



# Sinalgo Tutorial

## Welcome to Sinalgo

Sinalgo is a simulation framework for testing and validating network algorithms. Unlike most other network simulators, which spend most time simulating the different layers of the network stack, Sinalgo focuses on the verification of network algorithms, and abstracts from the underlying layers: It offers a message passing view of the network, which captures well the view of actual network devices. Sinalgo was designed, but is not limited to simulate wireless networks.

The key to successful development of network algorithms is a comprehensive test suite. Thanks to the fast algorithm prototyping in JAVA, Sinalgo offers itself as a first test environment, prior to deploy the algorithm to the hardware. Prototyping in JAVA instead of the hardware specific language is not only much faster and easier, but also simplifies debugging. Sinalgo offers a broad set of network conditions, under which you may test your algorithms. In addition, Sinalgo may be used as a stand-alone application to obtain simulation results in network algorithms research.

Sinalgo's view of network devices is close to the view of real hardware devices (e.g. in TinyOS): A node may send a message to a specific neighbor or all its neighbors, react to received messages, set timers to schedule actions in the future, and much more.

Some of the key features of Sinalgo:

- Quick prototyping of your network algorithms in JAVA
- Straight forward extensibility to cover nearly any simulation scenario
- Many built-in, but still adjustable plug-ins
- High performance - run simulations with 100000s of nodes in acceptable time
- Support for 2D and 3D
- Asynchronous and synchronous simulation
- Customizable visualization of the network graph
- Platform independent - the project is written in Java
- Sinalgo is for *free*, published under a BSD license

To guarantee easy extensibility, Sinalgo offers a set of extension points, the so called *models*. The following list gives an overview of the available models, to each of which you may add your own extension. To facilitate your life, Sinalgo ships with a set of frequently used models.

- The *mobility model* describes how the nodes change their position over time. Examples are

*random waypoint, random walk, random direction*, and many others.

- The *connectivity model* defines when two nodes are in communication range. The best known examples are the *unit disk graph (UDG)* and the *quasi-UDG (QUDG)*.
- The *distribution model* is responsible to initially place the network nodes in the simulation area. E.g. place the nodes *randomly*, evenly distributed on a *line* or *grid* or according to a stationary regime of a mobility model.
- Use the *interference model* to define whether simultaneous message transmissions may interfere.
- The *reliability model* is a simplified form of the interference model and lets you define for every message whether it should arrive or not. E.g. drop one percent of all messages.
- Last but not least, the *transmission model* lets you define how long a message takes until it arrives at its destination.

Please refer to the [TUTORIAL](#) for more information on how to get started.

This software was developed by the [DISTRIBUTED COMPUTING GROUP](#) at [ETH ZURICH](#).



Screenshots

## Getting Started

This tutorial gives you a brief introduction to Sinalgo. It covers details from the installation process to a detailed look into the clockwork of Sinalgo.

Running a simulation is actually quite easy. The real difficulty is to understand what one has simulated, and to interpret the obtained results in this context. With this in mind, we hope to give you enough information to not only understand how you can use this simulation framework, but also understand on a high level how the simulation executes. For this purpose, we have added a section [ARCHITECTURE](#) that gives an insight into the clockwork of Sinalgo.

## Roadmap of this Tutorial

- We start with some information on how to [SETUP](#) Sinalgo on your machine. Don't worry, it's quite easy.
- The [EXECUTION](#) section describes the different ways to start Sinalgo, as well as the command-line arguments to pre-configure Sinalgo.
- In the [PROJECTS](#) section, we describe how you can add your own project to Sinalgo...
- ... and how to [IMPLEMENT](#) the desired behavior.
- The [CONFIGURATION](#) section shows how you can configure the framework to your needs, and

also add your project-specific configuration settings.

- Don't miss the [TOOLS](#) page! It contains many hints on how to use the framework and describes the tools Sinalgo already provides.
- Finally, some information on how Sinalgo works is given in the [ARCHITECTURE](#) section.

## Printable Version of this Tutorial

If you wish to print the entire tutorial, try the **ALL-IN-ONE TUTORIAL**, which contains all sections of the tutorial on a single website. To print some pages of this tutorial, click on the **Printable Version** link on top of each site to get a printer friendly version of the page.

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## Sinalgo Setup

There are two flavors of Sinalgo: The [TOY RELEASE](#) and the [REGULAR RELEASE](#). Download the toy release if you just want to have a glance at the project, but do not intend to run any simulations. For any other objectives, download the regular release for full access to all features of Sinalgo.

## Requirements

- Sinalgo requires [JAVA 5.0 \(J2SE 5.0 JDK\)](#) or a more recent version.
- Optionally, you may install a development tool, e.g. [ECLIPSE](#). In the following, we will briefly sketch the setup of Sinalgo with Eclipse.
- Optionally, you may also install [APACHE ANT](#), a tool that lets you easily build the framework from the command-line.

## Toy Release

After downloading the toy release, unpack the compressed folder and double click the included jar file.

In case you have several versions of Java installed, ensure that the default version is 5.0 or higher.

**Note:** If another application than java executes jar files on your system, you may need to launch Sinalgo from the command line. This is probably the case if you see a window showing a directory structure after double clicking the jar file. To start Sinalgo from the command line, open the a command line and change to the unpacked directory of the toy release. Then, type `java -jar sinalgo.jar`

## Regular Release

After downloading the regular release, unpack the compressed folder to your favorite location to work from. Depending on the IDE you are using, the following steps may differ. We first describe the general settings you need to achieve and then how to obtain these settings with Eclipse.

### *Class Paths*

The following settings need to be set, either in your IDE, or on the command-line to compile and run the application.

- The source-code is located in the folder `src`
- The binaries are located in the folder `binaries/bin`

To compile from the command-line using ANT, call `ant compile`.

To run the application from the command line, call (for example)

```
java -cp binaries/bin sinalgo.Run
```

Refer to the [COMMAND LINE ARGUMENTS](#) section of the tutorial for more information about the command-line arguments to Sinalgo.

## Setup in Eclipse

To setup Sinalgo for Eclipse, you need to create a new project in Eclipse and associate it with the downloaded regular release of Sinalgo.

1. Start Eclipse, and create a new project ('File' -> 'New' -> 'Project')
2. Select to create a 'Java Project' and click to proceed
3. Name the new project, e.g. 'sinalgo'
4. If you wish to import Sinalgo into your workspace, then
  1. Click on 'Finish' to create an empty project.
  2. Unpack the regular release to a temporary directory, and copy its content into the new project, overwriting the `.classpath` file.

If you wish to store the source of Sinalgo in any different location, then

1. Unpack the regular release to the desired location
2. Select to create the project from an existing source, and point to the unpacked regular release of Sinalgo.
3. Click on 'Finish' to create the project. The required settings are set automatically.
5. Ensure that Eclipse is configured to use Java 5.0 or later:  
Open the Preferences dialog ('Window' -> 'Preferences') and select 'Java' -> 'Compiler'. The compiler compliance level should be set to 5.0 or higher.  
Also, ensure that Eclipse uses the JRE 5.0 or higher. In the Preferences dialog, ('Window' -> 'Preferences'), select 'Java' -> 'Installed JREs'. Ensure that the installed JRE points to the correct Java installation.

**Note:** Do not use the option *Java Project from Existing Ant Build File*. This feature creates symbolic links to the source of Sinalgo, and creates a local copy of the binaries only. Such a setup is not supported by Sinalgo, which expects the `src` and `bin` folder to be located in the same directory.

To start the application, right-click on the `src` folder in the Package Explorer or the Navigator of Eclipse, and select 'Run As' -> 'Java Application'.

## Running Sinalgo

We have already seen that the toy release of Sinalgo only needs a double click to start. This section describes the more advanced possibilities to launch and configure Sinalgo.

- To launch Sinalgo from within your IDE, execute the Run class, which is located in the folder `sinalgo`. Remember that your IDE needs to have the class paths set as described in the [INSTALLATION](#) tutorial.

**For Eclipse Users:** In the *Navigator* or *Package Explorer* of Eclipse, open the folder `src/sinalgo/`. Right-click on `Run.java` and select *Run As -> Java Application*. (There are several alternatives to launch an application in Eclipse, please consult the documentation of Eclipse for more details.)

- To launch the framework from the command line, change to the root directory of the Sinalgo installation and execute the following command  
`java -cp binaries/bin sinalgo.Run`

## Increase the VM Memory

With increasing size of the networks you simulate, Sinalgo requires more memory. By default, Java provides only around 128MB. In order to increase the amount of memory Java is allowed to use, modify the configuration file of your project and set the entry `javaVMmaxMem` to an appropriate value (in MB).

**Note:** Do not use the `-Xmx` flag for the virtual machine. This flag only affects the Run application, which starts the simulation in a separate process.

## The Run Command

The Run command used to launch Sinalgo is a helper process to start the simulation process. I.e. when starting Sinalgo through `java -cp binaries/bin Sinalgo.Run`, the initial java process launches a second process, in which the simulation takes place. This allows the first process to read the configuration file of the selected project, set the maximum memory that may be used by the simulation process, and start the simulation process using the additional commands specified in the config file.

Depending on your OS and installed applications, you may have several tools at hand that may facilitate simulations with Sinalgo. Below is a brief list of how you may edit the `javaCmd` field in the config file:

<code>java</code>	The default. Just start the simulation process.
<code>nice -n XX java</code>	Start Sinalgo with modified priority XX.
<code>time java</code>	Display the total running time of the simulation (after the simulation stopped).

*Suggestions on how to modify `javaCmd` in the config file.*

## Command Line Configuration of Sinalgo

Calling Sinalgo without any arguments opens the project selection dialog. This dialog shows the available projects you may choose from, and gives you the possibility to alter the configuration of the projects. Refer to the [CONFIGURATION](#) section of the tutorial to learn more about how to configure your project.

By passing on arguments on the command line (or through your IDE), you can influence the execution of Sinalgo. The following list describes the recognized command line arguments.

<code>-help</code>	Prints the recognized command line arguments.
<code>-gui</code>	Starts the framework in GUI mode (default)
<code>-batch</code>	Starts the framework in batch mode, i.e. no windows. This mode is best suited to run long-lasting well-defined simulations.
<code>-project XX</code>	Indicates that Sinalgo should be started for project XX. If this argument is missing, the project selector dialog will be displayed.
<code>-rounds XX</code>	The framework performs XX simulation rounds immediately after startup. Defaults to zero.
<code>-refreshRate XX</code>	Sets that the GUI should be updated only every XX round. Defaults to 1.

<pre>-gen ...</pre>	<p>This argument lets you automatically generate network nodes. It has the following form:</p> <pre>-gen #n T D {(params)} {CIMR {(params)}}*</pre> <p>The command generates #n nodes of node-type T and distributes them according to the distribution model D. (Optionally, the distribution model may take parameters in parentheses.)</p> <p>Optionally, you may specify in arbitrary order the connectivity, interference, mobility, and reliability models by appending the corresponding model name(*) to the -gen command. If a model is not specified, the default model (as specified in the project's configuration file) is used. (Again, any of the model names may be followed by model-specific arguments enclosed in parentheses.)</p> <p>(*) <b>Model and Node Naming Convention:</b> The name of models is composed of the project name in which the model is located and the name of the model itself: projectName:modelName. The same holds for the name of the node. <i>Exception:</i> Models and nodes stored in the defaultProject of the framework need not be prefixed with "defaultProject:".</p> <p>For disambiguation, the models may be prefixed with X=, where X={C I M R}. The mapping is as following:  C - Connectivity Model  I - Interference Model  M - Mobility Model  R - Reliability Model</p>
<pre>-overwrite key=value (key=value)*</pre>	<p>Overwrites the configuration entry named key to have the new value value. key may specify a framework configuration entry, or a custom configuration entry specified in the project's configuration file.</p>

Command line parameters that may be used to configure a simulation.

## Example 1

The following arguments open project sample1, and generate 1000 nodes of type S1Node from project sample1. The nodes are distributed according to the Random distribution model. After generating the nodes, the framework performs 10 rounds, but only draws the GUI every second round.

```
-project sample1 -gen 1000 sample1:S1Node Random -rounds 10 -refreshRate 2
```

## Example 2

The following arguments open project sample2, and generate 10000 nodes of type S2Node from project sample2. The nodes are distributed according to the Random distribution model. Furthermore, the connectivity model is set to QUDG (which is in the default project), and the mobility model is set to LakeAvoid from project sample2.

```
-project sample2 -gen 10000 sample2:S2Node Random C=QUDG M=sample2:LakeAvoid
```

Note that in this case, the disambiguation is not necessary, and the following arguments result in the same behavior.

```
-project sample2 -gen 10000 sample2:S2Node Random QUDG sample2:LakeAvoid
```

## Example 3

In order to enable mobility, disable interference, and set rMax of the GeometricNodeCollection to 50 you would add the following -overwrite argument:



```
-overwrite mobility=true interference=false GeometricNodeCollection/rMax=50
```

## Example 4

You may place several `-gen` arguments to generate distinct sets of nodes:

```
-project sample1 -gen 100 sample1:S1Node Random UDG -gen 50 DummyNode Circle QUDG -gen 10
sample2:S2Node Random
```

Thus, it is possible to use nodes and models from several projects. But note that the configuration is loaded from the selected project.

## True batch mode without windows

Running Sinalgo without any windows in true batch mode may require that you start the application with the flag

```
-Djava.awt.headless=true
```

If you launch Sinalgo via the `Run` class, you may need to specify this flag twice: once for calling `Run`, and once in the project configuration through the `javaCmd` property.

*Thanks to Denis Rochat for pointing out this issue.*

## Running Sinalgo from Scripts

Instead of typing the basic java command for every run, you may make use of a script (batch) file that encapsulates the call to java with the necessary parameters described above. Two such scripts are included in the root directory of the regular release: `sinalgo.bat` for the Microsoft Windows *cmd* shell, and `sinalgo` for *bash* shells. Instead of typing

```
java -cp binaries/bin sinalgo.Run -project sample1
```

only write:

```
sinalgo -project sample1
```

## Automating Sinalgo

A simulation often consists of several runs of Sinalgo, each time with slightly different parameters. The variation of the parameters is achieved easiest by using the `-overwrite` command line parameter, as described above. To call Sinalgo automatically several times with the distinct command line parameters, we propose to use a scripting language, the example below uses *perl*.

```
#!/usr/bin/perl

$numRounds = 100; # number of rounds to perform per simulation

for($numNodes=200; $numNodes<=500; $numNodes+=100) {
    system("java -cp binaries/bin sinalgo.Run " .
        "-project sample1 " . # choose the project
        "-gen $numNodes sample1:S1Node Random RandomDirection " . # generate
        nodes
        "-overwrite " . # Overwrite configuration file
        parameters
        "exitAfter=true exitAfter/Rounds=$numRounds " . # number of rounds to
        perform & stop
```

```

"exitOnTerminationInGUI=true " . # Close GUI when hasTerminated()
returns true
"AutoStart=true " . # Automatically start communication
protocol
"outputToConsole=false " . # Create a framework log-file for each
run
"extendedControl=false " . # Don't show the extended control in
the GUI
"-rounds $numRounds " . # Number of rounds to start simulation
"-refreshRate 20"); # Don't draw GUI often
}

```

A sample perl script that demonstrates how Sinalgo may be called several times in sequence with modified command line arguments. In this example, project sample1 is started with 200, 300, 400, and 500 nodes, respectively.

The flags -project, -gen, -rounds, and -refreshRate are presented above. The remaining parameters overwrite the default entries in the project specific configuration file. Alternatively, we could add the flag -batch to run the simulation in batch mode. For huge simulations with many nodes, this may be preferable. But if memory is not a limiting factor, the GUI may provide a good interface to supervise the simulation. Setting the refresh rate to a fairly high value, the GUI does not use a significant amount of simulation time. Note that pressing the stop button, and then continuing a simulation is perfectly OK and does not change the simulation result.

**Note:** Project sample1 contains a more sophisticated run-script to demonstrate the possibilities of perl.

**Remember:** Depending on your platform, you may need to adjust the class path separator. In the example above, we used the semicolon. But for instance on Linux, the separator is a colon, and yet other separators may be used on other platforms.

**Hint:** Set the logToTimeDirectory such that log-files are not overwritten by a subsequent simulation. To collect simulation data from the different simulations, designate a log-file to which each simulation appends to. See [Logging](#) for more information.

**Installing perl:** You may obtain a copy of perl from [WWW.PERL.ORG](http://WWW.PERL.ORG). Alternatively, install [CYGWIN](#) and include the perl package.

## Debugging

The Run class launches Sinalgo in a separate process. This has immediate consequences for running a debugger, as the simulation itself does not run in launched application. In order to use the debugger of your IDE to analyze the implemented algorithms, you probably need to do one of the steps below.

**a)** Start Sinalgo directly using the following slightly modified command line.

```
java -Xmx800m -cp binaries/bin sinalgo.runtime.Main
```

This launches the simulation process directly, but does not allow to specify the maximum memory to be used through the config file. The -Xmx800m flag indicates that the JVM may use at most 800 MB of memory, adjust the value to your needs.

**b)** Use remote debugging: Some java debuggers can be attached to a remote process (even running on a different machine). Remote debugging requires two steps.

**b.1)** First, modify the run command for the simulation process s.t. it can communicate with the debugger. I.e. set the javaCmd entry of the config file to

```
java -agentlib:jdwp=transport=dt_socket,address=localhost:8000,suspend=n,server=y
```

This configures the JVM to receive connections. You are free to choose any (unused) port



number in the address-flag.

**b.2)** After starting the simulation, launch the debugger and attach it to the application. In Eclipse, call Run -> Debug... and create a new configuration for a *Remote Java Application*. Select the Connection Type to be *Standard (Socket Attach)*, and the Connection Properties to match the address specified in the javaCmd.

## Hot Code Replace

The exchange of class files at runtime is called 'hot code replace' and can be performed by most IDEs, e.g. Eclipse. For that purpose, your IDE transfers the new class files over the debugging channel to the JVM running Sinalgo. Therefore, hot code replace requires Sinalgo to run in [debugging mode](#).



**Note:** Hot code replace is only possible if the signature of the replaced class files remains the same. I.e. you may change the body of a method, but not the signature of the method. It is neither possible to add/remove methods or global variables.

## GUI Description

This section summarizes the methods and helper-functions provided through the GUI of Sinalgo.

### Menus








The **Graph** menu provides the following tasks:

Generate Nodes 	Opens a dialog that adds new nodes to the simulation. You can specify the number of nodes to add, their initial distribution, as well as the node specific models.
Clear Graph 	Removes all nodes from the simulation.
Reevaluate Connections	Loops over all nodes and determines for each node the set of neighbor nodes, according to the node's connectivity model. This function is especially useful in the asynchronous simulation mode, where the connections are not updated automatically.
Infos	Prints some information about the current network graph, including the number of nodes and the number of (unidirectional) edges.
Export	Creates a vector graphic image of the current view of the network graph and writes it to an EPS or PDF file. To output the graphic in PDF format, your machine needs to provide a tool that can convert from EPS to PDF. By default, the framework calls the epstopdf application. Change the field epsToPdfCommand in the framework section of the <a href="#">CONFIGURATION FILE</a> to specify a different application.
Preferences	Some preferences you are allowed to change at runtime. This includes the type of the edges and the message transmission model, which is the same for all nodes.

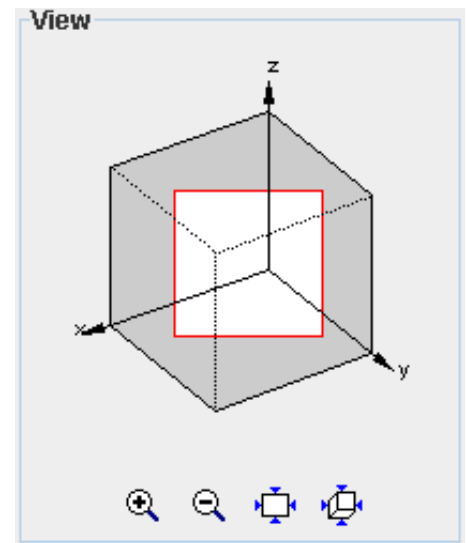
*Methods provided in the Graph menu*

The **Global** menu contains all [GLOBAL CUSTOM METHODS](#) and the Settings dialog, which displays a list of all settings.

## GUI Interaction

Perform a simulation step / execute the next event	Press the  button. In synchronous simulation mode, this executes the number of rounds specified in the <i>Rounds to Perform</i> text field. In asynchronous simulation mode, this executes the number of events specified in the <i>Events to Perform</i> text field.
Abort a running simulation	<p>Press the  button. After pressing the button, the simulation will finish the currently executing round/event before it stops. Thus, this button is only useful if you set the <i>Rounds to Perform</i> or <i>Events to Perform</i> field to a value above 1.</p> <p>The framework finishes the current round/event to ensure integrity of the system, and that the simulation can be continued by pressing .</p>
Add an edge from node A to node B.	Left-click on node A. Keep the mouse pressed, move it to node B and release it.
Move a node in 2D	Right-click on the node and drag it to the new place. Alternatively, right-click on the node to obtain the popup menu for the node and select the 'Info' dialog to key in the new coordinates. The latter approach is also supported in 3D.
Zoom in / Zoom out	<p>Position the mouse in the area containing the network and use the wheel to change the zoom factor. Alternatively, use the zoom-in / zoom-out buttons  .</p> <p>This operation may also be performed in the 'View' panel of the extended control panel.</p>
Zoom to Fit	<p>Press the  button to set the zoom factor such that the simulation area just fits on the screen.</p> <p>In 3D mode, press the  button to reset the default view of the cube.</p>
Translate the displayed simulation area	<p>Press the right mouse-button on a free spot of the simulation area. Keep the mouse button pressed and move the mouse to translate the simulation area.</p> <p>This operation may also be performed in the 'View' panel of the extended control panel, with the difference that the network graph is only updated once the mouse button is released. This may be handy for huge networks graphs with a long drawing time.</p>
Rotate the 3D cube	<p>Press the left mouse-button on a free spot of the simulation area. Keep the mouse button pressed and move the mouse to rotate the simulation area. By default, the rotation keeps the Z-axis vertical. To turn off this feature, press the Ctrl button while pressing the left mouse-button.</p> <p>This operation may also be performed in the 'View' panel of the extended control panel, with the difference that the network graph is only updated once the mouse button is released. This may be handy for huge networks graphs with a long drawing time.</p>

The view panel in the extended control shows the entire cube even though the main view of the network graph only shows a cut-out. The red rectangle indicates the portion of the simulation area currently displayed. The zoom, translate and rotate operations may also be performed in this area.



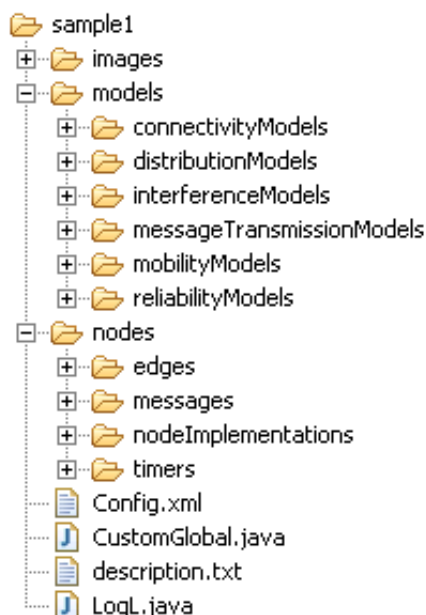
## Sinalgo Project

Once Sinalgo is installed, you may run several independent simulations with the same installation. To distinguish between the different simulations, the files belonging to one simulation are grouped in a project. This includes the project specific configurations and the actual network implementations. At startup of the framework, Sinalgo asks which project to use and then initializes as defined in the chosen project.

**Note:** It is recommended to generate a project for each algorithm one simulates. However, this often results in quite a lot of common code, e.g. models that are used for several projects. Instead of *copying* this code to all projects, it is preferred to create a *dummy project* that holds this common code from where all other projects access it. In fact, the defaultProject shipped with Sinalgo is such a dummy project and gathers quite some default implementations that may be handy for you.

## Creating a Project

From the view of a developer, a project is nothing else than a folder located in the src/projects/ folder of Sinalgo. The name of the project is given by the name of this folder. The content of the project folder for a project named sample1 may look as following:



To create a new project, rename a copy of the template project. This gives you an empty folder structure as shown above.

## Project Content

The project folder contains three sub-folders:

- `images` This folder contains the images for project specific buttons.
- `models` All project specific model implementations are stored in the corresponding sub-folder.
- `nodes` This folder contains network-node specific implementations, stored in the following four sub-folders:
  - `edges` Classes describing project specific connection-behavior.
  - `messages` Classes describing the messages this project uses.
  - `nodeImplementations` Classes describing the network-nodes and their behavior.
  - `timers` Classes describing project specific timers.

**Note:** You may omit any of the folders if it does not contain any files.

Each project contains the four following files in the root directory:

- `Config.xml` contains the project specific configuration. When you select Sinalgo to work with a project, the framework initializes according to this configuration file in the project's root folder. The file contains framework specific settings as well as project specific setting, which you may extend to fit your needs.
- `description.txt` contains a user-defined description of the project. This text is shown in the project selector dialog.
- `CustomGlobal.java` contains framework-wide visible methods for this project.
- `LogL.java` is used to specify custom Log-Levels to control the logging. Check the [DOCUMENTATION OF THE LOGGER](#) to get more information about the logging mechanism.

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## Node Implementation

The implementation of a project consists of several tasks:

- Implement the node behavior
- Implement additional models as needed
- Configure the project using the configuration file

## Node Basics

Each simulated node is an instance of a subclass of `sinalgo.nodes.Node`. Each node has its proper instances of the Mobility, Connectivity, Interference, and Reliability model. These four model instances are created when the node is created. The Message Transmission Model is globally unique, and the distribution model is only used to initially place the nodes and is created for each set of generated nodes.

As in reality, the nodes implement their own behavior. Among others, they have a method that is called when the node receives a message, and they implement the functionality to send messages to neighboring nodes. Depending on the simulation mode, the node's methods are called in a slightly different way. The following shows a high-level picture of the calling-sequences of the synchronous and asynchronous mode, which are described in more detail in the

**ARCHITECTURE** section of this tutorial.

## Calling Sequence in Synchronous Simulation

In the synchronous simulation mode, the framework performs the following actions for each **round**. Bold text indicates methods that you may overwrite or implement to define the behavior of the network nodes and the simulation. Note that the execution is strictly sequential, i.e. a single thread executes the following actions. As a result, no synchronization is needed to access global information.

1. The framework increments the global time by 1.
2. **CustomGlobal.preRound()**; *(Optional, project specific code. This method is called at the beginning of every round.)*
3. The framework handles **global timers** that fire in this round.
4. The framework moves the nodes according to their **mobility models**, if mobility is enabled.
5. The framework calls each node to update its set of outgoing connections according to its **connectivity models**.
6. The framework calls **interference** tests for all messages being sent, if interference is enabled.
7. The framework iterates over all nodes and calls **Node.step()** on each node. *The method 'step' performs the following actions for each node:*
  1. The node gathers all messages that arrive in this round.
  2. **Node.preStep()**; *(Optional, project specific code. This method is called at the beginning of every step.)*
  3. If this node's set of outgoing connections has changed in this round, the node calls **Node.neighborhoodChange()**;
  4. The node handles **timers** that fire in this round.
  5. **Node.handleNAckMessages()**; *(Handle dropped messages, if generateNAckMessages is enabled.)*
  6. **Node.handleMessages()**; *(Handle the arriving messages.)*
  7. **Node.postStep()**; *(Optional, project specific code. This method is called at the end of each step.)*
8. **CustomGlobal.postRound()**; *(Optional, project specific code. This method is called at the end of every round.)*
9. If **CustomGlobal.hasTerminated()**; returns true, the simulation exits.

## Events in Asynchronous Simulation

In asynchronous simulation mode, there are only two events upon which nodes react: Arriving messages and timer events. Thus, only the methods **Node.handleMessages()**, (**Node.handleNAckMessages()**), and **Timer.fire()** are called. Before performing a scheduled event, the global time of the system is set to the time when the event happens.

Remember that mobility is not possible in the asynchronous mode. However, the messages may be checked for interference if interference is turned on in the configuration file.

## Node Behavior

To implement the node behavior (this includes your algorithm), create a class which inherits from **sinalgo.nodes.Node** and place the source file in the **node/nodeImplementation/** folder of your project. Implement the method **Node.handleMessages()**; and optionally any of the other

abstract methods from the `sinalgo.nodes.Node` class.

The following list gives the most useful members of the `sinalgo.nodes.Node` class you may use. For a complete description of their functionality, refer to the documentation in the code.

<b>Public Member Variables</b>	
<code>int ID</code>	Each node is assigned a unique ID when it is created. This ID may be used to distinguish the nodes.
<code>Connections outgoingConnections;</code>	A collection of all edges outgoing from this node. Note that all edges are directed, the bidirectional edges just ensure that there is an edge in both directions.
<b>Methods</b>	
<code>void send(Message m, int target) throws NoConnectionException;</code>	Sends a message to a neighbor node with the default intensity of the node.
<code>void send(Message m, int target, double intensity) throws NoConnectionException;</code>	Sends a message to a neighbor node with the given intensity.
<code>void send(Message m, Node target) throws NoConnectionException;</code>	Sends a message to a neighbor node with the default intensity of the node.
<code>void send(Message m, Node target, double intensity) throws NoConnectionException;</code>	Sends a message to a neighbor node with the given intensity.
<code>void sendDirect(Message msg, Node target);</code>	Sends a message to any node in the network, independent of whether there is a connection between the two nodes or not.
<code>void broadcast(Message m);</code>	Broadcasts a message to all neighboring nodes with the default intensity of the node.
<code>void broadcast(Message m, double intensity);</code>	Broadcasts a message to all neighboring nodes with the given intensity.
<code>Position getPosition();</code>	Returns the current position of the node.
<code>TimerCollection getTimers();</code>	Returns a collection of all timers currently active at the node.
<code>void setRadioIntensity(double i);</code>	Sets the radio intensity of the node.
<code>double getRadioIntensity();</code>	Gets the radio intensity of the node.
<code>void setColor(Color c);</code>	Sets the color in which the node is painted on the GUI.
<code>Color getColor();</code>	Gets the color in which the node is painted on the GUI.
<code>void draw(...);</code>	Implements how the node is drawn on the GUI. You may overwrite this method in your subclass of <code>sinalgo.node.Node</code> to define a customized drawing.
<code>void drawAsDisk(..., int sizeInPixels);</code>	A helper method provided by <code>sinalgo.node.Node</code> that draws the node as a disk. Call this method in your <code>draw(...)</code> method.
<code>void drawNodeWithText(..., String text, int fontSize, Color textColor);</code>	A helper method provided by <code>sinalgo.node.Node</code> that draws the node as a disk and with text. Call this method in your <code>draw(...)</code> method.



```
void drawToPostScript(...);
```

Implements how the node is exported to PostScript. You may overwrite this method in your subclass of `sinalgo.node.Node` to define a customized drawing to PostScript.

*Methods of the superclass `sinalgo.nodes.Node` you may use to implement the node behavior.*

To control the creation of a node object, the super-class provides the two methods `init()` and `checkRequirements()` which you may overwrite in your subclass:

`Node.init()` is called once at the beginning of the lifecycle of a node object. It may be used to initialize the start state of the node. Note that this function may not depend on the neighborhood of the node as the `init` function is called before the connections are set up and before the set of all nodes is available.

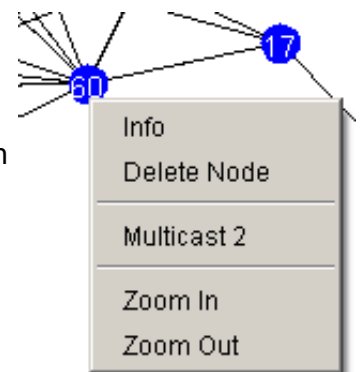
`Node.checkRequirements()` is called after the `init()` method to check whether all requirements to use this node type are met. This may include a test whether appropriate models have been selected.

## Project Specific Popup Methods

To facilitate interaction in the GUI mode, you may register methods of your `Node` subclass to a popup menu that shows up when the user right-clicks on a node.

The annotation `@NodePopupMethod(menuText="XXX")` in the following code sample declares the method `myPopupMenu()` to be included in the popup menu with the menu text `XXX`. Note that the methods to register with the popup menu may not take any parameters and need to be located in the source-file of the specific `Node` subclass.

```
@NodePopupMethod(menuText="Multicast 2")
public void myPopupMenu() {
    IntMessage msg = new IntMessage(2);
    MessageTimer timer = new MessageTimer(msg);
    timer.startRelative(1, this);
}
```



*Customized node popup menu*

The sample code generates a message carrying an int-value, and broadcasts it to all its neighbors. Note that the method does not broadcast the message directly, but creates a timer, which will be triggered in the next round when the node performs its step. This is necessary for the synchronous simulation mode, because nodes are only allowed to send messages while they are executing their [STEP](#). However, the user can only interact with the GUI while the simulation is not running. Therefore, the methods called through the popup menu always execute when the simulation is stopped. The preferred solution is to create a timer which fires in the next round and performs the desired action.

**Note:** The `MessageTimer` is available in the `defaultProject`. This timer may send a unicast message to a given node, or multicast a message to all immediate neighbors. Please consult the documentation of the source code for more details.

In some cases, it may be desirable to determine only at runtime the set of methods to be included in the menu, and on their menu text. This is possible because the popup menu for the node is assembled every time the user right-clicks on a node. The framework includes all methods annotated with the `NodePopupMenu` annotation of the corresponding node class. But before including such a method in the list, the framework calls the node-method `includeMethodInPopupMenu(Method m, String defaultText)`, which allows to decide at runtime whether the menu should be included or not, and, change the menu text if necessary.

To obtain control over the included menu entries, overwrite the `includeMethodInPopupMenu(Method m, String defaultText)` method in your node subclass. Return `null` if the method should not be included, otherwise the menu text to be displayed.

## Messages

Nodes communicate by the means of messages. To implement your own message class, derive from `sinalgo.nodes.messages.Message` and place your source file in the `nodes/messages/` folder of your project.

The abstract class `Message` requires you to implement a single method that returns a clone of the message, i.e. an exact *copy* of the message object:

```
public Message clone()
```

**Implementation Note:** When a node sends a message to a neighbor node, it is assumed that the destination receives the message-content that was sent through the `send()` method. The framework has however no means to test whether the sender still has a reference to the sent message-object, and therefore may be able to alter its content. To avoid such problems, the framework sends separate copies to all receivers of a `send()` or `multicast()` call. Thus, for a multicast to  $n$  neighbors, the framework obtains  $n$  copies of the message and sends a copy to each of the neighbors.

If **and only if** your project ensures that a message-object is not altered after it was sent, you may omit the copying process by providing the following implementation of the `clone()` method. (Note that the process of sending or receiving a message does not alter the message-object. Thus, a node may safely forward the same message-object it has received.)

```
public Message clone() {
    return this; // This message requires a read-only policy
}
```

## Inbox / handleMessages()

Each node stores the messages it receives in an instance of the `Inbox` class. The inbox provides an iterator-like view over the set of messages that are received in the current round in synchronous simulation mode. In asynchronous simulation mode, the inbox contains only the single message that triggered the event. The method `handleMessages(Inbox inbox)` provides this inbox as single parameter.

For each received message, this iterator stores meta-information, such as the sender of the message. This meta-information is available for the packet that was last returned through the `next()` method.

In order to iterate several times over the set of packets, you may reset the inbox by calling `reset()`, `size()` returns the number of messages in the inbox. Call `remove()` to remove the message from the inbox that was returned by the last call to `next()`.

Typically, a node iterates over all messages in the inbox with the following code:

```
while(inbox.hasNext()) {
    Message msg = inbox.next();
    if(msg instanceof ...) {
        \\ handle this type of message
    }
}
```

## NackBox / handleNAckMessages()

Messages may be dropped, due to changes to the connectivity graph, interference, or the message transmission model. The framework provides a means to inform the sender node whenever a *unicast* message sent by the node does not reach the destination. This is an optional feature that needs to be enabled through the project configuration: set the entry `generateNAckMessages` to `true`. If your project does not drop messages at all, or if your nodes are

not interested in this information, you should disable this feature to speed up the simulation.

In asynchronous simulation mode, messages are kept in message-events, which are scheduled to execute when the message is supposed to arrive. At the time of execution, the framework decides whether the message arrives. If the message arrives, the method `handleMessages()` is called on the receiver node. If the message does not arrive, the method `handleNAckMessages()` is called on the sender node.

In synchronous simulation mode, a sender node can handle the set of messages that were scheduled to arrive in the previous round, but were dropped. The method `handleNAckMessages()` is called prior to handling the messages that arrive on the node, and passes on the set of dropped messages.

The use of the `NackBox` object, which holds the set of dropped messages, is equivalent to the `Inbox`.

A typical implementation of the `handleNAckMessages()`, which needs to be added to your node implementation if you want to use this feature, looks as following:

```
public void handleNAckMessages(NackBox nackBox) {
    while(nackBox.hasNext()) {
        Message msg = nackBox.next();
        if(msg instanceof ...) {
            // handle this type of message
        }
    }
}
```

## Edges

Nodes are connected by edges. Most projects may be happy with the default edge implementation (which is unidirectional!) or one of the implementations provided in the `defaultProject`. If you need a more specialized edge, create a subclass from `sinalgo.nodes.edges.Edge` and put the source file in the `nodes/edges/` folder of your project.

**Note:** The framework only supports one edge type at any time. The type to use can be specified in the configuration file, and it may be switched at runtime through the Preferences menu. Changing the edge type at runtime only affects edges created after the change. It does not replace the already existing edges.

The following edges are already available:

<code>sinalgo.nodes.edges.Edge</code>	The default edge implementation, superclass of all edges. This edge is directional. As a result, Sinalgo does not really support bidirectional edges in the sense that there is a single object for a bidirectional edge. The bidirectional edge implementation solves this problem by adding an edge in both directions. By default, this edge draws itself as a black line between the two end-nodes, and colors itself red when a message is sent over the edge.
<code>sinalgo.nodes.edges.BidirectionalEdge</code>	The default bidirectional edge implementation. It ensures that there is an edge in both directions between the two end nodes. By default, this edge draws itself as a black line between the two end-nodes, and colors itself red when a message is sent over the edge.
<code>projects.defaultProject.nodes.edges.BooleanEdge</code>	The <code>BooleanEdge</code> extends the default edge implementation with a boolean member <code>flag</code> that

	may be used arbitrarily. It also carries a static member <code>onlyUseFlagedEdges</code> , which may be used to enable or disable globally the use of the flag. The provided implementation uses <code>onlyUseFlagedEdges</code> and <code>flag</code> to decide whether the edge is drawn or not: If <code>onlyUseFlagedEdges</code> is true, the edge only draws itself if <code>flag</code> is set to true.
<code>projects.defaultProject.nodes.edges.BidirectionalBooleanEdge</code>	A bidirectional edge with the features of the boolean edge.
<code>projects.defaultProject.nodes.edges.GreenEdge</code>	The same as the default edge implementation, but it draws itself as a green line between the two end-nodes.

*Edge implementations which are available by default.* To manually insert a connection from node *u* to node *v*, you may use the method `u.addConnectionTo(v)`. Project `sample6` demonstrates how a static network may be built.

## Timers

A timer is an object that allows a node to schedule a task in the future. When the task is due, the timer wakes up the node and performs the given task. Any timer object is a subclass of `sinalgo.nodes.timers.Timer` and implements the method `void fire()`, which contains the task this timer needs to perform.

To write a project specific timer, implement a subclass of `sinalgo.nodes.timers.Timer` and put the source file in the `nodes/timers/` folder of your project. A timer instance is started by calling either the `startAbsolute(double absoluteTime, Node n)` method or the `startRelative(double relativeTime, Node n)` method of the super class. The time specifies when the task should be scheduled, and the node specifies the node on which the task should be executed.

**Hint:** The default project provides a `MessageTimer` that schedules to send a message at a given time. The message may be unicast to a specified recipient, or multicast to all immediate neighbors.

### Global Timers

A timer object can also be used to perform a task for the simulation framework at a given time. Such a global task is not executing on a particular node, and is suited to perform simulation specific tasks (e.g. add/drop some nodes, select a random node to perform an action, change the network, ...) In synchronous simulation mode, the global timers are handled after the `CustomGlobal.preRound()` method. In asynchronous simulation mode, a global timer becomes an event that executes when the simulation time reached the execution time of the timer.

To create a global timer, implement a subclass of `sinalgo.nodes.timers.Timer` just as for the regular node timers. But in contrast to the node related timers, start the timer with its method `startGlobalTimer(double relativeTime)`.

**Hint:** You may use the same timer implementation as a node-related timer and as a global timer. Just make sure that the `fire()` method of the timer class does not access the node member when the timer was started as a global timer. This member is set only when the timer is started as a node-related timer.

## Customized, Globally Visible Methods: CustomGlobal.java

Each project comes with a `CustomGlobal` class, which collects global methods specific to the

project. This class extends `sinalgo.runtime.AbstractCustomGlobal` and is located in the root folder of your project. The following table gives an overview of the methods you may overwrite in your project specific `CustomGlobal.java`. (These methods are defined in the abstract superclass `AbstractCustomGlobal.java` with an empty body.)

<code>customPaint(...)</code>	This paint method is called after the network graph has been drawn. It allows for customizing the drawing of the graph by painting additional information onto the graphics.
<code>handleEmptyEventQueue()</code>	<p>The framework calls this method when running in asynchronous mode and there is no event left in the queue. You may generate new events in this method to keep the simulation going.</p> <p>Note that the batch mode terminates when the event queue is emptied and this method does not insert any new events.</p>
<code>preRun()</code>	Called <i>once</i> prior to starting the first round in synchronous mode, or prior to executing the first event in asynchronous mode. Use this method to initialize the simulation.
<code>onExit()</code>	Called by the framework before shutting down. To ensure that this method is called in all cases, you should use <code>sinalgo.tools.Tools.exit()</code> to exit, instead of <code>System.exit()</code> .
<code>preRound()</code>	Called in synchronous mode prior to every round. This method may be suited to perform statistics and write log-files.
<code>postRound()</code>	Called in synchronous mode after every round. This method may be suited to perform statistics and write log-files.
<code>checkProjectRequirements()</code>	The framework calls this method at startup after having selected a project to check whether the necessary requirements for this project are given. For algorithms that only work correctly in synchronous mode this method check that the user didn't try to execute it in asynchronous mode. If the requirements are not met, you may call <code>sinalgo.tools.Tools.fatalError(String msg)</code> to terminate the application with a fatal error.
<code>nodeAddedEvent(Node n)</code>	<p>Called by the framework whenever a node is added to the framework (which is done through the method <code>Runtime.addNode(Node n)</code>). This event may be useful for applications that need to update some graph properties whenever a new node is added (e.g. by the user through the GUI).</p> <p>Note that this method is also called individually for each node created through the <code>-gen</code> command-line tool, and when the user creates nodes using the GUI menu.</p>
<code>nodeRemovedEvent(Node n)</code>	<p>Called by the framework whenever a node is removed from the framework (which is done through the method <code>Runtime.removeNode(Node n)</code>). This event may be useful for applications that need to update some graph properties whenever a node is removed (e.g. by the user through the GUI).</p> <p>Note that this method is <i>not</i> called when the user removes all nodes using the <code>Runtime.clearAllNodes()</code> method.</p>

Methods you may overwrite in the project owned `CustomGlobal` class.

## Stopping the Simulation

Most importantly for the batch mode, the `hasTerminated()` method in the `CustomGlobal` class lets you specify whether a *synchronous* simulation has reached the final state and

the framework may exit. See the [CALLING SEQUENCE](#) of the synchronous mode for details on when `hasTerminated()` is called. In asynchronous simulation, the simulation terminates when all events have been handled. To stop execution prior to handling all events, or at an arbitrary place in synchronous mode, call `sinalgo.tools.Tools.exit()`. This method executes some cleanup and is preferred to calling `System.exit()`. In particular, `sinalgo.tools.Tools.exit()` calls `AbstractCustomGlobal.onExit()`, which you may overwrite in your project specific `CustomGlobal.java` file.

**Hint:** The `onExit()` method may be a good place to perform final logging steps and project specific cleanup.

## Project Specific Drop Down Methods and Buttons

You may extend the GUI with project specific drop down menus and buttons: Add a dummy-method that takes no parameters to your `CustomGlobal` and implement the desired behavior in its body. There are three different ways to register the method with the GUI:

**1) Drop Down Menu Entry:** Prefix the method with the annotation `@AbstractCustomGlobal.GlobalMethod` and specify the `menuText`. E.g.

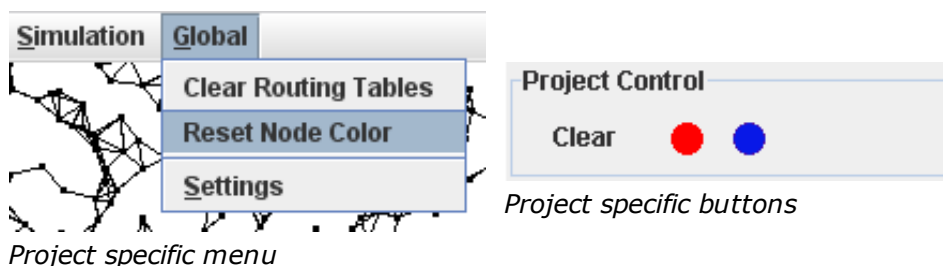
```
@AbstractCustomGlobal.GlobalMethod( menuText="Toggle TC view")
public void myMenuMethod() {
    // ...
}
```

**2) Icon Button:** Prefix the method with the annotation `@AbstractCustomGlobal.CustomButton` and specify the `imageName` and `toolTipText`. The `imageName` should be the name of a gif image of size 21x21 pixels, located in the `images` folder of the project. E.g.

```
@CustomButton( imageName="myImage.gif", toolTipText="Click me!")
public void myImageButtonMethod() {
    // ...
}
```

**3) Text Button:** Prefix the method with the annotation `@AbstractCustomGlobal.CustomButton` and specify the `buttonText` and `toolTipText`. E.g.

```
@CustomButton( buttonText="Clear", toolTipText="Click me!")
public void myTextButtonMethod() {
    // ...
}
```



The drop down menu entries (but not the buttons) may be adapted at runtime: Every time the user opens the 'Global' menu, the menu is assembled and includes methods annotated with the `GlobalMethod` annotation. Before including such a method in the list, the framework calls `AbstractCustomGlobal.includeGlobalMethodInMenu(Method m, String defaultText)` to allow the project to decide at runtime whether the method should be included or not, and, if necessary, change the default menu text.

Overwrite the method `includeGlobalMethodInMenu(Method m, String defaultText)` in your project specific `CustomGlobal.java` file to control the appearance of the 'Global' menu at



runtime. The method returns the text to be displayed for each method, or null if the method should not be included.

## Model Implementation

The models are a plug-in based system to describe the environment in which the network is simulated. E.g. the mobility model describes how the nodes move in the synchronous simulation mode. Each node object carries an instance of the following four models: Connectivity, Mobility, Interference, and Reliability. As a result, the nodes may carry different model implementation and may act differently. The message-transmission model describes how long the messages travel until arrival. This model applies globally, the framework only holds one instance. Finally, the distribution model describes how the nodes are placed in the deployment upon creation.

## Connectivity Model

The connectivity model decides to which neighbors a node has a connection and inserts/removes the edges. To write your own connectivity model, create a subclass of `sinalgo.models.ConnectivityModel` and place the source-file in the `models/connectivityModels/` folder of your project. Instances of this model implement

**boolean** `updateConnections(Node n)` **throws** `WrongConfigurationException`;  
which determines for a given node `n` the set of neighbor nodes and returns whether the neighborhood has changed since the last call. This method needs to update the `outgoingConnections` member of node `n`, such that this collection contains an [EDGE](#) to every neighbor of `n`.

In synchronous simulation mode, each node updates its connections in every round. Refer to the [SYNCHRONOUS CALLING SEQUENCE](#) section of this tutorial for more details. For the asynchronous simulation, the framework does not support mobile nodes. As a result, the framework does not call the connectivity model at all, as it is often only necessary to setup the edges once after the nodes have been created. Thus, the project is responsible to call the following method at an appropriate time:

```
sinalgo.tools.Tools.reevaluateConnections();
```

This method calls the `updateConnections(Node n)` method on all nodes.

To facilitate the implementation of a new connectivity model, you may create a subclass of `sinalgo.models.ConnectivityModelHelper`. This helper class implements the `updateConnections(Node n)` method, and asks the subclass to implement the method

**boolean** `isConnected(Node from, Node to)`;  
which is often easier to implement.

The `ConnectivityModelHelper` assumes that the connectivity is geometric. I.e. there is a maximum distance between connected nodes, above which no node pair is connected. This assumption permits to drastically cut down the neighbor-nodes the helper class needs to test. **Note** that this maximum distance needs to be specified for each project. Refer to the [CONFIGURATION](#) and [ARCHITECTURE](#) section of this tutorial to learn more about how to configure a project and how the *geometric node collection* stores the nodes to perform range queries for neighbor nodes.

For your convenience, the `defaultProject` already contains the following connectivity models. Note that these models are written as generic as possible. Therefore, you may need to add [CONFIGURATION SETTINGS](#) to your project, depending on which model you select.

UDG	The Unit Disk Graph connectivity is a purely geometric connectivity model: Two nodes are within communication range iff their mutual distance is below a given threshold. The maximal transmission radius, <code>rMax</code> needs to be specified in the configuration file of the project with an entry of the form <code>&lt;UDG rMax="..."&gt;</code> .
-----	---

QUDG	The Quasi Unit Disk Graph is similar to the UDG model, but does not have a sharp upper bound on the transmission range. In the QUDG model, a pair of nodes is always connected if their mutual distance is below a certain value $r_{Min}$ , and is never connected if their distance is above $r_{Max}$ . If the distance is between $r_{Min}$ and $r_{Max}$ , the nodes are connected with a certain probability, which has to be specified in the project configuration. See the source documentation of the QUDG class for more details.
StaticUDG	The static UDG model is the same as the UDG model, but it evaluates the connections only the very first time it is called. This may be beneficial for projects where nodes do not move, and the connectivity does not change over time.
StaticConnectivity	The static connectivity model does not change the edges of a node at all. This model may be useful if the project has other means to generate and update the edges between neighboring nodes.

*Connectivity models provided by the defaultProject project.*

## Interference Model

Each node carries an interference model instance that decides for each message sent to this node, whether the message may not arrive due to interference caused by other packets or other environmental noise. To create your own interference model, implement a subclass of `sinalgo.models.InterferenceModel` and place the file in the `models/interferenceModels/` folder of your project.

The model requires to implement the method **boolean isDisturbed(Packet p)**, which tests, whether a message arriving at this node may be disturbed by interference.

**Implementation Notes:** The `Packet` object passed to the `isDisturbed(Packet p)` method holds the message, the sender and receiver node, the intensity at which the sender is sending this packet, and other information that may be useful. To obtain a collection of all messages being sent at this moment, call `sinalgo.tools.Tools.getPacketsInTheAir()`.

In synchronous simulation mode, the framework performs the interference test in every round. Refer to the [SYNCHRONOUS CALLING SEQUENCE](#) section of this tutorial for more details. For asynchronous simulations, the interference test is performed whenever an additional message is being sent or a message arrived.

**Additive interference in asynchronous mode:** By default, the asynchronous mode performs an interference test on all messages that have not yet arrived whenever an additional message is sent, or a message arrives. This is a quite expensive operation, and is not necessary in most cases, where the interference is **additive**. We call interference *additive*, if

- a) an additional message can only increase (or not alter) the interference at any other receiver node, and
  - b) the interference decreases (or remains the same) if any of the messages is not considered.
- If all used interference models are *additive*, the framework can reduce the calls to the interference test drastically. Additive interference can be enabled/disabled in the configuration file of the project.

For your convenience, the `defaultProject` already contains the following interference models. Note that these models are written as generic as possible. Therefore, you may need to add [CONFIGURATION SETTINGS](#) to your project, depending on which model you select.

SINR	The signal to interference model is probably the best known interference model. It determines a quotient $q = s / (i+n)$ between the received signal $s$ and the sum of the ambient background noise $n$ and the interference $i$ caused by all concurrent transmissions. The transmission succeeds if $q > \text{beta}$ , where $\text{beta}$ is a small constant.
------	---

	<p>This model assumes that the intensity of an electric signal decays exponentially with the distance from the sender. This decrease is parameterized by the path-loss exponent alpha: <math>\text{Intensity}(r) = \text{sendPower}/r^{\alpha}</math>. The value of alpha is often chosen in the range between 2 and 6.</p> <p>To the interference caused by concurrent transmissions, we add an ambient noise level N.</p> <p>This model requires the following entry in the configuration file:</p> <pre>&lt;SINR alpha="..." beta="..." noise="..." /&gt;</pre> <p>where alpha, beta, and noise are floating point values.</p>
NoInterference	<p>A dummy interference model that does not drop any messages due to interference. When using this model for all nodes, you should turn off the support for interference in the project configuration.</p>

*Interference models provided by the defaultProject project.*

## Mobility Model

The mobility model on each node object describes how the node moves in the synchronous simulation. (Asynchronous simulation does not support mobile nodes.) To create your own mobility model, implement a subclass of `sinalgo.models.MobilityModel` and place the file in the `models/mobilityModels/` folder of your project.

The model requires to implement the method **Position getNextPos(Node n)**, which returns the new position of node n.

In Sinalgo, mobility is simulated in terms of rounds. At the beginning of each round, the nodes are allowed to move to a new position, where they remain for the remainder of the round. (Refer to the [CALLING SEQUENCE](#) for more details.)

**Implementation Note:** The discretization of the movement may be refined in the following way: Assume a simulation, where nodes move 1 distance unit per round. At the same time, a message takes 1 round to arrive at its destination. To achieve a higher resolution of the movement, you may reduce the node speed to 0.1 distance units per round, and increase the message transmission time to 10. Along this line, you may achieve arbitrarily close approximations to a continuous system, paying with simulation time.

For your convenience, the `defaultProject` already contains the following mobility models. Note that these models are written as generic as possible. Therefore, you may need to add [CONFIGURATION SETTINGS](#) to your project, depending on which model you select.

RandomWayPoint	<p>A node that moves according to the random way point mobility model moves on a straight line to a (uniformly and randomly selected) position in the deployment field. Once arrived, it waits for a predefined amount of time, before it selects a new position to walk to.</p> <p>The node speed and waiting time have to be configured through the project configuration. Both of them are defined through <a href="#">DISTRIBUTIONS</a>. An entry in the configuration file may look as following:</p> <pre>&lt;RandomWayPoint&gt;   &lt;Speed distribution="Gaussian" mean="10" variance="20" /&gt;   &lt;WaitingTime distribution="Poisson" lambda="10" /&gt; &lt;/RandomWayPoint&gt;</pre> <p><b>Note:</b> The stationary distribution of nodes moving according to the random way point model is <i>not</i> uniformly distributed. The nodes tend to be more often around the center of the deployment area than close to the boundary.</p>
RandomDirection	<p>Similarly to the random way point model, the random direction model alternates between waiting and moving periods. The only difference is the</p>

	<p>choice of the target: Instead of picking a random point from the deployment field, the random direction chooses a direction in which the node should walk, and how long the node should walk in this direction. If the node hits the boundary of the deployment area, it is reflected just as a billard ball.</p> <p>The node speed, move-time, and waiting time have to be configured through the project configuration and are defined through <a href="#">DISTRIBUTIONS</a>. An entry in the configuration file may look as following:</p> <pre>&lt;RandomDirection&gt;   &lt;NodeSpeed distribution="Constant" constant="0.4" /&gt;   &lt;WaitingTime distribution="Exponential" lambda="10" /&gt;   &lt;MoveTime distribution="Uniform" min="5" max="20" /&gt; &lt;/RandomDirection&gt;</pre> <p><b>Note:</b> The stationary distribution of nodes moving according to the random direction model is uniformly distributed.</p>
NoMobility	A dummy mobility model that does not move the nodes. When using this model for all nodes, you should turn off the support for mobility in the project configuration.

*Mobility models provided by the defaultProject project.*

## Reliability Model

The reliability model installed on each node decides for each message, whether it should arrive at the destination or not. This model may be interesting to simulate a lossy packet networks, where some messages do not arrive for various reasons. To create your own reliability model, implement a subclass of `sinalgo.models.ReliabilityModel` and place the file in the `models/reliabilityModels/` folder of your project.

The model requires to implement the method `boolean reachesDestination(Packet p)`, which determines whether the message arrives at the destination or not. Note that the interference model may overrule this decision and drop a message due to interference. However, the interference model cannot reincarnate an already dropped message.

For your convenience, the defaultProject already contains the following reliability models. Note that these models are written as generic as possible. Therefore, you may need to add [CONFIGURATION SETTINGS](#) to your project, depending on which model you select.

LossyDelivery	<p>A lossy reliability model that drops messages with a constant probability. The percentage of dropped messages has to be specified in the configuration file:</p> <pre>&lt;LossyDelivery dropRate="..." /&gt;</pre>
ReliableDelivery	A dummy implementation of the reliability model that does not drop any messages.

*Reliability models provided by the defaultProject project.*

## Message Transmission Model

The message transmission model determines the time a message needs until it arrives at the destination node. The framework holds only one instance of this model, which applies for all nodes and all message types. To create your own message transmission model, implement a subclass of `sinalgo.models.MessageTransmissionModel` and place the file in the `models/messageTransmissionModels/` folder of your project.

The model requires to implement the method **double timeToReach(Node startNode, Node endNode, Message msg)**, which determines the time to send a message from the startNode to the endNode. For synchronous simulations, the time is specified in rounds, where a time of 1 specifies the following round. In the asynchronous setting, this method returns the time units after which the message should arrive. ....

The defaultProject contains the following two message transmission models.

ConstantTime	Delivers the messages after a constant delay. It requires a configuration entry of the following form to specify the delay: <code>&lt;MessageTransmission ConstantTime="..." /&gt;</code>
RandomTime	Delivers the messages after a random delay, which is defined through a distribution. It requires a configuration entry of the following form to specify the delay: <code>&lt;RandomMessageTransmission distribution="Uniform" min="0.1" max="4.2" /&gt;</code>

*Message transmission models provided by the defaultProject project.*

## Distribution Model

The distribution model describes how the nodes are placed initially onto the deployment field when they are created. Whenever the framework creates a set of nodes, there needs to be an instance of a distribution model that places the nodes. To create your own distribution model, implement a subclass of `sinalgo.models.DistributionModel` and place the file in the `models/distributionModels/` folder of your project.

The distribution models implement an iterator-like interface that allows to retrieve the node positions in sequence. The model requires to implement the method **Position getNextPosition()**, which returns the position of a node. The framework calls this method exactly once for each created node.

**Initialization:** After creating an instance of the distribution model, the framework sets the member variable `numberOfNodes`, and then calls the `initialize()` method. This method may be used to pre-calculate the positions of the nodes and obtain an iterator instance on the positions. The positions are retrieved only after this call.

For your convenience, the defaultProject already contains the following distribution models. Note that these models are written as generic as possible. Therefore, you may need to add [CONFIGURATION SETTINGS](#) to your project, depending on which model you select.

Random	Places the nodes randomly on the deployment area. This model may be used in 2D and 3D.
Circle	Places the nodes on a circle.
Grid2D	Places the nodes on a regular grid in the XY plane.
Line2D	Places the nodes evenly distributed on a line. You may specify the start and end point of the line in the project configuration.

*Distribution models provided by the defaultProject project.*

## Tools

This section covers some tools you may use for your project.

## Tools.java - a Collection of Useful Methods

The class **Tools** in the package `sinalgo.tools` is a collection of *static* methods that may be useful in several circumstances. It contains

- Error handling
- Settings of the framework
- Information about the current simulation
- Access to the set of nodes
- Access to the set of messages currently being sent
- Stop or exit the simulation
- GUI related methods
- And others...

**Note:** Most of the methods provided in this class are wrapper methods. The **Tools** class just collects these helpful methods, which are sometimes difficult to find in their original place.

## Random Numbers

Many algorithms and models rely on random values to implement randomized decisions. At the same time, it is often desirable to run the exactly same simulation several times, either to understand its behavior, or to find errors. However, when the algorithms take some decisions purely randomly, it is impossible to rerun the exactly same simulation. To circumvent this problem, Sinalgo offers its own instance of a random number generator, which **should be used exclusively**. To access this instance, write

```
java.util.Random rand = sinalgo.tools.Tools.getRandomNumberGenerator();
```

This random number generator instance depends on the [CONFIGURATION FILE](#) of the project. If the framework entry `useFixedSeed` is set, the random number generator is initialized with the `fixedSeed`, also provided in the configuration file. Otherwise, the random number generator is initialized randomly, such that subsequent simulations receive different random numbers.

## Random Distributions

The package `sinalgo.tools.statistics` provides several random number generators that return random numbers according to a certain distribution probability. Available distributions are:

ExponentialDistribution	Returns random values exponentially distributed with parameter lambda.
PoissonDistribution	Returns random values Poisson distributed with parameter lambda.
GaussianDistribution	Returns random values Gaussian distributed according to a given mean and variance.
UniformDistribution	Returns random values randomly chosen in a given interval.
ConstantDistribution	Returns a always the same constant. (Thus not really a random number.)

*Available random number distributions in the package `sinalgo.tools.statistics`.*

All of these distributions extend from `sinalgo.tools.statistics.Distribution` and implement the method **double nextSample()**, which returns the next random sample of the distribution. To obtain an instance of the Gaussian distribution, you can write:



```
GaussianDistribution gauss = new GaussianDistribution(mean, var);
gauss.nextSample(); // returns a random variable, normally distributed with the given
mean and var
```

Alternatively, you can specify the type and settings of the distribution from within the [CONFIGURATION FILE](#) of the project. The configuration entry needs to specify the name of the distribution as well as the distribution-specific parameters. The key of the tag that contains the attributes holding this information is used to retrieve the information. E.g. add to your configuration file the following entry in the Custom section:

```
<MyNode>
  <speed distribution="Gaussian" mean="10" variance="20"/>
</MyNode>
```

In order to generate a distribution object from this entry, write

```
Distribution dist = Distribution.getDistributionFromConfigFile("MyNode/speed");
dist.nextSample(); // Returns a random variable distributed according to the chosen
distribution.
```

**Note:** These classes base upon the random number generator of the framework and implement the seed-feature described in the [RANDOM NUMBERS](#) section. Thus, a rerun of the exact same simulation is possible.

## Sampling Data

The class `DataSet` in the package `sinalgo.tools.statistics` is a statistic tool to determine simple statistic properties such as the mean and standard deviation of a series of measurements.

For each series of data you want to have a statistical analysis on, create a new object of this class and add the samples using the `addSample()` method. You can retrieve the **mean**, **variance**, **standard deviance**, **sum**, **minimum**, **maximum**, and **count** of the added samples.

**Implementation Note:** A `DataSet` object does *not* store the added samples individually. Instead, it processes the samples immediately upon addition. Therefore, you may sample many huge data series without using up a lot of memory.

## Export Network Graph to EPS or PDF

Sinalgo can export the current view of the network graph to a vector graphic in EPS or PDF format. To export the current view, click on the Graph menu, and select Export.

Sinalgo itself writes the graphics directly in EPS format. It does not support PDF itself, and calls an external application to convert the EPS file to a PDF file, if you choose to export to PDF. By default, the framework calls the `epstopdf` application. Change the field `epsToPdfCommand` in the framework section of the [CONFIGURATION FILE](#) to specify a different application.

The export is similar to drawing the network graph on the screen: The framework iterates over all nodes and first draws for each node the connections. In a second iteration, it also draws the nodes, such that the nodes are not covered by the lines of the edges. For this purpose, the `sinalgo.nodes.Node` and `sinalgo.nodes.edges.Edge` classes implement the `drawToPostScript()` method. You may overwrite this method in your own node or edge subclasses to customize their appearance.

## Logging

Sinalgo provides tools to facilitate logging, i.e. write certain output to files. The logging support is located in `sinalgo.tools.logging`. The class `Logging` provides methods to create log-files and add logging statements to an existing log-file.

The creation of a log-file is straight forward: To create a log-file with the name 'myLog.txt', write

```
Logging myLog = Logging.getLogger("myLog.txt");
```

By default, the log-files are placed in the `logs` folder in the root directory of Sinalgo. To put the log-file in a sub-directory, write

```
Logging myLog = Logging.getLogger("dir1/dir2/myLog.txt");
```

Then, to add log-statements, use the methods `log(String)` and `logln(String)`. E.g.

```
myLog.log("Test"); myLog.logln("Test"); // appends a new-line to the given string
```

Subsequent calls to `Logging.getLogger("myLog.txt")` will return the same singleton `Logging` object. I.e. to access the same log-file from several classes, you need not make the logging object public or accessible, but can access it directly with the `Logging.getLogger(String)` method.

The framework already provides one global log-file, which may be used for logging, especially logging of errors. The file name of this framework log-file is specified in the [PROJECT CONFIGURATION FILE](#) of each project. For this framework log-file (and only for this log-file), you can specify in the configuration file, whether a file should be created, or whether its content should be printed onto the standard output. You can access this framework log-file by calling `Logging.getLogger()` or through `sinalgo.runtime.Global.log`.

## Log to Time Directory

By default, the log files are created in a folder `logs` of the root directory of the Sinalgo installation. I.e. subsequent runs of a simulation will overwrite the log-files. As this overwriting may be undesirable, the log-files may be placed in a unique folder, which gets created for each simulation run. The name of this unique folder is composed of the project-name and the time when the simulation started, these folders are placed in the 'logs' directory. You can turn on this feature in the [PROJECT CONFIGURATION FILE](#), by setting the entry `logToTimeDirectory` to `true`.

## Logging with Levels

Logging statements may be used to debug a system. But after debugging, these statements are often not needed anymore. However, removing manually the log statements may be time consuming and often not desirable, as they need to be re-inserted if the problem occurs again. To avoid the removal of log-statements in the code, we support the concept of logging with levels. I.e. each log-statement takes as optional parameter a boolean indicating whether it should be printed or not. Collecting all of these boolean variables in a single file lets you quickly turn on or off different sets of log-statements. Therefore, when adding log-statements for a certain topic, assign to all of them the same boolean flag, such that all of them can be enabled or disabled by this flag (at compile-time).

In theory, this flag can be stored anywhere. We suggest that you collect all of these flags and store them in the class `LogL` in the root directory of your project. The file `LogL.java` may look as following:

```
public class LogL extends sinalgo.tools.logging.LogL {
    public static final boolean testLog = false;
    public static final boolean nodeSpeed = true;
}
```

The log-statements now look as following:

```
Logging myLog = Logging.getLogger("myLog.txt");
myLog.log(LogL.testLog, "Test");
myLog.logln(LogL.nodeSpeed, "Test");
```

The first log-statement won't be printed, as `LogL.testLog` is set to `false`.

**Implementation Remark:** In order to change the log-levels at runtime, you need to remove the `final` modifier for the corresponding log-levels in the `LogL.java` file.

## Appending to Log Files

The logging class allows to append to an existing log-file from a previous run. To do so, call the `getLogger()` method with the second optional parameter set to `true`. Note that log-files created with the append flag set to `true` are always placed in the `logs` folder and ignore the `logToTimeDirectory` flag.

## Logging the Code Position

When a log-file collects log-statements from several code fragments, it is often difficult to remember which piece of code was responsible for a given log statement. Therefore, the logging class provides methods to automatically prefix a log-statement with the class name, method name, and line number of the source-file where the log-statement executed. To prefix a statement with the code position, use either `logPos(...)` or `logPosln(...)`. For personalized use, you may also consider the method `Logging.getCodePosition()`, which returns a string representation of the code position where the method is being called.

## Performance Issues

Turning off logging by setting the corresponding flag to `false` still triggers the corresponding log method to be called. Even more costly is often the composition of the string that is passed to the log-method. [The composition of the string is not only costly in terms of time, but also allocates new memory cells, which need to be reclaimed by the garbage collector later on.]

Most of the time, this is no problem. E.g. when the log-statement is placed in a part of the code that executes rarely. But when the log-statement is located in a piece of code that executes very often, e.g. in every step of every round, this may decrease simulation performance noticeably. A possible work-around for such exposed log-statements is to not use the log-level flag in the method-call, but surround the log-statements with an `if()` clause, that only executes if the corresponding log-level is set to `true`:

```
if(LogL.testLog) {
    myLog.log("Test"); //we don't need the Log-Level anymore
}
```

## Background Map

By default, the deployment area is a rectangular region in 2D, and a cuboid in 3D, whose dimensions are specified in the project specific configuration file. For the 2D case, Sinalgo offers an extension to display a picture on the deployment area. The interpretation of this background map is purely project specific. E.g. colored areas may denote obstacles, where no nodes can be placed.

The usage of the background image can be enabled in the configuration file, which also contains the path of the image file to use. The search path for the image is the root directory of the project. The image formats that Sinalgo can decode depends on your JAVA installation. Most likely, the following formats are supported: GIF, PNG, BMP, JPG.

The background image is scaled along the x and y axis to exactly fit the deployment area. As a result, the provided image may be quite small. In fact, huge images allow to encode more and finer details, but take also more time to display.

The instance of `sinalgo.io.mapIO.Map`, which may be accessed through `Tools.getBackgroundMap()`, provides methods to determine the color of any position on the deployment area.

# Insight Into the Clockwork of Sinalgo

Sinalgo is a simulation framework that helps you simulate computer networks in different scenarios. Its main target networks are wireless networks, which are well described by the message passing model.

While running any simulation, it is crucial to understand how the simulation simplifies from a real network. For example, Sinalgo simulates the physical propagation of transmissions only very superficially (in contrast to other simulators, such as ns2). In the remainder of this section, we describe the operating mode of Sinalgo on a high level. We stick as close as possible to the implementation, such that the simplifications/abstractions from reality can be easily spotted.

## Node Storage

Many connectivity models such as UDG and QUDG have a well defined upper bound on the Euclidean distance between two connected nodes. Sinalgo uses this upper bound to speed up the connectivity model, which determines the set of neighbors to each node. (Remember that the connectivity model is called in every [ROUND](#) of the synchronous simulation, and makes up a considerable part of the simulation time.) When the connectivity model is called for a given node  $n$ , it could test whether  $n$  is connected to any of the other nodes. However, if there is an upper bound on the Euclidean distance between any two connected nodes, it is sufficient to test a subset of nodes in an Euclidean proximity of  $n$ , which corresponds to a range query.

Sinalgo provides support to perform range queries, which return a set of potential neighbors for a given node. To perform these range queries, Sinalgo stores the nodes in a specialized data structure. In the default distribution, Sinalgo stores the nodes in a `GeometricNodeCollection`, which implements the `NodeCollectionInterface`. Because these range queries depend on the maximum distance between any two connected nodes, the `GeometricNodeCollection` needs to be configured through the project configuration file. It requires an entry of the following form, where `rMax` specifies the maximum distance between any two connected nodes.

```
<GeometricNodeCollection rMax="150"/>
```

The `NodeCollectionInterface` interface provides a method `getPossibleNeighborsEnumeration(Node n)`, which returns an enumeration over all potential neighbors of a given node. Using this method, the connectivity model only needs to test a subset of all nodes, which increases the simulation time considerably. The [CONNECTIVITYMODELHELPER](#) located in the package `sinalgo.models` gives an example on how to use this range query.

**Note:** The `GeometricNodeCollection` comes in two flavors, one for 2D and one for 3D. However, you may implement your own subclass of `NodeCollectionInterface` to obtain range queries that depend on other criteria. The project configuration file contains an entry which specifies the node collection implementation to use.

**Implementation Note:** The `GeometricNodeCollection` partitions the deployment area in a 2-dimensional (3-dimensional) grid with cell-size `rMax`. Each cell stores the nodes that are contained within its boundaries. Whenever a node moves into a different cell, this data structure is updated to reflect the new situation. A range query for a given node  $n$  determines the cell  $c$  in which  $n$  is located, and returns the nodes contained in  $c$  and any cell adjacent to  $c$ . Thus, `getPossibleNeighborsEnumeration(Node n)` returns the nodes contained in 9 cells in 2D, and the content of 27 cells in 3D.

## Synchronous vs Asynchronous Mode

Most importantly, Sinalgo either runs as an asynchronous, event triggered simulator, or in synchronous mode, where events happen in parallel in fixed time slots. The two modes result in different calling sequences of the methods implemented by the network nodes. The calling sequences are described in the [NODE IMPLEMENTATION TUTORIAL](#).

The simulation mode determines when exactly the method `handleMessage()` is called when a node receives a message, and when exactly the timers are fired when they expired.

## Synchronous Simulation

The synchronous simulation is based on *rounds*. At the beginning of each round, the framework increments the global time by one unit. Then, it moves the nodes according to their mobility models and updates the connections according to the connectivity model. After that, the framework iterates over the set of nodes and performs the method `step()` on each node. The calling sequence of this method is described in the [NODE IMPLEMENTATION TUTORIAL](#). The nodes are visited in a framework specific order, which the simulation should not rely on.

Each message and timer carries a time stamp that indicates at which time the event (arrival of message, execution of timer-handler) should happen. Because the time advances in steps of 1 unit, each node handles in its `step()` method all events whose time stamp is smaller or equal to the current time. For both, the set of messages and the set of timers, the node sorts the events according to their time stamp, such that the events happen in order on each individual node.

**Note:** From a global view, the message receptions and timer-handlers may not be executed *in order*: Suppose the case where node A receives a message M1 at 15.23 and M2 at 15.88 and node B receives a message M3 at 15.17 and M4 at 15.77. If the framework first executes the `step()` method on node A, then the messages M1 and M2 are handled prior to the messages M3 and M4, which are only handled in the call to `step()` of node B.

**Implementation Note:** If your project simulates mobile nodes, the position of the nodes is updated at the beginning of every round. As a result, the nodes hop around, which does not quite correspond a continuous path. To achieve a better approximation, you may increase the time resolution of the simulation by a given factor, e.g. 10: Decrease the node speed by this factor, and increase the message delivery time, as well as the countdown-time of all timers by the same factor. This inserts several (in this case 9) more rounds for the same distance a node moves, which gives a better approximation of the movement.

## Asynchronous Simulation

The asynchronous simulation is purely event based. The framework holds a list of message events and timer events, which is sorted by the time when these events should happen (arrival of message, execution of timer-handler). The framework repeatedly picks the most recent event and executes it.

In a typical simulation, some of the events issue further events, which prevent the event list from draining. If the list empties anyways, the framework calls the `handleEmptyEventQueue` method of the project's `CustomGlobal` class. This method may issue further events to continue the simulation.

In general, the asynchronous simulation mode runs much faster than the synchronous mode. The main reason lies in the fact that the synchronous simulation mode loops over all nodes and performs for each node the `step()` method even if most of the nodes may not do anything at all. This is in sharp contrast to the asynchronous mode, where only message and timer events are processed and no unnecessary cycles are wasted. But to achieve its speed, the asynchronous mode is more limited: it does not support mobility. I.e. the nodes cannot change their position over time. (The framework configuration entry `mobility` needs to be set to `false`, such that the mobility model assigned to each node is not considered.) The reason for this limitation on the asynchronous mode is the continuity of the node movement, which does not allow to be described in terms of events. (Note that also the synchronous mode does not perform continuous moves, but moves the nodes in hops at the beginning of every round.)

## Message Delivery

Whenever a node sends a message to another node of the network, the framework encapsulates the message object in a *packet* object, which contains the following meta information for the message delivery.

- The sender of the message
- The receiver of the message
- The time when the message arrives
- The time when the message was sent
- The edge over which the message is being sent
- The intensity at which the message is being sent
- A unique ID for the packet

The receiver of the message can retrieve this information for each received message in the `handleMessages()` through the `Inbox` object.

Project developers only get in touch with `Packet` objects when implementing a new interference model. The member

```
public boolean positiveDelivery
```

indicates whether the message hold in the packet will be received properly at the destination. If this flag is set to false, the receiving node will not include the corresponding message in the inbox, handed over to the `handleMessages()` method.

Refer to the [NODE IMPLEMENTATION](#) part of this tutorial for more information on how to implement project specific messages.

## Network Edges

In the network abstraction of Sinalgo, an edge is present between any two nodes in communication range. The [CONNECTIVITY MODEL](#) is responsible to decide which node pairs are within communication range. Each node carries a list of its *outgoing connections*. I.e. the set of edges through which the node is connected to its direct neighbors. Because the edges are *unidirectional*, an edge object is contained in exactly one set of outgoing connections. Furthermore, if two nodes are connected in both directions, there are *two* edge objects, one hold by each end node.

Sinalgo requires that the *same* edge object is present between two nodes until the connection breaks. Upon reconnection of the two nodes, a new edge object has to be used. To distinguish edges, each edge object carries a *unique ID*.

The `send` and `broadcast` methods provided by the node superclass deliver messages only if the sending node has an outgoing edge to the destination. The method `sendDirect` is an exception: it is the only method that does not test whether the sender and receiver are really interconnected. This latter method may be used to simulate a wired overlay network, or to send messages between network nodes that are connected through another means.

**Note:** Especially when manually adding an edge in GUI mode, remember that the added edge is *unidirectional*. To connect two nodes A and B in both direction, you need to add an edge from A to B, and another edge from B to A. To avoid this issue, you may want to use *bidirectional* edges.

### *Bidirectional Edges*

The use of unidirectional links may be desirable to simulate lossy and unpredictable networks. However, one may often want to abstract from these low-level issues and only consider bidirectional links. To ensure, that there is either no link at all between two nodes, or a link in both directions (a bidirectional link), use the `BidirectionalEdge`. This edge implementation automatically ensures that there is an edge in both directions between a given pair of nodes.



To implement bidirectional edges, and to draw edges properly, each edge (not only the bidirectional ones) has a member `oppositeEdge`, which points to the edge that connects the two end-nodes in the opposite direction, or is null, if there is no such edge.

## Edge Creation, *valid Flag*

At any time, Sinalgo uses the *same edge type for all edges* - the framework holds one global factory that creates the new edges. The type of edges to be used is defined in the configuration file, and may be changed at runtime. But note that when changing the edge type at runtime, the existing edge objects are not replaced and thus implement the previous edge type. A change of the edge time at runtime only affects edges that are added to the network graph afterwards.

We have seen that the `CONNECTIVITY MODEL` determines to which other nodes a given node `N` is connected by adding and removing edges from the `outgoingConnections` list of `N`. In most cases, this model is too powerful, and the simpler `ConnectivityModelHelper` class can be used, where the subclass only needs to answer whether node `N` is connected to another node `B`. If node `N` has a (unidirectional) connection to node `A`, the model calls `N.outgoingConnections.add(N, B, true);`, which adds an edge `NB` to the set of outgoing connections of node `N`. If the edge already exists, the call to add does *not* replace the existing edge.

The removal of the edges is somewhat more involved, because Sinalgo requires the *same* edge object to remain installed until the corresponding connection breaks up. Therefore, we may not just empty the set of outgoing connections before calling the connectivity model. Sinalgo proposes to handle this issue using the `valid` member of each edge: Whenever the connectivity model calls `N.outgoingConnections.add(N,B,true)` to ensure that there is an edge `NB`, the `valid` flag of the added (or already existing) edge is set to `true`. Before the connectivity model returns, it calls `N.outgoingConnections.removeInvalidLinks()`, which iterates over all outgoing edges of `N` and removes the ones whose `valid` flag is `false`. (At the same time, the method resets the `valid` flags to `false` for the next round.)

## Interference

Computing the interference created by a set of network nodes can be quite a challenge, especially if real physical characteristics of the wireless transportation medium, perhaps even reflection are considered. Sinalgo offers a simplified view of the node signals which may cause interference. At any point in time, the framework holds a list of all messages that are being sent at that time. This list is called `PacketsInTheAir` and may be accessed through `Tools.getPacketsInTheAir()`. Note that this list only contains the packets if interference is enabled in the configuration file.

Each sender node can send its message with a given signal power, which we call *intensity*. The interference model can use the set of all messages and their corresponding intensity to determine the noise-level a given receiver node experiences.

One example is the SINR interference model, which assumes a signal decay exponential to the Euclidean distance to the sender. Roughly speaking, SINR drops a message if the signal of the message at the receiver is below the sum of all interfering signals times a given constant. A sample implementation of SINR is provided in the `defaultProject`.

## Memory Management

Our choice to use Java was mainly based on its platform independence, modularity, and its wide acceptance. However, running a simulation in the Java environment quickly brings up memory problems, mainly related to garbage collection.

It seems that Java's garbage collector (GC) has a hard time when the application constantly creates a huge amount of small, short living objects. But that's exactly what our simulation framework does: For every message that is being sent, there are at least two new objects allocated, and if the network graph changes frequently, many edge objects need to be allocated.

To alleviate this problem, Sinalgo tries to *recycle* objects as often as possible: Instead of returning a removed edge to the GC, Sinalgo stores the edge object for reuse the next time an edge object of this type is needed. The same holds for the packets, which encapsulate the messages sent by the nodes. After a message arrived at its destination, the corresponding packet object is returned to Sinalgo for storage. Whenever a message is sent, Sinalgo only creates a new packet object if there is no recycled packet left.

**Note:** Remind from the [MESSAGE IMPLEMENTATION SECTION](#) that a sent message object is cloned by default. To save memory, a project may apply a read-only policy for all messages, in which case the cloning of the messages can be circumvented. This preserves a lot of memory, especially for broadcast messages.

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