locate the suspect variables as soon as a bug occurs. An active diagnosis tool works simultaneously with sensor networks, which can provide a real-time monitoring on the system.One of the disadvantages is that it needs a carefulinteraction with the host;because there are many sensitive aspects that it has to deal with, such as hardware resource management, switch between different contexts and system performance. ‘SUSE’ is a passive designed diagnosis tool, so if it works together with an active diagnosis tool, it is possible to increase the detect rate and decrease the miss rate.

‘SUSE’ is not only a diagnosis tool, but also provides us a lot of new availabilities to sensor networks, such as file transfer between different platforms and files collection among several nodes. Namely, ‘SUSE’ fulfills the requirements when we upload source code from simulator to test bed by providing an efficient variables level diagnosis method on both platforms. We saw that ‘SUSE’ has provided a smooth transition from simulator to test bed. Namely, we do not need to have in mind bugs that produced on test bed but never appeared in simulator.

Biblliography

[1] Sundaram, V., Eugster, P., and Zhang, X., Addanki, Efficient Diagnostic Tracing for Wireless Sensor Networks. SenSys '10 Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems, Page 169-192, 2010.

[2] Lilia Paradis, Qi Han, A Survey of Fault Management in WirelessSensor Networks, Journal of Network and Systems Management, 2007, Volume 15 Issue 2, Pages 171 – 190.

[3] Xiaoqiao Meng, Thyaga Nandagopal, Songwu Lu.Contour Maps: Monitoring and Diagnosis in Sensor Networks.   Computer Networks - COMPUT NETW , 2006, vol. 50, no. 15.

[4] Anmol Sheth, Carl Hartung, Richard Han, A Decentralized Fault Diagnosis System for Wireless Sensor Networks, Mobile Adhoc and Sensor Systems Conference, IEEE, 2005

[5] Fredrik Österlind,Adam Dunkels, Thiemo Voigt, Nicolas Tsiftes, Joakim Eriksson, Niclas Finne. Sensornet Checkpointing: Enabling Repeatability in Testbeds and Realism in Simulations, EWSN '09 Proceedings of the 6th European Conference on Wireless Sensor Networks, 2007.

[6] V. Krunic, E. Trumpler, and R. Han. NodeMD: Diagnosing node-level faults in remote wireless sensor systems. MobiSys '07 Proceedings of the 5th international conference on Mobile systems, applications and services, 2007.

[7] Luca Mottola, Thiemo Voigt, and Fredrik Österlind: enabling efficient static verification of sensor network software. SESENA '10 Proceedings of the 2010 ICSE Workshop on Software Engineering for Sensor Network Applications, 2010.

[8] Santi Kumari Behera, Prabira Kumar Sethy, Dr. Pabitra Mohan Khilar. Fault Diagnosis in Wireless Sensor Network using Timed Automata, International Journal of Computer Applications, 2011, Volume 29– No.7.

[9] Xin Miao, Kebin Liu, Yuan He, Yunhao Liu, Dimitris Papadias. Agnostic Diagnosis: Discovering Silent Failures in Wireless Sensor Networks. INFOCOM, 2011 Proceedings IEEE, 2011.

[10] R. Costa, S. Sargento, R. Aguiar, Instituto de Telecomunicac¸oes, Aveiro,and W.Zhang, Development of a Hybrid Simulation and Emulation Testbed For VANETs, Revista do DETUA, 2009,Volume. 4, No. 10.

Appendix A
Quick start

A.1Usage for ‘Snapshots Collector’

1. Unpack Diagnose.tar.gz somewhere in your hard drive.
2. Copy the checkpoint.c and checkpoint file into /Contiki -2.5/apps/shell/, and overwrite the original files.
3. Copy all files in Contiki /tools/Cooja/…./plugins/ to the same directory.
4. Copy the 'recv_Cooja.c' and 'send_Cooja.c' into some folders then compile them.
5. Copy the 'recv_testbed.c' and 'send_testbed.c' into some folders then compile them.
6. Copy the 'collectdata.c' into /Contiki /examples/rime.
7. Copy the 'MAKEFILE' into /Contiki /examples/rime.
8. Enter /Contiki /tools/Cooja, and use 'ant run' to start Cooja.
9. Use 'ant clean' can delete cache from Cooja.
10. Start a new simulation in Cooja
11. Create three new sky motes from the file 'collectdata.c', and place them relatively close so they can hear from each other.
12. Start to run.
13. There are 30 seconds for transferring data to computer in each round of running.

A.2Usage for ‘Up/Downloader’

A.2.1 Transfer from Coojato Computer

1. Wait until data collection process finishes, Coojadisplays a hint message for starting the file transfer.
2. Single click on the sink node, and select 'socket server'
3. Use recv_Cooja.c to build a socket connection with Cooja.
4. Then write click on the sink node then select 'click the button'.
5. File transfer start and then the checkpoint files are transfer onto the hard disk.
6. Repeatedly to receive the other checkpoint file.

A.2.2 Transfer from Computer to Cooja

1. Start Coojathen create a new simulation.
2. Create a node with '/rime/collectdata.c'.
3. Start a socket server from the node.
4. Right click on the node and select 'click the button'.
5. From another terminal window, run the 'send_Cooja.c' with './sendCooja' 127.0.0.1 60001 Snapshot_xx-xx-xx.
6. The node inside Coojareceives the checkpoint file.
7. Repeatedly, we can receive other checkpoint files.
8. Right click on the node and select 'click the button'.
9. Close the socket connection, and open shell terminal inside Cooja.
10. Roll back from any checkpoint.
11. Coojadisplays hint message after each transmission.

A.2.3 Transfer from Testbed to Computer

1. Wire the sink node with an USB port from computer.
2. There are 30 seconds between each two running for file transfer to computer.
3. Start the sensors.
4. Use serial-dump to inspect the running status of sink node.

5. When collecting stops, use recv_testbed.c to build a serial connection with sink node.
6. Push the button on sink node.
7. Data transfers from sink node to computer.
8. Repeatedly to receive other checkpoint files.

A.2.4Transfer from Computer to TestBed

1. Wire a sensor with an USB port to a computer.
2. Push the button on this sensor, it displays hint message for starting the transmission.
3. Use send_testbed.c to send a checkpoint file to this sensor: ./sendtestbed -b115200 /dev/ttyUSB0 Snapshot_xx-xx-xx
4. Repeatedly to receive other checkpoint files.
5. Now login to the shell of the sensor through a serial-dump.
6. Rollback from any checkpoint files.

A.3Usage for 'Standard Mask Creator'

1. Start a new simulation in Cooja.
2. Create 3 nodes with the same code base that are going to debug with.
3. Click on 'C->DB' repeatly.
4. Click on 'C-Mask' to generate Coojamask.
5. Burn the code base to test bed.
6. Start the test bed to run.
7. Collect checkpoint from test bed to computer follows the steps in A.2.
8. For example, if the algorithm is running on two working nodes, and if the program is running within a loop, then sink node collects 2 snapshots from them in each round.
9. Upload the checkpoint files downloaded from test bed to Cooja.
10. Rollback one checkpoint file in node 1.

11. Click ‘T->DB’.
12. Repeatedly, untill all checkpoint files imported into database.
13. Click ‘T->Mask’ to create test bed mask.
14. Click ‘Create Final mask’ to create the standard mask.

A.4Usage for ‘Evaluator’

1. Run the code on test bedthat is going to debug with.
2. Download checkpoint files from test bed to computer.
3. Upload checkpoint files to Cooja(which nodes run the same code base).
4. Click ‘Dic’ to create the variables dictionary.
5. Rollback one checkpoint file in node 1.
6. Click ‘D->DB’.
7. Repeatedly, import all data checkpoint files into database.
8. Click ‘D-Mask’ to create mask for the source code that are going to debug with.
9. Click ‘Diagnose’ to generate the final report.
10. Open a database query tool to check the result.

Note: A.4 is available only after generating standard mask from same code base that are going to debug with.

Appendix B

User manual

B.1 Basic Usage of Cooja

1. Open a terminal in Linux then find the Cooja's folder by: cd Contiki /tools/Cooja
2. Use command 'ant run' to start Cooja.
3. Use file->new simulation to start a new simulation.
4. Use Mote-types-> Sky mote to select mote type.
5. Select the sensor code that going to run on the motes.
6. Support for select different code base for different nodes.
7. Press start in the control panel to start the simulations.
8. Plugins can be added/ removed by 'motes' menu.
9. Left click on mote can find other useful options.

B.2 Node_id Burning

New sensor nodes should be burned with a unique node_id as their only identification. Contiki provide a program named burn-nodeid.c, which located in Contiki /platform/sky/apps.

B.3 Upload Code

Use 'make codename.upload TARGET=sky' to upload sensor code onto testbeds, for example: 'make collect.upload TARGET=sky'.
Code can upload simultaneously to all sensor nodes if they are connected with a hub.

Appendix C

Sensor Code

SourceCode.zip