Scaling up Routing in Nanonetworks with Asynchronous Node Sleeping

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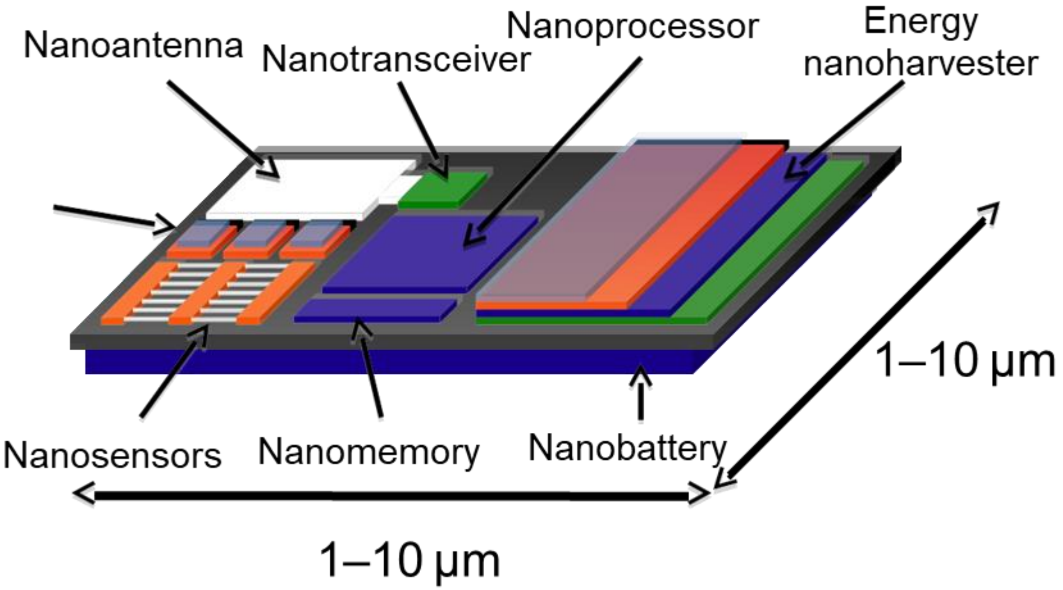
Wireless Nanonetwork Characteristics

- Nano-thing size ➔ 1..1000 nm (< 1 µm)
- Wireless nanonetworks built from tiny nodes
- Nanonodes have limited embedded computing, sensing and actuating devices



Constraints and Problematic in nanonetwork

- Limited hardware resources (CPU, memory, battery) due to fabrication constraints

- Nanonode buffer limitation

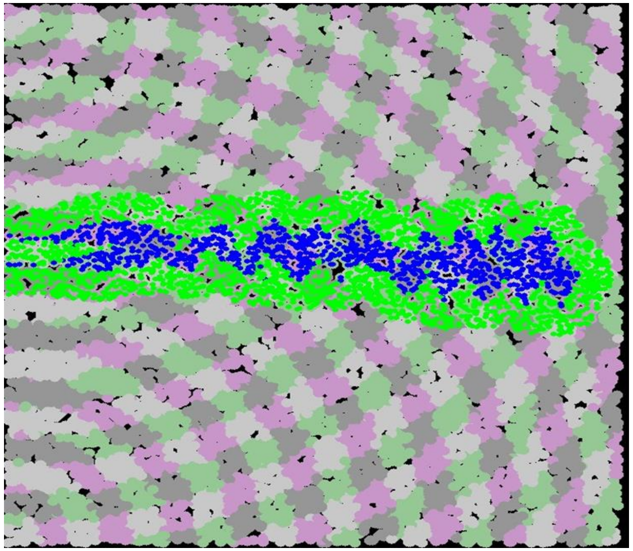
- Low network lifetime

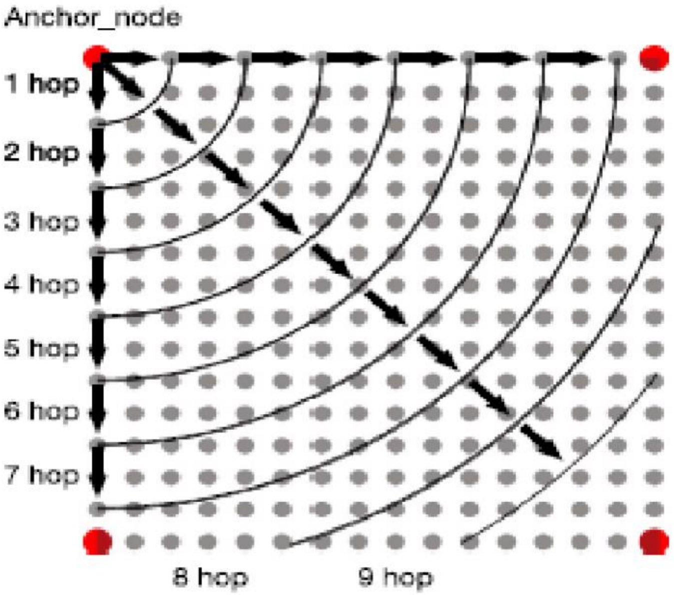
The main challenge in nanonetworks is the routing protocol used by nodes

SLR Addressing and Routing Protocol

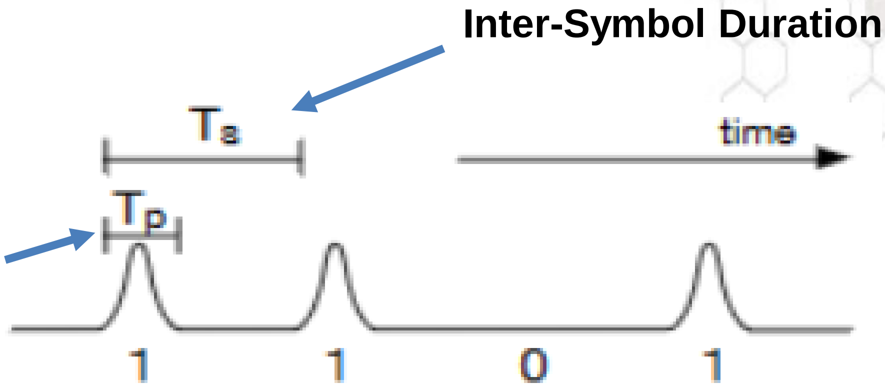
- SLR (Stateless Linear-path Routing) implements a coordinate-based routing, packets are forwarded if and only if they are on the path between the source and the destination of the packet

- SLR has 2 phases :
  - Initial phase (nodes coordinates)
  - Routing phase





Channel Modulation Technique


Inter-Symbol Duration

Pulse Duration
100 femtoseconds

- Time Spread On-Off Keying is a modulation technique used to share the radio terahertz channel for nanodevices in a nano-network
- “1” bits are encoded with a power pulse of duration “Tp” and “0” bits are encoded as silence
- Symbol rate β determined by the ratio Ts/Tp
- Packets are transmitted as a sequence of pulses interleaved by a given duration

Proposed Mechanism (Enhancement)

- Improving SLR protocol with a **sleeping mechanism** , giving the ability to the nodes to not still awake all the time

- Expected Results

  - Reducing congestion in nanonetworks
  - Dispatching traffic over all nodes ➔ sharing the load
  - Preserving nanonode resources (CPU, memory, energy)
  - Increasing network lifetime

Sleeping Mechanism

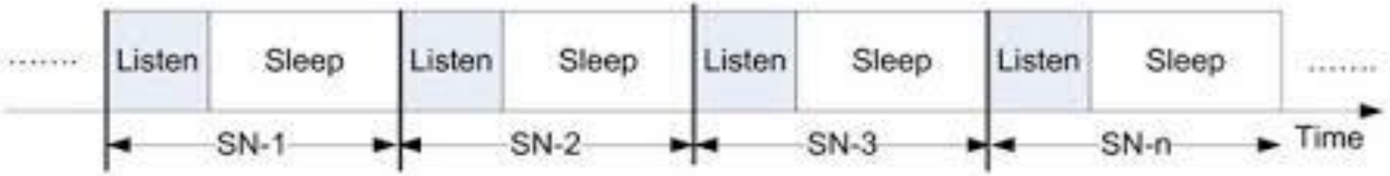
- Keep nodes awake all the time, lead to lose their resources rapidly

- The technique where the nodes periodically sleep and awake for a short period is called duty-cycling

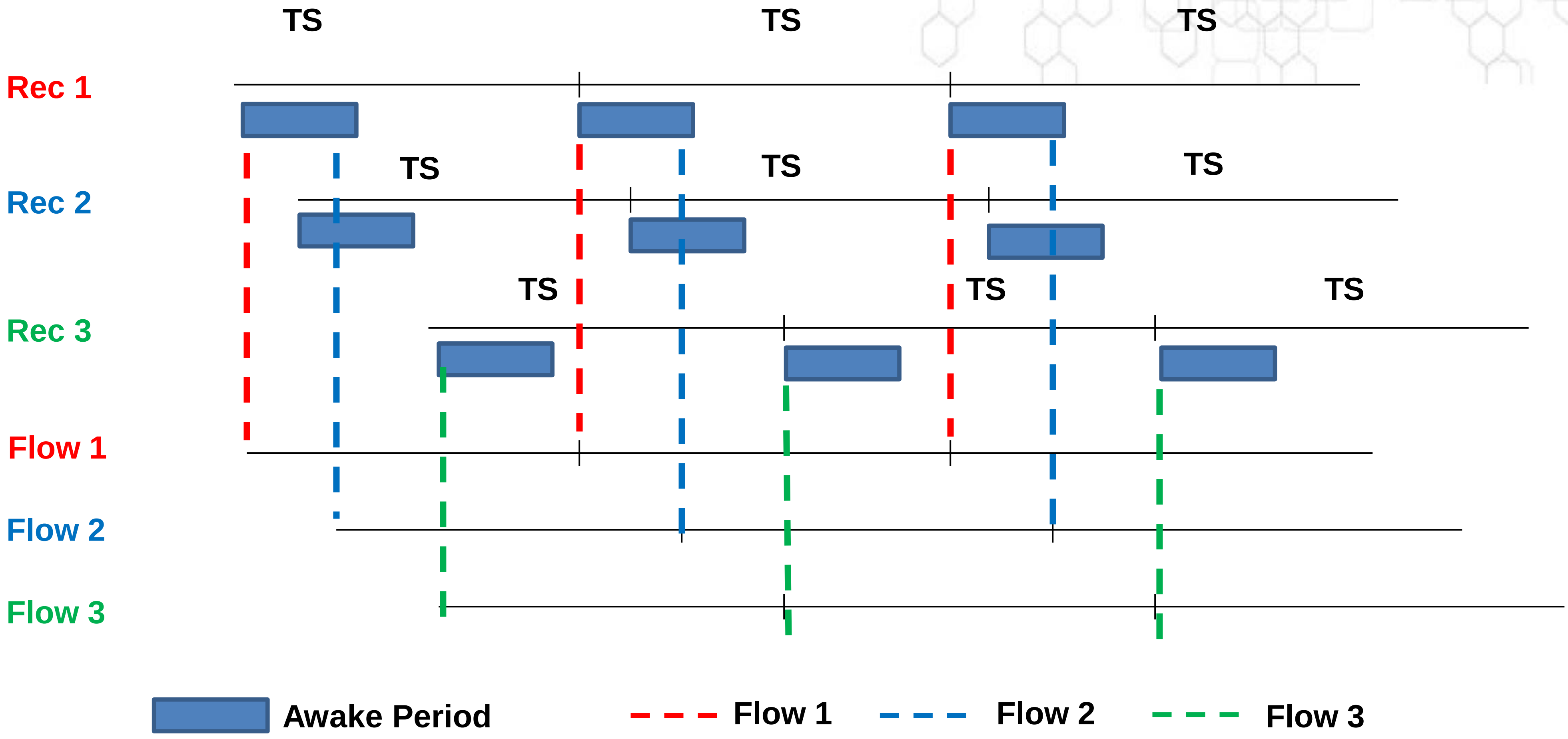
- Our proposed mechanism differs from those used in macro-scale network on two main aspects:

  - Fine granularity

  - Asynchronism, decentralization



Sleeping Mechanism (2)

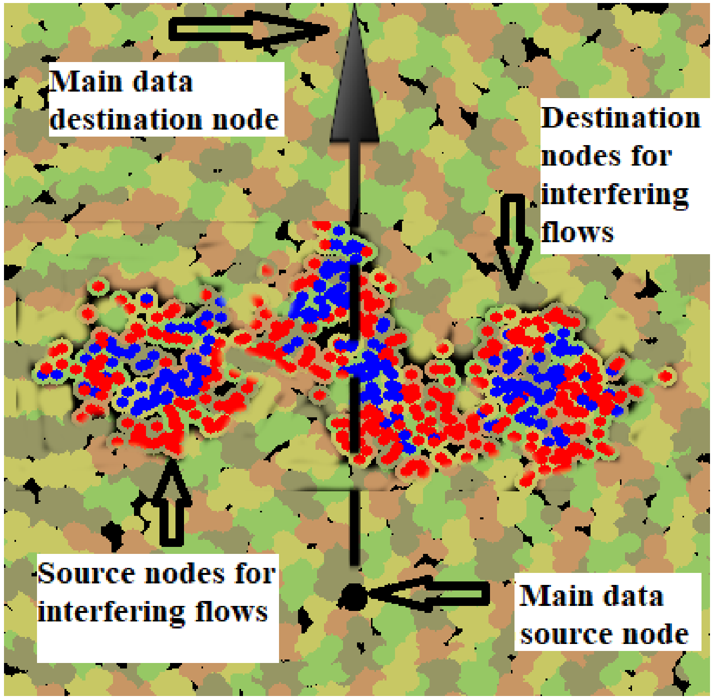


Evaluated Network (Scenario)

The evaluated network is of:

-2D area with different nodes density (3000, 5000, 8000 and 15000)
-Main flow direction (Bottom to the top)
-Packets to be sends : 100 / 92 interfering flows
-15 simulations of different RNG seeds have been used to avoid random effects
-Packets interval time 0(null) / 5 times the duration of a packet

Simulated area size	6 mm * 6 mm
Number of nodes	3000 to 15000
Communication Radius	350 µm
β	1000
Tp	100 fs
Packet Size	1000 bit



Main data destination node

Destination nodes for interfering flows

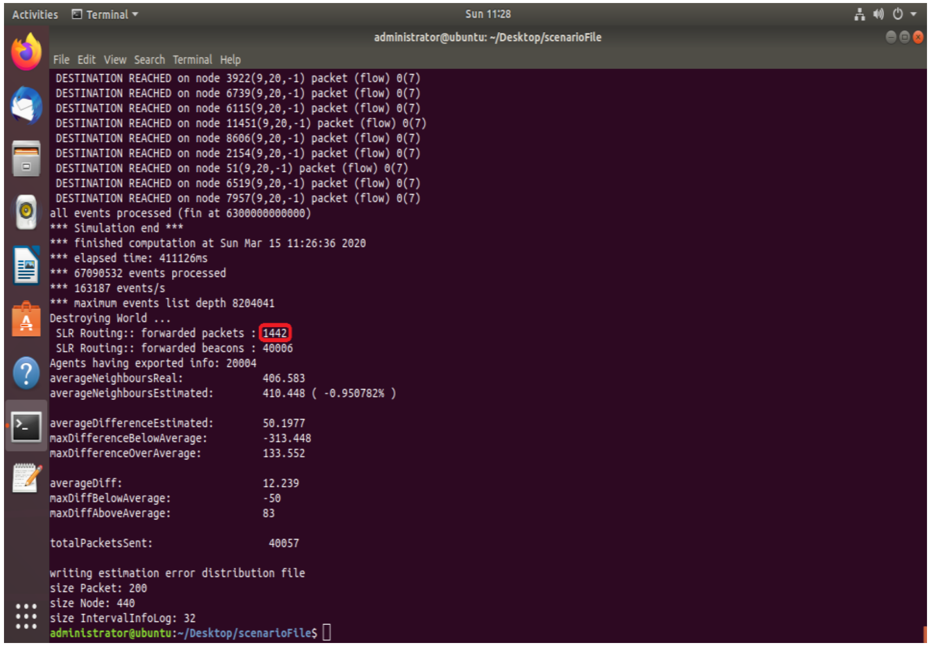
Source nodes for interfering flows

Main data source node

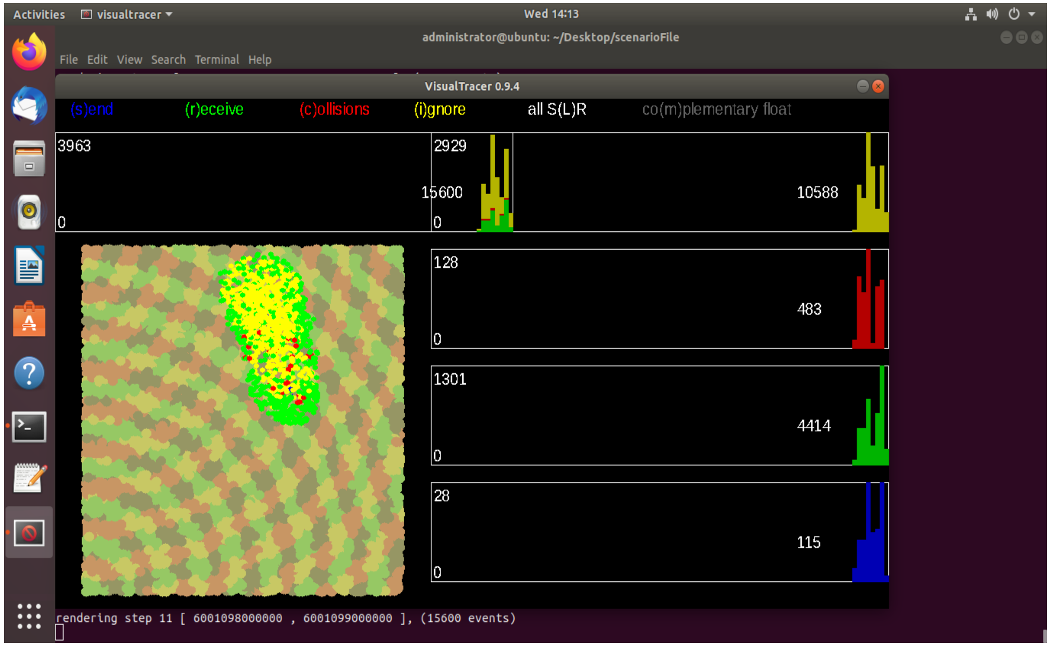
Simulation Platform

We use BitSimulator to evaluate our proposed ideas

This simulator uses the TS-OOK modulation, allows the simulation of applications and routing protocols, and display graphically the simulation events


Activities
Terminal
Sun 11:28
administrator@ubuntu: ~/Desktop/scenarioFile
File Edit View Search Terminal Help

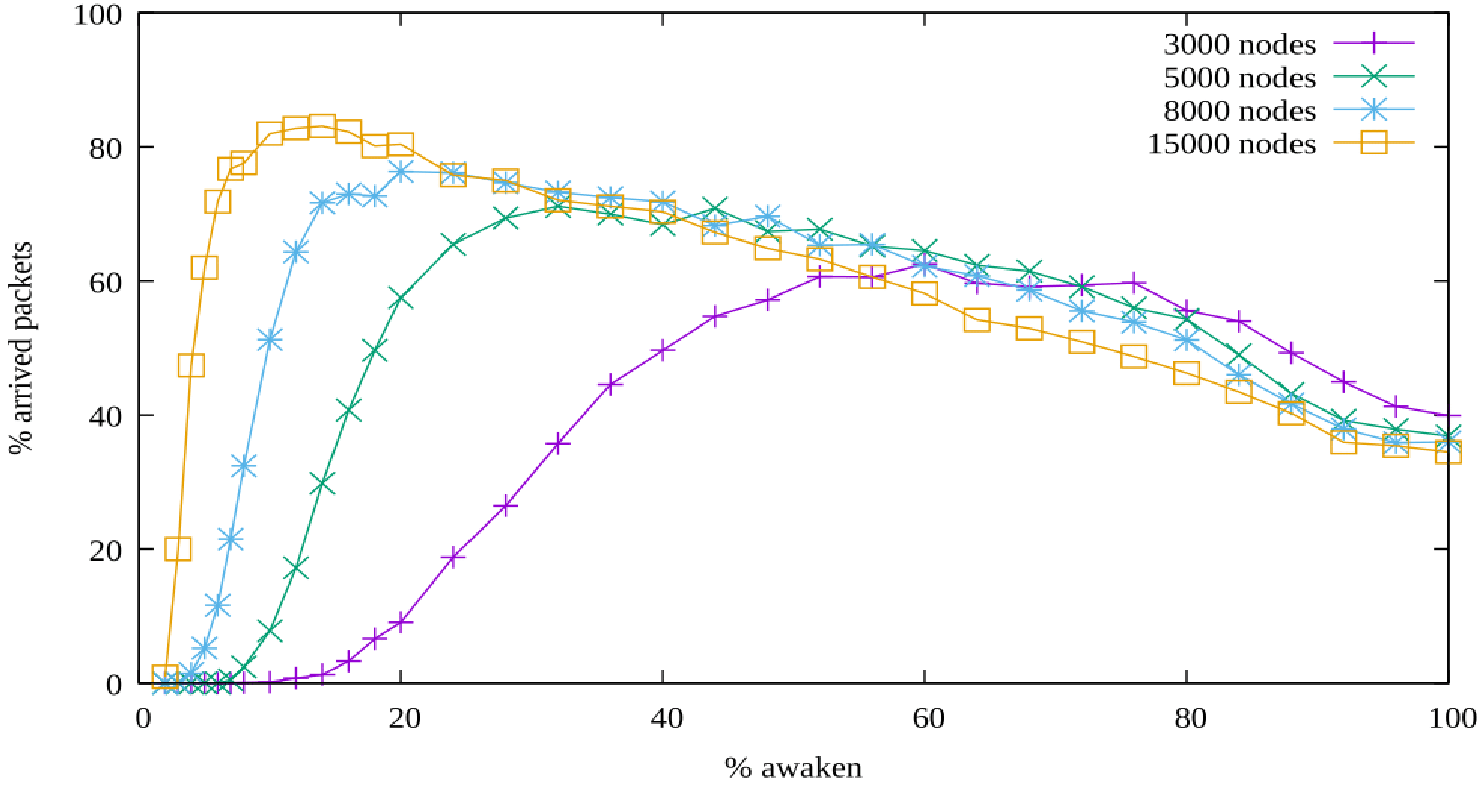
```
 DESTINATION REACHED on node 3922(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 6739(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 6115(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 11451(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 8606(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 2154(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 51(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 6519(9,20,-1) packet (flow) 0(7)
 DESTINATION REACHED on node 7957(9,20,-1) packet (flow) 0(7)
all events processed (fin at 6300000000000)
*** Simulation end ***
*** finished computation at Sun Mar 15 11:26:36 2020
*** elapsed time: 411126ms
*** 67090532 events processed
*** 163187 events/s
*** maximum events list depth 8204041
Destroying World ...
 SLR Routing:: forwarded packets : 1442
 SLR Routing:: forwarded beacons : 40006
Agents having exported info: 20004
averageNeighboursReal:              406.583
averageNeighboursEstimated:         410.448 ( -0.950782% )

averageDifferenceEstimated:         50.1977
maxDifferenceBelowAverage:          -313.448
maxDifferenceOverAverage:           133.552

averageDiff:                        12.239
maxDiffBelowAverage:                -50
maxDiffAboveAverage:                83

totalPacketsSent:                    40057

writing estimation error distribution file
size Packet: 200
size Node: 440
size IntervalInfoLog: 32
administrator@ubuntu:~/Desktop/scenarioFile$ 
```



```
rendering step 11 [ 6001098000000 , 6001099000000 ], (15600 events)
```

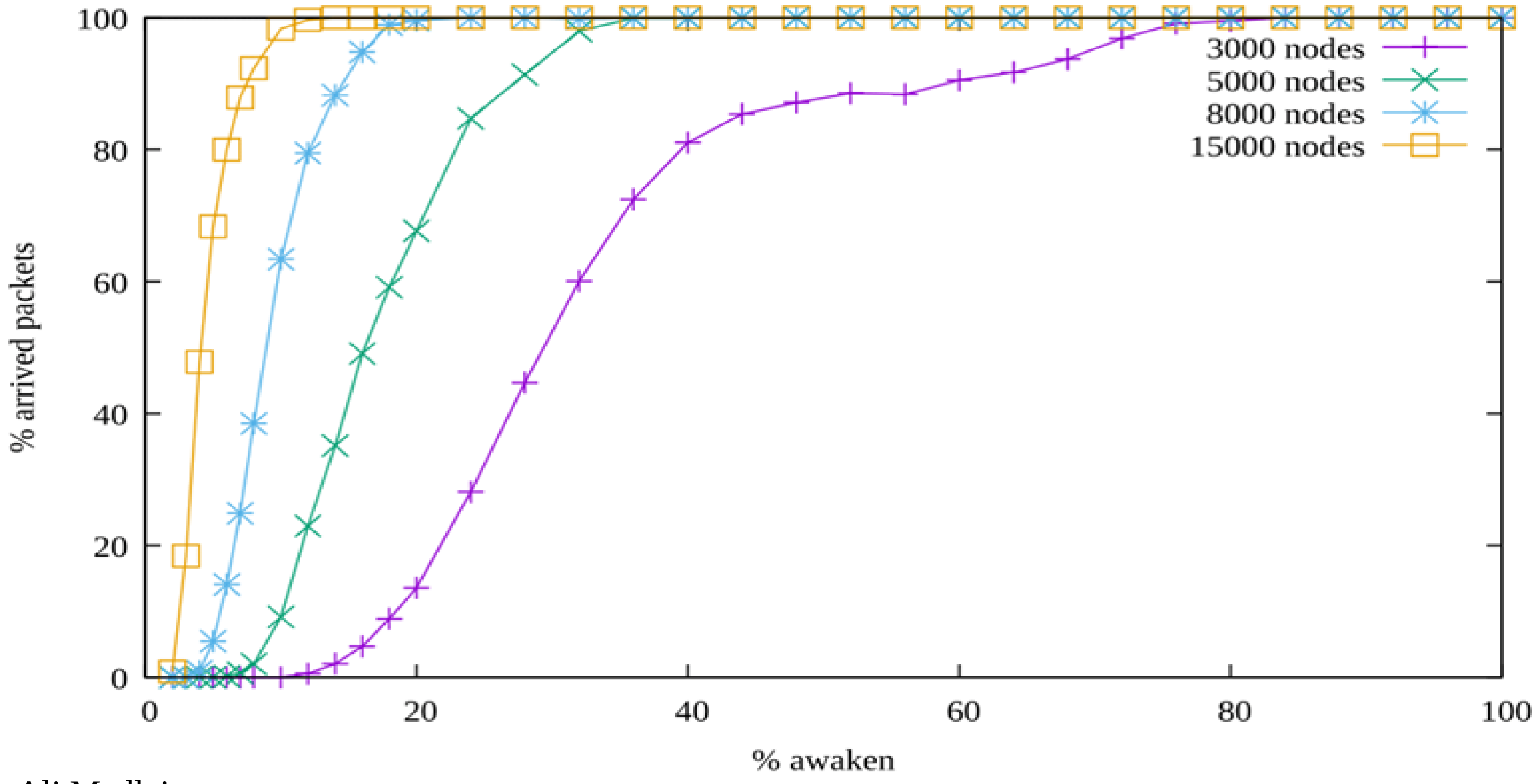
Scenario 1- No interfering flows / No inter-packet waiting period

- 40% of unique packets reach the destination for 100% awake nodes (on horizontal axis)



Scenario 1- No interfering flows / With inter-packet waiting period

- Decreasing the awake time ➔ slightly reduce the number of arrived packets



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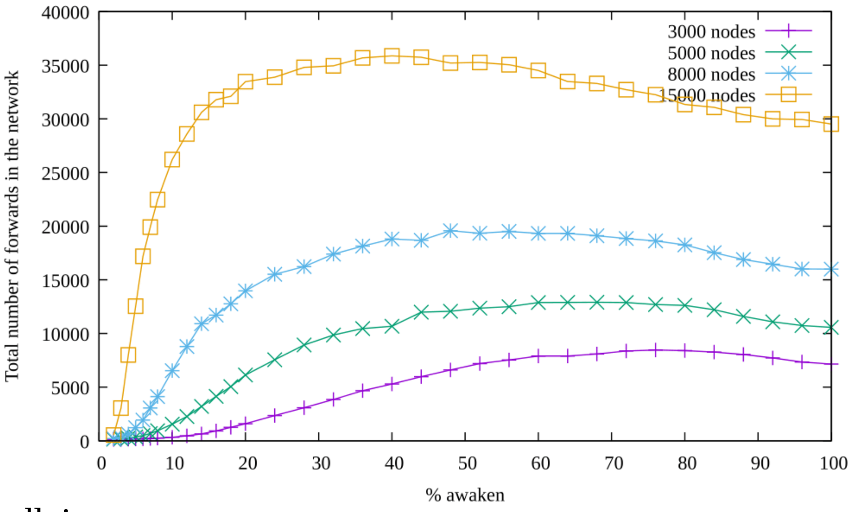
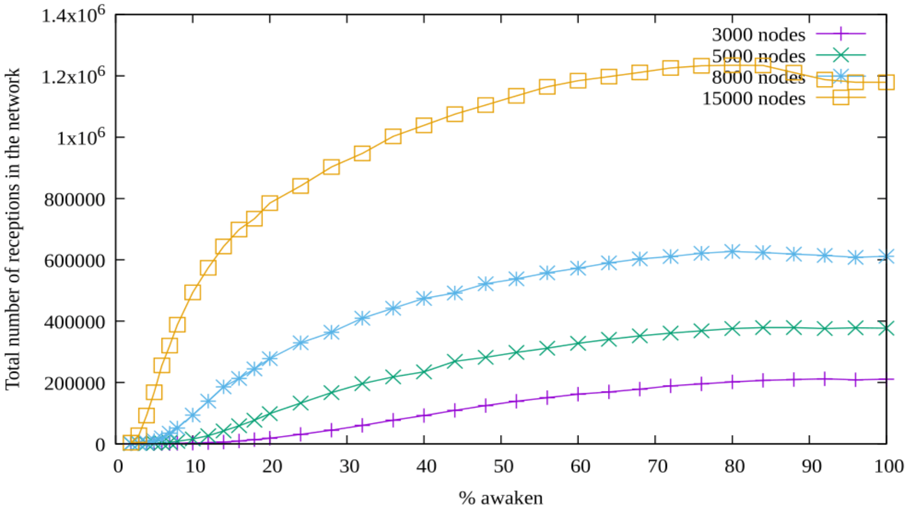
Sleeping Mechanism - Unexpected Behavior

A lower awake time ➔ Data packets cannot be forwarded anymore
Larger percentages of awake time ➔ curves are mostly stable

Reasons:

- The load of forwarding packets dispatched among neighboring nodes ➔ Increase network capacity
- Forwarded packets can be repeated along the whole path



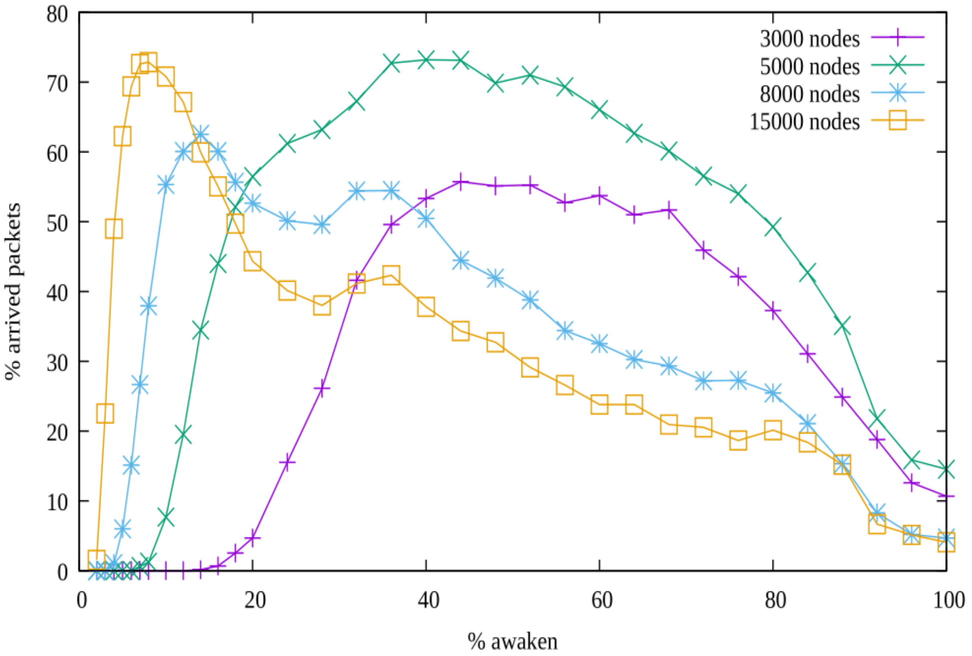


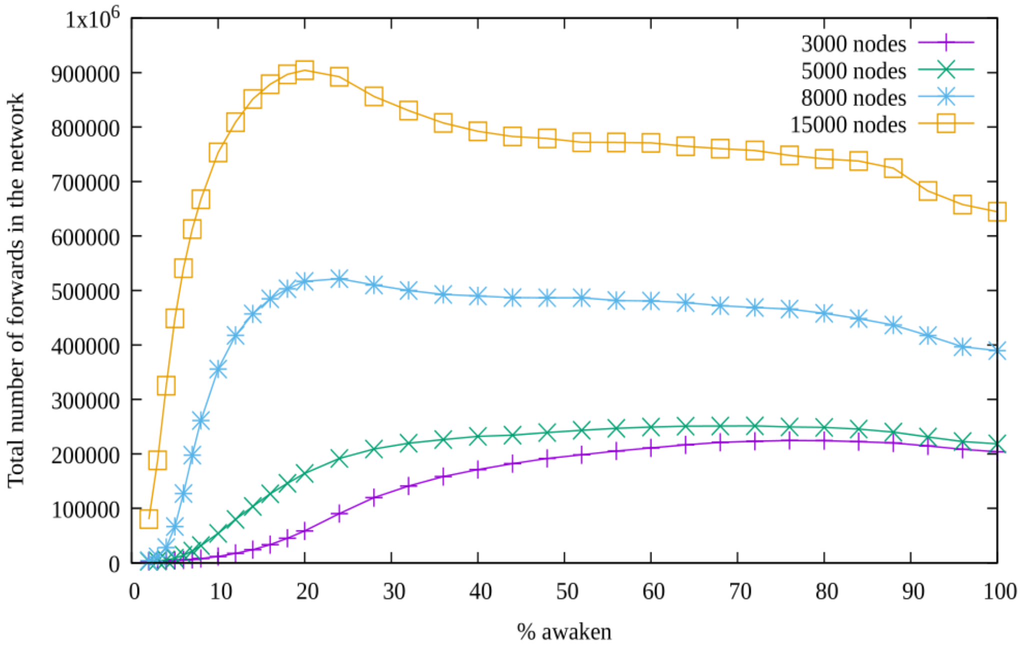
Scenario 2- With Interfering Flows

- More flows (interfering) was added to study the network behavior

- Reception rate significantly improved ➔ More packets arrive for 50% than for 100% of awaken nodes

- Improving the usable capacity of the channel





Conclusion and Future Work

- Improving network behavior by limiting the amount of traffic an individual node can see

- Dispatching traffic over all nodes ➔ sharing the load

- Preserving nodes resources (energy, CPU, memory, ...)

- Improving network reliability by decreasing congestion

- Future work

  -Integrating the sleep mechanism with backoff flooding

  -Automatic tuning of the awaken duration based on the neighborhood density

Questions ?