Energy Consumption Optimization for Software Defined Networks Considering Dynamic Traffic

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Agenda

• Software Defined Networking
• Energy consumption management
• Proposed approach
• Performance Evaluation
• Conclusion
Current communication Network

• Distributed state: Control and forwarding in same device

• Mass of protocols

• OSI model: elegant abstraction for the data plane - however no foundation for control protocols
Software Defined Networking

- Global network state view
- Controlled by a centralized software

**Controller**

<table>
<thead>
<tr>
<th>MAC SRC</th>
<th>MAC DST</th>
<th>IP DST</th>
<th>TCP DST</th>
<th>...</th>
<th>Action</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>10.20.2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>port 1</td>
<td>387</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>5.6.7.8</td>
<td>x</td>
<td>x</td>
<td>port 2</td>
<td>272</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>25</td>
<td>x</td>
<td>drop</td>
<td>783</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>372</td>
<td>x</td>
<td>controller</td>
<td>480</td>
</tr>
</tbody>
</table>
Advantage of SDN

• Easy QoS improvement
• Less error-prone maintenance
• Enhanced innovation and research
• Easy testing and verification
• ...

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Energy consumption in ICT

- Global network power usage grows 10% each year
- 1.8% of the world's total energy consumption
Energy consumption

How to switch off SDN switches to save energy, while still serving all traffic demands?

- Current power usage
- Traffic routed
- Desired power usage

Time

0:00 4:00 8:00 12:00 16:00 20:00

0 25 50 75 100
Mathematical formulation

Objective function

\[ \min \left\{ \sum_{l=1}^{L} a_l c_{1,l} + \sum_{n=1}^{N} b_n c_{2,n} \right\} \]

Link capacity constraint

\[ \sum_{p=1}^{P} \sum_{r=1}^{R} \delta_{p,r} t_{p,r} \leq a_l \beta_l , \quad \forall l \]

Traffic demand

\[ \sum_{r=1}^{R} t_{p,r} = d_p , \quad \forall p \]

Node-link relationship

\[ w_n a \leq b_n , \quad \forall n \]

Variables:

- \( a_l \)
  - denoting if link \( l \) is on

- \( b_n \)
  - denoting if node \( n \) is on

- \( t_{p,r} \)
  - traffic of node pair \( p \) routed through route \( r \)

Parameters:

- \( c_{1,l} \)
  - power usage of link \( l \)

- \( c_{2,n} \)
  - power usage of switch \( n \)

- \( \delta_{l,p} \)
  - \( 1 \) if link \( l \) belongs to \( r \) of \( p \)

- \( \beta_l \)
  - bandwidth of link \( l \)

- \( d_p \)
  - demand of node pair \( p \)

- \( w_n \)
  - links belonging to node \( n \)
Heuristic algorithm

Start

sort node pair order; \(d=0\)

select one node pair

find the path with lowest additional cost

all pairs served?

Y

End

N

Shortest Path First
Longest Path First
Smallest Demand First
Highest Demand First
Performance Evaluation
Campus Network Scenario

<table>
<thead>
<tr>
<th>Type</th>
<th>Switch e.c. (W)</th>
<th>Line Card e.c. (W)</th>
<th>Bandwidth (Gbit/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>2000</td>
<td>150</td>
<td>400</td>
</tr>
<tr>
<td>Distribution</td>
<td>1000</td>
<td>80</td>
<td>150</td>
</tr>
<tr>
<td>WAN</td>
<td>700</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Access</td>
<td>200</td>
<td>-/-. 5W Port</td>
<td>50</td>
</tr>
</tbody>
</table>

- Traffic demands are randomly generated at low, medium and high level
Results: optimal solution

- At low traffic load, energy consumption can be saved up to 45% compared to “always on” networks
Optimal vs. heuristic solution

![Graph showing energy savings (%)]

- **Optimal solution**
- **Best heuristic solution**

**Y-axis:** Energy savings (%)

**X-axis:** Overall traffic routed

- **Low**
- **Mid**
- **High**

The graph compares the energy savings between the optimal solution and the best heuristic solution across different traffic levels.
Comparison of heuristics

Longest Path First (LPF) is the best heuristic strategy!
Robustness of heuristic algorithm

Campus network scenario
Heuristic solution for Random Mesh Network Scenario

40 homogeneous switches
Average node degree: 4

Longest Path First (LPF) is the best heuristic strategy!
Robustness of heuristic algorithm (2)

Random mesh network scenario
Conclusion

• Energy saving potential in SDN was investigated.
  – Up to more than 40% energy saving at low traffic load
• Four heuristic algorithms to dynamically switch on and off SDN switches to reduce energy consumption was proposed.
• LPF is the best heuristic in terms of energy saving
Thank you for your attention!

Questions?