Dynamic ring-based forwarder selection to improve packet delivery in ultra-dense nanonetworks

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Context

- **Thematic:** Electromagnetic nanonetworks (and ultra-dense ad hoc networks)
- **Nanonetwork group in Montbéliard:**
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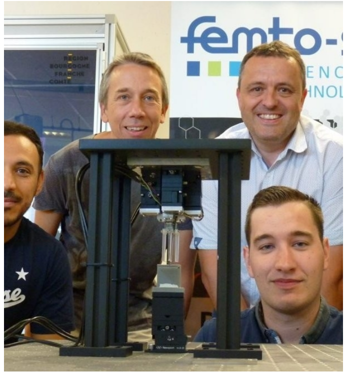
  - E. Dedu
  - PhD students:
    - F. Hoteit
    - A. Medlej
    - C. Al Mawla
    - T. Arrabal
    - M. A. Zainuddin
- Collaborations:
  - W. Seah (New Zealand)
  - K. Beydoun (Lebanon)
  - S. Fischer, F. Büther (Germany)
  - C. Liaskos, A. Tsioliaridou (Greece)

Montbéliard. Source: http://francegeo.free.fr/

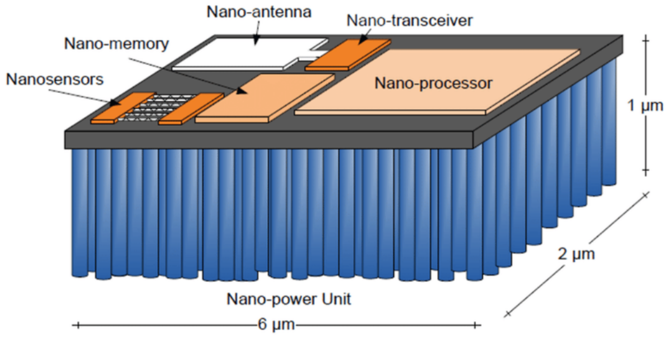
Our office. Source: https://numericabfc.com/



MiGriBot world's fastest microrobot (our lab, 09/2022). Source: https://news.cnrs.fr/articles/meet-the-worlds-fastest-microrobot

Introduction

- **Internet of Things (IoT): billions** of connected devices
- **Internet of Nano Things (IoNT): nanodevices**
- **Electromagnetic nanonetworks:**
  - **THz** band (0.1–10 THz)
  - **High data rates** (up to a few terabits per second)
  - **Resource-constrained** nanodevices
  - **Large** network size (e.g., 10^3 to 10^9 nodes)
  - **High** node **density** (e.g., 10^2 or 10^3 of neighbors)



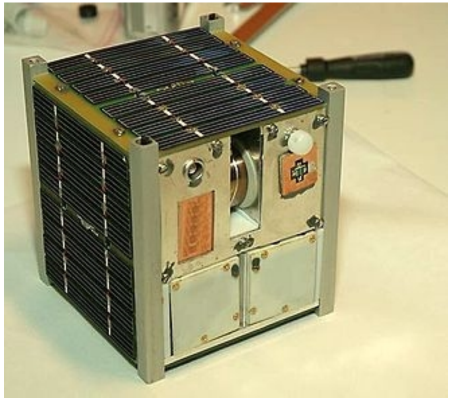
Integrated nanodevice hardware architecture.
Source: Nanoscale Communication: State-of-Art and Recent Advances.

Requirements	Software-defined metamaterials Gen. 1	Software-defined metamaterials Gen. 2	Wireless robotic materials	In-body communication	On-chip communication
Network size	10^3 to 10^6	10^9	10 to 10^6	10^3 to 10^9	Up to 10^3
Node density	100 to 10000 nodes per cm^2		1 to 100 nodes per cm^2	$>10^3$ nodes per cm^3	10-100 per mm^2

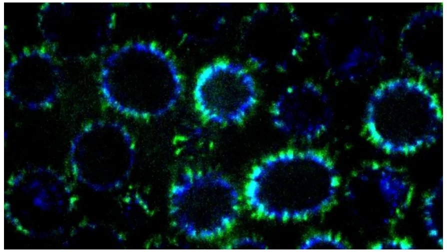
Applications' requirements of nanonetworks. Source: Survey on Terahertz Nanocommunication and Networking: A Top-Down Perspective.

Applications

- Military:
  - Nanosatellites
  - Nanoweapons
- In-body:
  - Health monitoring
  - Drug delivery
  - Genetic engineering



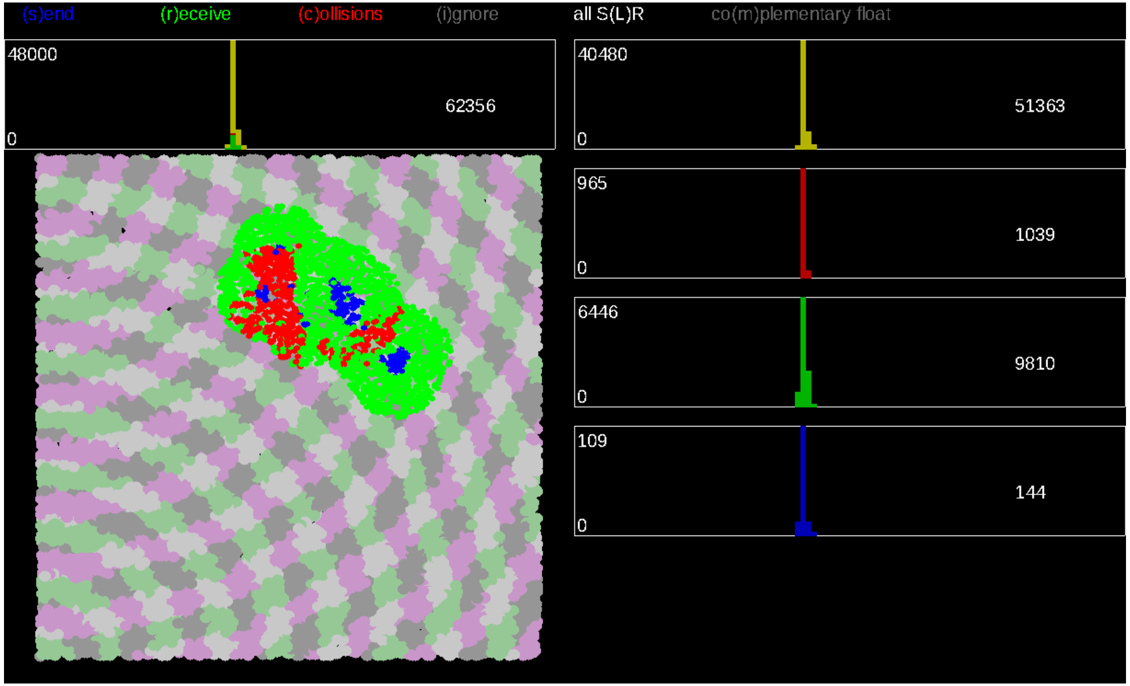
Steps towards satellite's miniaturization: Ncube-2, a Norwegian CubeSat (10 cm (3.9 in) cube). Source: Bjørn Pedersen.



Nanotubes for drug delivery.
Source: Johns Hopkins University.

BitSimulator

- Nanonetwork simulator
- Designed by our team
- Highly scalable (hundreds of thousands of nodes simulated on a laptop)
- Routing and transport layers
- VisualTracer shows the events
- Full reproducibility (through RNG seeds)

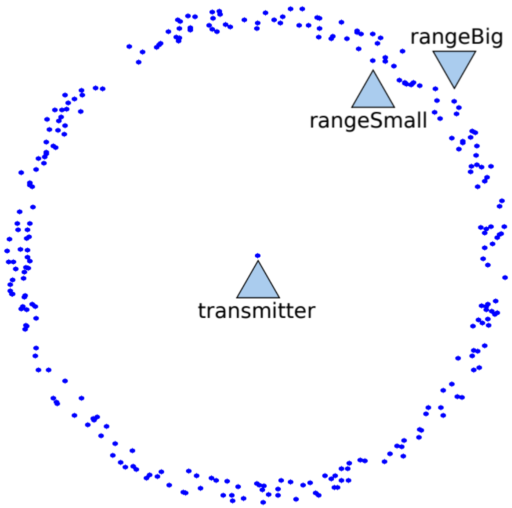


http://eugen.dedu.free.fr/bitsimulator/

Problem

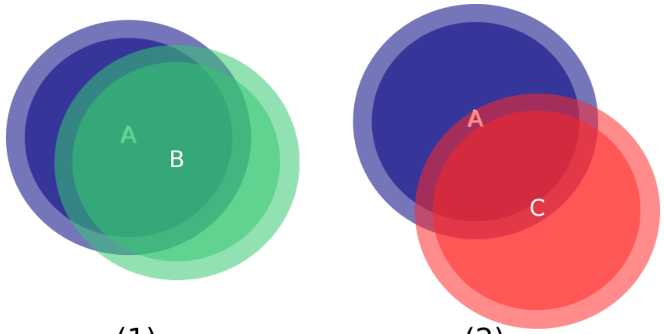
- Flooding/routing in **ultra-dense** ad hoc networks → Selection of large number of **forwarders** → **Congestion** and short network lifetime
- Previously we proposed the **Ring**

Previous contribution: Ring



- Implemented **above existing routing** protocols
- **No need** for:
  - Complete neighborhood or network knowledge
  - Routing tables
  - GPS or RSSI
- Each forwarder sends:
  - **High-power** control packet
  - **Low-power** control packet

  only **once** before the very first data packet
- **Forwarders** are nodes
  - **Selected** by the routing protocol AND
  - In the **ring**:
    - Have received high-power control packet AND
    - Not low-power control packet

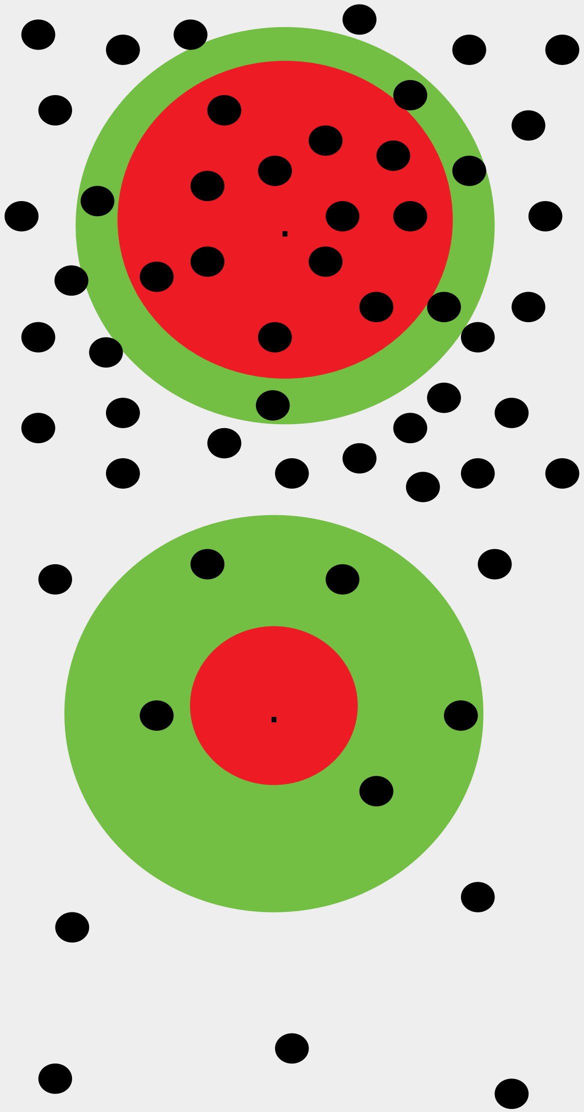


(1) (2)

C forward achieves more forwarding progress than B

Current contribution: Dynamic ring

- **Automatically** selects the **ring width** based on the local node density
- Density Estimator for Dense Networks (**DEDeN**)
- **Acknowledgment** methods → **High overhead**



Scenario

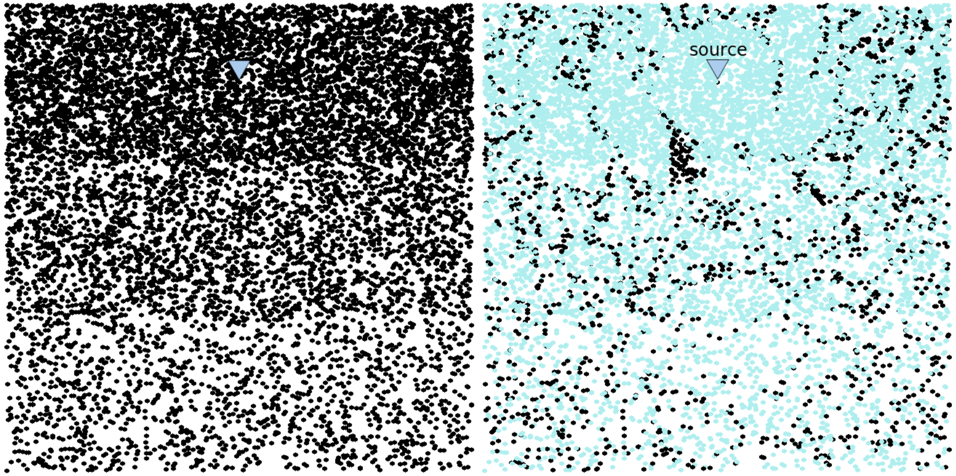
- A source node generates a CBR flow of **50** packets
  - to all the nodes (**flooding**)
  - to the destination (**unicast**)
- **Heterogeneous, shadowing**
- **Ring:**
  - **RangeBig = constant**
  - **RangeSmall = variable to fit (N = 60)** ring neighbors (fwds + non fwds)
  - L = local density (**DEDeN)**

$$rangeSmall = \sqrt{rangeBig^2 - N * rangeBig^2 / L}$$

Parameter	Value
Size of simulated area	6 mm * 6 mm
Number of nodes	10 000
Communication range	1 000 µm
RangeBig	1 000 µm
RangeSmall	variable
Data packet size	1 003 bit
Control packet sizes	101, 102 bit

Scenario parameters

Pure flooding with dynamic ring



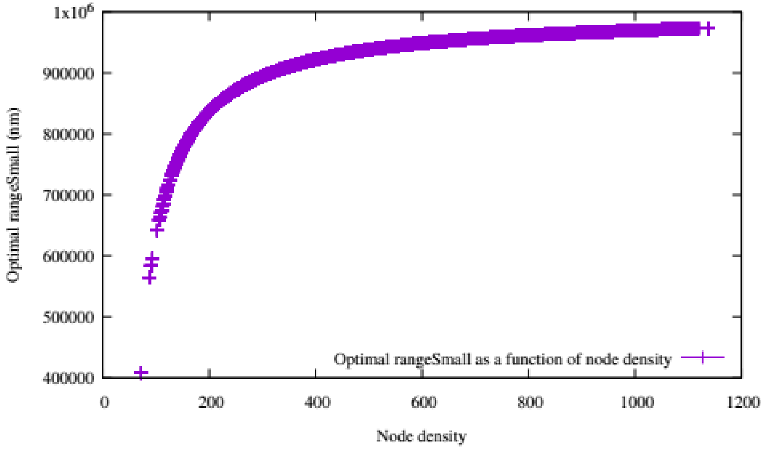
Pure flooding (left) vs pure flooding with dynamic ring (right),

Fwds (black), Receivers (blue)

- Fewer and better positioned forwarders
- Adaptation to local density
- Successful packet delivery

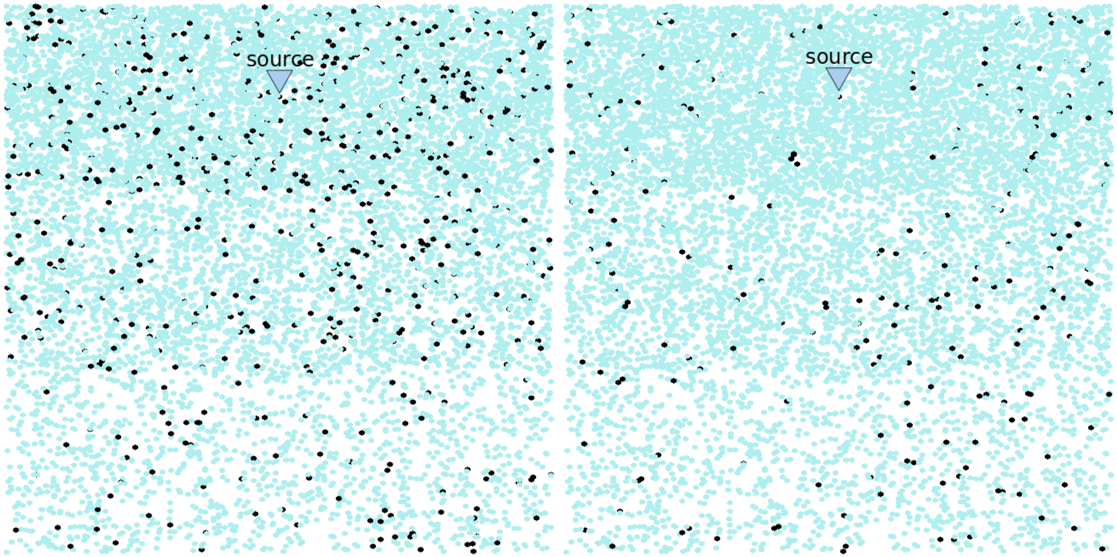
	Without ring	With dynamic ring
Pure flooding:		
forwarders per packet	10 000	1 949.2
receivers per packet	10 000	10 000

Values averaged for **80** simulations with 50 packets each



The dynamic ring assigning different rangeSmall values for nodes depending on their density

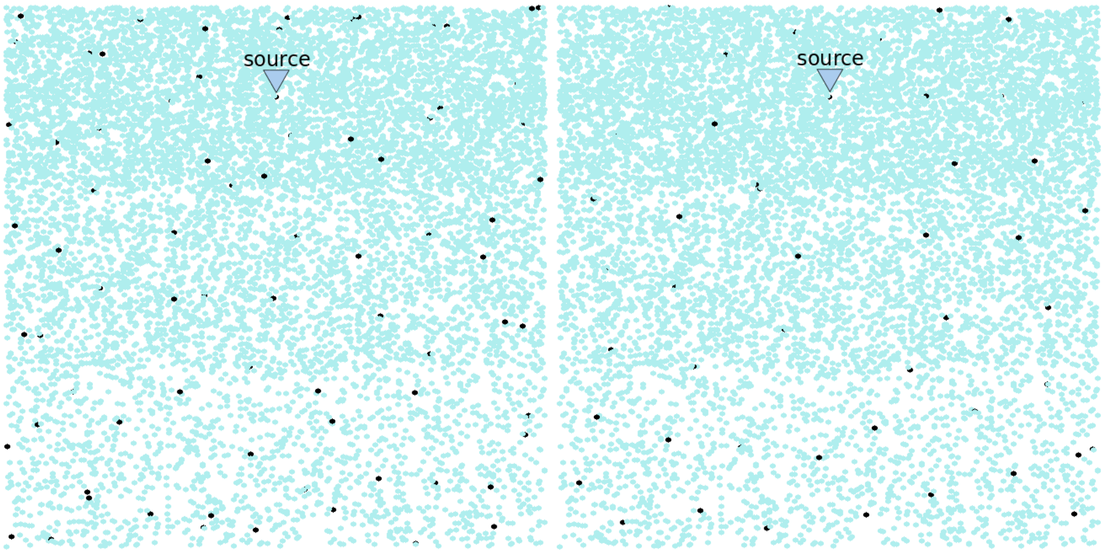
Probabilistic flooding with dynamic ring



Proba flooding (left) vs proba flooding with dynamic ring (right)

Probabilistic flooding:	$proba = 6\%$	$proba = 10\%$
forwarders per packet	601.59	273.512
receivers per packet	9 999.9	9 999.47

Backoff flooding with dynamic ring

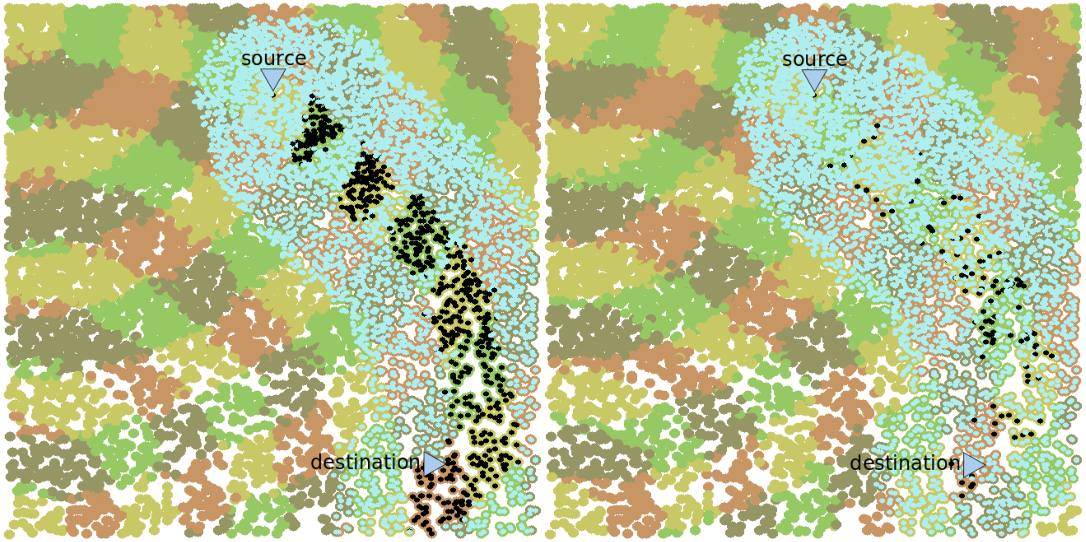


Backoff flooding (left) vs backoff flooding with dynamic ring (right)

Backoff flooding:

forwarders per packet	79.934	52.242
receivers per packet	9 999.97	9 999.55

SLR with dynamic ring



SLR (left) vs SLR with dynamic ring (right)

SLR:

forwarders per packet	901.688	129.116
Destination reached	100%	100%

Conclusion and future work

- The ring **scales-up** existing routing protocols, **optimizing** the **forwarder selection** and keeping a **successful packet delivery**
- Future work includes understanding the effect of **local number of forwarders** on the packet delivery