Beamform MATLAB Code

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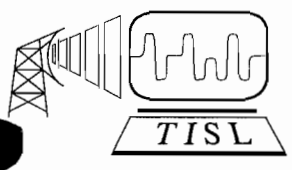

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```
function GPS = AddRandPt(GPS,v)

%   ADDS A UNIFORM RANDOM PT BOUNDED BY v TO GPS
%   Syntax: GPS = AddRandPt(GPS,v) where v = [Xmin Xmax Ymin Ymax]

      %This function creates two uniformly distributed random
      %numbers on the interval specified boundaries in v

      %Input: GPS = Coordinate matrix
      %       v = [Xmin Xmax Ymin Ymax]
      %Output: GPS = New Coordinate Matrix

%   DEFINE VARIABLES

      SizeOfGPS = size(GPS);
      rand('seed',sum(clock*100));


%   GENERATE RANDOM X COORDINATE

      GPS(SizeOfGPS(1,1)+1,1) = v(1)+(v(2)-v(1))*rand(1);

%   GENERATE RANDOM Y COORDINATE

      GPS(SizeOfGPS(1,1)+1,2) = v(3)+(v(4)-v(3))*rand(1);

%   SORT MATRIX

      GPS = SortGPS(GPS);
```

```
function ClassNew = AddToClass(ClassOld,Add)

%    ADDS A GROUP OF STATES TO A CLASS
%    Syntax: ClassNew = AddToClass(ClassOld,Add)

        %This function appends ClassOld with the states
        %specified in Add.

        %Input: ClassOld = Current class needing appending (Row Vector)
        %       Add = States to add to ClassOld (Row Vector)
        %Output: ClassNew = Class containing all the states in ClassOld
        %                   and Add (Row Vector)

%    DEFINE VARIABLES

        OldSize = size(ClassOld);
        AddSize = size(Add);

%    APPEND ClassOld WITH THE STATES IN Add

        if AddSize(1,1) ~= 0
                ClassNew = ClassOld;
                ClassNew(1,OldSize(1,2)+1:OldSize(1,2)+AddSize(1,2)) = Add;
        else
                ClassNew = ClassOld;
        end %if%
```

```
function Next = AdjState(ProbMat,State)

%   RETURNS THE STATES WHICH State CAN COMMUNICATE DIRECTLY WITH
%   Syntax: Next = AdjState(ProbMat,State)

        %This function will determine which states can be reached
        %directly from the current state (State).  It does not
        %necessarily ensure 2 way communication between the two.

        %Input: ProbMat = Stochastic matrix of one step transition probabilities
        %       State = Current state of process
        %Output: Next = Row vector of adjacent states

%   DEFINE VARIABLES

        k = 0;
        SizeOfProbMat = size(ProbMat);

%   SEARCH State'S ROW AND DETERMINE ADJACENT STATES

        for i = 1:SizeOfProbMat(1,2)
                if ProbMat(State,i) > 0
                        k = k + 1;
                        Next(1,k) = i;
                end %if%
        end %for%
```

```
function C = Ang(p1,p2,p3)

%   CALCULATES ANGLE BETWEEN THREE PTS
%   Syntax: C = Ang(p1,p2,p3)    *** Radians ***

    %This function calculates the angle formed by the points p1, p2,
    %and p3 where p2 is the vertex.  Law of Cosines is applied.

    %Inputs: p1,p2,p3 = points where p2 is the vertex
    %Outputs: C = angle made by lines connecting the points

%   CALCULATE a, b, c (DISTANCES)

    a = Dist(p2,p3);
    b = Dist(p1,p2);
    c = Dist(p1,p3);

%   CALCULATE C

    C = acos((c.^2-a.^2-b.^2)./(-2*a.*b));
```

```
function CLTrue = AreCL(T,R,CLPropose)

%   DETERMINES IF A MATRIX OF PROPOSED LABELINGS ARE CONSISTENT WITH T AND R
%   Syntax: CLTrue = AreCL(T,R,CLPropose)

      %This function takes each proposed labeling in CLPropose
      %and tests it to determine if it is a consistent labeling
      %with respect to T and R.  Those labelings which pass
      %the test are add to CLTrue.

      %Input: T = Unit constraint relation
      %       R = Unit label constraint relation
      %       CLPropose = All labelings to be checked
      %Output: CLTrue = Those labelings from CLPropose which are
      %                  consistent labelings

%   DEFINE VARIABLES

      k = 0;
      SizeOfCLPropose = size(CLPropose);

%   SELECT AND TEST EACH LABELING

      for i = 1:SizeOfCLPropose(1,2)/2
              CL = SelectCL(CLPropose,i);
              X = IsCL(T,R,CL);
              if X
                      CLTrue = CLAdd(CLTrue,CL);
              end %if%
              Progress = i/(SizeOfCLPropose(1,2)/2)*100;
              clc
              fprintf('Checking Labelings...\n');
              fprintf('Progress: %1.2f\n',Progress);
      end %for%
```

```
function Mat = CL2Mat(CL,U,NetSize)

%   CONVERTS A CONSISTENT LABELING INTO A PSEUDO STOCHASTIC MATRIX
%   Syntax: Mat = CL2Mat(CL,U,NetSize)

    %This creates a matrix which shows the connectivity
    %of the network.  Ones represent a connection between
    %two nodes which have the numbers of the index values.
    %For example if Mat(2,4) = 1 then node 2 has a link
    %to node 4.

    %Input: CL = Consistent labeling
    %       NetSize = Number of nodes in the network
    %Output: Mat = Connectivity matrix

%   TRY EACH PAIR OF NODES AND DETERMINE HOW THEY COMMUNICATE

    for i = 1:NetSize
            for j = 1:NetSize
                    Link = Node2Link(i,j);
                    [X,Index] = IsElement(CL,Link);
                    Y = IsElement(U,Link);
                    if X
                            if CL(Index(1,1),2) == 0
                                    Mat(i,j) = 0;
                                    Mat(j,i) = 0;
                            else
                                    Mat(i,j) = 1;
                                    Mat(j,i) = 1;
                            end %if%
                    elseif Y
                            Mat(i,j) = 1;
                            Mat(j,i) = 1;
                    end %if%
            end %for%
    end %for%
```

```
function CLNew = CLAdd(CLOld,CL)

%   ADDS A CONSISTENT LABELING TO A CONSISTENT LABELING SOLUTION
%   Syntax: CLNew = CLAdd(CLOld,CL)

        %This function will add a found consistent labeling to
        %a matrix of consistent labeling previously found

        %Input: CLOld = Previously found consistent labelings
        %       CL = Consistent labeling to add
        %Output: CLNew = Combined matrix of CLOld and CL

%   DEFINE VARIABLES

        SizeOfCLOld = size(CLOld);
        SizeOfCL = size(CL);

%   APPEND CLOld WITH CL

        CLNew = CLOld;
        CLNew(1:SizeOfCL(1,1),SizeOfCLOld(1,2)+1:SizeOfCLOld(1,2)+2) = CL;
```

```
function CL = CLabel(U,R)

%   RETURNS A CONSISTENT LABELING OF A SINGLE VALUED R
%   Syntax: CL = CLabel(U,R)

      %This function will return a [unit label] solution given
      %an R which is single valued.  Single valued means that
      %for each unit in R there is only one label given to it
      %throughout R.

      %Input: U = Units
      %       R = Single valued unit label relation
      %Output: CL = Solution matrix consisting of units and their labels
      %             in a [Unit Label] format

%   DEFINE VARIABLES

      UList = UnitOfR(U,R);
      SizeOfUList = size(UList);

%   GET CORRESPONDING LABELING FOR EACH UNIT

      for i = 1:SizeOfUList(1,1)
              [X,Index] = IsElement(R,UList(i,1));
              CL(i,1) = UList(i,1);
              CL(i,2) = R(Index(1,1),Index(1,2)+1);
      end %for%
```

```
function List = CanAccess(ProbMat,State,List)

%   FINDS THE STATES THAT State CAN ACCESS OR REACH
%   Syntax: List = CanAccess(ProbMat,State,List)

        %This function finds all of the states which can be reached
        %both directly and indirectly from State.  This is a recursive
        %function.  Note: List is a ROW vector

        %Input: ProbMat = Stochastic matrix of one step transition prob
        %       State = Current state in search
        %       List = States which have been found to be in class
        %Output: List = States which have been found to be in class

%   DEFINE VARIABLES

        k = 0;
        Flag = 1;

%   ADD ADJACENT STATES TO List IF THEY ARE NOT ALREADY THERE

        NextState = AdjState(ProbMat,State);
        SizeOfNextState = size(NextState);
        for i = 1:SizeOfNextState(1,2)
                X = IsElement(List,NextState(1,i));
                if ~X
                        k = k + 1;
                        Temp(1,k) = NextState(1,i);
                end %if%
        end %for%
        NextState = Temp;
        List = AddToClass(List,NextState);

%   CHECK EACH NextState FOR STATES THEY CAN REACH

        if size(NextState) ~= 0
                while Flag
                        [s,NextState] = RemoveOneState(NextState);
                        SizeOfNextState = size(NextState);
                        if SizeOfNextState(1,2) == 0
                                Flag = 0;
                        end %if%
                        List = CanAccess(ProbMat,s,List);
                end %while%
        end %if%
```

```
function Class = CanComm(ProbMat,State)

%   DETERMINES WHICH STATES State CAN COMMUNICATE WITH
%   Syntax: Class = CanComm(ProbMat,State)

      %This function finds all of the states which State can
      %for two way communication with directly or indirectly.

      %Input: ProbMat = Stochastic matrix of one step probabilities
      %       State = State to consider
      %Output: List = List of states State can communicate with

%   WHO CAN State ACCESS?

      List = CanAccess(ProbMat,State,[]);
      SizeOfList = size(List);

%   CHECK EACH STATE State CAN REACH AND DETERMINE WHICH ONES CAN REACH State

      k = 0;
      for i = 1:SizeOfList(1,2)
            NewList = CanAccess(ProbMat,List(1,i),[]);
            X = IsElement(NewList,State);
            if X
                  k = k + 1;
                  Class(1,k) = List(1,i);
            end %if%
      end %for%
```

```
function ClearLinkGUI(l,hAllQuery)

%    CLEARS A LINK FROM THE QUERY CONTROL BOX
%    Syntax: ClearLinkGUI(l,hAllQuery)

        %Places null strings in all the text boxes of
        %the specified link

        %Input: l = Link to be cleared
        %       hAllQuery = Handles for objects in the box

%  CLEAR TEXT OBJECTS INVOLVING THE SPECIFIED LINK

        set(hAllQuery(25),'str','');
        if l == 1
                set(hAllQuery(13),'str','');
                set(hAllQuery(17),'str','');
                set(hAllQuery(14),'str','');
                set(hAllQuery(18),'str','');
                set(hAllQuery(22),'str','');
                set(hAllQuery(7),'str','');
        else
                set(hAllQuery(15),'str','');
                set(hAllQuery(19),'str','');
                set(hAllQuery(16),'str','');
                set(hAllQuery(20),'str','');
                set(hAllQuery(23),'str','');
                set(hAllQuery(8),'str','');
        end %if%
```

```
%   GUI FOR CONFIGURATION CONTROLS

%   CREATE BOX

        figure(hConfigBox);
        set(hConfigBox,'name','Configuration Controls');

%   LINK RADIUS

hAllConfig(1) = uicontrol('sty','text','str','Link Radius',...
'pos',[.3 .9 .25 .05],'unit','norm');
hAllConfig(2) = uicontrol('sty','edit','pos',[.6 .9 .1 .05],'unit',...
'norm','back',CMap1,'call','Config=SetConfigGUI(hAllConfig,1,DefConfig);');

%   FREQ MAX

hAllConfig(3) = uicontrol('sty','text','str','Max Frequencies',...
'pos',[.3 .8 .25 .05],'unit','norm');
hAllConfig(4) = uicontrol('sty','edit','pos',[.6 .8 .1 .05],'unit',...
'norm','back',CMap1,'call','Config=SetConfigGUI(hAllConfig,1,DefConfig);');

%   INTERFERENCE MULTIPLIER

hAllConfig(5) = uicontrol('sty','text','str','Interference Mult',...
'pos',[.3 .7 .25 .05],'unit','norm');
hAllConfig(6) = uicontrol('sty','edit','pos',[.6 .7 .1 .05],'unit',...
'norm','back',CMap1,'call','Config=SetConfigGUI(hAllConfig,1,DefConfig);');

%   BEAM WIDTH

hAllConfig(7) = uicontrol('sty','text','str','Beam Width',...
'pos',[.3 .6 .25 .05],'unit','norm');
hAllConfig(8) = uicontrol('sty','edit','pos',[.6 .6 .1 .05],'unit',...
'norm','back',CMap1,'call','Config=SetConfigGUI(hAllConfig,0,DefConfig);');

%   BEAM WIDTH SLIDER

hAllConfig(9) = uicontrol('sty','slide','pos',[.35 .5 .3 .060],...
'min',0,'max',360,'call','Config=SetConfigGUI(hAllConfig,1,DefConfig);',...
'units','norm','back',CMap1);
hAllConfig(10) = uicontrol('sty','text','pos',[.275 .5 .05 .05],...
'units','norm','str','0');
hAllConfig(11) = uicontrol('sty','text','pos',[.675 .5 .05 .05],...
'units','norm','str','360');

%   CREATE U

hAllConfig(12) = uicontrol('sty','push','pos',[.1 .375 .35 .05],...
'unit','norm','str','Make U','call','U = MakeU(GPS,Config(1))',...
'back',CMap1);

%   CREATE T

hAllConfig(13) = uicontrol('sty','push','pos',[.55 .375 .35 .05],...
'unit','norm','str','Make T','back',CMap1,...
'call','[T,X1,X2] = MakeT2(GPS,U,Config(3),Config(4),Config(5))');

%   CREATE L

hAllConfig(14) = uicontrol('sty','push','pos',[.1 .305 .35 .05],...
'unit','norm','str','Make L','call','L = MakeL2(Config(2))',...
'back',CMap1);

%   CREATE R

hAllConfig(15) = uicontrol('sty','push','pos',[.55 .305 .35 .05],...
```

```
'unit','norm','str','Make R','call','R = MakeR2(L,T,X1,X2)',...
'back',CMap1);

%   CREATE ULTR

hAllConfig(16) = uicontrol('sty','push','pos',[.1 .17 .8 .1],...
'unit','norm','str','Make [U,L,T,R] Model',...
'call','tic;[U,L,T,R,X1,X2] = MakeULTR2(GPS,Config);t1=toc','back',CMap1);

%   SOLVE MODEL

hAllConfig(17) = uicontrol('sty','push','pos',[.1 .05 .8 .1],...
'unit','norm','str','Find All Network Configurations','back',CMap1,...
'call','tic;s=size(GPS);NetTot = SolveModel([],T(1,1),U,L,T,R,s(1,1));SetTotGUI(h
```

```
function Link = DefineLinkGUI(GPS,l,hNodePlot,hAllQuery)

%   FUNCTION WHICH DISPLAYS QUERY INFORMATION FROM QueryBox.m
%   Syntax: Link = DefineLinkGUI(GPS,l,hNodePlot,hAllQuery)

    %This function displays various information about
    %the link chosen.  If another link has already been
    %chosen or defined then the angle between the two
    %is computed.

    %Input: GPS = Coordinate Matrix
    %       l = 1 or 2 depending on which botton pressed
    %       hNodePlot = Figure handle of plot to consider
    %       hAllQuery = Object handles of QueryBox

%    DISPLAY INDIVIDUAL LINK INFORMATION

    CurFig = gcf;
    figure(hNodePlot)
    n1 = gSelectNode(GPS);
    n2 = gSelectNode(GPS);
    Link = Node2Link(n1,n2);
    if l == 1
            %Display Link
            set(hAllQuery(7),'str',int2str(Link));
            %Display Node Coordinates
            [n1,n2] = Link2Node(Link);
            [x1,y1] = Node2Coord(GPS,n1);
            [x2,y2] = Node2Coord(GPS,n2);
            set(hAllQuery(13),'str',num2str(x1));
            set(hAllQuery(17),'str',num2str(y1));
            set(hAllQuery(14),'str',num2str(x2));
            set(hAllQuery(18),'str',num2str(y2));
            set(hAllQuery(22),'str',num2str(LinkLength(GPS,Link)));
    else
            %Display Link
            set(hAllQuery(8),'str',int2str(Link));
            %Display Node Coordinates
            [n1,n2] = Link2Node(Link);
            [x1,y1] = Node2Coord(GPS,n1);
            [x2,y2] = Node2Coord(GPS,n2);
            set(hAllQuery(15),'str',num2str(x1));
            set(hAllQuery(19),'str',num2str(y1));
            set(hAllQuery(16),'str',num2str(x2));
            set(hAllQuery(20),'str',num2str(y2));
            set(hAllQuery(23),'str',num2str(LinkLength(GPS,Link)));
    end %if%

%   IF LINK 1 AND 2 HAVE BEEN DEFINED...CALCULATE ANGLE

    l1 = str2num(get(hAllQuery(7),'str'));
    l2 = str2num(get(hAllQuery(8),'str'));
    if (l1 ~= []) & (l2 ~= [])
            set(hAllQuery(25),'str',num2str(Rad2Deg(LinkAngle(GPS,l1,l2))));
    end %if%
    figure(CurFig);
```

```
function Rad = Deg2Rad(Deg)

%    CONVERTS: DEG -> RAD
%    Syntax: Rad = Deg2Rad(Deg)

        %This function converts an angle which is in degrees to radians

        %Input:  Deg = Angle in degrees
        %Output: Rad = Converted angle in radians

%    CONVERT ANGLE

        Rad = Deg/180*pi;
```

```
function GPS = DeleteNode(GPS,n)

%   REMOVES A NODE FROM THE GPS MATRIX
%   Syntax: GPS = DeleteNode(GPS,n)

    %This function removes node n from the GPS matrix

    %Input: GPS = Coordinate Matrix
    %       n = Node to be removed (index)
    %Output: GPS = New Coordinate Matrix

%   DEFINE VARIABLES

    SizeOfGPS = size(GPS);

%   3 CASES: n == 1 OR 1 < n < SizeOfGPS(1,1) OR n == SizeOfGPS(1,1)

    if n == 1  %Remove 1st node
            GPS = GPS(2:SizeOfGPS(1,1),:);
    elseif n == SizeOfGPS(1,1)
            GPS = GPS(1:SizeOfGPS(1,1)-1,:);
    else
            Top = GPS(1:n-1,:);
            Bot = GPS(n+1:SizeOfGPS(1,1),:);
            GPS = Top;
            GPS(n:SizeOfGPS(1,1)-1,:) = Bot;
    end %if%
```

```
%   DISPLAY CONTROLS FOR VIEWING NETWORK CONFIGURATIONS

%   TOTAL CONFIGS FOUND

figure(hDisplayBox);
set(hDisplayBox,'name','Network Display Controls');
hAllDisplay(1) = uicontrol('sty','text','pos',[.15 .75 .5 .2],...
'str','Total Configurations Found','unit','norm');
hAllDisplay(2) = uicontrol('sty','text','pos',[.7 .75 .15 .2],'unit','norm',...
'back',CMap2);

%   SHOW ALL CONFIGS

hAllDisplay(3) = uicontrol('sty','push','pos',[.15 .425 .7 .25],'unit','norm',...
'str','Show All Configurations',...
'call','ShowConfigGUI(hAllDisplay,hDispPlot,GPS,U,NetTot,FMap2,1)',...
'back',CMap1);

%   SELECT CONFIGURATION

hAllDisplay(4) = uicontrol('sty','text','pos',[.15 .1 .45 .25],'unit','norm',...
'str','Selected Configuration');
hAllDisplay(5) = uicontrol('sty','edit','pos',[.65 .1 .2 .25],'unit','norm',...
'call','ShowConfigGUI(hAllDisplay,hDispPlot,GPS,U,NetTot,FMap2,0);','back',CMap1)
```

```
function d = Dist(pt1,pt2)

%   CALCULATES DISTANCE BETWEEN TWO PTS
%   Syntax: d = Dist(pt1,pt2)

    %This function calculates the distance between two points

    %Inputs: pt1 = Row vector containing the coordinates of pt 1
    %        pt2 = Row vector containing the coordinates of pt 2
    %Outputs: D = distance between pt1 and pt2


%   CALCULATE DISTANCE

    d = sqrt(sum((pt1-pt2).^2));
```

```
function h = DrawAllU(GPS,U)

%   DRAWS ALL THE LINKS IN U
%   Syntax: h = DrawAllU(GPS,U)

        %This function allows a quick and easy glance at the network
        %to check for connectivity.

        %Input: GPS = Coordinate matrix
        %       U = Column vector of links
        %Output: h = handles for each link

%   DEFINE VARIABLES

        SizeOfU = size(U);

%   DRAW EACH LINK IN U

        for i = 1:SizeOfU(1,1)
                h(i,1) = DrawLink(GPS,U(i,1),[1 1 1]);
        end %for%
```

```
function h = DrawLink(GPS,Link,Color)

%   DRAWS A LINE REPRESENTING A LINK IN A GIVEN COLOR
%   Syntax: h = DrawLink(GPS,Link,Color)

    %This function draws a line between two nodes representing
    %a link.

    %Inputs: GPS = Coordinates of nodes
    %        Link = Link to be drawn
    %        Color = Color of line
    %Output: h = Handle of Line

%   GET COORDINATES

    [n1,n2] = Link2Node(Link);

    x1 = GPS(n1,1);
    x2 = GPS(n2,1);
    y1 = GPS(n1,2);
    y2 = GPS(n2,2);

%   DRAW LINE

    h = line([x1,x2],[y1,y2],'Color',Color);
```

```
function h = DrawLink2(GPS,Link,Label,FMap2)

%   DRAWS SEND/RECEIVE LINES REPRESENTING A LINK IN A GIVEN COLOR
%   THE SEND BEAM (f1) IS ON TOP
%   Syntax: h = DrawLink2(GPS,Link,Label,FMap2)

        %This function draws a line between two nodes representing
        %a link.

        %Inputs: GPS = Coordinates of nodes
        %        Link = Link to be drawn
        %        Label = Frequency label of link
        %        FMap2 = Map of colors for frequencies
        %        Note: 1st row is for no link
        %              2nd row is for f1 ...
        %Output: h = Handle of Line

%   GET COORDINATES

        [n1,n2] = Link2Node(Link);

        x1 = GPS(n1,1);
        x2 = GPS(n2,1);
        y1 = GPS(n1,2);
        y2 = GPS(n2,2);

%   DEFINE OFFSETS

        v = axis;
        dy = (v(1,4)-v(1,3))/80;

%  DRAW EACH FREQUENCY

        [f1,f2] = Label2Freq(Label);
        h(1) = line([x1,x2],[y1+dy,y2+dy],'Color',FMap2(f1+1,:));
        h(2) = line([x1,x2],[y1-dy,y2-dy],'Color',FMap2(f2+1,:));
```

```
function NetHand = DrawNet(GPS,U,CL,FList,ColorMap)

%   DRAWS A NETWORK BASED ON A CONSISTENT LABELING SOLUTION
%   Syntax: NetHand = DrawNet(GPS,U,CL,FList,ColorMap)

    %This function draws a network using different color lines
    %representing links on send/receive frequency pairs

    %Input: GPS = Coordinate Matrix
    %       U = Units of ULTR model
    %       CL = Consistent labeling solution
    %       FList = Label list of frequency pairs
    %       ColorMap = Matrix of color maps for frequencies
    %Output: NetHand = [Link,LinkHandle] Matrix of line handles

%   PLOT GPS

    PlotGPS(GPS);

%   PLOT EACH LINK

    SizeOfU = size(U);
    for i = 1:SizeOfU(1,1)
            [InCL,Index] = IsElement(CL,U(i,1));
            if InCL
                    Index = Index(1,1);
                    Freq = CL(Index,2);
                    [X,FIndex] = IsElement(FList,Freq);
                    FIndex = FIndex(1,1);
                    Color = ColorMap(FIndex,:);
            else
                    Color = [1 1 1];
            end %if%
            NetHand(i,1) = U(i,1);
            NetHand(i,2) = DrawLink(GPS,U(i,1),Color);
    end %for%
```

```
function DrawNet(GPS,U,CL,FMap2)

%   DRAWS A NETWORK BASED ON A CONSISTENT LABELING SOLUTION WITH
%   SEND RECEIVE FREQUENCY LINES
%   Syntax: DrawNet2(GPS,U,CL,FMap2)

        %This function draws a network using different color lines
        %representing links on send/receive frequency pairs

        %Input: GPS = Coordinate Matrix
        %       U = Units of ULTR model
        %       CL = Consistent labeling solution
        %       FMap2 = Matrix of color maps for indiv frequencies

%   PLOT GPS

        PlotGPS(GPS);

%   PLOT EACH LINK

        SizeOfU = size(U);
        for i = 1:SizeOfU(1,1)
                [InCL,Index] = IsElement(CL,U(i,1));
                if InCL
                        Freq = CL(Index(1,1),2);
                        DrawLink2(GPS,U(i,1),Freq,FMap2);
                else
                        DrawLink(GPS,U(i,1),[1 1 1]);
                end %if%
        end %for%
```

```
function h = DrawPat(GPS,Link,Node,Length,Width,Map,Style)

%   DRAWS A BEAM PATTERN FOR A LINK
%   Syntax: h = DrawPat(GPS,Link,Node,Length,Width,Map,'Sytle')

    %This function draws the beam pattern for a link.  The radius
    %of this pattern is specified by Length, and the total
    %beam width is given by Width.

    %Input: GPS = Coordinate matrix
    %       Link = Link for pattern center
    %       Node = Pattern from this point
    %       Length = Radius of pattern
    %       Width = Beamwidth (Degrees)
    %       Map = Color of Lines
    %       Sytle = Sytle of line ( '-' = solid , '--' = dashed)
    %Output: h = Handles for both lines

%   DEFINE VARIABLES

    [n1,n2] = Link2Node(Link);
    if Node == n1  %Define: (x1,y1) as the coordinates of Node
            [x1,y1] = Node2Coord(GPS,n1);
            [x2,y2] = Node2Coord(GPS,n2);
    else
            [x1,y1] = Node2Coord(GPS,n2);
            [x2,y2] = Node2Coord(GPS,n1);
    end %if%
    l = LinkLength(GPS,Link);
    Theta = atan2((y2-y1),(x2-x1)); %Angle of elevation
    Tau = Deg2Rad(Width/2);         %Half the beamwidth

%   DRAW LINE 1

    x3 = Length*cos(Theta + Tau) + x1;
    y3 = Length*sin(Theta + Tau) + y1;
    h(1) = line([x1,x3],[y1,y3],'color',Map,'LineStyle',Style);

%   DRAW LINE 2

    x4 = Length*cos(Theta - Tau) + x1;
    y4 = Length*sin(Theta - Tau) + y1;
    h(2) = line([x1,x4],[y1,y4],'color',Map,'LineStyle',Style);
```

```
function d = FarDist(GPS,Link1,Link2)

%   CALCULATES THE DISTANCE BETWEEN FARTHEST NODES IN LINKS
%   Syntax: d = FarDist(GPS,Link1,Link2)

        %This function calculates the distance bewteen the node in
        %Link1 which is farthest from the the nodes in Link2

        %Input: GPS = Coordinate Matrix
        %       Link1, Link2 = Links to be considered
        %Output: d = distance

%   DEFINE VARIABLES

        [n_11,n_12] = Link2Node(Link1);
        [x_11,y_11] = Node2Coord(GPS,n_11);
        [x_12,y_12] = Node2Coord(GPS,n_12);
        [n_21,n_22] = Link2Node(Link2);
        [x_21,y_21] = Node2Coord(GPS,n_21);
        [x_22,y_22] = Node2Coord(GPS,n_22);

%   CALCULATE DISTANCES

        d11_21 = Dist([x_11,y_11],[x_21,y_21]);
        d11_22 = Dist([x_11,y_11],[x_22,y_22]);
        d12_21 = Dist([x_12,y_12],[x_21,y_21]);
        d12_22 = Dist([x_12,y_12],[x_22,y_22]);

        d = max([d11_21,d11_22,d12_21,d12_22]);
```

```
function Class = FindClass(ProbMat,State,Class)

%   FINDS THE CLASS WHICH HAS State AS A MEMBER
%   Syntax: Class = FindClass(ProbMat,State,Class)

    %This function finds all of the states which can be reached
    %both directly and indirectly from State.  This is a recursive
    %function.  Note: Class is a ROW vector

    %Input: ProbMat = Stochastic matrix of one step transition prob
    %       State = Current state in search
    %       Class = States which have been found to be in class
    %Output: Class = States which have been found to be in class

%   DEFINE VARIABLES

    k = 0;
    Flag = 1;

%   ADD ADJACENT STATES TO Class IF THEY ARE NOT ALREADY THERE

    NextState = AdjState(ProbMat,State);
    SizeOfNextState = size(NextState);
    for i = 1:SizeOfNextState(1,2)
            X = IsElement(Class,NextState(1,i));
            if ~X
                    k = k + 1;
                    Temp(1,k) = NextState(1,i);
            end %if%
    end %for%
    NextState = Temp;
    Class = AddToClass(Class,NextState);

%   CHECK EACH NextState FOR STATES THEY COMMUNICATE WITH

    if size(NextState) ~= 0
            while Flag
                    [s,NextState] = RemoveOneState(NextState);
                    SizeOfNextState = size(NextState);
                    if SizeOfNextState(1,2) == 0
                            Flag = 0;
                    end %if%
                    Class = FindClass(ProbMat,s,Class);
            end %while%
    end %if%
```

```
function [V,VList] = FindV(R,Fail)

%   FINDS THE UNIT WITH THE LEAST AMOUNT OF LABELS LEFT IN R
%   Syntax: [V,VList] = FindV(R,Fail)

      %This function will find the unit in R that has the
      %fewest possible permitted labelings left.  The
      %procedure uses Fail which is the output of the
      %IsSingle routine.

      %Input: R = Unit label constraint relation
      %       Fail = Units which have more than one label left
      %Output: V = Unit with the least number of labels left in R
      %        VList = Possible labels for V

%   DEFINE VARIABLES

      SizeOfFail = size(Fail);
      if SizeOfFail ~= 0
            V = Fail(1,1);
            [SizeOfVList,VList] = LabelLeft(R,Fail(1,1));


%   FIND EACH UNIT AND DETERMINE THE ONE WITH THE SMALLEST NUMBER OF LABELS

            for i = 1:SizeOfFail(1,1)
                  [N,List] = LabelLeft(R,Fail(i,1));
                  if N < SizeOfVList(1,1)
                        V = Fail(i,1);
                        VList = List;
                        SizeOfVList = N;
                  end %if%
            end %for%
      end %if%
```

```
function Color = Freq2Color(Freq,Map)

%   CONVERTS A FREQUENCY PAIR INTO THEIR CORRESPONDING COLOR REPRESENTATION
%   Syntax: Color = Freq2Color(Freq,Map)

    %This function will take a frequency and give it a color
    %based on Map.

    %Input: Freq = Index of frequency pair
    %       Map = Color maps of all frequency pairs with first row
    %             corresponding to the color of the first frequency pair.
    %Output: Color = Frequency pair color map

%   DETERMINE IF LINK IS NIL

    if Freq == 0
            Color = [0 0 0]
    else
            Color = Map(Freq,:)
    end %if%
```

```
function Label = Freq2Label(f1,f2)

%    CONVERTS: Frequencies -> Label
%    Syntax: Label = Freq2Label(f1,f2)

        %This function combines two frequencies into a label
        %in the form of n1777n2

        %Inputs: f1,f2 = Frequencies to be in link
        %Outputs: Label = Label formed

%    COMBINE n1,n2

        if (f1 == 0) & (f2 == 0)
                Label = 0;
        else
                Label = str2num([num2str(f1),'777',num2str(f2)]);
        end %if%
```

```
%   GUI INTERFACE FOR MANIPULATING NODE COORDINATES

%   MAKE PUSHBOTTON "Plot GPS" -> PlotGPS(GPS)

gure(hGPSBox);
t(hGPSBox,'name','GPS Coordinate Controls');
posPlot = [.1 .1 .8 .2];
hPlotGPS = uicontrol('sty','push','pos',posPlot,'unit','norm',...
'call','figure(hNodePlot);PlotGPS(GPS);','str','Plot GPS','background',...
[.5020 .5020 .5020]);

%   MAKE PUSHBOTTON "Add Node" -> GPS = gAddGPS(GPS,1)

figure(hGPSBox);
posAdd = [.1 .4 .35 .15];
hAdd = uicontrol('sty','push','pos',posAdd,'unit','norm',...
'call','figure(hNodePlot);GPS = gAddGPS(GPS,1);v=axis;PlotGPS(GPS);axis(v);ClearI
'back',[.5020 .5020 .5020]);

%   MAKE PUSHBOTTON "Add Node (Random)" -> AddRandPt(GPS,v)

figure(hGPSBox);
posAddR = [.55 .4 .35 .15];
hAddR = uicontrol('sty','push','pos',posAddR,'unit','norm',...
'call','figure(hNodePlot);v=axis;GPS=AddRandPt(GPS,v);PlotGPS(GPS);axis(v);ClearI
'str','Add Node (Random)','back',[.5020 .5020 .5020]);

%   MAKE PUSHBOTTON "Clear GPS" -> clear(GPS);axis([0 10 0 10])

figure(hGPSBox)
posClear = [.25 .8 .5 .15];
hClear = uicontrol('sty','push','pos',posClear,'unit','norm',...
all','figure(hNodePlot);clear GPS;clg;axis([0 10 0 10]);grid;ClearLinkGUI(1,hA]
tr','Clear GPS','back',[.5020 .5020 .5020]);


%   MAKE PUSHBOTTON "Delete Node" -> n=gSelectNode(GPS),GPS=DeleteNode(GPS,n)

figure(hGPSBox)
posDel1 = [.35 .65 .3 .1];
hDel1 = uicontrol('sty','push','pos',posDel1,'unit','norm',...
'call','figure(hNodePlot);n=gSelectNode(GPS);GPS=DeleteNode(GPS,n);ClearLinkGUI(1
'str','Delete Node','back',[.5020 .5020 .5020]);
```

```
function [X,Fail] = IS(U,R)

%   DETERMINES IF R IS A SINGLE VALUED R
%   Syntax: [X,Fail] = IS(R)

        %This function will return a 1 if R contains only one label
        %for each unit present.  If R is not a single labeling
        %then Fail will contain those units in R that have more than one
        %label left

        %Input: R = Unit label constraint relation
        %Output: X = Boolean value (Consistent labeling = 1)
        %        Fail = Those units which have more than one label
        %               left in R

%   DEFINE VARIABLES

        X = 1;
        k = 0;
        UList = UnitOfR(U,R);
        SizeOfUList = size(UList);

%   FOR EACH UNIT DETERMINE IF IT HAS ONLY ONE LABEL PRESENT IN R

        if SizeOfUList(1,1) ~= 0
                for i = 1:SizeOfUList(1,1)
                        [E,Index] = IsElement(R,UList(i,1));
                        SizeOfIndex = size(Index);
                        Label = R(Index(1,1),Index(1,2)+1);
                        for j = 1:SizeOfIndex(1,1)
                                LPrime = R(Index(j,1),Index(j,2)+1);
                                if Label ~= LPrime
                                        X = 0;
                                        Y = IsElement(Fail,UList(i,1));
                                        if ~Y
                                                k = k + 1;
                                                Fail(k,1) = UList(i,1);
                                        end %if%
                                end %if%
                        end %for%
                end %for%
        else
                X = 0;
        end %if%
```

```
function X = IntRange2(GPS,Link1,Link2,IMult,TransmitWidth,ReceiveWidth)

%   DETERMINES IF Link1 WILL POTENTIALLY INTERFERE WITH Link2
%   NEW AND IMPROVED IntRange.m
    Syntax: X = IntRange2(GPS,Link1,Link2,IMult,TransmitWidth,ReceiveWidth)
    ALL ANGLES IN DEGREES

        %Link1 will interfere with Link2 iff any transmitting pattern
        %from a node in Link1 can be received by a node in Link2.
        %This means that the receiving node is in the transmission
        %pattern and the transmitting node is in the receiving pattern.
        %A transmit pattern has a finite range directly proportional
        %to the link length (IMult*LinkLength(GPS,Link1)).  The receive
        %pattern has an infinite range.  In addition the angles
        %(in degrees) are the total angle of propagation.

%   DEFINE VARIABLES

        [N(1),N(2)] = Link2Node(Link1);
        [N(3),N(4)] = Link2Node(Link2);
        IntDist = LinkLength(GPS,Link1)*IMult;
        TAng = Deg2Rad(TransmitWidth/2);
        RAng = Deg2Rad(ReceiveWidth/2);
        k = 0;
        X = [0 0 0 0];

%   CHECK EACH NODE FROM Link1 TO SEE IF ITS TRANSMITTING PATTERN
%   CAN BE RECEIVED BY A NODE FROM Link2

        for i = 1:2
                Tn = N(i);
                for j = 3:4
                        k = k + 1;
                        Rn = N(j);
                        TestLink = Node2Link(Tn,Rn);
                        if Rn ~= Tn
                                % Is Rn close enough to Tn
                                TFlag1 = LinkLength(GPS,TestLink) <= IntDist;
                                % Can TPattern from Tn reach Rn
                                TFlag2 = LinkAngle(GPS,TestLink,Link1) <= TAng;
                                % Can RPattern from Rn reach Tn
                                RFlag = LinkAngle(GPS,TestLink,Link2) <= RAng;
                                if TFlag1 & TFlag2 & RFlag
                                        X(k) = 1;
                                else
                                        X(k) = 0;
                                end %if%
                        end %if%
                end %for%
        end %for%

%disp('X = [1w3   1w4    2w3    2w4]');
```

```
function X = IsCL(T,R,CL)

%   DETERMINES IF A LABELING IS A CONSISTENT LABELING WITH RESPECT TO T AND R
%   FOR A ULTR MODEL WITH N = 2
%   Syntax: X = IsCL(T,R,CL)

      %This function determines if the proposed labeling (CL) is
      %a consistent labeling with respect to T and R.  A consistent
      %labeling means that when the labeling is assigned to T the
      %2N-tuples formed are members of R

      %Input: T = Unit constraint relation
      %       R = Unit label constraint relation
      %       CL = Proposed labeling
      %Output: X = Boolean value (Consistent labeling = 1)

%   DEFINE VARIABLES

      X = 1;
      SizeOfT = size(T);

%   ASSIGN LABELS TO UNITS IN T AND CHECK FOR THEIR OCCURENCE IN R

      for i = 1:SizeOfT(1,1)
              u1 = T(i,1);
              u2 = T(i,2);
              [Nil,I1] = IsElement(CL,u1);
              [Nil,I2] = IsElement(CL,u2);
              l1 = CL(I1(1,1),2);
              l2 = CL(I2(1,1),2);
              Y = IsMember(R,[u1 l1 u2 l2]);
              y = IsMember(R,[u2 l2 u1 l1]);
              if ~(y|Y) & (u1~=u2)
                      X = 0;
              end %if%
      end %for%
```

```
function [x,Index] = IsElement(Matrix,Element)

%   DETERMINES WHETHER AN ELEMENT EXISTS IN A MATRIX
%   Syntax: [x,Index] = IsElement(Matrix,Element)

    %This function is used to determine whether an element exists
    %in any cell of the matrix

    %Input: Matrix = Matrix to be considered
    %       Element = Element to be searched for
    %Output: x = boolean value (1 -> Exist)
    %        Index = Indices of Element's locations in Matrix


%   SUBTRACT DESIRED VALUE AND THEN CHECK FOR ZERO ELEMENTS

    [Row,Col] = find(~(Matrix-Element));
    [x] = ~isempty(Row);
    if x
            Index(:,1) = Row;
            Index(:,2) = Col;
    end %if%
```

```
function [X,Index] = IsMember(Matrix,Member)

%   DETERMINES IF Member IS EXISTS AS A ROW IN Matrix
%   Syntax: [X,Index] = IsMember(Matrix,Member)

        %The function finds a set of elements within a row of a matrix.
        %A 1 is returned if Member is found within Matrix.

        %Input: Matrix = Matrix to be searched
        %       Member = Elements to be searched for
        %Output: X = Boolean value (1 -> Member is in Matrix)

%   SEARCH EVERY ROW FOR Member

        SizeOfMatrix = size(Matrix);
        SizeOfMember = size(Member);
        if Matrix ~= [] & Member ~= []
                for i = 1:SizeOfMember(1,2)
                        SubMat(:,i) = Matrix(:,i)-Member(1,i);
                end %for%
                X = any(find(all(~SubMat')));
                Index = find(all(~SubMat'));
        else
                X = 0;
        end %if%
```

```
function X = IsOneClass(CL,U,NetSize)

%   DETERMINES IF ALL OF THE NODES CAN COMMUNICATE WITH EACH OTHER
%   Syntax: X = IsOneClass(CL,U,NetSize)

      %This function converts a consistent labeling into a
      %connectivity matrix of ones and zeros.  It then
      %checks to see if all of the nodes are in communication
      %with each other.

%   DEFINE VARIABLES

      X = 0;
      PMat = CL2Mat(CL,U,NetSize);
      Class = FindClass(PMat,1,[]);
      SizeOfClass = size(Class);

%   ARE ALL NODES INCLUDED IN THE CLASS?

      if SizeOfClass(1,2) == NetSize
            X = 1;
      end %if%
```

```
function [X,Fail] = IsTInR(T,R)

%   DETERMINES IF ALL MEMBERS OF T ARE IN R
%   Syntax: [X,Fail] = IsTInR(T,R)

        %This function takes each member of T and searches
        %R to see if it is contained within.

        %Input: T = Unit Constraint Relation (N = 2)
        %       R = Unit Label Constraint Relation (N = 2)
        %Ouput: X = Boolean value (1 = T was found in R)
        %       Fail = Members of T not in R

%   DEFINE VARIABLES

        R2(:,1) = R(:,1);
        R2(:,2) = R(:,3);
        X = 1;
        k = 0;
        SizeOfT = size(T);

%   TAKE EACH MEMBER OF T AND SEARCH R

        for i = 1:SizeOfT(1,1)
                M = IsMember(R2,T(i,:));
                if ~M
                        k = k + 1;
                        Fail(k,:) = T(i,:);
                        X = 0;
                end %if%
        end %for%
```

```
function [X,Index] = IsULPair(R,Unit,Label)

%   DETERMINES IF THE UNIT LABEL PAIR OCCURS IN R
%   Syntax: [X,Index] = IsULPair(R,Unit,Label)

    %This function will determine if and where a unit label
    %pair occurs in R.

    %Input: Unit, Label = Pair to be searched for
    %       R = Unit Label Constraint Relation
    %Output: X = Boolean value (1 = Pair exists)
    %        Index = (Row,Col) Index of every occurence of the pair
    %                Note: The index is of the unit

%  DEFINE VARIABLES

    X = 0;
    k = 0;
    SizeOfR = size(R);

%  SEARCH EVERY ROW AND COLUMN FOR THE PAIR

    for i = 1:SizeOfR(1,1)                    %  Do for each row
        for j = 1:2:SizeOfR(1,2)              %  Do for every odd column
            if (R(i,j)==Unit) & (R(i,j+1)==Label)
                k = k + 1;
                X = 1;
                Index(k,1) = i;
                Index(k,2) = j;
            end %if%
        end %for%
    end %for%
```

```
function [f1,f2] = Label2Freq(Label)

%   CONVERTS: Label -> Frequencies
%   Syntax: [f1,f2] = Label2Freq(Label)

        %This function converts a label (format of 'freq 1' '777' 'freq 2')
        %back into its frequency components


%   GET FREQ 1

        if Label == 0
                f1 = '0';
        else
                Label = abs(int2str(Label));
                SizeOfLabel = size(Label);
                for i = 1:max(findstr(Label,'777'))-1
                        f1(1,i) = Label(1,i);
                end %for%
        end %if%

%   GET FREQ 2

        if Label == 0
                f2 = '0';
        else
                j = 0;
                for i = max(findstr(Label,'777'))+3:SizeOfLabel(1,2)
                        j = j + 1;
                        f2(1,j) = Label(1,i);
                end %for%
        end %if%

%   CONVERT NODES TO NUMBERS


        f1 = str2num(setstr(f1));
        f2 = str2num(setstr(f2));
```

```
function LabelGPS(GPS)

%   DISPLAYS INDEX LABELS ON NODES
%   Syntax: LabelGPS(GPS)

      %This function labels the nodes defined by GPS.  Labels are the
      %index of each node

      %Input: GPS = Coordinate Matrix

%   DEFINE VARIABLES

      x = GPS(:,1);
      y = GPS(:,2);
      SizeOfGPS = size(GPS); SizeOfGPS = SizeOfGPS(1,1);

%   LABEL NODES

      for i = 1:SizeOfGPS
            text(x(i)+max(x)/100,y(i),num2str(i));
      end %for%
```

```
function [N,List] = LabelLeft(R,Unit)

%   RETURNS A THE NUMBER OF LABELS LEFT AND A LIST OF THOSE IN R
%   Syntax: [N,List] = LabelLeft(R,Unit)

        %This function returns all the labels associated with a unit in
        %R as well as the number of labels left.

        %Input: R = Unit label constraint relation
        %       Unit = Unit to be considered
        %Output: N = Number of labels paired with Unit
        %        List = List of those labels paired with Unit

%   DEFINE VARIABLES

        N = 0;
        [X,Index] = IsElement(R,Unit);
        SizeOfIndex = size(Index);

%   SEARCH R FOR Unit AND RECORD THE LABEL

        for i = 1:SizeOfIndex(1,1)
                Label = R(Index(i,1),Index(i,2)+1);
                Y = IsElement(List,Label);
                if ~Y
                        N = N + 1;
                        List(N,1) = Label;
                end %if%
        end %for%
```

```
function [n1,n2] = Link2Node(Link)

%    CONVERTS: Link -> Node
%    Syntax: [n1,n2] = Link2Node(Link)

        %This function converts a link (format of 'node 1' '000' 'node 2')
        %back into its node components


%    GET NODE 1

        Link = abs(int2str(Link));
        SizeOfLink = size(Link);
        for i = 1:max(findstr(Link,'000'))-1
                n1(1,i) = Link(1,i);
        end %for%

%    GET NODE 2

        j = 0;
        for i = max(findstr(Link,'000'))+3:SizeOfLink(1,2)
                j = j + 1;
                n2(1,j) = Link(1,i);
        end %for%

%    CONVERT NODES TO NUMBERS

        n1 = str2num(setstr(n1));
        n2 = str2num(setstr(n2));
```

```
function Theta = LinkAngle(GPS,Link1,Link2)

%   CALCULATES THE ANGLE BETWEEN TWO LINKS
%   Syntax: Theta = LinkAngle(GPS,Link1,Link2)  *** Radians ***

      %This function determines the angle between two links

      %Inputs: GPS = Matrix of node coordinates
      %        Link1,Link2 = Links to be considered
      %Outputs: Theta = angle between two links

%   DEFINE VARIABLES

      [n_11,n_12] = Link2Node(Link1);
      [x_11,y_11] = Node2Coord(GPS,n_11);
      [x_12,y_12] = Node2Coord(GPS,n_12);
      [n_21,n_22] = Link2Node(Link2);
      [x_21,y_21] = Node2Coord(GPS,n_21);
      [x_22,y_22] = Node2Coord(GPS,n_22);
      [x_i,y_i] = LinkInter(GPS,Link1,Link2);

%   DETERMINE ANGLE

      if n_11 == n_21
            Theta = Ang([x_12,y_12],[x_11,y_11],[x_22,y_22]);
      elseif n_11 == n_22
            Theta = Ang([x_12,y_12],[x_11,y_11],[x_21,y_21]);
      elseif n_12 == n_21
            Theta = Ang([x_11,y_11],[x_12,y_12],[x_22,y_22]);
      elseif n_12 == n_22
            Theta = Ang([x_11,y_11],[x_12,y_12],[x_21,y_21]);
      elseif (x_i == Inf) & (y_i == Inf)  %Parallel links
            Theta = Inf;
      else
            Theta = Ang([x_11,y_11],[x_i,y_i],[x_21,y_21]);
      end %if%
```

```
function [x,y] = LinkInter(GPS,Link1,Link2)

%   FINDS THE PT OF INTERSECTION BETWEEN TWO NODES
%   Syntax: [x,y] = LinkInter(GPS,Link1,Link2)

    %This function finds the point of intersection of the lines
    %defined by Link1,Link2)

    %Input: GPS = Matrix of Coordinates
    %       Link1,Link2 = Links which define lines
    %Output: [x,y] =  Point of intersection

%   DEFINE VARIABLES

    [a1,b1] = LinkLine(GPS,Link1);
    [a2,b2] = LinkLine(GPS,Link2);

%   FIND INTERSECTION

    if a1 ~= a2     %Non Parallel Lines
            if abs(a1) == Inf       % Vertical Line
                    x = b1;
                    y = a2*x + b2;
            elseif abs(a2) == Inf   %Vertical Line
                    x = b2;
                    y = a1*x + b1;
            else                    %Non Vertical Line
                    x = (b2-b1)/(a1-a2);
                    y = a1*x + b1;
            end %if%
    else            % Parallel Lines
            x = Inf;
            y = Inf;
    end %if%
```

```
function d = LinkLength(GPS,Link)

%   RETURNS THE LENGTH OF A LINK
%   Syntax: d = LinkLength(GPS,Link)

        %This function calculates the distance between the two nodes
        %of the Link.

        %Input: GPS = Coordinat Matrix
        %       Link = Link to be considered
        %Output: d = Length of link

%  DEFINE VARIABLES

        [n1,n2] = Link2Node(Link);
        [x1,y1] = Node2Coord(GPS,n1);
        [x2,y2] = Node2Coord(GPS,n2);

%  CALCULATE DISTANCE

        d = Dist([x1,y1],[x2,y2]);
```

```
function [a,b] = LinkLine(GPS,Link)

%   CALCULATES THE COEFF OF THE LINE THRO LINK
%   Syntax: [a,b] = LinkLine(GPS,Link)

    %This function returns the coeffiecients of the link
    %that is formed by a link

    %Inputs: GPS = Coordinate Matrix
    %        Link = Link from which line is defined
    %Outputs: [a,b] = [Slope,Y-Intercept] or for a vertical line
    %                 [Inf,X-Intercept]

%   DEFINE VARIABLES

    [n1,n2] = Link2Node(Link);
    x1 = GPS(n1,1);
    y1 = GPS(n1,2);
    x2 = GPS(n2,1);
    y2 = GPS(n2,2);

%   CALCULATE SLOPE

    m = (y2-y1)/(x2-x1);

%   CALCULATE LINE

    if abs(m) ~= Inf
            a = [m];
            b = [(-m*x1 + y1)];
    else
            a = [m];
            b = [x1];
    end %if%
```

```
function [x,y] = LinkMid(GPS,Link)

%   CALCULATES THE MIDPOINT OF A LINK
%   Syntax: [x,y] = LinkMid(GPS,Link)

        %This function calculates the midpoint of a link

        %Input: GPS = Coordinate matrix
        %       Link = Link to be considered
        %Output: [x,y] = Coordinates of MidPoint


%   CALCULATE MIDPOINT

%   DEFINE VARIABLES

        [n1,n2] = Link2Node(Link);
        [x1,y1] = Node2Coord(GPS,n1);
        [x2,y2] = Node2Coord(GPS,n2);

%   CALCULATE

        x = (x1 + x2)/2;
        y = (y1 + y2)/2;
```

```
function [GPS,x,y] = MakeGPS(Size)

%   CREATES, SORTS, GRAPHS, AND LABELS RANDOM GPS COORDINATES
%   Syntax: [GPS,x,y] = MakeGPS(Size)

    %This function creates a matrix of size (Size) of random
    %coordinates.

%   MAKE COORDINATES

    GPS = 100*SortGPS(rand(Size));
    x = GPS(:,1);
    y = GPS(:,2);

%   PLOT AND LABEL NOBES

    plot(x,y,'*');
    axis('equal');
    axis('square');
    SizeX = size(x);
    for i = 1:SizeX(1,1);
            text(x(i)+1,y(i),num2str(i));
    end %for%
```

```
function L = MakeL2(MaxFreq)

%    CREATES A MATRIX OF LABELS FOR LINKS
%    NEW AND IMPROVED MakeL.m
%    Syntax: L = MakeL2(MaxFreq)

        %This function creates the label column vector (L) by permutating
        %the possible frequencies taking 2 at a time

        %Input: MaxFreq = Maximum Frequencies Permitted
        %Output: L = Label list of frequencies

%    INITIALIZE VARIABLES

        Flag = 1;
        k = 1;
        L(1,1) = 0;
%    CREATE L

        fprintf('**** MakeL2.m Started ****\n\n')
        for f1 = 1:MaxFreq
                for f2 = 1:MaxFreq
                        if f1 ~= f2
                                k = k + 1;
                                L(k,1) = Freq2Label(f1,f2);
                        end %if%
                end %for%
        end %for%
```

```
function R = MakeR2(L,T,X1,X2)

%    CREATES THE UNIT-LABEL CONSTRAINT R
%    NEW AND IMPROVED MakeR.m
     Syntax: R = MakeR2(L,T,X1,X2)

         %This function assigns allowable frequency labels to members
         %of T based on the constraining nodes in X (X is created by MakeT2.m)
         %If link 10002 and link 30004 operating on f1777f2 and
         %f3777f4 contain nodes which interfere, the
         %assignment of frequencies would go as follows.
         %If 1 interferes with 3 then f1 ~= f4
         %If 1 interferes with 4 then f1 ~= f3
         %If 2 interferes with 3 then f2 ~= f4
         %If 2 interferes with 4 then f2 ~= f3

         %Input: L = Set of Labels (Pairs in this case)
         %       T = Unit Constraint Relation
         %       X1,X2 = Explicit node constraints from MakeT2.m
         %Output: R = Unit-Label Constraint Relation

%    CREATE R

         fprintf('**** MakeR2.m Started ****\n\n')
         z = 0;
         SizeOfL = size(L);SizeOfL = SizeOfL(1,1);
         SizeOfT = size(T);SizeOfT = SizeOfT(1,1);

         for i = 1:SizeOfT
                 tic
                 for j = 1:SizeOfL
                         [f1 f2] = Label2Freq(L(j,1));
                         for k = 1:SizeOfL
                                 [f3 f4] = Label2Freq(L(k,1));
                                 %Restrict frequencies based
                                 %on nodes from link1 interfering
                                 %with nodes on link2
                                 I13 = ~((X1(i,1) > 0) & (f1 == f4));
                                 I14 = ~((X1(i,2) > 0) & (f1 == f3));
                                 I23 = ~((X1(i,3) > 0) & (f2 == f4));
                                 I24 = ~((X1(i,4) > 0) & (f2 == f3));
                                 C1 = (I13 & I14 & I23 & I24);
                                 %Restrict frequencies based on nodes
                                 %from link2 interfering
                                 %with nodes on link1
                                 I31 = ~((X2(i,1) > 0) & (f3 == f2));
                                 I32 = ~((X2(i,2) > 0) & (f3 == f1));
                                 I41 = ~((X2(i,3) > 0) & (f4 == f2));
                                 I42 = ~((X2(i,4) > 0) & (f4 == f1));
                                 C2 = (I31 & I32 & I41 & I42);
                                 if (C1 & C2) | (f1==0 & f2==0)
                                         z = z + 1;
                                         R(z,1) = T(i,1);
                                         R(z,2) = L(j,1);
                                         R(z,3) = T(i,2);
                                         R(z,4) = L(k,1);
                                 end %if%
                         end %for%
                 end %for%
                 fprintf('Progress: %3.2f percent\n',i/SizeOfT*100);
                 fprintf('Time per Outer Loop: %1.3f seconds\n',toc)
         end %for%
```

```
function [T,X1,X2] = MakeT2(GPS,U,IMult,TWidth,RWidth)

%   CREATES MATRIX OF UNIT CONSTRAINT RELATIONS
%   NEW AND IMPROVED MakeT.m
%   Syntax: [T,X1,X2] = MakeT2(GPS,U,IMult,TWidth,RWidth)
%   ALL ANGLES IN DEGREES

      %This function produces the matrix T which contains all of the
      %links that constrain each other.  Two links will constrain
      %each other iff they are potentially interfering.
      %Link1 will interfere with Link2 iff any transmitting pattern
      %from a node in Link1 can be received by a node in Link2.
      %This means that the receiving node is in the transmission
      %pattern and the transmitting node is in the receiving pattern.
      %A transmit pattern has a finite range directly proportional
      %to the link length (IMult*LinkLength(GPS,Link1)).  The receive
      %pattern has an infinite range.  In addition the angles
      %(in degrees) are the total angle of propagation.

      %Inputs: GPS = Coordinates of nodes (One row per node)
      %        U = Units or possible links
      %        IMult = The multiplier used to determine
      %                the interference radius.
      %        TWidth = Total bandwidth of transmitting pattern
      %        RWidth = Total bandwidth of receiving pattern
      %Outputs: T = Unit Constraint Relationship of (U,L,T,R) model
      %         X1 = Explicitly shows which nodes on Link 1
      %              constrain those nodes on Link 2
      %              (X1 = [1w3 1w4 2w3 2w4]) where Link1 = 10002
      %                                            Link2 = 30004
      %              and the member of T = [Link1 Link2]
      %         X2 = Explicitly shows which nodes on Link2 constrain
      %              those nodes on Link1. X2 is the same
      %              as above but now Link1 = 30004, Link2 = 10002

%   FIND ALL LINKS WHICH CONSTRAIN EACH OTHER

      fprintf('**** MakeT2.m Started ****\n\n');
      SizeOfU = size(U);SizeOfU = SizeOfU(1,1);
      k = 0;
      for i = 1:SizeOfU
              tic
              for j = (i+1):SizeOfU
                   %tic
                   if i~=j
                       I1 = IntRange2(GPS,U(i),U(j),IMult,TWidth,RWidth);
                       I2 = IntRange2(GPS,U(j),U(i),IMult,TWidth,RWidth);
                              %Rearrange I2 to match node pairs of I1
                              %and add
                       %I = I1 + 2*[I2(1),I2(3),I2(2),I2(4)];
                       M = ~(IsMember(T,[U(i),U(j)])|IsMember(T,[U(j),U(i)]));
                       if (max(I1) >= 1 | max(I2) >= 1) & M
                              k = k + 1;
                              X1(k,:) = I1;
                              X2(k,:) = I2;
                              T(k,1) = U(i);
                              T(k,2) = U(j);
                       end %if%
                      end %if%
                      %ILoop = toc;
                      %fprintf('Inner Loop Time %3.1f\n',ILoop);
                   end %for%
              Progress = i/SizeOfU*100;
              fprintf('MakeT Progress: %3.2f percent\n',Progress);
              OLoop = toc;
              fprintf('Time per Outer Loop: %1.3f seconds\n',OLoop);
```

```
end %for%
```

```
function U = MakeU(GPS,LRad)

%    CREATES COLUMN VECTOR OF UNITS
%    Syntax: U = MakeU(GPS,LRad)

        %This function produces the vector U which contains all of the
        %links which are possible given LRad.

        %Inputs: GPS = Coordinates of nodes (One row per node)
        %        LRad = Maximum Link Radius
        %Outputs: U = Unit Vecor of the (U,L,T,R) model

%    UNITS BASED ON LINK RADIUS

        fprintf('**** MakeU.m Started ****\n\n');
        SizeOfGPS = size(GPS);
        k = 0;
        for i = 1:SizeOfGPS(1,1)
                for j = i:SizeOfGPS(1,1)
                        if i ~= j
                                p1 = GPS(i,:);
                                p2 = GPS(j,:);
                                d = Dist(p1,p2);
                                if d <= LRad
                                        k = k + 1;
                                        U(k,1) = Node2Link(i,j);
                                end %if%
                        end %if%
                end %for%
        end %for%
```

```
function [U,L,T,R,X1,X2] = MakeULTR2(GPS,Config)

%   GENERATES THE HARALICK U,L,T,R MODEL
%   NEW AND IMPROVED MakeULTR.m
%   Syntax: [U,L,T,R,X1,X2] = MakeULTR2(GPS,Config)

    %This function generates a (U,L,T,R) Model as described by Haralick
    %in his paper "Consistent Labeling".  The model describes a radio
    %network in which the links interfere with each other

    %Input: GPS = Coordinate Matrix (Row Vector)
    %       Config = Configuration Matrix
    %                [LRad = Max linking radius
    %                 FreqMax = Maximum number of frequencies
    %                 IMult = Multiplier for determining interference rad
    %                 TWidth = Total beamwidth of transmitting pattern
    %                 RWidth = Total beamwidth of receiving pattern
    %Output: U = Set of units (Links)
    %        L = Set of labels for units (Frequencies)
    %        T = Unit constraint relation
    %        R = Unit-Label constrain relation

%   READ Config MATRIX

    clc;
    disp('Loading Configuration');
    LRad = Config(1,1);
    FreqMax = Config(1,2);
    IMult = Config(1,3);
    TWidth = Config(1,4);
    RWidth = Config(1,5);

    CREATE U

    disp('Creating U:  Units');
    U = MakeU(GPS,LRad);

%   CREATE L

    disp('Creating L:  Labels');
    L = MakeL2(FreqMax);

%   CREATE T

    clc;
    disp('Creating T:  Unit Constraint Relation');
    [T,X1,X2] = MakeT2(GPS,U,IMult,TWidth,RWidth);

%   CREATE R

    clc;
    disp('Creating R:  Unit-Label Constraint Relation');
    R = MakeR2(L,T,X1,X2);
```

```
function d = MidDist(GPS,Link1,Link2)

%   CALCULATE DISTANCE BETWEEN LINK MIDPOINTS
%   Syntax: d = MidDist(GPS,Link1,Link2)

        %This function returns the distance between the midpoints of
        %two links

        %Input: GPS = Matrix of Coordinates
        %       Link1,Link2 = Links to be considered
        %Output: d = Distance between midpoints

%   DEFINE VARIABLES

        [x1,y1] = LinkMid(GPS,Link1);
        [x2,y2] = LinkMid(GPS,Link2);

%   CALCULATE DISTANCE

        d = Dist([x1,y1],[x2,y2]);
```

```
function [x,y] = Node2Coord(GPS,Node)

%    CONVERTS: Node -> Coord
%    Syntax: [x,y] = Node2Coord(GPS,Node)

        %This function converts a the Node (index) into its GPS
        %coordinates

        %Input: GPS = Matrix of Coordinates
        %       Node = Index of desired node
        %Output: [x,y] = Coordinates of node

%    GET COORDINATES

        x = GPS(Node,1);
        y = GPS(Node,2);
```

```
function Out = Node2Link(n1,n2)

%    CONVERTS: Node -> Link
%    Syntax: Node2Link(n1,n2)

        %This function combines two node indices into a link
        %in the form of n1000n2

        %Inputs: n1,n2 = Nodes to be incorporated into link
        %Outputs: Out = Link formed from nodes

%    COMBINE n1,n2

        if n1 <= n2
                Out = str2num([num2str(n1),'000',num2str(n2)]);
        else
                Out = str2num([num2str(n2),'000',num2str(n1)]);
        end %if%
```

```
function d = PDist(Coeff,pt)

%   CALCULATES THE PERPENDICULAR DISTANCE BETWEEN LINE AND PT
%   Syntax: d = PDist(Coeff,pt)

      %This function finds the perpendicular distance from the line
      %y = ax + b and the point pt.

      %Inputs: Coeff = Coefficients of line
      %        pt = Point to be considered
      %Outputs: d = Perpendicular distance

%  DEFINE VARIABLES AND MATRICES

      xo = pt(1,1);
      yo = pt(1,2);
      a = Coeff(1,1);
      b = Coeff(1,2);

% FIND INTERSECTION OF LINE (y = ax + b) AND ITS PERP LINE THRO pt

      if a == 0                %horizonal line
            x = xo;
            y = a*x + b;
      elseif abs(a) == Inf            %vertical line
            x = b;
            y = yo;
      else
            x = (yo+1/a*xo-b)/(a+1/a);
            y = a*x+b;
      end %if%

%  CALCULATE DISTANCE BETWEEN [x,y] AND [xo,yo]

      d = Dist([x,y],pt);
```

```
function PlotGPS(GPS)

%   PLOTS AND LABELS THE NODES IN GPS
%   Syntax: PlotGPS(GPS)

        %This function plots the nodes defined by GPS.

        %Input: GPS = Coordinate Matrix

%   DEFINE VARIABLES

        x = GPS(:,1);
        y = GPS(:,2);

%   PLOT

        plot(x,y,'*')
        axis('square')
        axis('equal')

%   LABEL

        LabelGPS(GPS);
        title('Network of ATM Switch Nodes');...
        xlabel('Distance Units');...
        ylabel('Distance Units');...
        grid;
```

```
%   GUI FOR QUERY CONTROLS

%   "Select Link 1" PUSHBOTTON

CMap1 = [.5020 .5020 .5020];
CMap2 = [.85 .85 .85];

figure(hQueryBox)
set(hQueryBox,'name','Link Query Controls')

posSel1 = [.1 .85 .35 .1];
hAllQuery(1) = uicontrol('sty','push','pos',posSel1,'unit','norm',...
'call','Link1=SelectLinkGUI(GPS,U,1,hNodePlot,hAllQuery);ZoomBox',...
'str','Select Link 1','back',CMap1);

%   "Select Link 2" PUSHBOTTON

figure(hQueryBox)
posSel2 = [.55 .85 .35 .1];
hAllQuery(2) = uicontrol('sty','push','pos',posSel2,'unit','norm',...
'call','Link2=SelectLinkGUI(GPS,U,2,hNodePlot,hAllQuery);ZoomBox',...
'str','Select Link 2','back',CMap1);

%   "Define Link 1" PUSHBOTTON

figure(hQueryBox)
posDef1 = [.1 .7 .35 .1];
hAllQuery(3) = uicontrol('sty','push','pos',posDef1,'unit','norm',...
'call','Link1=DefineLinkGUI(GPS,1,hNodePlot,hAllQuery);ZoomBox',...
'str','Define Link 1','back',CMap1);

%   "Define Link 2" PUSHBOTTON

figure(hQueryBox)
posDef2 = [.55 .7 .35 .1];
hAllQuery(4) = uicontrol('sty','push','pos',posDef2,'unit','norm',...
'call','Link2=DefineLinkGUI(GPS,2,hNodePlot,hAllQuery);ZoomBox',...
'str','Define Link 2','back',CMap1);

%   TEXT DISPLAY "Link 1"

figure(hQueryBox)
posLink1Txt = [.18 .625 .2 .05];
hAllQuery(5) = uicontrol('sty','text','pos',posLink1Txt,'unit','norm',...
'str','Link 1');

%   TEXT DISPLAY "Link 2"

figure(hQueryBox)
posLink2Txt = [.62 .625 .2 .05];
hAllQuery(6) = uicontrol('sty','text','pos',posLink2Txt,'unit','norm',...
'str','Link 2');

%   TEXT DISPLAY of Link1

figure(hQueryBox)
posLink1Val = [.18 .55 .2 .05];
hAllQuery(7) = uicontrol('sty','text','pos',posLink1Val,'unit','norm',...
'back',CMap2);

%   TEXT DISPLAY of Link2

figure(hQueryBox)
posLink2Val = [.62 .55 .2 .05];
hAllQuery(8) = uicontrol('sty','text','pos',posLink2Val,'unit','norm',...
'back',CMap2);
```

```
%   NODE COORDINATES

figure(hQueryBox)
hAllQuery(9) = uicontrol('sty','text','pos',[.4 .45 .2 .065],'unit','norm',...
'str','Node Information');
hAllQuery(10) = uicontrol('sty','text','pos',[.225 .4 .05 .05],...
'unit','norm','str','1');
hAllQuery(11) = uicontrol('sty','text','pos',[.725 .4 .05 .05],...
'unit','norm','str','2');
hAllQuery(12) = uicontrol('sty','text','pos',[.45 .39 .1 .05],...
'unit','norm','str','[x;y]');
hAllQuery(13) = uicontrol('sty','text','pos',[.05 .325 .15 .05],...
'back',CMap2,'unit','norm');
hAllQuery(14) = uicontrol('sty','text','pos',[.3  .325 .15 .05],...
'back',CMap2,'unit','norm');
hAllQuery(17) = uicontrol('sty','text','pos',[.05 .265 .15 .05],...
'back',CMap2,'unit','norm');
hAllQuery(18) = uicontrol('sty','text','pos',[.3  .265 .15 .05],...
'back',CMap2,'unit','norm');
hAllQuery(15) = uicontrol('sty','text','pos',[.55 .325 .15 .05],...
'back',CMap2,'unit','norm');
hAllQuery(16) = uicontrol('sty','text','pos',[.8  .325 .15 .05],...
'back',CMap2,'unit','norm');
hAllQuery(19) = uicontrol('sty','text','pos',[.55 .265 .15 .05],...
'back',CMap2,'unit','norm');
hAllQuery(20) = uicontrol('sty','text','pos',[.8  .265 .15 .05],...
'back',CMap2,'unit','norm');

%   "LinkLength"

hAllQuery(21) = uicontrol('sty','text','pos',[.4 .175 .2 .065],'unit',...
'norm', 'str','Length');
hAllQuery(22) = uicontrol('sty','text','pos',[.15 .165 .2 .05],...
'back',CMap2,'unit','norm');
hAllQuery(23) = uicontrol('sty','text','pos',[.645 .165 .2 .05],...
'back',CMap2,'unit','norm');

%   "Angle"

hAllQuery(24) = uicontrol('sty','text','pos',[.4 .08 .2 .065],'unit','norm',...
'str','Angle (Deg)');
hAllQuery(25) = uicontrol('sty','text','pos',[.4 .01 .2 .05],...
'back',CMap2,'unit','norm');

%   "Clear Link 1"

hAllQuery(26) = uicontrol('sty','push','pos',[.1 .01 .15 .037],...
'unit','norm','call','ClearLinkGUI(1,hAllQuery);ZoomBox',...
'str','Clear Link 1',...
'back',CMap1);

%   "Clear Link 2"

hAllQuery(27) = uicontrol('sty','push','pos',[.75 .01 .15 .037],...
'unit','norm','call','ClearLinkGUI(2,hAllQuery);ZoomBox',...
'str','Clear Link 2',...
'back',CMap1);
```

```
%   MAIN CONTROL FOR RDRN

    %This m file loads a graphic user interface
    %for use with a consistent labeling algorithm for
    %frequency assignments for RDRN


%   SET FIGURE HANDLES

    hGPSBox = 1;
    hQueryBox = 2;
    hZoomBox = 3;
    hConfigBox = 4;
    hNodePlot = 5;
    hDisplayBox = 6;
    hDispPlot = 7;

%   DEFAULT CONFIGURATIONS

    DefConfig = [5 3 3 10 10];
    FMap = [0 0 0;1 0 0;0 1 0;0 0 1;1 1 0;1 0 1;0 1 1];
    FMap2 = [0 0 0;1 0 0;0 1 0;0 0 1];

%   BRING UP GPSBox

    figure(hGPSBox);...
    set(hGPSBox,'pos',[6 830 553 164]);
    GPSBox;

%   BRING UP QUERY BOX;

    figure(hQueryBox);...
    set(hQueryBox,'pos',[4 375 557 425]);
    QueryBox;

%   BRING UP ZOOM BOX

    figure(hZoomBox);
    set(hZoomBox,'pos',[828 42 440 383],...
    'name','Zoom Window of Chosen Links');

%   BRING UP CONFIG BOX

    figure(hConfigBox);...
    set(hConfigBox,'pos',[571 337 479 309]);
    ConfigBox;
    Config = SetConfigGUI(hAllConfig,0,DefConfig);

%   BRING UP MAIN NODE PLOT

    figure(hNodePlot);...
    set(hNodePlot,'pos',[575 578 560 420],'name','Main Plot of ATM Nodes');
    axis([0 10 0 10]);...
    grid

%   BRING UP DISPLAY CONTROLS

    figure(hDisplayBox);...
    set(hDisplayBox,'pos',[700   344   392    90]);...
    set(hDisplayBox,'name','Network Display Controls');...
    DisplayBox;

%   BRING UP NETWORK DISPLAY PLOT

    figure(hDispPlot);...
    set(hDispPlot,'pos',[658   466   438   341]);...
```

```
set(hDispPlot,'name','Network Display Plot');
```

```
function Deg = Rad2Deg(Rad)

%  CONVERTS: Radians -> Degrees
%  Syntax: Deg = Rad2Deg(Rad)

        %This function converts an angle which is in degrees to radians

        %Input:  Rad = Angle in radians
        %Output: Deg = Converted angle in degrees

%   CONVERT ANGLE

        Deg = Rad*180/pi;
```

```
function [l,NewList] = RemoveOneLabel(OldList)

%    REMOVES THE FIRST LABEL FROM A LIST AND RETURNS BOTH
%    Syntax: [l, NewList] = RemoveOneLabel(OldList)

     %This function will remove the first label from a list
     %and then return that label and the list minus the removed
     %label

     %Input: OldList = List of labels (Column Vector)
     %Output: l = First label from OldList
     %        NewList = OldList minus l (Column Vector)

%    DEFINE VARIABLES

     SizeOfOldList = size(OldList);

%    REMOVE 1st LABEL

     l = OldList(1,1);

%    GENERATE NEWLIST

     for i = 2:SizeOfOldList(1,1)
          NewList(i-1,1) = OldList(i,1);
     end %for%
```

```
function [s,NewList] = RemoveOneState(List)

%    REMOVES ONE STATE FROM A LIST
%    Syntax: [s,NewList] = RemoveOneState(List)

        %This function removes the first state of a row of states
        %and then returns the row minus the taken state.

        %Input: List = List of states (Row Vector)
        %Output: s = First state in List
        %         NewList = List minus s

%    DEFINE VARIABLES

        SizeOfList = size(List);

%    SELECT s

        s = List(1,1);

%    CREATE NewList

        for i = 2:SizeOfList(1,2)
                NewList(1,i-1) = List(1,i);
        end %for%
```

```
function [RPrime,Index] = RestrictR(R,Unit,Label)

%   RESTRICTS R TO THOSE 2N-TUPLES WHERE Unit HAS Label
%   Syntax: [RPrime,Index] = RestrictR(R,Unit,Label)

     %This function reduces the unit label constraint relation (R)
     %into RPrime.  RPrime contains those 2N-tuples where Unit has
     %Label.  It also has those 2N-tuples in which Unit does not
     %appear.

     %Input: R = Unit label constraint relation
     %       Unit, Label = Unit label pair that restricts R
     %Output: RPrime = Restricted R whose Unit has Label
     %        Index = Column vector containing the removed row index

%   DEFINE VARIABLES

     k = 0;
     SizeOfR = size(R);
     Flag = 1;

%   SEARCH R FOR THOSE 2N-TUPLES ALLOWED IN RPrime

     for i = 1:SizeOfR(1,1)                          %Do for every row
          for j = 1:2:SizeOfR(1,2)                   %Do for every odd column
               if R(i,j) == Unit
                    if R(i,j+1) == Label
                         Flag = 1;
                    else
                         Flag = 0;
                    end %if%
               end %if%
          end %for%
          if Flag                                    %If row meets criteria
               k = k + 1;
               RPrime(k,:) = R(i,:);
               Index(k,1) = i;
          end %if%
          Flag = 1;
     end %for%
```

```
function CL = SelectCL(CLFound,n)

%   SELECTS A CONSISTENT LABELING FROM ALL THE CONSISTENT LABELINGS FOUND
    Syntax: CL = SelectCL(CLFound,n)

        %This function selects the [Unit Label] consistent
        %labelings from those in CLFound.  CLFound consists
        %of a matrix in which labelings are stored in column pairs

        %Input: CLFound = All consistent labelings found
        %       n = Number of labeling to choose
        %Output: CL = Labeling chosen

%   CHOOSE CORRECT LABELING

        SizeOfCLFound = size(CLFound);
        Row = SizeOfCLFound(1,1);
        Col = SizeOfCLFound(1,2);
        if n*2 <= Col
                CL = CLFound(1:Row, (n*2-1):n*2);
        else
                CL = [NaN NaN];
        end %if%
```

```
function Link = SelectLinkGUI(GPS,U,l,hNodePlot,hAllQuery)

%   FUNCTION WHICH DISPLAYS QUERY INFORMATION FROM QueryBox.m
%   Syntax: Link = SelectLinkGUI(GPS,U,l,hNodePlot,hAllQuery)

        %This function displays various information about
        %the link chosen.  If another link has already been
        %chosen or defined then the angle between the two
        %is computed.

        %Input: GPS = Coordinate Matrix
        %       U = Column vectors of links
        %       l = 1 or 2 depending on which botton pressed
        %       hNodePlot = Figure handle of plot to consider
        %       hAllQuery = Object handles of QueryBox

%    DISPLAY INDIVIDUAL LINK INFORMATION

        CurFig = gcf;
        figure(hNodePlot)
        Link = gSelectLink(GPS,U);
        if l == 1
                %Display Link
                set(hAllQuery(7),'str',int2str(Link));
                %Display Node Coordinates
                [n1,n2] = Link2Node(Link);
                [x1,y1] = Node2Coord(GPS,n1);
                [x2,y2] = Node2Coord(GPS,n2);
                set(hAllQuery(13),'str',num2str(x1));
                set(hAllQuery(17),'str',num2str(y1));
                set(hAllQuery(14),'str',num2str(x2));
                set(hAllQuery(18),'str',num2str(y2));
                set(hAllQuery(22),'str',num2str(LinkLength(GPS,Link)));
        else
                %Display Link
                set(hAllQuery(8),'str',int2str(Link));
                %Display Node Coordinates
                [n1,n2] = Link2Node(Link);
                [x1,y1] = Node2Coord(GPS,n1);
                [x2,y2] = Node2Coord(GPS,n2);
                set(hAllQuery(15),'str',num2str(x1));
                set(hAllQuery(19),'str',num2str(y1));
                set(hAllQuery(16),'str',num2str(x2));
                set(hAllQuery(20),'str',num2str(y2));
                set(hAllQuery(23),'str',num2str(LinkLength(GPS,Link)));
        end %if%

%   IF LINK 1 AND 2 HAVE BEEN DEFINED...CALCULATE ANGLE

        l1 = str2num(get(hAllQuery(7),'str'));
        l2 = str2num(get(hAllQuery(8),'str'));
        if (l1 ~= []) & (l2 ~= [])
                set(hAllQuery(25),'str',num2str(Rad2Deg(LinkAngle(GPS,l1,l2))));
        end %if%
        figure(CurFig);
```

```
function Config = SetConfigGUI(hAllConfig,Slider,Default)

%    THIS FUNCTION TAKES THE VALUES FROM ConfigBox
%    AND WRITES THEM TO Config
%    Sytnax: SetConfigGUI(hAllConfig,Slider)
%    THE CONFIG VECTOR
%        [LRad,MaxFreq,IMult,TWidth,RWidth]

        %This function creates or updates the Config
        %matrix which has the configuation parameters.

        %Input: hAllConfig = Handles for the ConfigBox
        %       Slider = Boolean Value (1 = Take slider
        %                               value for beamwidth)
        %       Default = Default Values

%    LINK RADIUS

        Config = Default;
        LRad = str2num(get(hAllConfig(2),'str'));
        if LRad ~= []
                Config(1) = LRad;
        end %if%
        set(hAllConfig(2),'str',num2str(Config(1)));

%    MAX FREQUENCIES

        MaxFreq = str2num(get(hAllConfig(4),'str'));
        if MaxFreq ~= []
                Config(2) = MaxFreq;
        end %if%
        set(hAllConfig(4),'str',num2str(Config(2)));

    INTERFERENCE MULTIPLIER

        IMult = str2num(get(hAllConfig(6),'str'));
        if IMult ~= []
                Config(3) = IMult;
        end %if%
        set(hAllConfig(6),'str',num2str(Config(3)));

%    BEAM WIDTH

        if Slider
                BW = get(hAllConfig(9),'val');
                Config(4) = BW;
                Config(5) = BW;
        else
                BW = str2num(get(hAllConfig(8),'str'));
                if BW ~= []
                        Config(4) = BW;
                        Config(5) = BW;
                end %if%
        end %if%
        set(hAllConfig(9),'val',Config(4));
        set(hAllConfig(8),'str',num2str(Config(4)));
```

```
function SetTotGUI(hAllDisplay,NetTot)

%    THIS FUNCTION UPDATES THE TOTAL CONFIGS FOUND BOX
%    Syntax: SetTotGUI(hAllDisplay,NetTot)

        %Inputs: hAllDisplay = Handles from DisplayBox
        %        NetTot = Total Network Configuations

        Tot = size(NetTot)/2;
        set(hAllDisplay(2),'str',num2str(Tot(1,2)));
```

```
function ShowConfigGUI(hAllDisplay,hDispPlot,GPS,U,NetTot,FMap2,All)

%    THIS FUNCTION SHOWS NETWORK CONFIGURATIONS
%    Syntax: ShowConfigGUI(hAllDisplay,hDispPlot,GPS,U,NetTot,CMap,All)

        %This function allows the user to select viewing of all
        %or one network configurations in NetTot.

        %Input: hAllDisplay = Handles to the Display Box
        %       hDispPlot = Handle to the Network Display Plot
        %       GPS = Coordinate matrix
        %       U = Column vector of all links
        %       NetTot = Matrix of all network configurations
        %       FMap2 = Color map for each indiv frequency
        %       All = Switch to display all configurations

%  DISPLAY SINGLE CONFIG

        figure(hDispPlot);
        Tot = size(NetTot)/2;
        if ~All
                n = str2num(get(hAllDisplay(5),'string'));
                if n <= Tot(1,2)
                        CL = SelectCL(NetTot,n);
                        DrawNet2(GPS,U,CL,FMap2);
                end %if%
        else
                for n = 1:Tot(1,2)
                        CL = SelectCL(NetTot,n);
                        DrawNet2(GPS,U,CL,FMap2);
                        set(hAllDisplay(5),'string',num2str(n));
                        pause
                end %for%
        end %if%
```

```
function NetTot = SolveModel(NetTot,u,U,L,T,R,NetSize)

%   RECURSIVE TREE SEARCH ROUTINE TO FIND A Connected Network
%   Syntax: NetTot = SolveModel(NetTot,u,U,L,T,R,NetSize)

        %This function performs a tree search through R in order
        %to find all of the consistent labelings located within R.
        %If a single labeling is found to be consistent, it is checked
        %to see if it is a connected network.  If so, the CL is
        %recorded.  The branch of the tree terminates when a member
        %of T cannot find a consistent labeling within R.  It also
        %stops when RPrime is a single valued labeling.
        %This is a recursive procedure which keeps calling itself
        %until L = [].

        %Input: NetTot = Previous configurations found
        %       u = Unit to be considered
        %       U = All units of the model
        %       L = List of labels allowable for Unit (COLUMN VECTOR)
        %       T = Unit constraint relation
        %       R = Unit label constraint relation
        %       u = Unit which will restrict R into RPrime
        %Output: NetTot = Current list of all solutions found

%   DEFINE VARIABLES

        if L == [] | R == []
                Flag = 0;
        else
                Flag = 1;
        end %if%

%   STAY IN LOOP UNTIL SizeOfList = [0,0] OR A UNIT OF T IS ELIMINATED
%   FROM RPrime
%tic
        while Flag

                [l,L] = RemoveOneLabel(L);
                RPrime = RestrictR(R,u,l);
                [TInR,Fail] = IsTInR(T,RPrime);
                if (L == [])
                        Flag = 0;
                end %if%
                [S,Fail] = IS(U,RPrime);
%toc
                if S & (TInR)
                        CL = CLabel(U,RPrime);
                        C1 = IsOneClass(CL,U,NetSize);
                        if C1  %If the network is connected
                                NetTot = CLAdd(NetTot,CL);
                                s = size(NetTot);s = s(1,2)/2;
                                disp(['Configuration Found: ',num2str(s)]);
                        end %if%
%toc
                elseif (R ~= []) & (TInR)
                        [v,NewL] = FindV(RPrime,Fail);
%toc
%disp('Calling Myself again')
                        NetTot = SolveModel(NetTot,v,U,NewL,T,RPrime,NetSize);
                end %if%
        end %while%
```

```
function GPSOut = SortGPS(GPSIn)

%   SORTS THE GPS MATRIX IN ASCENDING X VALUES
%   Syntax: GPSOut = SortGPS(GPSIn)

        %This function sorts the GPS coordinates based on ascending
        %x value

        %Inputs: GPSIn = Coordinate Matrix (one node per row)
        %Outputs: GPSOut = Sorted Matrix

%  SORT GPS

        SizeOfGPS = size(GPSIn);
        if SizeOfGPS(1,1) == 1
                GPSOut = GPSIn;
        else
                [GPSOut,i] = sort(GPSIn);
                for j = 1:SizeOfGPS(1,1)
                        GPSOut(j,:) = GPSIn(i(j),:);
                end %for%
        end %if%
```

```
%  TRIAL 1: 20 Node Network

%  LOAD GPS DATA

       load data/20Node

%  MAKE MODEL

       tic;
       [U,L,T,R,X1,X2] = MakeULTR2(GPS,Config);
       Model_Time = toc;

%  SOLVE MODEL

       tic;
       NetTot = SolveModel([],T(1,1),U,L,T,R,20);
       TS_Time = toc;

%  SAVE DATA

       save data/20Node

%  EXIT

       exit
```

```
function [List] = UnitOfR(U,R)

%    RETURNS A LIST OF UNITS IN R
%    Syntax: [List] = UnitsOfR(U,R)

     %This function returns a list of those units which are
     %constrained in R.

     %Input: R = Unit label constraint relation
        %    U = All possible units
     %Output: List = List of units in R

%    DEFINE VARIABLES

     k = 0;
     SizeOfU = size(U);

%    SEARCH R TO GATHER LIST

         for i = 1:SizeOfU(1,1)
                X = IsElement(R,U(i,1));
                 if X
                         k = k + 1;
                         List(k,1) = U(i,1);
                 end %if%
         end %for%
```

```
function List = UnitOfT(T)

%    RETURNS A LIST OF UNITS IN T
%    Syntax: List = UnitsOfT(T)

     %This function returns a list of those units which are
     %constrained in T.

     %Input: T = Unit constraint relation
     %Output: List = List of units in T

%    DEFINE VATIABLES

     k = 0;
     SizeOfT = size(T);

%    SEARCH T TO GATHER LIST

     for i = 1:SizeOfT(1,1)
          for j = 1:SizeOfT(1,2)
               X = IsElement(List,T(i,j));
               if ~X
                    k = k + 1;
                    List(k,1) = T(i,j);
               end %if%
          end %for%
     end %for%
```

```
%   ZOOM WINDOW FOR SHOWING PAIRS OF LINKS

%   SET AXIS

    figure(hZoomBox)
    set(hZoomBox,'name','Zoom Window of Chosen Links');
    PlotGPS(GPS);
    title('Plot of Beam Patterns')
    l1 = str2num(get(hAllQuery(7),'str'));
    if l1 ~= []
        hl1 = DrawLink(GPS,l1,[1 0 0]);
        set(hl1,'LineWidth',3);
    end %if%
    l2 = str2num(get(hAllQuery(8),'str'));
    if l2 ~= []
        hl2 = DrawLink(GPS,l2,[0 0 1]);
        set(hl2,'LineWidth',3);
    end %if%

    [n11,n12] = Link2Node(l1);
    [n21,n22] = Link2Node(l2);
    [x11,y11] = Node2Coord(GPS,n11);
    [x12,y12] = Node2Coord(GPS,n12);
    [x21,y21] = Node2Coord(GPS,n21);
    [x22,y22] = Node2Coord(GPS,n22);
    Xmax = max([x11 x12 x21 x22]);
    Xmin = min([x11 x12 x21 x22]);
    Ymax = max([y11 y12 y21 y22]);
    Ymin = min([y11 y12 y21 y22]);

    %if Xmax ~= [] & Xmin ~= [] & Ymax ~= [] & Ymin ~= [] & (Xmin~=Xmax)
    %       axis([Xmin,Xmax,Ymin,Ymax]);
    %else
    %       axis('normal')
    %end %if%

%   DRAW PATTERNS

    IMult = Config(3);
    Width = Config(4);
    IntL1 = IMult*LinkLength(GPS,l1);
    IntL2 = IMult*LinkLength(GPS,l2);

    if l1 ~= []
        hPat(1,:) = DrawPat(GPS,l1,n11,IntL1,Width,[1 0 0],'--');
        hPat(2,:) = DrawPat(GPS,l1,n12,IntL1,Width,[1 0 0],'--');
    end %if%
    if l2 ~=[]
        hPat(3,:) = DrawPat(GPS,l2,n21,IntL2,Width,[0 0 1],'-.');
        hPat(4,:) = DrawPat(GPS,l2,n22,IntL2,Width,[0 0 1],'-.');
    end %if%

    axis('auto')
```

```
function GPSNew = gAddGPS(GPSOld,n)

%    ADDS COORDINATES TO GPS VIA THE MOUSE
%    Syntax: GPSNew = gAddGPS(GPSOld,n)

        %This function adds a new coordinate to GPS by allowing
        %the user to specify it using the mouse

        %Input: GPSOld = Coordinate matrix to be added on
        %       n = Number of coordinates to add
        %Output: GPSNew = Coordinate matrix with added value

%    DEFINE VARIABLES

        if ~exist('GPSOld')
                GPSOld = [];
        end %if%
        SizeOfGPS = size(GPSOld);

%    GET NEW COORDINATE

        [x,y] = ginput(n);

%    ADD TO GPS AND SORT

        for i = 1:n
                GPSOld(SizeOfGPS(1,1)+i,:) = [x(i),y(i)];
        end %for%
        GPSNew = SortGPS(GPSOld);
```

```
function Link = gSelectLink(GPS,U)

%    SELECTS THE NEAREST LINK TO THE MOUSE CLICK
%    Syntax: Link = gSelectLink(GPS,U)

        %This function finds the link whose perpendicular
        %distance from the mouse click is least.

        %Input: GPS = Coordinate matrix
        %       U = Column vector of links
        %Output: Link = Nearest link

%    GET COORDINATE

        [x,y] = ginput(1);

%    FIND CLOSEST LINK

        dMin = inf;
        SizeOfU = size(U);
        for i = 1:SizeOfU(1,1)
                [n1,n2] = Link2Node(U(i,1));
                [x1,y1] = Node2Coord(GPS,n1);
                [x2,y2] = Node2Coord(GPS,n2);
                xm = (x1+x2)/2;
                ym = (y1+y2)/2;
                d = Dist([x,y],[xm,ym]);
                if d < dMin
                        Link = U(i,1);
                        dMin = d;
                end %if%
        end %for%
```

```
function [Node,NCoord] = gSelectNode(GPS)

%   GRAPHICALLY SELECTS THE NODE CLOSEST TO THE MOUSE CLICK
%   Syntax: [Node,NCoord] = gSelectNode(GPS)

        %This node gets a ginput from the figure and returns
        %the node closest to it

        %Input: GPS = Coordinate matrix
        %Output: Node = Closest node to point selected

%  GET INPUT FROM MOUSE

        [x,y] = ginput(1);

%  DETERMINE WHICH NODE IS CLOSEST

        DMin = inf;
        SizeOfGPS = size(GPS);
        for i = 1:SizeOfGPS(1,1)
                d = Dist([x,y],GPS(i,:));
                if d < DMin
                        DMin = d;
                        Node = i;
                        NCoord = GPS(i,:);
                end %if%
        end %for%
```