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13. ABSTRACT (Maximum 200 words)

The goal of our research is to develop practical models and efficient algorithms to analyze the reliability/availability/maintainability of complex systems in which component failures are statistically dependent and each component is subject to degradations before complete failure. The Cause-Based Multimode Model (CBMM) was developed. Practical and computationally tractable solution methods were designed. In addition, an ordered enumeration approach was developed to solve the network survivability enhancement problem. Preliminary computational experiments showed that this approach is very efficient.

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BASIC RESEARCH IN RELIABILITY FOR REAL SYSTEMS

Final Technical Report
Report Period 8/1/88 - 7/31/90
Grant No. AFOSR 88-0259

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Summary

The goal of our research is to develop practical models and efficient algorithms to analyze the reliability/availability/maintainability of complex systems in which component failures are statistically dependent and each component is subject to degradations before complete failure. The Cause-Based Multimode Model (CBMM) was developed. Practical and computationally tractable solution methods were designed. In addition, an ordered enumeration approach was developed to solve the network survivability enhancement problem. Preliminary computational experiments showed that this approach is very efficient.

Research Objectives

Our research program focuses on complex systems in which failures are statistically dependent and each component is subject to degradations before complete failure. The goal is to develop practical models and efficient algorithms to analyze the reliability/availability/maintainability and to define optimal design, management and maintenance strategies.

Accomplishments and Progress

In the previous research period, the Event-Based Reliability Model (EBRM) was developed for the reliability modeling and analysis of real systems in which component failures are statistically dependent. Most existing reliability models assume that system component failures are statistically independent. This assumption, though it greatly simplifies the problem, is often not valid, and the result is usually an overestimation of network reliability. Some researchers have tried to model dependent failures by conditional probabilities with limited success. The major problem is that an exponentially large number of parameters have to be dealt with. The EBRM does not make use of conditional probabilities, but tries to model explicitly the events that cause component failures. Major advantages of EBRM over the traditional use of conditional probabilities include a reduction in the number of parameters to be handled and a physically more meaningful set of parameters. We have shown that the EBRM can be used to represent exactly the same kind of statistical dependencies between component failures as described by any given set of conditional probabilities. This means that the EBRM is a completely general model which can be applied to any kind of failure dependencies.

We have also developed a model to approximate the reliability of systems with multimode components. Previous research on reliability has been focused on models which assume that each component may be in one of two modes, namely, operative or failed. In real life, a component may undergo degradations in performance before a complete outage, and will therefore operate in more than two modes. Since it has been proved that the exact calculation of system reliability (even for two-mode models) is an NP-complete problem, we have developed an approximation method to calculate this reliability measure. This method requires us to work with the states of the system in order of decreasing probability. An algorithm ORDER-M has been developed to generate these states in the proper order.

In this research period, we have developed the Cause-based Multimode Model (CBMM), which allows one to consider failure dependencies of components which are subject to degradations. The model is very flexible and general and has physically meaningful parameters. Practical methods to approximate and bound network reliability and performance measures have been developed, based on a state enumeration approach. The methods are very efficient when components are reliable – which is the case in most real systems – because only a small fraction of the total number of states need be considered to achieve a very good approximation.

In the framework of the CBMM, we have developed a new algorithm to enumerate the states of systems having dependent failures and degraded components, which requires less computing time and memory space. We have also developed a path-based approach to efficiently approximate reliability of systems having a path structure. A system has a path structure if we can identify subsystems called paths such that the system is working if and only if there is at least one working subsystem. This assumption is usually applicable, since most real systems exhibit a path structure. Tests on representative examples have shown that the path-based approach can reduce the processing time by orders of magnitude. The Cause-based Multimode Model and the solution methods are detailed in publications #2, #3, #4 and #5.

An important issue in the management of a communication network is the enhancement of an existing network. We focus on survivability enhancement. Network survivability is usually expressed in terms of edge (node) connectivity, i.e. the minimum number of edges (nodes) that must be removed in order to disrupt network operation. In real world communication networks, this measure is inappropriate, because components may not have the same probability of failure, and failures may be correlated. A more appropriate measure is the probability that the network survives, i.e. keeps on operating successfully in the presence of failures.

Therefore, we formulate the problem as: given an existing network, with failprone links, find a minimum-cost set of links to be added so that the probability of survival is at least a specified value.

Solving this problem requires to check that the solution satisfies the survivability constraint, which is NP-hard. Our method is a combination of ordered enumeration and heuristics. The ordered enumeration (OE) generates the possible enhancements in order of increasing cost, and for each generated enhancement, tests whether the resulting network satisfies the survivability constraint. The first satisfactory enhancement encountered is the cost-optimal solution. If the OE cannot find an optimal solution within a predetermined time, then the heuristic is used to find a good solution within a reasonable computation time. The heuristic first finds a feasible solution, i.e. an enhancement that satisfies the survivability constraint. The cost is then optimized by performing a cost ordered enumeration of all the enhancements which are subsets of the feasible solution. The first satisfactory enhancement found is the solution.

Since the number of enhancements grows exponentially with the number of candidate links, and since the set of candidate links for the cost ordered enumeration of the heuristic is much smaller than the candidate set for OE, the heuristic requires much less time than OE, especially for larger networks.

Tests on randomly generated networks show that:

1. The heuristic finds a good solution within a reasonable computation time for networks of practical size (about one hour on the average for a 30 node network).

2. The heuristic finds an optimal solution in a large majority of cases (typically more than 80% of the time).

3. For small enhancements, the OE always finds the optimum within a reasonable time, even for relatively large networks (a few hours on the average for a 40 node network).

One of the advantages of the method is that, unlike most heuristic methods, one can assess the quality of the solution, since the OE always gives a lower bound of the optimal cost. The method developed here can also be used to enhance the survivability of transportation or flow networks. Details can be found in publication #1.

Research Personnel

Principal Investigator - Victor O. K. Li
Graduate Research Assistant - Khiem Le

Ph.D. Thesis completed

1. Le, K.V., "Reliability issues in communication networks with dependent failures and multimode components," Ph.D. Thesis, Department of Electrical Engineering, USC, August 1990.

Publications

1. Le, K. V. and Li, V. O. K. , "Network survivability enhancement and analysis," submitted for publication, 1990.

2. Le, K.V. and Li, V.O.K., "Efficient enumeration of most probable states for systems with dependent failures and multimode components." *Proc. IEEE GLOBECOM*, San Diego, CA, December 1990, pp. 693–697.

3. Le, K.V. and Li, V.O.K., "A Path-based approach for analyzing Reliability of Systems with Dependent Failures and Multimode Components." *Proc. IEEE INFOCOM*, San Francisco, CA, June 1990, pp. 495–503.

4. Le, K.V. and Li, V.O.K., "Modeling and analysis of systems with multimode components and dependent failures." *IEEE Trans. on Reliability*, Vol. 38, No. 1, April 1989, pp. 68–75.

5. Le, K.V. and Li, V.O.K., "Modeling and analysis of systems with multimode components and dependent failures," *Proc. IEEE INFOCOM*, Ottawa, Ontario, Canada, April 1989, pp. 972–980.

6. Choudhury, A.K. and Li, V.O.K., "A new reliability measure for computer networks," *Proc. IEEE TENCON*, Bombay, India, November 1989, pp. 293–297.