Algorithmic Foundations of Sensor Networks

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ContikiOS Introduction

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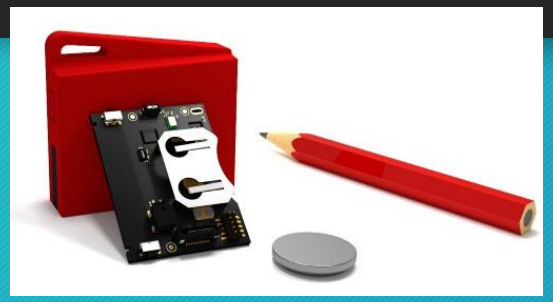
Sensor nodes

- Low power
- Low computational resources
- Collection of sensors
- Connectivity

Examples of sensor nodes

- Sensortsag CC2650



- TelosB mote

- List of sensing nodes: https://en.wikipedia.org/wiki/List_of_wireless_sensor_nodes

TelosB Skymote

- Texas Instruments MSP430 Microcontroller 8MHz
- Low power
- 10 kB RAM
- Integrated Temperature, Light, Humidity sensor
- Integrated Onboard Antenna, support of IEEE 802.15.4 protocol of wireless communication for low power devices, operating at 2.4GHz
- USB programmable
- Energy-efficient management of node components (radio,
- sensors, actuators)

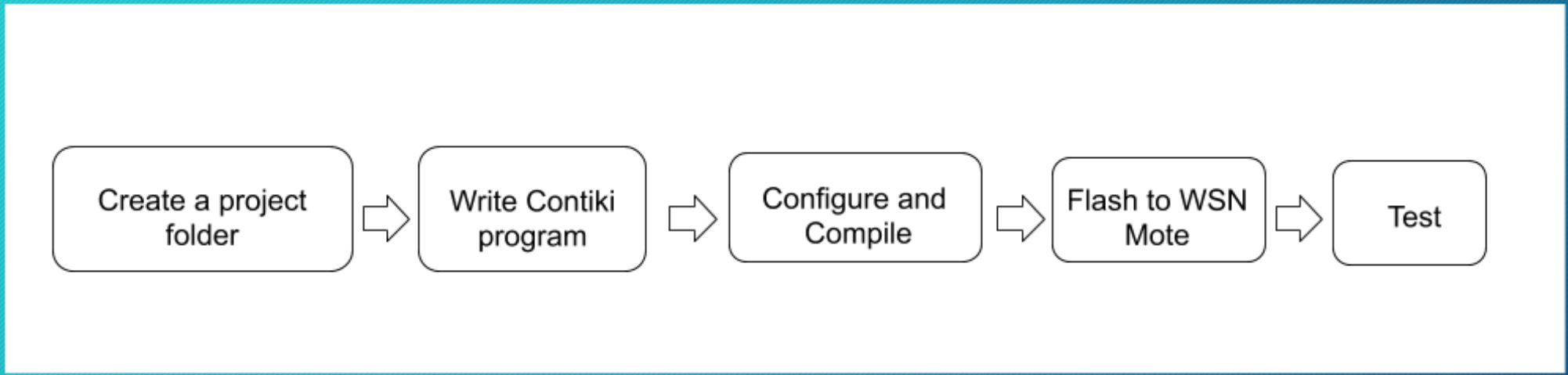
Contiki OS

- Contiki OS is an operating system for resource-constrained devices in the Internet of Things.
- Started at 2003 by Adam Dunkels who works for the Swedish Institute of Computer Science.
- Implemented stack supports various protocols for connection and application layers (IPv6 support, 6LoWPAN, RPL, CoAP etc.)
- Support for many constrained devices.
- Large community of developers and users (Atmel, Cisco, SAP)
- Open source
- Written in C

Contiki-NG

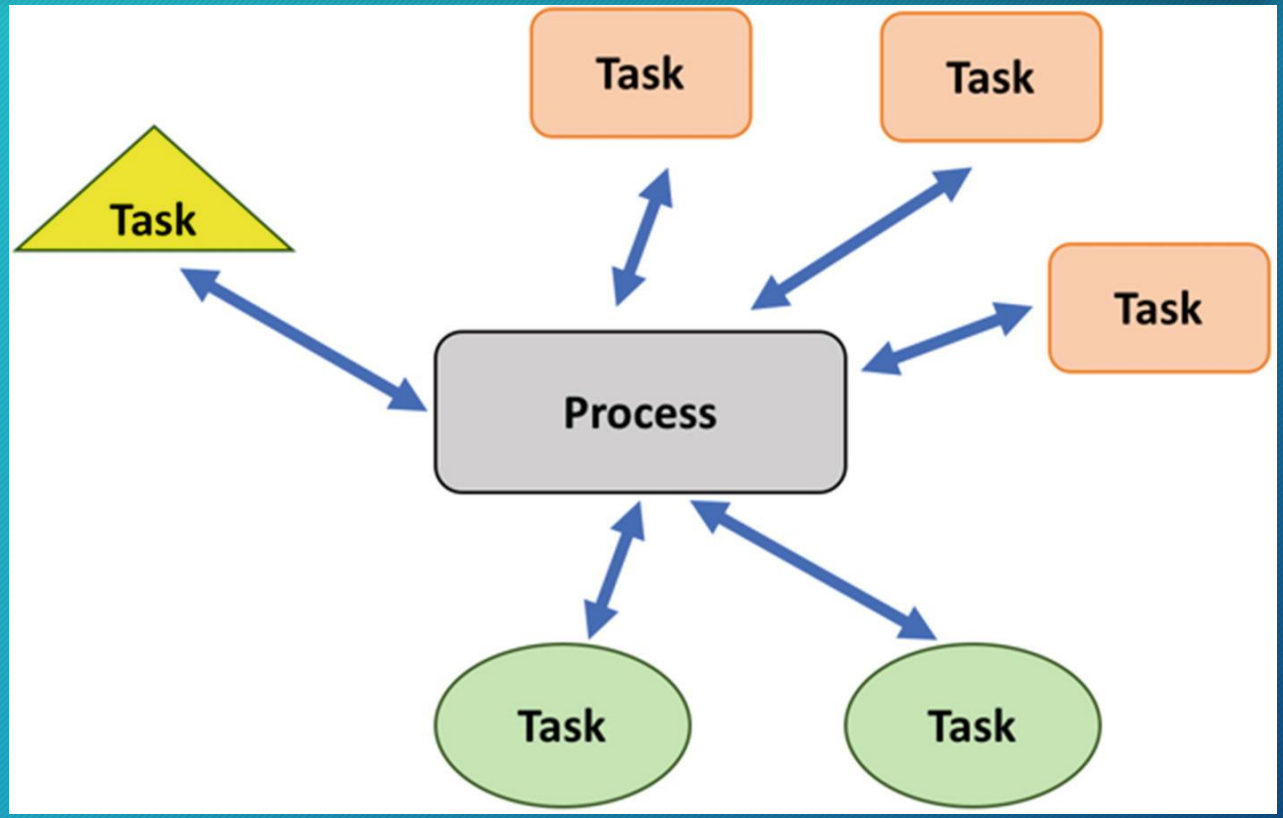
- Support for modern IOT platforms and tools.
- Updated guides and tutorials.
- Rebuilded configuration system
- New data logging and shell systems
- MCU-based ARM support

Programming in Contiki



Task scheduling

- Process
- Timers
- Threading
- Task scheduling



- Documentation: Multitasking and scheduling

Hello-world.c in ContikiOS

```
36   * \author
37   *         Adam Dunkels <adam@sics.se>
38   */
39
40  #include "contiki.h"
41
42  #include <stdio.h> /* For printf() */
43  /*---------------------------------------------------------------------
44  PROCESS(hello_world_process, "Hello world process");
45  AUTOSTART_PROCESSES(&hello_world_process);
46  /*---------------------------------------------------------------------
47  PROCESS_THREAD(hello_world_process, ev, data)
48  {
49    static struct etimer timer;
50
51    PROCESS_BEGIN();
52
53    /* Setup a periodic timer that expires after 10 seconds. */
54    etimer_set(&timer, CLOCK_SECOND * 10);
55
56    while(1) {
57      printf("Hello, world\n");
58
59      /* Wait for the periodic timer to expire and then restart t
60      PROCESS_WAIT_EVENT_UNTIL(etimer_expired(&timer));
61      etimer_reset(&timer);
62    }
63
64    PROCESS_END();
65  }
```

Architecture – timer libraries

- Clock
- Timer - functions for setting, resetting, and restarting timers.
- Stimer - similar to the timer library, but uses time values in seconds.
- Etimer - event timer library
- Ctimer – Provides a function callback that will be called when timer expiration occurs.
- Rtimer - scheduling and execution for real-time tasks.

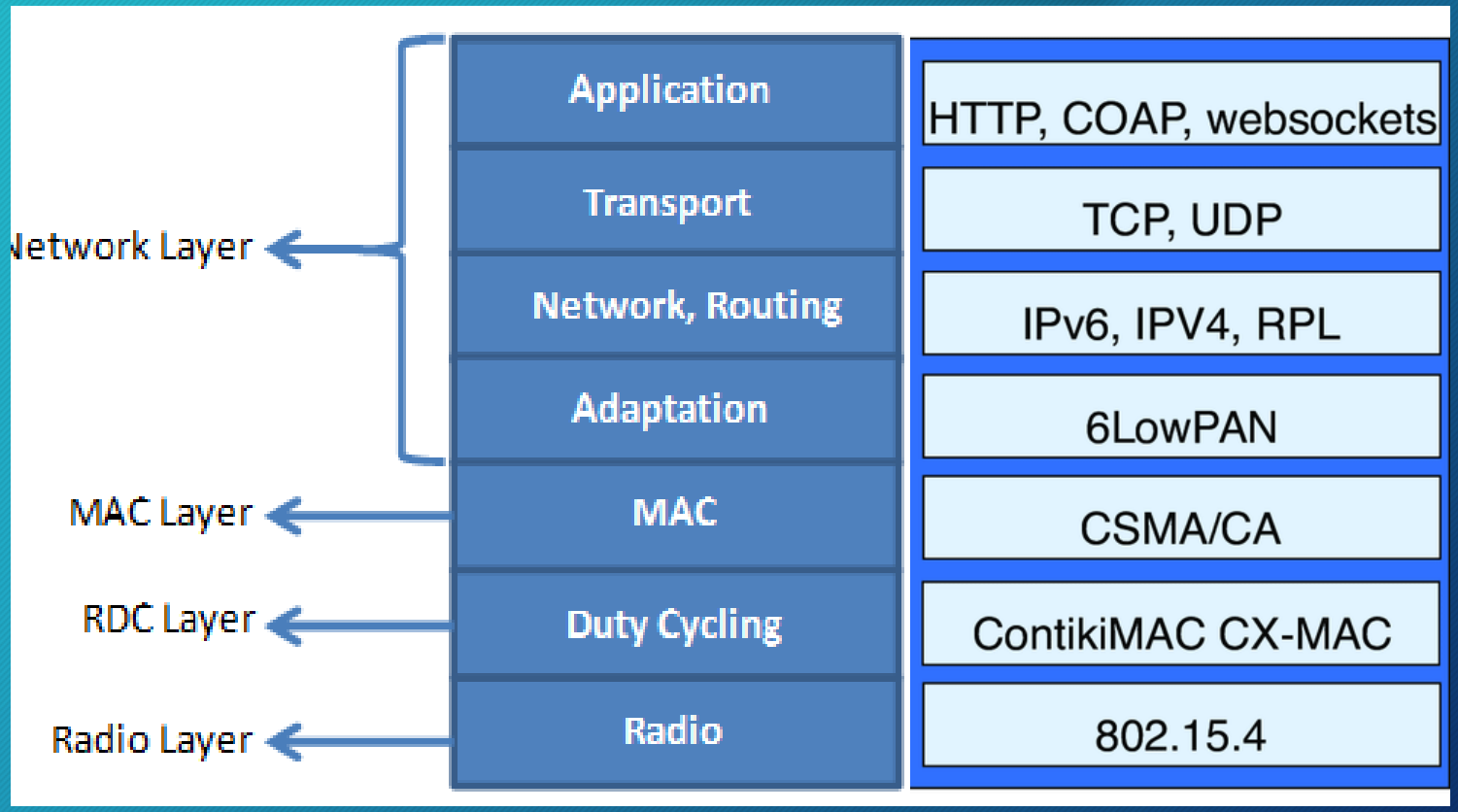
Energy monitoring

- Useful to estimate what affects a node energy consumption
- Estimation through *powertrace* and *energest* modules.
- Software based estimation by calculating which modes are on/off.
- By knowing the estimated power consumption of each component of the running device, it is possible to estimate the energy consumption.

- Zolertia Z1 energy usage simulation with Cooja simulator

Networking in Contiki

- IEEE 802.15.4
- IPv6 addressing
- MAC drivers – CSMA
- Radio Duty Cycling protocols
- RPL – Routing Protocol for Low Power and Lossy Networks

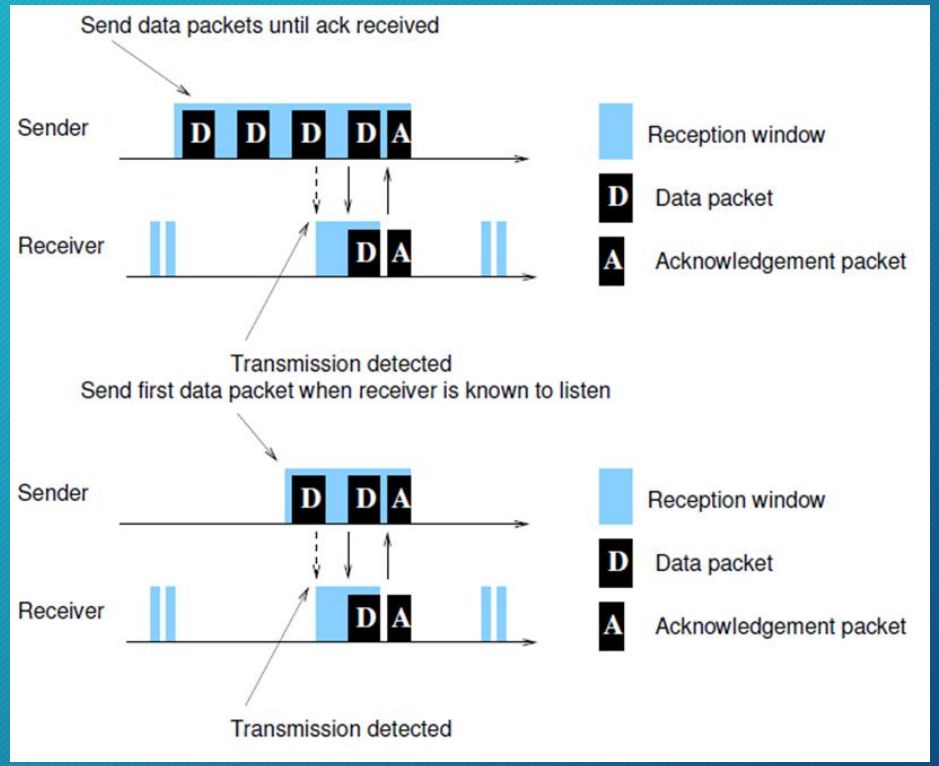


Radio Duty Cycling - I

- Radio module is the most energy hungry module of a sensing node.
  - Solution – Turn it on / off to save energy.
- RDC protocols provide mechanisms for time rendez-vous of communicating nodes.
  - Low Power Listening
  - Low Power Probing

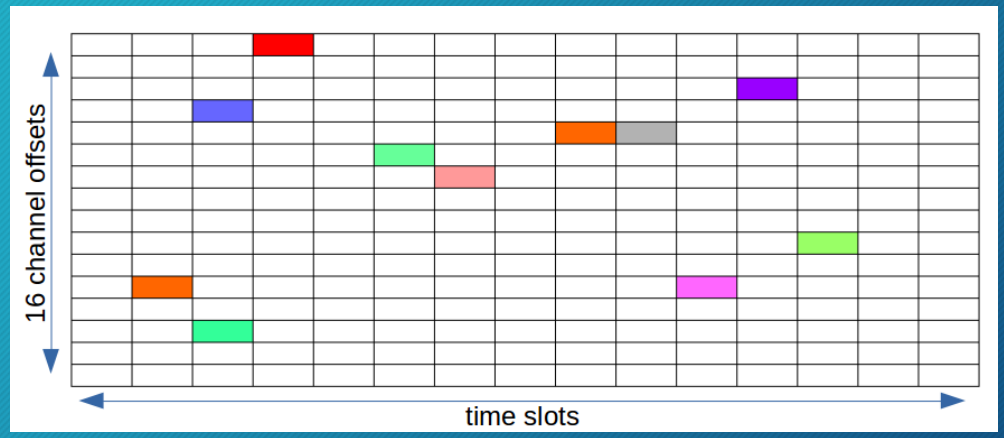
Radio Duty Cycling - II

- Contiki MAC protocols
  - Low-Power-Listening
    - ContikiMAC
    - X-MAC(first low-power listening protocol)
  - Low-Power-Probing
    - Contiki LPP



Evolution of RDC - TSCH

- TSCH - **Time Slotted Channel Hopping**
  - **Connection rendez-vous not only in time but also in frequency.**
  - **Applied in** into the IEEE 802.15.4 in 2015
  - **Offers better reliability**



6TiSCH - TSCH in Contiki-ng

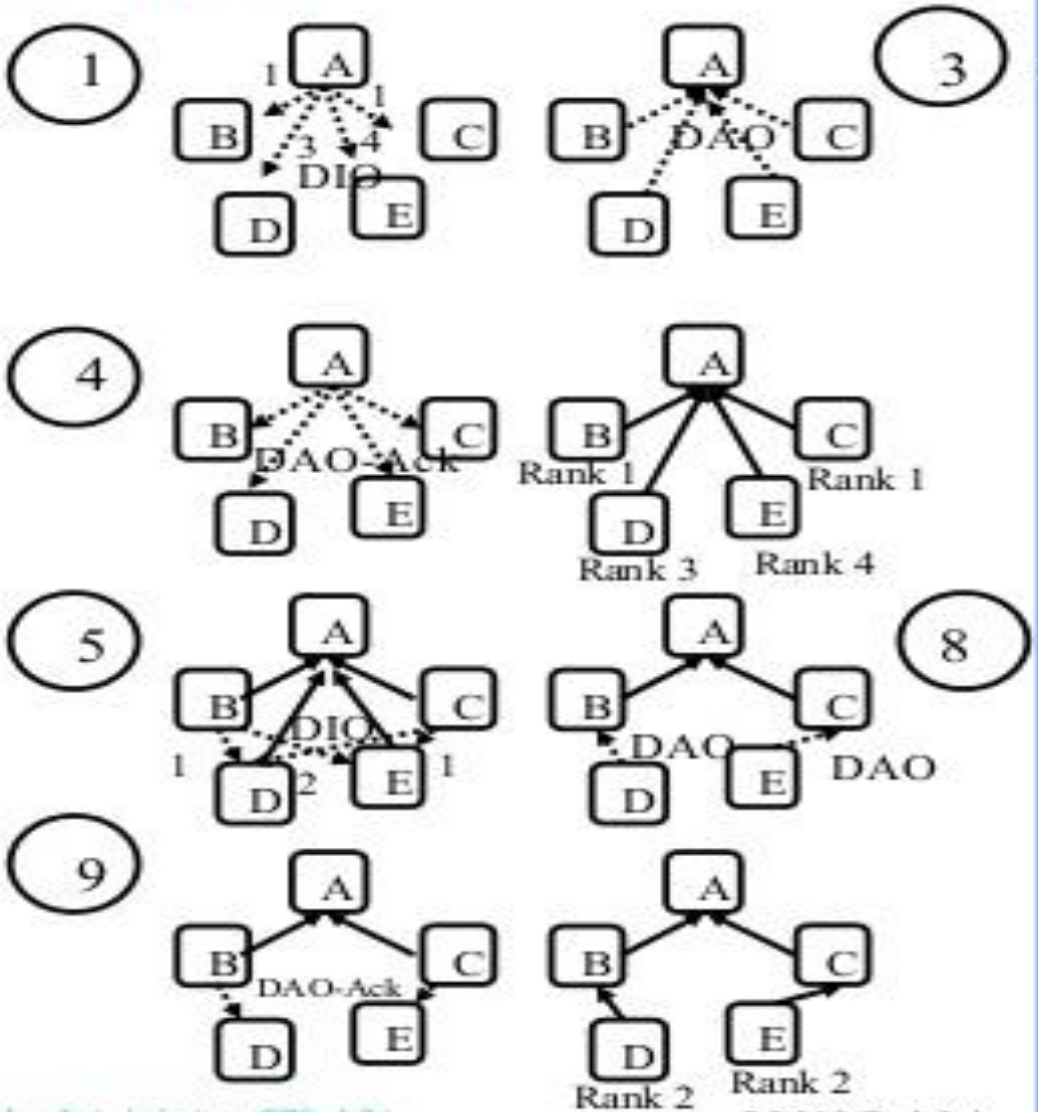
- Synchronization in large (340 nodes) networks is possible at high accuracy (97% of the time under 160 us) for a low cost (duty cycle of 0.3%)
- TSCH, when running dedicated slots, outperforms LPL in all key metrics: reliability, latency, duty cycle.
- At a micro-level, a TSCH and LPL spend about the same amount of energy for receptions, but TSCH has an edge (factor 3) on transmissions.
- S. Duquennoy, A. Elsts, B. A. Nahas and G. Oikonomo, "TSCH and 6TiSCH for Contiki: Challenges, Design and Evaluation," 2017 13th International Conference on Distributed Computing in Sensor Systems (DCOSS), Ottawa, ON, 2017, pp. 11-18.

Routing in Sensor Network - RPL

- RPL – Routing Protocol for Low Power and Lossy Networks (RFC 6550)
- Principle: All nodes form a Destination Oriented Directed Acyclic Graph (DODAG), where the sink node is the root of the DAG.
- Graph is implemented with the use of 3 types of messages:
- DIO (broadcast/ multicast), DIS, DAO (unicast)
- Supports 3 directions of traffic :
  - Upward: from any node toward a root
  - Downward: from the root to any node
  - Any-to-any: flows among arbitrary pairs of nodes in the DODAG graph

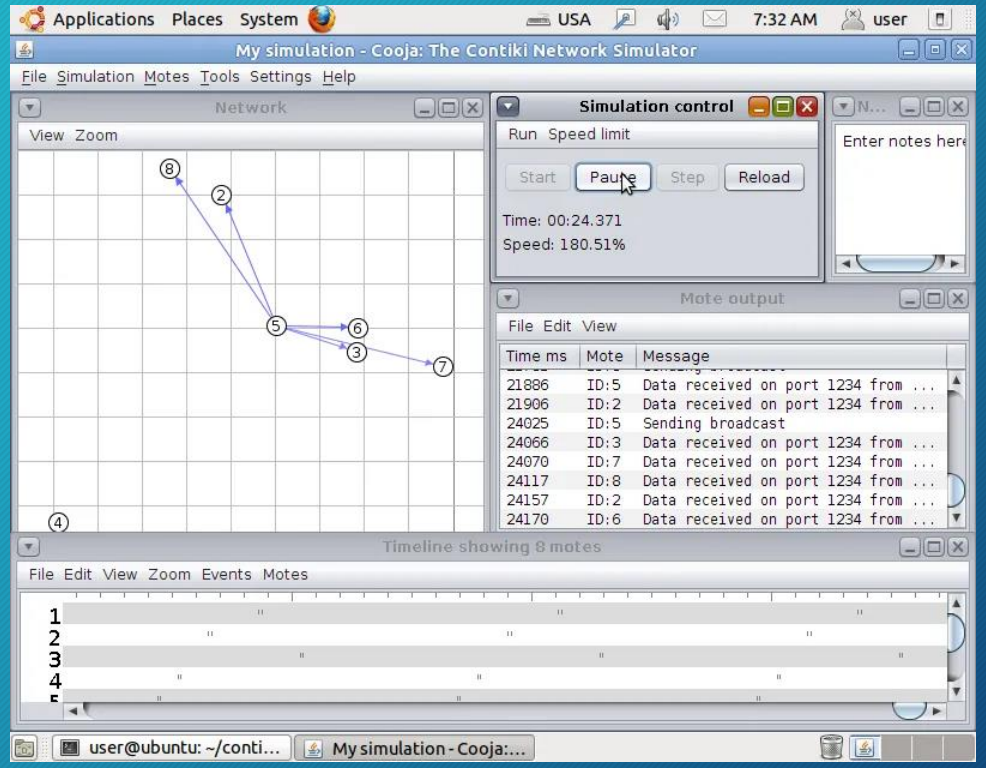
DODAG Formation Example

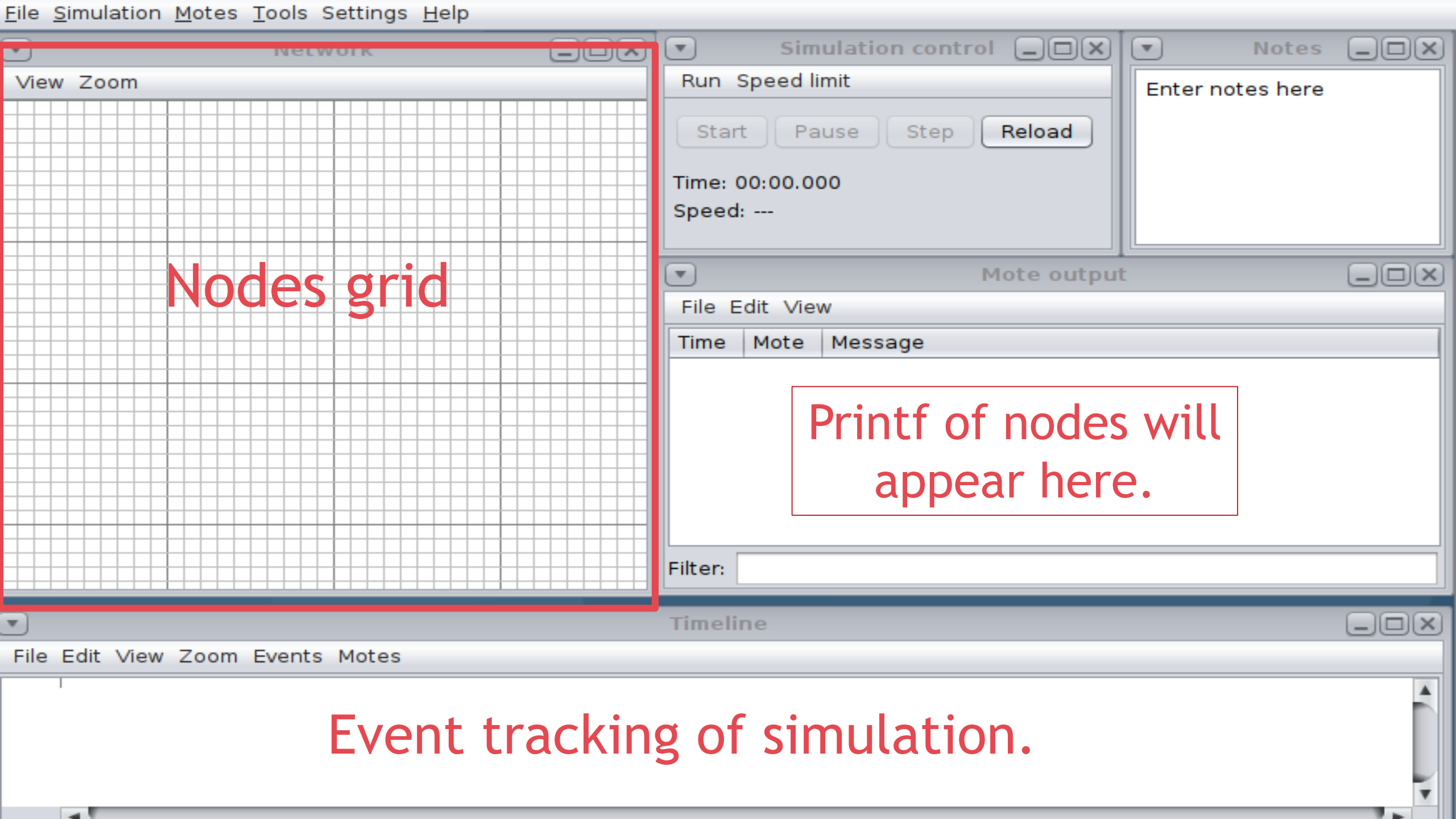
1. A multicasts DIOs that it's member of DODAG ID itself with Rank 0.
2. B, C, D, E hear and determine that their rank (distance) is 1, 1, 3, 4, respectively from A
3. B, C, D, E send DAOs to A.
4. A accepts all
5. B and C multicast DIOs
6. D hears those and determines that its distance from B and C is 1, 2
7. E hears both B, C and determines that its distance from B and C is 2, 1
8. D sends a DAO to B
   E sends a DAO to C
9. B sends a DAO-Ack to D
   C sends a DAO-Ack to E



Cooja – Simulator for Contiki OS

- Useful for rapid prototyping
- Allows quick deployment of large scale experiments.
- Implemented in JAVA
- Core features
  - Code compilation for Contiki-enabled platforms
  - Grid for motes deployment.
  - Radio Medium simulation
  - Simulation timeline

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Nodes grid
Simulation control
Run Speed limit
Start Pause Step Reload
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Notes
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Mote output
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Filter:
Timeline
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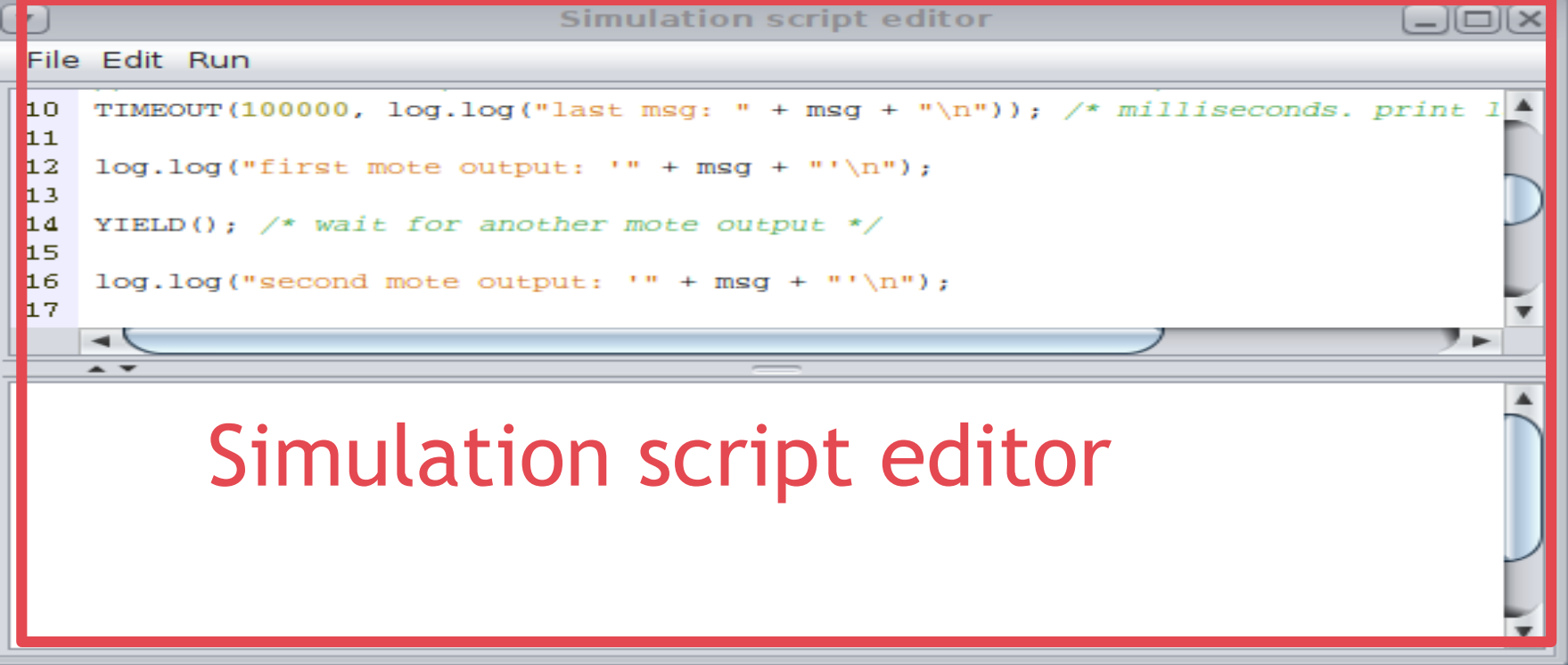
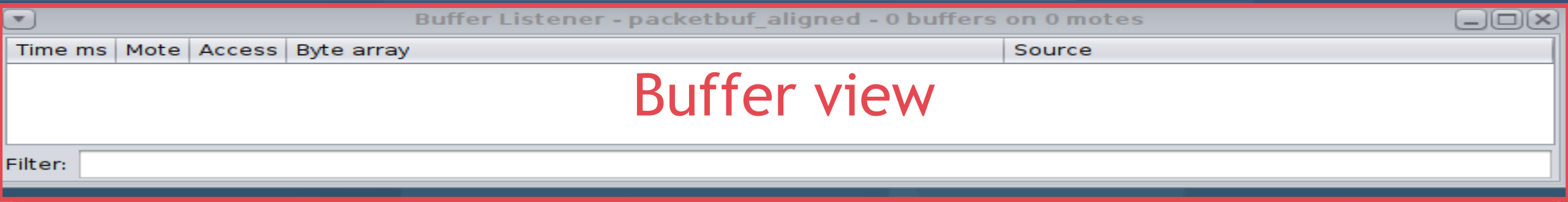
Event tracking of simulation.


Simulation script editor
File Edit Run
10 TIMEOUT(100000, log.log("last msg: " + msg + "\n")); /* milliseconds. print l
11
12 log.log("first mote output: '" + msg + "'\n");
13
14 YIELD(); /* wait for another mote output */
15
16 log.log("second mote output: '" + msg + "'\n");
17
Simulation script editor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Time ms
Mote
Access
Byte array
Source
Buffer view
Filter:


PowerTracker
Mote
Radio on (%)
Radio TX (%)
Radio RX (%)
AVERAGE
NaN%
NaN%
NaN%
Trace of Radio usage
Print to console/Copy to clipboard
Reset

Cooja simulation

- Getting started:
  - Cooja example from contiki-ng wiki
  - Autonomous Networks Research Group guide on Contiki

“Questions?

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Thank you!