A Shared Segment Protection Approach for Distributed Sub-Tree Based Optical Multicasting Scheme in Elastic Optical Datacenter Networks

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Group Meeting Presentation

Survivable Multicast Provisioning

- Emerging high-bandwidth multicast applications, such as cloud computing, high-definition television (HDTV), etc.
- To serve a multicast request, a light-tree rather than several light-paths is usually established with low cost and energy consumption.
- Protection is important since a failure occurred on a link of a light-tree may lead to traffic interruption for many destination users.
- Failure detection and traffic restoration time is also important.
- In EODNs, the required multicast service can be distributed and maintained in multiple datacenters.

Different Protection Methods

- **Segment-based protection with single light-tree (SP-SLT):** The required multicast service is hosted in a single datacenter, the primary light-tree is divided into several nonoverlapping segments according to multicast splitting nodes and destination nodes, then the disjoint backup segment is calculated.
- **Path-based protection with single light-tree (PP-SLT):** For each path from the source node to the user along a light-tree, a disjoint backup path is calculated.
- **Segment protection for multicast based on distributed light-tree (SP-DLT):** The required multicast service is hosted in multiple datacenters, the users can access it from its nearest datacenter.

Different Protection Methods

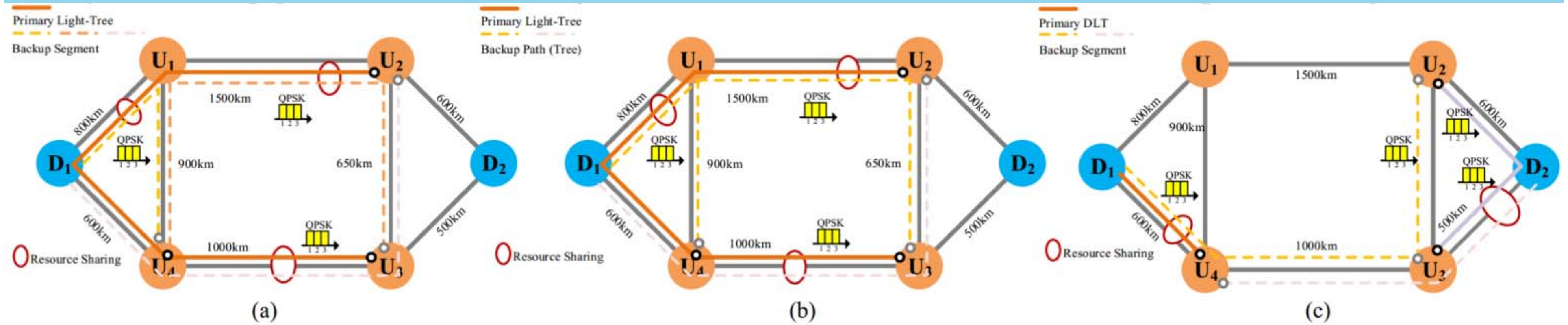

Fig. 1. Protection approaches for multicast request (a) SP-SLT (b) PP-SLT (c) SP-DLT

- The transmission rate of the multicast service requested by users U_2, U_3, and U_4 is 75Gbps.
- Modulation format QPSK is adopted (each spectrum slot (FS) carries 25 Gbps capacity), and hence the number of required FSs is 3.
- The total consumed FS number is 24 in SP-SLT
- The total consumed FS number is 21 in PP-SLT
- The required FSs are 18 in SP-DLT and furthermore, SP-DLT can protect from any datacenter failure.

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ILP Model

Given:

$G=\{V, D, U, E\}$: EODNs, V is the set of optical nodes, D is the set of datacenters, U is the set of user nodes, and E is the set of fiber links.

S: Set of multicast services.

R: Set of multicast requests (MR), $r \in R$, $r=<s_r, F_r, b_r>$ representing multicast service s is transmitted to set of users F_r at a transmission rate of b_r Gbps.

K: The maximum number of light-trees which can be constructed for multicast requests

O: Specified maximum number of backup segments.

Variables:

$t^{r,k}_{u,(i,j)}$ $\{0,1\}$: Link (i,j) is occupied by light-tree k of MR r, which terminates at user u.

$q^{r,k}_{d,u}$ $\{0,1\}$: Light-tree k of MR r originates from datacenter d and terminates at user u.

$p^{r,k}_{(i,j)} \in \{0,1\}$: Light-tree k of MR r traverses link (i,j).

$f^{r,k}, f^{*r,o}$: The starting FS index of light-tree k and backup segment o of MR r respectively.

$h^{r,k}_{r',k'}, h^{*r,o}_{r',o'}$: The starting FS index of light-tree k' (backup segment o') of MR r' is smaller than that of light-tree k (backup segment o) of MR r.

$x^{r,o}_v, y^{r,o}_v$: Node v is the start (end) of segment o of r.

$w^{r,o}_{(i,j)}, w^{*r,o}_{(i,j)}$: Link (i,j) is traversed by the primary (backup) segment of MR r.

$g^{r,k}_{r',k'}, g^{*r,o}_{r',o'}$ $\{0,1\}$: There is any common link traversed by light-tree k (segment o) of r and light-tree k' (segment o') of r' at the same time.

$\gamma^{r,o}_{r',o'}$ $\{0,1\}$: Primary segment o of r and primary segment o' of r' are joint.

Objective Function: minimize(z)

ILP Model

$$\sum_{j:(i,j)\in E} t_{u,(i,j)}^{r,k} - \sum_{j:(j,i)\in E} t_{u,(j,i)}^{r,k} = \begin{cases} -\sum_{d\in D} q_{d,i}^{r,k} & i=u \\ q_{i,u}^{r,k} & i\in D \\ 0 & i\in U, i\neq u \end{cases}, \forall r\in R, k\in[1,K], u\in F_r, i\in V \quad (1)$$

$$\sum_{u\in F_r} t_{u,(i,j)}^{r,k} \geq p_{(i,j)}^{r,k} \geq \sum_{u\in F_r} t_{u,(i,j)}^{r,k} / \Delta, \forall r\in R, k\in[1,K], (i,j)\in E \quad (2)$$

$$\sum_{o\in O} x_v^{r,o}, \sum_{o\in O} y_v^{r,o} \geq \left(\sum_{j:(v,j)\in E} p_{(v,j)}^{r,k} - \sum_{j:(j,v)\in E} p_{(j,v)}^{r,k} \right) / \varphi, \forall r\in R, k\in[1,K], o\in O, v\in (V/F_r) \quad (3)$$

$$x_v^{r,o}, y_v^{r,o} \leq \Delta \left(\sum_{j:(j,v)\in E} p_{(j,v)}^{r,k} - \sum_{j:(v,j)\in E} p_{(v,j)}^{r,k} \right), \forall r\in R, k\in[1,K], o\in O, v\in (U/F_r) \quad (4)$$

$$\sum_{k\in[1,K]} p_{(i,j)}^{r,k} \leq \sum_{o\in O} w_{(i,j)}^{r,o} \leq \Delta \sum_{k\in[1,K]} p_{(i,j)}^{r,k}, \forall r\in R, (i,j)\in E \quad (5)$$

$$\lambda_o^{r,k} \geq w_{(i,j)}^{r,o} + p_{(i,j)}^{r,k}, \forall r\in R, k\in[1,K], o\in O, (i,j)\in E \quad (6)$$

$$\begin{matrix} f^{*r,o} \leq \Delta\left(2 - w_{(i,j)}^{r,o} - p_{(i,j)}^{r,k}\right) + f^{r,k} \\ f^{*r,o} \geq -\Delta\left(2 - w_{(i,j)}^{r,o} - p_{(i,j)}^{r,k}\right) + f^{r,k} \end{matrix}, \forall r\in R, k\in[1,K], o\in O, (i,j)\in E \quad (7)$$

$$\left(f^{r,k} + b_r - f^{r',k'}\right) \leq \varphi\left(h_{r',k'}^{r,k} + 1 - g_{r',k'}^{r,k}\right), \forall r,r'\in R, k,k'\in[1,K] \quad (8)$$

$$\left(f^{*r,o} + b_r - f^{*r',o'}\right) \leq \varphi\left(h_{r',o'}^{*r,o} + 2 - g_{r',o'}^{*r,o} - \gamma_{r',o'}^{r,o}\right), \forall r,r'\in R, o,o'\in O \quad (9)$$

$$w_{(i,j)}^{r,o} + w_{(i,j)}^{*r,o} \leq 1, \forall r\in R, o\in O, (i,j)\in E \quad (10)$$

$$z \geq \left(\Delta\,(p_{(i,j)}^{r,k} - 1) + f^{r,k} + b_r - 1\right), \forall r\in R, k\in[1,K], (i,j)\in E \quad (11)$$

$$z \geq \left(\Delta\,(w_{(i,j)}^{*r,o} - 1) + f^{*r,o} + b_r - 1\right), \forall r\in R, o\in O, (i,j)\in E \quad (12)$$

Eqs. (3) – (6) decide the start and end node of a segment and divide the DLT into several primary segments.

Eqs. (7) – (9) allocate spectrum resource for DLTs and reserve spectrum resource for backup segments, where the spectrum resource can be shared between two backup segments of different multicast requests as long as the corresponding primary segments are disjoint.

Eq. (10) ensures that the primary and backup segments are disjoint

Heuristic Approach

Algorithm 1 SP-DLT Algorithm

Step 1: For each MR r, find out the set of datacenters D hosting the required multicast service s_r. For each user $u \in F_r$, calculate the nearest datacenter $d \in D$, and add the user to the group G_d.

Step 2: For each G_d, calculate the minimum-cost Steiner Tree T_d. Divide T_d into several segments and add them to set PS.

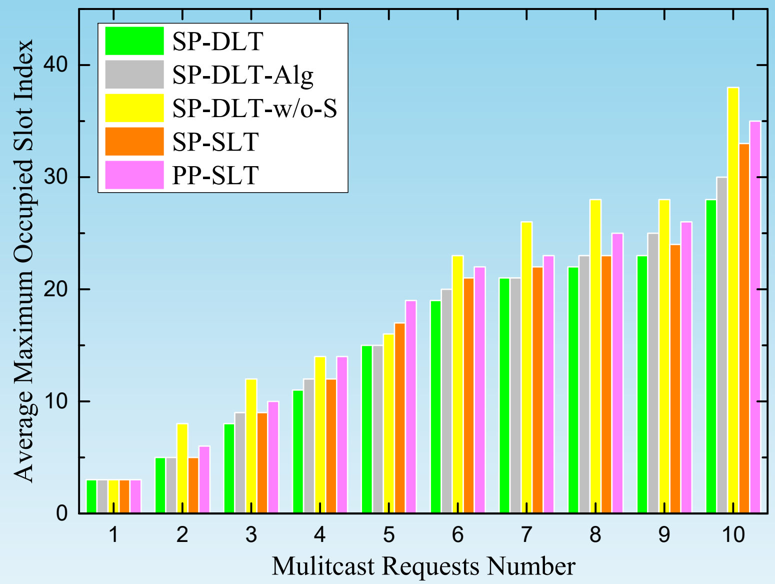
Step 3: For each primary segment $p \in PS$, update link cost $c_{(i,j)}$ as follows: if link (i,j) is used by p, set $c_{(i,j)}$ to infinity; if link (i,j) is used by other backup segments of MR r, set $c_{(i,j)}$ to 0; if link (i,j) is used by other primary segments of MR r, set $c_{(i,j)}$ to a very small value (ε); if others, calculate the cost value according to the spectrum resource reserved for backup segments of other MRs. Calculate the backup segment.

Step 4: For each DLT T_d, determine the modulation format M_d adopted according to the distance from the source node to users. Calculate the number of required FSs with the adopted modulation level M_d.

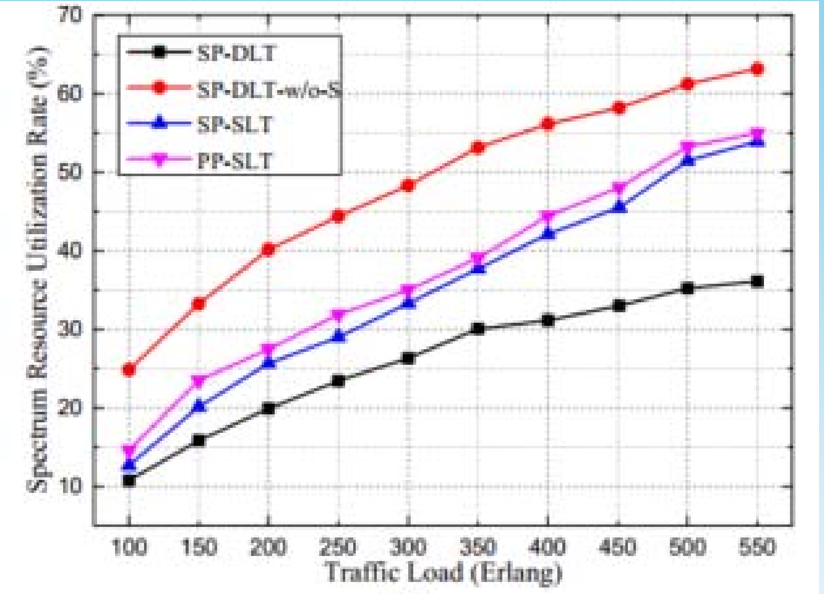
Step 5: Allocate spectrum resource for DLT using the first-fit (FF) algorithm and reserve resource for the backup segments. Meanwhile, spectrum continuity and contiguity constraints are satisfied.

$$c_{(i,j)}^{r,seg} = \begin{cases} +\infty, & \forall (i,j) \in P_{seg}^{r} \\ 0, & \forall (i,j) \in B_{seg'}^{r}, seg \neq seg' \\ \varepsilon, & \forall (i,j) \in P_{seg'}^{r}, seg \neq seg' \\ c_{(i,j)} - \sum_{r \neq r'} \sum_{f \in [1,\Omega]} b_{f,(i,j)}^{r'} / \Omega, & others \end{cases}$$

Numerical Results



(a)

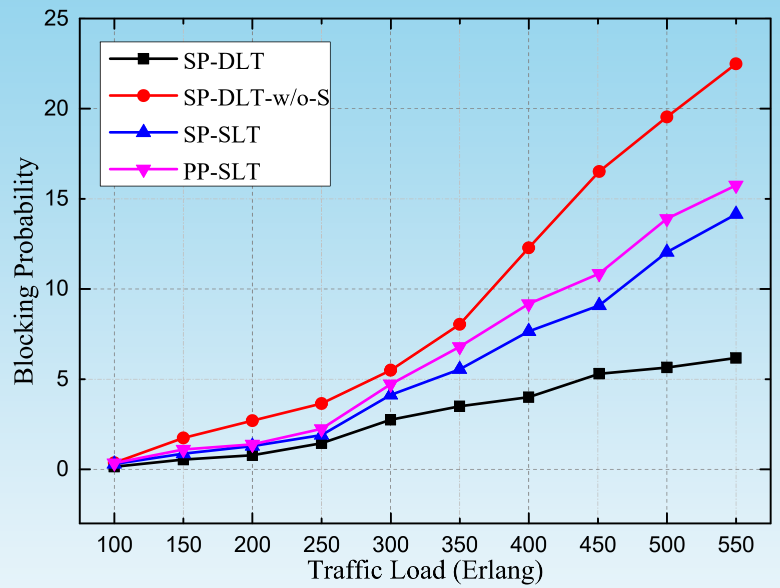


(b)

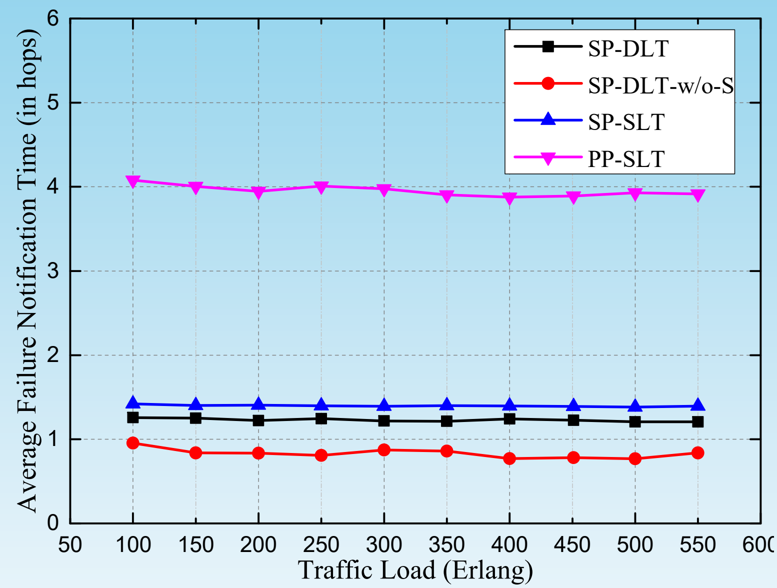
The ILP model and the heuristic approach are conducted on the n6e8 network and the 28-node US Backbone network

- In Fig. (a), compared with conventional SP-SLT scheme and PP-SLT scheme, the SP-DLT scheme can reduce spectrum consumption by over 17.8% and 25% respectively
- In dynamic traffic scenario, SP-DLT reduces as high as 57% and 54 % spectrum consumption compared with PP-SLT and SP-SLT respectively.
- Without cross- and self-sharing, the survivable scheme consumes much more spectrum resource.

Numerical Results



(c)



(d)

- SP-DLT achieves much lower blocking probability (over 77% and 81% respectively) compared with SP-SLT and PP-SLT.
- All the segment-based protection schemes outperform the path-based one in average failure notification time, which benefits from the shorter length of segments.

Aspects to Extend

Disaster model

1. Each link has a different probability to fail. The survivable model must consider that the risk of overall networks.
   - In ILP model, the spectrum resource consumption is minimized with the risk of overall networks under a certain threshold.
   - In heuristic approach, the path calculation is based on the spectrum usage and the failure probability of the link.
2. Shared risk link group (SRLG): denotes the correlated failure, for which the link group shares common physical resources (that is, shares common components that can fail), such as fiber cables and conduits.

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Aspects to Extend

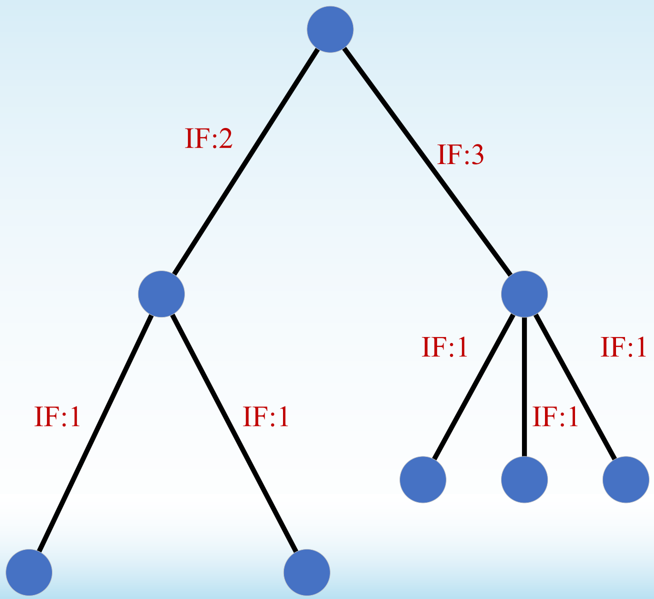
Importance factor and recovery time

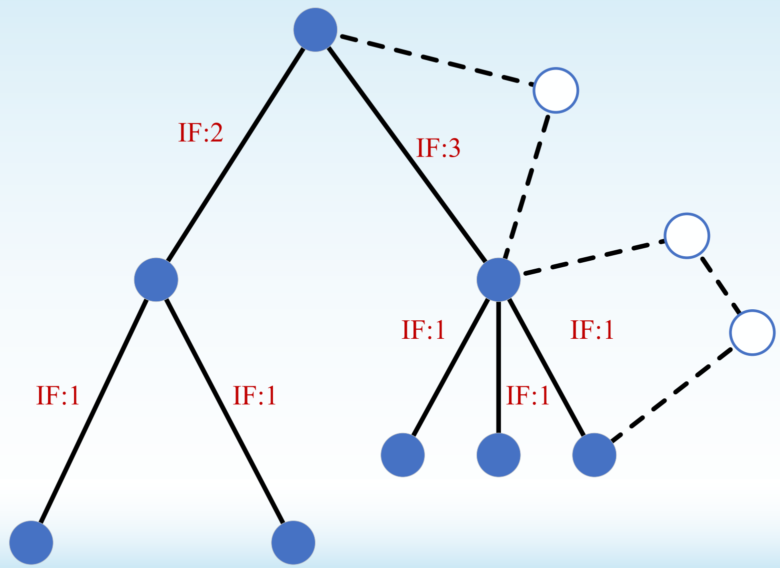
More specifically, recovery time of shared-path protection schemes in general includes the time required for **fault detection, alarm holdoff** (to allow recovery at the low layer and/or to avoid false alarms), **failure notification, detour setup, and traffic rerouting**. Clearly, the first two terms are more or less independent of which protection scheme is used. The third term is usually proportional to the length of the primary path (segment) while the fourth and fifth are normally proportional to the length of the backup path (segment).

Aspects to Extend

Importance factor and recovery time

1. Each link in a light-tree has a different importance factor.
2. For a primary segment with high importance, a shorter backup segments is preferred to be selected. More important segment should be recovered faster under failure.





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Aspects to Extend

User grouping

1. Because the multicast service is hosted in multiple distributed datacenters, it is important to divide the users of a multicast demand into different groups.
2. Each group of users will be served by a distributed sub-light-tree and the sub-light-tree will employ its own modulation level.
3. The group number is limited by the number of available transmitters in an optical node.

Aspects to Extend

User grouping

Algorithm 1 Modulation Level based User Grouping Algorithm

Input: MR r, the shortest path from each datacenter d to each user u in F_r as $p_{d,u}$, maximum number of primary DSLT MP can be constructed

Output: User group UG_r for MR r

1. Find out the set of datacenters D_{s_r} hosting required multicast service s_r;
2. Initialize the set of user group UG_i^d, which will be served by the DSLT using the i_{th} transmitter originated from datacenter d, i.e. $UG_i^d \leftarrow \varnothing$, the modulation level it adopts m_i^d, i.e. $m_i^d = 0$, and the set of user group for MR r (i.e. UG_r), where $UG_r \leftarrow \{UG_i^d \mid d \in D_{s_r}, i \in [1, K]\}$;
3. Sort the users in descending order according to the distance to their nearest datacenter;
4. **for** each user u in F **do**
5. Sort the paths $p_{d,u}$ in increasing order according to the distance and add them to the path set P_u for u;
6. **for** $i = 1$ to MP **do**
7. **for** each path $p_{d,u} \in P_u$ **do**
8. **if** $UG_i^d \neq \varnothing$ and $S_{m,n+1} \geq l_{d,u}$, where $m = m_i^d, n = |UG_i^d|$ **do**
9. $UG_i^d \leftarrow UG_i^d \cup u$, update UG_r, go to **Step 4**;
10. **if** $\Delta_{d,u} < \Delta_{d',u}$ $\|$ $p_{d',u} = \varnothing$, where $p_{d',u} = \{P_u / p_{d,u}\}[1]$ **do**
11. Go to **Step 6**;
12. **end if**
13. **else if** $UG_i^d == \varnothing$ **do**
14. Add u to UG_i^d and set $m_i^d = m$, where $S_{m,1} \geq l_{d,u}$ and $S_{m+1,1} \leq l_{d,u}$, update UG_r, go to **Step 4**;
15. **end if**
16. **end for**
17. **end for**
18. Select the smallest UG_i^d among $\{UG_i^d \mid d \in D_{s_r}, i \in [1, MP]\}$, $UG_i^d \leftarrow UG_i^d \cup u$, and reset m_i^d, update UG_r;
19. **end for**
20. **return** UG_r

$$S_{m,n} = l_m / (\log_{10}(n) + 1)$$

1. For a user of the multicast request, first select the group without modulation level degradation.
2. If failed, create a new group if there are available transmitters.
3. If failed, select the group with minimum modulation level degradation.

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Comments & Suggestions?

Thanks!