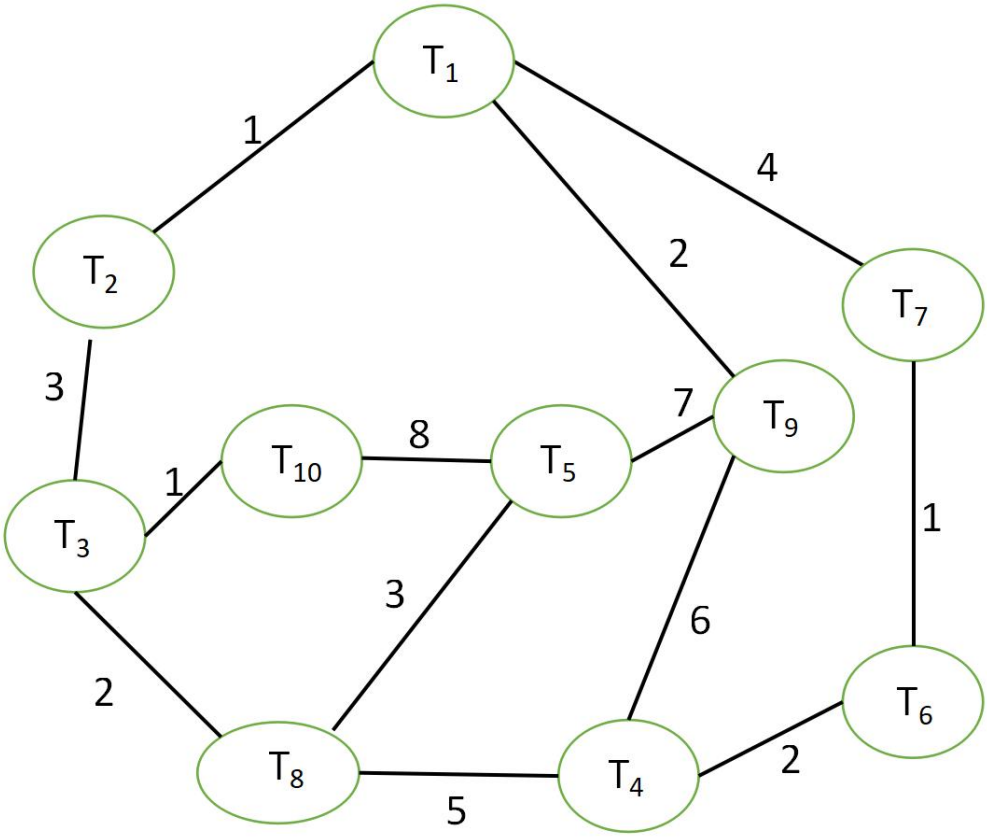
1 实验目的

- 编程实现多模块化划分算法MMM（单链接、全链接、均链接），输入是通信代价、模块数、每个模块最大任务数，输出为划分好的模块，并给出划分代价

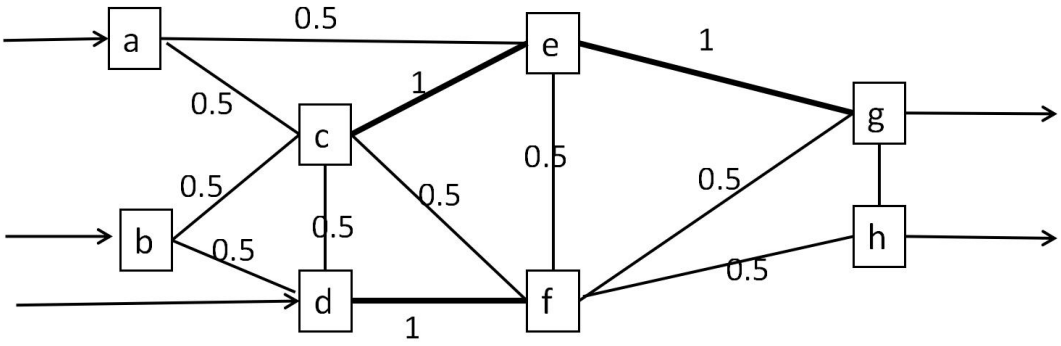
1.1 任务1

- 使用实现的程序将下图的10个任务划分成4个模块，每个块内任务个数不超过3



1.2 任务2

- 使用实现的程序将下图中的8个任务a，b，c，d，f，g，h分成2个模块，每个模块含有4个任务，使得模块间通信代价最小，任务间通信代价见下表



Cxy	a	b	C	d	e	f	g	h
a	0	0	0.5	0	0.5	0	0	0
b	0	0	0.5	0.5	0	0	0	0
c	0.5	0.5	0	0.5	1	0.5	0	0
d	0	0.5	0.5	0	0	1	0	0
e	0.5	0	1	0	0	0.5	1	0
f	0	0	0.5	1	0.5	0	0.5	0.5
g	0	0	0	0	1	0.5	0	0.5
h	0	0	0	0	0	0.5	0.5	0

2 算法设计

- 针对单链接、全链接、均链接实现对应的多模块化划分算法

2.1 单链接

```
#include <iostream>
#include <vector>
#include <map>
#include <algorithm>
using namespace std;

int n;
map<string,double> mp;
vector<vector<string>> v;
typedef struct cluster{
    double weight;
    int k;
    vector<vector<string>> v;
}Cluster;
vector<Cluster> ans_v;

// 读输入数据，建立关系
double read_data(){
    int edge;
    double weight,max_weight=0;
    string task_i,task_j;
    for(int i = 0;i < n;i++){
        vector<string> temp;
        cin >> task_i >> edge;
        temp.push_back(task_i);
        v.push_back(temp);  // {{"T1"},{"T2"},...}
        for(int j = 0;j < edge;j++){
            cin >> task_j >> weight;
            if(weight > max_weight)
                max_weight = weight;
            mp[task_i+task_j] = weight;
        }
    }
    return max_weight;
}

// 单链接核心部分
double MuSSA(vector<string> v1,vector<string>v2){
    double larc = 0;
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            if(mp[v1[i]+v2[j]] > larc)
                larc = mp[v1[i]+v2[j]];
        }
    }
    return larc;
}
```

```
// 公共部分，遍历逻辑
void MM(int model_num,int max_task_num,int max_weight,double cost){
    double weight = max_weight + 1;
    int k = v.size();
    Cluster temp;
    temp.weight = weight;
    temp.k = v.size();
    temp.v = v;
    ans_v.push_back(temp);
    weight = weight-1;
    while(weight != 0 && k != model_num){
        bool back = false;
        vector<vector<string>> v_temp;
        for(int i = 0;i < v.size();i++){
            v_temp.push_back(v[i]);
        }
        v.clear();
        for(int i = 0;i < v_temp.size();i++){
            for(int j = i+1;j < v_temp.size();j++){
                double larc = MuSSA(v_temp[i],v_temp[j]);
                if(larc >= weight && v_temp[i].size() + v_temp[j].size() <=
max_task_num){
                    vector<string> merge_v,tmp_1,tmp_2;
                    for(int k = 0;k < v_temp[i].size();k++){
                        tmp_1.push_back(v_temp[i][k]);
                    }
                    for(int k = 0;k < v_temp[j].size();k++){
                        tmp_2.push_back(v_temp[j][k]);
                    }

 merge_v.insert(merge_v.end(),v_temp[i].begin(),v_temp[i].end());

 merge_v.insert(merge_v.end(),v_temp[j].begin(),v_temp[j].end());
                    v.push_back(merge_v);

 v_temp.erase(remove(v_temp.begin(),v_temp.end(),tmp_1),v_temp.end());

 v_temp.erase(remove(v_temp.begin(),v_temp.end(),tmp_2),v_temp.end());
                    for(int k = 0;k < v_temp.size();k++){
                        v.push_back(v_temp[k]);
                    }
                    back = true;
                    break;
                }
            }
            if(back)
                break;
        }
        if(back)
            continue;
        for(int i = 0;i < v_temp.size();i++){
            v.push_back(v_temp[i]);
        }
        temp.weight = weight;
        temp.k = v.size();
```

```
            temp.v = v;
            ans_v.push_back(temp);
            k = v.size();
            weight -= cost;
        }

    }

    // 展示划分结果
    void show_ans(){
        for(int i = 0;i < ans_v.size();i++){
            cout << ans_v[i].weight << " " << ans_v[i].k << " \t{" ;
            for(int j = 0;j < ans_v[i].v.size();j++){
                cout << "{" << ans_v[i].v[j][0];
                for(int k = 1;k < ans_v[i].v[j].size();k++){
                    cout << " " <<  ans_v[i].v[j][k];
                }
                cout << "}";
            }
            cout << "}" << endl;
        }
    }

    double cal(vector<string> v1,vector<string>v2){
        double larc = 0;
        for(int i = 0;i < v1.size();i++){
            for(int j = 0;j < v2.size();j++){
                if(mp[v1[i]+v2[j]] > 0)
                    larc += mp[v1[i]+v2[j]];
            }
        }
        return larc;
    }

    // 计算通信代价
    void cal_cost(){
        double all_cost;
        int dst = ans_v.size() - 1;
        for(int i = 0;i < ans_v[dst].v.size();i++){
            for(int j = i+1;j < ans_v[dst].v.size();j++){
                all_cost += cal(ans_v[dst].v[i],ans_v[dst].v[j]);
            }
        }
        cout << "all cost: " << all_cost << endl;
    }

    int main() {
        int model_num,max_task_num;
        double max_weight,cost;
        cin >> n >> model_num >> max_task_num >> cost;
        max_weight = read_data();
        MM(model_num,max_task_num,max_weight,cost);
        show_ans();
        cal_cost();
        return 0;
```

```
}
```

2.2 全链接

- ```
#include <iostream>
#include <vector>
#include <map>
#include <algorithm>
using namespace std;

int n;
map<string,double> mp;
vector<vector<string>> v;
typedef struct cluster{
    double weight;
    int k;
    vector<vector<string>> v;
}Cluster;
vector<Cluster> ans_v;

// 读输入数据，建立关系
double read_data(){
    int edge;
    double weight,max_weight=0;
    string task_i,task_j;
    for(int i = 0;i < n;i++){
        vector<string> temp;
        cin >> task_i >> edge;
        temp.push_back(task_i);
        v.push_back(temp); // {{"T1"},{"T2"},...}
        for(int j = 0;j < edge;j++){
            cin >> task_j >> weight;
            if(weight > max_weight)
                max_weight = weight;
            mp[task_i+task_j] = weight;
        }
    }
    return max_weight;
}

// 单链接核心部分
double MuSAA(vector<string> v1,vector<string>v2){
    double larc = 0;
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            if(mp[v1[i]+v2[j]] > larc)
                larc = mp[v1[i]+v2[j]];
        }
    }
    return larc;
}

// 全链接核心部分
double MuCAA(vector<string> v1,vector<string>v2){
    double larc = 999;
```
```

```
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            if(mp[v1[i]+v2[j]] < larc)
                larc = mp[v1[i]+v2[j]];
        }
    }
    return larc;
}

// 公共部分，遍历逻辑
void MM(int model_num,int max_task_num,int max_weight,double cost, double
(*pfun)(vector<string>,vector<string>)){
    double weight = max_weight + 1;
    int k = v.size();
    Cluster temp;
    temp.weight = weight;
    temp.k = v.size();
    temp.v = v;
    ans_v.push_back(temp);
    weight = weight-1;
    while(weight != 0 && k != model_num){
        bool back = false;
        vector<vector<string>> v_temp;
        for(int i = 0;i < v.size();i++){
            v_temp.push_back(v[i]);
        }
        v.clear();
        for(int i = 0;i < v_temp.size();i++){
            for(int j = i+1;j < v_temp.size();j++){
                double larc = pfun(v_temp[i],v_temp[j]);
                if(larc >= weight && v_temp[i].size() + v_temp[j].size() <=
max_task_num){
                    vector<string> merge_v,tmp_1,tmp_2;
                    for(int k = 0;k < v_temp[i].size();k++){
                        tmp_1.push_back(v_temp[i][k]);
                    }
                    for(int k = 0;k < v_temp[j].size();k++){
                        tmp_2.push_back(v_temp[j][k]);
                    }

 merge_v.insert(merge_v.end(),v_temp[i].begin(),v_temp[i].end());

 merge_v.insert(merge_v.end(),v_temp[j].begin(),v_temp[j].end());
                    v.push_back(merge_v);

 v_temp.erase(remove(v_temp.begin(),v_temp.end(),tmp_1),v_temp.end());

 v_temp.erase(remove(v_temp.begin(),v_temp.end(),tmp_2),v_temp.end());
                    for(int k = 0;k < v_temp.size();k++){
                        v.push_back(v_temp[k]);
                    }
                    back = true;
                    break;
                }
            }
```

```
            if(back)
                break;
        }
        if(back)
            continue;
        for(int i = 0;i < v_temp.size();i++){
            v.push_back(v_temp[i]);
        }
        temp.weight = weight;
        temp.k = v.size();
        temp.v = v;
        ans_v.push_back(temp);
        k = v.size();
        weight -= cost;
    }
    if(weight == 0 && k > model_num){
        MM(model_num,max_task_num,max_weight,cost,MuSAA);
    }
}

// 展示划分结果
void show_ans(){
    for(int i = 0;i < ans_v.size();i++){
        cout << ans_v[i].weight << " " << ans_v[i].k << " \t{" ;
        for(int j = 0;j < ans_v[i].v.size();j++){
            cout << "{" << ans_v[i].v[j][0];
            for(int k = 1;k < ans_v[i].v[j].size();k++){
                cout << " " <<  ans_v[i].v[j][k];
            }
            cout << "}";
        }
        cout << "}" << endl;
    }
}

double cal(vector<string> v1,vector<string>v2){
    double larc = 0;
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            if(mp[v1[i]+v2[j]] > 0)
                larc += mp[v1[i]+v2[j]];
        }
    }
    return larc;
}

// 计算通信代价
void cal_cost(){
    double all_cost;
    int dst = ans_v.size() - 1;
    for(int i = 0;i < ans_v[dst].v.size();i++){
        for(int j = i+1;j < ans_v[dst].v.size();j++){
            all_cost += cal(ans_v[dst].v[i],ans_v[dst].v[j]);
        }
    }
```

```
    cout << "all cost: " << all_cost << endl;
}

int main() {
    int model_num,max_task_num;
    double max_weight,cost;
    cin >> n >> model_num >> max_task_num >> cost;
    max_weight = read_data();
    MM(model_num,max_task_num,max_weight,cost,MuCAA);
    show_ans();
    cal_cost();
    return 0;
}
```

2.3 均链接

- ```
#include <iostream>
#include <vector>
#include <map>
#include <algorithm>
using namespace std;

int n;
map<string,double> mp;
vector<vector<string>> v;
typedef struct cluster{
    double weight;
    int k;
    vector<vector<string>> v;
}Cluster;
vector<Cluster> ans_v;

// 读输入数据，建立关系
double read_data(){
    int edge;
    double weight,max_weight=0;
    string task_i,task_j;
    for(int i = 0;i < n;i++){
        vector<string> temp;
        cin >> task_i >> edge;
        temp.push_back(task_i);
        v.push_back(temp); // {{"T1"},{"T2"},...}
        for(int j = 0;j < edge;j++){
            cin >> task_j >> weight;
            if(weight > max_weight)
                max_weight = weight;
            mp[task_i+task_j] = weight;
        }
    }
    return max_weight;
}

// 单链接核心部分
double MuSAA(vector<string> v1,vector<string>v2){
    double larc = 0;
```
```

```
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            if(mp[v1[i]+v2[j]] > larc)
                larc = mp[v1[i]+v2[j]];
        }
    }
    return larc;
}

// 全链接核心部分
double MuCAA(vector<string> v1,vector<string>v2){
    double larc = 999;
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            if(mp[v1[i]+v2[j]] < larc)
                larc = mp[v1[i]+v2[j]];
        }
    }
    return larc;
}

// 均链接核心部分
double MuAAA(vector<string> v1,vector<string>v2){
    double larc,all_larc = 0;
    int count = 0;
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            all_larc += mp[v1[i]+v2[j]];
            count++;
        }
    }
    larc = all_larc/count;
    return larc;
}

// 公共部分，遍历逻辑
void MM(int model_num,int max_task_num,int max_weight,double cost, double
(*pfun)(vector<string>,vector<string>)){
    double weight = max_weight + 1;
    int k = v.size();
    Cluster temp;
    temp.weight = weight;
    temp.k = v.size();
    temp.v = v;
    ans_v.push_back(temp);
    weight = weight-1;
    while(weight != 0 && k != model_num){
        bool back = false;
        vector<vector<string>> v_temp;
        for(int i = 0;i < v.size();i++){
            v_temp.push_back(v[i]);
        }
        v.clear();
        for(int i = 0;i < v_temp.size();i++){
            for(int j = i+1;j < v_temp.size();j++){
```

```
                double larc = pfun(v_temp[i],v_temp[j]);
                if(larc >= weight && v_temp[i].size() + v_temp[j].size() <=
max_task_num){
                    vector<string> merge_v,tmp_1,tmp_2;
                    for(int k = 0;k < v_temp[i].size();k++){
                        tmp_1.push_back(v_temp[i][k]);
                    }
                    for(int k = 0;k < v_temp[j].size();k++){
                        tmp_2.push_back(v_temp[j][k]);
                    }

 merge_v.insert(merge_v.end(),v_temp[i].begin(),v_temp[i].end());

 merge_v.insert(merge_v.end(),v_temp[j].begin(),v_temp[j].end());
                    v.push_back(merge_v);

 v_temp.erase(remove(v_temp.begin(),v_temp.end(),tmp_1),v_temp.end());

 v_temp.erase(remove(v_temp.begin(),v_temp.end(),tmp_2),v_temp.end());
                    for(int k = 0;k < v_temp.size();k++){
                        v.push_back(v_temp[k]);
                    }
                    back = true;
                    break;
                }
            }
            if(back)
                break;
        }
        if(back)
            continue;
        for(int i = 0;i < v_temp.size();i++){
            v.push_back(v_temp[i]);
        }
        temp.weight = weight;
        temp.k = v.size();
        temp.v = v;
        ans_v.push_back(temp);
        k = v.size();
        weight -= cost;
    }
    if(weight == 0 && k > model_num){
        MM(model_num,max_task_num,max_weight,cost,MuSAA);
    }
}

// 展示划分结果
void show_ans(){
    for(int i = 0;i < ans_v.size();i++){
        cout << ans_v[i].weight << " " << ans_v[i].k << " \t{" ;
        for(int j = 0;j < ans_v[i].v.size();j++){
            cout << "{" << ans_v[i].v[j][0];
            for(int k = 1;k < ans_v[i].v[j].size();k++){
                cout << " " <<  ans_v[i].v[j][k];
            }
```

```
            cout << "}";
        }
        cout << "}" << endl;
    }
}

double cal(vector<string> v1,vector<string>v2){
    double larc = 0;
    for(int i = 0;i < v1.size();i++){
        for(int j = 0;j < v2.size();j++){
            if(mp[v1[i]+v2[j]] > 0)
                larc += mp[v1[i]+v2[j]];
        }
    }
    return larc;
}

// 计算通信代价
void cal_cost(){
    double all_cost;
    int dst = ans_v.size() - 1;
    for(int i = 0;i < ans_v[dst].v.size();i++){
        for(int j = i+1;j < ans_v[dst].v.size();j++){
            all_cost += cal(ans_v[dst].v[i],ans_v[dst].v[j]);
        }
    }
    cout << "all cost: " << all_cost << endl;
}

int main() {
    int model_num,max_task_num;
    double max_weight,cost;
    cin >> n >> model_num >> max_task_num >> cost;
    max_weight = read_data();
    MM(model_num,max_task_num,max_weight,cost,MuAAA);
    show_ans();
    cal_cost();
    return 0;
}
```

3 实验过程

- 定义数据输入格式
- 执行算法
- 获得结果

3.1 数据输入格式

- ```
  n model_num max_task_num cost   n：任务数；model_num：模块数；max_task_num：模块内最大任务数 cost：阈值下降速率
  loop n:
      Ti k                 Ti：任务i；k：k条边
      loop k:
          Tj q             Tj：与任务i存在关系的任务j；q：两个任务边的权值
  ```

3.1.1 表征任务1输入

- ```
  10 4 3 1
  T1 3
  T2 1
  T7 4
  T9 2
  T2 2
  T1 1
  T3 3
  T3 3
  T2 3
  T8 2
  T10 1
  T4 3
  T6 2
  T8 5
  T9 6
  T5 3
  T8 3
  T9 7
  T10 8
  T6 2
  T4 2
  T7 1
  T7 2
  T1 4
  T6 1
  T8 3
  T3 2
  T5 3
  T4 5
  T9 3
  T4 6
  T5 7
  T1 2
  T10 2
  T3 1
  ```

```
T5 8
```

3.1.2 表征任务2输入

- ```
  8 2 4 0.5
  a 2
  e 0.5
  c 0.5
  b 2
  c 0.5
  d 0.5
  c 5
  a 0.5
  b 0.5
  d 0.5
  f 0.5
  e 1
  d 3
  b 0.5
  c 0.5
  f 1
  e 4
  a 0.5
  c 1
  f 0.5
  g 1
  f 5
  d 1
  c 0.5
  e 0.5
  g 0.5
  h 0.5
  g 3
  e 1
  f 0.5
  h 0.5
  h 2
  f 0.5
  g 0.5
  ```

3.2 实验结果

3.2.1 任务1

- 单链接划分结果及代价
  ```

```
9 10    {{T1}{T2}{T3}{T4}{T5}{T6}{T7}{T8}{T9}{T10}}
8 9     {{T5 T10}{T1}{T2}{T3}{T4}{T6}{T7}{T8}{T9}}
7 8     {{T5 T10 T9}{T1}{T2}{T3}{T4}{T6}{T7}{T8}}
6 8     {{T5 T10 T9}{T1}{T2}{T3}{T4}{T6}{T7}{T8}}
5 7     {{T4 T8}{T5 T10 T9}{T1}{T2}{T3}{T6}{T7}}
4 6     {{T1 T7}{T4 T8}{T5 T10 T9}{T2}{T3}{T6}}
3 5     {{T2 T3}{T1 T7}{T4 T8}{T5 T10 T9}{T6}}
2 4     {{T4 T8 T6}{T2 T3}{T1 T7}{T5 T10 T9}}
all cost: 16
```

- 全链接划分结果及代价

```
9 10    {{T1}{T2}{T3}{T4}{T5}{T6}{T7}{T8}{T9}{T10}}
8 9     {{T5 T10}{T1}{T2}{T3}{T4}{T6}{T7}{T8}{T9}}
7 9     {{T5 T10}{T1}{T2}{T3}{T4}{T6}{T7}{T8}{T9}}
6 8     {{T4 T9}{T5 T10}{T1}{T2}{T3}{T6}{T7}{T8}}
5 8     {{T4 T9}{T5 T10}{T1}{T2}{T3}{T6}{T7}{T8}}
4 7     {{T1 T7}{T4 T9}{T5 T10}{T2}{T3}{T6}{T8}}
3 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
2 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
1 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
9 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
8 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
7 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
6 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
5 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
4 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
3 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
2 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
1 4     {{T1 T7 T6}{T4 T9 T8}{T2 T3}{T5 T10}}
all cost: 18
```

- 均链接划分结果及代价

```
9 10    {{T1}{T2}{T3}{T4}{T5}{T6}{T7}{T8}{T9}{T10}}
8 9     {{T5 T10}{T1}{T2}{T3}{T4}{T6}{T7}{T8}{T9}}
7 9     {{T5 T10}{T1}{T2}{T3}{T4}{T6}{T7}{T8}{T9}}
6 8     {{T4 T9}{T5 T10}{T1}{T2}{T3}{T6}{T7}{T8}}
5 8     {{T4 T9}{T5 T10}{T1}{T2}{T3}{T6}{T7}{T8}}
4 7     {{T1 T7}{T4 T9}{T5 T10}{T2}{T3}{T6}{T8}}
3 6     {{T2 T3}{T1 T7}{T4 T9}{T5 T10}{T6}{T8}}
2 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
1 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
9 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
8 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
7 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
6 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
5 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
4 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
3 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
2 5     {{T4 T9 T8}{T2 T3}{T1 T7}{T5 T10}{T6}}
1 4     {{T1 T7 T6}{T4 T9 T8}{T2 T3}{T5 T10}}
all cost: 18
```

3.2.2 任务2

- 单链接划分结果及代价

```
2 8     {{a}{b}{c}{d}{e}{f}{g}{h}}
1 5     {{d f}{c e g}{a}{b}{h}}
0.5 2   {{c e g a}{d f b h}}
all cost: 3
```

- 全链接划分结果及代价

```
2 8     {{a}{b}{c}{d}{e}{f}{g}{h}}
1 6     {{d f}{c e}{a}{b}{g}{h}}
0.5 4   {{g h}{c e a}{d f}{b}}
2 4     {{g h}{c e a}{d f}{b}}
1 4     {{g h}{c e a}{d f}{b}}
0.5 2   {{c e a b}{g h d f}}
all cost: 3
```

- 均链接划分结果及代价

```
2 8     {{a}{b}{c}{d}{e}{f}{g}{h}}
1 6     {{d f}{c e}{a}{b}{g}{h}}
0.5 4   {{g h}{c e a}{d f}{b}}
2 4     {{g h}{c e a}{d f}{b}}
1 4     {{g h}{c e a}{d f}{b}}
0.5 2   {{c e a b}{g h d f}}
all cost: 3
```

4 实验结论

- 从实验结果看，单链接相较于全链接和均链接有更少的通信代价开销
- 对于任务1，虽然均链接和全链接的最终划分结果和划分代价一致，但是，可以从划分情况看到，实际上，划分过程是不一致的，但是由于均链接和全链接均无法完成独立完成整个划分过程，最终仍然需要落实到单链接的方式，导致最终划分结果一致
- 对于两个模型的多模块划分结果，可以看到单链接总是能独立完成，而均链接和全链接至少在此任务中无法实现独立划分，增大了开销，降低了效率