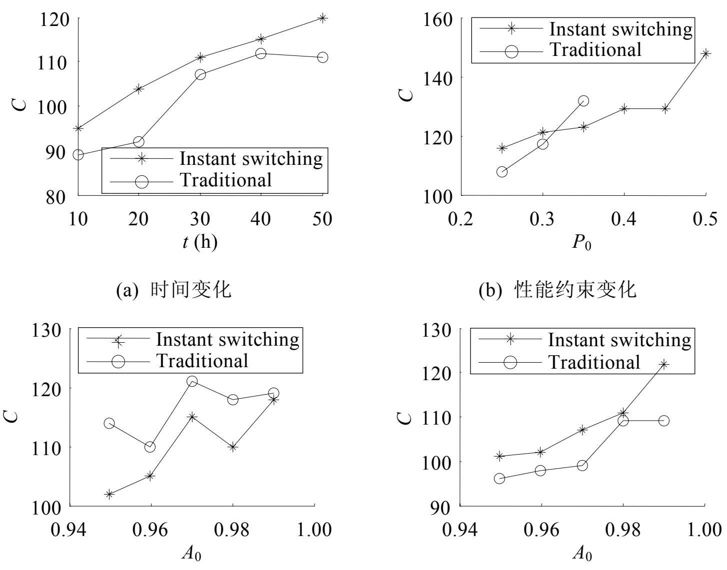
在本实验中,所获得的最优冗余配置代价为 112,相应的每个子系统的冗余度见表 3.表 3 中也给出了采用传统混合冗余策略的每个子系统冗余度值,采用该策略,所有冗余度配置代价为 106.

Table 3 Allocation result for two types of mixed redundancy strategy

表 3 两种混合冗余策略的冗余分配结果

组件编号	支持实时替换的混合冗余策略		传统混合冗余策略	
	n_{Ai}	n_{Si}	n_{Ai}	n_{Si}
1	3	2	2	2
2	2	3	4	1
3	2	2	2	1
4	2	2	3	1
5	2	2	3	1
6	2	3	3	2
7	2	3	3	2
8	2	4	4	2

在下面的实验中,对系统时间 t 和系统约束进行了变化,分别计算两种策略相应的冗余分配结果.由于遗传算法是一种随机搜索算法,每次实验可能生成不同的近似最优解,所以对每次实验分别执行了 5 次算法,将 5 次算法中计算的最优解作为最终解.首先在性能约束=0.3,可靠性约束=0.99 的前提下,将系统时间 t 从 10 小时增加到 50 小时,相应的冗余分配结果如图 11(a)所示.该图的横坐标为时间变化的趋势,纵坐标为系统总体代价 C_{sys}(图中简写为 C)的变化.然后设定系统时间为 50 小时,可靠性约束为 0.99,将性能约束从 0.25 变化至 0.5,每种配置策略相应的冗余度配置代价如图 11(b)所示.图中的横坐标为性能约束值 P_0 的变化.之后,将性能约束分别设定为 0.25 及 0.3,系统时间为 50 小时,在可靠性约束从 0.95 到 0.99 变化的过程中,相应的冗余配置代价分别如图 11(c)和图 11(d)所示.上述两图的横坐标均为可靠性约束值 A_0 的变化,纵坐标与前图相同.



(a) 时间变化 (b) 性能约束变化

(c) 可靠性约束变化(P_0=0.25) (d) 可靠性约束变化(P_0=0.30)

Fig.11 Change of redundancy cost of two mixed redundancy strategies with the change of constraints and time t

图 11 随着时间 t 以及系统约束值的变化,两种混合冗余配置策略相应的冗余度配置代价变化

图 11 中的结果表明,当系统性能约束相对较低(<0.3)时,传统策略配置所消耗的冗余代价比支持实时替换的新策略消耗的代价少,但是,随着性能约束值的增加,传统策略所消耗的代价将超过本文中的新策略.当性能约束值超过 0.35 时,传统的冗余配置策略已经难以获得最优冗余度从而达到系统约束要求,而支持实时替换的

新策略能够获得最优的冗余度配置.

5 结论及展望

虽然现有研究已对系统中的多种冗余配置策略以及相应的混合配置策略进行了讨论,但它们基本假设只有当所有积极冗余组件失效时才启用冷备份冗余组件.但是,在需要长时间持续运行的软件系统,如云计算系统中,对系统持续运行时间和任务响应速度的需求增加使得对系统可靠性及性能保障同等重要.在此类系统中,采用基于监控替换的机制,一旦监测到积极冗余组件出错,备份组件将马上被启用,否则系统性能将受到一定的影响.针对性能与可靠性同等重要的系统,考虑采用支持组件实时替换机制的混合冗余策略,提出了针对新混合冗余配置策略的冗余度分配模型.基于马尔可夫链理论首先构建了子系统状态迁移图,并用于系统分析,采用了实时可用性评估系统可靠性,采用任务完成效率评估系统性能,通过数值计算方法对上述指标进行计算.在此基础上建立了冗余度分配模型以便在系统可靠性及性能约束的条件下对系统冗余度代价进行最小化.由于该分配模型不是传统的具有闭合形式的非线性优化模型,所以采用遗传算法对该模型进行求解,并使用实例系统对求解过程进行说明.实验结果表明:采用新型混合冗余配置策略的系统评估指标值与采用传统混合策略的系统有较大的不同,所以即使在相同的约束条件下,针对不同类型的系统也需要配置不同的冗余度.在相同的实验条件下,当系统性能约束较高时,无法通过冗余度的优化配置使传统的混合冗余配置策略达到系统约束要求,但是采用新型的混合策略,能够通过冗余度的优化满足系统需求.

本文对支持实时替换的混合冗余配置策略中的冗余度优化分配进行了初步研究,但该研究的模型基于较多假设条件构建,例如假设子系统中的每个组件无故障工作时间均满足指数分布.假设条件可能影响模型对实际运行系统真实状态的描述,所以,在未来的研究中将对系统运行环境进行更通用的假设,并进一步改进系统评估模型.同时,也需要在遗传算法中增加自定义的局部搜索算子以提高算法搜索效率.

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