Autonomous Networking Schemes: in-network service composition

Mikhail.Smirnov@fokus.fraunhofer.de

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Roadmap

• Motivating *ecosystem* as a new unit of design
• Examples of eco-driven design
  – Micro-ecosystem (QoS)
  – Macro-ecosystem (Traffic Engineering)
  – Learning ecosystem (Cognitive Networking)
The focus of this talk is on

- Robust control under multiplexing
  - Decisions in uncertainty
- Driving Models
  - Model driven decision (sensing) in-network processes
- Network SOA
  - SLA-based spontaneous networking
The Service face of the Net

**Organic growth** of coverage: 20 millions of installed APs, growth – tens of mio per year

【Gunnar Karlsson, KTH】

"Translate policy rules into radio behavior controls" and "control operating rules based on policies and situations"

【Preston Marshall, DARPA XG】

Energy market: hour-to-hour exchange demand. Licensed "spectrum commodity" secondary market": near-real-time demand?

【Bill Lane, FCC】

Self-management by informed autonomic decisions through "distributed continuous query processing"

【Timothy Roscoe, Intel】

"New EcoSystem is evolving, new ways of interaction, in which network orchestrates"

【Joelle Gauthier, Alcatel】
Ecosystems!

“We should embrace both developing and maintaining open architectures to reinforce the multistakeholder approach.” [Bob Kahn, IGF-2]
Ecosystem as the Unit of Design

Complexity

We are here

New design construct helps to keep complexity under control

Unit of Design

Client-server protocol
Midcom
SON
ecosystem

Overlay
Ecosystem

Client-server
Midcom

Fairness
Cost-Efficiency

Versatility
Robustness
What used to be a tiny hourglass just interconnecting transport associations over heterogeneous link layers is emerging as rich interconnectivity of network features. What used to be a tiny hourglass just interconnecting transport associations over heterogeneous link layers is emerging as rich interconnectivity of network features.

Next: foster even richer connectivity aiming at Network SOA.

-the future Internet or ‘Post-IP’ is an optimised network- and service- layer solution

[F.-U. Andersen, List of Post-IP Recommendations, Brussels 2006-12-08]
The "end-to-end argument" postulates that no functionality, and/or intelligence critical for end-to-end communication should be placed inside the network.

The AC "end-to-end argument" postulates that no functionality, and/or intelligence that **cannot self-recover** should be placed inside the network.
# UoD Assessment

<table>
<thead>
<tr>
<th>Per user group</th>
<th>Per service</th>
<th>SON</th>
<th>Automated SLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best Effort</td>
<td>Provider Preference</td>
<td>Flat Rate</td>
<td>OSS/BSS</td>
</tr>
<tr>
<td>Versatility</td>
<td></td>
<td>TE in SON</td>
<td>Self-TE in underlay</td>
</tr>
<tr>
<td>Internet Protocol</td>
<td>Service Delivery Platform</td>
<td>E2E (TCP)</td>
<td>Over-provisioning</td>
</tr>
<tr>
<td>P2P/Overlay</td>
<td>Per feature service creation</td>
<td>Cost-Efficiency</td>
<td>Robustness</td>
</tr>
</tbody>
</table>
Ecosystem Examples

• Micro-ecosystem (focus on fairness)
  – Control theory: implicit model-driven information coupling

• Macro-ecosystem (focus on robustness)
  – Control theory: explicit model-driven information coupling

• Learning ecosystem (focus on self-assessment)
  – Control & policy theory: explicit model-driven composition
Control Theory

• Unsolved Problems in Mathematical Systems and Control Theory, V. D. Blondel, A. Megretski (Eds), Princeton University Press, 2004

• Problem 4.4 Decentralized control with communication between controllers Jan H. van Schuppen http://homepages.cwi.nl/~schuppen

Each Controller is given the control purpose, Has partial observations of the system Partial observations of each pair are different PROTOCOL = Constraints on communication channel between each pair

• van Schuppen: “The basic underlying problem seems to be: what information of a controller is so essential in regard to the control purpose that it has to be communicated to other controllers?”

This information is the driving model
Micro Ecosystem

Fairness of in-network drop decisions
TCP and RED

TCP Fairness → FIFO Fairness

Synchronised shift to slow start by all connections

Similar packet-loss for all connections

Previously congested link is underutilized

Congestion

Popular in-network solution:

RED

Random ← no flow

Early ← before congestion

Detection ← signal to slow down

“RED makes Quality of Service (QoS) differentiation impossible”


Think of Eco-RED as a CAC | MUX
Eco RED Control

- Implicit information coupling between 2 types of controllers (TCP CA, Eco-RED)
- Driving Model: ‘Entropy’ ($H_i$) computed per microflow (based on, say $2b$ datagrams [Nyquist])
- Decision:
  \[ \text{Drop}(i : H_i = \max(H_1, \ldots, H_N) \] 
- Motivation: TCP warms up to 100 Mbps during 5-7 s
- Eco-RED is as fair as CAC
Macro Ecosystem

Robustness of AS Traffic Engineering
Inter-AS Routing

- BGP (Border Gateway Protocol)
  - Directly controls traffic distribution between ASes
  - Local decision making process, but coordinated within fully meshed group of
    - Internal BGP peers and External BGP peers
- Internet traffic governance system
  - > 100,000 of ASes (Tier1 AS’s have ~100 BGP speakers)
  - Hundreds of updates per sec per address prefix
- BGP spec. is being constantly updated
IETF Concerns (1/2)?

- BGP is unique among deployed IP routing protocols in that routing is determined using semantically rich routing policies, languages
- Lacking vendor-independent standards
- The complexity of typical BGP configurations has been steadily increasing
- Vendor command set is continually expanding
- Many providers allow customers, and sometimes peers, to set communities that determine the scope and preference of their routes

Source:
IETF Concerns (2/2)?

- This policy flexibility is one of the main reasons why BGP is so well suited to the commercial environment of the current Internet.
- However, this rich policy expressiveness has come with a cost that is often not recognized.
- It is possible to construct locally defined routing policies that can lead to protocol divergence and unexpected global routing anomalies such as (unintended) non-determinism.
- If the interacting policies causing such anomalies are defined in different autonomous systems, then these problems can be very difficult to debug and correct.

Eco-BGP Challenges

• Existing BGP instability is due to the lack of
  – *functional support* for inter-domain traffic engineering
    • BGP selects routes but routing is by IGP (e.g. OSPF)?
  – *model* to facilitate the traffic engineering function
    • An obvious model would be Traffic Matrix but its estimation is very hard problem currently
      – Traffic self-similarity
      – Opaque decisions by neighbour ASes

• Eco-BGP:
AS Traffic Matrix

- **AS:** $A = \langle I_A, P_A, E_A \rangle$
- **Policy maps traffic from** $i_k$ **to** $e_p$
- **Egress selection at ingress by BGP decision process:**
  $$e(i_k, d, d(i_k)) = e_p$$
- **Traffic matrix:**
  $$T_{A,e} = S\sum_{i=1}^{N} d(i_k, d)$$
  is the composition of the demands and the egress point selection under the assumption that $e = const$

Legend:
- $d$ – destination [prefix], $P$ - policy
- $I = \{i_1, i_2, \ldots\}$ - ingress points
- $E = \{e_1, e_2, \ldots\}$ - egress points,
- $d(i_k)$ – traffic demand at k-th ingress
- $A = \sum_{k=1,N} d(i_k)$ - full AS demand

After: *Traffic Matrix Reloaded: Impact of Routing Changes* Renata Teixeira, Nick Duffield, Jennifer Rexford, Matthew Roughan
For each destination [prefix] BGP selects **one and only one** egress, i.e. Next AS to Dst
Eco-BGP: AS Path Convergence

• Let Eco-BGP select always two egresses per Dst:
  – Make MED obligatory or let BGP speakers negotiate
    • Internally: min=2, max=4 paths to the same Dst prefix
    • OSPF can handle these through TOS-based routing
    • Can associate SLA with ingress/egress pair
  – The closer to source/destination the more likely is the convergence on the shortest AS_PATH
  – The middle part has good TE opportunities

MED = MULTI_EXIT_DISCcretionary [integer], AS_PATH attribute
BGPng: Driving Model

AS collaboration (Eco-BGP decision process knows traffic & PLR):

\[
C = D_i \cdot \begin{bmatrix}
C_{p,p} & C_{p,b} \\
C_{b,p} & C_{b,b}
\end{bmatrix}
\]

\[
C_{p,p} = \sin(\alpha \cdot (1 + pp)) \quad C_{p,b} = \sin(\gamma \cdot (1 + pb))
\]

\[
C_{b,p} = \sin(\gamma \cdot (1 + bp)) \quad C_{b,b} = \sin(\beta \cdot (1 + bb))
\]

Eco-BGP is AS Multi-Path

- Instead of selecting one and only one egress to each destination prefix Eco-BGP should *compose* optimal traffic mix for always [at least] two alternatives (Note: RFC 4451 allows this)
- AS Multi-Path converges to the shortest AS Path (min-stretch routing)
- The driving model - Route-View Diagram - allows self-engineering of inter-domain traffic
- All AS resources are under single control
- Potentially single standard OSS/BSS
- Variety of SLA types
  - Single-sided: Ingress → Egress
  - Double-sided: Ingress ↔ Egress
  - Double Protected: Ingress → {Primary | Secondary} Egress
- A clear step towards Network SOA
Business Opportunities

- (Eco-) Open BGP breaks topological dependencies thus expanding the market of potential customers for any AS
  - topological dependencies (AS adjacencies) currently strongly influence service value chain dependencies
  - “Book your own SLA-based Internet!”
  - Spontaneity of communication is facilitated
- Possibility to define and automate the SLA workflow
  - covering the complete lifecycle, and
  - strongly coupled with traffic engineering (resource control in general)?
- SLA-based AS service becomes a well-defined product
  - Liquidity of Primary and Secondary markets
  - Spontaneity of communication is facilitated
Discussion: New Hierarchy

- Emergent Control Hierarchy Organisation – ECHO

- Emergence of layers:
  - evolution at many layers
  - traditional middleware will create a layer on top of a protocol stack
  - network infrastructure evolution will create layers in-between existing stack layers
    - a new abstraction layer
    - needs to create two interfaces

“Sandwiched emergence” of layers [D. Lane]

MPLS = layer 2,5
IPSec = 3,5
transport security = 4,5
HIP = 3,5+

- Host Extension principle:
  - a host shall not depend on any type of infrastructure but can rely on it when eventually available:
    - Virtual servers (DNS, DHCP, CIB, …) at each host are hooks of potential control trees rooted at host (e.g. LUNARng)
Learning Ecosystem

Through Self-Assessment to Cognitive Networking
Decision Making in Uncertainty

Sharing the same motivation with IBM’s Autonomic Computing (self-management of IT) Autonomic Communication’s main goal is to enable in-network decision making that is challenged by incomplete or uncertain information.

Autonomic Computing

Knowledge Plane

Sense
Assess Risk
Behave
Autonomic NE

Fitness

Network Climate

Monitor
Analyze
Plan
Execute

Autonomic Decision Making in deep uncertainty

Autonomic Communications
Architecture is a program!

© Michel Riguidel (ENST, Paris)

Architecture = program

Architecture = policy

Program = policy
Self-Management

- Self-management ~ a synergie of self-x to perform the purpose as well as possible

![Diagram showing roles and policies in traditional and autonomic systems]

These roles can be assigned dynamically.
Some Results in Policy

• Illuminating definition:

  Policy is a rule that defines a choice in the behaviour of a system

  © Moris Sloman, (ICL, London)?

• Types and modalities:

  (obligation, authorisation) x (positive, negative)

• Conflict resolution:

  policy admission control by meta-policies ~ policy domain
## Agenda of the approach

- Extend the policy domain to fit the self-management requirements
- Propose sensing self-assessment model
- Propose decision self-assessment model
  - Both are assessment models, meaning that the concrete sensing/decision logic is irrelevant
- Propose primary cognition metrics and their derivatives
- Sketch the assessment process
Policy semantics: middleware viewpoint

\[ S \rightarrow A^+ \rightarrow T(\alpha_i) \]  
- subject may request the i-th action on target object

\[ S \rightarrow A^- \rightarrow T(\alpha_i) \]  
- subject may not request the i-th action on target object

\[ S \rightarrow O^+ \rightarrow T(\alpha_i) \]  
- subject must request the i-th action on target object

\[ S \rightarrow O^- \rightarrow T(\alpha_i) \]  
- subject must not request the i-th action on target object

- These semantics are the ones of RMI, of a glue code based on Abstract Data Types, “rendezvous semantics”

- Too tight coupling between S and T, we need dynamic composition
### Policy semantics: compositional viewpoint

<table>
<thead>
<tr>
<th>Role</th>
<th>Relation</th>
<th>Configured policy</th>
<th>Discovered policy</th>
<th>Configuration purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object</td>
<td>Server</td>
<td>Authorisation</td>
<td>Obligation</td>
<td>Safeguard</td>
</tr>
<tr>
<td>Subject</td>
<td>Client</td>
<td>Obligation</td>
<td>Authorisation</td>
<td>Behaviour Definition</td>
</tr>
</tbody>
</table>

- These semantics are the ones of a glue code based on Abstract Behaviour Types
- But how we engineer purposeful (controlled, predictable) behaviour by composing those?
- To apply control theory we need extended policy domain
Note that Monitors can (& usually are)? belong to different realms.

### Extended Policy Domain

Subjective monitoring

Objective monitoring
Control-theoretical view

Policy (control purpose) interface: to specify **process correctness** (later)

**Distributed controller system:** Subject, Object, S.Monitor, O.Monitor are controllers pairwise coupled to perform the control purpose; they adapt but very differently to the changes in the environment.

This is the common (for the assessment) framework, which can be instantiated per realm. In Cognitive Radio realm the same framework can be instantiated to adapt in frequency, time, beam steering, bit loading, power control, etc.
## Policy semantics: control viewpoint

<table>
<thead>
<tr>
<th>Policy type modality</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>O+</td>
<td>Request a behaviour change (adaptation)?</td>
</tr>
<tr>
<td>O-</td>
<td>Refrain from behaviour change (stability, robustness)?</td>
</tr>
<tr>
<td>A+</td>
<td>Admit behaviour change request (multiplex the request)?</td>
</tr>
<tr>
<td>A-</td>
<td>Deny behaviour change request (for multiplexer fairness)?</td>
</tr>
<tr>
<td>M⁰⁺</td>
<td>Detect change/opportunity (external feedback)?</td>
</tr>
<tr>
<td>M⁰⁻</td>
<td>Refrain from notification (uncertainty, conflict)?</td>
</tr>
<tr>
<td>Mₜ⁺</td>
<td>Detect change/opportunity (internal feedback)?</td>
</tr>
<tr>
<td>Mₜ⁻</td>
<td>Refrain from notification (uncertainty, conflict)?</td>
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</tbody>
</table>
Some words about cognition

- Assessment is the evaluation of systems that learn
- A system learns in the environment where others learn as well
- Learning and deciding can be different for coexisting systems
- The environment is noisy and may contain dumb systems
- Ideal cognition (unlimited resources) is not realistic
- Hence, control purpose should be formulated in terms of process correctness® Simon Dobson (UCD, Dublin) rather than point correctness
  - The uncertainty can be captured by the confidence level – situation characterisation per controller (= cognition) type
  - Cognition type is defined by the purpose of cognition
    - What for these events need to be detected?
Objective Monitoring: Primary Metrics

All metrics assume that the target event is detected:
MiSR - Minimal Sensing Resource – required to trigger cognition
MxSR - Maximal Sensing Resource – allowed to spend
CSR – Cognition Start Range = max(MiSR) – min(MiSR)
CFR – Cognition Finish Range = max(MxSR) – min(MxSR)
MiCR – Minimal Cognition Range = min(MxSR – MiSR)
MxCR – Maximal Cognition Range = max(MxSR - MiSR)
Objective Monitoring: Derivatives

Cognition entropy is different in the two areas:
In (Uncertainty – Low Confidence) larger entropy might be required \cite{Belavkin e.a.}
In (Low Confidence – High Confidence) another sensing/cognition might be needed
Roles := Instances

Oversimplified, yet allows to reason on behaviour choices as a composition:
objective monitoring attempts to detect target events (e.g. is there an opportunity
for secondary use of a frequency band?)?
subjective monitoring when triggered attempts to detect the highest confidence (min. risk)
in objective monitoring
Assessment of Process Correctness

• The assessment of process correctness is the assessment of how well the control purpose is met by the composed behaviour of our distributed controller system
  – Composition happens internally (S-O) and externally
  – When all pairs of controllers are in High confidence level for all cognition types the control purpose is met 100%
  – In uncertainty Subject's decisions may yield policy conflicts:
    • O+ & A- - false positive (unauthorised use attempt)
    • O- & A+ - false negative (missed opportunity)
  – Sequence of cognition cycles ~ sequence of tests

• Assessment is the evaluation of continuous distributed consensus building
  – Do all S's predictions match all O's predictions?
Cognition Dynamics

Keeping Learning Forgetting

(a) major cognition phases

(b) resource constraints in the cognition dynamics

(c) expected cognition process

\[ R_{UL} \leq \frac{CSR}{2} + M_S SR \]
\[ R_{LK} - R_{UL} \leq \frac{CFR}{2} \]
\[ R_{LU} - R_{UL} \leq \frac{CSR}{2} \]
\[ R_{KL} - R_{LK} \leq \frac{CFR}{2} \]

Corresponds to average (50%) ability of an object
Specific Objectivity Framework

- Georg Rasch, Copenhagen
- A framework for comparison of test outcomes
- Basically, tells what to measure

Outcome = Ability\(\text{Subject|Object}\) \cdot\text{Easiness}_{\text{Test}}
Assessment Process

• Situation generation environment
  – Should be able to generate all target events in arbitrary combinations with arbitrary noise

• Calibration in isolation
  – Evaluate primary metrics of the objective sensing

• Training in isolation
  – Evaluate derivative metrics – this is already an evaluation of distributed controller system

• Training in Ecosystem
  – Future work
Conclusions

• Ecosystem can be fruitful unit of design
  – Tough non-functional challenges (fairness, robustness, service orientation = composition) can be addressed directly
• Extended policy domain can act as a distributed controller system
• Self-assessment and its metrics appear to be independent of particular cognition algorithm
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On model-driven self-engineering of inter-domain traffic

Mikhail Smirnov *
Fraunhofer FOKUS, NET, Kaiserin-Augusta-Allee 31, Berlin 10589, Germany

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Mikhail Smirnov, Jens Tiemann, Klaus Nolte

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