Good Network Updates for Bad Packets

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Updates happen

- Network updates happen
  - Changing security policies
- Network updates are challenging
  - Even with global view
- Potential high damage if fail
  - Security policy violation
Example
Example
Example

Waypoint Enforcement (WPE)
Example

- Eventual consistency
Example

- Eventual consistency
- Transient consistency?
Example

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✔ Eventual consistency
✗ Transient consistency
Outline

- What could possibly go wrong?
- It's not a trivial thing!
- But we present an optimal solution.
Model and a Trivial Compression

Solid lines = current path
Model and a Trivial Compression

- Solid lines = current path
- Dashed lines = new path
- Flow-specific path

Diagram:

- Nodes labeled as $s_1$, $s_2$, $s_3$, $s_4$
Model and a Trivial Compression

Solid lines = current path
Dashed lines = new path
Flow-specific path
Model and a Trivial Compression

- Solid lines = current path
- Dashed lines = new path
- Flow-specific path

- Safe to be updated
- Safe to be left untouched
Consistency Properties

- WPE = every packet traverses the waypoint at least once
- LF = loop freedom
Update all “simultaneously“?
Update all “simultaneously“?

Not possible in practice!
What could possibly go wrong?
Update all “simultaneously“?

Not possible in practice!

What could possibly go wrong?

Update times can vary significantly
(up to 10x higher than median
[Dionysus – SIGCOMM'14])
Update all “simultaneously“?
Update all “simultaneously“?

- Not waypoint enforced!
Delay $s_1$?
Delay $s_1$?

- Not loop free!
Update possible?
Update possible?
Update possible?
Update possible?

- Consistent transient states!
Rounds

- Round = set of parallel updates
- $R_1 = \{s_2\}, \; R_2 = \{s_3\}, \; R_3 = \{s_1\}$

→ Minimize number of rounds / communication overhead
Greedy Update Fails

• Greedy approach may:
  – take up to $\Omega(n)$ times more rounds
  – fail to find solution
Greedy Update Fails

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  – take up to $\Omega(n)$ times more rounds
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WPE - Update Algorithm

1. Switches $< WP$ (new), $> WP$ (old)
WPE - Update Algorithm

1. Switches < WP (new), > WP (old)
WPE - Update Algorithm

1. Switches $< \text{WP (new)}, > \text{WP (old)}$
WPE - Update Algorithm

1. Switches < WP (new), > WP (old)
2. Switches < WP (new), < WP (old)
WPE - Update Algorithm

1. Switches < WP (new), > WP (old)
2. Switches < WP (new), < WP (old)
WPE - Update Algorithm

1. Switches $< \text{WP (new)}, > \text{WP (old)}$
2. Switches $< \text{WP (new)}, < \text{WP (old)}$
3. Remaining switches
WPE - Update Algorithm

1. Switches < WP (new), > WP (old)
2. Switches < WP (new), < WP (old)
3. Remaining switches

Constant in 3 rounds, but not LF!
LF and WPE Conflict
LF and WPE Conflict

- $s_1, s_2$ violate WPE; $s_3, s_4$ violate LF
Mixed Integer Program

Minimize
Rounds

\[
\begin{align*}
\text{min} & \quad R \\
\text{subject to} & \quad R \geq r \cdot x_v^r, \quad r \in \mathcal{R}, v \in V \quad (1) \\
1 & = \sum_{r \in \mathcal{R}} x_v^r, \quad v \in V \quad (2) \\
y_{u,v}^r & = 1 - \sum_{r' \leq r} x_u^{r'}, \quad r \in \mathcal{R}, (u,v) \in E_{\pi_1} \quad (3) \\
y_{u,v}^r & = \sum_{r' \leq r} x_u^{r'}, \quad r \in \mathcal{R}, (u,v) \in E_{\pi_2} \quad (4) \\
a_s^r & = 1, \quad r \in \mathcal{R} \quad (5) \\
a_v^r & \geq a_u^r + y_{u,v}^{r-1} - 1, \quad r \in \mathcal{R}, (u,v) \in E \quad (6) \\
a_v^r & \geq a_u^r + y_{u,v}^r - 1, \quad r \in \mathcal{R}, (u,v) \in E \quad (7) \\
y_{u,v}^{r-1\forall r} & \geq a_u^r + y_{u,v}^{r-1} - 1, \quad r \in \mathcal{R}, (u,v) \in E \quad (8) \\
y_{u,v}^{r-1\forall r} & \geq a_u^r + y_{u,v}^r - 1, \quad r \in \mathcal{R}, (u,v) \in E \quad (9) \\
y_{u,v}^{r-1\forall r} & \leq \frac{l_v - l_u - 1}{|V| - 1} + 1, \quad r \in \mathcal{R}, (u,v) \in E \quad (10) \\
a_s^r & = 1, \quad r \in \mathcal{R} \quad (11) \\
a_v^r & \geq a_u^r + y_{u,v}^{r-1} - 1, \quad r \in \mathcal{R}, (u,v) \in E_{\text{WP}} \quad (12) \\
a_v^r & \geq a_u^r + y_{u,v}^r - 1, \quad r \in \mathcal{R}, (u,v) \in E_{\text{WP}} \quad (13) \\
a_t^r & = 0, \quad r \in \mathcal{R} \quad (14)
\end{align*}
\]
Mixed Integer Program

- Optimal solution
- Unclassified (stopped 600sec)
- Not solvable (provably)
Solvability Analysis

- % of solvable instances?
- % of failed greedy?
- 1k random permutations per size
- Max duration 600 seconds
Solvability Analysis

- Greedy
- MIP
- Unclear
- No solution

Percentage of solvable instances

Number of switches

5  10  15  20  25  30  35
Solvability Analysis

Percentage of solvable instances

Number of switches

Greedy  MIP  Unclear  No solution
Conclusion

- Transient consistency is not easy to guarantee
- LF and WPE might even conflict
- Greedy can fail to find consistent updates

Dynamic WPE + LF updates are hard to find!