Terra System
Low abstraction level built-in functionalities
(TerraNet v0.2)

Introduction & user guide

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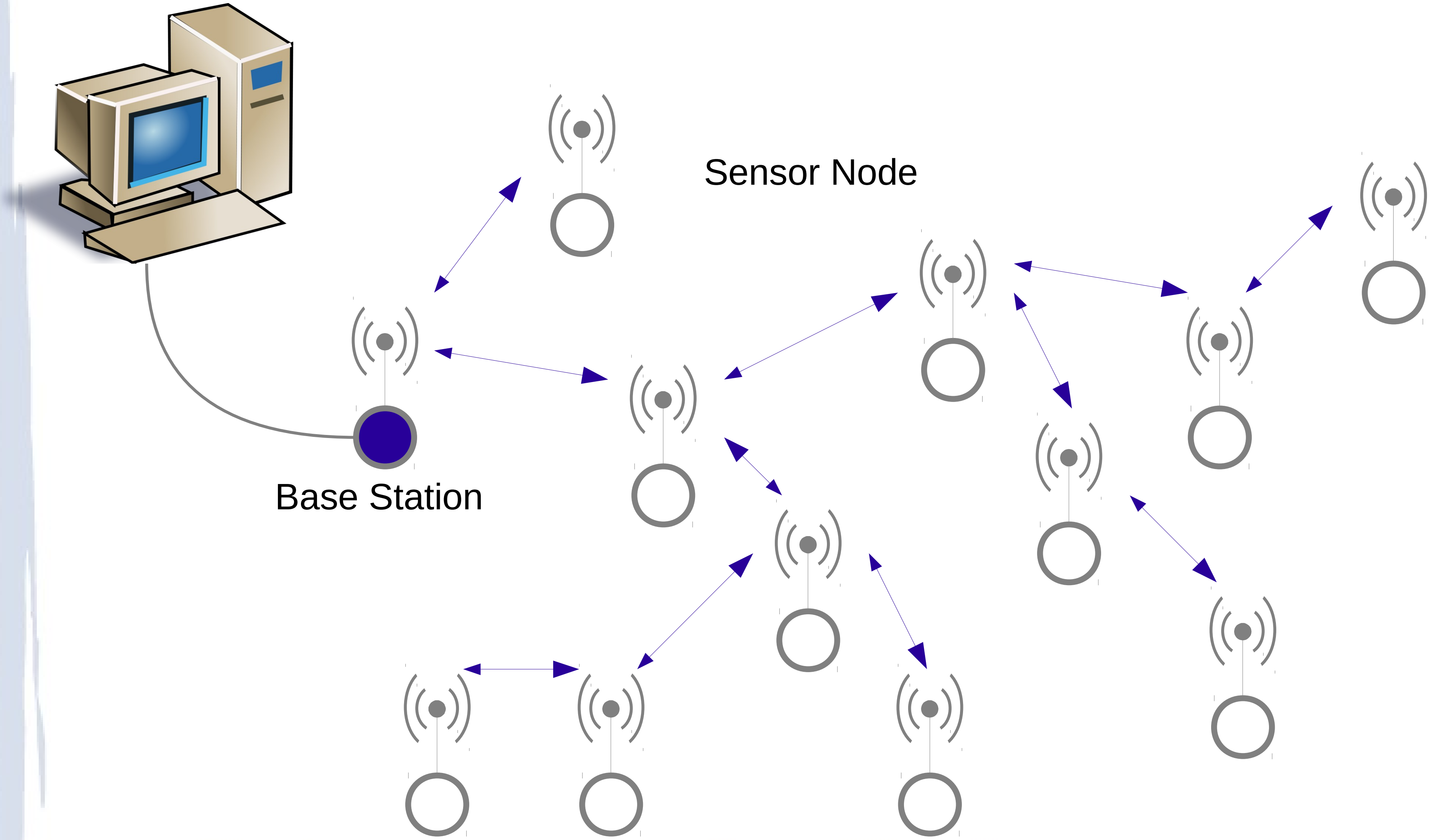
Wireless Sensor Network



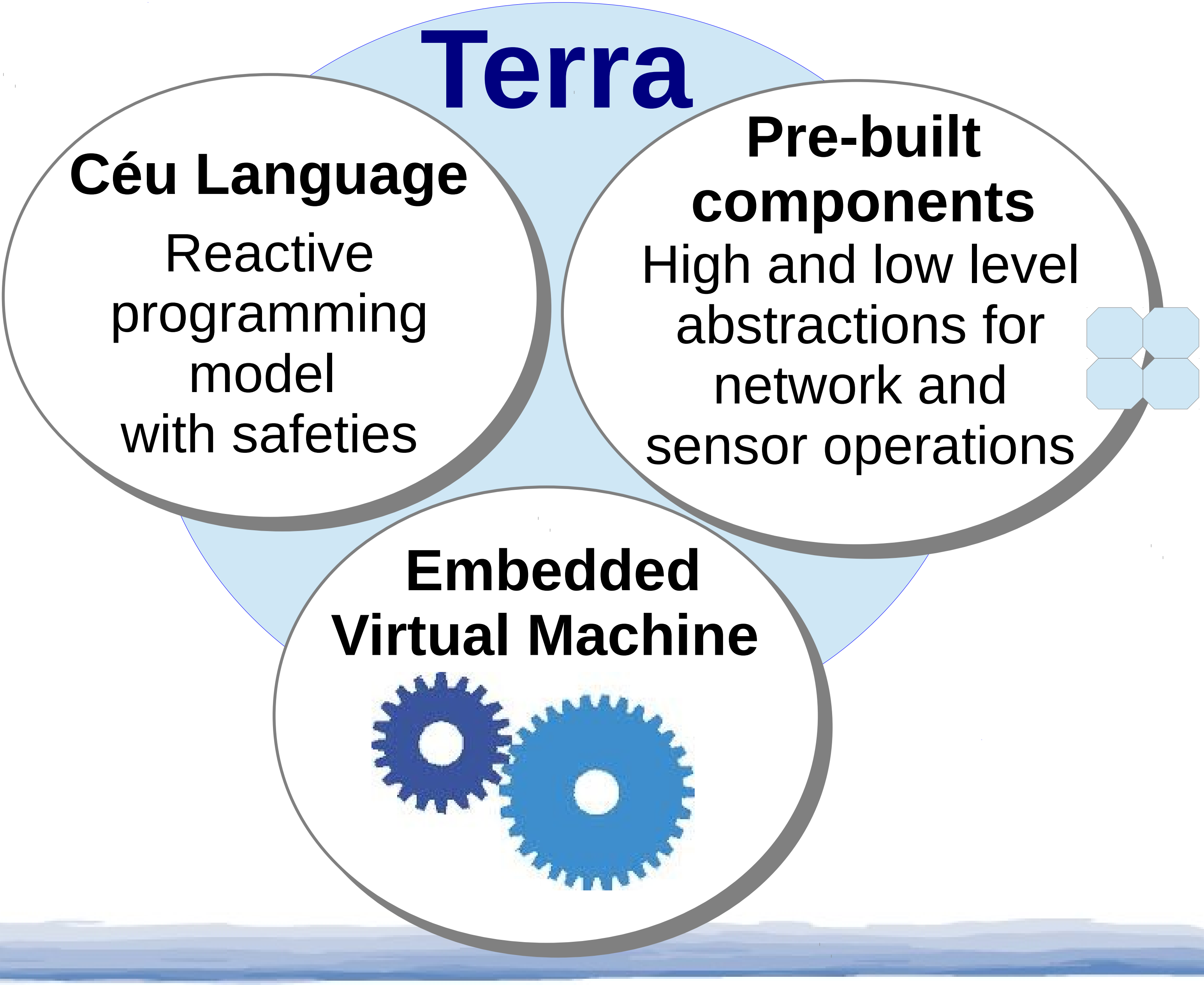
Main Challenges

- Resource scarcity
  - Battery lifetime - radio is the main battery consumer
  - Micro-controller – RAM size (4K~10K)
- Communication
  - Ad-hoc network, node volatility, noise, radio collision, etc
- Programming
  - Event driven model and distributed system
  - Remote programming

Terra System Motivation

- WSN – Wireless Sensor Network
  - Small devices: µController + Radio + Sensors + Battery
- Programming challenges:
  - Event-oriented
  - Distributed application – intra-coordination
  - Resource scarcity
  - Application and communication layers merge
  - Remote programming & configuration

Proposed System



Terra

Céu Language

Reactive programming model with safeties

Pre-built components

High and low level abstractions for network and sensor operations

Embedded Virtual Machine

Sample Code

```
var ushort tValue,pValue;
loop do                                   // Main Loop
    par/and do                            // Starts two parallel blocks
        emit REQ_PHOTO();                 // Requests PHOTO value
        pValue=await PHOTO;               // Waits for “sensor done”
    with
        emit REQ_TEMP();                  // Requests TEMP value
        tValue = await TEMP;              // Waits for “sensor done”
    end
    if pValue > 200 or tValue > 300 then
        emit LED0(ON);
    end
    await 1min;
    emit LED0(OFF);
end
```

Infinite loop

Waits for sensor reads

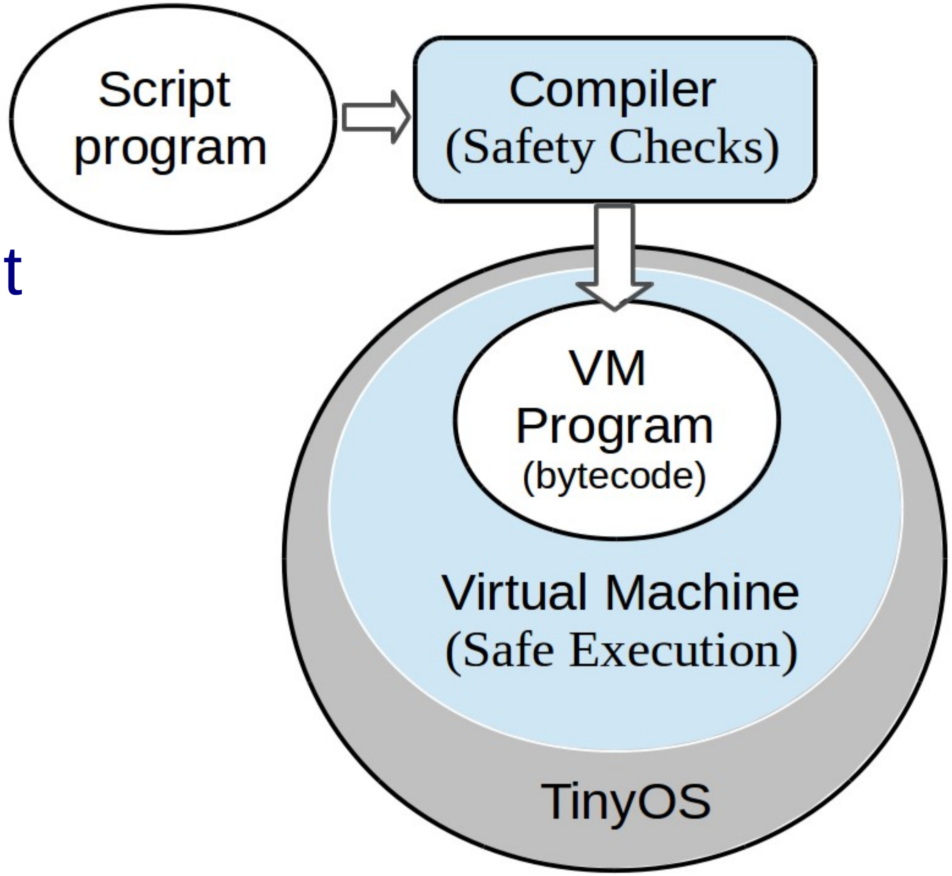
photo

temp.

Alarm

Terra/Céu Main characteristics

- The synchronous execution model enables race-free concurrency.
- The compiler verifies if event reactions are deterministic.
- Applications execute within bounded memory and CPU time.
- VM embedded components escape from Céu static analysis.



Céu

- Reactive
  - Execution is split in trails (lines of code)
  - A trail react to an event (timer, external, or internal)
  - Run to completion each trail (never overlap trails execution)
- Safety guarantees
  - All loops must contain an await statement
  - Avoid trails triggered from same event to share same variable.

Non determinism

warning

```
loop do
 par/and do
   await A;
   y = 1;
 with
   await A;
   y = 2;
 end
 emit LEDS(y);
end
```

A → y = ?

correct

```
loop do
 par/and do
   emit REQ_SENSOR1()
   await EV1
   y = 1;
 with
   emit REQ_SENSOR2()
   await EV2
   y = 2;
 end
 emit LEDS(y);
end
```

EV1 → EV2 → y = 2
EV2 → EV1 → y = 1

Terra scripting language in one page

(Based on Céu language)

Operators:

infix: or, and, |, ^, &,

!= , ==, <=, >=,

<, >, <<, >>,

+, -, *, /, %;

prefix: not, &, -, +, ~, *;

Var types:

byte, ubyte (8bits)

short, ushort (16bits)

long, ulong (32bits)

Statements:

var <type> name;

event <type> name;

await (event | time);

emit event;

If <cond> then <blk> [else <blk>] end

loop do <blk> [break] <blk> end

(par | par/and | par/or) do <blk> [with <blk>]* end

Terra/Céu examples

Try to continue

```
var ushort a=0;
loop do
    await 1min;
    a = // do something
    If a == 0 then
        break;
    end
end
// do continue
```

do-wait-continue

```
par/and do
   // do something
with
   await 1min;
end
// do continue
```

Periodic action

```
loop do
   await 1min;
    // do something
end
```

Time-out

```
event ushort a;
par/or do
   // do something
    await a;
   // do other-thing 1
with
   await 1min;
end
// do continue
```

Repeat[do-wait]-while

```
event ushort a;
par/or do
    loop do
        par/and do
           // do something
           await a;
           // do other-thing 1
        with
           await 1min;
        end
    end
with
   await 4h;
 end
```

Obs: We use only timers and internal events to explain the language basics.

TerraNet

- Implement a thin Terra version using only basic components like radio and sensors.
- The user application must implement its own communication protocol.
- Main functionalities:
  - Radio communication uses only the radio primitives SEND and RECEIVE at the radio range.
  - Support for message queue.
  - Support for radio message acknowledge.
  - Sensors read, Leds set, and a custom digital I/O.

TerraNet Functionalities

- TerraNet components use only low abstraction level
  - Radio
    - Basic send/receive - 1-hop radio range
    - Send broadcast
    - Send to specific target with option to have acknowledge
    - User defined message structure up to 20 bytes
    - Small local message queue
  - Local sensor/actuator
    - Leds
    - Temperature, Luminosity, and battery voltage sensors
    - Digital output
    - Digital input (read and interruption)

Implemented Emits and Awaits (1/2)

Group	emit	await
Radio	SEND(usr_msg_t)	ubyte SEND_DONE() ubyte SEND_DONE(type)
	SEND_ACK(usr_msg_t)	ubyte SEND_DONE_ACK ubyte SEND_DONE_ACK(type)
		usr_msg_t RECEIVE() usr_msg_t RECEIVE(type)
Sensor	REQ_TEMP()	ushort TEMP
	REQ_PHOTO()	ushort PHOTO
	REQ_VOLTS()	ushort VOLTS
LEDS	LED1(u8)	
	LED2(u8)	
	LED3(u8)	
	LEDS(u8)	
Internal Error		ubyte ERROR() ubyte ERROR(err_id)
Message Queue		Ubyte Q_READY()

Implemented Emits and Awaits (2/2)

Group	emit	await
Digital I/O	CFG_PORT_A(u8)	
	CFG_PORT_B(u8)	
	SET_PORT_A(u8)	
	SET_PORT_B(u8)	
	REQ_PORT_A()	u8 PORT_A
	REQ_PORT_B()	u8 PORT_B
Digital HW Interrupt	CFG_INT_A(u8)	INT_A
	CFG_INT_B(u8)	INT_B
Loop-back event	REQ_CUSTOM(u8)	u8 CUSTOM_A

Implemented Functions

Group	Functiom	Description
Basic	ushort getNodeId()	Return NodeID
	ushort random()	Return 16bit Random
Message Queue	ubyte qPut(radioMsg)	Put msg into queue
	ubyte qGet(radioMsg)	Get msg from queue
	ubyte qSize()	Return Queue Size
	ubyte qClear()	Clear all queue entries

Basic use - Radio

```
#include "TerraNet.defs"
var ushort nodeId = getNodeId();
pktype usrMsg from radioMsg with
    var ubyte[4]  d8;
    var ushort[4] d16;
    var ulong[2]  d32;
end
var usrMsg msgRadio;
msgRadio.d8[0] = 0;
if nodeId == 1 then
  msgRadio.source = nodeId;
  msgRadio.target = BROADCAST;
  loop do
    await 10s;
    inc msgRadio.d8[0];
    emit SEND(msgRadio);
    await SEND_DONE;
  end
else
  loop do
    msgRadio = await RECEIVE;
    emit LEDS(msgRadio.d8[0]);
  end
end
```

Include specific TerraNet configuration

Define new usrMsg type from radioMsg packet

Create a msgRadio variable of type usrMsg

Broadcast a
radio message

Waits for a
radio message

RadioMsg packet:

```
  var ubyte type;
  var ushort source;
  var ushort target;
  var payload[20] data;
```

usrMsg type:

```
  var ubyte type;
  var ushort source;
  var ushort target;
  var ubyte[4] d8;
  var ushort[4] d16;
  var ulong[2] d32;
```

Basic use - Queue

```
…
var ubyte stat;
par do
    …
    stat=qPut(msgTemp);
    ...
with
    loop do
        await Q_READY;
        stat = qGet(msgRadio);
        emit SEND(msgRadio);
        await SEND_DONE;
    end
end
```

Insert a msg into queue.

Waits for a new message

Get msg from queue.

Send msg via radio

Terra Local Operations

- Local operations extensions includes operations to access local inputs or outputs.
- Currently TerraNet implements:
  - TEMP – Temperature sensor
  - PHOTO – Luminosity sensor
  - LEDS – On board leds
  - VOLT – Battery voltage sensor
  - PORT_A/B – In/Out digital pin 1/2
  - INT_A/B – Interrupt pin 1/2

Terra Local Operations

Sensors

We need two steps to read a sensor. First we call an “emit <outEvent>**()**;” command to start the A/D converter. Then, we wait for the results using an “xx=await<inEvent>;”. The 10 bits A/D converter always returns an u16 type var.

Terra sensor events: (outEvent x inEvent)

- REQ_TEMP x TEMP
- REQ_PHOTO x PHOTO
- REQ_VOLTS x VOLTS

Ex:

```
var ushort temp;
emit REQ_TEMP();
temp = await TEMP;
```

Terra Local Operations

Leds

It's possible to set the value for each led or all three values together. When setting a individual led value, you may write 'OFF' to have led off, 'ON' to have led on, or 'TOGGLE' to toggle the led state. The LEDS command uses the three least significant bits.

Terra Leds events: (outEvent)

- LEDS, LED0, LED1, LED2

Ex:

```
var ubyte count=0
emit LED0(ON);
...
count=count+1;
emit LEDS(count);
```

Terra Local Operations

Port A and B (only on Mica)

Currently Terra implements access to two I/O pin[*] (port A and B). Each port has to be configured as input or output before the use. Reading a input port uses the two steps like to read a sensor. Configuring a port and setting a output port is like to set a led.

Terra Port events: (outEvent / inEvent)

- CFG_PORT_A
- CFG_PORT_B
- SET_PORT_A
- SET_PORT_B
- REQ_PORT_A / PORT_A
- REQ_PORT_B / PORT_B

Obs: Use 'OUT' and 'IN' constants to configure ports.

[*] PortA=6F and PortB=7F on MDA100CB sensor board.

Terra Local Operations

Interrupt A and B (only on Mica)

Currently Terra implements access to two interrupt pin(*) (int A and B). Each pin has to be configured as rising or falling before the use. The interruptions are received by “await” command.

Terra Port events: (outEvent / inEvent)

- CFG_INT_A / INT_A
- CFG_INT_B / INT_B

Obs: Use 'RISING','FALLING', and 'DISABLE' constants to configure interrupt pins.

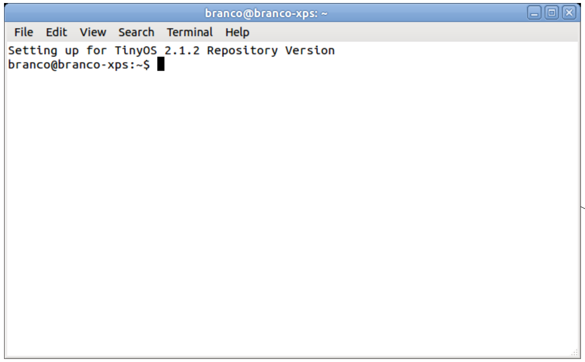
(*) IntA=5D and IntB=4D on MDA100CB sensor board.

Using Terra

- Preparation
  - Upload TerraVM.exe to all nodes
- Application
  - Edit your Terra application
  - Compile it – > ./terrac app.terra (F5 in editor)
  - Load application using terravm java tool.
- Application Operation using an user java/lua app or terravmTool
  - Receive BaseStation Messages

Using Terra

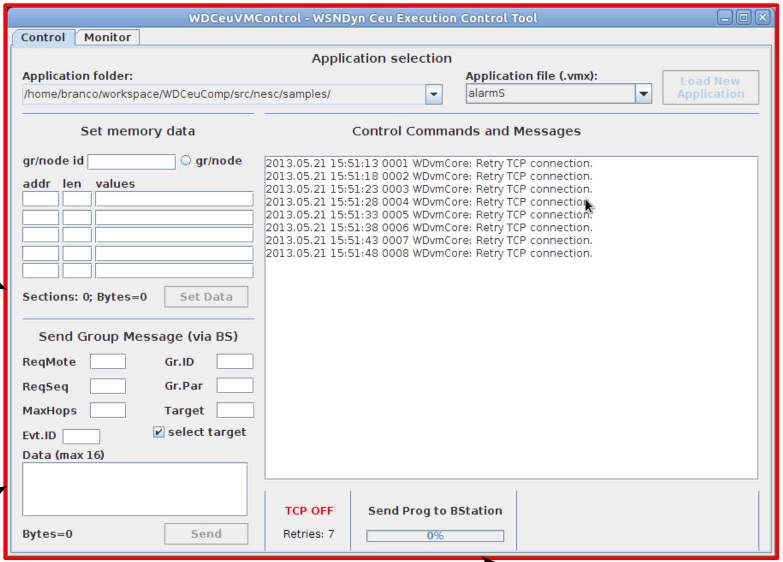
TOSSIM Python Script(3)



```
Setting up for TinyOS 2.1.2 Repository Version
branco@branco-xps:~$ █
```

IP, porta 9002

terravm Java Tool(2)



Application folder: /home/branco/workspace/WDCeuComp/src/nesc/samples/

Application file (.vmx): alarmS

Sections: 0; Bytes=0

☑ select target

Data (max 16)

Bytes=0

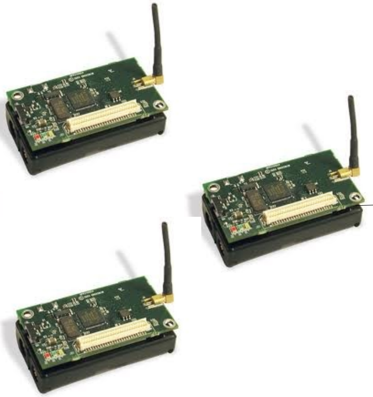
TCP OFF

Retries: 7

```
2013.05.21 15:51:13 0001 WDvmCore: Retry TCP connection.
2013.05.21 15:51:18 0002 WDvmCore: Retry TCP connection.
2013.05.21 15:51:23 0003 WDvmCore: Retry TCP connection.
2013.05.21 15:51:28 0004 WDvmCore: Retry TCP connection.
2013.05.21 15:51:33 0005 WDvmCore: Retry TCP connection.
2013.05.21 15:51:38 0006 WDvmCore: Retry TCP connection.
2013.05.21 15:51:43 0007 WDvmCore: Retry TCP connection.
2013.05.21 15:51:48 0008 WDvmCore: Retry TCP connection.
```

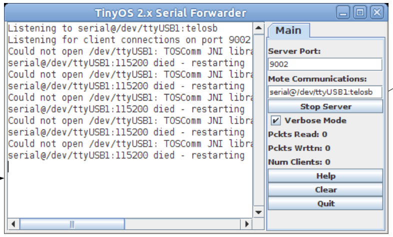
Simulator

Real nodes



USB

SerialForwarder(1)



```
Listening to serial@/dev/ttyUSB1:telosb
Listening for client connections on port 9002
Could not open /dev/ttyUSB1: TOSComm JNI libra
serial@/dev/ttyUSB1:115200 died - restarting
Could not open /dev/ttyUSB1: TOSComm JNI libra
serial@/dev/ttyUSB1:115200 died - restarting
Could not open /dev/ttyUSB1: TOSComm JNI libra
serial@/dev/ttyUSB1:115200 died - restarting
Could not open /dev/ttyUSB1: TOSComm JNI libra
serial@/dev/ttyUSB1:115200 died - restarting
Could not open /dev/ttyUSB1: TOSComm JNI libra
serial@/dev/ttyUSB1:115200 died - restarting
```

Server Port: 9002

Mote Communications: serial@/dev/ttyUSB1:telosb

☑ Verbose Mode

Pckts Read: 0

Pckts Wrttn: 0

Num Clients: 0

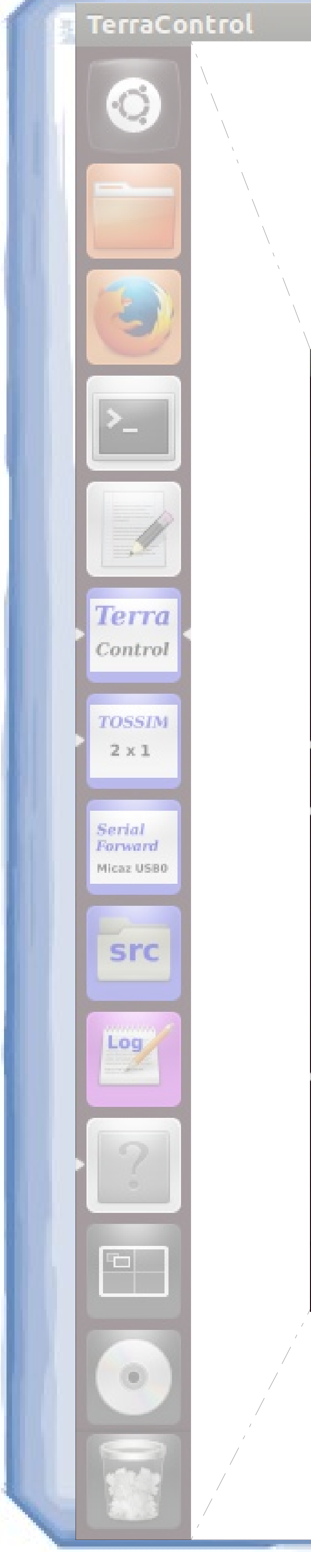
IP, porta 9002

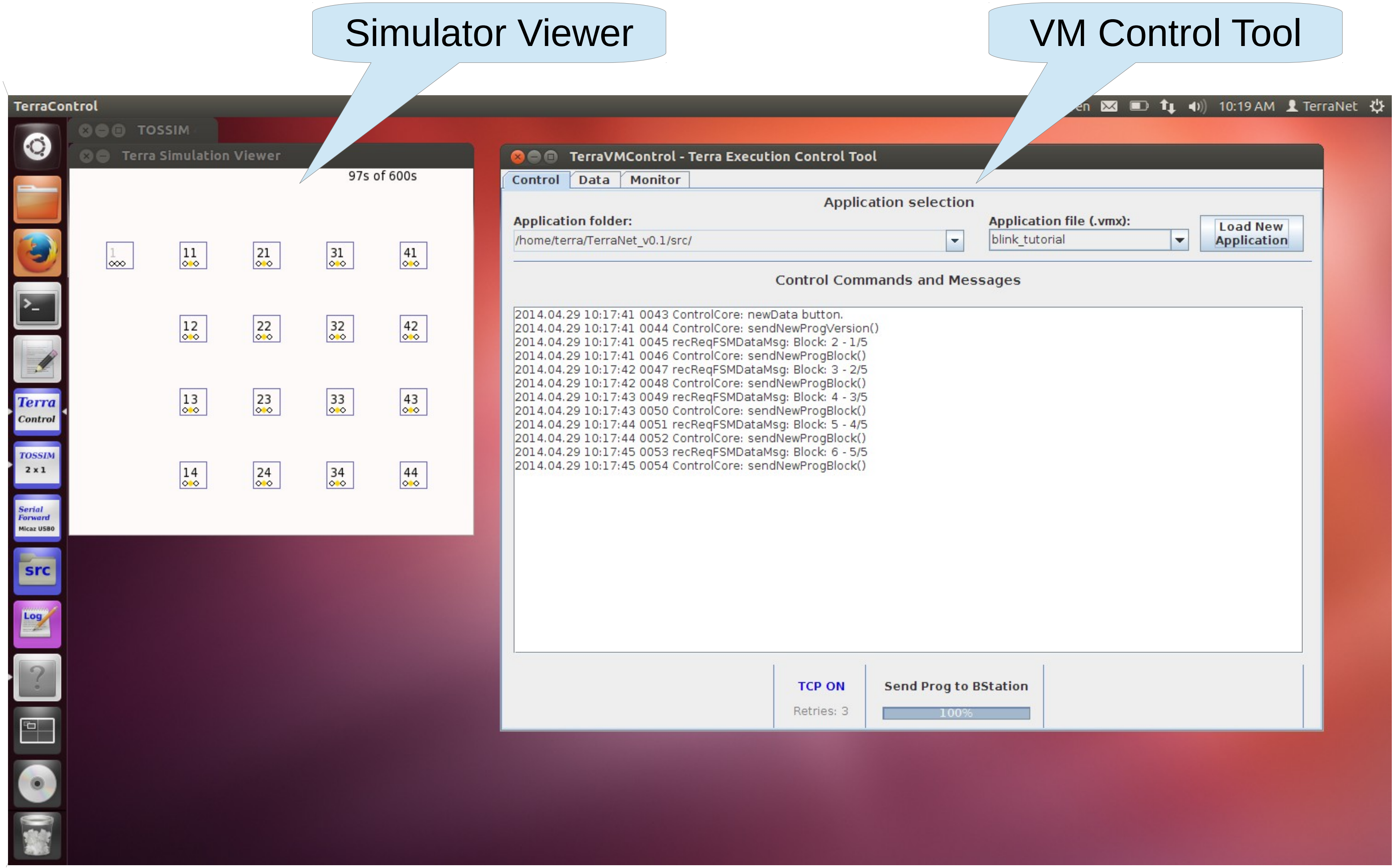
Terra Comp.(5)

Network(4)

Commands:
home (1): java net.tinyos.sf.SerialForwarder -comm serial@/dev/ttyUSB1:micaz
/tools (2) java -jar terravmcontrol.jar
/sim (3) ./TerraSim..py
/bin (4) ./load_mica.sh <USB id> TerraNet_v01_NOBS_micaz <id>
/terra (5) ./terrac xxx.terra

Linux environment





Application folder: /home/terra/TerraNet_v0.1/src/

Application file (.vmx): blink_tutorial

```
2014.04.29 10:17:41 0043 ControlCore: newData button.
2014.04.29 10:17:41 0044 ControlCore: sendNewProgVersion()
2014.04.29 10:17:41 0045 recReqFSMDataMsg: Block: 2 - 1/5
2014.04.29 10:17:41 0046 ControlCore: sendNewProgBlock()
2014.04.29 10:17:42 0047 recReqFSMDataMsg: Block: 3 - 2/5
2014.04.29 10:17:42 0048 ControlCore: sendNewProgBlock()
2014.04.29 10:17:43 0049 recReqFSMDataMsg: Block: 4 - 3/5
2014.04.29 10:17:43 0050 ControlCore: sendNewProgBlock()
2014.04.29 10:17:44 0051 recReqFSMDataMsg: Block: 5 - 4/5
2014.04.29 10:17:44 0052 ControlCore: sendNewProgBlock()
2014.04.29 10:17:45 0053 recReqFSMDataMsg: Block: 6 - 5/5
2014.04.29 10:17:45 0054 ControlCore: sendNewProgBlock()
```

TCP ON

Retries: 3

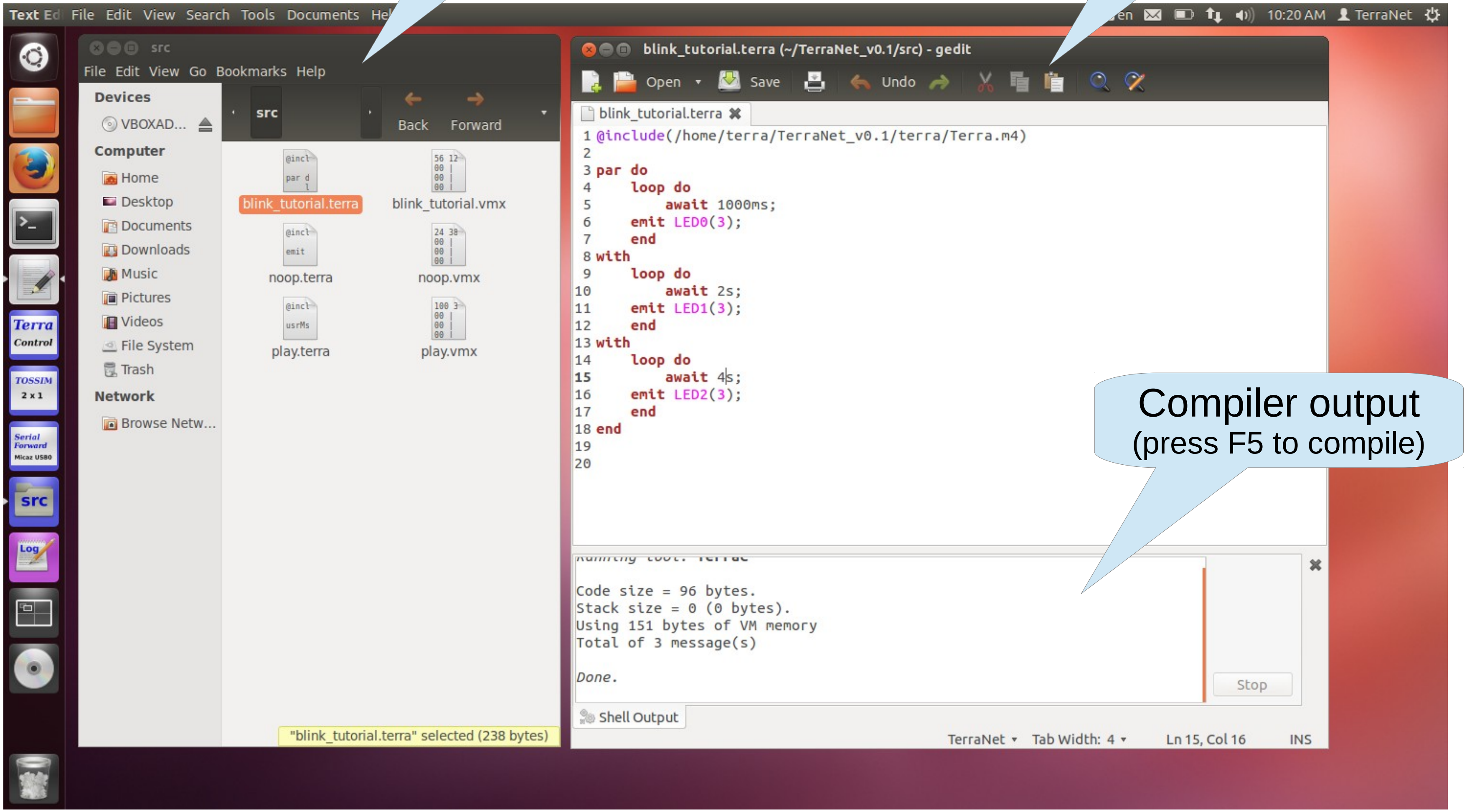
100%

Linux environment

Source dir

Text Editor

Compiler output
(press F5 to compile)



```
@include(/home/terra/TerraNet_v0.1/terra/Terra.m4)

par do
    loop do
        await 1000ms;
    emit LED0(3);
    end
with
    loop do
        await 2s;
    emit LED1(3);
    end
with
    loop do
        await 4s;
    emit LED2(3);
    end
end
```

```
Running tool: Terrac

Code size = 96 bytes.
Stack size = 0 (0 bytes).
Using 151 bytes of VM memory
Total of 3 message(s)

Done.
```

TerraNet Motes

- Simulator (TOSSIM)
  - n x n MicaZ grid – neighbor radio range
  - TerraNet script – max size of 1488 bytes
  - All nodes execute the same script
- Real nodes (Testbed ceunaterra.voip.ufrj.br)
  - MicaZ
  - TelosB

Tarefa Blink

- Selecionar o icone 'src' para abrir a pasta dos arquivos fontes.
- Abrir o arquivo Blink_tutorial.terra
- Pressionar 'F5' para compilar o programa.
- Iniciar simulador Terra com 2 nós.
- Selecionar o icone TerraControl.
- Carregar o Blink_Tutorial.
- Verificar o piscar dos Leds.
- Alterar os tempos no arquivo fonte, compilar e recarregar o programa.

Tarefa Monitor 1

- Faça um programa Terra em que o nó 11 envie periodicamente para a Estação Base (nó 1) o valor do seu sensor de temperatura.
- Opcional:
  - Teste a recepção do valor com o programa ex1.lua do diretório 'tossam'

Tarefa Monitor 2

- Assumindo uma numeração sequencial para os nós, faça um programa que:
  - O nó lê periodicamente seu valor de temperatura e envie para o nó com (NodeId-1).
  - O nó que receber uma mensagem de temperatura deve repassar para o nó (NodeId-1)
  - O nó 11 sempre deve repassar as mensagens para o nó 1 (BaseStation)
- Teste no simulador e no testbed e verifique se todas mensagens estão chegando.
- Imagine e implemente uma possível solução para evitar a perda de mensagens.

Mini projeto
Árvore geradora mínima + roteamento para raiz.

- Monte uma árvore geradora mínima com os nós da rede. Considere o nó ligado na BaseStation como nó raiz da árvore. (Nó 11 no simulador)
- A mensagem de dados de qualquer nó da rede deverá ser roteada até a BaseStation (Nó 1).
- Cada nó deverá enviar periodicamente o seu valor de Temperatura.
- Teste no simulador com redes de 4x4 e 8x8 e no Testbed.
- Tratar erros de colisão e perda de mensagens. Experimentar o uso de fila e envio aleatório ou sincronizado.

Final