高效的方法.

由于 D{0-1}KP 的提出时间较晚,利用 EAs 对其求解研究相对较少,因此,如何利用 DE,ABC,ACO 和 HSA 等算法有效求解 D{0-1}KP 问题,将会成为今后的一个研究热点.

5.3 MMKP问题

MMKP[11,12]是由 MCKP 与 MDKP 组合而成的一个 KP 问题,它的一般描述为:给定 n 个项集的集合 $J=\{J_1, J_2,\ldots,J_n\}$和 m 个载重分别为 $C_1,C_2,\ldots,C_m$ 的背包,其中,$J_p\cap J_q=\varnothing,1\leqslant p\neq q\leqslant n$,每个项 $j\in J_i$ 具有一个价值 p_{ij} 和 m 个重量 $w_{ij1},w_{ij2},\ldots,w_{ijm}$,其中,$w_{ijk}$ 是项 $j\in J_i$ 被装入载重为 C_k 的背包时的重量,并且 p_{ij},w_{ijk} 和 C_k 均为正整数,$1\leqslant i\leqslant n$, $j\in J_i$ 且 $1\leqslant |J_i|=r_i,1\leqslant k\leqslant m$.如何从每个项集中恰好选择一个项装入所有的背包中,在使得装入每个背包中项的重量之和均不超重的前提下,所有背包中项的价值之和达到最大?MMKP 的数学模型为

$$\text{Max} f(Y)=\text{Max}\sum_{i=1}^{n}\sum_{j=1}^{r_i} y_{ij}p_{ij} \tag{25}$$

$$\text{s.t. } \sum_{i=1}^{n}\sum_{j=1}^{r_i} w_{ijk}y_{ij}\leqslant C_k,\ k=1,2,...,m \tag{26}$$

$$\sum\nolimits_{j=1}^{r_i} y_{ij}=1,\ i=1,2,...,n \tag{27}$$

$$y_{ij}\in\{0,1\},\ i=1,2,\ldots,n,\ j=1,2,\ldots,r_i \tag{28}$$

其中,$y_{ij}=0$ 表示项 $j\in J_i$ 未装入任何背包中,$y_{ij}=1$ 表示项 $j\in J_i$ 被装入了所有背包中.MMKP 的 Benchmark 请参考文献[12].

为了利用 ACO 求解 MMKP,文献[12]将最大-最小蚁群系统(max-min ant system)与拉格朗日松弛法(Lagrangian relaxation,简称 LR)相结合,利用 LR 获得各项的值作为 ACO 的启发式因子,利用修复法处理不可行解,给出了求解 MMKP 的一种有效方法.计算结果表明,它比已有算法 HMMKP,CCFT,RLS 和 MRLS 的求解效果更优.文献[91]提出了一种求解 MMKP 的多群体遗传算法(multi-population genetic algorithm,简称 MPGA), MPGA 用两个种群执行进化搜索,用一个种群进行归档以平衡算法在可行空间和不可行空间之间的搜索偏差,具有较好的求解效果.

MCKP 与 MDKP 的难解性决定了 MMKP 的求解困难性,因此,基于 EAs 的已有求解方法对于复杂的大规模 MMKP 实例的求解性能有待进一步提高.显然,如何利用 EAs 高效求解 MMKP,是一个有待于今后进一步深入研究的问题.

5.4 MOKP问题

MOKP[1,92]是 KP 问题中的一个多目标优化问题,其一般描述为:给定 n 个项和 m 个载重分别为 $C_1,C_2,\ldots,C_m$ 的背包,项 j 相对于背包 i 的价值为 p_{ij},重量为 w_{ij},$1\leqslant j\leqslant n$ 且 $1\leqslant i\leqslant m$.求 0-1 向量 $Y=[y_1,y_2,...,y_n]\in\{0,1\}^n$,在满足 m 个约束不等式:

$$\sum\nolimits_{j=1}^{n} w_{ij}y_j\leqslant C_i,\ i=1,2,...,m \tag{29}$$

的前提下,使得 $f(Y)=[g_1(Y),g_2(Y),\ldots,g_m(Y)]$最大.其中,

$$g_i(Y)=\sum\nolimits_{j=1}^{n} p_{ij}y_j,\ i=1,2,...,m \tag{30}$$

文献[92]提出了求解 MOKP 的一种混合评估分布算法(hybrid estimation of distribution algorithm,简称 MOHEDA),给出了一种基于加权和的局部搜索方法,并利用随机修复法处理不可行解.Lu 和 Yu[93]提出了一种自适应种群多目标量子演化算法(adaptive population multi-objective quantum-inspired evolutionary algorithm,简称 APMQEA)以求解 MOKP,其个体表示为量子比特,并分成若干个子群求解不同的目标函数.计算表明:APMQEA 求得的结果非常接近 Pareto 最优前沿,而且非支配集有一个良好的分布.文献[94]基于量子人工免疫算法(QAIS)和人工免疫系统(BAIS)提出了一个新的量子人工免疫系统(MOQAIS),可有效求解 MOKP 问题.文献[95]提出了求解 MOKP 的一种基于指标的蚁群算法(indicator-based ant colony optimization,简称 IBACO),

在 IBACO 中,使用二元质量指标(binary quality indicator)指导蚂蚁进行搜索来提高算法的求解性能.

由于 MOKP 的多目标和多约束条件限制,导致它的求解难度较大.目前,用于求解 MOKP 的 EAs 仅限于以上几种算法,今后还有待进一步探讨利用更多 EAs 有效求解 MOKP 的方法.

6 总结与展望

EAs 以其极强的全局寻优能力和极好的通用性,在求解 KP 问题的研究中越来越受到人们的重视.从已有的研究结果来看,利用 EAs 求解 0-1 KP,MDKP 和 QKP 的研究相对比较成熟,人们基于不同的 EAs 提出了求解这 3 个问题的许多高效方法.但是,利用 EAs 求解其他 KP 问题还存在许多不足:一方面,利用 EAs 求解这些问题的研究较少,很多性能优越的 EAs 还未被用于求解这些问题,如求解 MKP,RTVKP,MOKP,MMKP,QMKP 和 D{0-1}KP 等问题的 EAs 还仅限于少数几个,而 PCKP,SUKP,MmKP 和 OLKP 等问题甚至还未见利用 EAs 的求解研究报道;另一方面,在利用 EAs 求解 KP 时,表示问题潜在解或可行解的方法还仅限于 0-1 向量编码和自然数编码等经典方法,新的更适宜的编码方法还有待研究.此外,处理不可行解的方法与技术相对比较单调,缺乏与已有先进技术相结合的新的研究成果.

综合以上分析,下面给出利用 EAs 求解 KP 时有待解决的若干问题与研究思路.

(1) 利用 EAs 求解 PCKP,SUKP,MmKP 和 OLKP 等典型 KP 的有效算法的设计问题;

(2) 由于 EAs 是一类随机近似算法,在利用它们求解 KP 时,算法近似性能的估算问题有待解决.对此,是利用经典近似算法中的近似性能(即近似比)进行估算?还是给出一种新的度量方法?值得深入研究;

(3) 利用 EAs 求解 KP 时,潜在解或可行解的表示方法问题.例如,利用二进制数、自然数以及其他符号进行混合编码是否可行?利用量子比特矩阵编码是否可行?

(4) 能否基于机器学习、复杂网络、量子纠缠以及并行计算等方法设计比现有 EAs 更适于求解 KP 的高效进化算子?这既是关乎 KP 高效求解的一个关键问题,更是 EAs 算法设计中的一个核心问题;

(5) 能否利用松弛技术、原对偶技术、代理技术、次梯度方法和 Bundle 方法等给出处理 KP 不可行解的更为高效的方法?

(6) 对于还未利用 EAs 求解的 KP,构造具有一定难度的大规模实例,为比较求解它的各 EAs 优劣提供通用的 Benchmark 实例;

(7) 利用新提出的 EAs(例如果蝇优化(fruit fly optimization)[96]、头脑风暴优化(brain storm optimization)[97]等)求解 KP 问题的研究.

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