# Simulation Step 1 Generate Map Data

March 13, 2024

[1]:
```python
import matplotlib.pyplot as plt
import math
import random
import numpy as np
```

**Hints for students:** The utility section contains code you need to use *unchanged* to generate the test data required. You may use this code for your final solution, beware not to overwrite function definitions in this section. Otherwise you can ignore the code in this section.

## 1 Utilities

**Note:** Section 1.1-1.4 is identical to the MST example (Week 3). 1.5-1.10 are adjustments of the data structures for the current problem.

### 1.1 Points and Distances

Euclidean Distance between two points

[2]:
```python
def dist(p1, p2):
    (x1, y1) = p1
    (x2, y2) = p2
    return int(math.sqrt((x1-x2)**2+(y1-y2)**2))
```

The nearest link between two point sets

[3]:
```python
def nearest(X, P):
    minD = math.inf
    minP = None
    for p in P:
        for x in X:
            d=dist(x, p)
            if d<minD:
                minX, minP, minD = x, p, d
    return minX, minP
```

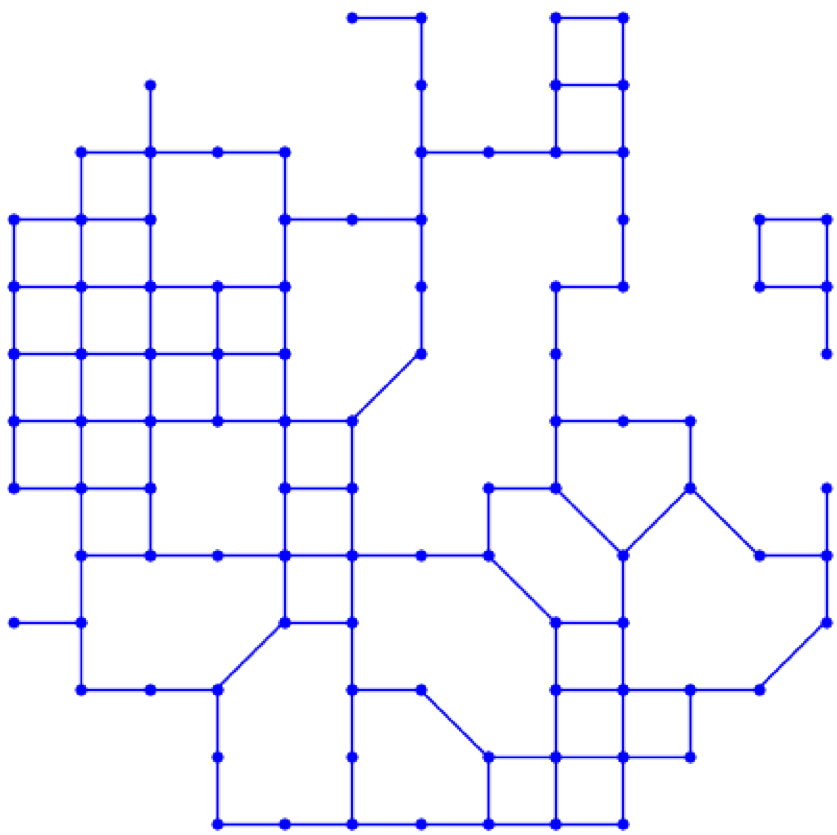
### 1.2 Graphs

[4]:
```
def generateRandomGraph(n, x0, y0, r):

    def rounding(x):
        return int(math.floor(x/10))*10

    x0 = rounding(x0)
    y0 = rounding(y0)
    gridsize = rounding(r / math.sqrt(n) * 1.4)
    r = int(math.floor(r/gridsize))*gridsize
    split = int(2*r/gridsize)+1
    X = np.linspace(x0-r, x0+r, split)
    Y = np.linspace(y0-r, y0+r, split)
    P = [ (int(x), int(y)) for x in X for y in Y if dist((x,y), (x0,y0)) < r ]
    P = random.sample(P, k=n)

    E = []

    def addEdge(p, q):
        if p in P and q in P and (p, q) not in E and (q, p) not in E:
            E.append((p, q))
    def addDiagonalEdge(p, q):
        (xp, yp) = p
        (xq, yq) = q
        if p in P and q in P and (xp, yq) not in P and (xq, yp) not in P and␣
↪(p, q) not in E and (q, p) not in E:
            E.append((p, q))

    for (x, y) in P:
        addEdge( (x, y), (x, y+gridsize) )
        addEdge( (x, y), (x, y-gridsize) )
        addEdge( (x, y), (x+gridsize, y) )
        addEdge( (x, y), (x-gridsize, y) )
        addDiagonalEdge( (x, y), (x+gridsize, y+gridsize) )
        addDiagonalEdge( (x, y), (x+gridsize, y-gridsize) )
        addDiagonalEdge( (x, y), (x-gridsize, y+gridsize) )
        addDiagonalEdge( (x, y), (x-gridsize, y-gridsize) )

    return sorted(P), sorted(E)
```

[5]:
```
def plotGraph(P, E, col='b', grid=False):
    fig = plt.gcf()
    fig.set_size_inches(6, 6)
    if not grid:
        plt.axis('off')
    plt.plot( [ p[0] for p in P ], [ p[1] for p in P ], col+'o', lw=1, ms=3)
```

```python
    for (p, q) in E:
        plt.plot( [ p[0], q[0] ], [ p[1], q[1] ], col+'-o', lw=1, ms=3)
    if grid:
        plt.grid()
```

[6]:
```python
random.seed(42)
V, E = generateRandomGraph(100, 5000, 5000, 4500)
plotGraph(V, E)
```



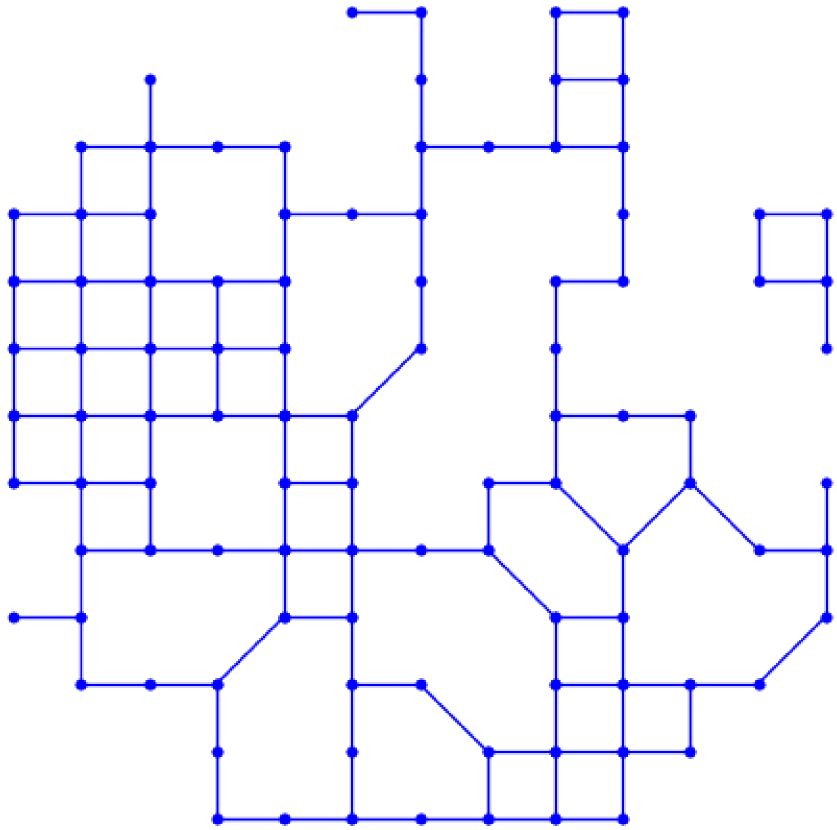
The random generation may result in a graph consisting of multiple not connected subgraphs. Split a graph into not connected subgraphs, if any.

[7]:
```python
def subgraph(P, E):
    P = P.copy()
    E = E.copy()
    PP = [ P[0] ]
    EE = []
    P = P[1:]
    extended = True
```

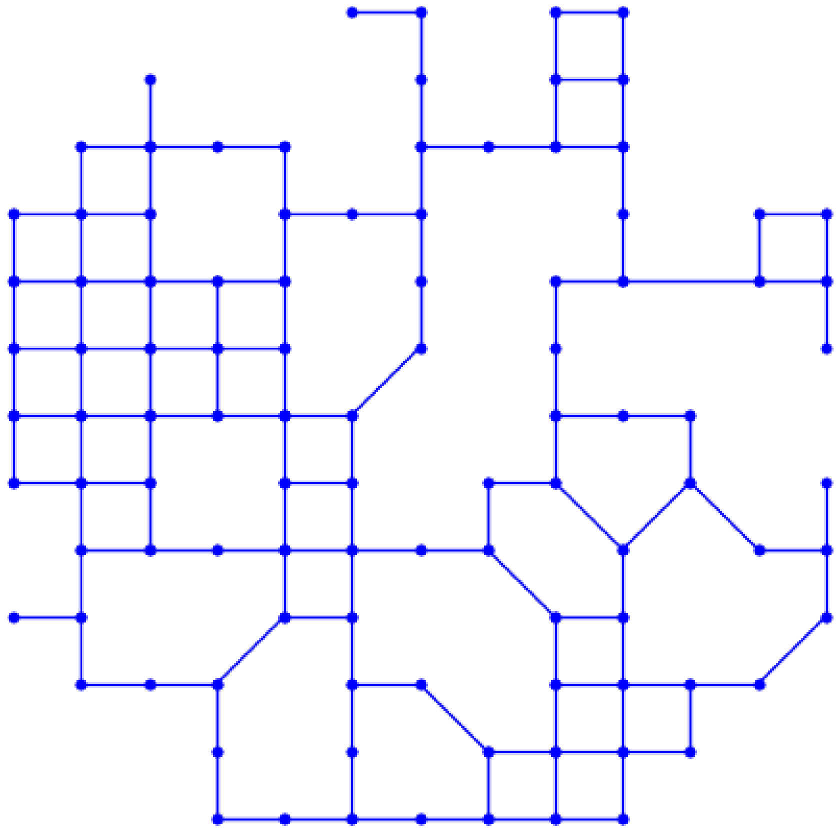
```
    while extended:
        extended = False
        for (a, b) in E:
            if a in PP and b in P:
                PP.append(b)
                P.remove(b)
                EE.append((a, b))
                E.remove((a, b))
                extended = True
                break
            if a in P and b in PP:
                PP.append(a)
                P.remove(a)
                EE.append((a, b))
                E.remove((a, b))
                extended = True
                break
            if a in PP and b in PP:
                EE.append((a, b))
                E.remove((a, b))
                extended = True
                break
    return PP, EE, P, E
```

[8]:
```
def generateGraph(n, x0, y0, r):
    P, E = generateRandomGraph(n, x0, y0, r)
    P0, _, P1, _ = subgraph(P, E)
    while len(P1)>0:
        (p, q) = nearest(P0, P1)
        E.append((p, q))
        P0, _, P1, _ = subgraph(P, E)
    return P, E
```

[9]:
```
random.seed(42)
V, E = generateRandomGraph(100, 5000, 5000, 4500)
plotGraph(V, E)
```

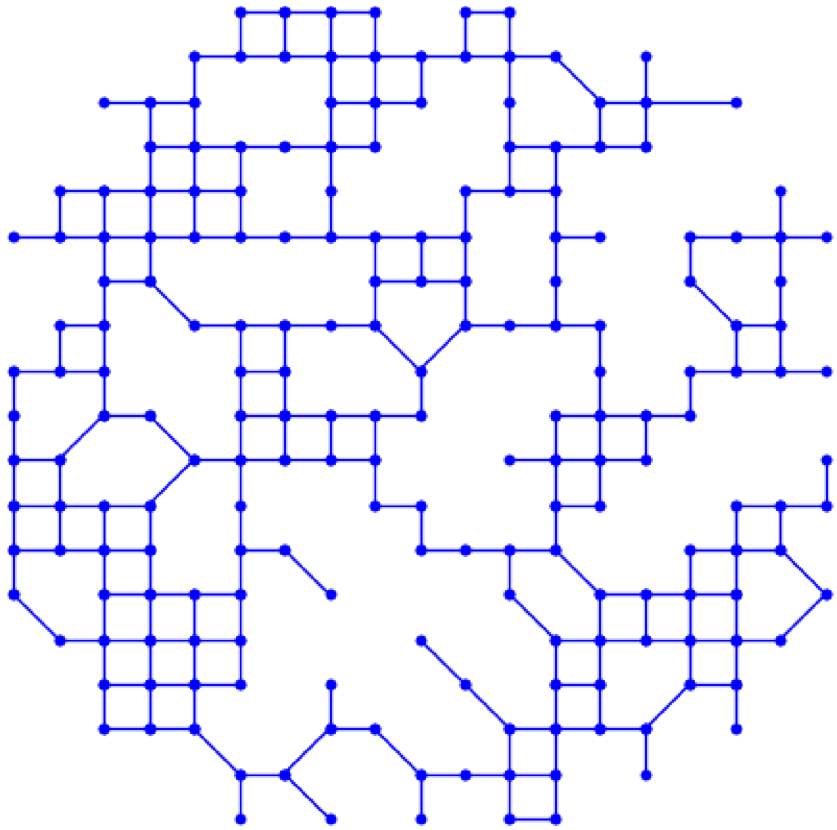


[10]:
```
random.seed(42)
V, E = generateGraph(100, 5000, 5000, 4500)
plotGraph(V, E)
```

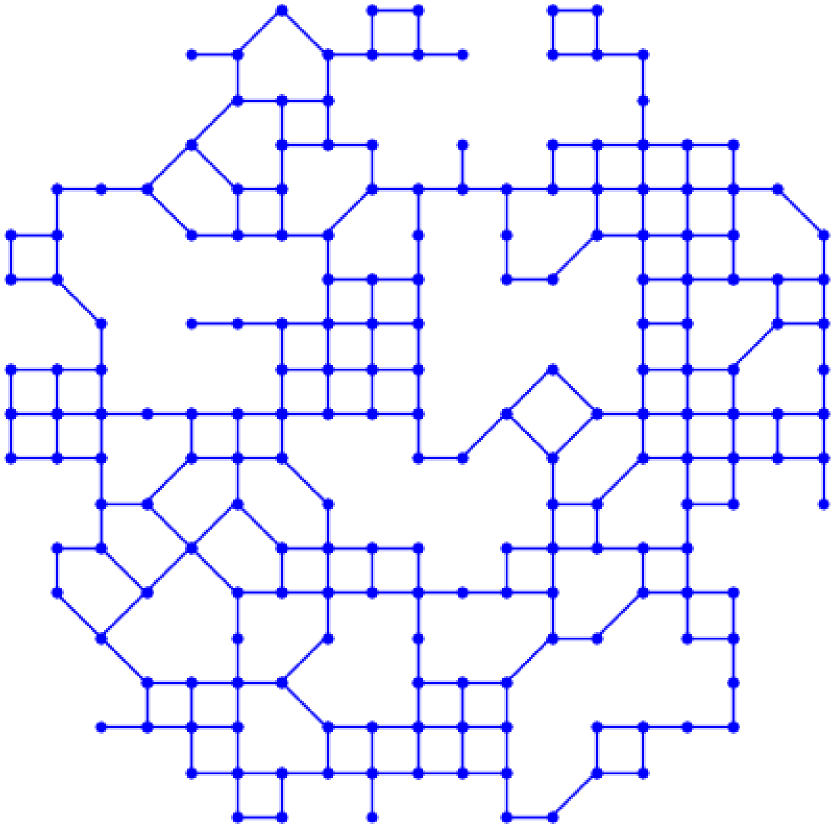


[11]:
```python
for i in range(7000, 7005):
    random.seed(i)
    P, E = generateGraph(200, 4000, 4000, 4000)
    print("Graph for seed", i, "has", len(P), "vertices and", len(E), "edges")
    plotGraph(P, E)
    plt.show()
```

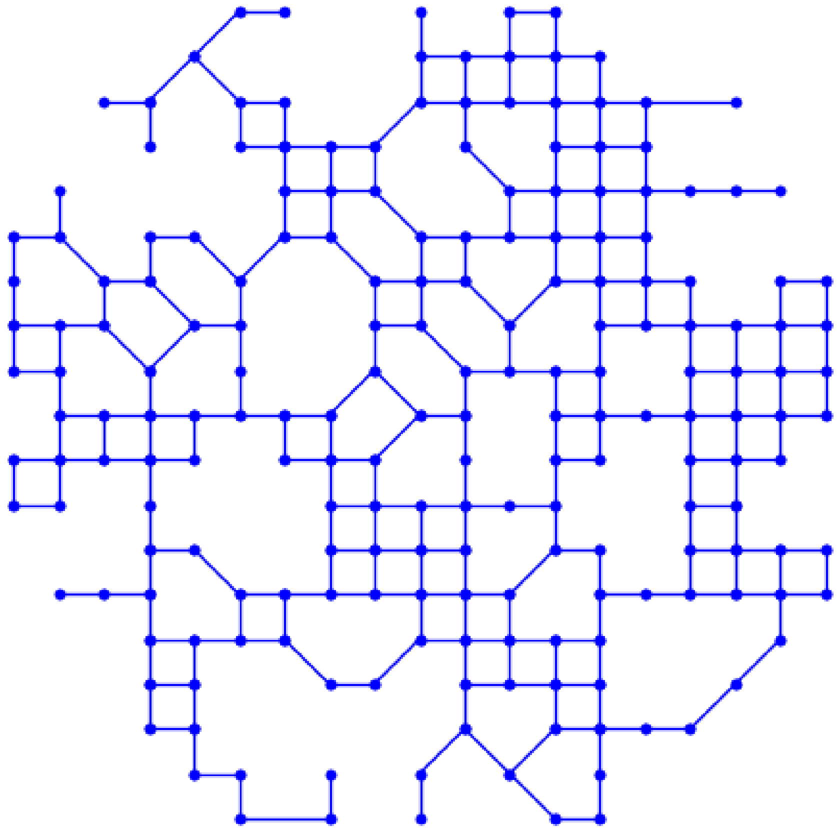
```
Graph for seed 7000 has 200 vertices and 270 edges
```



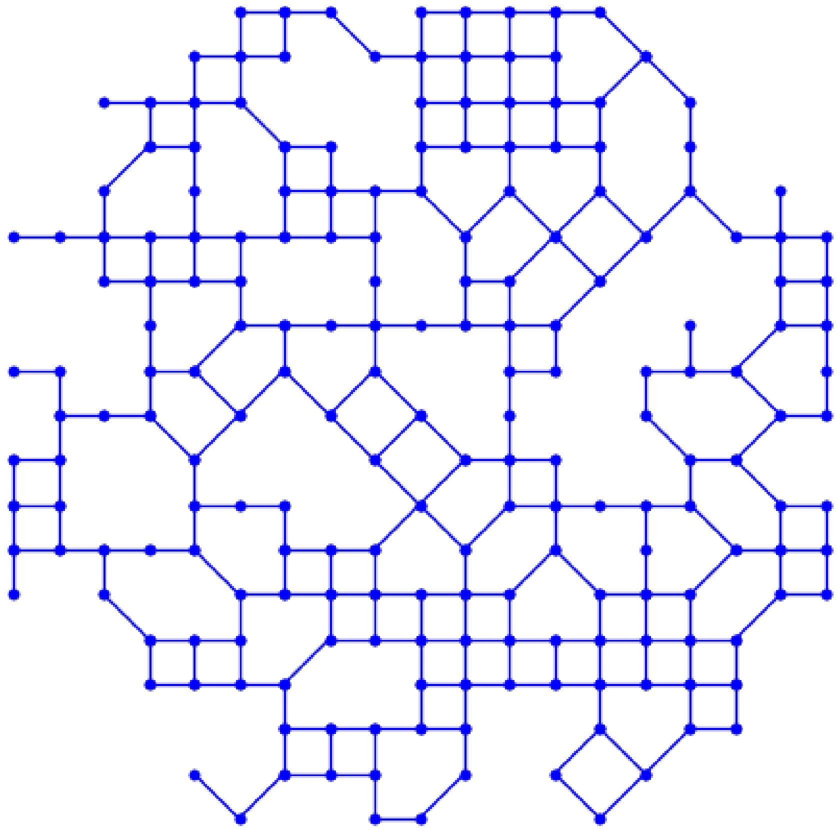
Graph for seed 7001 has 200 vertices and 283 edges



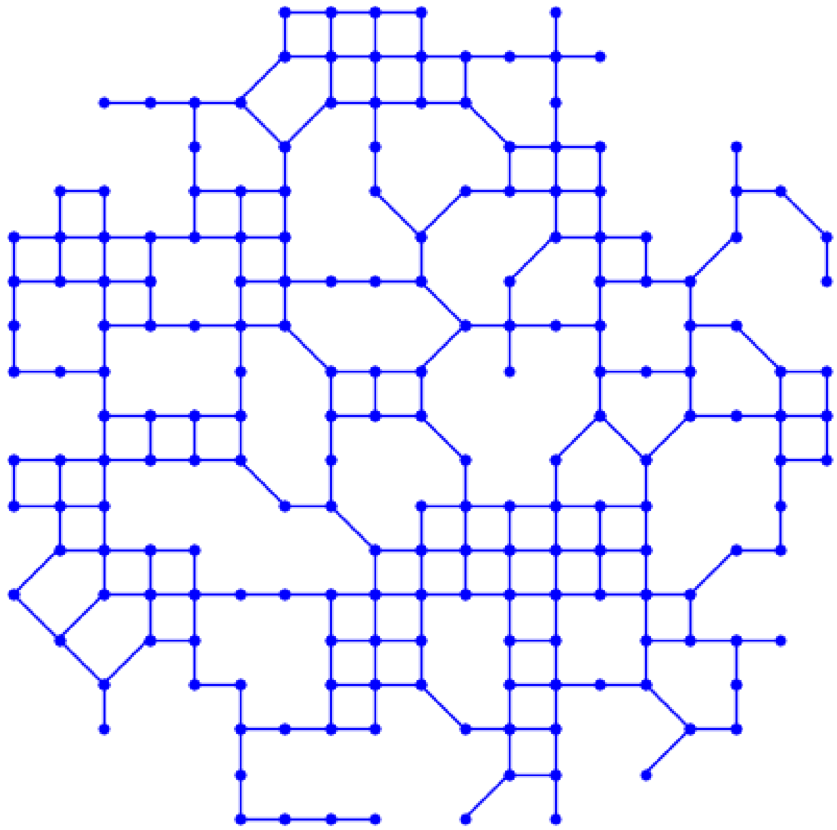
Graph for seed 7002 has 200 vertices and 285 edges



Graph for seed 7003 has 200 vertices and 287 edges



Graph for seed 7004 has 200 vertices and 278 edges



## 1.3 Lists and Paths

[12]:
```
def pathLength(P):
    return 0 if len(P)<=1 else \
            dist(P[0], P[1])+pathLength(P[1:])
```

[13]:
```
def reverse(P):
    return [ P[-i] for i in range(1,len(P)+1) ]
```

[14]:
```
def index(x, L):
    for i in range(len(L)):
        if x==L[i]:
            return i
    return None
```

[15]:
```
def addWithoutDuplicates(L, X):
    for i in range(len(X)):
        if X[i] not in L:
```

```
            L.append(X[i])
    return L
```

### 1.4 Generate Customer Locations

[16]:
```
def splitEdgeRandomly(V, E, s):
    A, B = s
    p = random.uniform(0.3,0.7)
    x = int(A[0]+p*(B[0]-A[0]))
    y = int(A[1]+p*(B[1]-A[1]))
    t = (x,y)
    E.remove(s)
    E.append((A, t))
    E.append((t, B))
    V.append(t)
    return (V, E), t
```

[17]:
```
def generateRandomTargets(V, E, n=5):
    V, E = V.copy(), E.copy()
    T = []
    # we want to ensure that the beginning of the
    # sequence of points generated randomly stays
    # the same
    mindist = 300
    while len(T)<n:
        s = random.choice(E)
        A, B = s
        if dist(A,B)>mindist: # avoid targets placed narrowly
            (V, E), t = splitEdgeRandomly(V, E, s)
            T.append(t)
    return sorted(T)
```

[18]:
```
def addTargets(M, T):
    V, E = M
    E = E.copy()
    V = V.copy()
    for t in T:
        minD = math.inf
        minE = None
        for e in E:
            P, Q = e
            distT = dist(P, t)+dist(t, Q)-dist(P, Q)
            if distT < minD:
                minD = distT
                minE = e
        P, Q = minE
        E.remove( (P, Q) )
```

```
            E.append( (P, t) )
            E.append( (t, Q) )
            V.append(t)
    return V, E
```

### 1.5 Generate Warehouse Locations

[19]:
```
def generateWarehouseLocation(M):
    V, _ = M
    W = random.sample(V, k=1)[0]
    return W
```

[20]:
```
def generateWarehouseLocations(M, seed=None):
    if seed is not None:
        random.seed(seed)
    V, _ = M
    W = random.sample(V, k=len(V)//10)
    return W
```

### 1.6 Plot Map with Delivery Route

[21]:
```
def plotMap(G, T=[], P=[], W=None,
            style='r-o', lw=1, ms=3,
            styleT='go', msT=5,
            styleP='b-o', lwP=3, msP=1,
            stylePT='go', msPT=7,
            styleW='bo', msW=7,
            text=None, grid=False):
    fig = plt.gcf()
    fig.set_size_inches(6, 6)
    V, E = G

    if not grid:
        plt.axis('off')
    plt.plot( [ p[0] for p in V ], [ p[1] for p in V ], 'ro', lw=lw, ms=ms)
    for (p, q) in E:
        plt.plot( [ p[0], q[0] ], [ p[1], q[1] ], 'r-o', lw=lw, ms=ms)
    for t in T:
        plt.plot( [ t[0] ], [ t[1] ],
                  styleT, ms=msT)
    plt.plot( [ p[0] for p in P ],
              [ p[1] for p in P ],
              styleP, lw=lwP, ms=msP)
    for p in P:
        if p in T:
            plt.plot( [ p[0] ], [ p[1] ],
                      stylePT, ms=msPT)
```

```python
    if W is not None:
        plt.plot( [ W[0] ], [ W[1] ],
                  styleW, ms=msW)
    if text is not None:
        minX = min([p[0] for p in V])
        plt.text(minX, 0, text)
    if grid:
        plt.grid()
    plt.show()
```

### 1.7 Generate Data

[22]:
```python
def generateData(seed=None, nodes=100, customers=150,
                 plot=False, log=False):

    if seed is None:

        print("Usage:  M, C = generateData(seed=None, ")
        print("                             nodes=100, customers=50, ")
        print("                             plot=False, log=False)")
        print("")
        print("  seed  the seed value to be used for data generation. ")
        print("        To test the application use seed=0, it will create")
        print("        a small map, with a very few customer locations and")
        print("        a small set of delivery data.")
        print("")
        print("  nodes the number of intersections (vertices) in the generated␣
↪map")
        print("")
        print("  customers  the number of customers generated on the map")
        print("")
        print("  log   Controls print output during data generation.")
        print("")
        print("  plot  Controls graphical output during data generation.")
        print("")
        print("Returns:")
        print("")
        print("  M = (V, E) is the generated map given as a graph")
        print("    where V is a list of vertices, with each vertice ")
        print("    given as a pair (x, y) of integer coordinates, ")
        print("    and E is a list of edges, with each edge given")
        print("    as a pair (A, B) of vertices, with each vertex again")
        print("    given as a pair (x, y) of integer coordinates")
        print("")
        # print("  W   V  is the location of the distribution warehouse")
        # print("    given as a pair (x, y) of integer coordinates")
        # print("")
```

```
        print("  C is a list of customer locations")
        print("    given as pairs (x, y) of integer coordinates on or near")
        print("    existing edges E. To integrate a set of customer locations")
        print("    into a given map M = (V, E), use addTarget(M, C)")
        print("")

        seed = 0

    if seed==0:           # generate very simple test data
        nodes = 20        # number of points in map
        customers = 5     # number of  customers
        grid = True

    else:
        grid = False

    random.seed(seed)

    V, E = generateGraph(nodes, 4000, 4000, 4000)

    C = generateRandomTargets(V, E, customers)

    if log:
        print(f"Generated map with {nodes:d} nodes and "
              f"{customers:d} customer locations")
    if plot:
        label="" if seed==0 else f"seed={seed:4d}"
        plotMap((V, E), T=C, text=label, grid=grid)

    return (V, E), C
```

Data Generation is reproducible

[23]:
```
D1 = generateData(1234)
D2 = generateData(1234)
D1 == D2
```

[23]: True

# 2 Generating Data

This section demonstrates how you can generate the test data for the problem.

## 2.1 General Help Message

If you use `generateData()` without any parameters you will get a general help message.

[24]:
```
M, C = generateData()
```

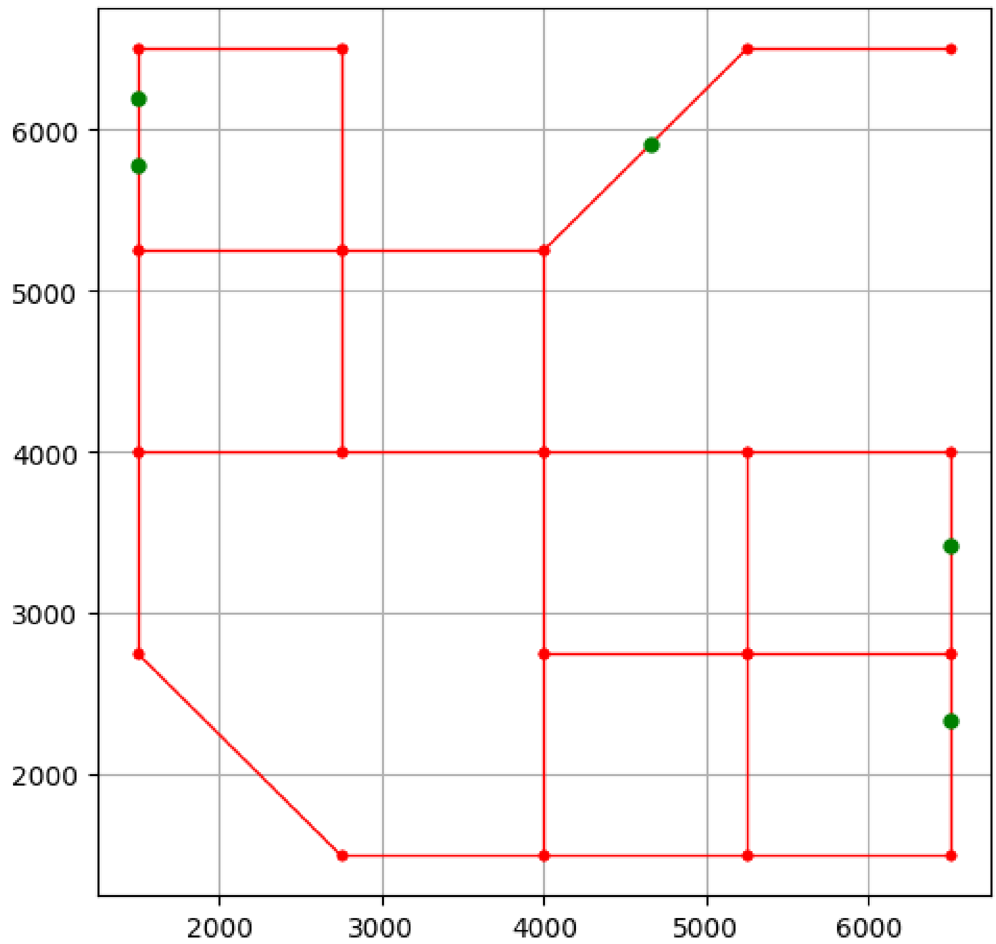
```
Usage:  M, C = generateData(seed=None,
                            nodes=100, customers=50,
                            plot=False, log=False)

  seed  the seed value to be used for data generation.
        To test the application use seed=0, it will create
        a small map, with a very few customer locations and
        a small set of delivery data.

  nodes the number of intersections (vertices) in the generated map

  customers  the number of customers generated on the map

  log   Controls print output during data generation.

  plot  Controls graphical output during data generation.

Returns:

  M = (V, E) is the generated map given as a graph
    where V is a list of vertices, with each vertice
    given as a pair (x, y) of integer coordinates,
    and E is a list of edges, with each edge given
    as a pair (A, B) of vertices, with each vertex again
    given as a pair (x, y) of integer coordinates

  C is a list of customer locations
    given as pairs (x, y) of integer coordinates on or near
    existing edges E. To integrate a set of customer locations
    into a given map M = (V, E), use addTarget(M, C)
```

### 2.2 Analysing Simple Test Data

This section illustrates the data structure generated.

[25]:
```python
sampleData = generateData(seed=0, log=True, plot=True)
```

```
Generated map with 20 nodes and 5 customer locations
```




[26]:
```
import pickle
with open('sampleData.pickled', 'wb') as f:
    pickle.dump(sampleData, f)
```

[27]:
```
M, C = sampleData
```

#### 2.2.1 The Graph

You can identify the points in the grid above. The vertices of the graph are:

[28]:
```
V, E = M
V
```

[28]:
```
[(1500, 2750),
 (1500, 4000),
 (1500, 5250),
 (1500, 6500),
```

```
 (2750, 1500),
 (2750, 4000),
 (2750, 5250),
 (2750, 6500),
 (4000, 1500),
 (4000, 2750),
 (4000, 4000),
 (4000, 5250),
 (5250, 1500),
 (5250, 2750),
 (5250, 4000),
 (5250, 6500),
 (6500, 1500),
 (6500, 2750),
 (6500, 4000),
 (6500, 6500)]
```

The edges of the graph are:

[29]:
```
E
```

[29]:
```
[((1500, 2750), (1500, 4000)),
 ((1500, 2750), (2750, 1500)),
 ((1500, 4000), (2750, 4000)),
 ((1500, 5250), (1500, 4000)),
 ((1500, 5250), (1500, 6500)),
 ((2750, 5250), (1500, 5250)),
 ((2750, 5250), (2750, 4000)),
 ((2750, 5250), (2750, 6500)),
 ((2750, 6500), (1500, 6500)),
 ((4000, 1500), (2750, 1500)),
 ((4000, 2750), (4000, 1500)),
 ((4000, 4000), (2750, 4000)),
 ((4000, 4000), (4000, 2750)),
 ((4000, 4000), (4000, 5250)),
 ((4000, 4000), (5250, 4000)),
 ((4000, 5250), (2750, 5250)),
 ((4000, 5250), (5250, 6500)),
 ((5250, 1500), (4000, 1500)),
 ((5250, 1500), (6500, 1500)),
 ((5250, 2750), (4000, 2750)),
 ((5250, 2750), (5250, 1500)),
 ((5250, 2750), (5250, 4000)),
 ((5250, 2750), (6500, 2750)),
 ((5250, 4000), (6500, 4000)),
 ((6500, 2750), (6500, 1500)),
 ((6500, 2750), (6500, 4000)),
 ((6500, 6500), (5250, 6500))]
```

### 2.2.2 Customer Addresses

The customer addresses (green dots in the map) are:

[30]:
```
C
```

[30]: [(1500, 5780), (1500, 6192), (4654, 5904), (6500, 2338), (6500, 3425)]

### 2.2.3 The Warehouse Address

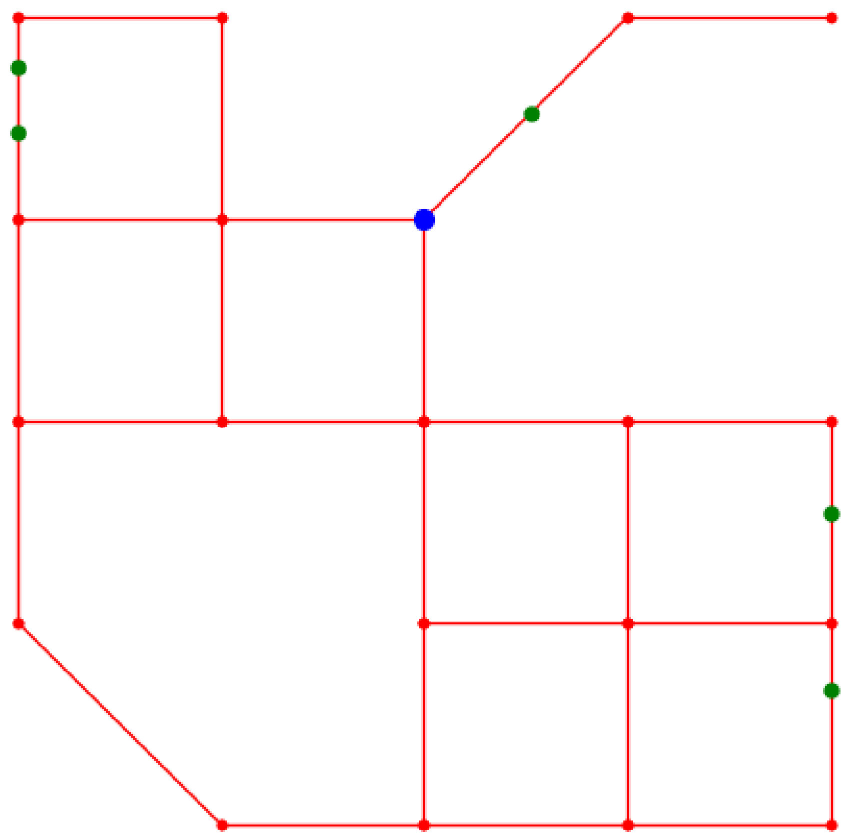
Warehouses should be located on or near an intersection on the map. To generate a warehouse address use:

[31]:
```
W = generateWarehouseLocation(M)
```

[32]:
```
W
```

[32]: (4000, 5250)

[33]:
```
plotMap((V, E), T=C, W=W)
```

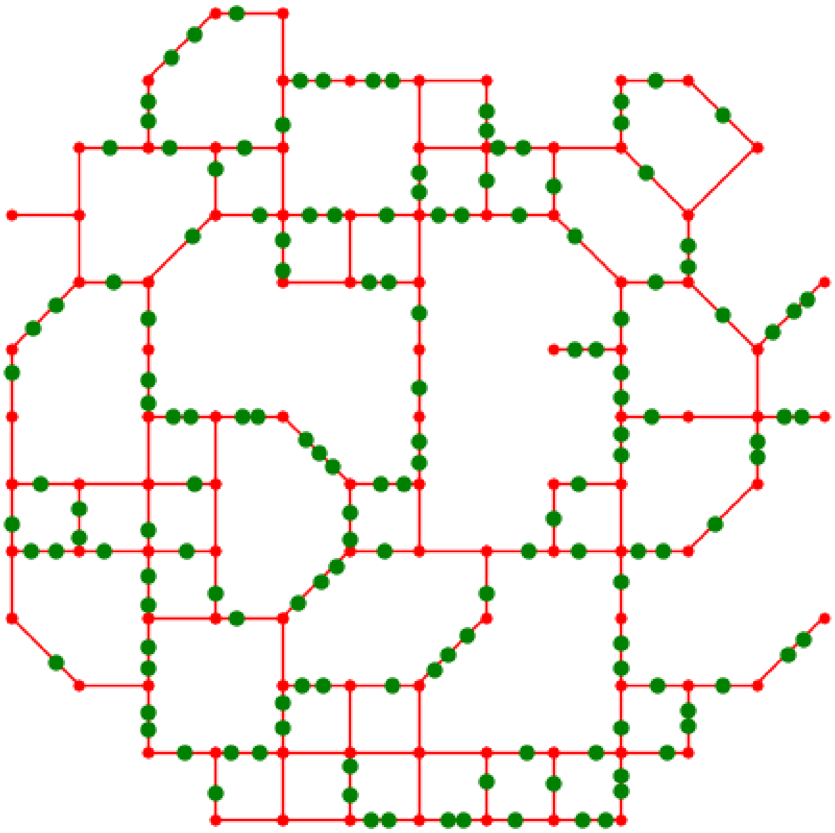


## 2.3 Real Sample Data

This section shows sample data as you you may get them for your required simulation.

[34]:
```
data = generateData(9999, plot=True, log=True)
```

```
Generated map with 100 nodes and 150 customer locations
```



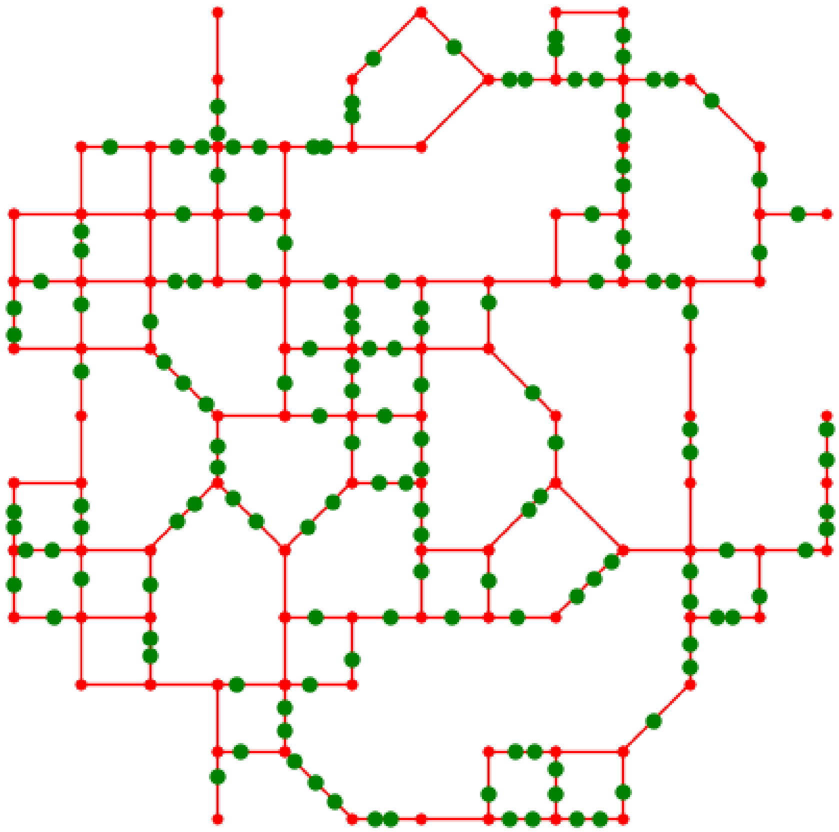
seed=9999

Save sample data as pickle file:

[35]:
```
import pickle
with open('data.pickled', 'wb') as f:
    pickle.dump(data, f)
```

[36]:
```
xdata = generateData(9261, plot=True, log=True)
```

```
Generated map with 100 nodes and 150 customer locations
```

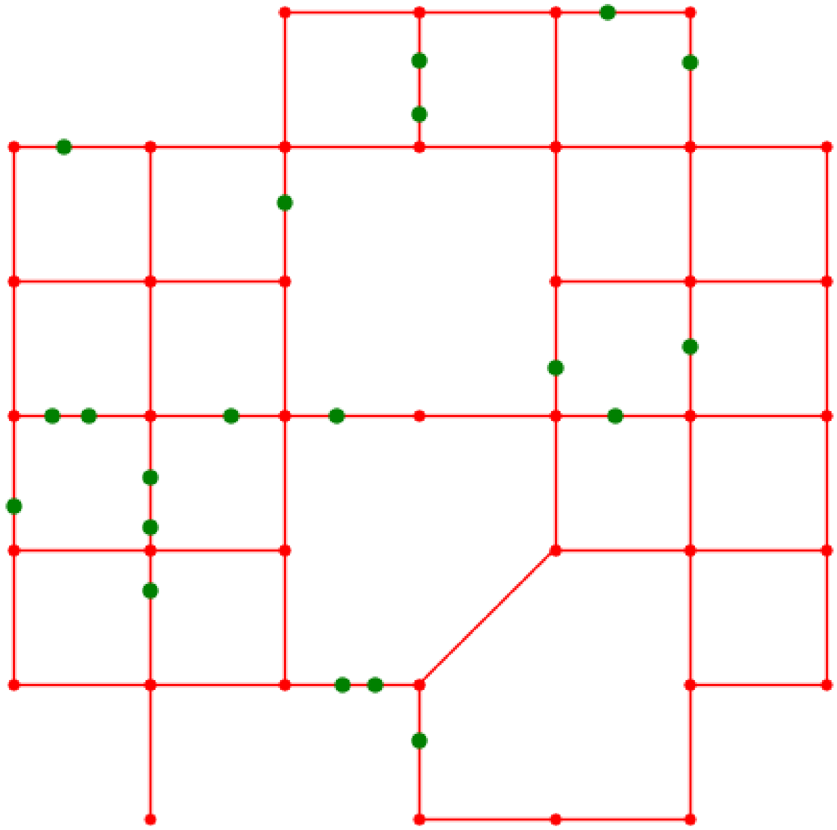


seed=9261

[37]:
```python
import pickle
with open('xdata.pickled', 'wb') as f:
    pickle.dump(xdata, f)
```

[38]:
```python
myData = generateData(1234, nodes=40, customers=20, plot=True, log=True)
```

```
Generated map with 40 nodes and 20 customer locations
```



seed=1234

[39]:

```
import pickle
with open('myData.pickled', 'wb') as f:
    pickle.dump(myData, f)
```