The prospects of self-aware networks

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Advances in communication networks: The perfectly engineered Telecommunications Management Network

Human switch

Advances in communication networks: A perfectly simple Net

Diverse global services

General-purpose transport

Diverse physical transmission media
Advances in communication networks:
The (unsuccessful) re-engineered IP

Diverse global services

Diverse physical transmission media

Advances in communication networks:
The Java syndrome

P2P, IPTV, …anything

Re-engineered IP

TCP/IP

TMN

TCP/IP

QoS, DiffServ, MPLS, …

Diverse physical transmission media

TMN

Human switch

Human switch
Advances in communication networks: Everything in the cloud

Advances in communication networks: Triumph of the Apps and “near”-ubiquitous connectivity
Advances in communication networks: Next ????

Immense diversity of core and access networks

Multi-dimensional evolution

- Any application on any terminal
- Any application in the Cloud
- Communic. is spontaneous, on-demand, erratic and opportunistic
- Real-time services over best-effort Net

Human switch

Triumph of the Apps

Java syndrome

Re-engineered IP

TCP/IP

TMN
Immediate scenarios to deal with

- Massive routing networks (anything can route)
- Ultra-complex contextual combinations (terminals, apps, content, preferences...)
- Huge range of dynamics (anything can change)
- Ubiquity beyond the managed infrastructure

... these translate into unavoidable research riddles ...

1) Heisenberg’s indetermination principle hits the network

How can we monitor these massive, ultra-dynamic networks?

- Passive probes
- Active probes
- Polling
- Event based
... these translate into unavoidable research riddles ...

1) Heisenberg’s indetermination principle hits the network

→ How can we monitor these massive, ultra-dynamic networks?

Passive probes
Active probes
Polling
Event based
SLA Monitoring

"I don’t have a big screen, I’d prefer voice interaction"
... these translate into unavoidable research riddles ...

1) Heisenberg’s indetermination principle hits the network
   ➔ How can we monitor these massive, ultra-dynamic networks?

   Perhaps we shouldn’t try to monitor in the conventional way. Time to look at new monitoring paradigms

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... these translate into unavoidable research riddles ...

1) Heisenberg’s indetermination principle hits the network
   ➔ How can we monitor these massive, ultra-dynamic networks?

   Passive probes
   Active probes
   Polling
   Event based
   SLA Monitoring
   Terminal capabil
   Offline QoE

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TCP/IP

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No Monitoring
2) The possibility of human intervention onto networked system becomes very limited

- How can we translate high-level business goals and orchestration policies onto the network?

Policy-based management is still reflecting the conventional management vision: we need to have solved the monitoring problem first

3) Self-management is probably the only way to go forward

- Can we really expect the network to stabilize and survive?

The relentless clash between overlay and underlay networks

Average upload from UK host: ~60 Kbps
Average download onto UK host: ~600 Kbps
4) The network must make sense of complex context and respond adaptively: autonomic networks and autonomic management

- Will distributed ML and distributed data mining work for autonomic networks?

A cognitive routing system according to FP7 ECODE (Experimental Cognitive Distributed Engine)

Substantial skepticism in the NM community about AI:
How can we know whether the system is doing what is supposed to do? What do we do if things go wrong?

5) The network must learn how to deliver quality of experience (QoE).

- The networks of today cannot even manage QoS
  - QoS processes do not consider the users' perception of services
  - The provision of QoS conditions does not guarantee a satisfied user
  - The outcome of QoS processes is quite often
    - The over-provisioning of network resources
    - A lack of knowledge regarding the user's satisfaction
  - QoS management is predominantly
    - open-loop
    - off-line

QoS researchers might be aiming at the wrong target
Before we see how network might handle QoE, let's see how well humans understand QoE.

Objective measurements show a clear difference between different types of video.

**Original Clips**

- News clip
- Sport clip

**Difference in Temporal Motion**

- News clip: Image of a person
- Sport clip: Image of a soccer field
But if we want to capture a real set of contextual variables (terminal, network, people category, etc) we need subjective tests.

What is the acceptability threshold of these two “degrading” videos?

<table>
<thead>
<tr>
<th>Segment</th>
<th>Time (seconds)</th>
<th>Video Encoding Bitrates (kbps)</th>
<th>Audio Encoding Bitrates (kbps)</th>
<th>Frame Rate (FPS)</th>
<th>Image Size (Pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-5</td>
<td>285</td>
<td>32</td>
<td>20</td>
<td>320×240</td>
</tr>
<tr>
<td>2</td>
<td>6-10</td>
<td>224</td>
<td>32</td>
<td>15</td>
<td>320×240</td>
</tr>
<tr>
<td>3</td>
<td>11-15</td>
<td>128</td>
<td>32</td>
<td>10</td>
<td>320×240</td>
</tr>
<tr>
<td>4</td>
<td>16-20</td>
<td>96</td>
<td>32</td>
<td>10</td>
<td>320×240</td>
</tr>
<tr>
<td>5</td>
<td>21-25</td>
<td>64</td>
<td>32</td>
<td>6</td>
<td>320×240</td>
</tr>
<tr>
<td>6</td>
<td>26-30</td>
<td>32</td>
<td>32</td>
<td>6</td>
<td>320×240</td>
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<tr>
<td>7</td>
<td>31-35</td>
<td>21</td>
<td>32</td>
<td>6</td>
<td>320×240</td>
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<tr>
<td>8</td>
<td>36-40</td>
<td>16</td>
<td>32</td>
<td>6</td>
<td>320×240</td>
</tr>
</tbody>
</table>

- Every five seconds we degrade the video
- We asked people to indicate WHEN the video becomes unacceptably bad
- We repeat for 11 different videos, 3 different terminals to assess the influence of more variables (but in reality there are many more)
What is the acceptability threshold of the following two “degrading” videos? – “News”

What is the acceptability threshold of the following two “degrading” videos? – “Football”
What is the acceptability threshold of the following two “degrading” videos? - results

High tolerance

Low tolerance

One quality → different perceptions

A bit of discriminant Analysis on the subjective responses

<table>
<thead>
<tr>
<th>Content types</th>
<th>Standardized Coefficients for the predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Encoding bitrate</td>
</tr>
<tr>
<td>News</td>
<td>1.430</td>
</tr>
<tr>
<td>Romance movie</td>
<td>1.430</td>
</tr>
<tr>
<td>Cartoon</td>
<td>1.189</td>
</tr>
<tr>
<td>Comedy</td>
<td>1.362</td>
</tr>
<tr>
<td>Music video</td>
<td>0.153</td>
</tr>
<tr>
<td>Action movie</td>
<td>-0.938</td>
</tr>
<tr>
<td>Music concert</td>
<td>-0.924</td>
</tr>
<tr>
<td>Cricket</td>
<td>-0.325</td>
</tr>
<tr>
<td>Football</td>
<td>-0.267</td>
</tr>
</tbody>
</table>

This content is less sensitive to frame rate

This content is more sensitive to frame rate
Tricks of the brain

One quality ➞ different perceptions

Which of the following two videos has better quality?
1) The “pedestrian area” video


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Which of the following two videos has better quality?

2) The “station” video

Both videos are encoded exactly in the same way but the “pedestrian” one is “perceived” as worse

- On average the “pedestrian” video was perceived worse compared to “unimpaired” reference
- But the overlapping Gaussians indicate that many subjects actually had an opposite perception of quality
- It’s all about human perception, but even humans cannot agree

Subjective test on 150 impaired videos show a huge variation of perceived QoE

<table>
<thead>
<tr>
<th>Pedestrian Area</th>
<th>Riverbed</th>
<th>Bush</th>
<th>Tree</th>
<th>Station</th>
<th>Sunflower</th>
<th>Sky</th>
<th>Ships</th>
<th>Mobile and TV</th>
<th>Park run</th>
</tr>
</thead>
</table>

Analysis by V. Menkovski (TU/e) based on data accessible at http://live.ece.utexas.edu/
Prof. Antonio Liotta <a.liotta@tue.nl>

So far we have established that we, the humans, don’t have a good grasp of QoE perception

Perhaps we should look at the QoE-delivery issue from new perspectives

We are not good at judging QoE but if we are given the right level of QoE we can recognize it

Perhaps a machine can learn what a “good” QoE is and how to deliver it

I believe that that machine is “the network”
Networks are in the best position to make clever correlations

- Every terminal / sensor is a network element
- Most nodes are able to sense at least their immediate neighborhood and also their environment (integration with sensors)
- There are tools to gather
  - session-level information
  - terminal-level information
  - user patterns
- Most nodes (except the simplest sensors) are able to run simple ML algorithms

Networks can easily build accurate / self-learning QoS-to-QoE mapping predictions

Accuracy vs. number of introduced datapoints for the OzaBag
HoeffdingOptionNB Adaptive Tree
We want to minimize resource consumption but be sure that QoE is unaffected

Action movie on mobile phone

![Graph showing bandwidth (kbps) vs. time (seconds) for different frame rates and bitrates.]

We want to minimize resource consumption but be sure that QoE is unaffected

News clip on mobile phone

![Graph showing bandwidth (kbps) vs. time (seconds) for different QoE-aware scenarios.]

One day networks will …

• Make sense of what happens around them
• Understand and manage the QoE perceived by the end users
• Adapt to whatever happens without generating instability

and fill the gap between “automatic” and “autonomic” behavior

Good prospect for research jobs

There is still a lot to explore. Autonomic self-awareness requires:
• Means to gather subjective QoE data automatically
• Effective “feature” monitoring techniques
• To understand how to apply distributed ML to networks
• Network “actuators” (formerly QoS mechanisms)
• Evidence about stability, reliability, optimality, …
• Develop high-level management and orchestration tools (manage / influence the autonomies)
• Business and economic models
• Regulatory obligations
• … and much more
The ultimate switch... quite a few decades ago.
The “switching & routing” paradigm has not changed that much

Thank you!

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