POLITECNICO MILANO 1863 | DEPARTMENT OF ELECTRONICS INFORMATION AND BIOENGINEERING

Communication Network Design

(a course by Prof. Massimo Tornatore)

CND LAB 1

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Outline

- Introduction to Net2Plan (demo)
- Flow Formulation (FF)
  - Net2Plan demo (Part B)
    - Splittable flow formulation
  - Unsplittable flow formulation (homework)
  - Task #1 description
- Route Formulation (RF) without wavelength continuity
  - Exercise: Route Formulation (RF) vs. Flow Formulation (FF)

Introduction to Net2Plan (demo)

- All lab material is found in the WeBeep channel of the course
  - Lab Material ➔ 0-AY-2025-2026
  - A sub-folder for each lab
  - Relevant software found here: **01 - Instructions to download N2P and other components - v2.pdf**
  - Download software directly from here (based on your machine's OS): CND-Lab-software

Introduction to Net2Plan (demo)

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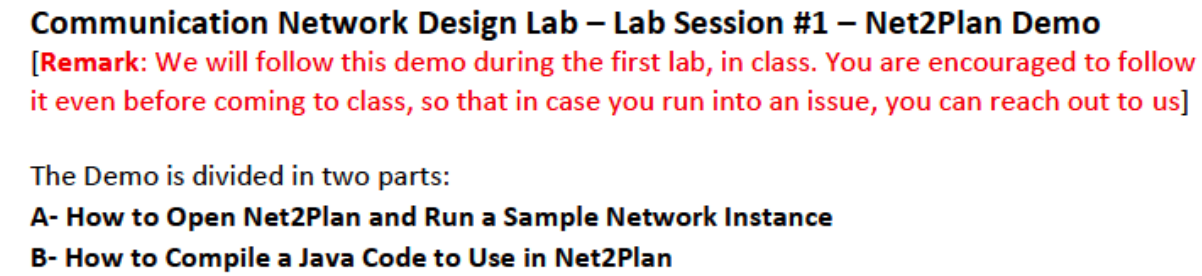
  - Download software directly from here (based on your machine's OS): CND-Lab-software

- Once you have downloaded all relevant material
  - We can proceed with the N2P demo as described here 02 - Net2plan Demo.pdf



Communication Network Design Lab – Lab Session #1 – Net2Plan Demo

[**Remark**: We will follow this demo during the first lab, in class. You are encouraged to follow it even before coming to class, so that in case you run into an issue, you can reach out to us]

The Demo is divided in two parts:

A- How to Open Net2Plan and Run a Sample Network Instance

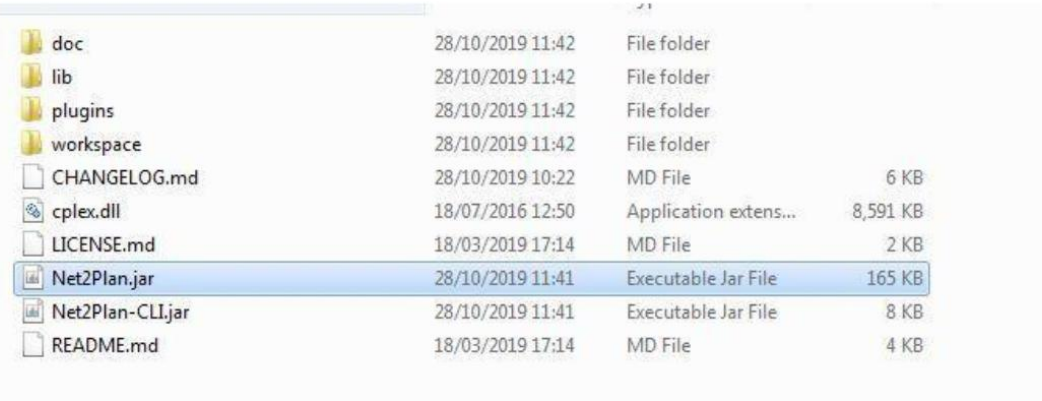
B- How to Compile a Java Code to Use in Net2Plan

Introduction to Net2Plan (demo)

A- How to Open Net2Plan and Run a Sample Network Instance

- N2P demo as described in [02 - Net2plan Demo.pdf]

1. To run Net2Plan in GUI mode, just double click on Net2Plan.jar, or execute the following command in a terminal: "java -jar Net2Plan.jar"



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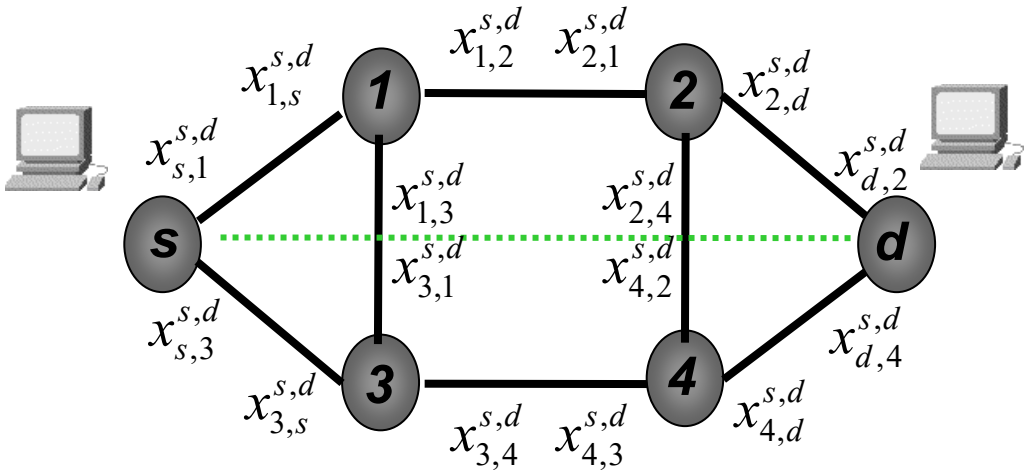
Flow Formulation

Splittable Flow

Graph G(N,E)	*N set of Nodes, E set of Links*
c	*node pair (source s_c, destination d_c) having requested connection request(s)*
l,k	*link identifiers (source-destination pairs)*
V_c	*number of connection requests having s_c as source and d_c as destination*
x_{lkc}	(integer) number of connections of *c* routed on link *l,k*
W	*Link capacity, number of wavelengths*



Flow Formulation

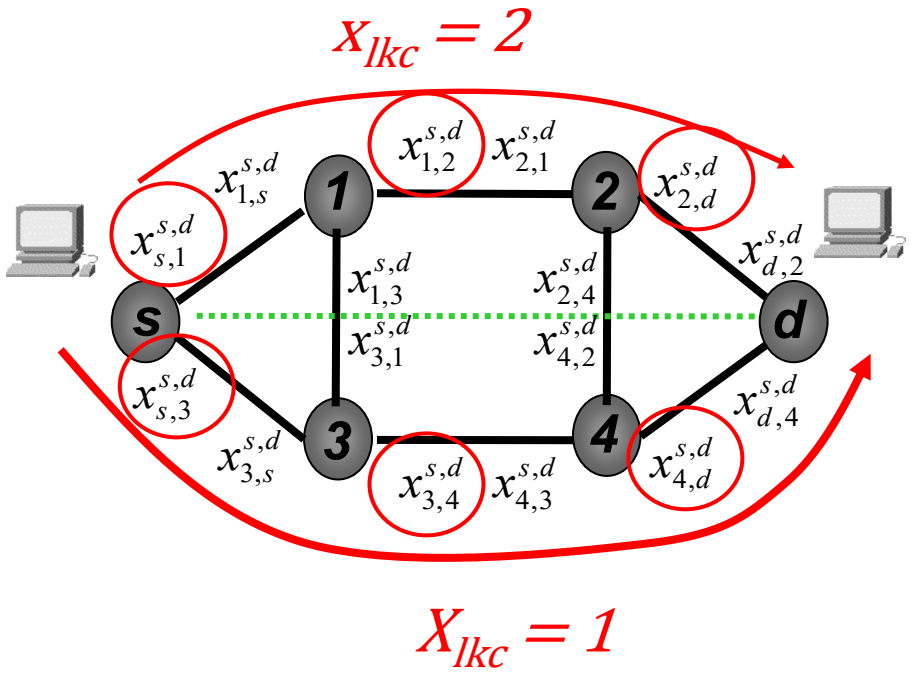
Splittable Flow

- Routing of demands uses 'flow-link' decision variables
  - x_{lkc} = (integer) number of connections of c routed on link l,k

$$x_{lkc} \geq 0$$

Example, assume V_c ($V^{s,d}$) = 3

V_c *number of connection requests having* s_c *as source and* d_c *as destination*



Flow Formulation

Splittable Flow

- **Objective function**: minimize total amount of traffic routed on all links

$$\min \sum_{c \in C, lk \in E} x_{lkc}$$

- **Subject to**:

Solenoidality	$\sum_{k \in A_l} x_{k,l,c} - \sum_{k \in A_l} x_{l,k,c} = \begin{cases} v_c & \text{if } l = d_c \\ -v_c & \text{if } l = s_c \\ 0 & \text{otherwise} \end{cases} \quad \forall\, l, c$
Capacity	$\sum_c x_{l,k,c} \le W \cdot F_{l,k} \quad \forall (l,k)$
Integrity	$x_{l,k,c}$ integer $\quad \forall c,(l,k)$ $F_{l,k}$ integer $\quad \forall (l,k)$

Number of fibers on link l,k

Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

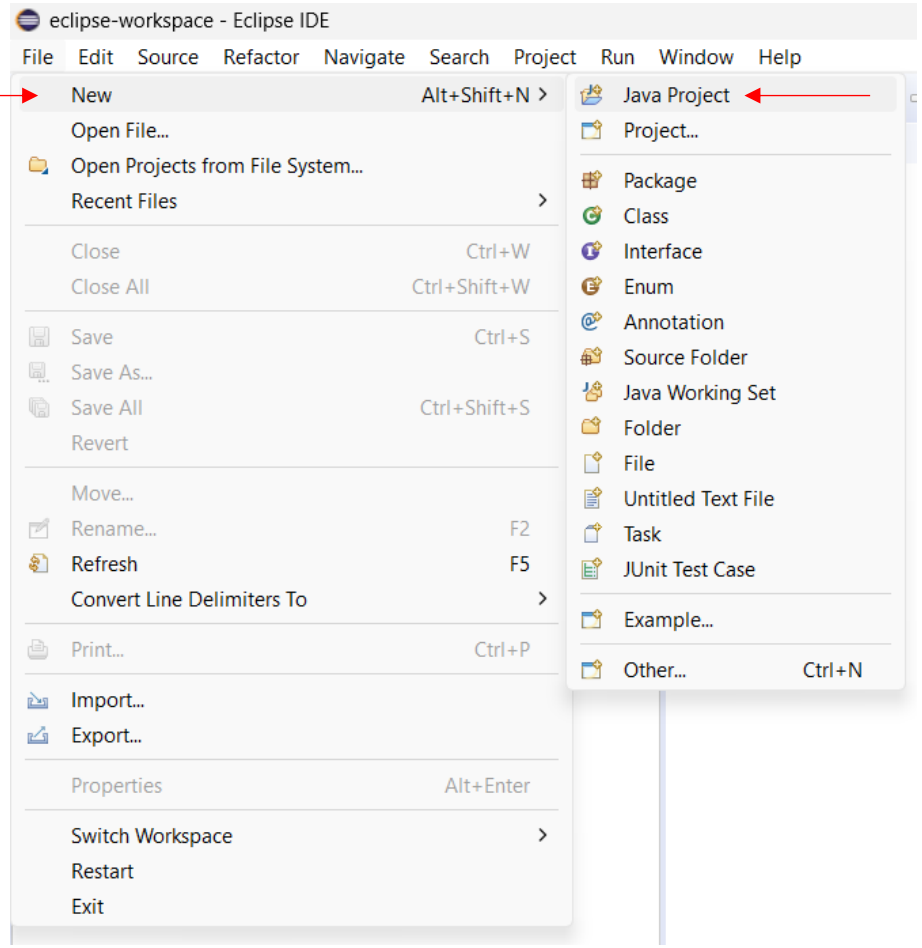
- N2P demo as described in [02 - Net2plan Demo.pdf]

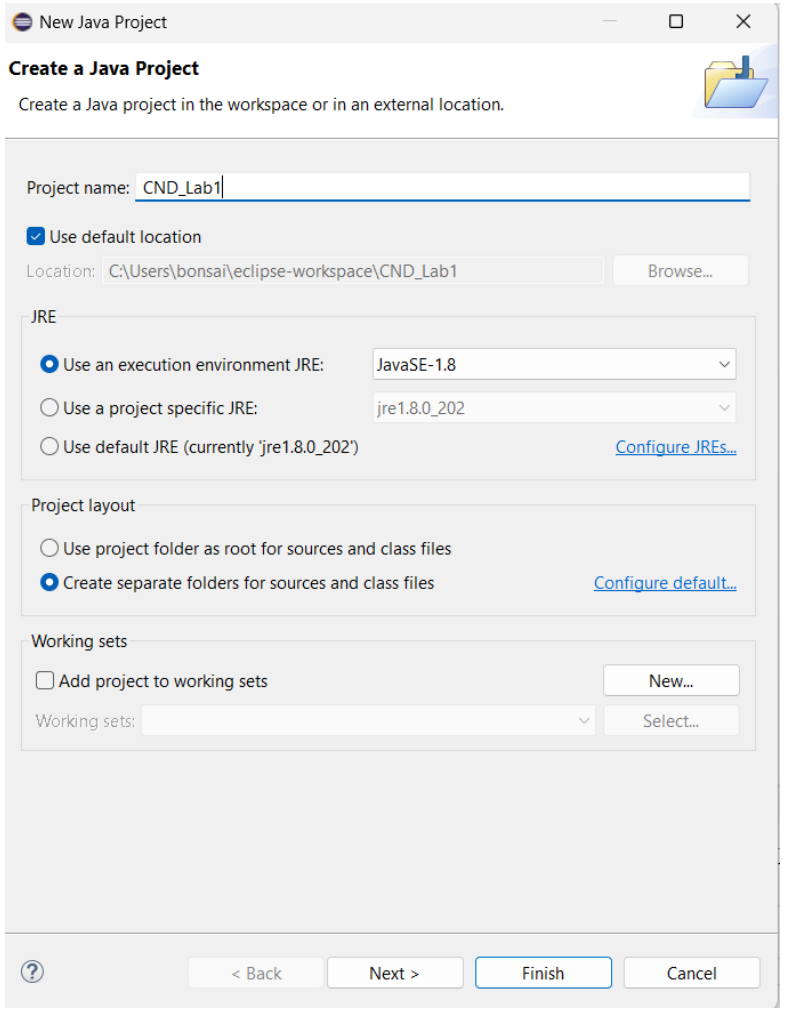
1. Open **Eclipse** and go to **File-> New-> Java Project** to create a new project.
2. Name the project you created, e.g., *MyProject*, and click on **Finish.**
3. Go to **Package Explorer** window (where there is the list of projects, left side of your screen) and right click on the project you created.
4. Go to **Build Path-> Configure build path** and Click on **Add External Jars** (found on the right side of the window).
5. Now we need to add external Net2Plan jars. To do so, locate the directory where Net2plan folder is, go to **lib** folder, select **all** and click **open,** and then click on **Apply and Close** (this loads all Net2plan libraries to your project).
6. Now go to the **workspace** of Eclipse on your hard drive [Hint: you might want to create a shortcut of eclipse workspace on your desktop to easily access it]. **Locate the folder of your java project** and **copy** your java code file "SplitableFlowFormulation.java" in folder '**src**'.
7. **Refresh** your java project in Eclipse and **open** java code "SplitableFlowFormulation.java". The code represents the splittable flow formulation.

Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

- Create a new Java project

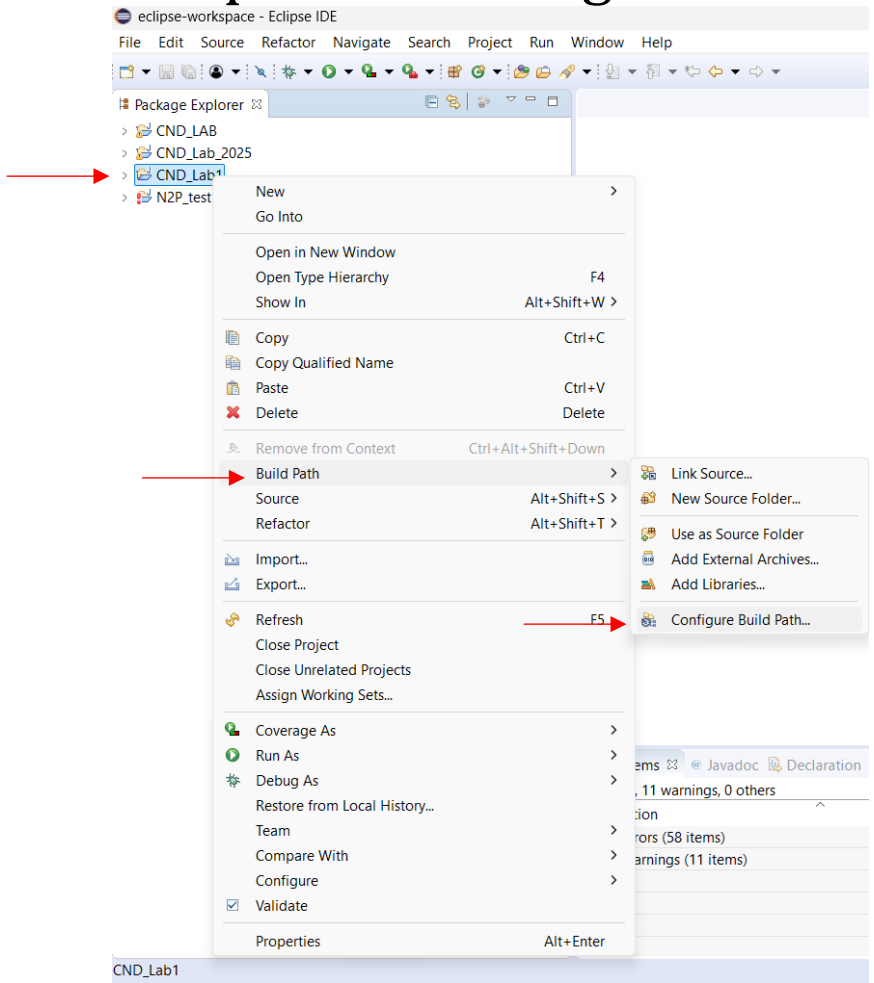


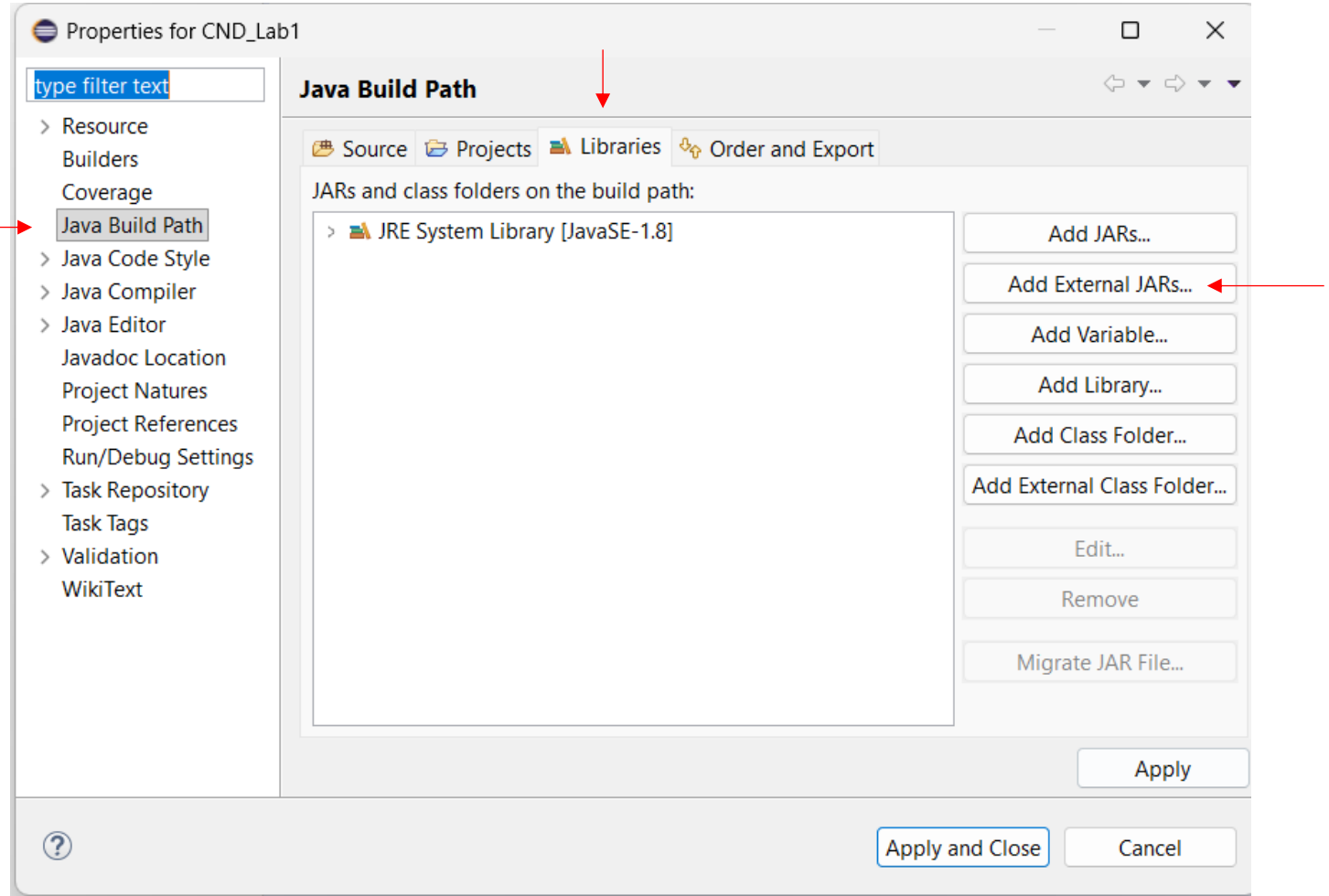


Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

- Build path → Configure build path….

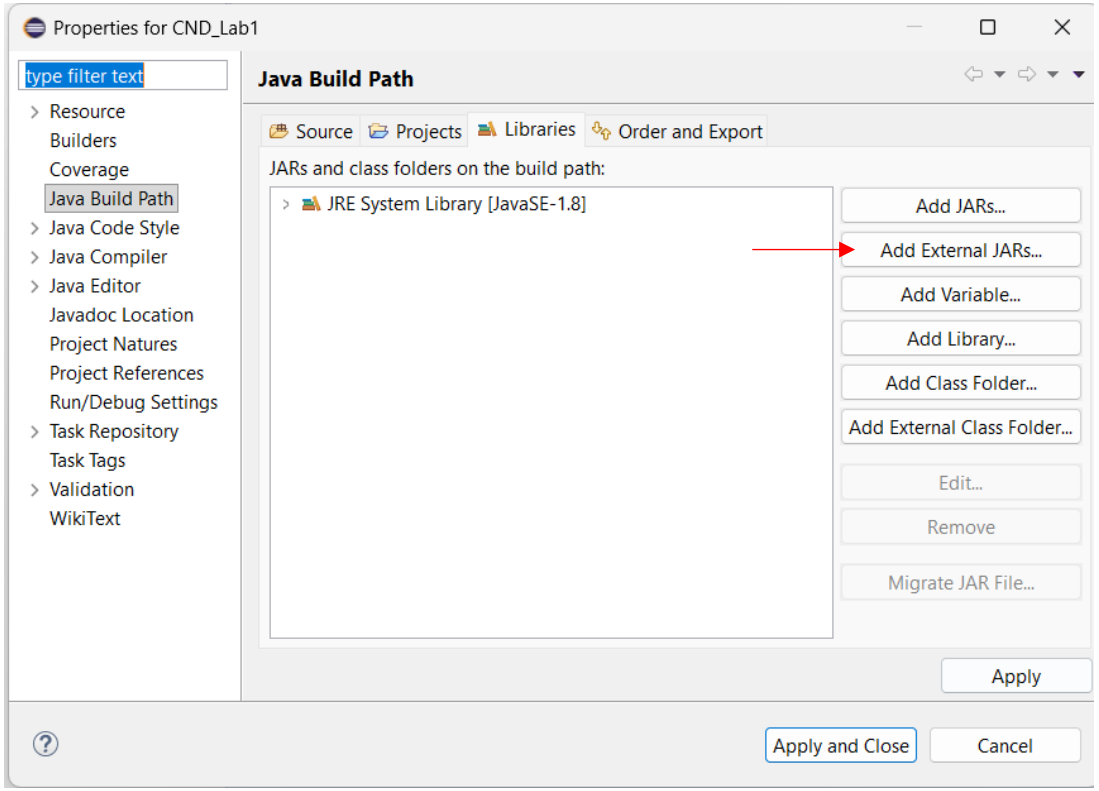


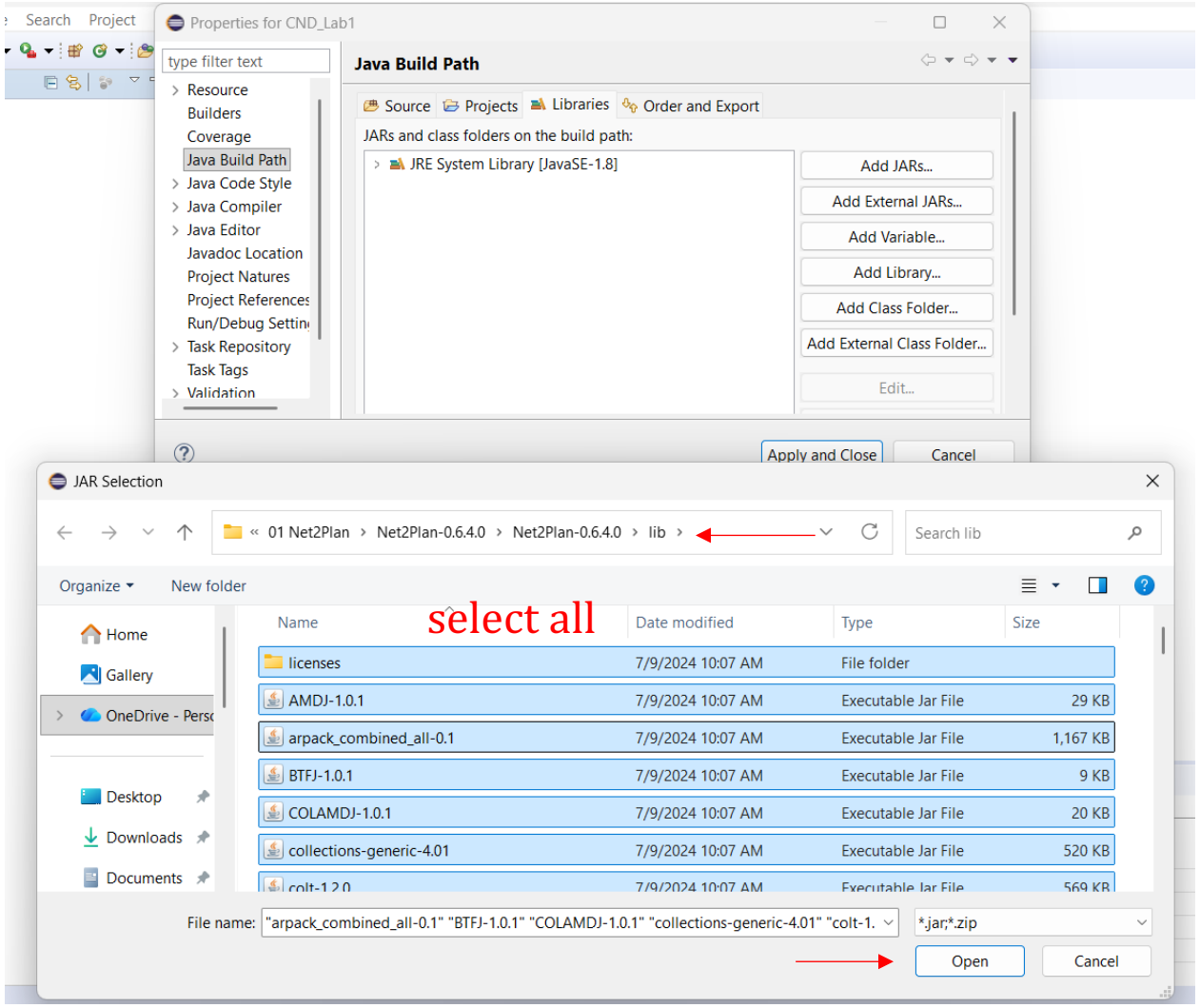


Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

- Add External Jars
- Import libraries from “lib” folder

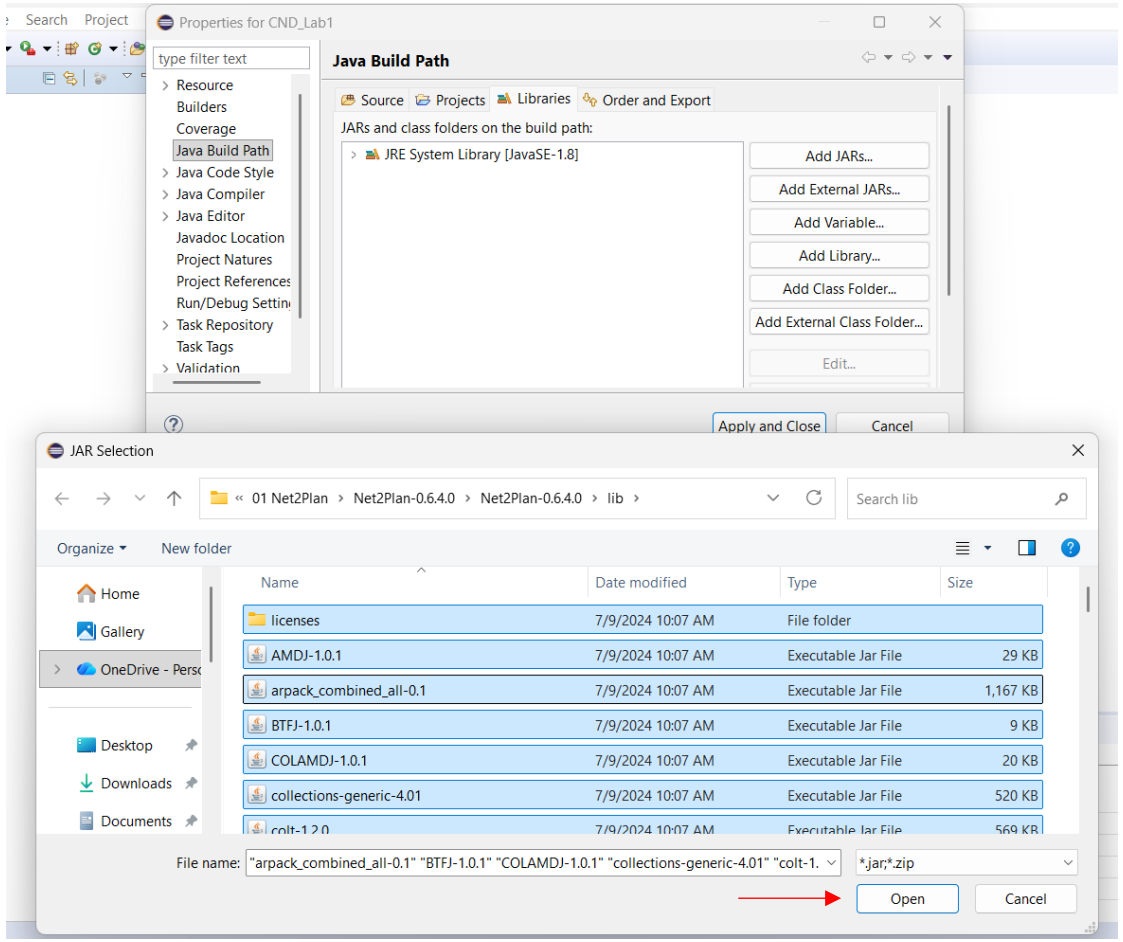


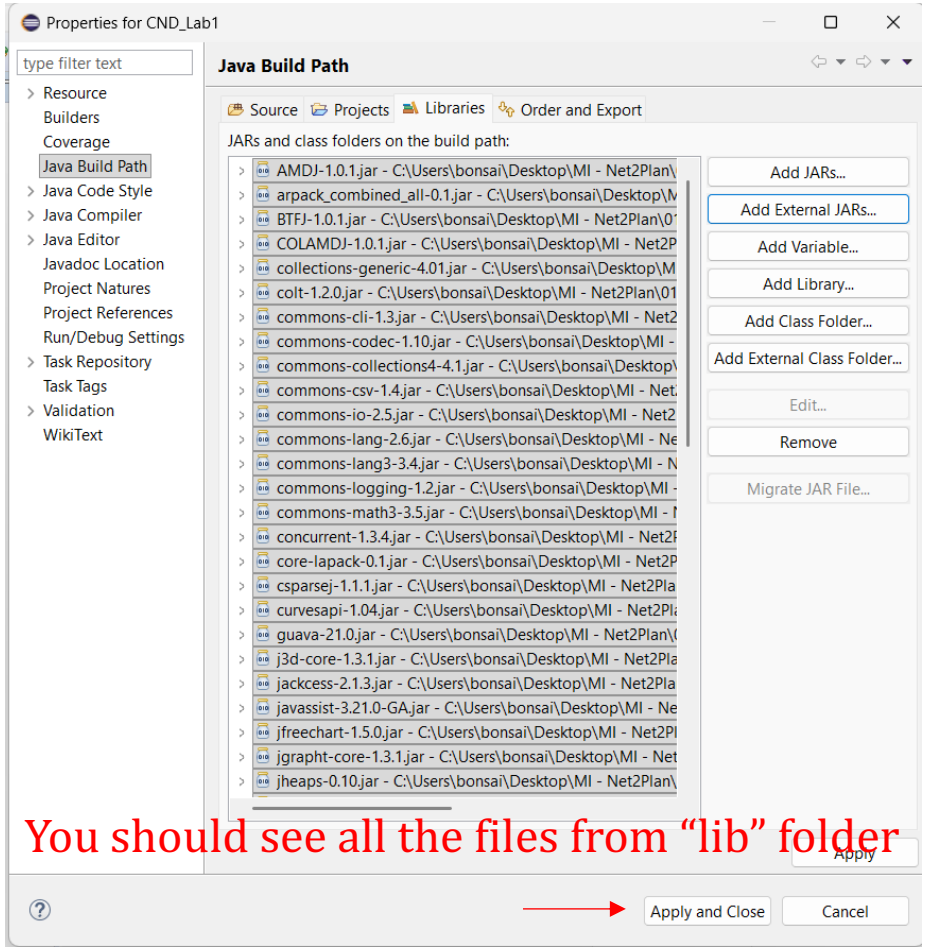


Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

- Import libraries from “lib” folder in Net2Plan-0.6.4



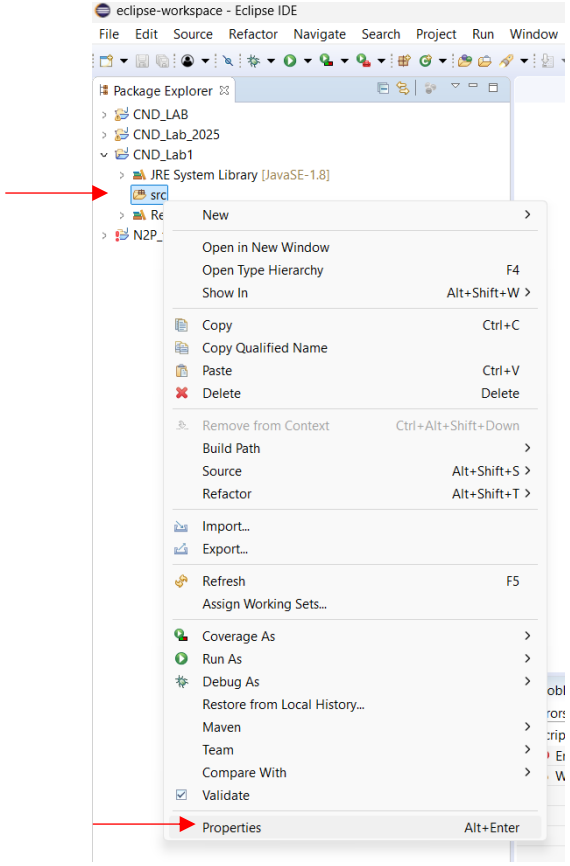


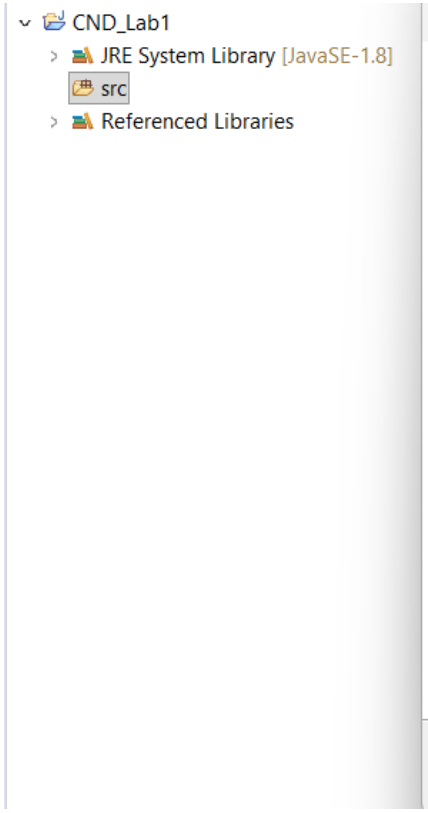
You should see all the files from “lib” folder

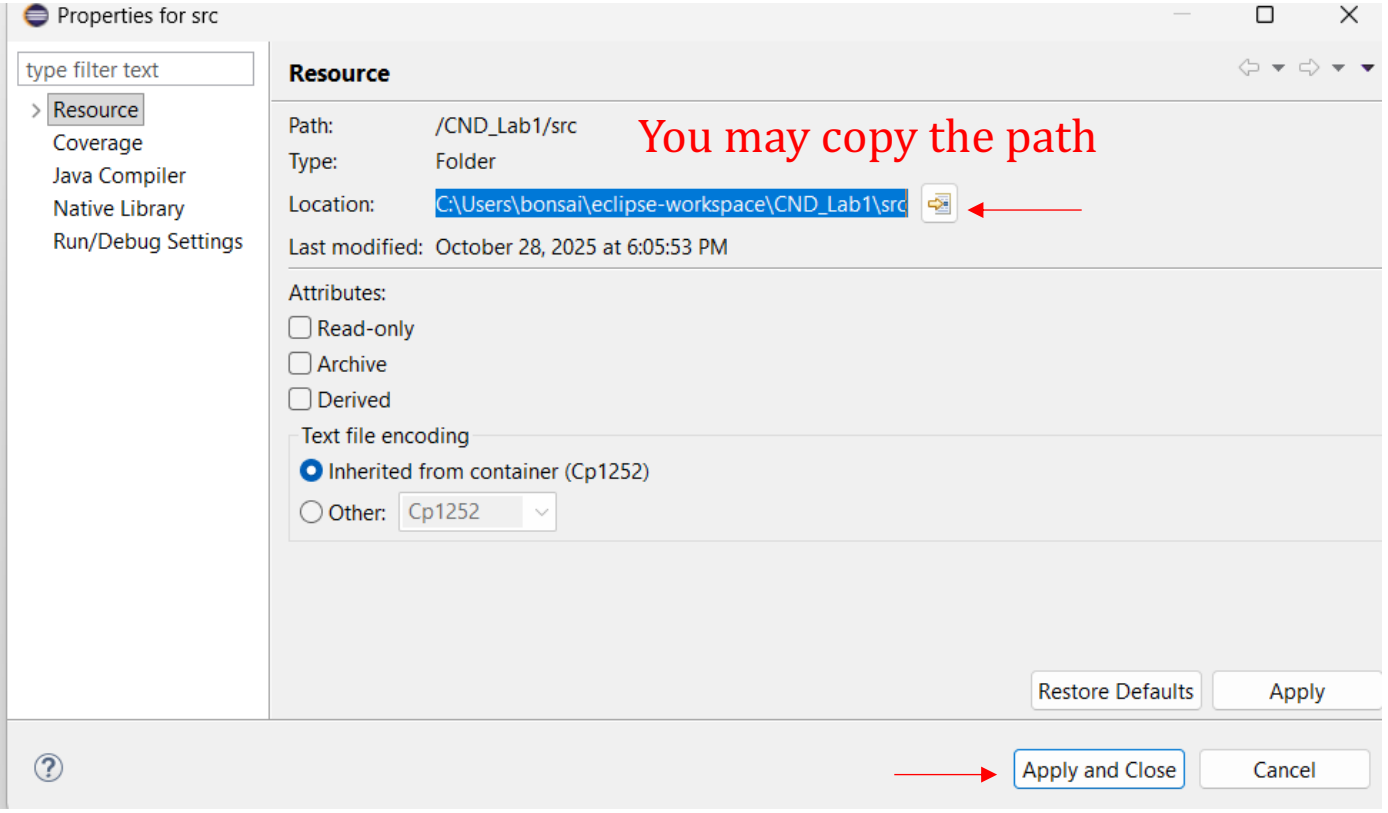
Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

- Copy the ".java" file in the "src" folder of the Java project you just created
- Follow these steps to find the path where the "src" folder is in your machine



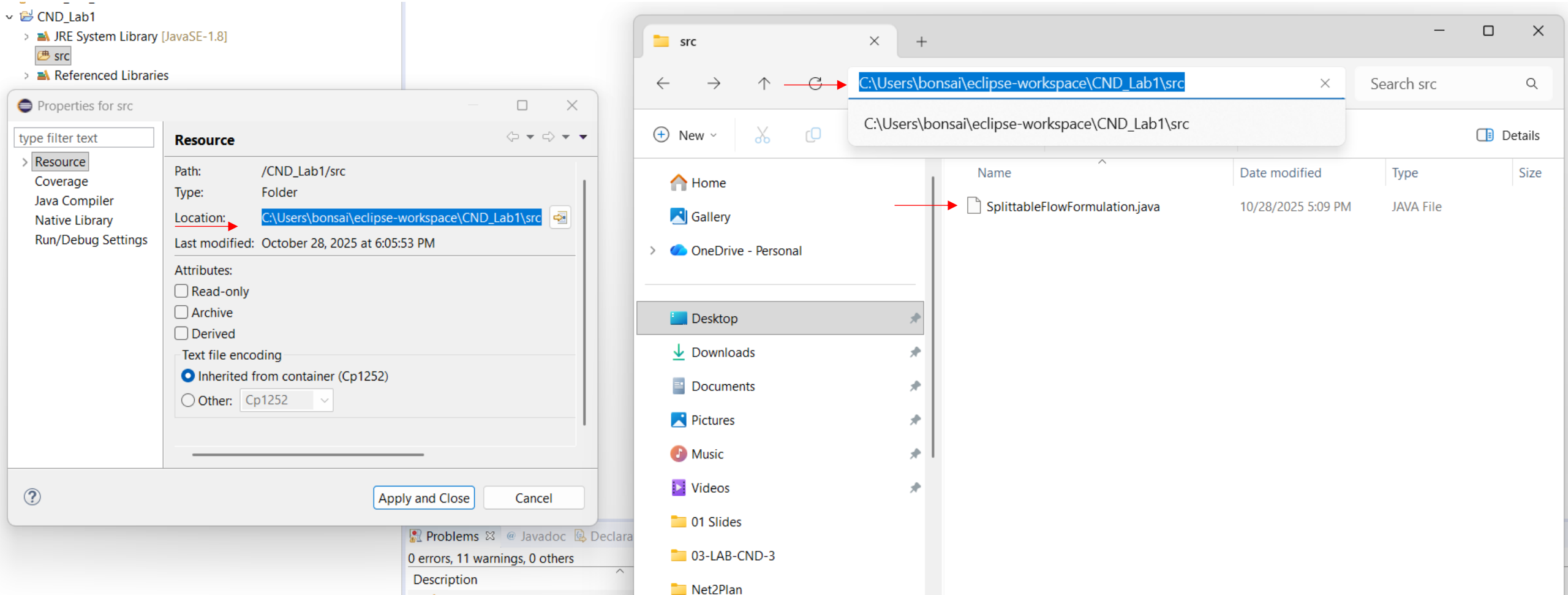




Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

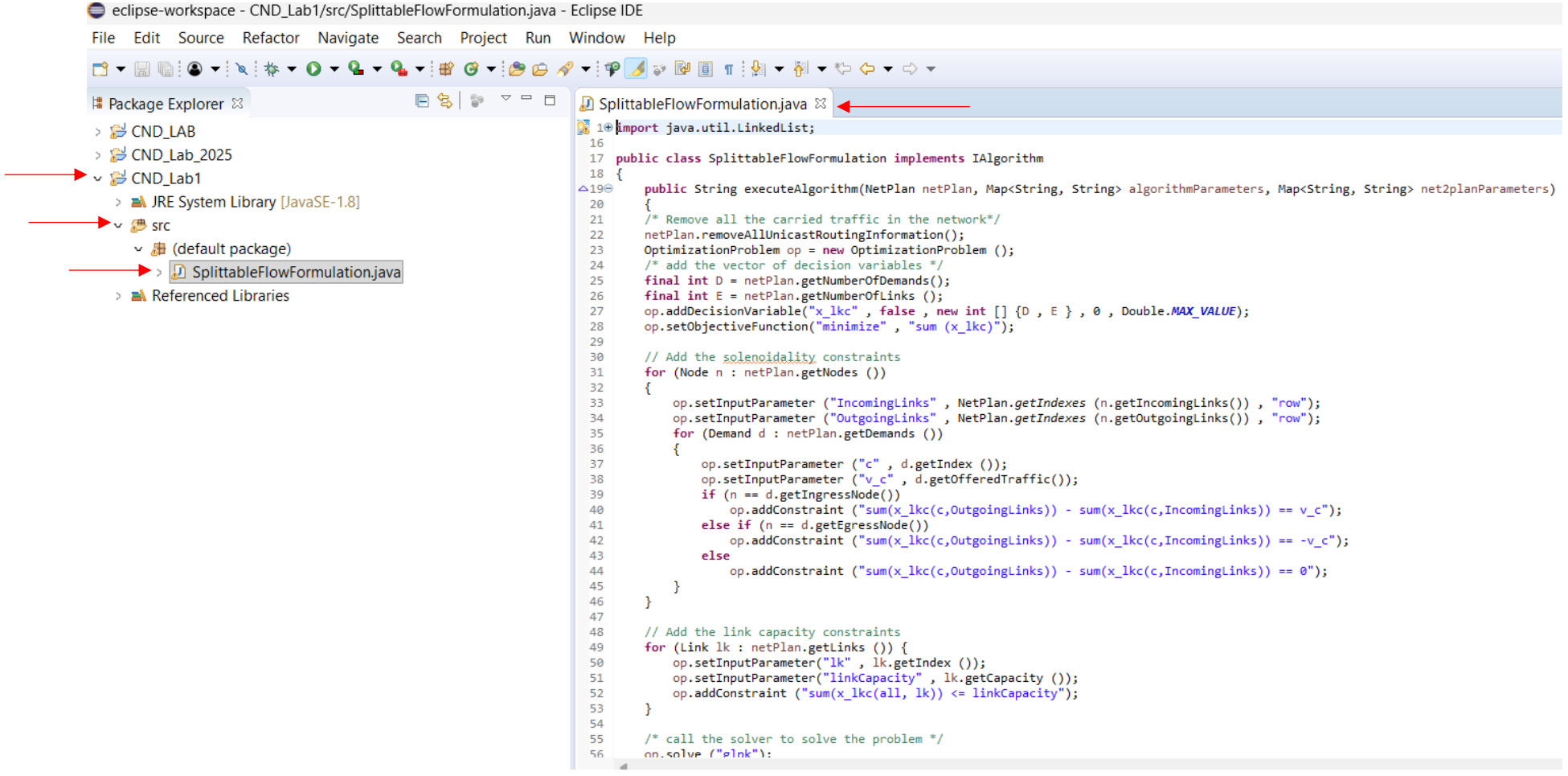
- Copy the ".java" file in the "src" folder



Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

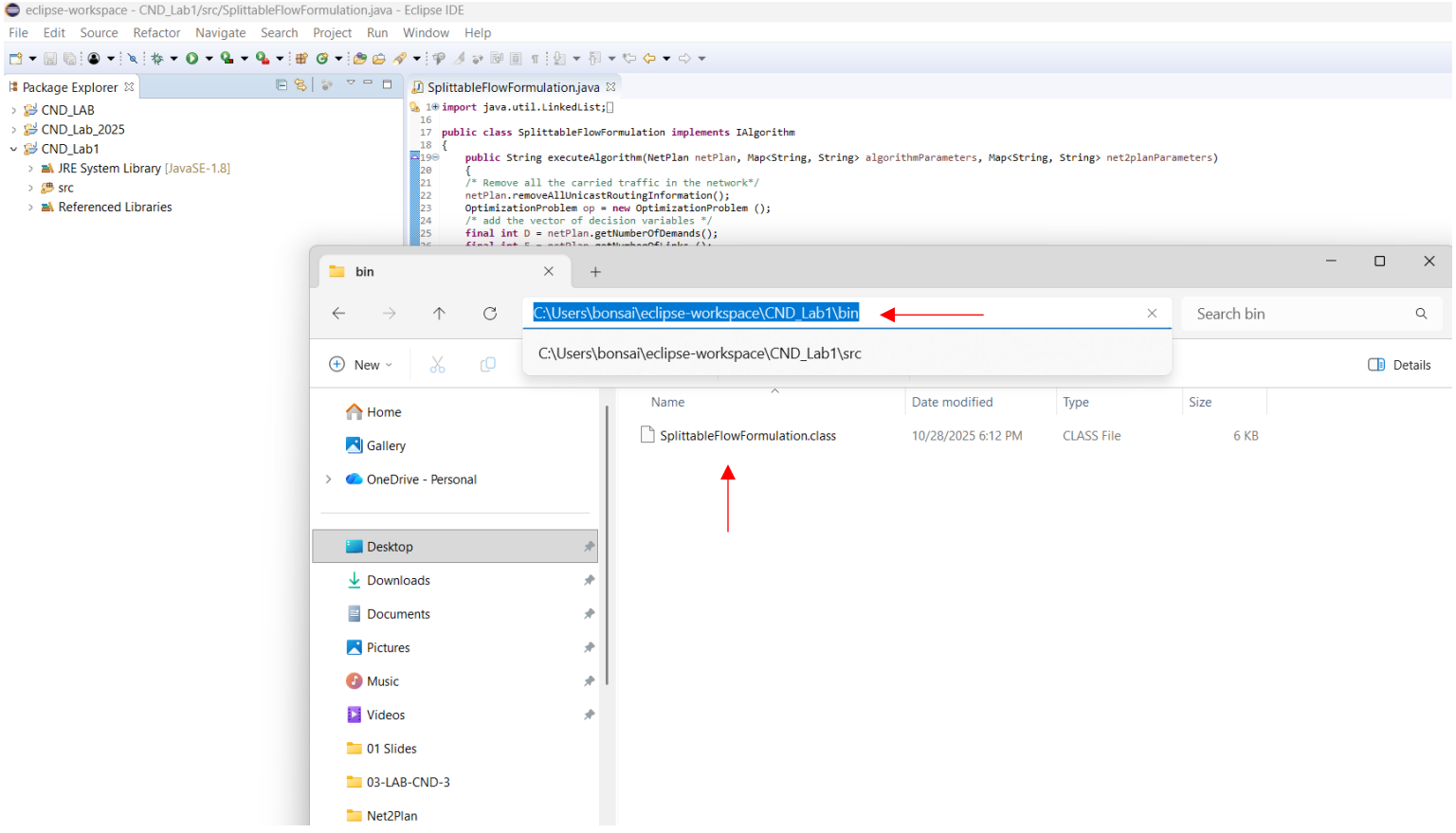
- You can now find the ".java" file in the "src" folder in Eclipse



Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

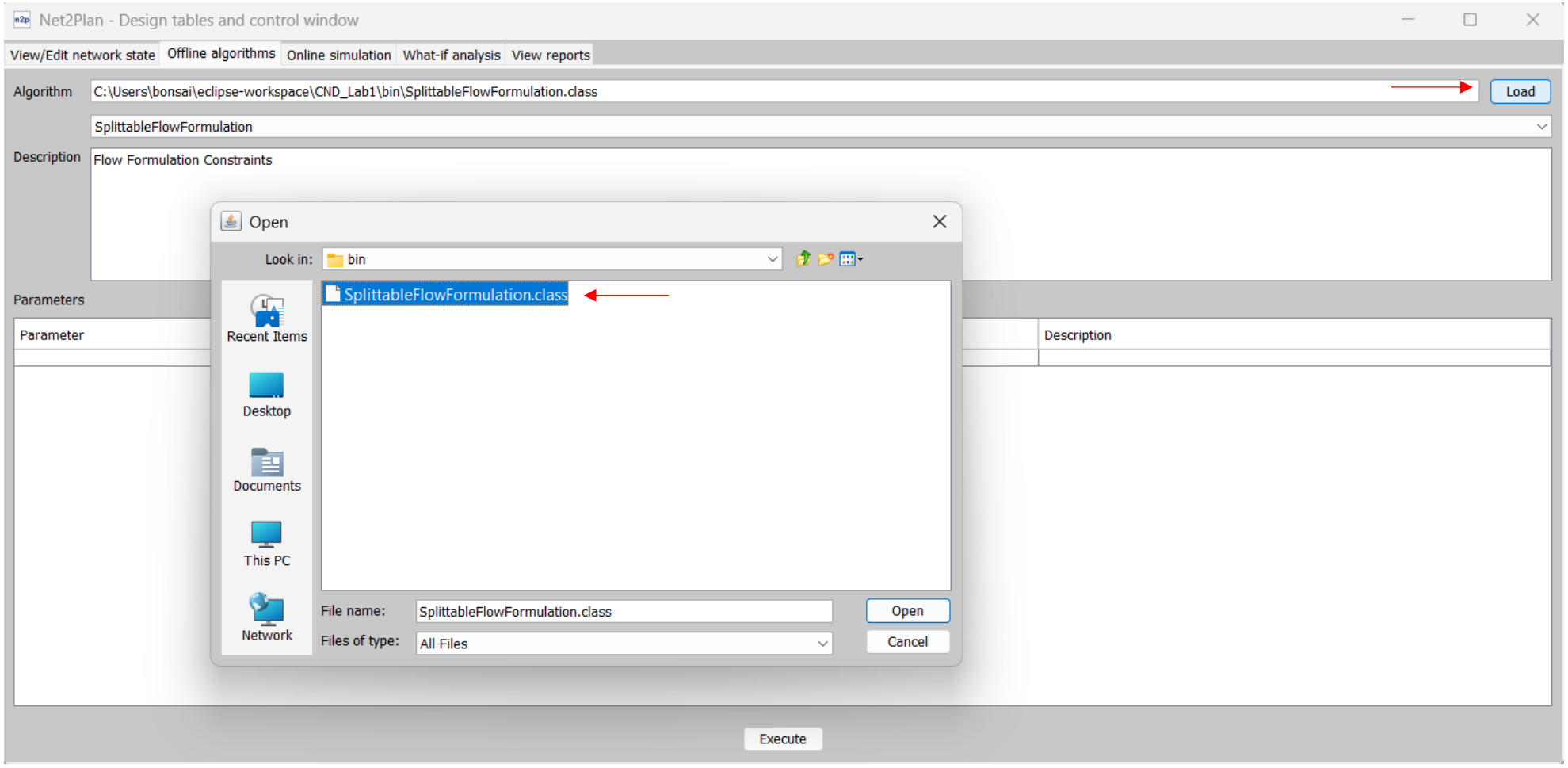
- Save the code (Ctrl+S) and you will have a ".class" file in the "bin" folder
- You find the "bin" folder in the Eclipse workspace



Introduction to Net2Plan (demo)

B- How to Compile a Java Code to Use in Net2Plan

- You may now import the created ".class" file in Net2Plan

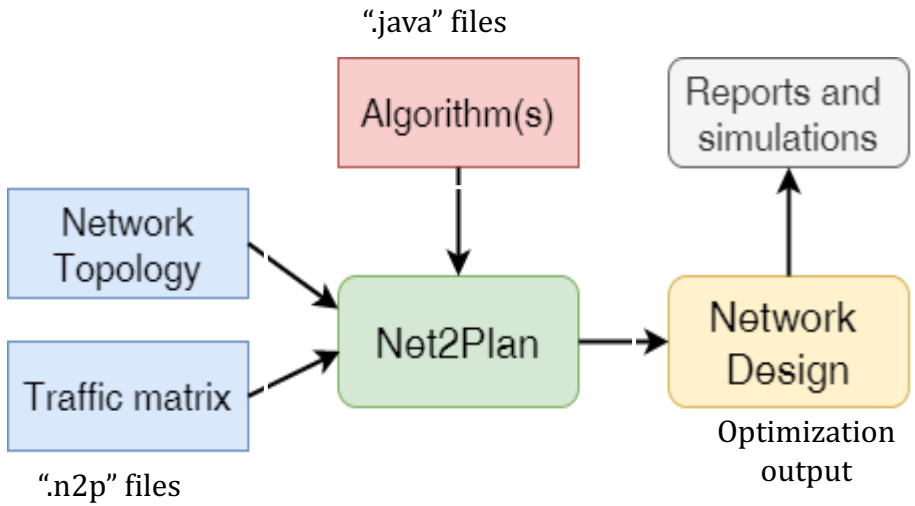


Flow Formulation

Splittable Flow

- Found in "*1 - LAB SESSION #1 - 30-10-2025*" folder → "*01 – Code*" sub-folder
- ILP in "*SplittableFlowFormulation.java*"→"*SplittableFlowFormulation.class*"
- Remark: use the following input file "*example7nodes_withTrafficWavelength.n2p*"

Link Capacity (Gbps)	*Objective Function*	*Time (seconds)*
10		
15		
20		
30		
50		



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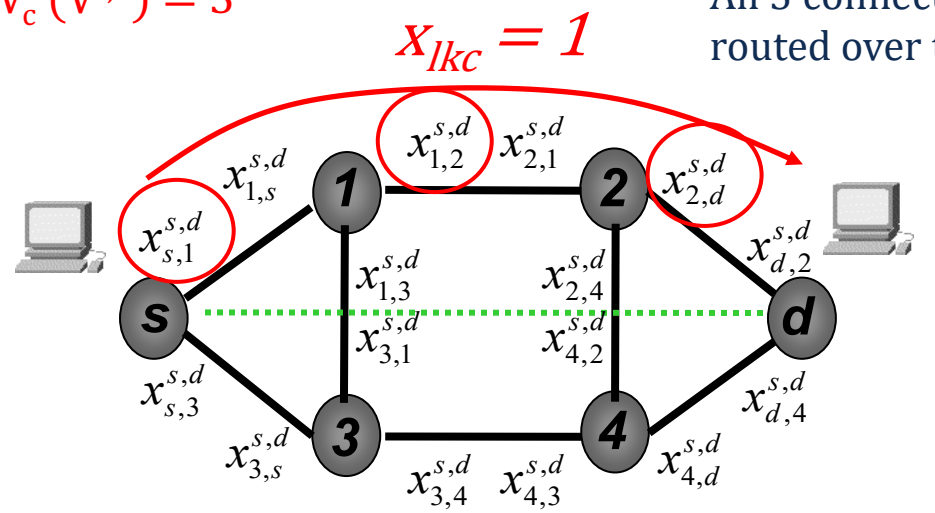
Flow Formulation

Unsplittable Flow

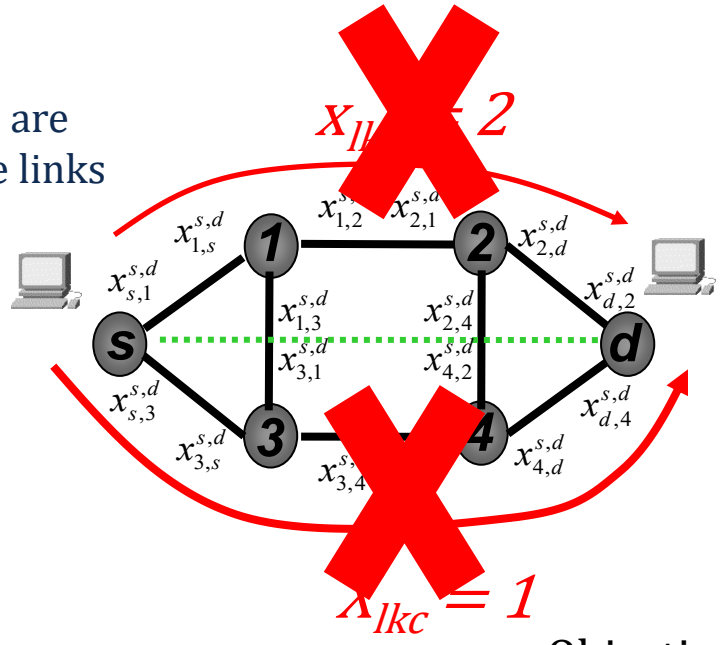
- Routing of demands uses 'flow-link' decision variables
- $x_{lkc} = \{0,1\}$ if offered traffic of c is routed on link l,k

Example, assume V_c ($V^{s,d}$) = 3



All 3 connections are routed over these links

Decision variable is now binary



V_c *number of connection requests having* s_c *as source and* d_c *as destination*

$$\min \sum_{c \in C, lk \in E} V_c \, x_{lkc}$$

Objective function changes with respect to splittable FF

- ***Objective function****: minimize the total amount of traffic routed on all links*

Flow Formulation

Unsplittable Flow

- **Subject to:**

$$\sum_{k \in Al} x_{klc} - \sum_{k \in Al} x_{lkc} = \begin{cases} 1 & l = d_c \\ -1 & l = s_c \\ 0 & Otherwise \end{cases} \qquad \forall\ l, c$$

Decision variable is now binary, flow constraint → 1 and not Vc

$$\sum_{c \in C} V_c\, x_{lkc} \leq WF_{lk} \qquad \forall\ l, k$$

Capacity constraint also changes. Decision variable of demand c on link l,k * connections of demand c <= link capacity l,k

x_{lkc} is binary $\qquad \forall\ l, k, c$

Task #1

- Modify ***FlowFormulation.java*** to assume unsplittable flows
  - What are the differences with respect to splittable FF?
    - Check the ILP formulation
- Load the 7-node network topology with traffic (Part B of the demo)
  - Compare '*splittable*' & '*unsplittable*' varying link capacity
    $C = \{10, 15, 17, 20, 30, 40, 50\}$
  - Plot/tabulate total carried traffic with respect to C

Link Capacity (Gbps)	*FF Splittable*	*FF Unsplittable*
10		
15		
17		
20		
30		
40		
50		

Task #1

Hints for task completion

1. Include “HashSet” and “Set” java libraries

   “import java.util.HashSet;”

   “import java.util.Set;”

2. Important modification to the code for unsplittable FF
   - Comment line-64 and uncomment line-65 and line-66
3. Modify the objective function according to equations given in the slides
4. Modify solenoidality and capacity constraints according to equations discussed in the slides

Link Capacity (Gbps)	*Splittable*	*Unsplittable*
10		
15		
17		
20		
30		
40		
50		

Task #1

Deadline and submission

- The task can be done by at most three students
- Please tabulate the table and follow the template for the task submission
  - Include snippets (screenshots) of the code you have implemented
  - Comment and justify the results you report
- Submit pdf file and code via e-mail with the subject "**LAB_CND_task_1**" to qiaolun.zhang@polimi.it and memedhe.ibrahimi@polimi.it
- Name the file you submit with the person code of the group members
  - Example: "*10110201_10110202_10110203.pdf*"
- Deadline is Tuesday, 04/11/2025, at 16:00

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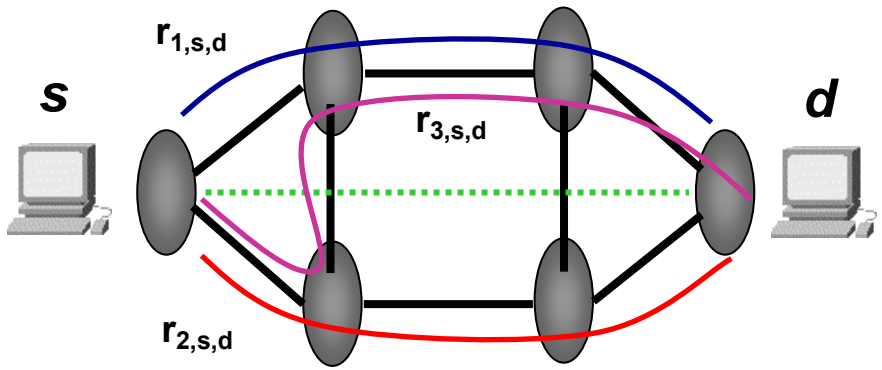
RF without wavelength continuity

- (All) possible paths between each *(s, d)* -pair are evaluated *a priori*
  - Constrained routing (k shortest paths)
- Variables represent which path is used for a given connection
  - r_{cn}: path n is used by r_{cn} connections between s_c and d_c

$G(N,E)$	N set of Nodes, E set of Links
c	node pair (s_c and d_c)
l,k	link identifiers (source-destination pairs)
n	path identifier
V_c	number of connections requests having s_c as source and d_c as destination
$r_{c,n}$	(integer) number of connections routed on n-th admissible path for node-couple c
W	Link capacity, number of wavelengths
P_n	Number of links on path n



RF without wavelength continuity

- **Objective function**: *minimize the total amount of capacity used (capacity consumption) to route demands on all links*

$$\min \sum_{c,n} r_{cn} \cdot P_n$$

Wavelength is not accounted for:
no wavelength continuity

Solenoidality	$\sum_{n} r_{c,n} = v_c \quad \forall\, c$
Capacity	$\sum_{r_{c,n} \in R_{l,k}} r_{c,n} \le W \cdot F_{l,k} \quad \forall (l,k)$
Integrity	$r_{c,n}$ integer $\quad \forall\,(c,n)$ $F_{l,k}$ integer $\quad \forall (l,k)$

$R_{(l,k)}$: set of (all) admissible paths passing through link (l,k)

RF without wavelength continuity

Route Formulation (RF) vs. Flow Formulation (FF)

- We need two formulation files (WeBeep: "*1 - LAB SESSION #1 - 30-10-2025*" folder)
  - "*SplittableFlowFormulation.java*" → "*SplittableFlowFormulation.class*"
  - *"RouteFormulationVWP.java"* → *"RouteFormulationVWP.class"*

- According to Part-B of Demo
  1) Copy '*RouteFormulationVWP.java*' to Eclipse workspace in '*src*' folder of the java project you created during Lab-1
  2) In 'Eclipse' you find and open '*RouteFormulationVWP.java*' and click '*Ctrl +S*' '*RouteFormulationVWP.class*' file is generated in '*bin*' folder of the project
  3) We can now import the '*RouteFormulationVWP.class*' in Net2Plan

Flow Formulation (FF) vs. Route Formulation (RF)

- "*SplittableFlowFormulation.class*"
- *"RouteFormulationVWP.class"* (we can modify the value of $k = \{1, 2, 3\}$)
- Load *'example7nodes_withTrafficWavelength.n2p'* (set $C = 25, 30, 35$)
- Compare FF and RF in terms of capacity consumption and execution time in seconds

Formulation	k	C = 25	C = 30	C = 35	Time (sec.)
FF	NA				
RF	1				
	2				
	3				

Flow Formulation (FF) vs. Route Formulation (RF)

	k	(4) C = ?	(2) C = ?	(3) C = ?	C = 25	(1) C = ?	C = 30	C = 35	Time (s)
FF	NA								
RF	1								
	2								
	3								

- (1) – (4): follow these steps to find the values of C for which there is no solution when $k = 1, 2, 3$ in RF
  1) What value of C ensures a solution in the case of k = 1?
  2) What value of C leads to having no solution for k = 2?
  3) Objective function values for C values between (2) and C = 25?
  4) Is there a value of C for which there is no solution, also in the case k = 3?