Routing Strategies for Satellite Swarms in Space Missions

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Agenda

- Introduction
- Swarm simulator
- Results
  - Routing strategy
  - Impact of topology
- Conclusion

Introduction

Context

- Rise of nanosatellite Swarms
  - Economically viable, but not mature enough
- Advantages
  - Allow to divide instruments of several satellites, and lower their dimensions
  - Reduced cost compared to a constellation
- New challenges
  - Autonomy
  - Synchronisation
  - Communications

Context

- Case of routing
  - Dynamic topology
    - 3 to 50 satellites moving, with unpredictable movement
    - ISL links created and lost over time
  - Need frequent communications between satellites
    - Navigation
    - Instruments
    - TM/TC
    - etc.
- Need to optimize routing to avoid useless overconsumption

Examples of missions:

- **NOIRE (Nanosatellites pour un Observatoire Interférométrie Radio dans l'Espace)**
- **The Soil Moisture and Ocean Salinity (SMOS)**
- **Apophis asteroid**

Routing strategies

- Re-use of TCP-IP stack
- Several routing protocols identified
  - OSPF
    - Computes dynamically shortest route
  - PIM-SSM
    - Multicast routing protocol
    - Creates multicast routes from sender to all subscribed receivers
    - Need exchange of control messages

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On Selecting a Routing Protocol for Nanosatellite Swarm Networks

Riadh DHAOU*, Emmanuel LOCHIN†, Louis BASSET*, Bastien TAURAN‡, David PRADAS‡, Bernard PONTET§

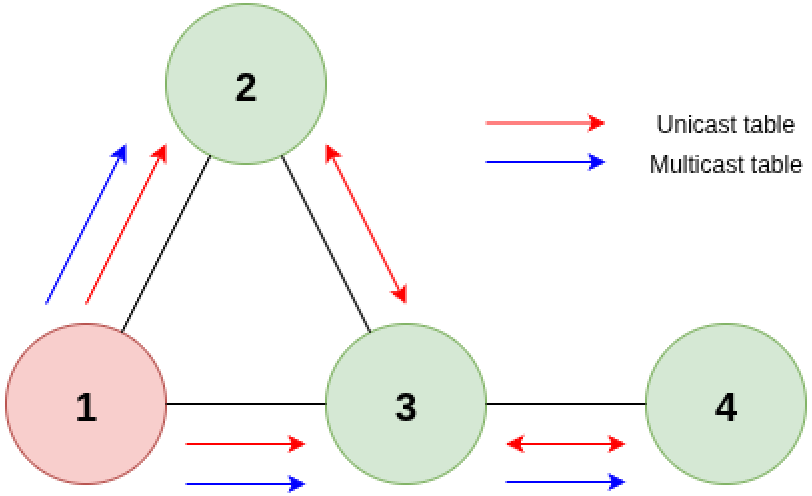
Swarm simulator

Swarm simulator

- Development of a simple discrete event network simulator
  - Packet generation
    - Payload + headers IP and UDP
  - Periodic handling of packets in the routers
    - Fixed maximum number of packets handled per second
  - Perform unicast and multicast/broadcast routing
    - Pre-computed routes
    - No control messages exchanged
  - Use several input parameters
  - Produce several detailed statistics

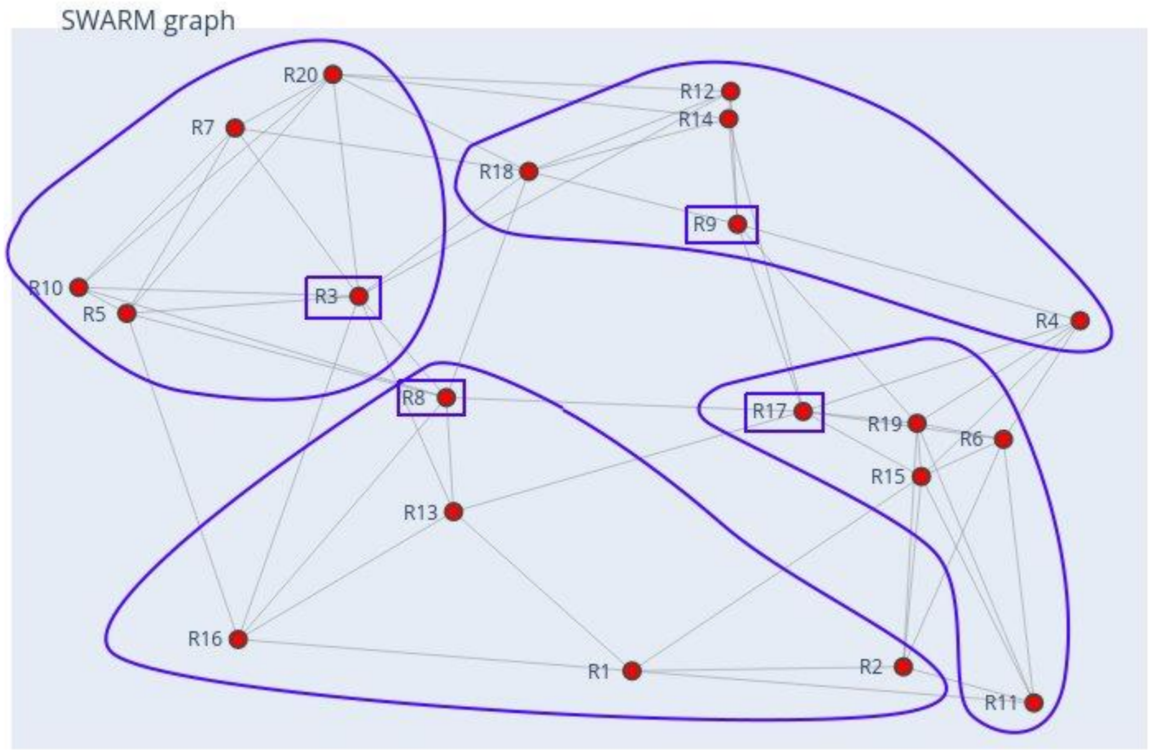
Goal: compare routing strategies

- Communication between satellites
  - Unicast
    - Via OSPF
  - Multicast/Broadcast
    - Via OSPF + router optimization
      - Filtering of duplicated packets
      - Anti-return filter
      - Initial TTL of packets
    - Via PIM-SSM



Scenarios tested

- Traffic profile
  - Multicast: one node sends to 5 other (1 to 5)
  - Broadcast: one node sends to all other (1 to all)
  - **Broadcast: all nodes sends to all other (all to all)**
  - **Broadcast: use of clusters (5 nodes per cluster)**
    - Each node sends to all other in the cluster
    - A representative of each cluster sends to all other representatives



Results

Routing strategy

Results with unicast routing

- Need to use optimization parameters in routers
  - Filtering of duplicated packets
  - Anti-return filter
  - No impact of initial TTL
- Comparison of performance with several scenarios, for 20 satellites

Scenario	Maximum proportion of received packets	Median load in routers
1 to 5	100%	30 pkts/s
1 to all	100%	50 pkts/s
All to all	18%	100 pkts/s
All to all + clusters	70%	100 pkts/s

Impact of PIM

- PIM highly increase performance
  - Clustering is necessary to ensure 100% of packets received.
  - Some nodes have to handle more load than others.
  - This is made at the cost of more control messages exchanged.
- Comparison of performance with scenarios all to all, for 20 satellites

Scenario	Routing strategy	Maximum proportion of received packets	Median load in routers
All to all	Unicast via OSPF	18%	100 pkts/s
All to all	PIM	55%	100 pkts/s
All to all + clusters	Unicast via OSPF	70%	100 pkts/s
All to all + clusters	PIM	100%	50 pkts/s

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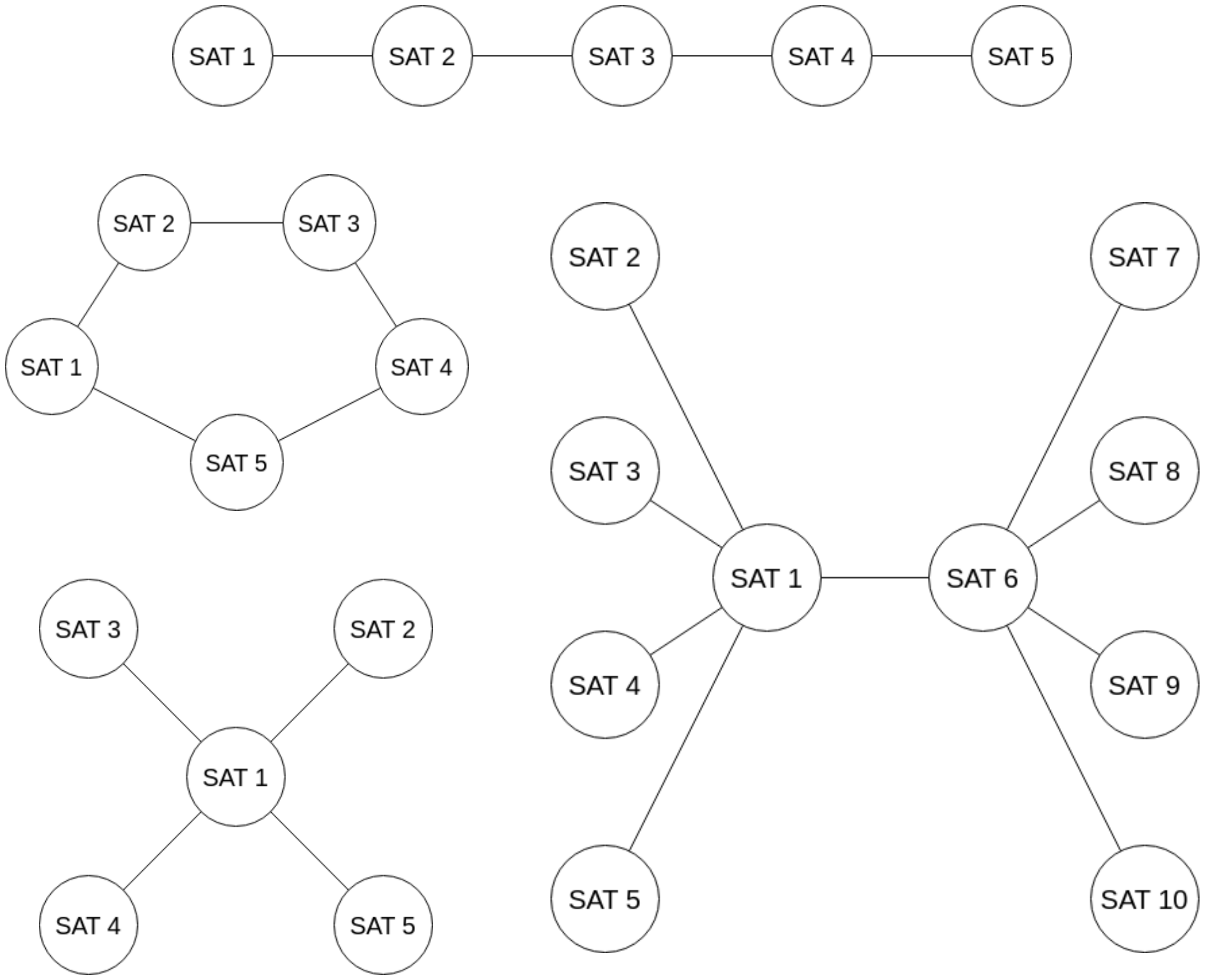
Results

Impact of topology

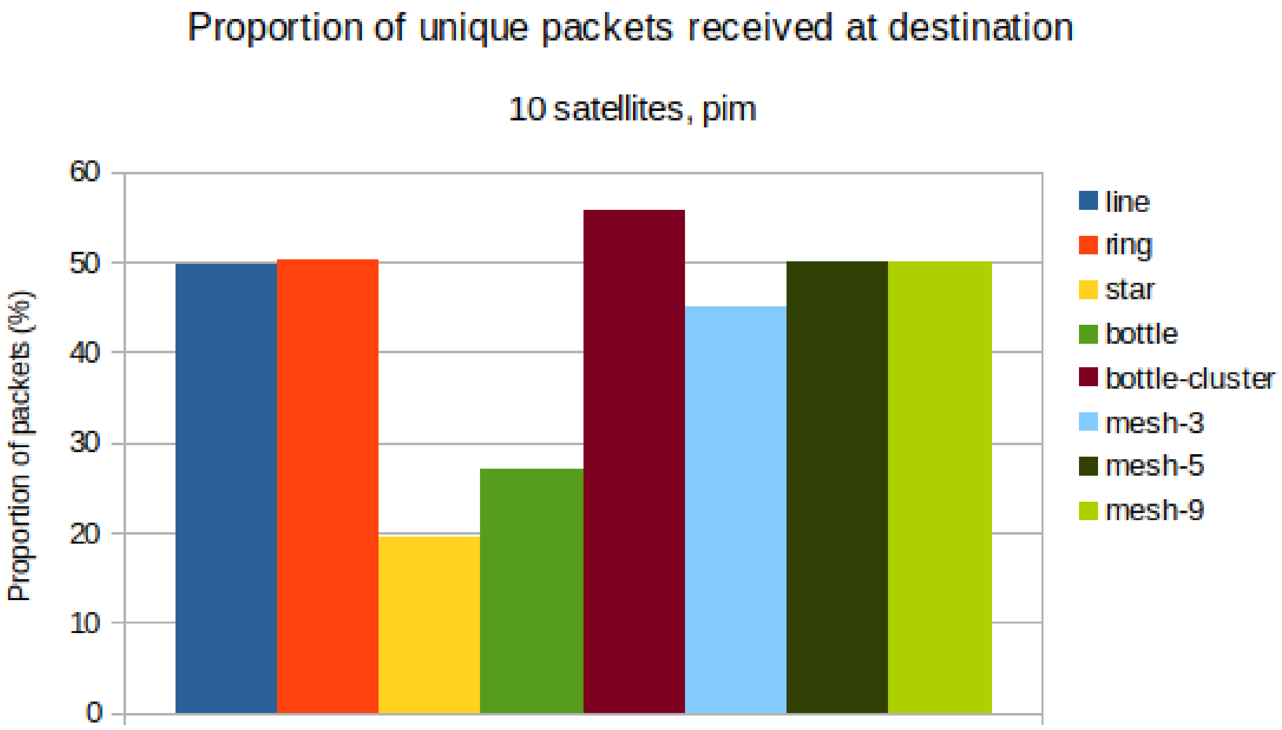
Impact of Swarm topology

- Several topologies tested
  - Line
  - Ring
  - Star
  - With bottleneck
    - Without clusters
    - With clusters
  - Meshed network
    - Average of 3 neighbours
    - Average of 5 neighbours
    - Average of 9 neighbours



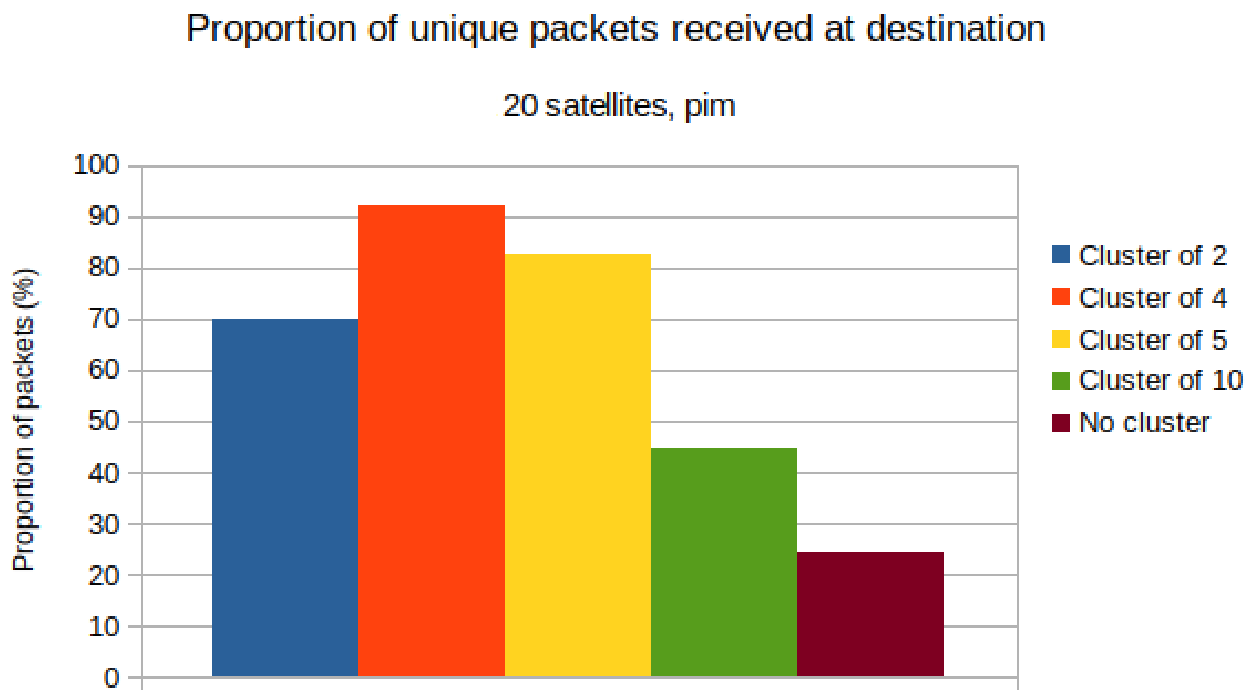
Impact of Swarm topology

- Conclusions on impact of topology
  - Meshed networks are more efficient when satellites have many neighbours
  - We need to avoid having a central node
    - Star topology
    - Bottleneck topology without clusters
  - If bottleneck, use clusters on each side and interconnexion on bottleneck
  - Line and ring networks have good performance, but do not scale



Impact of cluster size on mesh networks

- Impact of cluster size on performance
  - In a swarm of 20 satellites, optimal cluster size is around 4 or 5
    - Cluster must be chosen carefully
  - The number of packets to handle increases with cluster size
    - Whatever the configuration, some nodes are saturated
  - These conclusions may not apply to other swarm sizes or shapes



Conclusion

Conclusion

- Test of impact of routing strategies

Routing strategy	Global network performance
Using OSPF unicast tables	**Not working**
Using OSPF unicast tables with optimizations	**Bad**
Using OSPF unicast tables with optimizations and clusters	**Good**
Using PIM	**Good**
Using PIM and clusters	**Best**

- Assessment of the impact of topology and cluster size on performance

Next steps…

- **Thesis : Protocols and Reinforcement Learning Optimization for Nanosatellite Swarm Networks**

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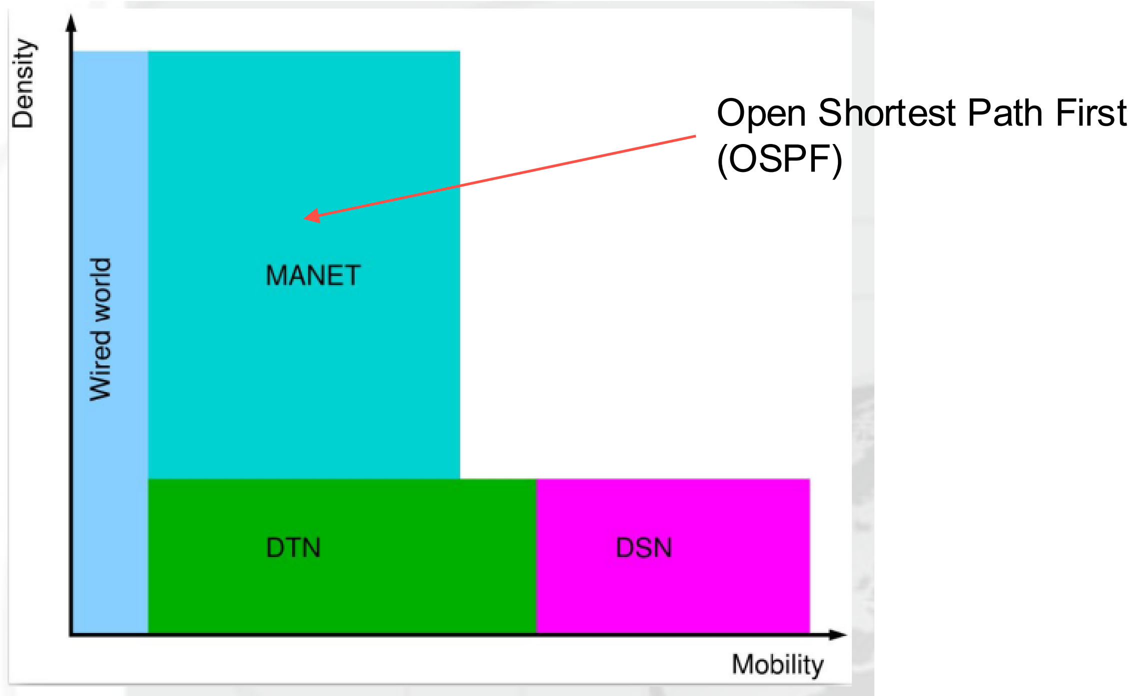
Choice of routing strategy

- **Task 1:** identify protocol stacks and routing algorithms allowing for a swarm constellation

DTN (Delay-tolerant networking)

MANET (Mobile Ad-hoc Network)

DSN (Deep Space Network)



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