Analysis of Signaling in GMPLS-Based WSONs: Distributed Wavelength Assignment in Bidirectional Lightpath Provisioning

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Outlines

• Introduction
• Requirement for enhancing distributed wavelength assignment (WA) support with signaling
• Performance measures and selected Findings
• Some constraints in consideration
• Candidates of distributed WA approaches
• Numerical results
• Summary
Introduction

- Lightpath services in wavelength switched optical network (WSON)
  - Unidirectional lightpath
  - Bi-directional lightpath
- Current topics in IETF: extensions of GMPLS for better WSON support
- Focus of this talk:
  - Efficient Signaling support for distributed wavelength assignment (WA) in the GMPLS-based control plane of WSON
  - Co-routed bi-directional LSP provisioning support, per RFC 3945, RFC 3473
  - Is the current standard RSVP-TE per RFC 3473 enough?
    - What perspective can be improved further?
    - Any other cost-efficient signaling schemes?
  - Conduct protocol analysis and share the findings
- Out of the scope of this talk (other perspectives)
  - Physical impairment concern
  - 3R concern
  - Wavelength conversion concern
Architectures for Co-Routed **Bi-directional** Lightpath Provisioning

cf) *RFC 6163*

**Architecture Categories:**

1. Combined RWA (R&WA) computation + Signaling
2. Separated RWA (R+WA) computation + Signaling
3. Routing + Signaling-based *distributed* wavelength assignment (**R+DWA**)  

- **Three phases** in **R&WA** and **R+WA** architectures
  - Routing (or NMS) collects the *up-to-date* wavelength availability **information**
  - PCE, or C-SPF performs **RWA** calculation
  - A *simple signaling* performs the *wavelength allocation* which is specified by RWA optimization

**Current standard RSVP-TE is applicable in R&WA, R+WA modes**  
(Single RWA solution: specify **one** wavelength in the *Upstream Label* obj, per *RFC 3471, RFC 3473*)
R&WA and R+WA WSONs Also Needs Robust Distributed WA Support with Signaling

- RSVP-TE only supports single RWA solution specification
- feasible WA solution highly depends on the up-to-date info
- acquiring the up-to-date info leads to the increased information dissemination, resulting in heavy load in control plane

- Restrict the scalability of WSON
- Limit the possibility for dynamic lightpath service in WSON

Needs robust Distributed WA support with Signaling (not highly relying on up-to-date info)

- Already standardized novel DWA mechanisms in RFC 3471, 3473
  - Unidirectional lightpath
    - Label Set obj CAN convey the multiple wavelengths (labels) assignment solutions in the downstream direction (Increasing the possibility of successful lightpath provisioning)
  - Bidirectional lightpath with Upstream Label (UL)?
    - Upstream Label obj conveys only one specified wavelength in the upstream direction
    - Acceptable Label Set conveys the available wavelengths in case the upstream label in the Upstream Label obj is blocked
      - Relies on crank-back (a second time signaling)

Any other possibilities to provide more cost-efficient bidirectional lightpath provisioning?
Performance Measures and Selected Findings’ Highlight

What measures do we use in signaling evaluation?
- **Blocking** performance (efficiency measure)
  - Single lightpath
  - Multiple lightpaths Restoration
    - Number of the successfully re-established lightpaths by signaling (with evenly distributed re-routing)
  - Long-term view of performance potential (future-proof signaling solution)
    - Upgrade WSON with more wavelengths, fibers
- **Protocol cost** (cost measure)
  - Total number of traversed Hops in one set of signaling
  - Accumulated label-processing “times”

**After restoration**
- Significant improvement brought by extensions of the current standard 1st and 2nd time signaling

**After upgrading**
- Current standard’s gain
- Remarkable gain of extensions

High utilization rate $p=0.8$

Current standard's gain

Remarkable gain of extensions

High utilization rate $p=0.8$
Constraint Concerns in Protocol Behavior Analysis

- CI-Incapable
- Co-routed bi-directional lightpath
- Is it necessary to use the same wavelength in both directions?
  - Yes. Either initiator or terminator are the colored edge (with the port/wavelength restriction at edges)
  - No. Both initiator and terminator are the colorless edge

<table>
<thead>
<tr>
<th>Terminator</th>
<th>Colored edge</th>
<th>Colorless edge</th>
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<tbody>
<tr>
<td>Colored edge</td>
<td>Same wavelength use</td>
<td>Same wavelength use</td>
</tr>
<tr>
<td>Colorless edge</td>
<td>Same wavelength use</td>
<td>Different wavelengths use</td>
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Scenarios and corresponding Signaling candidate schemes
- Same wavelength use scenario
  - UL, ULS, TU, LS
- Different wavelengths use scenario
  - UL, ULS, TU
Upstream Label Approach (UL) *RFC 3473* ’s Behavior
- Needs 2nd Time Signaling *(Crank-back)* *(Same Wavelength Use)*

**Blocking situations in UL (1st time signaling)**

**Forward blocking**
A: The specified upstream label has been occupied by other lightpath
B: The specified upstream label is not appeared in final Label Set (cannot use the same wavelength)
C: Initiator receives an empty Acceptable Label Set, indicating that no wavelength is available along this path, resulting in rerouting

**Backward blocking**
D: Upstream label is successfully reserved in the upstream direction, and is in Label Set (available in downstream), however, the label is firstly reserved by other concurrent competitive lightpath request. This label happens to be the last available wavelength. No support in RSVP-TE per RFC 3473 can indicate this situation, resulting in useless crank-back
E: Similar to D, but there still are other available wavelengths
Upstream Label Approach (UL) **RFC 3473**’s Behavior
- Needs 2nd Time Signaling (**Crank-back**) (**Diff Wavelength User**)
Upstream Label Set Approach (ULS)’s Behavior (Same Wavelength Use)


Different blocking situations in 1\textsuperscript{st} time signaling result in different blocking probability in 2\textsuperscript{nd} time signaling

**Blocking situations in ULS (1st time signaling)**

**Forward blocking**

\textbf{A}: There is not any common wavelength in Upstream Label Set and Label Set at terminator. This includes the situation which either Label Set obj is empty during the Path message processing

**Backward blocking**

\textbf{B}: Upstream label (upstream) or label (downstream) is firstly reserved by other concurrent competitive lightpath request. This label happens to be the last available wavelength (a rare case)

\textbf{C}: Similar to \textbf{B}, but there still are other available wavelengths

We can extend ULS by adding a new object to inform the initiator the number of available wavelengths. Initiator can correctly decide if a new route should be employed, in case no wavelength is available.
Upstream Label Set Approach (ULS)’s Behavior (Diff Wavelength Use)


Blocking situations in ULS (1st time signaling)

**Forward blocking**

A: There is not any wavelength in either Upstream Label Set or Label Set

**Backward blocking**

B: Either upstream label (upstream) or label (downstream) is firstly reserved by other concurrent competitive lightpath request. This label happens to be the last available wavelength (a rare case)

C: Both upstream label (upstream) and label (downstream) are blocked by other concurrent competitive lightpath request(s), but there are other available wavelengths left to use

D: One direction is blocked, the other direction is not blocked, but there are other available wavelength to use

We can extend ULS by adding a new object to inform the initiator the number of available wavelengths.

Initiator can correctly decide if a new route should be tried, in case no wavelength is available.
Two **Unidirectional** Lightpaths Approach (TU) ‘s Behavior (One set signaling for two directions)

**Different Implementation Different Performance !!**

Because TU is of the most flexibility in implementation, in principle, in both “Same Wavelength Use” and “Different Wavelength Use” scenarios, TU may reach the same blocking level as that of ULS.
Label Set + LSP_ATTRIBUTES Approach (LS)’s Behavior (Same Wavelength Use Only)

cf) G. Bernstein et al., “draft-ietf-ccamp-wson-signaling-01.txt”

1st time signaling

Different blocking situations in 1st time signaling result in different blocking probability in 2nd time signaling

**Blocking situations in LS (1st time signaling)**

**Forward blocking**

A: There is not any wavelength in Label Set

**Backward blocking**

B: Upstream label (upstream) or label (downstream) is firstly reserved by other concurrent competitive lightpath request. This label happens to be the last available wavelength (a rare case)

C: Similar to B, but there still are other available wavelengths

We can extend LS by adding a new object to inform the initiator the number of available wavelengths. Initiator can correctly decide if a new route should be tried, in case no wavelength is available.
Network Model

For each wavelength $\lambda i$ in one fiber:
- Average utilization rate (the cause of forward blocking): $p$
- Competition rate (the cause of backward blocking): $b$

Exist available disjoined route in case of rerouting

Blocking probability $P$ is the function of $p$, $b$, $H$, $F$, $W$. $P(p, b, H, F, W)$
### Probabilistic Analysis—Blocking Probability (1\textsuperscript{st} Time Signaling)

2\textsuperscript{nd} Time Signaling (crank-back) Analysis is not shown here, due to time limitation. Please refer to Proc.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Approaches</th>
<th>Same Wavelength Use</th>
<th>Different Wavelength Use</th>
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</table>
| 1) UL     | Upstream Label + Acceptable Label Set | \[ P_b(p, H, F, W, b) = \left( 1 - \left( 1 - \left( 1 - p^F \right)^2 \right)^W \right) \cdot \left( 1 - b^F \right)^2 \cdot (1 - \left( 1 - \left( 1 - p^F \right)^H \right)^{-1}) \cdot (1 - b^F)^H \] | \[ P_b(p, H, F, W, b) = 1 - \left( 1 - p^F \cdot (1 - p^F)^{H-1} \cdot (1 - \left( 1 - (1 - p^F)^H \right)^W \cdot (1 - b^F)^H \right) \]
| 2) TU     | Associated two uni-LSPs | \[ P_b(p, H, F, W, b) = \left( 1 - \left( 1 - (1-p^F)^2 \cdot H \right)^W \right) \cdot (1-b^F)^H \] | \[ P_b(p, H, F, W, b) = 1 - \left( 1 - \left( 1 - (1-p^F)^H \right)^W \right)^2 \cdot (1-b^F)^{2 \cdot H} \]
| 3) ULS    | Upstream Label Set + Label Set | \[ P_b(p, H, F, W, b) = \left( 1 - \left( 1 - (1-p^F)^2 \cdot H \right)^W \right) \cdot (1-b^F)^H \] | \[ P_b(p, H, F, W, b) = 1 - \left( 1 - \left( 1 - (1-p^F)^H \right)^W \right)^2 \cdot (1-b^F)^{2 \cdot H} \]
| 4) LS     | Label Set + LSP\_ATTRIBUTES | \[ P_b(p, H, F, W, b) = \left( 1 - \left( 1 - (1-p^F)^2 \cdot H \right)^W \right) \cdot (1-b^F)^H \] | not support |

\[ H \]: number of hops \hspace{1cm} \[ W \]: number of wavelengths \hspace{1cm} \[ F \]: number of fibers \hspace{1cm} \[ p \]: wavelength utilization rate per fiber link \hspace{1cm} \[ b \]: competition rate
Blocking Probabilities after the 1st and 2nd Signaling

(a) Same-wavelength-use

(b) Different-wavelength-use

\(F=1, \ W=64, \ H=4, \ b=0.001\)
The Signaling Caused **Extra Forward Blocking** vs. the Number of Hops in UL (after the 2nd signaling)

(a) Same-wavelength-use

(b) Different-wavelength-use

(F=1, W=64, b=0, p=0.2, 0.4 and 0.6)
Blocking Probability in the Restoration Scenarios

- ULS/LS/TU can successfully recover most of paths, outperforming UL significantly.
- In particular, if recover time needs to be kept short, and reduce the burst control overhead, only 1\textsuperscript{st} time signaling might be preferred.

\begin{itemize}
  \item \textbf{(a) Same-wavelength-use}
  \item \textbf{(b) Different-wavelength-use}
\end{itemize}

\textit{(F=1, W=64, H=4, b=0.001)}
Blocking Probability in the Upgrade Scenarios

- UL cannot effectively take advantage of expended resource (fiber/wavelength)
- Even $p=0.8$, multifiber WSON has the perfect performance (if ULS/LS/TU is employed)

(a) Same-wavelength-use

(b) Different-wavelength-use

($H=4, p=0.8, b=0.001, F=1$ and 6)
Protocol Cost Issue-1: Total Number of Traversed Hops in One Set of Signaling

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<tr>
<th></th>
<th>ULS</th>
<th>LS</th>
<th>TU</th>
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<tbody>
<tr>
<td>Same-wave-use</td>
<td>3H</td>
<td>3H</td>
<td>11H</td>
</tr>
<tr>
<td>Different-wave-use</td>
<td>3H</td>
<td>N/A</td>
<td>9H</td>
</tr>
</tbody>
</table>

Cost of TU is implementation dependent
Protocol Cost Issue-2: Accumulated Label-processing “Times” for ULS and LS (Same Wavelength Use)

\[ 2 \cdot W \cdot \left( 1 - \left( 1 - (1 - p^F)^H \right)^W \right) \cdot \sum_{i=1}^{H} (1 - p^F)^i \]

ULS independently operates two Label Sets

\[ W \cdot \sum_{i=1}^{H} (1 - p^F)^{2 \cdot i} \]

LS operates only one Label Set

\( L_{\text{fore}} \) stands for the labels amount in singling of forwarding direction

\( F=1, W=64, b=0.001, H=4 \) and \( H=8 \)
Major Findings Summary

- Focused on the signaling-based wavelength assignment needs and performance analysis for co-routed bi-directional lightpath provisioning

- **Single RWA solution specification** approach in simple current signaling (RSVP-TE per RFC3471, RFC3473 highly relies on the up-to-date info dissemination (resulting in a heavy load of routing on control plane)
  - Needs robust distributed WA support with signaling even in centralized RWA architectures (relaxing the strict dependency on the up-to-date info and frequent routing)

- Review the questions again. How about the capability of Signaling schemes on Distributed WA?:
  Q: Is the current standard RSVP-TE enough?
  Finding: Upstream Label (UL) approach is of poor performance in terms of distributed WA capability

  Q: Are there any possibilities for service providers to provide more cost efficient lightpath service?
  Finding: Three signaling-based WA approaches are available
  - **Two-Uni** has the highest flexibility but the performance depends on implementation
  - **ULS** extends the idea of Label Set in upstream direction
  - **LS** reuses the Label Set (optimizes signaling in the same-wavelength-use scenario)

  Q: How about the possible gain by employing the extension?
  Finding: The candidate approaches outperform the UL significantly (blocking performance)
  - Especially, in **restoration** scenario and a **long-term** view (in case of future WSON upgrading)
Thank you!