Topology Dynamics and Routing for Predictable Mobile Networks

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Talk Outline

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

- Work is motivated by practical problems in space communication systems.
- Spacecraft communication is mostly based on point-to-point links between ground stations and spacecrafts.
  - Limited scalability
  - High cost
  - Limited constellation control
- ESA and other space agencies are investigating the use of heterogeneous spacecraft networks.
  - Inter-spacecraft communication links
  - Introduction of network layer functionalities
- Existing spacecraft network concepts:
  - 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
Talk Outline

Problem Definition & Motivation

Topology Model

Predictable Link State Routing

Simulation Results

Conclusions & Future Work
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 planned 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 hold 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