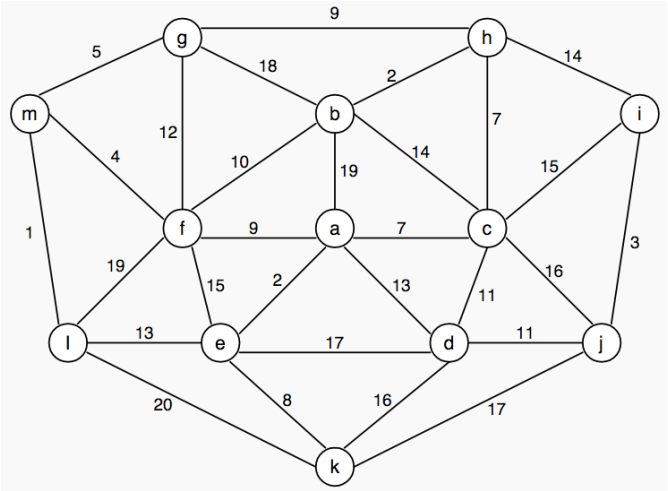
Telecommunication network

Consider the network in the figure, where each node represents a terminal/router, and each edge represents a bidirectional link. For each link, the bandwidth in Mbps is indicated.



1. Given a linear programming formulation for the problem of finding the maximum quantity of data that can be sent, per second, from node c to node f.
2. Give a formulation for the multi-commodity version of the problem where we are to maximize the sum of the flow between the pairs of nodes $\{b, d\}$, $\{d, e\}$, and $\{e, b\}$?

AMPL model sketch (file `network.mod`)

```
# SETS

set V;
set E within {V,V};
set A within {V,V} :=
   E union setof{(i,j) in E} (j,i);

# PARAMS

param s symbolic in V;
param t symbolic in V;
param k{(i,j) in A} >= 0, default if (j,i) in E then k[j,i];
```

For each edge $\{i, j\} \in E$, the set A contains the arc (i, j) and the arc (j, i).

Data (file `network.dat`), optimal value: 62

```
data;

set V := a b c d e f g h i j k l m;

param s := c;
param t := f;

param: E: k :=
        a b 19
        a c 7
        a d 13
        a e 2
        a f 9
        b c 14
        b f 10
        b g 18
        b h 2
        c d 11
        c h 7
        c i 15
        c j 16
        d e 17
        d j 11
        d k 16
        e f 15
        e k 8
        e l 13
        f g 12
        f l 19
        f m 4
        g h 9
        g m 5
        h i 14
        i j 3
        j k 17
        k l 20
        l m 1
;
```

Scheme for the AMPL model of the variant (file `network-2.mod`)

```
# SETS

set V;
set E within {V,V};
set A within {V,V} :=
   E union setof{(i,j) in E} (j,i);
set D;

# PARAMS

param s{D} symbolic in V;
param t{D} symbolic in V;
param k{(i,j) in A} >= 0, default if (j,i) in E then k[j,i];
```

AMPL data file for the variant (file `network-2.dat`), optimal value: 106

```
data;

set V := a b c d e f g h i j k l m;

param: D: s t :=
        1       b  d,
        2       d  e,
        3       b  e;

param: E: k :=
        a b 19
        a c 7
        a d 13
        a e 2
        a f 9
        b c 14
        b f 10
        b g 18
        b h 2
        c d 11
        c h 7
        c i 15
        c j 16
        d e 17
        d j 11
        d k 16
        e f 15
        e k 8
        e l 13
        f g 12
        f l 19
        f m 4
        g h 9
        g m 5
        h i 14
        i j 3
        j k 17
        k l 20
        l m 1
;
```