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Reliability Evaluation of Highly Reliable Communication Network Configurations — New Topology Strategy, Quad-Loop —

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1. Introduction

Configuration of highly reliable communication networks, such as CCS (Common Channel Signaling) networks, multimedia networks handling security data, and so on, should be evaluated from four aspects: reliability, economy, operation and GoS. Here we deal with the reliability part of the evaluation. In Sec. 2, we define the class of network configurations to be evaluated here. In Sec. 3, we evaluate various configurations in terms of end-to-end unavailability. Analytical expressions of end-to-end unavailability U_{st} are explicitly derived for each configuration. In Sec. 4, we discuss the effect of dependent/simultaneous link failure. In Sec. 5, we evaluate configurations also from the standpoint of survivability. Finally, in Sec. 6 we recommend a quad-loop topology as a regional-level and inter-regional configuration.

2. Network configuration

We focus on a class of two-level networks, where nodes consist of T-nodes (or level-2 nodes) and L-nodes (level-1 nodes). A network is divided into regions and there can be more than one T-node in each region. L-nodes in region j can access only T-nodes of region j. Let h_j be the number of T-nodes in region j. When $h_j = 2$ and all L-nodes in region j are connected (by A-links) to this T-node pair, this intra-regional configuration between the T-nodes and L-nodes is called double homing. How the T-nodes are connected within each region (by C-links) also defines the intra-regional configuration. How the T-nodes in a region and the T-nodes in another region are connected (by B-links) defines the inter-regional configuration. Regarding a set of T-nodes in a region as a super-node and a set of B-links connecting two regions (or super-nodes) as a super-link, how super-nodes are connected by super-links defines the regional-level configuration.

3. End-to-end unavailability evaluation

First, notations are defined.

p_a: A-link unavailability
p_b: B-link unavailability
p_c: C-link unavailability
p: link unavailability when $p_a = p_b = p_c = p$
q_l: L-node unavailability
q_t: T-node unavailability
q: node unavailability when $q_l = q_t = q$
U_{st}: unavailability between L-node s and L-node t

End-to-end unavailability U_{st} will be evaluated for four regional-level configurations, Mesh, Loop, Star and Line. Let the number of regions be k.

First, U_{st} formulae for the case of double-homing A-links ($h_j = 2$ for all j's), quad B-links and no C-links will be evaluated.

U_{st} for Mesh topology is given by Eq. (1).

$$U_{st} = 2q_l + 2p_a^2 + 2q_t^2 + 4p_a q_t (+0) \quad k \geq 3 \qquad (1)$$

Here, the worst case s-t node pair is considered and only 1st and 2nd order terms are shown and 3rd order terms are shown in parentheses. When $p_a = p_b = p_c = p$, Eq.(1) reduces to Eq. (2).

$$U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t (+0), \quad k \geq 3 \qquad (2)$$

The result for the case $p_a = p_b = p_c = p$ is summarized in Table 1.

[Table 1. U_{st} formulae for double-homing A-links, quad B-links and no C-links]

Mesh: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t (+0), k \geq 3$

Star : $U_{st} = 2q_l + 2p^2 + 3q_t^2 + 4pq_t (+4p^3 + 8q_t p^2), k \geq 3$

Line : $U_{st} = 2q_l + 2p^2 + kq_t^2 + 4pq_t (+4p^3 + 4(k-1)q_t p^2), k \geq 1$

Loop: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t (+0), k \geq 3$

Next, U_{st} formulae for the case of double-homing A-links, quad B-links and C-links inserted are evaluated and are listed in Table 2.

[Table 2. U_{st} formulae for double-homing A-links, quad B-links and C-links inserted]

Mesh: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t(+0), k \geq 3$

Star : $U_{st} = 2q_l + 2p^2 + 3q_t^2 + 4pq_t(+8q_t p^2), k \geq 3$

Line : $U_{st} = 2q_l + 2p^2 + kq_t^2 + 4pq_t(+4(k-1)q_t p^2), k \geq 1$

Loop: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t(+0), k \geq 3$

Similarly, U_{st} formulae for other cases, such as cases with triple-homing A-links, partially-homing A-links, double B-links, partially-furnished B-links, and specific C-link topologies ($h_j > 2$) can be explicitly evaluated.

4. End-to-end unavailability evaluation under dependent failure

For each B-link quad, it is assumed in this section that there can be two patterns of simultaneous B-link failure as shown in Fig. 1. In pattern I, link 1 and link 4 fail simultaneously, i.e., failure of one link triggers failure of the other. In pattern II, it is link 2 and link 3 that fail simultaneously. This B-link failure pattern is a direct consequence of satisfying the B-link diversity requirement that at least three physically diverse link sets be provided for a B-link quad.

Tables 3 and 4 list U_{st} formulae considering this class of dependent B-link failure without C-links and with C-links, respectively.

[Table 3 U_{st} formulae for double-homing A-links, quad B-links of dependent failure and no C-links]

Mesh: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t(+0), k \geq 3$

Star : $U_{st} = 2q_l + 2p^2 + 3q_t^2 + 4pq_t(+6p^3 + 8q_t p^2), k \geq 3$

Line : $U_{st} = 2q_l + 2p^2 + kq_t^2 + 4pq_t \begin{pmatrix} +4p^3 + (k-1)p^3 \\ +4(k-1)q_t p^2 \end{pmatrix}, k \geq 1$

Loop: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t(+0), k \geq 3$

[Table 4 U_{st} formulae for double-homing A-links, quad B-links of dependent failure and C-links inserted]

Mesh: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t(+0), k \geq 3$

Star : $U_{st} = 2q_l + 2p^2 + 3q_t^2 + 4pq_t(+2p^3 + 8q_t p^2), k \geq 3$

Line : $U_{st} = 2q_l + 2p^2 + kq_t^2 + 4pq_t \begin{pmatrix} +(k-1)p^3 \\ +4(k-1)q_t p^2 \end{pmatrix}, k \geq 1$

Loop: $U_{st} = 2q_l + 2p^2 + 2q_t^2 + 4pq_t(+0), k \geq 3$

Comparing the sixteen U_{st} formulae in Tables 1 through 4, we reach the following conclusions under the condition of sufficiently small p- and q-values, such as $p \leq 10^{-4}$ and q_t, $q_l \leq 10^{-5}$:

(i) Estimated U_{st} values are approximately the same for the 16 cases.

(ii) The first term $2q_l$ is dominant.

(iii) End-to-end availability is little improved by inserting C-links.

(iv) Effect of dependent B-link failure is negligible as long as B-link diversity requirement is met.

5. Survivability evaluation

The reliability criterion "survivability" is defined as the capability that a whole network remains connected in the case all the T-nodes in a region failed. Mesh and Loop topologies satisfy the survivability criterion, while Star and Line topologies do not. Therefore, it is concluded that Mesh and Loop topologies are recommended from the viewpoints of end-to-end availability and survivability against the breakdown of a regional T-node group.

6. Conclusion

We have derived explicit approximate formulae for end-to-end unavailability U_{st} for various configurations, considering the cases of independent and dependent link failures. In terms of reliability, we recommend Mesh and Loop topologies as a regional-level configuration. Taking other criteria such as economy [1], operation flexibility, and end-to-end time delay GoS into consideration, we recommend use of Loop topology with quad B-links, as a regional-level and inter-regional configuration, or Quad-Loop. Since the loop belongs to a class of the regular graph, proposed quad-loop strategy can be generalized into **regularity** strategy [2].

References

[1] R. Matsumura, M. Inoue and M. Shinohara: Cost evaluation of telecommunications network from the viewpoint of its topology and modularity, B-7-65, p186, Fall Society Conference of IEICE, Japan (1998.9).

[2]M. Shinohara, M. Miyauchi and H. Yamamoto : Estimating teletraffic loads and designing network configurations for ITS services, MDMC98, pp.318-324(1998.9).

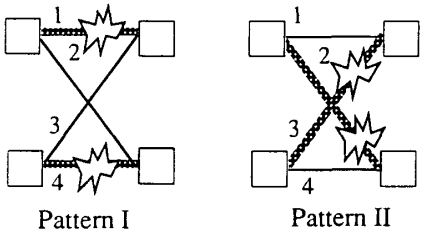

Fig. 1 Exclusive patterns of dependent/ simultaneous B-link failure in a B-link quad.