An Approach to Quantify Reconfiguration Methods for PIM-SM Trees

- A Network Complexity Perspective -

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Introduction

Motivation

- low predictability in network algorithms
- complete state space not transparent
- network algorithms also interact with underlying layers

Complexity

- some complexity is needed for robust networks
- stability decreases at a certain level of complexity

Aspects of Complexity

Efficiency

- classical measurement of effort for specified task

Robustness

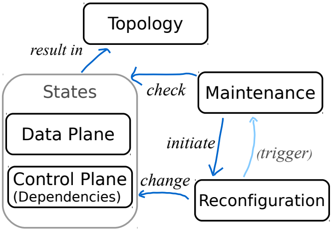
- ability to persist despite changes

Resilience

- ability to adapt to changed conditions

Control Loop

- behavior specification of a local node
- abstract view provides categorization of functions
- complexity arises from reconfiguration functions



Related Work

Stability of a Multicast Tree [1]

- quantifies the change of links in a multicast tree
- shows that the change follows a Poisson distribution
- formula to approximate the change of the tree depending on network size and number of receiver

Percolation Thresholds in Network Decay [2, 3]

- describes characteristics of network stability
- high stability until a network decays completely
- exist in several network scenarios

Current Work

Goal

- estimate the range of change initiated by link failures
- estimate the ability of a network to adjust to failures

PR 1 (work in progress)

- quantify effects of reconfiguration methods on distribution trees
- case study for PIM-SM [4]
  - join
  - reconfiguration at link failure
  - calculation based on expected state changes

PIM-SM Protocol Overview

- IP layer multicast protocol
- independent of underlying routing protocol
- PIM routers maintain a variety of states
    - e.g. joins(*,*,RP(G)), prunes(S,G), lost_assert(S,G), ...
- within two kinds of trees:
    - shared tree
    - source specific tree
- well known rendezvous point (RP) is root of the shared tree
- protocol consist of three main procedures (phases)

PIM-SM Phases

Phase One: RP Tree

- Receiver joins shared tree (`join(*,G)`)
- Sender packages are encapsulated sent to RP by DR

Phase Two: Register Stop

- RP joins source specific tree (`join(S,G)`)
- When RP receives Packages via SST, send `register_stop(S,G)` to the sources DR

Phase Three: Shortest Path Tree

- Receiver sends `join(S,G)` to source
- Receiver sends `prune(S,G,RPT)` to RP

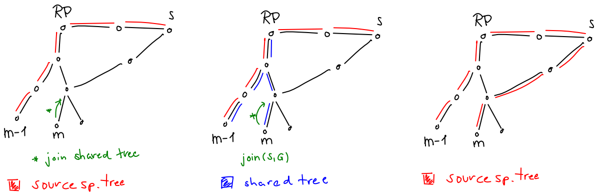
Approach

- Given: approximation of the expected amount of new links in a multicast distribution tree $E[\Delta_N(m)]$
  - if the m^{th} member joins (or leaves)
  - in a random network with N nodes
  - for big N and small m

Idea

> Consider the reconfiguration operations, e.g. following a link failure, as a sum of several $E[\Delta_N(m)]$-like tree operations

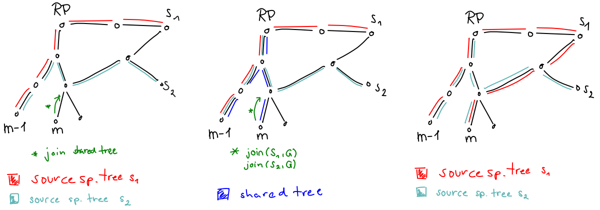
Join Group with One Source



m_{rp}	number of members in shared tree
m_S	number of members in source specific tree

1 source: $E[\Delta_N(m_{rp}, m_S)] \approx E[\Delta_N(m_{rp})] + E[\Delta_N(m_S)]$

Join Group with Multiple Sources



k sources:

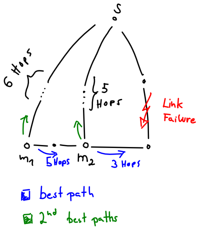
$$E[\Delta_N(m_{rp}, m_s)] \approx E[\Delta_N(m_{rp})] + k \cdot E[\Delta_N(m_s)] + \underbrace{k \cdot E[\Delta_N(m_{rp})]}_{\text{source specific prune}}$$

Problem

- source specific prune within the join procedure cannot be approximated with $E[\Delta_N(m_{rp})]$
- number of the receivers, which did not already prune a source, differs from m_{rp}

Effects of Link Failure

- link failure repaired by *multiple* rejoins
- How many nodes may be affected?
    - best case: 1
    - worst case: all nodes in the subtree



Influencing Factors

- size and shape of the downstream subtree
- node degree of the upstream node

Approach to Rejoin I

Provisional Assumption

> The existing distribution tree is a perfect k-ary tree.

Assuming a uniform link stability, the expected level of a link failure, can be calculated as

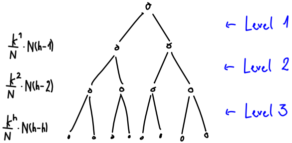
$$E(\ell) = \sum_{i=1}^{h} \frac{k^i}{N} \cdot i$$

(ℓ= level, N=number of links, k=downstream node degree, h=height of the tree)

A first idea how to approach such a problem analytically!

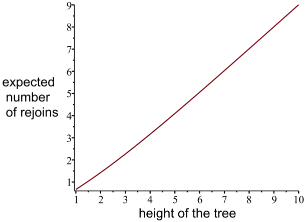
Approach to Rejoin II

Therefore the number of nodes which have to rejoin (avg. worst case) is:



$$E_{join}(h) = \sum_{i=1}^{h} \frac{k^i}{N(h)-1} \cdot N(h-i)$$

- $\frac{k^i}{N(h)-1}$: probability to choose a link from level i from all links in the tree
- $N(x)$: calculates the number of nodes from the number of levels x



Next Steps

- use a more realistic models to estimate the reach of reconfiguration methods (e.g. uniform recursive trees)
- add a time parameter to the calculations
- quantify the number of failing links per time, until the rejoin becomes ineffective
- check if the decay has a percolation threshold
- validate formulas against test results
    - e.g. from simulation or measurements

Chances

- mathematical description for the effect of reconfiguration methods
- finding environments under which the algorithm will produce suboptimal results without bruteforce testing
- staying abstract enough to do similar calculation for other algorithms

Risks

- interesting factors can be too difficult to model analytically
- too many expectancy values generalize the behavior to meaningless statements
- results do not validate in tests

Summary

- reconfiguration methods are assumed to be strongly responsible for robustness
- framework of specified trees and $E[\Delta_N(m)]$-like operations enables to approximate affected nodes
- approach to quantify the robustness and effects of reconfigurations methods of PIM-SM
  - join
  - rejoin after link failure

Future Work

- use of internet measurements for more detailed information on existing network structures
- check, how far analytical methods comply with measurements
- search for reasons why they would not comply
- consider not only multicast trees but tree creating algorithms in general (e.g. routing)

Thank you for your attention!

Questions?

References I

[1] P. Van Mieghem and M. Janic, "Stability of a Multicast Tree," in *INFOCOM 2002. Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, vol. 2. IEEE, 2002, pp. 1099–1108.

[2] R. Albert and A.-L. Barabási, "Statistical mechanics of complex networks," *Reviews of modern physics*, vol. 74, no. 1, p. 47, 2002.

[3] S. V. Buldyrev, R. Parshani, G. Paul, H. E. Stanley, and S. Havlin, "Catastrophic cascade of failures in interdependent networks," *Nature*, vol. 464, no. 7291, pp. 1025–1028, 2010.

[4] B. Fenner, M. Handley, H. Holbrook, and I. Kouvelas, "Protocol Independent Multicast - Sparse Mode (PIM-SM): Protocol Specification (Revised)," IETF, RFC 4601, August 2006.