Optimal Co-design of Local and Global Controllers

In this file, we will test a solution for optimal co-design of local and global controllers.

Demonstration

Test the co-design approach with 3 parameters (pHat,pBar and gammaHat):

```
clear all
close all
clc

% To help local design:     Larger pHat, Smaller pBar, and Larger gammaHat
% To help global design:    Smaller pHat, Larger pBar, and Smaller gammaHat

% 0 < pHat < p < pBar
pHat = 0.10
```

```
pHat = 0.1000
```

```
pBar = 0.11
```

```
pBar = 0.1100
```

```

% 0 < gammaHat < gamma < gammaBar
gammaHat = 2.5
```

```
gammaHat = 2.5000
```

```

load TempNet3.mat
platoonObj = net.platoons(1)
```

```
platoonObj =
  Platoon with properties:

     platoonIndex: 1
    numOfVehicles: 6
         vehicles: [1×6 Vehicle]
         topology: [1×1 Topology]
       graphics1: [40.0184 42.0184 44.0184 46.0184 48.0184 50.0184 52.0184 54.0184 58.0131 60.0131 62.0131 64.0129
       graphics2: [41.0184 43.0184 45.0184 47.0184 49.0184 51.0184 53.0184 55.0184 59.0131 61.0131 63.0131 65.0129
```

```

for i = 1:1:1
    disp(['Iteration ',num2str(i)])

    [statusL,nuVal,rhoVal,LVal] = synthesizeLocalControllers(gammaHat,pHat,pBar)
    if statusL == 0
        pHat = pHat + 0.1;
        pBar = pBar - 0.1;
        gammaHat = gammaHat + 0.01;
        continue
    end
```

```
    [statusG,gammaVal,Kval] = synthesizeGlobalRobustControllers(platoonObj,gammaHat,pHat,pBar,r
    if statusG == 0
        pHat = pHat - 0.1;
        pBar = pBar + 0.1;
        gammaHat = gammaHat - 0.01;
        continue
    end

    pHat = pHat - 0.01;
    pBar = pBar + 0.1;
    gammaHat = gammaHat - 1;
end
```

```
Iteration 1
Local Synthesis Success
statusL = logical
   1
nuVal = -22.5647
rhoVal = 10.2122
LVal = 1×3
 -594.2726 -658.9661  -52.9221
Global Synthesis Success
statusG = logical
   1
gammaVal = 2.3600
Kval = 5×5 cell
```

	1	2	3	4	5
1	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...
2	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...
3	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...
4	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...
5	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...

Test the co-design approach with 1 parameter (pVal)

(this approach is also called the "compact" co-design approach):

```
clear all
close all
clc

load TempNet3.mat
platoonObj = net.platoons(1)
```

```
platoonObj =
  Platoon with properties:

     platoonIndex: 1
    numOfVehicles: 6
         vehicles: [1×6 Vehicle]
         topology: [1×1 Topology]
```

```
graphics1: [40.0184 42.0184 44.0184 46.0184 48.0184 50.0184 52.0184 54.0184 58.0131 60.0131 62.0131 64.0129]
graphics2: [41.0184 43.0184 45.0184 47.0184 49.0184 51.0184 53.0184 55.0184 59.0131 61.0131 63.0131 65.0129]
```

```
p = 0.15
```

```
p = 0.1500
```

```
[statusL,nuVal,rhoVal,LVal] = synthesizeLocalControllersCompact(p)
```

```
Local Synthesis Success with gammaSq=2.9519
statusL = logical
   1
nuVal = -19.6793
rhoVal = 7.0547
LVal = 1×3
  -75.5069  -93.6429  -16.8442
```

```
[statusG,gammaVal,KVal] = synthesizeGlobalRobustControllersCompact(platoonObj,nuVal,rhoVal)
```

```
Global Synthesis Success with gammaSq=3.0366
statusG = logical
   1
gammaVal = 3.0366
KVal = 5×5 cell
```

	1	2	3	4	5
1	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...
2	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...
3	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...
4	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...
5	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...

```
[feasibility,Ceq] = synthesizeControllersCompactFeasibility(platoonObj,p)
```

```
Local Synthesis Success with gammaSq=2.9519
Global Synthesis Success with gammaSq=3.0366
feasibility = 3×1
     0
     0
     0
Ceq =

     []
```

Finding the Optimal Parameters (Using "fmincon")

For the co-design approach with 3 parameters:

```
clear all
close all
clc

% To help local design:     Larger pHat, Smaller pBar, and Larger gammaHat
% To help global design:    Smaller pHat, Larger pBar, and Smaller gammaHat
```

```
% 0 < pHat < p < pBar
pHat = 0.1
```

```
pHat = 0.1000
```

```
pBar = 1
```

```
pBar = 1
```

```
% 0 < gammaHat < gamma < gammaBar
gammaHat = 20
```

```
gammaHat = 20
```

```
load TempNet3.mat
platoonObj = net.platoons(1)
```

```
platoonObj =
  Platoon with properties:

     platoonIndex: 1
    numOfVehicles: 6
         vehicles: [1×6 Vehicle]
         topology: [1×1 Topology]
        graphics1: [40.0184 42.0184 44.0184 46.0184 48.0184 50.0184 52.0184 54.0184 58.0131 60.0131 62.0131 64.0129
        graphics2: [41.0184 43.0184 45.0184 47.0184 49.0184 51.0184 53.0184 55.0184 59.0131 61.0131 63.0131 65.0129
```

```
% x0 = [pHat,pBar,gammaHat];
x0 = [0.1003    0.1072    2.1107]
```

```
x0 = 1×3
    0.1003    0.1072    2.1107
```

```
f = @(x)synthesizeControllers(platoonObj,x);

[x,fval] = fmincon(f,x0)
```

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Local minimum possible. Constraints satisfied.

fmincon stopped because the size of the current step is less than
the value of the step size tolerance and constraints are
satisfied to within the value of the constraint tolerance.

<stopping criteria details>
x = 1×3
    0.0783    0.2565    8.6906
fval = 2.8046
```

```
% x = [0.3816    1.0063    4.8777] % L is too large
% x = [0.3816    1.0063    4.9013]
% Lets use norm(L) in the objective, with a changing magnitude
% x = [0.1003    0.1072    2.1107]
% x = [0.1001    0.1036    2.1481]
% x = [0.1028    0.1046    2.2569]
% x = [0.1047    0.1047    2.2575]
% x = [0.1047    0.1047    2.2575]
% x = [0.1047    0.1047    2.2575]
% With an intersection motivating term in the objective function
% x = [0.1080    0.1082    2.5054]
% x = [0.1003    0.1072    2.1107]
% x = [0.1003    0.1072    2.1107]
% x = [0.0611    0.0611    2.2250]

x
```

```
x = 1×3
    0.0783    0.2565    8.6906
```

```
pHat = x(1)
```

```
pHat = 0.0783
```

```
pBar = x(2)
```

```
pBar = 0.2565
```

```
gammaHat = x(3)
```

```
gammaHat = 8.6906
```

```
% For: nuBar < nu < nuHat < 0
nuBar = -gammaHat/pBar
```

```
nuBar = -33.8846
```

```
% For: 0 < rhoHat1,rhoHat2 < rho < rhoBar
```

```
rhoHat1 = pBar/(4*gammaHat)
```

```
rhoHat1 = 0.0074
```

```
rhoHat2 = 1/pHat
```

```
rhoHat2 = 12.7732
```

```
[statusL,nuVal,rhoVal,LVal] = synthesizeLocalControllers(gammaHat,pHat,pBar)
```

```
Local Synthesis Success
statusL = logical
   1
nuVal = -31.7173
rhoVal = 13.3949
LVal = 1×3
 -209.4463 -239.2597  -25.9213
```

```
[statusG,gammaVal,KVal] = synthesizeGlobalRobustControllers(platoonObj,gammaHat,pHat,pBar,nuVal
```

```
Global Synthesis Success
statusG = logical
   1
gammaVal = 2.4856
KVal = 5×5 cell
```

	1	2	3	4	5
1	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0,0,...
2	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...
3	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...
4	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...
5	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...

For the co-design approach with 1 parameter (pVal)

```
clear all
close all
clc

load TempNet3.mat
platoonObj = net.platoons(1)
```

```
platoonObj =
  Platoon with properties:

     platoonIndex: 1
    numOfVehicles: 6
         vehicles: [1×6 Vehicle]
         topology: [1×1 Topology]
       graphics1: [40.0184 42.0184 44.0184 46.0184 48.0184 50.0184 52.0184 54.0184 58.0131 60.0131 62.0131 64.0129
       graphics2: [41.0184 43.0184 45.0184 47.0184 49.0184 51.0184 53.0184 55.0184 59.0131 61.0131 63.0131 65.0129
```

```
f = @(x)synthesizeControllersCompact(platoonObj,x);
```

```
nonlcon = @(x)synthesizeControllersCompactFeasibility(platoonObj,x);

A = [];
b = [];
Aeq = [];
beq = [];
lb = [0];
ub = [inf];

p0 = 0.15;
[p,fval] = fmincon(f,p0,A,b,Aeq,beq,lb,ub,nonlcon)
```

```
Local Synthesis Success with gammaSq=2.9519
Global Synthesis Success with gammaSq=3.0366
Local Synthesis Success with gammaSq=2.9519
Global Synthesis Success with gammaSq=3.0366
Local Synthesis Success with gammaSq=2.9519
Global Synthesis Success with gammaSq=3.0366
Local Synthesis Success with gammaSq=2.9519
Global Synthesis Success with gammaSq=3.0366
Local Synthesis Success with gammaSq=2.7325
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Local Synthesis Success with gammaSq=2.6886
Global Synthesis Success with gammaSq=2.586
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Global Synthesis Success with gammaSq=2.586
Local Synthesis Su...
p = 0.0449
fval = 2.5860
```

```
% p = 0.0449

p
```

```
p = 0.0449
```

```
[statusL,nuVal,rhoVal,LVal] = synthesizeLocalControllersCompact(p)
```

```
Local Synthesis Success with gammaSq=2.6886
statusL = logical
   1
nuVal = -59.8227
rhoVal = 23.7548
LVal = 1×3
 -215.4697 -247.8309  -28.2575
```

```
[statusG,gammaVal,KVal] = synthesizeGlobalRobustControllersCompact(platoonObj,nuVal,rhoVal)
```

```
Global Synthesis Success with gammaSq=2.586
statusG = logical
   1
gammaVal = 2.5860
KVal = 5×5 cell
```

	1	2	3	4	5
1	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0,0,...
2	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...
3	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...
4	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0,0,...
5	[0,0,0;0,0,...	[0,0,0;0...	[0,0,0;0...	[0,0,0;0,0,...	[0,0,0;0...

Necessary Functions

Functions for co-design approach with 3 parameters:

For local synthesis:

```
function [status,nuVal,rhoVal,LVal] = synthesizeLocalControllers(gammaHat,pHat,pBar)
    % Here we will synthesize the local controllers for local error
    % dynamics to optimize the passivity properties

    errorDynamicsType = 2;
    if errorDynamicsType == 1
        A = [0,1,0;0,0,0;0,0,0]; % For error dynamics type 1
    else
        A = [0,1,0;0,0,1;0,0,0]; % For error dynamics type 2
    end
    B = [0;0;1];
    I = eye(3);
    O = zeros(3);

    % For: nuBar < nu < nuHat < 0
    nuBar = -gammaHat/pBar;
    % nuHat = -0.001;

    % For: 0 < rhoHat1,rhoHat2 < rho < rhoBar
    % rhoBar = 10;
    rhoHat1 = pBar/(4*gammaHat);
    rhoHat2 = 1/pHat;

    % For: 0 < rhoTildeHat < rhoTilde < rhoTildeBar1,rhoTildeBar2
    % rhoTildeHat = 1/rhoBar;
    rhoTildeBar1 = 1/rhoHat1;
    rhoTildeBar2 = 1/rhoHat2;

    % Set up the LMI problem
    solverOptions = sdpsettings('solver','mosek','verbose',0);
    P = sdpvar(3,3,'symmetric');
    K = sdpvar(1,3,'full');

    rhoTilde = sdpvar(1,1,'full'); %Representing: 1/rho
```

```
    nu = sdpvar(1,1,'full');

    % Basic Constraints
    con1 = P >= 0;

    % Approach 4 with rho = prespecified, nu < 0 and nu is free to maximize
    DMat = [rhoTilde*I];
    MMat = [P, O];
    ThetaMat = [-A*P-P*A'-B*K-K'*B', -I+0.5*P; -I+0.5*P, -nu*I];
    W = [DMat, MMat; MMat', ThetaMat];
    con2 = W >= 0;

    %%Constraints on resulting nu and rho from the local design

    % nuBar < nu < nuHat < 0
    con3 = nu >= nuBar;              % Helps global design
    %con4 = nu <= nuHat;

    % 0 < rhoTildeHat < rhoTilde < rhoTildeBar1,rhoTildeBar2
    % con5 = rhoTilde >= rhoTildeHat;
    con6 = rhoTilde <= rhoTildeBar1;    % Helps global design
    con7 = rhoTilde <= rhoTildeBar2;    % Helps global design

    % Total Cost and Constraints
    cons = [con1,con2,con3,con6,con7];
    %costFun =  0*(-nu + rhoBar);           % For stabilizing, set coefficient to 0
    %costFun = 0.0000001*(-nu + rhoBar);    % Otherwise set to 0.0000001.
    costFun = 0;

    % Solution
    sol = optimize(cons,costFun,solverOptions);
    status = sol.problem == 0; % sol.info;

    PVal = value(P);
    KVal = value(K);
    LVal = KVal/PVal;

    nuVal = value(nu);
    rhoVal = 1/value(rhoTilde);

    if status == 1
        disp(['Local Synthesis Success'])
    else
        disp(['Local Synthesis Failed'])
    end

end
```

For global synthesis:

```
function [status,gammaSqVal,K] = synthesizeGlobalRobustControllers(platoonObj,gammaHat,pHat,pBa
```

```
% Number of follower vehicles
N = platoonObj.numOfVehicles-1;

% Creating the adgacency matrix, null matrix and cost matrix
G = platoonObj.topology.graph;
A = adjacency(G);
for i = 1:1:N
    for j = 1:1:N
        % Structure of K_ij (which is a 3x3 matrix) should be embedded here
        if i~=j
            if A(j+1,i+1)==1
                adjMatBlock{i,j} = [0,0,0; 0,0,0; 1,1,1];
                nullMatBlock{i,j} = [1,1,1; 1,1,1; 0,0,0];
                costMatBlock{i,j} = 1*[0,0,0; 0,0,0; 1,1,1];
            else
                adjMatBlock{i,j} = [0,0,0; 0,0,0; 0,0,0];
                nullMatBlock{i,j} = [1,1,1; 1,1,1; 0,0,0];
                costMatBlock{i,j} = 10*[0,0,0; 0,0,0; 1,1,1];
            end
        else
            adjMatBlock{i,j} = [0,0,0; 0,0,0; 1,1,1];
            nullMatBlock{i,j} = [1,1,1; 1,1,1; 0,0,0];
            costMatBlock{i,j} = 0*[0,0,0; 0,0,0; 1,1,1];
        end
    end
end
adjMatBlock = cell2mat(adjMatBlock);
nullMatBlock = cell2mat(nullMatBlock);
costMatBlock = cell2mat(costMatBlock);

% Set up the LMI problem
solverOptions = sdpsettings('solver','mosek','verbose',0);
I = eye(3*N);
I_n = eye(3);
O = zeros(3*N);

% Whether to use a soft or hard graph constraint
isSoft = 1;
normType = 2;

Q = sdpvar(3*N,3*N,'full');
P = sdpvar(N,N,'diagonal');
gammaSq = sdpvar(1,1,'full');

X_p_11 = [];
X_p_12 = [];
X_12 = [];
X_p_22 = [];
for i = 1:1:N
```

```
        nu_i = nuVal;
        rho_i = rhoVal;

        X_p_11 = blkdiag(X_p_11,-nu_i*P(i,i)*I_n);
        X_p_12 = blkdiag(X_p_12,0.5*P(i,i)*I_n);
        X_12 = blkdiag(X_12,(-1/(2*nu_i))*I_n);
        X_p_22 = blkdiag(X_p_22,-rho_i*P(i,i)*I_n);
    end
    X_p_21 = X_p_12';
    X_21 = X_12';

    % Objective Function
    % costFun = 1*norm(Q.*costMatBlock,normType);
    costFun0 = sum(sum(Q.*costMatBlock));

    % Budget Constraints (Not at this stage)
    con0 = costFun0 >= 1;

    % Basic Constraints
    con1 = P >= 0;

    DMat = [X_p_11, O; O, I];
    MMat = [Q, X_p_11; I, O];
    ThetaMat = [-X_21*Q-Q'*X_12-X_p_22, -X_p_21; -X_p_12, gammaSq*I];
    con2 = [DMat, MMat; MMat', ThetaMat] >= 0; % The real one

    % For: 0 < gammaHat < gamma < gammaBar
    % gammaSqBar = 10000;
    % con3 = gammaSq <= gammaSqBar;
    % con4 = gammaSq >= gammaHat;

    % For: 0 < pHat < p_i < pBar
    % con5 = P >= pHat*eye(N);
    % con6 = P <= pBar*eye(N);

    % Structural constraints
    con7 = Q.*(nullMatBlock==1)==O;  % Structural limitations (due to the format of the control
    con8 = Q.*(adjMatBlock==0)==O;  % Graph structure : hard constraint

    % Total Cost and Constraints
    if isSoft
        cons = [con0,con1,con2,con7]; % Without the hard graph constraint con7
        costFun = 1*costFun0 + 1*gammaSq; % soft
    else
        cons = [con0,con1,con2,con7,con8]; % With the hard graph constraint con7
        costFun = 1*costFun0 + 1*gammaSq; % hard (same as soft)
    end

    sol = optimize(cons,[costFun],solverOptions);
    status = sol.problem == 0; %sol.info;
```

```
    costFunVal = value(costFun);
    PVal = value(P);
    QVal = value(Q);
    X_p_11Val = value(X_p_11);
    X_p_21Val = value(X_p_21);

    gammaSqVal = value(gammaSq);

    M_neVal = X_p_11Val\QVal;

    % Obtaining K_ij blocks
    M_neVal(nullMatBlock==1) = 0;
    maxNorm = 0;
    for i = 1:1:N
        for j = 1:1:N
            K{i,j} = M_neVal(3*(i-1)+1:3*i , 3*(j-1)+1:3*j); % (i,j)-th (3 x 3) block
            normVal = max(max(abs(K{i,j})));
            if normVal>maxNorm
                maxNorm = normVal;
            end
        end
    end

    % filtering out extremely small interconnections
    for i=1:1:N
        for j=1:1:N
            if i~=j
                if isSoft
                    K{i,j}(abs(K{i,j})<0.0001*maxNorm) = 0;
                else
                    if A(i+1,j+1)==0
                        K{i,j} = zeros(3);
                    end
                end
            end

            K_ijMax = max(abs(K{i,j}(:)));
            K{i,j}(abs(K{i,j})<0.01*K_ijMax) = 0;

        end
    end

    if status == 1
        disp(['Global Synthesis Success'])
    else
        disp(['Global Synthesis Failed'])
    end
end
```

The Overall Parametrized Cost Function

```
function gammaVal = synthesizeControllers(platoonObj,x)
    pHat = x(1);
    pBar = x(2);
    gammaHat = x(3);

    [statusL,nuVal,rhoVal,LVal] = synthesizeLocalControllers(gammaHat,pHat,pBar);
    if statusL == 0
         gammaVal = 10000;
         return
    end

    [statusG,gammaVal,KVal] = synthesizeGlobalRobustControllers(platoonObj,gammaHat,pHat,pBar,r
    if statusG == 0
        gammaVal = 10000;
        return
    end

    interSum = 0;
    for i = 1:1:size(KVal,1)
        for j = 1:1:size(KVal,2)
            if i~=j
                interSum = interSum + norm(KVal{i,j});
            end
        end
    end

    gammaVal = gammaVal + 0.001*norm(LVal) - 0*interSum;
end
```

Functions for co-design approach with 3 parameters:

For local synthesis (compact):

```
function [status,nuVal,rhoVal,LVal] = synthesizeLocalControllersCompact(pVal)
    % Here we will synthesize the local controllers for local error
    % dynamics to optimize the passivity properties

    errorDynamicsType = 2;
    if errorDynamicsType == 1
        A = [0,1,0;0,0,0;0,0,0]; % For error dynamics type 1
    else
        A = [0,1,0;0,0,1;0,0,0]; % For error dynamics type 2
    end
    B = [0;0;1];
    I = eye(3);
    O = zeros(3);

    % Set up the LMI problem
```

```
solverOptions = sdpsettings('solver','mosek','verbose',0);
P = sdpvar(3,3,'symmetric');
K = sdpvar(1,3,'full');

nu = sdpvar(1,1,'full');
rhoTilde = sdpvar(1,1,'full'); %Representing: 1/rho

gammaSq = sdpvar(1,1,'full');

% For: nuBar < nu < nuHat < 0
nuBar = -gammaSq/pVal;

% For: 0 < rhoHat1,rhoHat2 < rho < rhoBar
% For: 0 < rhoTildeHat < rhoTilde < rhoTildeBar1,rhoTildeBar2
rhoTildeBar1 = 4*gammaSq/pVal;
rhoTildeBar2 = pVal;

% Basic Constraints
con1 = P >= 0;

% Approach 4 with rho = prespecified, nu < 0 and nu is free to maximize
DMat = [rhoTilde*I];
MMat = [P, O];
ThetaMat = [-A*P-P*A'-B*K-K'*B', -I+0.5*P; -I+0.5*P, -nu*I];
W = [DMat, MMat; MMat', ThetaMat];
con2 = W >= 0;

%%Constraints on resulting nu and rho from the local design
% nuBar < nu < nuHat < 0
con3 = nu >= nuBar;              % Helps global design

% 0 < rhoTildeHat < rhoTilde < rhoTildeBar1,rhoTildeBar2
con4 = rhoTilde <= rhoTildeBar1;    % Helps global design
con5 = rhoTilde <= rhoTildeBar2;    % Helps global design


% Total Cost and Constraints
cons = [con1,con2,con3,con4,con5];
%costFun =  0*(-nu + rhoBar);           % For stabilizing, set coefficient to 0
%costFun = 0.0000001*(-nu + rhoBar);    % Otherwise set to 0.0000001.
costFun = 0*gammaSq;

% Solution
sol = optimize(cons,costFun,solverOptions);
status = sol.problem == 0; % sol.info;

PVal = value(P);
KVal = value(K);
LVal = KVal/PVal;
```

```
    nuVal = value(nu);
    rhoVal = 1/value(rhoTilde);
    gammaSqVal = value(gammaSq);

    if status == 1
        disp(['Local Synthesis Success with gammaSq=',num2str(value(gammaSqVal))])
    else
        disp(['Local Synthesis Failed'])
    end

end
```

For global synthesis (compact):

```
function [status,gammaSqVal,K] = synthesizeGlobalRobustControllersCompact(platoonObj,nuVal,rho

    % Number of follower vehicles
    N = platoonObj.numOfVehicles-1;

    % Creating the adgacency matrix, null matrix and cost matrix
    G = platoonObj.topology.graph;
    A = adjacency(G);
    for i = 1:1:N
        for j = 1:1:N
            % Structure of K_ij (which is a 3x3 matrix) should be embedded here
            if i~=j
                if A(j+1,i+1)==1
                    adjMatBlock{i,j} = [0,0,0; 0,0,0; 1,1,1];
                    nullMatBlock{i,j} = [1,1,1; 1,1,1; 0,0,0];
                    costMatBlock{i,j} = 1*[0,0,0; 0,0,0; 1,1,1];
                else
                    adjMatBlock{i,j} = [0,0,0; 0,0,0; 0,0,0];
                    nullMatBlock{i,j} = [1,1,1; 1,1,1; 0,0,0];
                    costMatBlock{i,j} = 10*[0,0,0; 0,0,0; 1,1,1];
                end
            else
                adjMatBlock{i,j} = [0,0,0; 0,0,0; 1,1,1];
                nullMatBlock{i,j} = [1,1,1; 1,1,1; 0,0,0];
                costMatBlock{i,j} = 0*[0,0,0; 0,0,0; 1,1,1];
            end
        end
    end
    adjMatBlock = cell2mat(adjMatBlock);
    nullMatBlock = cell2mat(nullMatBlock);
    costMatBlock = cell2mat(costMatBlock);

    % Some constants
    I = eye(3*N);
    I_n = eye(3);
    O = zeros(3*N);
```

```
    % Whether to use a soft or hard graph constraint
    isSoft = 1;
    normType = 2;

    % Set up the LMI problem
    solverOptions = sdpsettings('solver','mosek','verbose',0);

    Q = sdpvar(3*N,3*N,'full');
    P = sdpvar(N,N,'diagonal');
    gammaSq = sdpvar(1,1,'full');

    X_p_11 = [];
    X_p_12 = [];
    X_12 = [];
    X_p_22 = [];
    for i = 1:1:N
        nu_i = nuVal;
        rho_i = rhoVal;
        X_p_11 = blkdiag(X_p_11,-nu_i*P(i,i)*I_n);
        X_p_12 = blkdiag(X_p_12,0.5*P(i,i)*I_n);
        X_12 = blkdiag(X_12,(-1/(2*nu_i))*I_n);
        X_p_22 = blkdiag(X_p_22,-rho_i*P(i,i)*I_n);
    end
    X_p_21 = X_p_12';
    X_21 = X_12';

    % Objective Function
%     costFun0 = 1*norm(Q.*costMatBlock,normType);
    costFun0 = sum(sum(Q.*costMatBlock));

    % Minimum Budget Constraints
    con0 = costFun0 >= 1;

    % Basic Constraints
    con1 = P >= 0;

    DMat = [X_p_11, O; O, I];
    MMat = [Q, X_p_11; I, O];
    ThetaMat = [-X_21*Q-Q'*X_12-X_p_22, -X_p_21; -X_p_12, gammaSq*I];
    con2 = [DMat, MMat; MMat', ThetaMat] >= 0; % The real one

    % Structural constraints
    con3 = Q.*(nullMatBlock==1)==O;  % Structural limitations (due to the format of the control
    con4 = Q.*(adjMatBlock==0)==O;  % Graph structure : hard constraint

    % Total Cost and Constraints
    if isSoft
        cons = [con0,con1,con2,con3]; % Without the hard graph constraint con7
        costFun = 1*costFun0 + 1*gammaSq; % soft
    else
```

```
        cons = [con0,con1,con2,con3,con4]; % With the hard graph constraint con7
        costFun = 1*costFun0 + 1*gammaSq; % hard (same as soft)
    end

    sol = optimize(cons,[costFun],solverOptions);
    status = sol.problem == 0; %sol.info;

    costFun0Val = value(costFun0);
    costFunVal = value(costFun);
    PVal = value(P);
    QVal = value(Q);
    X_p_11Val = value(X_p_11);
    X_p_21Val = value(X_p_21);

    gammaSqVal = value(gammaSq);

    M_neVal = X_p_11Val\QVal;

    % Obtaining K_ij blocks
    M_neVal(nullMatBlock==1) = 0;
    maxNorm = 0;
    for i = 1:1:N
        for j = 1:1:N
            K{i,j} = M_neVal(3*(i-1)+1:3*i , 3*(j-1)+1:3*j); % (i,j)-th (3 x 3) block
            normVal = max(max(abs(K{i,j})));
            if normVal>maxNorm
                maxNorm = normVal;
            end
        end
    end

    % filtering out extremely small interconnections
    for i=1:1:N
        for j=1:1:N
            if i~=j
                if isSoft
                    K{i,j}(abs(K{i,j})<0.0001*maxNorm) = 0;
                else
                    if A(i+1,j+1)==0
                        K{i,j} = zeros(3);
                    end
                end
            end

            K_ijMax = max(abs(K{i,j}(:)));
            K{i,j}(abs(K{i,j})<0.01*K_ijMax) = 0;
        end
    end

    if status == 1
```

```
        disp(['Global Synthesis Success with gammaSq=',num2str(value(gammaSqVal))])
    else
        disp(['Global Synthesis Failed'])
    end

end
```

The Overall Parametrized Cost Function (Compact):

```
function gammaVal = synthesizeControllersCompact(platoonObj,pVal)

    [statusL,nuVal,rhoVal,LVal] = synthesizeLocalControllersCompact(pVal);
    if statusL == 0
         gammaVal = 1000000;
         return
    else
        [statusG,gammaVal,KVal] = synthesizeGlobalRobustControllersCompact(platoonObj,nuVal,rho
        if statusG == 0
            gammaVal = 1000000;
            return
        end
    end
end

function [C,Ceq] = synthesizeControllersCompactFeasibility(platoonObj,pVal)

    [statusL,nuVal,rhoVal,LVal] = synthesizeLocalControllersCompact(pVal);
    if statusL == 0
        statusG = 0;
    else
        [statusG,gammaVal,KVal] = synthesizeGlobalRobustControllersCompact(platoonObj,nuVal,rho
    end
    statusK = norm(LVal) <= 10000;

    C = [statusL-1; statusG-1; statusK-1];
    Ceq = [];

end
```