Building Connected Devices

With Thingsquare and Contiki

Day 2

thingsquare

Yesterday

- Learned about how to prototype apps
- Learned about the high-level operation of the protocols
- Got a bit of background

Today

- Deep-dive into the protocols
- More information about Contiki

Contiki

Contiki: an IoT OS

- Helps application programs
  - Processes and concurrency
  - Timers
  - Memory management
  - Networking
  - Device drivers

Timers

Time in Contiki

- Two system clocks in Contiki
  - Coarse-grained, most often 128 Hz
    - `CLOCK_SECOND`
  - Fine-grained, most often 32768 Hz
    - `RTIMER_SECOND`
  - Platform dependent
  - Power of two for simple math

Timers

- struct timer – coarse
  - Passive timer, only keeps track of its expiration time
- struct etimer – coarse
  - Active timer, sends an event when it expires
- struct ctimer – coarse
  - Active timer, calls a function when it expires
- struct rtimer – fine
  - Real-time timer, calls a function at an exact time

Etimer

- Periodically print the time

```
static struct etimer etim;
PROCESS_THREAD(my_process, ev, data) {
  PROCESS_BEGIN();
  while(1) {
    printf("Uptime (seconds): %lu\n", clock_seconds());
    etimer_set(&etim, CLOCK_SECOND);
    PROCESS_WAIT_EVENT_UNTIL(etimer_expired(&etim));
  }
  PROCESS_END();
}
```

Ctimer

- Print ”Hello, callback” after 1/8 second.

```
static struct ctimer callback_timer;
static void
callback(void *data)
{
  printf("%s\n", (char *) data);
}

void
application(void)
{
  ctimer_set(&callback_timer, CLOCK_SECOND / 8, callback,
      "Hello, callback!");
  return 0;
}
```

Rtimer

- Sets a hardware interrupt at set time
- Invokes a callback

```
static struct rtimer rt;
rtimer_set(&rt, /* pointer to rtimer struct */
  RTIMER_NOW() + RTIMER_SECOND/100, /* 10ms */
  1,              /* duration */
  rt_callback,    /* callback pointer */
  NULL);          /* pointer to data */
```

Rtimer

- Rtimer callback

```
static void
rt_callback(struct rtimer *rt, void *data)
{
  printf("callback!\n");
}
```

Hands-on: blink.c

- See the blink.c example on the Thingsquare cloud
- Uses etimer to blink LEDs
- Note the use of etimer_reset() to provide a stable timer

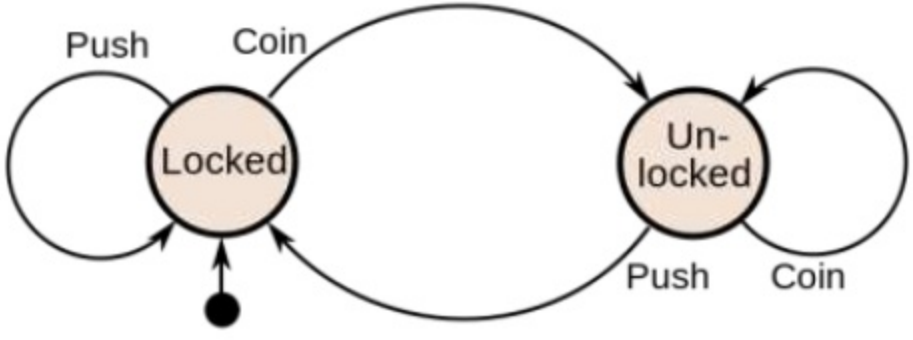
Processes and events

Programming concept: Multithreading

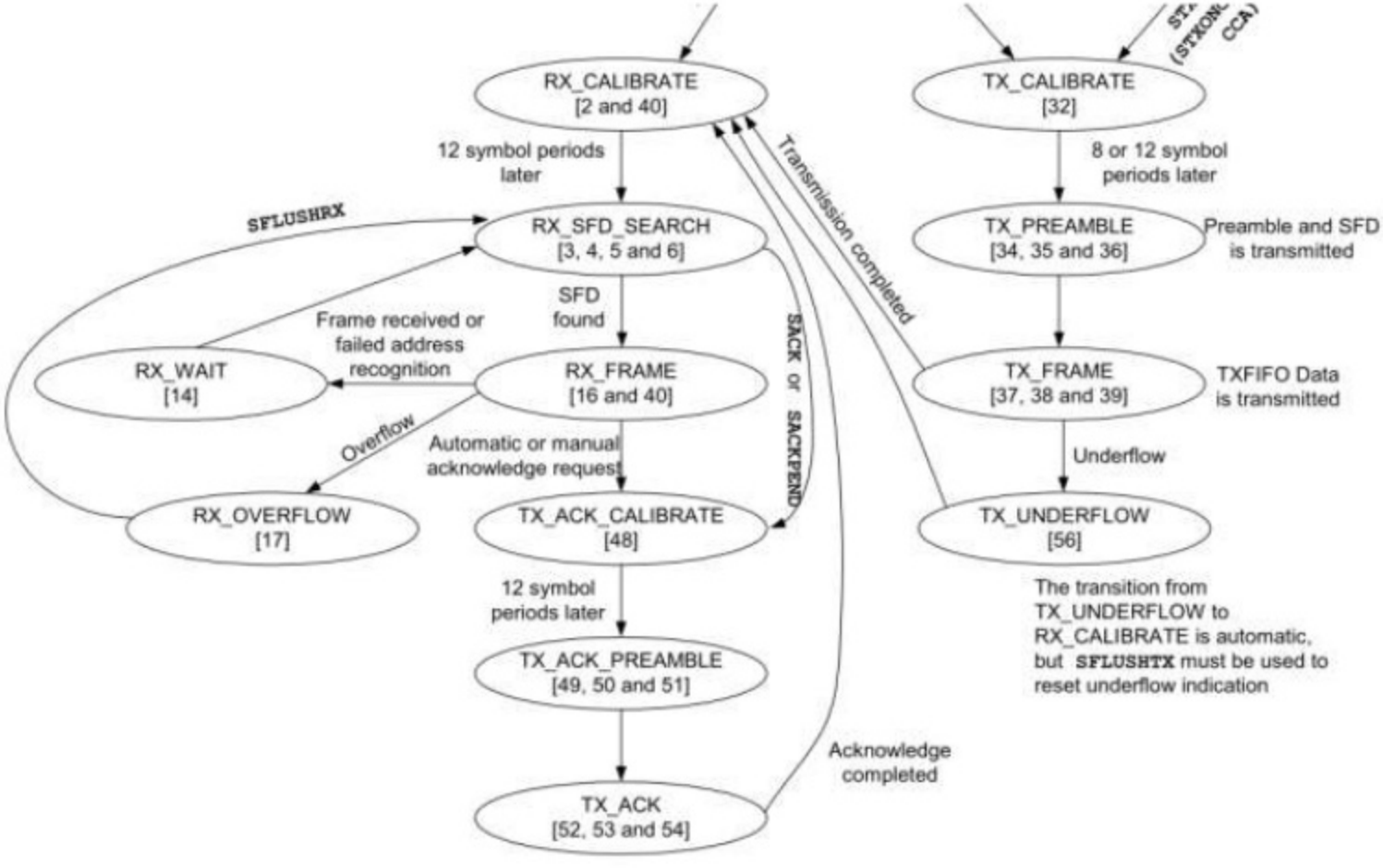
- Threads are given a timeslot to execute
- Paused / continued later by OS scheduler if not done
- Costly – stack space (RAM), CPU

Programming concept: Event driven / state machine

- Reactive - events control program flow
  - Timers, hardware interrupts, radio, etc
- More kind on resources
- However, callbacks and state variables makes programming harder



Event driven / state machine



State machine

- What state? What event? Conditions, transitions, headaches.

```
1  state_t
2  driver(event_t ev, uint8_t *data, uint32_t len)
3  {
4    static state_t state = DRIVER_INIT;
5    static uint8_t buffer[BUFLEN];
6
7    /* handle start and stop events */
8    if(state == DRIVER_INIT && ev == EVENT_START) {
9      memset(buffer, 0, BUFLEN);
10     state = DRIVER_RUNNING;
11     return DRIVER_RUNNING;
12   } else if(state == DRIVER_RUNNING && ev == EVENT_STOP) {
13     state = DRIVER_STOPPED;
14     return DRIVER_STOPPED;
15   }
16
17   if(state == DRIVER_RUNNING && ev == EVENT_IRQ) {
18     if(driver_check_irq() == 0) {
19       return DRIVER_RUNNING;
20     } else {
21       int handle_ret;
22       handle_ret = handle_irq();
23       if(handle_ret == 0) {
24         return DRIVER_RUNNING;
25       } else {
26         /* error, not handled */
27         state = DRIVER_ERROR;
28         return DRIVER_ERROR;
29       }
30     }
31   }
32 }
```

- Event driven is kinder on hw resources..
- Multithreaded is kinder on the programmer..

- can their strengths be combined?

Programming concept: Protothreads

- Threading without the overhead
  - RAM is limited, threads use too much RAM
- Protothreads are event-driven but with a threaded programming style
- Cooperative scheduling

C-switch expansion

```
int a_protothread(struct pt *pt) {
  PT_BEGIN(pt);

  PT_WAIT_UNTIL(pt, condition1);

  if(something) {

    PT_WAIT_UNTIL(pt, condition2);

  }

  PT_END(pt);
}
```

```
int a_protothread(struct pt *pt) {
  switch(pt->lc) { case 0:

  pt->lc = 5; case 5:
  if(!condition1) return 0;

  if(something) {

    pt->lc = 10; case 10:
    if(!condition2) return 0;

  }

} return 1;
}
```

Line numbers

Six-line implementation

- C compiler pre-processor replaces with switch-case
  - very efficient

```
struct pt { unsigned short lc; };


#define PT_INIT(pt)             pt->lc = 0

#define PT_BEGIN(pt)            switch(pt->lc) { case 0:

#define PT_EXIT(pt)             pt->lc = 0; return 2

#define PT_WAIT_UNTIL(pt, c)    pt->lc = __LINE__; case __LINE__: \
                                if(!(c)) return 0

#define PT_END(pt)              } pt->lc = 0; return 1
```

Protothread limitations

- Automatic variables not stored across a blocking wait
  - Workaround: use static local variables instead
- Constraints on the use of switch() constructs in programs
  - Workaround: don't use switches

Contiki processes

- Contiki processes are very lightweight
  - Execution is event-driven
  - Can receive events from other processes
  - Must not block in busy-wait loop
    - while(1) will crash the device
- Contiki processes are protothreads

Contiki processes

```
#include "contiki.h"
/*---------------------------------------------------------*/
PROCESS(hello_world_process, "Hello world process");
AUTOSTART_PROCESSES(&hello_world_process);
/*---------------------------------------------------------*/
PROCESS_THREAD(hello_world_process, ev, data)
{
  PROCESS_BEGIN();

  printf("Hello, world\n");

  PROCESS_END();
}
```

Contiki events

- How to wait for an event

```
PROCESS_THREAD(first_process, ev, data)
.. ..
PROCESS_WAIT_EVENT_UNTIL(ev == servo_event);
if(data != NULL) {
  handle_servo((struct servo_data *) data);
}
```

- ev contains the event number
- data is a void* to any data
  - Can be NULL

Hands-on: blink.c

- See how PROCESS_BEGIN(), PROCESS_END(), PROCESS_WAIT_UNTIL() are used

Starvation in Contiki

- Thread scheduling is cooperative
  - play nice
- The watchdog is on
  - on some platforms unable to turn off
- Don't hog the CPU
- Long-running, do
  - watchdog_periodic();
  - PROCESS_WAIT();

Memory management

Contiki memb

```
struct user_struct {
   int a, b;
}

MEMB(block, 10, struct user_struct);

m = memb_alloc(&block);
memb_free(&block, m);
```

Lists

```
LIST(a_list);

list_add(a_list, an_element);
an_element = list_pop(a_list):
```

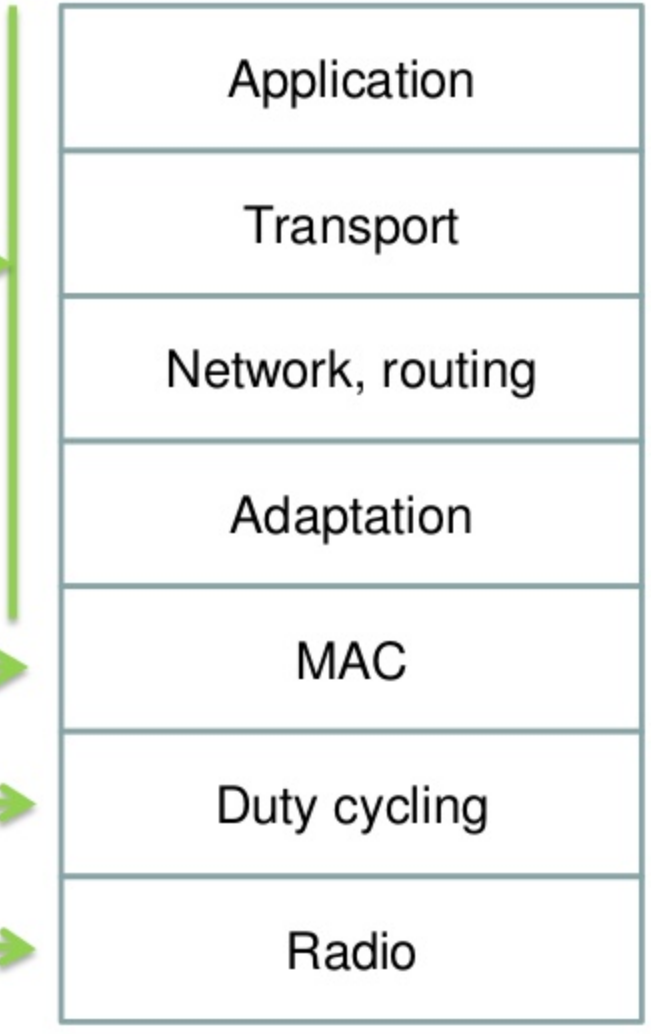
Networking

Contiki netstacks

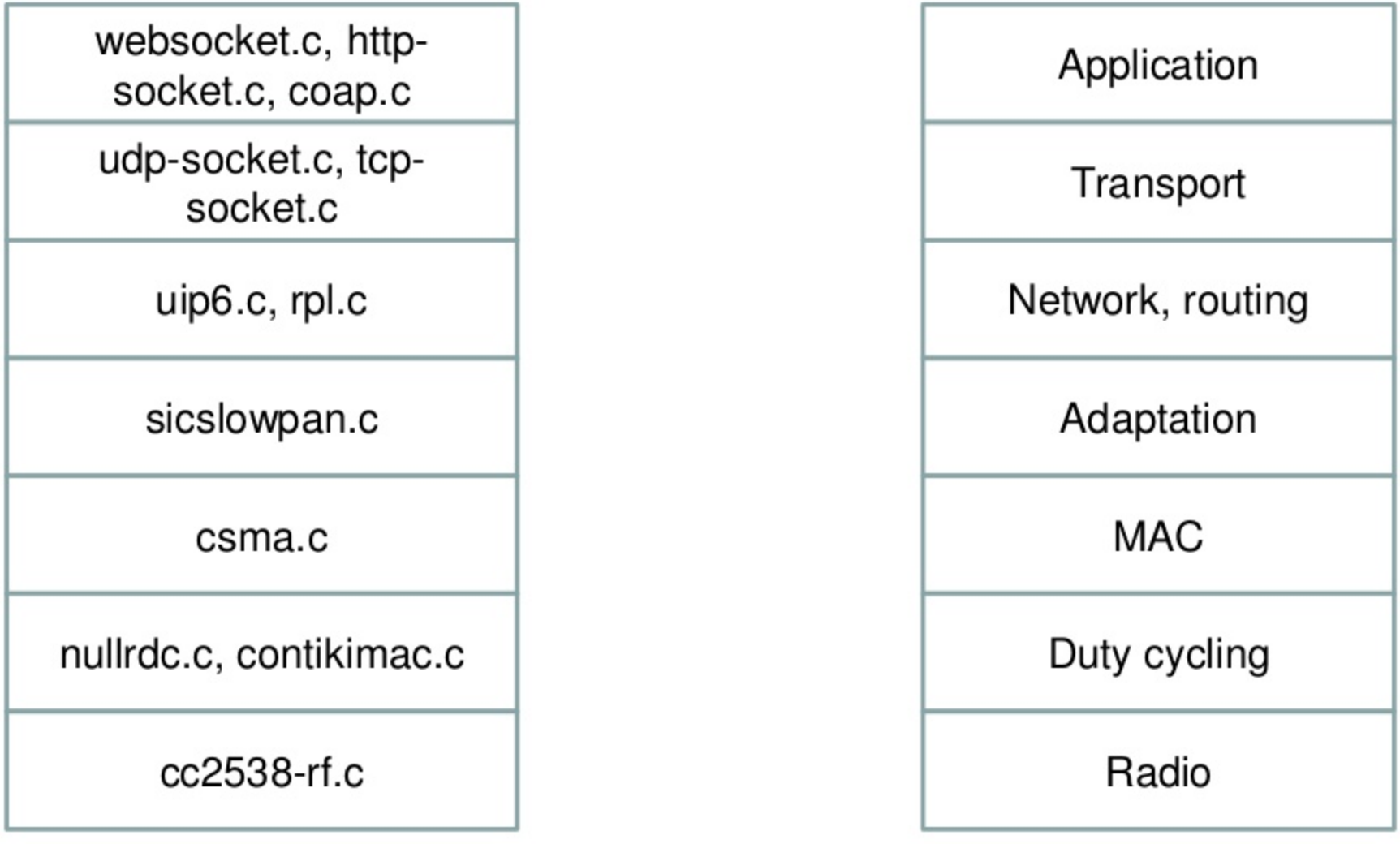
- Three network stacks
  - IPv6
  - IPv4
  - Rime

The Contiki netstack

- Four layers
  - Network layer
  - MAC layer
  - RDC layer
  - Radio layer



The Contiki IPv6 netstack



New Contiki 3.x APIs

- UDP socket
  - Send and receive data with UDP
  - Callback-based
- TCP socket
  - Listen for new connections (server)
  - Set up new connections (client)
  - Send and receive data
  - Callback-based

UDP socket API

```
int udp_socket_register(struct udp_socket *c,
                        void *ptr,
                        udp_socket_input_callback_t receive_callback);

int udp_socket_bind(struct udp_socket *c,
                    uint16_t local_port);

int udp_socket_connect(struct udp_socket *c,
                       uip_ipaddr_t *remote_addr,
                       uint16_t remote_port);

int udp_socket_send(struct udp_socket *c,
                    const void *data, uint16_t datalen);

int udp_socket_sendto(struct udp_socket *c,
                      const void *data, uint16_t datalen,
                      const uip_ipaddr_t *addr, uint16_t port);
```

UDP socket API

- Connected sockets: only receive data from the specified host/port
- Receiving data is simple
  - Get a pointer along with the callback
- Sending data is simple
  - For connected sockets: to the connected host/port
  - Send to any host/port

TCP socket API

- TCP significantly trickier than UDP
  - Connections
  - Retransmissions
  - Buffers

TCP socket API

```
void tcp_socket_register(struct tcp_socket *s, void *ptr,
                         uint8_t *input_databuf, int input_databuf_len,
                         uint8_t *output_databuf, int output_databuf_len,
                         tcp_socket_input_callback_t input_callback,
                         tcp_socket_event_callback_t event_callback);

int tcp_socket_connect(struct tcp_socket *s,
                       uip_ipaddr_t *ipaddr,
                       uint16_t port);

int tcp_socket_listen(struct tcp_socket *s,
                      uint16_t port);

int tcp_socket_unlisten(struct tcp_socket *s);

int tcp_socket_send(struct tcp_socket *s,
                    const uint8_t *dataptr,
                    int datalen);

int tcp_socket_send_str(struct tcp_socket *s,
                        const char *strptr);

int tcp_socket_close(struct tcp_socket *s);
```

TCP socket API

- Caller must provide input and output buffers
  - The caller knows how much data it is going to be sending and receiving
- Sending data is easy
  - Just call the send function
- Receiving data is trickier
  - Data may be retained in the buffer

Contiki directories and toolchains

The Contiki directory structure

- apps/
  - Contiki applications
- core/
  - Contiki core code
- cpu/
  - Contiki CPU-specific code
- doc/
  - Contiki documentation
- examples/
  - Contiki examples
- platform/
  - Contiki platform code
- regression-tests/
  - Contiki regression tests
- tools/
  - Contiki tools

Contiki 3.x directories

- dev/
  - Device drivers
- More fine-grained control through modules
  - New subdirectories under sys/net/

A project directory

- examples/hello-world
  - Makefile
    - Contains the top-level rules to build the project
  - project-conf.h
    - Project configuration
    - Optional – must be explicitly enabled by Makefile
  - hello-world.c
    - Project source code file

Toolchain Installation

- Embedded compiler toolchains with built-in IDE
  - IAR
- Gcc
  - Compiler
  - Linker
  - Use external editor (Eclipse, Emacs, vi, …)

Instant Contiki

- Full toolchain installation in a Linux VM
- Runs in VMware Player
- Compile in Instant Contiki, run on the hardware

Building firmware images

- Use C compiler to compile the full Contiki source code
- Compile in a project directory
- Need to change something? Re-compile

Contiki firmware images

- In a terminal, go to the project directory

```
make TARGET=platform file
```

- This will build the full source code tree for your project. Eg,

```
make TARGET=cc2538dk hello-world
```

Configuration

- Two layers of configuration
  - Platform level
    - Buffer sizes, radio drivers, etc
  - Project level
    - RDC mechanisms
- Don’t touch the platform configuration
- Do touch the project configuration

Uploading the firmware

- Some platforms have a convenient way to upload the firmware

```
make TARGET=sky hello-world.upload
```

- Some platforms are significantly trickier

Save target

- If you are using the same target a lot,

```
make TARGET=cc2538dk savetarget
```

- Then, simply

```
make blink.upload
```

Running as the native target

- Sometimes using the native target is useful

```
make TARGET=native hello-world
```

- Run the program

```
./hello-world.native
```

Other commands

- Connect to serial port

```
make TARGET=exp5438 login
make TARGET=exp5438 COMPORT=COM12 login
```

- Clean out previous compilation

```
make TARGET=exp5438 clean
```

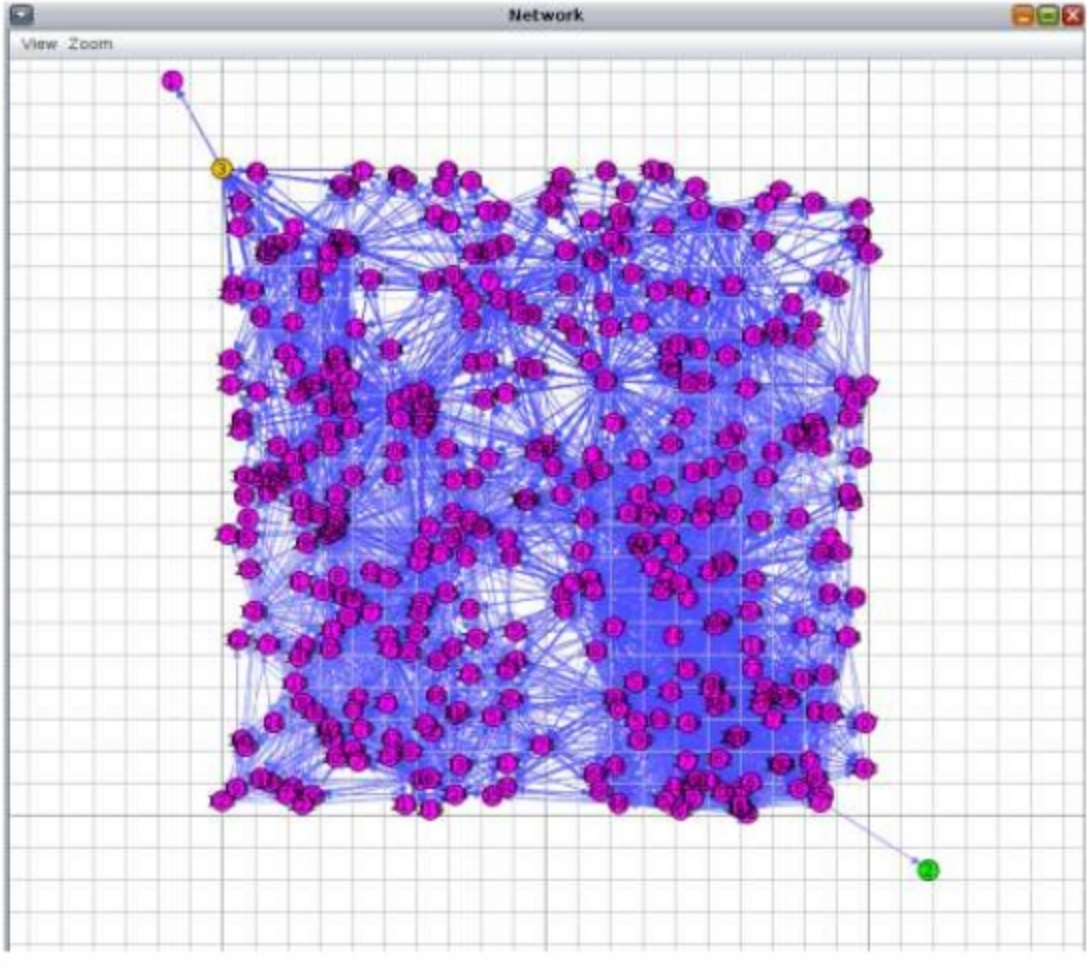
- List available commands

```
make TARGET=exp5438 help
```

Cooja

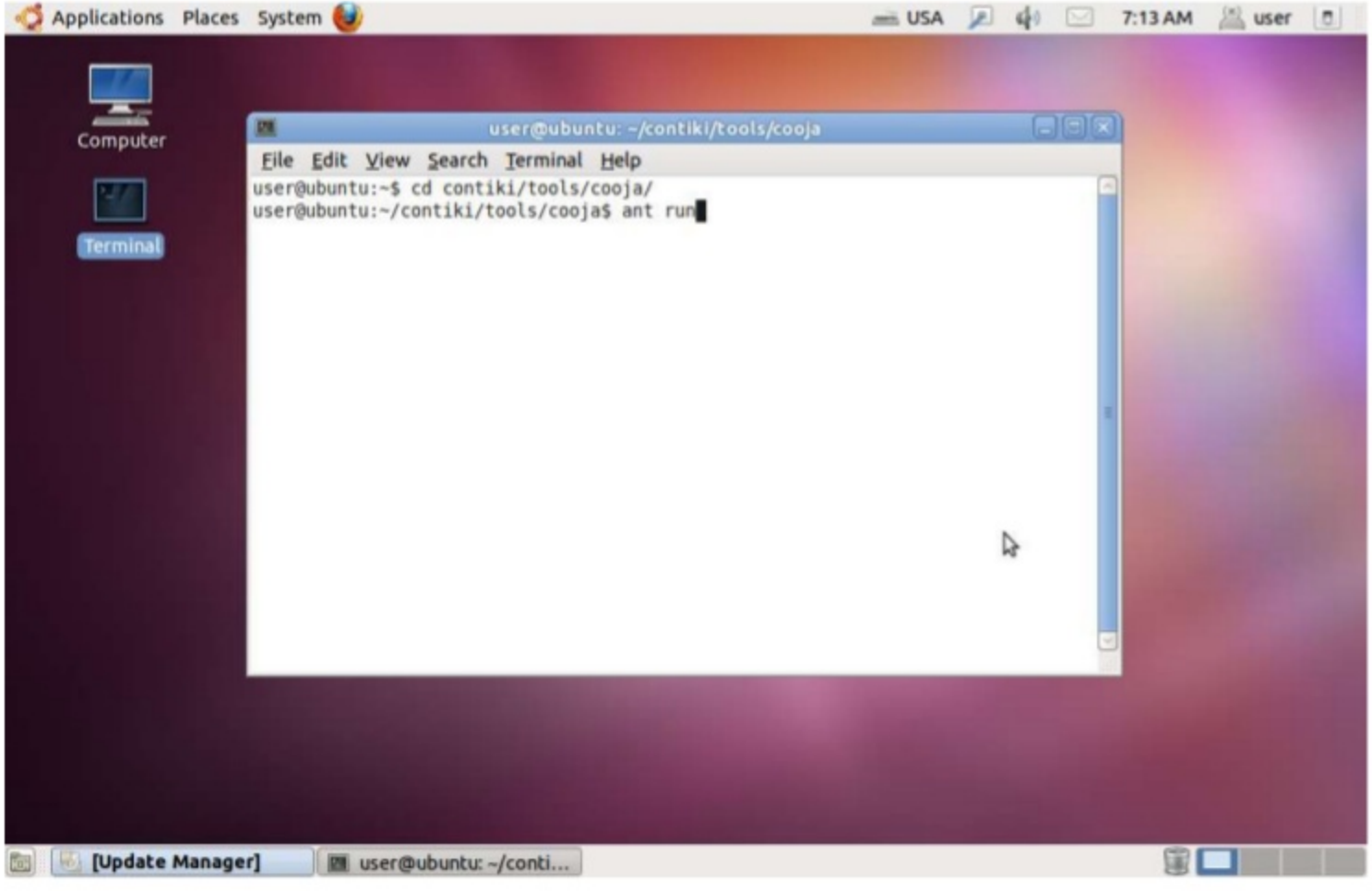
The Cooja Simulator

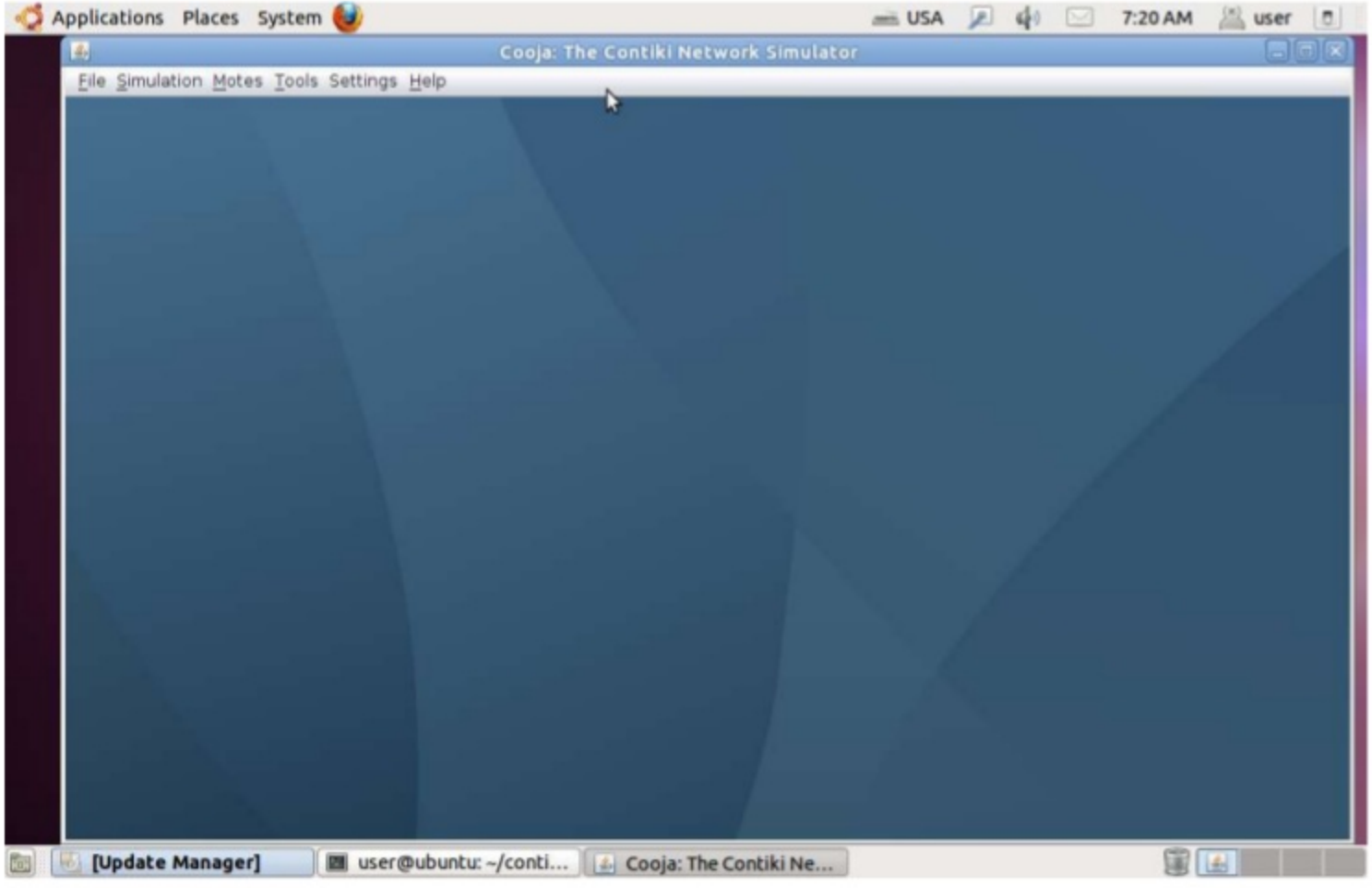
- Emulation mode
  - Run exact same firmware images as run on hardware
  - Slower, more exact
- Native mode
  - Run the Contiki code, compiled for the native system
  - Faster, can run (much) larger systems

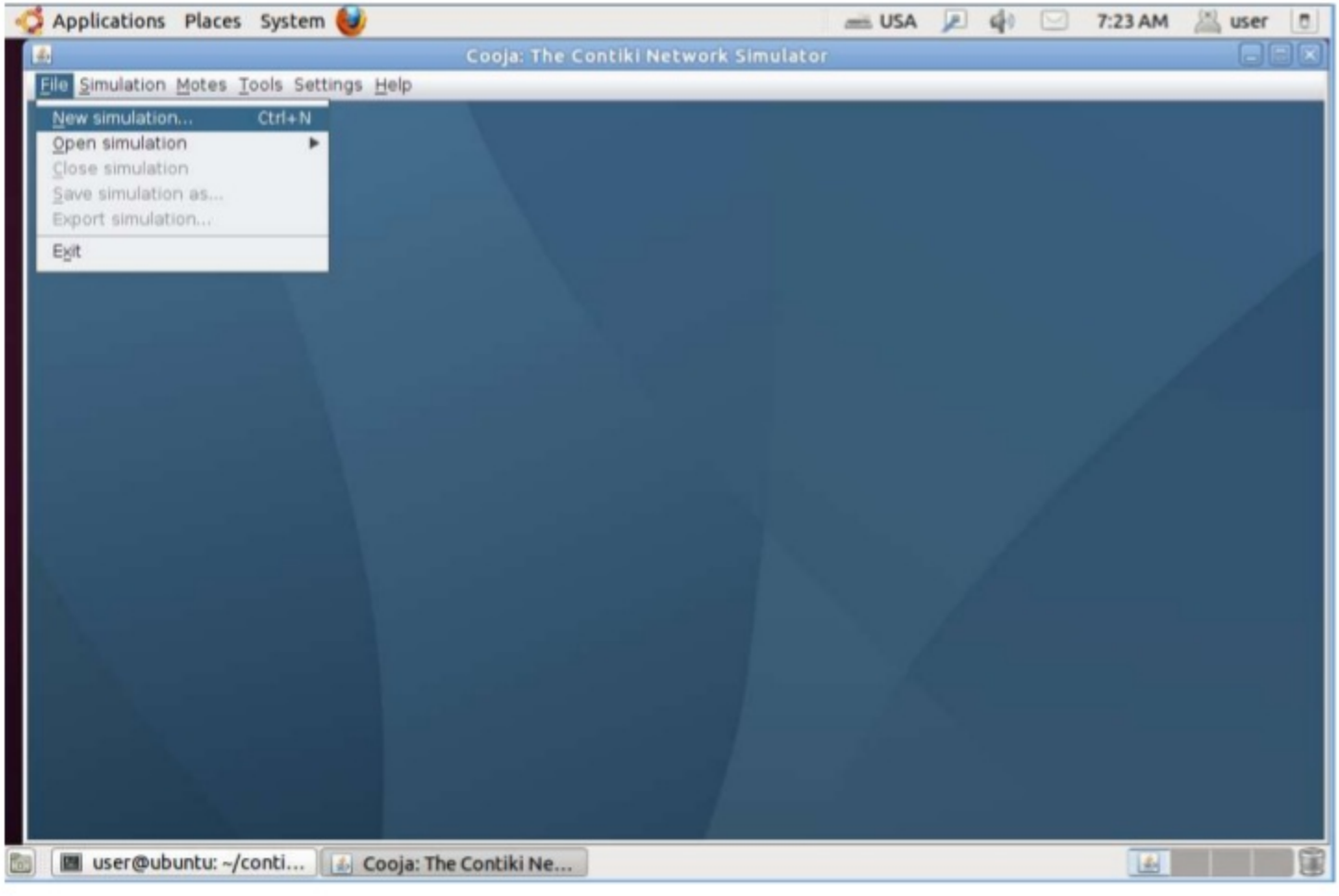

Network
View Zoom

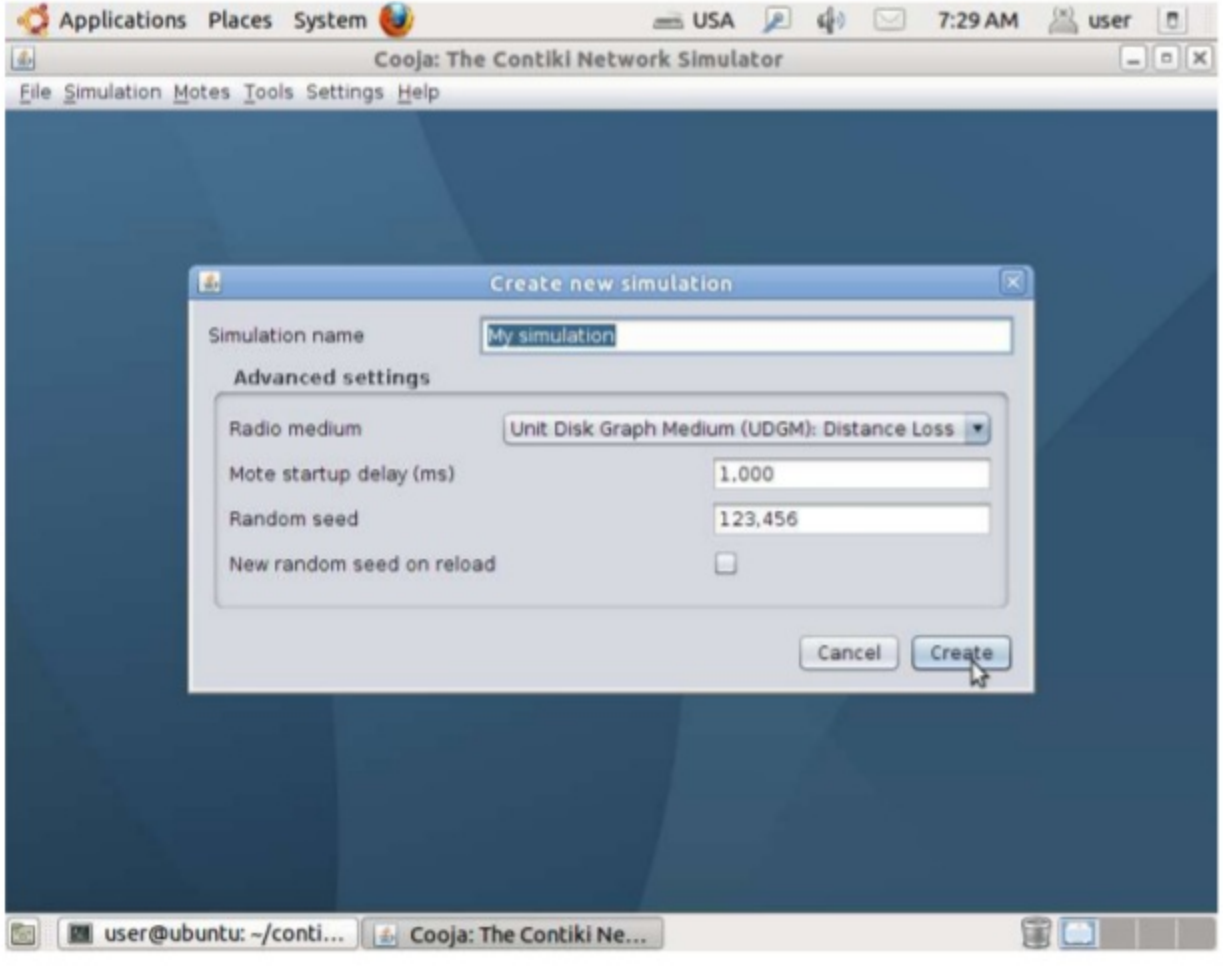
Running Cooja

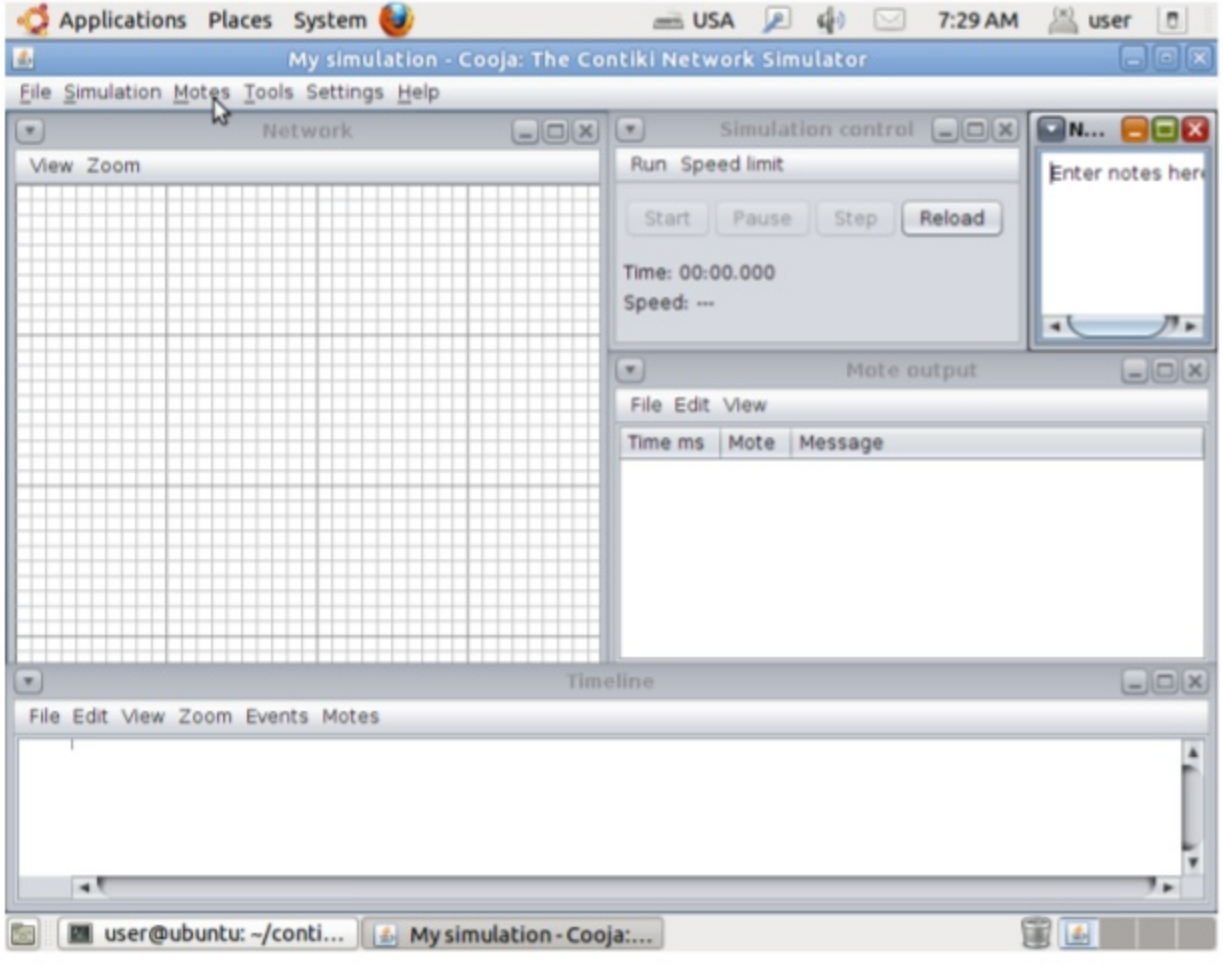
- Go to the Cooja directory
  - cd tools/cooja
  - ant run

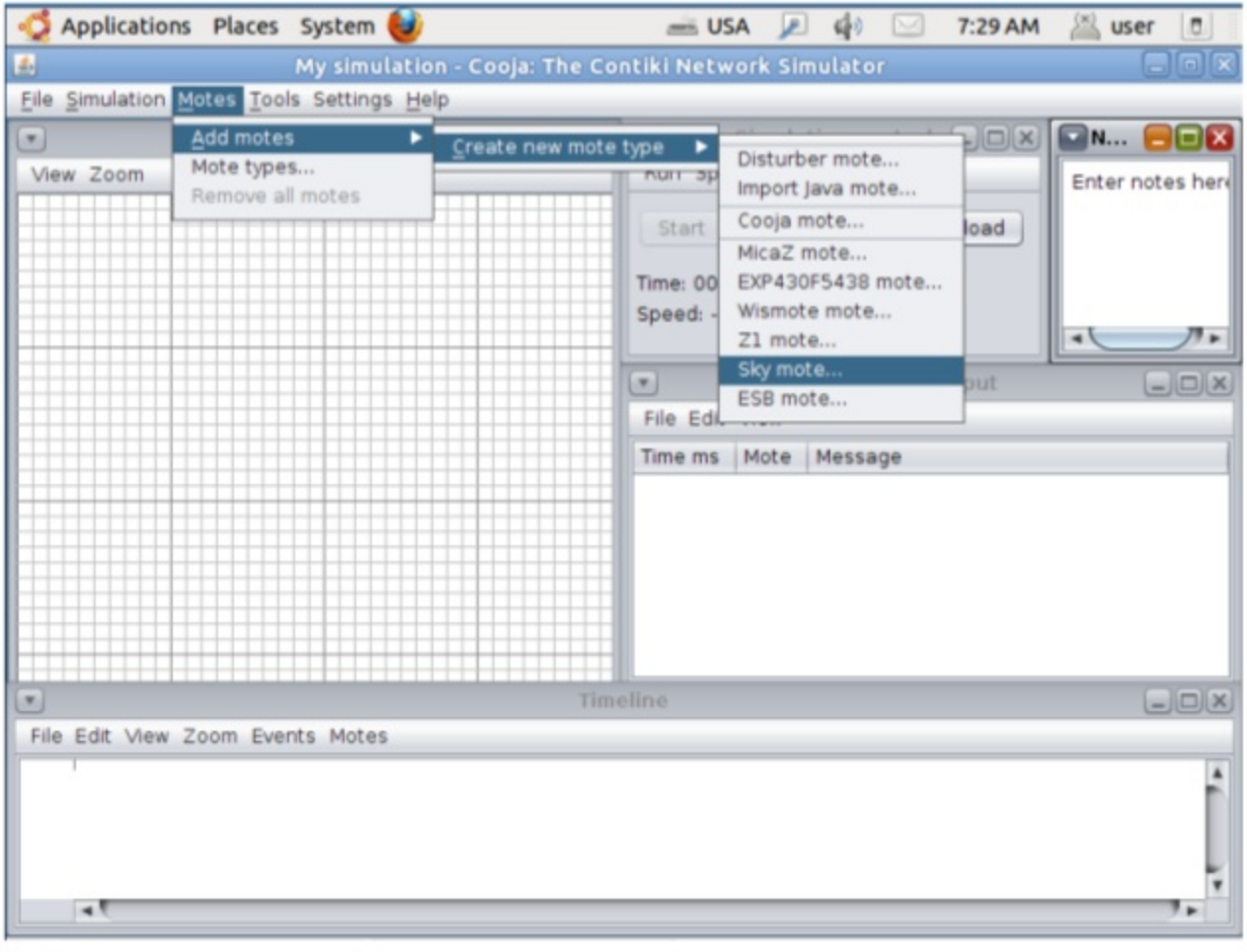

Applications
Places
System
USA
7:13 AM
user
Computer
Terminal
user@ubuntu: ~/contiki/tools/cooja
File Edit View Search Terminal Help
user@ubuntu:~$ cd contiki/tools/cooja/
user@ubuntu:~/contiki/tools/cooja$ ant run
[Update Manager]
user@ubuntu: ~/conti...

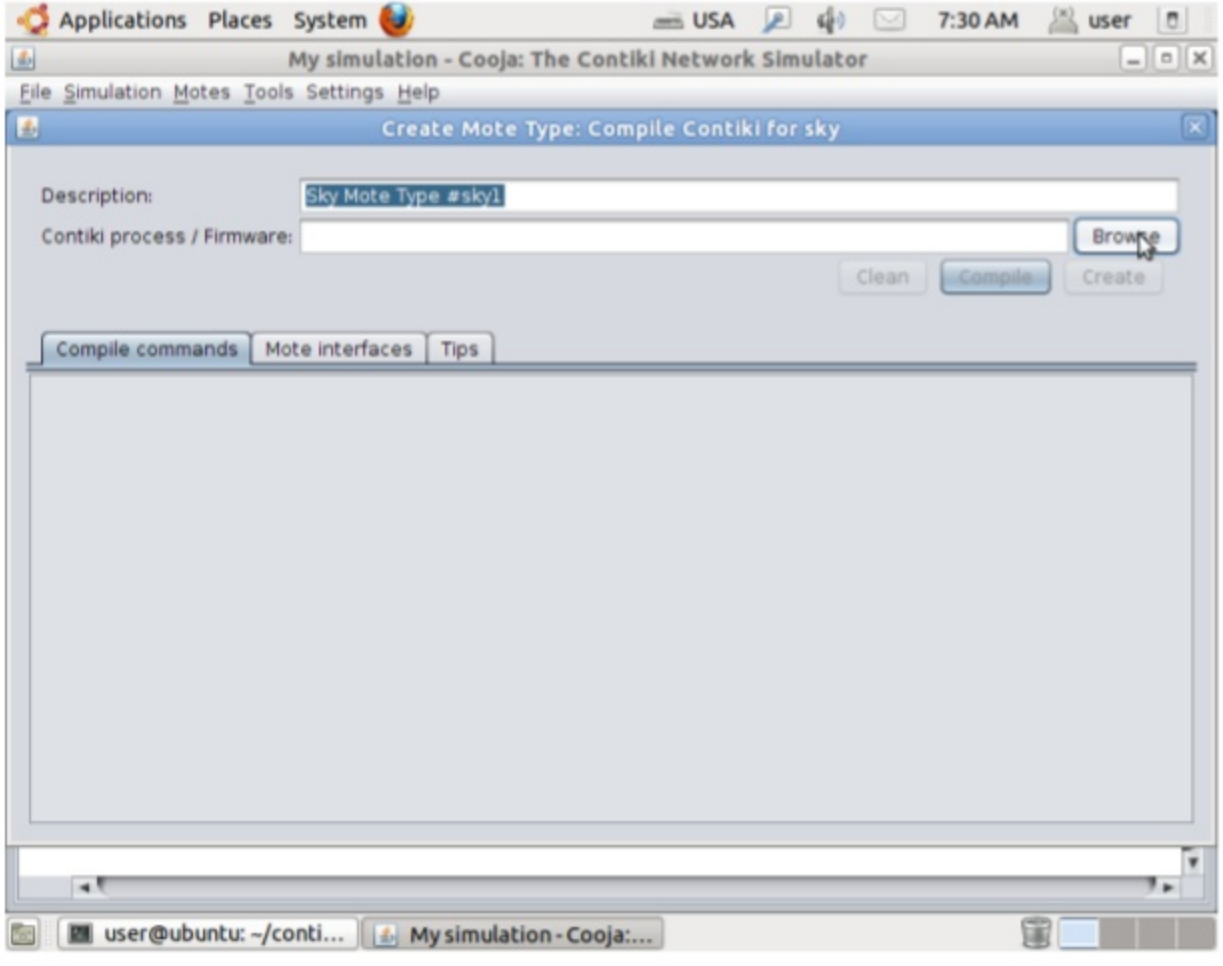

Applications
Places
System
USA
7:20 AM
user
Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
[Update Manager]
user@ubuntu: ~/conti...
Cooja: The Contiki Ne...

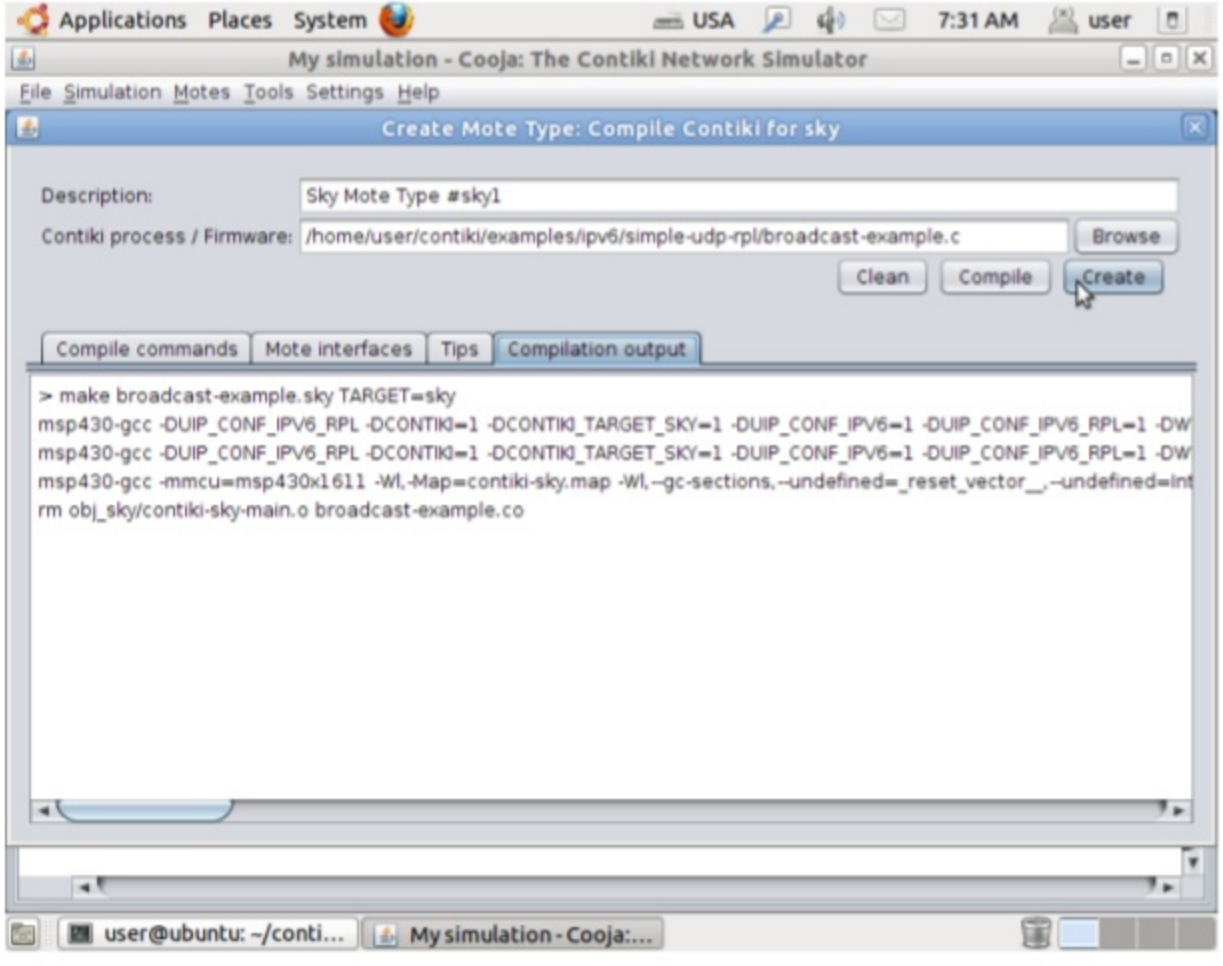

Applications Places System
USA
7:23 AM
user
Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
New simulation... Ctrl+N
Open simulation
Close simulation
Save simulation as...
Export simulation...
Exit
user@ubuntu: ~/conti...
Cooja: The Contiki Ne...

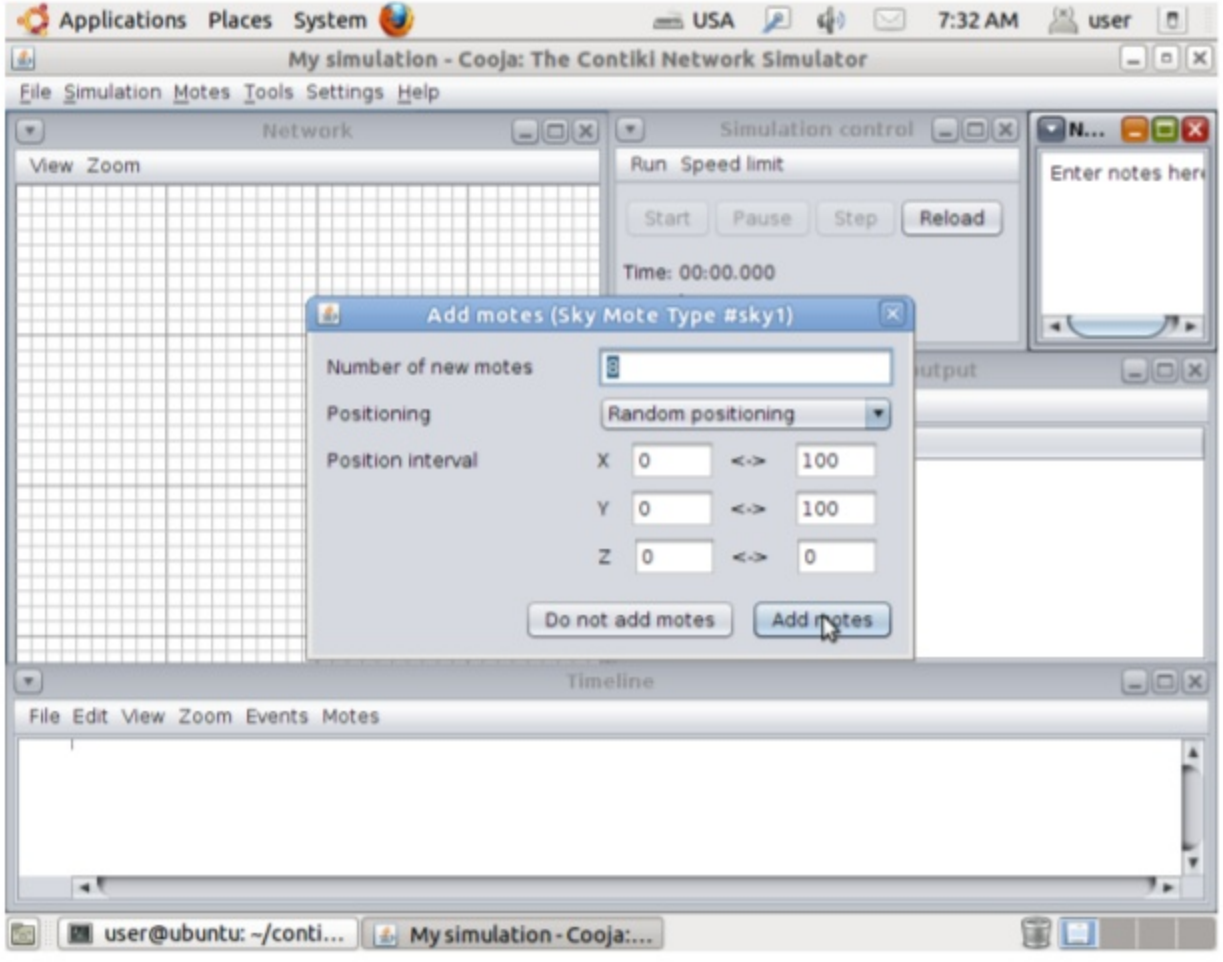

Applications Places System
USA
7:29 AM
user
Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
Create new simulation
Simulation name
My simulation
Advanced settings
Radio medium
Unit Disk Graph Medium (UDGM): Distance Loss
Mote startup delay (ms)
1,000
Random seed
123,456
New random seed on reload
Cancel
Create
user@ubuntu: ~/conti...
Cooja: The Contiki Ne...

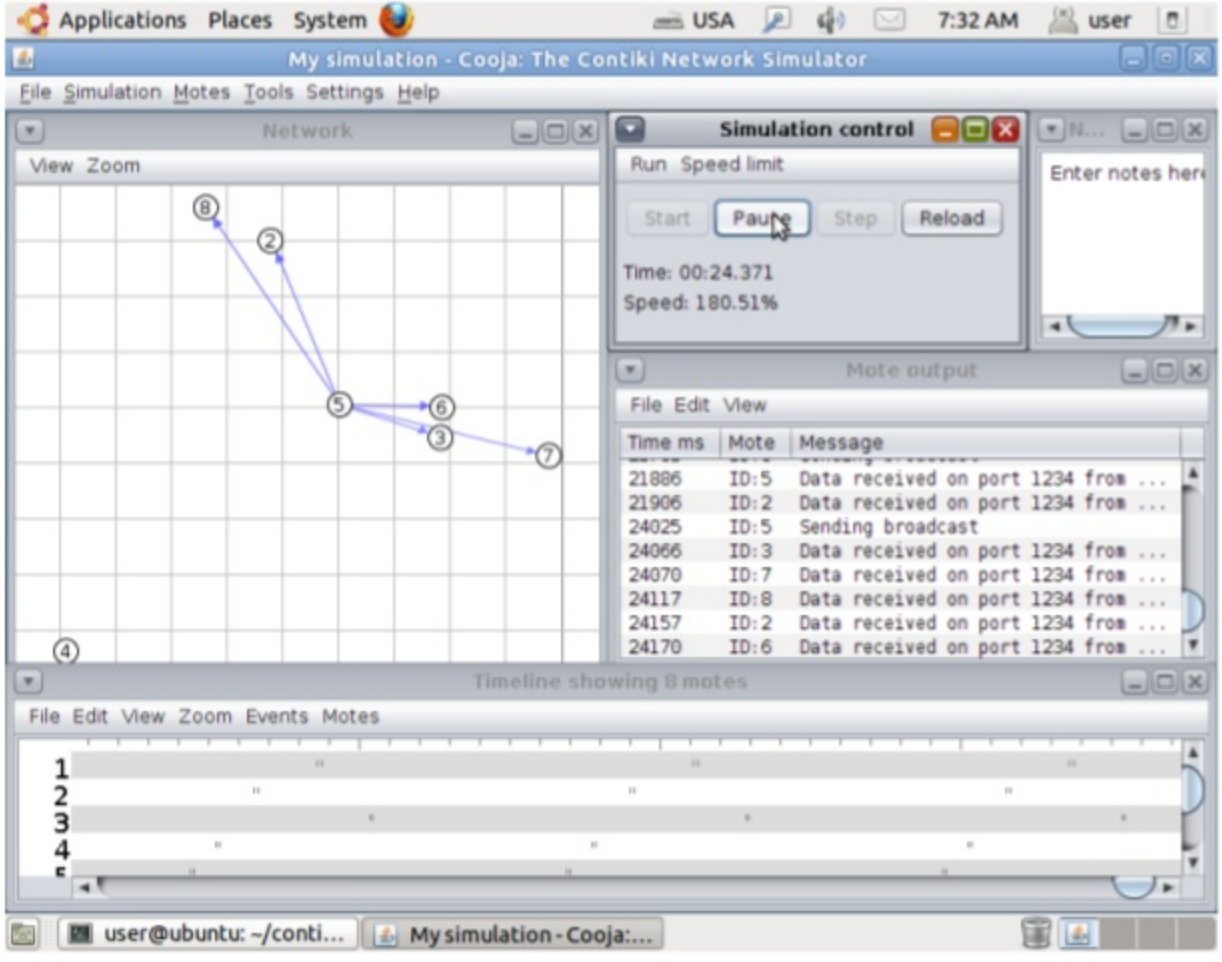

Applications Places System
USA
7:29 AM
user
My simulation - Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
Network
View Zoom
Simulation control
Run Speed limit
Start Pause Step Reload
Time: 00:00.000
Speed: ---
Enter notes here
Mote output
File Edit View
Time ms Mote Message
Timeline
File Edit View Zoom Events Motes
user@ubuntu: ~/conti...
My simulation - Cooja:...


Applications Places System
USA
7:29 AM
user
My simulation - Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
Add motes
Mote types...
Remove all motes
Create new mote type
Disturber mote...
Import Java mote...
Cooja mote...
MicaZ mote...
EXP430F5438 mote...
Wismote mote...
Z1 mote...
Sky mote...
ESB mote...
View Zoom
Start
Time: 00
Speed: -
Enter notes here
Time ms
Mote
Message
Timeline
File Edit View Zoom Events Motes


Applications Places System
USA
7:30 AM
user
My simulation - Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
Create Mote Type: Compile Contiki for sky
Description:
Sky Mote Type #sky1
Contiki process / Firmware:
Browse
Clean
Compile
Create
Compile commands
Mote interfaces
Tips
user@ubuntu: ~/conti...
My simulation - Cooja:...


Applications Places System
USA
7:31 AM
user
My simulation - Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
Create Mote Type: Compile Contiki for sky
Description:
Sky Mote Type #sky1
Contiki process / Firmware:
/home/user/contiki/examples/ipv6/simple-udp-rpl/broadcast-example.c
Browse
Clean
Compile
Create
Compile commands
Mote interfaces
Tips
Compilation output
> make broadcast-example.sky TARGET=sky
msp430-gcc -DUIP_CONF_IPV6_RPL -DCONTIKI=1 -DCONTIKI_TARGET_SKY=1 -DUIP_CONF_IPV6=1 -DUIP_CONF_IPV6_RPL=1 -DW
msp430-gcc -DUIP_CONF_IPV6_RPL -DCONTIKI=1 -DCONTIKI_TARGET_SKY=1 -DUIP_CONF_IPV6=1 -DUIP_CONF_IPV6_RPL=1 -DW
msp430-gcc -mmcu=msp430x1611 -Wl,-Map=contiki-sky.map -Wl,--gc-sections,--undefined=_reset_vector__,--undefined=Int
rm obj_sky/contiki-sky-main.o broadcast-example.co
user@ubuntu: ~/conti...
My simulation - Cooja:...


Applications Places System
USA
7:32 AM
user
My simulation - Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
Network
View Zoom
Simulation control
Run Speed limit
Start Pause Step Reload
Time: 00:00.000
Enter notes here
Add motes (Sky Mote Type #sky1)
Number of new motes
Positioning
Random positioning
Position interval
X 0 <-> 100
Y 0 <-> 100
Z 0 <-> 0
Do not add motes
Add motes
Timeline
File Edit View Zoom Events Motes
user@ubuntu: ~/conti...
My simulation - Cooja:...


Applications Places System
USA
7:32 AM
user
My simulation - Cooja: The Contiki Network Simulator
File Simulation Motes Tools Settings Help
Network
View Zoom
Simulation control
Run Speed limit
Start
Pause
Step
Reload
Time: 00:24.371
Speed: 180.51%
Enter notes here
Mote output
File Edit View
Time ms
Mote
Message
21886 ID:5 Data received on port 1234 from ...
21906 ID:2 Data received on port 1234 from ...
24025 ID:5 Sending broadcast
24066 ID:3 Data received on port 1234 from ...
24070 ID:7 Data received on port 1234 from ...
24117 ID:8 Data received on port 1234 from ...
24157 ID:2 Data received on port 1234 from ...
24170 ID:6 Data received on port 1234 from ...
Timeline showing 8 motes
File Edit View Zoom Events Motes
1
2
3
4
user@ubuntu: ~/conti...
My simulation - Cooja:...

The Contiki regression tests

- A great resource for seeing Cooja simulation setups
- contiki/regression-tests/

More



http://thingsquare.com