本文提出的多反馈机制(包括主反馈与局部反馈)算法实现简单、高效,主反馈是以底层网络主动休眠链路数量 *RSLink* 反馈给后续的虚拟网络映射,局部反馈是以当前虚拟网络映射结果进行反馈,能够保证在线虚拟网络映射实时性要求.本文所提算法具有良好的适应性,*NodeEmbed*(*index*)和 *LinkEmbed*(*index*)可采用当前多种典型的虚拟网络映射算法,能够应用在不同物理环境和网络拓扑上.本文所提算法具有较好的扩展性,可进一步扩展到虚拟机的在线迁移与部署,可根据需求动态增加节点与资源分配等.本文所提算法具有较强的实用性,能够有效地测量与管控底层网络资源状态,支持基础设施服务提供商与网络服务运营商角色的分离等,为绿色节能新型数据中心的构建提供直接的技术指导.在实际虚拟化网络创新环境平台以及大数据处理中验证算法的实用性与节能效果是我们下一步重点研究的方向.

本文提出的多反馈控制仿真模型和算法与实际物理环境具有一定的差异,例如对于 10Mbps、100Mbps、1Gbps 的端口,能耗与激活的端口数量线性相关[50],这与本文建立的模型一致,但是能耗与端口当前的配置有关,例如从 1Gbps 到 100Mbps、100Mbps 到 10Mpbs,能耗是不同的[50],本文统一端口的能耗,并未考虑其差异性;当激活或关闭链路和节点时,将引起节点和链路状态的切换,这会产生能量消耗.例如一个具有 48 个端口的交换机,当流量为 0 时,端口状态切换将引起不同配置下分别消耗了 21W、33W、43W 的能耗[17],本文考虑了切换的能耗代价,但未考虑端口的不同配置;当底层网络激活资源运行容量接近需求流量时,将会引起丢包或者延迟等现象[17]的发生;当发生单点故障时,应考虑虚拟网络的在线迁移;节点能耗与类型有关,例如核心节点能耗为 10kW、骨干节点能耗为 3kW、城域网节点能耗为 1kW、接入节点能耗为 2kW 等[51],底层网络链路的能耗与链路长度相关,每 70km 需要增加一个信号再生器[51]等等,本文给出的模型并未考虑节点类型与长度等.这些实际运行环境的特点使得仿真结果与实际运行过程存在差异,降低能耗将对容错性、系统性能等产生一定的影响.下一步,我们将对实际环境进行评估,重点研究本文所提算法在云数据中心的实际能耗以及在降低能耗情况下对容错性能与传输性能的影响.

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陈晓华(1977－),男,江西九江人,讲师,主要研究领域为下一代互联网,云计算.

李春芝(1982－),女,博士,讲师,主要研究领域为最优化方法,图像处理.

陈良育(1980－),男,博士,副教授,主要研究领域为并行计算,符号计算.

曾振柄(1963－),男,博士,教授,博士生导师,主要研究领域为数学机械化,组合优化,人工智能.

蒋云良(1967－),男,博士,教授,CCF 高级会员,主要研究领域为人工智能,信息融合,数据挖掘.