Topology Dynamics and Routing for Predictable Mobile Networks

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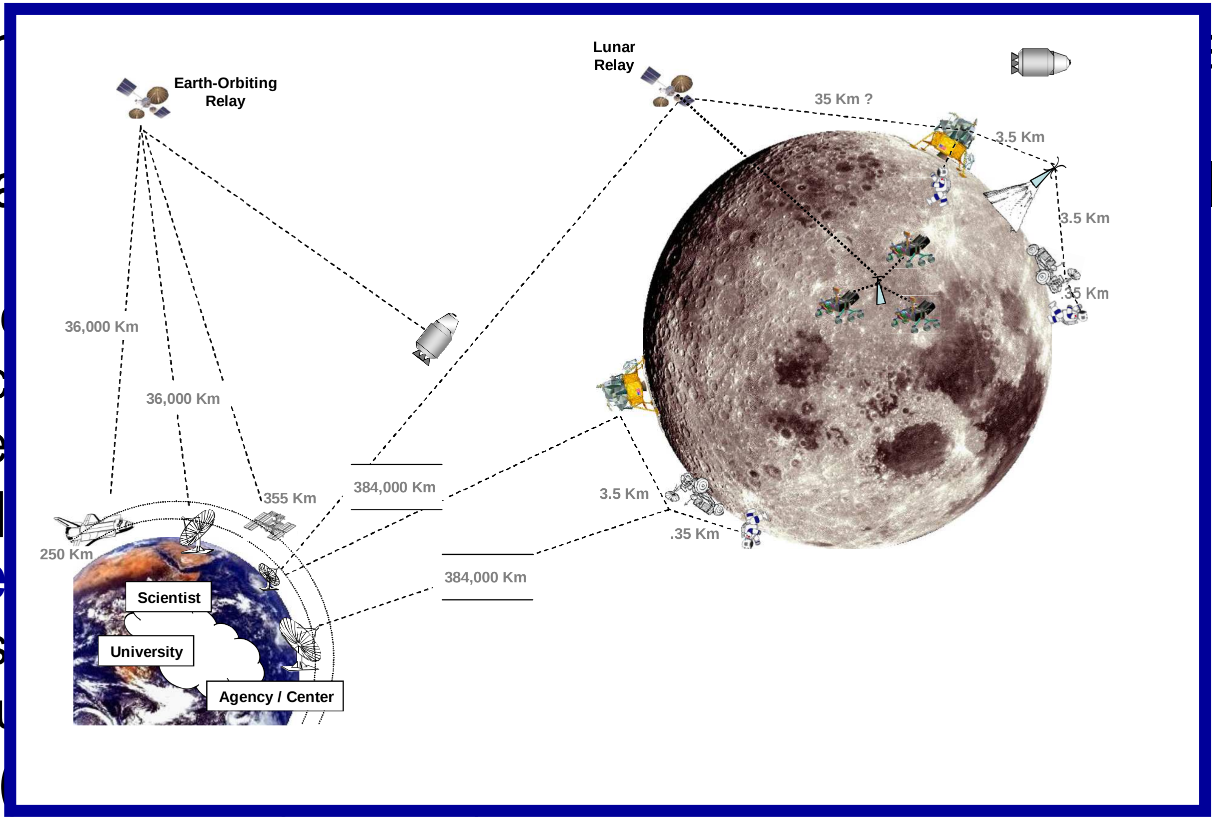
UNIVERSITÉ DU LUXEMBOURG

Talk Outline

- ➡ Problem Definition & Motivation
- Topology Model
- Predictable Link State Routing
- Simulation Results
- Conclusions & Future Work

Problem Definition & Motivation

- Work is r… …ation systems …
- Spacecra… …links between …
  - Limite…
  - High c…
  - Space…
- ESA and … heteroge…
  - Inter-s…
  - Introdu…
- Existing (…
  - Iridium (Flying)
  - Teledesic (Not implemented)



Predictable Mobile Networks

- Spacecrafts follow fixed flight paths that can be pre-computed
  - Their movement is therefore predictable
- ➢ In spacecraft networks, the connectivity graph is also predictable
- But space is a hazardous environment!
  - Spacecrafts can temporarily or totally fail to provide communication services (safe mode, spacecraft loss)
  - These outage events are unpredictable
- Contribution
  - Formalization of a suitable topology model using the snapshot approach
  - Design of a Routing Protocol for Predictable Mobile Networks (PLSR)
  - Concept validation via simulation and proof of correctness

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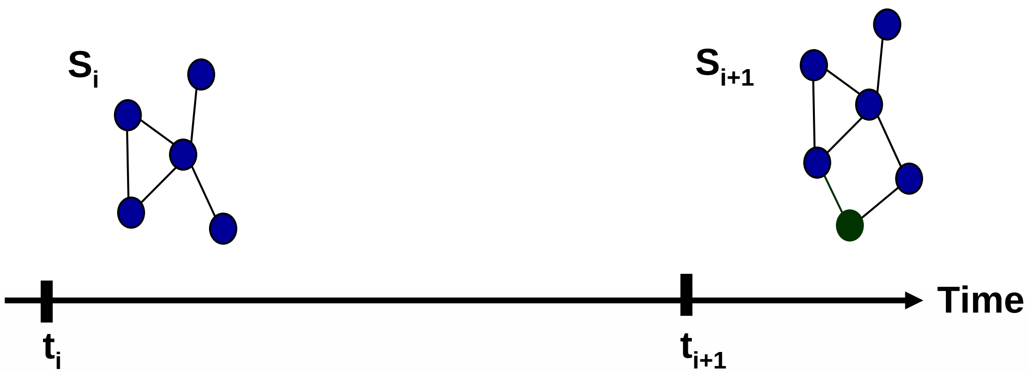
The Snapshot Model

- Predictable Topology Model
  - Dynamic topology graph broken down into a series of static topology graphs
  - Static connectivity graph describes the topology during a time period in which no predictable changes occur
  - Time points at which predictable changes occur are called transition points
- Snapshots
  - Snapshots associate transition points with static connectivity graphs
  - ➢ The topology evolution can be described by a sequence of snapshots and a transition function

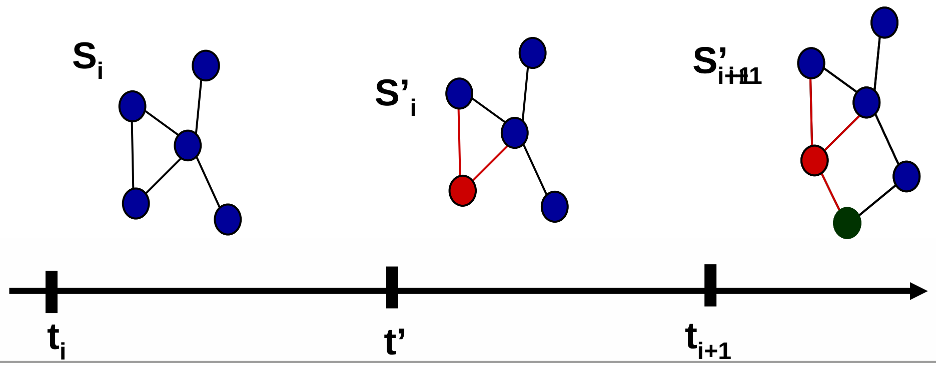


Snapshot Distribution

- To benefit from predictability, nodes require information on future snapshots
- Generation and Distribution of snapshot sequences
  - Repeating movement patterns are rare
  - Limited memory resources in nodes
- Solution is to utilize ground stations
  - Extensive computational resources allow computation of snapshot sequences
  - Ground Station nodes compute and distribute snapshot sequences
    - These sequences represent connectivity “reality” for each point in time
- Snapshot Distribution
  - Only distribute changes between snapshots and use multicast
  - Scalability: Node distance is low in terms of hops in spacecraft networks
    - Scalability in generic predictable mobile networks deserves further research
  - Propagation Delays: On-Time distribution required

Unpredictable Changes

- Unpredictable changes can occur at any time
  - Not covered by the transition function
  - Discovered using link-sensing
- Unpredictable Changes transform “reality” as represented by a given snapshot
  - Current snapshot connectivity graph is modified
  - Unpredictable changes then interact with predictable changes at transition points
  - Ground stations receive information on unpredictable changes
    - They can perform regular re-alignment of the predicted “reality”



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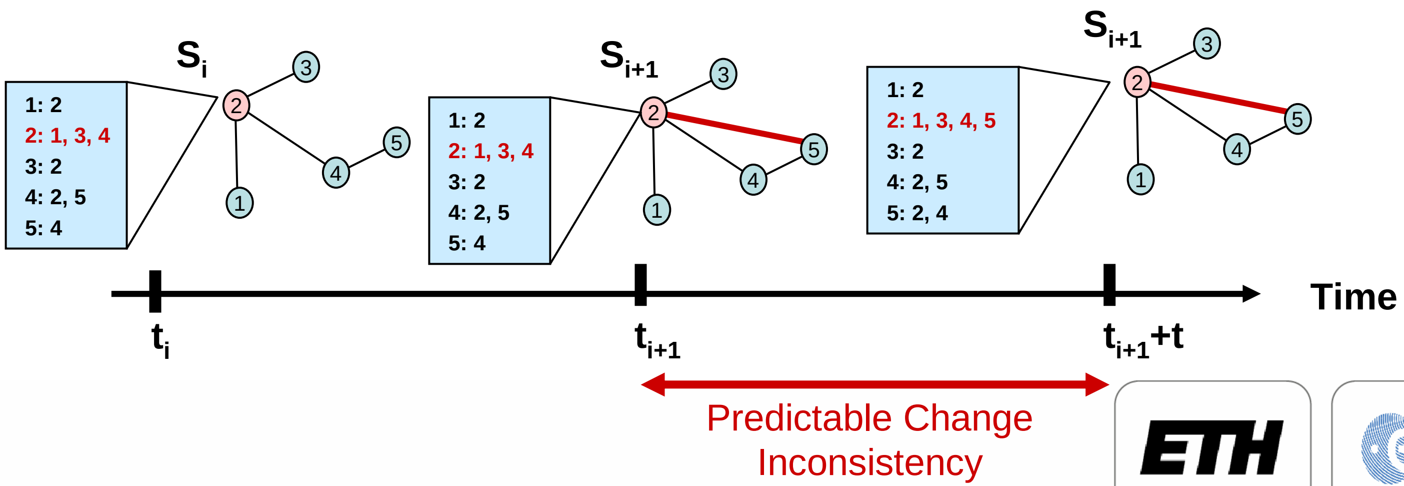
Routing Protocol Foundations

- Candidate Basic Algorithm Analysis
  - Mobile ad-hoc routing protocols found to be inadequate
    - No notion of predictability
    - Often limited topology knowledge
    - BUT: Quick adaptation of changes
  - Static routing protocols also inadequate
    - Not designed to cope with changes that result from rapid movement
    - BUT: Building and exploiting extensive knowledge of the topology
  - Predictable Mobile Networks share properties from both worlds
- Link-State routing is best suited as a foundation for the new routing protocol
- The Predictable Link State Routing (PLSR) protocol has been developed for Predictable Mobile Networks

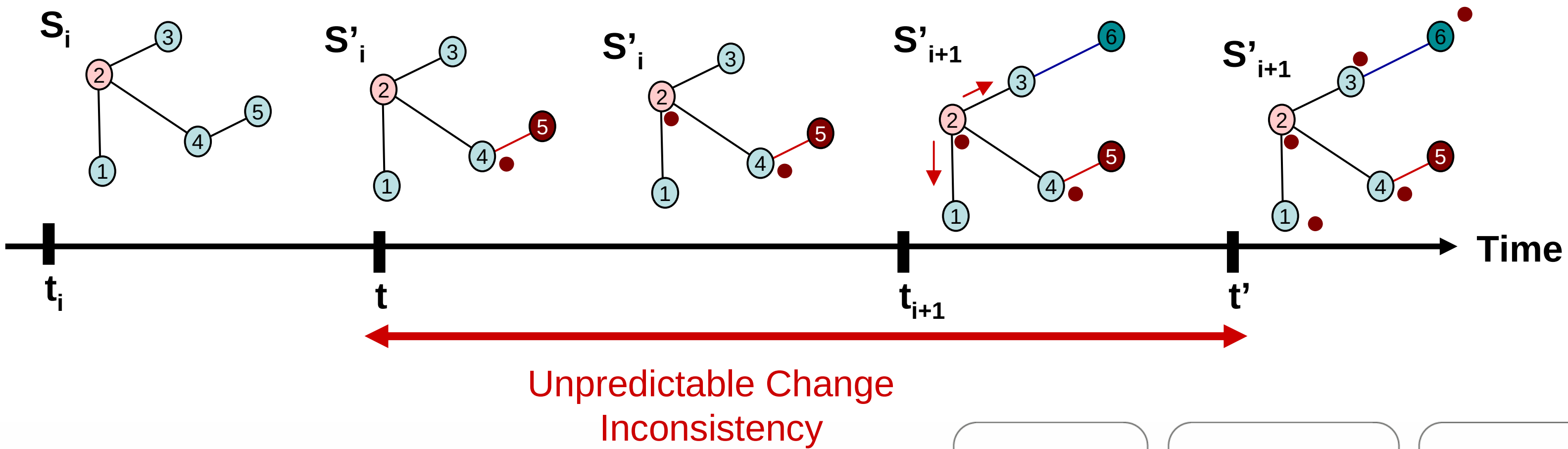
Desired Protocol Properties 1/2

- Two kinds of consistency are considered by PLSR
- Predictable Change Consistency
  - Following a snapshot transition point, all nodes share a consistent view of the network before the next transition point is reached
  - The inconsistency period is negligible and represents the time that the nodes require to compute their new link-state database
- In general, period is small enough to suspend packet forwarding
  - Packet loss due to routing failures is thereby avoided



Desired Protocol Properties 2/2

- Unpredictable Change Consistency
  - Following an unpredictable change that occurs at a time point **t**, at a later time point **t'**, all nodes have updated their link-state databases with the effect of the unpredictable change
  - The time period between **t** and **t'** represents the time that the link-state advertisements need to reach all network nodes
- Unpredictable change consistency is reached for all unpredictable changes at some point



Protocol Sketch

- PLSR takes actions at the following events:
  - Predictable Changes
    - Nodes locally update their link-state database
    - Existing unpredictable changes are preserved
  - Unpredictable Changes
    - Occurring unpredictable changes are handled as in basic-link state routing
    - Storage in local databases to record unpredictable changes at snapshot transitions
    - An unpredictable change is removed from this database if
      - a new, snapshot sequence is received that already includes the change
      - The topology changes such that the unpredictable change is no longer applicable
  - Interaction
    - At each transition point, predictable changes are applied prior to stored unpredictable changes

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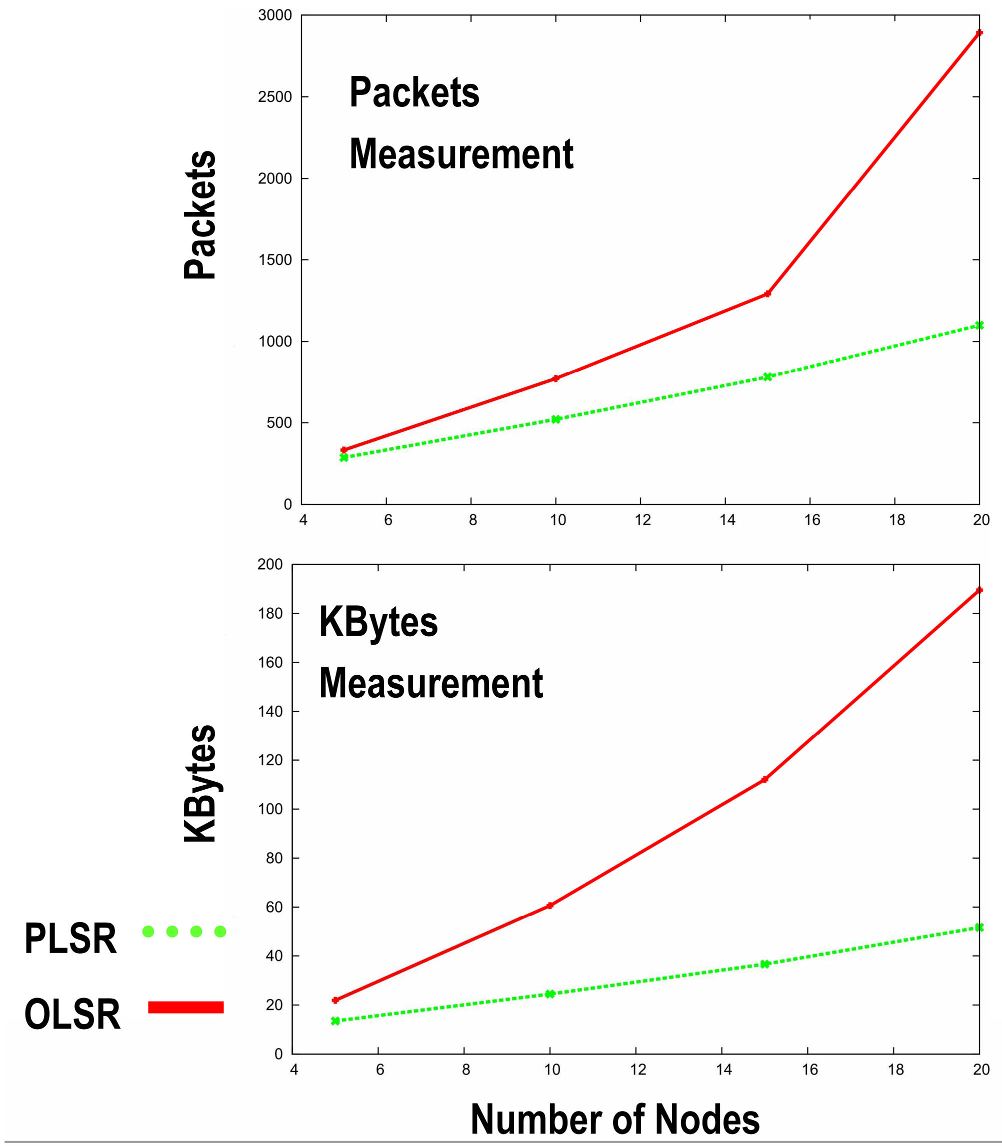
Protocol Simulation

- We compare the performance of PLSR to that of OLSR
- Simulation Setup
  - Ns-2 simulator using the standard wireless communication model
  - General mobile networking setting, independent of any specific spacecraft network scenario
    - Randomly generated, connected topologies for each simulation run
    - PLSR has knowledge of the topology via snapshot updates from a GS node
  - Vast majority of changes is predictable, but unpredictable changes may occur with a probability of 0.1
  - Number of nodes: 5-20 (typical spacecraft network size)
- Measurement Criteria:
  - Routing Overhead
  - Traffic Throughout
    - One traffic stream between two random nodes (UDP-CBR traffic)
  - Convergence time has not been considered

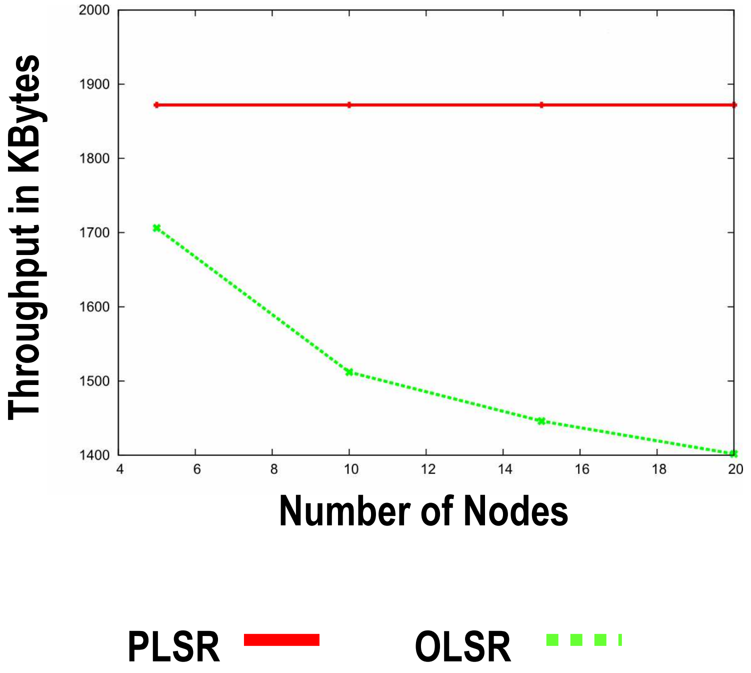
Routing Overhead Simulation



- PLSR causes a lot less routing overhead
  - No routing messages are produced following predictable changes
- PLSR overhead results from
  - Snapshot Distribution (small)
  - Periodic Link-Sensing
- Practical Consequences
  - Much higher bandwidth efficiency with PLSR
  - Especially valid in spacecraft networks

Traffic Throughput Simulation

- PLSR provides almost constant maximum throughput
  – Small variances due to unpredictable changes
- The more nodes, the more efficient is PLSR with respect to OLSR
  – Building stable routes gets more difficult for OLSR with a growing number of nodes
  – PLSR does not suffer from this and only has to correct few unpredictable changes
- Practical Consequences
  – May help to reduce the existing transport layer protocol problem for spacecraft networks
  – In long propagation delay environments, OLSR performance will be even worse
  ➢ PLSR is well suitable for spacecraft networks



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→ Conclusions & Current Work

Conclusion and Current Work

- We have developed PLSR for heterogeneous, predictable mobile networks
  - Protocol is correct under realistic assumptions for spacecraft networks
  - Simulations show superiority of the protocol over the OLSR protocol
  - Usage of PLSR in spacecraft networks brings direct cost savings and can slim down transport layer protocols
  - Other layers (e.g. DTN bundle layer or physical layer) may also benefit from distributed snapshot information
- Current Work
  - Simulation of the PLSR protocol in realistic spacecraft network scenarios that are planed by ESA using real flight-dynamics data
    - LEO/GEO spacecraft hybrid network
    - Mars rover scenario
  - Relaxation of assumptions and the impact on PLSR correctness and behavior
    - E.g. does PLSR correctness still holds if clock sync. is not present?
  - Investigate scalability of snapshot sequence information distribution

Thank You for Your Attention

Any Questions?

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http://wiki.uni.lu/secan-lab/Daniel+Fischer.html