Complexity of Multicast Communication Patterns and its Application in Smart Grid Networks

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Anwendung 1
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Outline

Motivation

Origin of Complexity:

- Formed by evolutionary development of networks
- Often created by adding additional functions to an initially lean network design
- Overloaded Design Goals
- Misplaced functions in the layered model

What is Complexity and how can it be measured?

- Code Complexity of Software
- Runtime Complexity of Algorithms
- Complexity of *Networks* → only vague Definitions:

Network complexity is proportional to state, dependencies between components, and rate of change in a network. Too much complexity can cause unpredictable, non-linear behaviour.

M.Behringer

Network Complexity

Influencing Factors

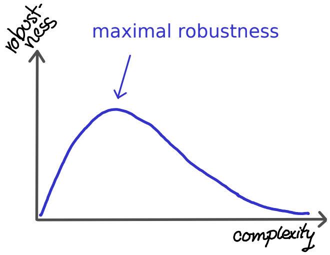
- States in a Network
- Dependencies on Configuration Parameters
- Interaction to propagate configuration
- Rate of change
- Total cost of ownership
- ...

Different Points of View

- Operator view *vs.*
- Software developer view (on application layer) *vs.*
- Developer view (of OSs and routers) *vs.*
- Structural approaches

Problem Space

- Unpredictable behaviour
  - Small change causes large change at a different node or layer
- Suboptimal routes
  - Lack of information
  - Expired information
- Robust yet fragile
  - Designing against one set of failures makes vulnerable against another set of failures
- Nevertheless: robustness needs some complexity

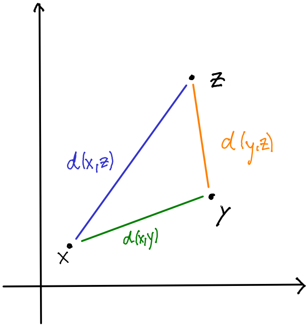


Metrics

- Goal: Comparing network solutions
- Estimating Complexity
- Mathematical approaches to get an reliable (predictable) environment
- First intuition: Metric

Metric Space

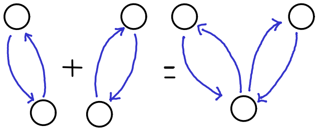
- Measurement of distances
  $d : M \times M \to \mathbb{R}_{\geq 0}$
- Triangle Inequality
  $d(x, z) \leq d(x, y) + d(y, z)$
- Symmetry $d(x, y) = d(y, x)$
- Positive definite $d(x, y) = 0 \Rightarrow x = y$

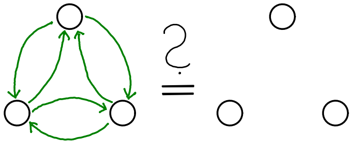


Graph Complexity

- Metric provides Distances between two networks only
- Getting "Complexity of one Network":
  - Calculating the distance to a *minimal Network*
- Empty Graph: $C(\emptyset) = 0$

Comparing 2 Networks... Which one is more complex?
Which graph characteristics should we count?





Deriving a Metric

- Difficult to include all complexity aspects
- Metric covers partial aspects of network complexity
- Usefulness of a Metric depends on the observers background
- Can we embed complexity into a metric space that always complies to the triangle inequality?

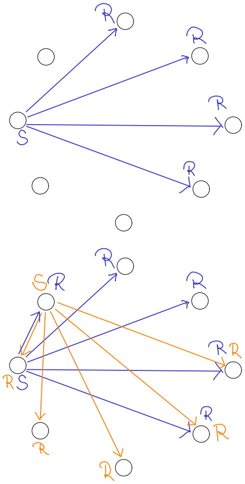
Objective

- Concentrate on specific part of network complexity
- find/calculate key indicators which fit to a metric space
- Provide a metric (or something similar), which covers this specific subtopic

Group Communication

What to achieve?

- sending message to a specific group of nodes
- One-to-Many
  - one dedicated sender in a group
  - star shape
  - Example: RSS
- Many-to-Many
  - more then one sender
  - Example: Chat, Multiplayer Games



Data Distribution

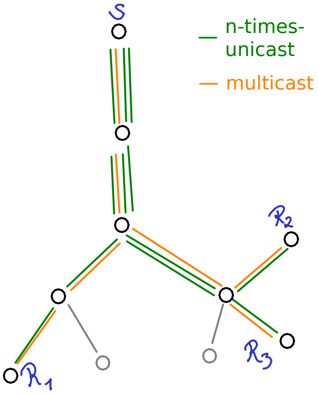
How to distribute the Data?

N-Times Unicast

- For each receiver:
  1 Connection from sender-receiver
- High load for sender and hops

Multicast

- Example: One-to-Many
- Reducing sender load
- Reducing overall traffic

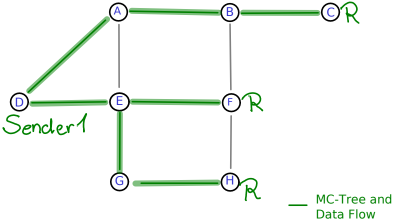


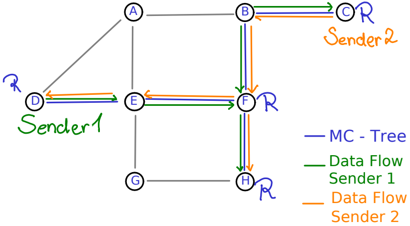
Multicast Tree Structures

How to create a distribution tree for Multicast?

One-to-many & Many-to-many

- One-to-many: shortest paths from *one* sender to receivers
- Many-to-many: minimizing expected path length from *every* sender to every receiver
  - Source-Tree
  - Shared-Tree
- Different distribution trees needed



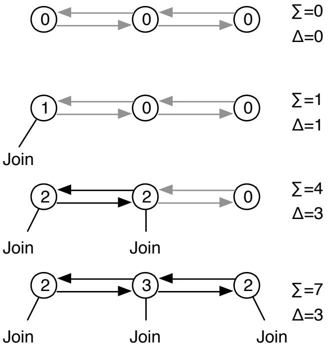


Rate of Change I

- Cost of specific actions
- Compare difference of states
  s_n: State before action
  s_{n+1}: State after action

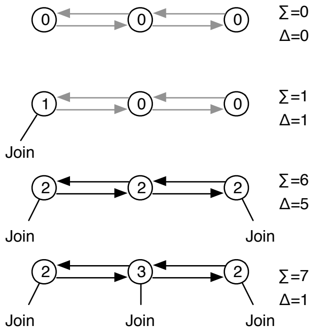
Example

$\sum$: Sum of the *multicast forwarding states*
Δ : Change of the state: $s_{n+1} - s_n$



Rate of Change II

- Δ depends on *location* of the joining node
- Graph results in the same sum $\sum$
- Difference only appears in the temporal sequence
- How to put it into numbers?
  $\rightarrow$ Probability Theory



Implementation

IP Multicast

- Multicast on IP level
- Shortest Path between source and receivers
- Requires support of all intermediate routers
- fastest Multicast solution

Application Layer Multicast (ALM)

- Multicast distribution tree on application layer
- independent of support of routers
- Slower and less efficient than IP Multicast
- Multiple Protocols available: Scribe, NICE, ...

Multicast Complexity

Aspects

- States of Multicast Nodes
- Rate of Change in Multicast Distribution Trees
- Layering of Networks

Related Work

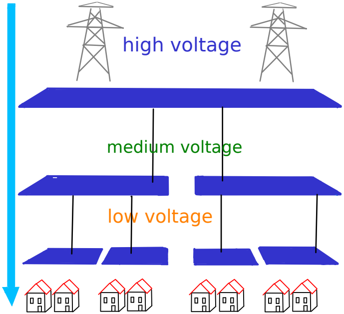
- Network Complexity Research Group (NCRG) - IRTF
- NetComplex [S. Ratnasami]
- Multicast Efficiency [P. van Mieghem]
- Graph Theory Metrics (e.g. Connected Components, Diameter, ...)

Related Conferences

- IRTF Meeting
- IFIP Networking
- USENIX NSDI

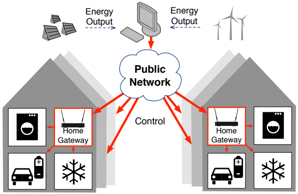
Electricity Grid

- Classic electricity grid as top down structure
  - Transmission grid:
    Long distance transmission
  - Distribution grid:
    Local distributions
- Increasing distributed generation of power, for example:
  - Photovoltaik
  - Combined Heat and Power (CHP)
  - Virtual power plant (VPP)
  - Traditional power plant
  - Wind power



Smart Grid

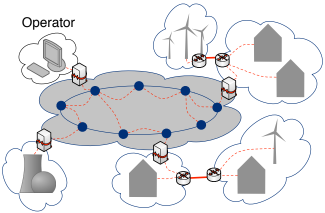
- Growing amount of intelligent devices
  - Virtual Power Plant (VPP)
  - Demand Side Manangement (DMS)
  - Advanced Metering Infrastructure (AMI)
- Change: view large producers → many small producers
- Distributed Coordination for:
  - Power Generation
  - Power Consumption



- Adjusting power consumption to current power capabilites (for stability)
- Approach: Home Gateway enables the connection between house-wide and area-wide communication

Multicast in Smart Grids

- Devices in Smart Grids require machine-to-machine communication
- Decentralized Communication
- Sorting groups by energy devices, regions, energy sources,...



- Communication of household energy devices via home gateways
- one-to-many: Controll Messages
- many-to-many: local device communication

Smart Grid communication seems to be a good use case for multicast complexity

Smart Grid
Research Context

Challenges

- Providing communication patterns (protocols)
- Optimizing power consumption on different levels
- participants maximizing the own profit $\neq$ optimizing the grid
- Measurements
- Robust security solutions

Conferences

- IEEE SmartGridComm
- IEEE ISGT
- ACM SAC
- Different conferences for electrical engineering

Summary

- Growing need for measuring Network Complexity
- Selecting Multicast as manageable network part
- Smart Grid requires complex group communication
  - so it provides an promising case study environment

Thank you for your attention.
Questions?

iNET: http://inet.cpt.haw-hamburg.de

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