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Implementation of Dynamic Spectrum Allocation for Cognitive Radio Networks based on Iterative Water Filling in OMNeT++/MiXiM

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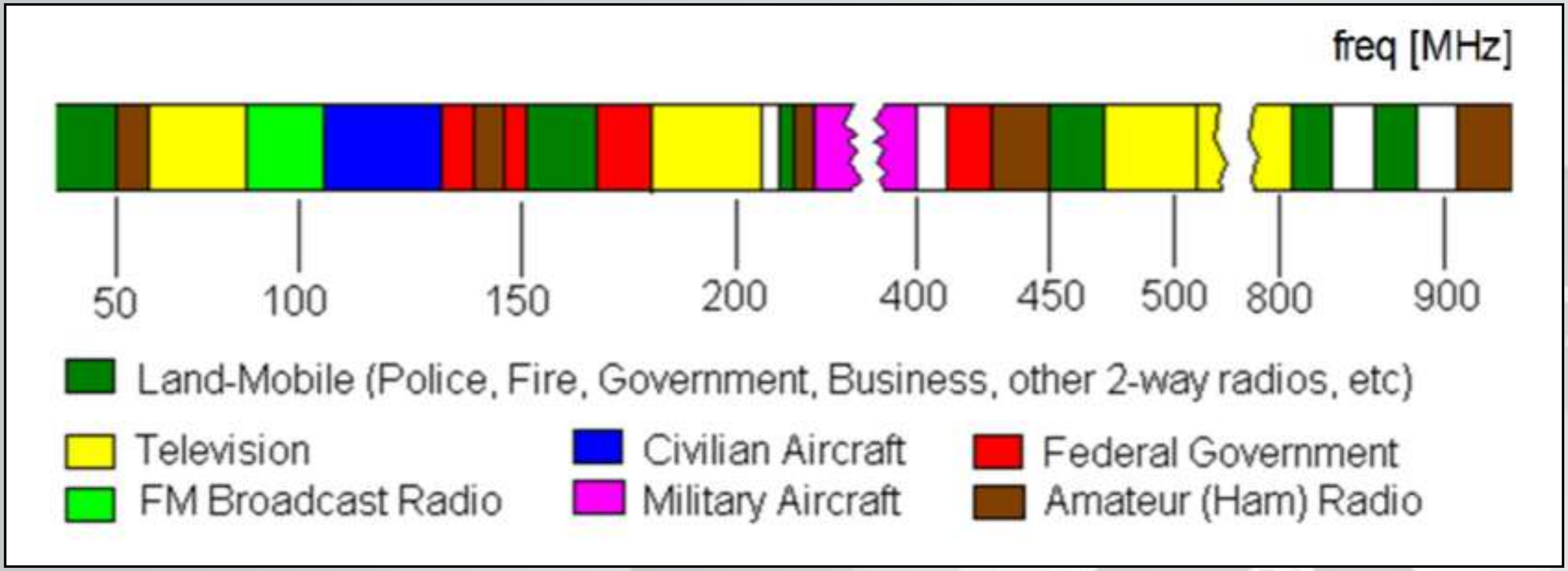
Plan

- Introduction
- Presentation of IWFA
- Implementation of IWFA
- Simulation results
- Conclusion

Introduction

Introduction



→ Potential approach : Cognitive Radio (Dynamic Spectrum Allocation)

Introduction

How to achieve Dynamic Spectrum Allocation?

→Use of **Game theory**

« Game theory is a mathematical modeling of strategic situations (= game), in which an individual's choice depends on the choices of the others. The choice is evaluated by an objective function »

→Cooperative vs. **competitive** approach

« Nash equilibrium (NE) can be reached. In a NE, no player can increase the outcome of its objective function by unilaterally changing its strategy »

→Iterative Water Filling Algorithm (IWFA)

« IWFA gives a sub-optimal allocation of the power by distributing the total power available at the transmit nodes on different sub-channels »

Introduction

Implementation of IWFA in OMNET++/MiXiM

→ IWFA has already been implemented in C/C++, matlab,…

…but never in an **event-driven** simulator

→ Improvement of IWFA thanks to the reduction of transmitted power

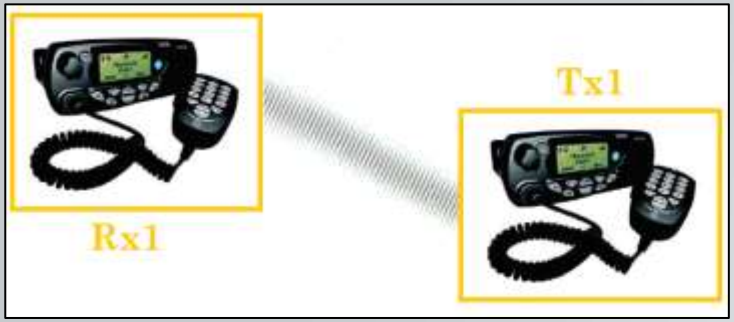
Total transmitted power is reduced (increased) if this power is higher (lower) than this necessary for reaching the desired data rate.

beneficial for :

- economy of power
- reducing interference with other networks

Presentation of the algorithm (1/3)

- WFA



N_c	Amount of sub-channels
P_i	Power delivered to sub-channel "i" by the transmitter
T	Target data rate for the network
R	Effective data rate in this network
H_i	Channel property for channel "i"
σ_i	Standard deviation of the noise for channel "i"
Γ	Signal to noise ratio (SNR) gap
Δf	Sub-channel bandwidth

$$\text{Minimize} \quad \sum_{i=1}^{N_c} P_i$$

$$\text{subject to:} \quad T \leq R \quad \text{with} \quad R = \Delta f . \sum_{i=1}^{N_c} \log_2 \left(1 + \frac{P_i . |H_i|^2}{\Gamma . (\sigma_i)^2}\right)$$

Presentation of the algorithm (1/3)

- WFA

Lagrange multiplier (dual form)

$$L(\lambda, T) = P_i - \lambda \left[\Delta f \sum_{i=1}^{N_c} \log_2 \left(1 + \frac{P_i.|H_i|^2}{\Gamma \sigma_i^2} \right) - T \right]$$

An additional variable (λ) is added in order to determine the maximum.

First derivative

$$\frac{\partial L(\lambda, T)}{\partial P_i} = 1 - \lambda \left[\Delta f \frac{|H_i|^2}{\Gamma \sigma_i^2.(1 + \frac{P_i.|H_i|^2}{\Gamma \sigma_i^2})} \right]$$

The first derivative is taken equal to zero.

Optimum

$$P_i = \left[\frac{1}{\lambda \Delta f} - \frac{\Gamma \sigma_i^2}{|H_i|^2} \right]^+$$

An optimum of the dual form is also an optimum of the initial form

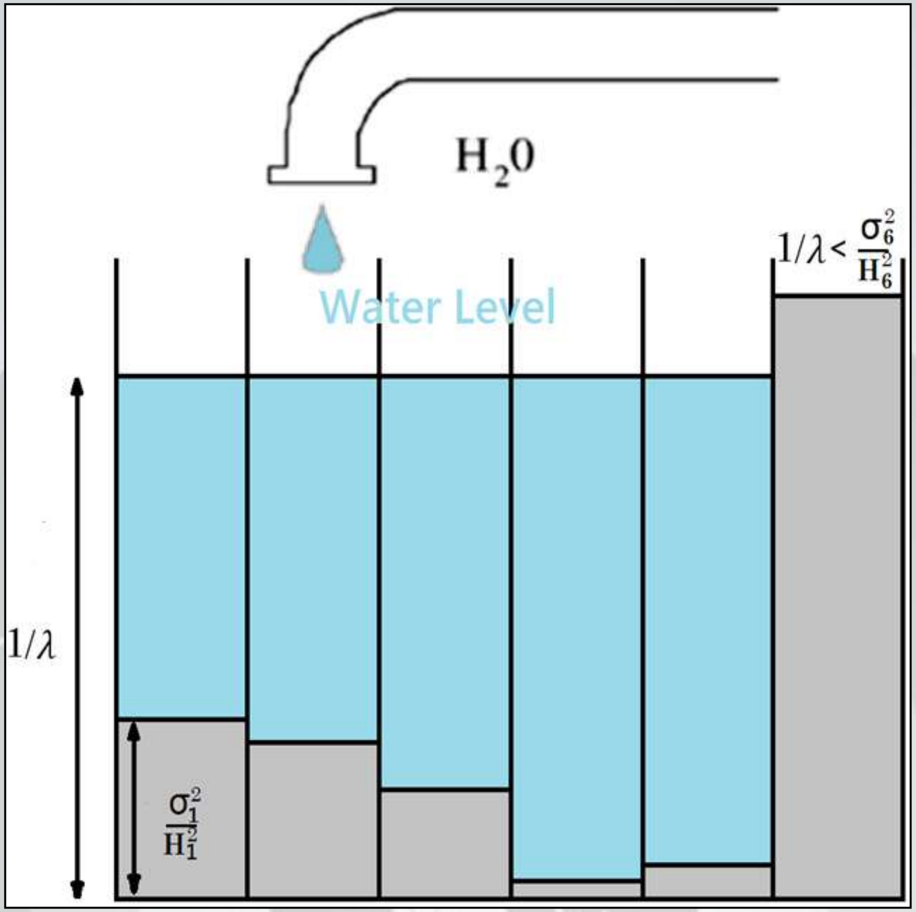
Presentation of the algorithm (1/3)

- WFA

$$P_i = \left[\frac{1}{\lambda \Delta f} - \frac{\Gamma \sigma_i^2}{|H_i|^2}\right]^+$$

$$\text{if} \quad \frac{\Gamma \sigma_i^2}{|H_i|^2} \geq \frac{1}{\lambda \Delta f} \rightarrow P_i = 0$$

$$\text{if} \quad \frac{\Gamma \sigma_i^2}{|H_i|^2} < \frac{1}{\lambda \Delta f} \rightarrow P_i = \frac{1}{\lambda \Delta f} - \frac{\Gamma \sigma_i^2}{|H_i|^2}$$



ANALOGY:

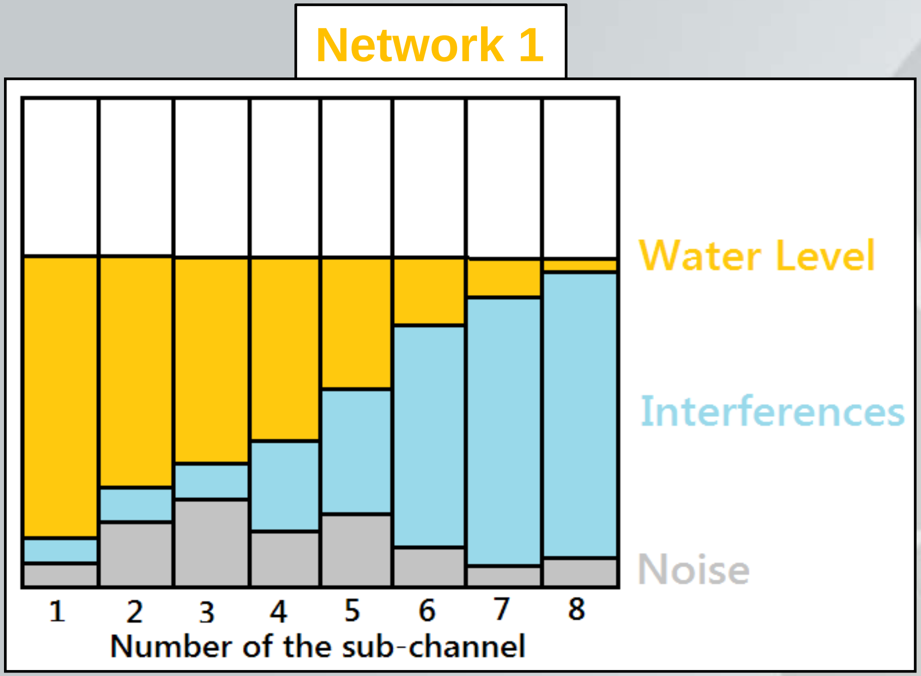
The water (= the power) has to be distributed
in the reservoir (= the normalized noise in the sub-channels)

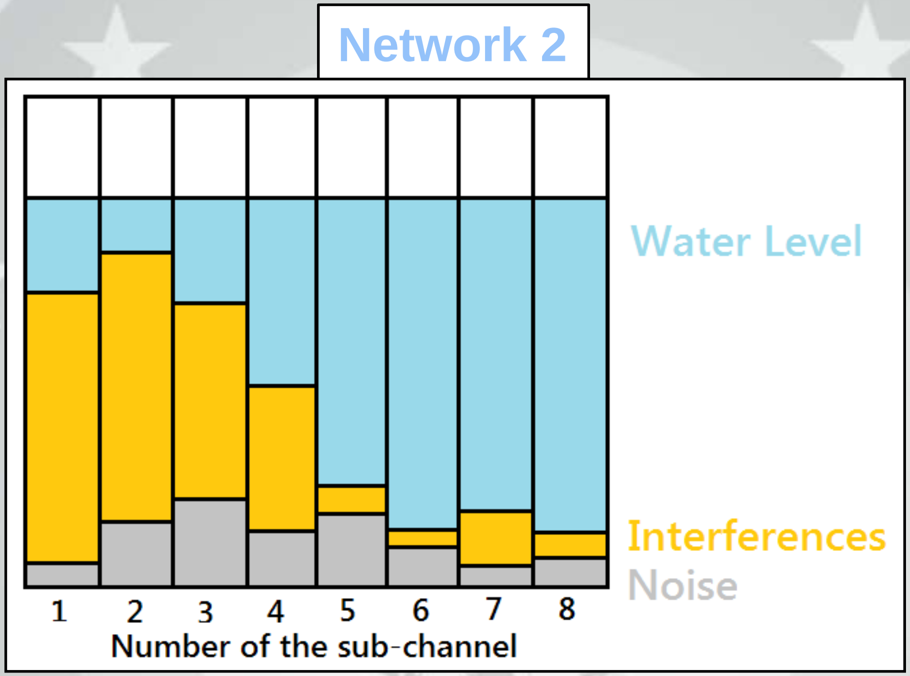
Presentation of the algorithm (2/3)

- IWFA

- Two couples of users
- Communication through the same sub-channels
- Noisy environment

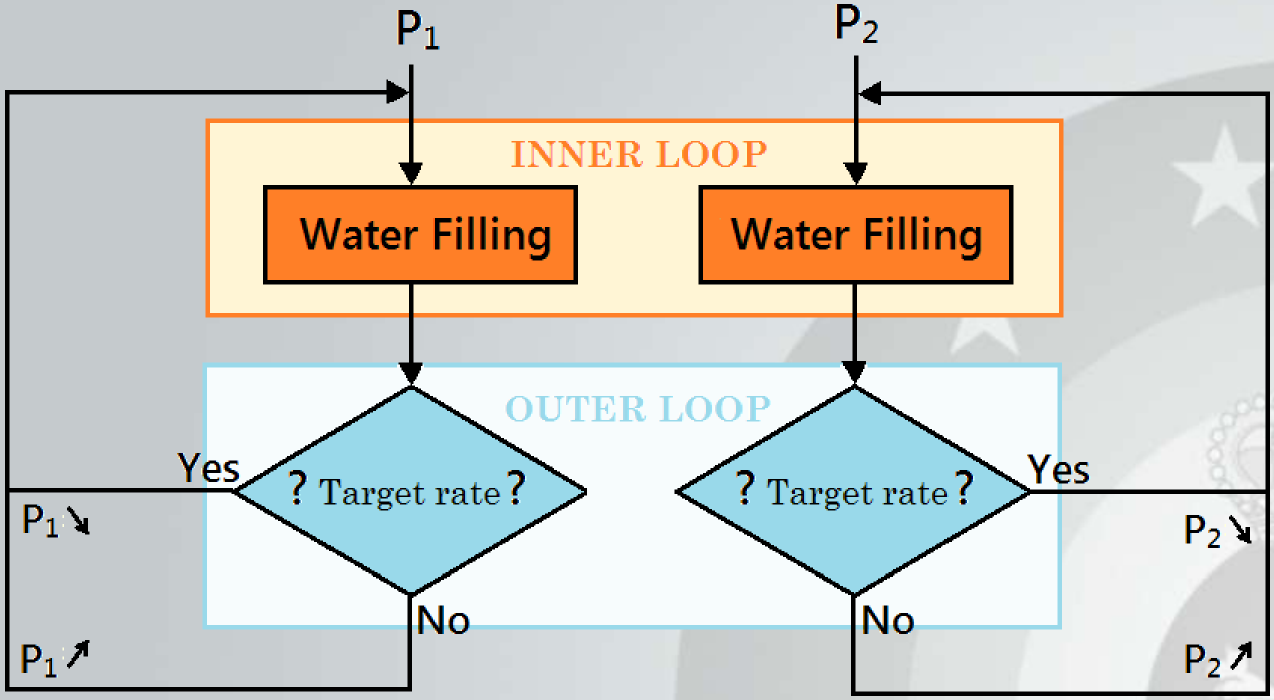
Both couples want to ensure an optimal communication





Presentation of the algorithm (3/3)

- IWFA with Power Control



+ Battery saved

+ Decreases potential interferences

Effective rate (R_j) > target rate (T_j) → Transmission power (P_j)↓

Effective rate (R_j) < target rate (T_j) → Transmission power (P_j)↑

Implementation of the simulation

To implement the IWFA in Omnet++/Mixim, we need to :

access and **control <u>multiple channels</u>** simultaneously.

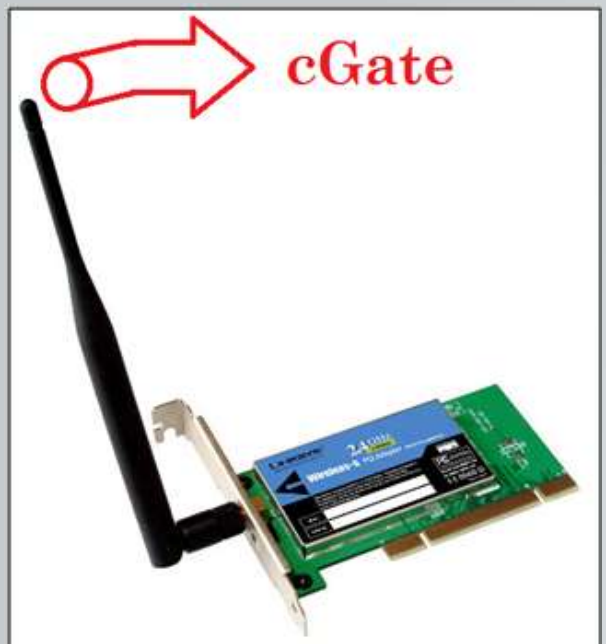
→A first possible approach: use the signal class of MiXiM

→Our approach: we extend existing modules in the connection manager

Implementation of the simulation

Extension of cGate into cMultiChannelGate

Before

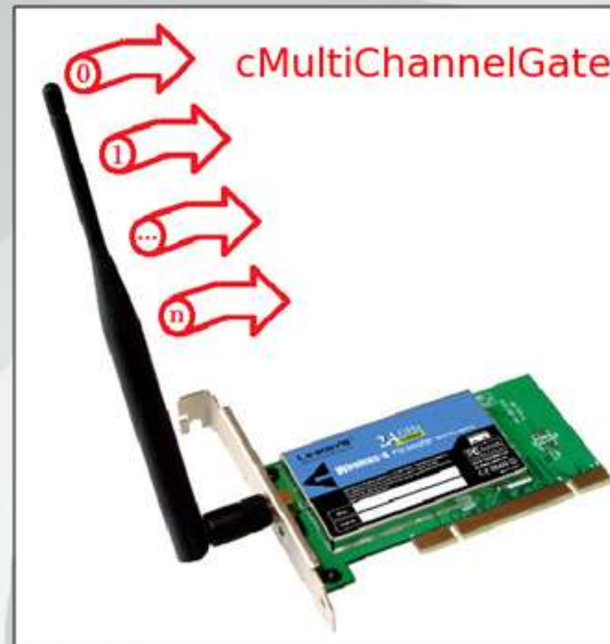


Tx ConnectTo(Rx)

Extension allows to specify the number of the sub-channel used for the transmission

Existing functions must be adapted with this supplementary parameter

After



Tx ConnectTo(Rx) through subchannel n

Implementation of the simulation

Customization of the connection manager

→The connection manager doesn't only manage the connection between nodes, but also the **sub-channels** that can be used for that purpose.

→Addition of the sub-channel dimension to several functions (to specify the sub-channel through which a message has to be sent).

"SendToChannel()", "ConnectTo()", and *"DisconnectFrom() "*

→Necessity of creating some new elements in order to stock data related to the execution of the algorithm.

3 new maps : "Node", "Waterfilling", and *"Receiver "*

Implementation of the simulation

Regulation of the power for each channel

Map Node

MultiChannelNicEntry*	int	double	double	int	double	double
node	indexchannel	pathloss	power	network	status	staticrandom

Map Waterfilling

double	double	int	double
maxpower	constraintpower	iteration	targetrate

Map Receiver

int	double	double	double
indexchannel	noiseandinterference	powerowntx	pathlossowntx

Implementation of the simulation

Regulation of the power for each channel

Map Node

MultiChannelNicEntry*	int	double	double	int	double	double
node	indexchannel	pathloss	power	network	status	staticrandom

Map Waterfilling

double	double	int	double
maxpower	constraintpower	iteration	targetrate

Localiterator - waterlevel - exponent - multiplicator - sumpower

Map Receiver

int	double	double	double
indexchannel	noiseandinterference	powerowntx	pathlossowntx

Implementation of the simulation

Three main functions are defined for the execution of IWF:

"**CalcPower()**": fill in the map linked to the the node class + updating pathloss value (function called with **UpdateNicConnection()**)

"IterationInnerLoop()": distributes the available power on the different sub-channels in order to maximize the data rate for this network.

"**IterationOuterLoop()**" : compares Target and Real data rate. This function determines if the total available power must be decreased or increased.

Implementation of the simulation

Scheduling of those functions :

Calcpower() executed with UpdateNicConnection()
→Every time a node has moved

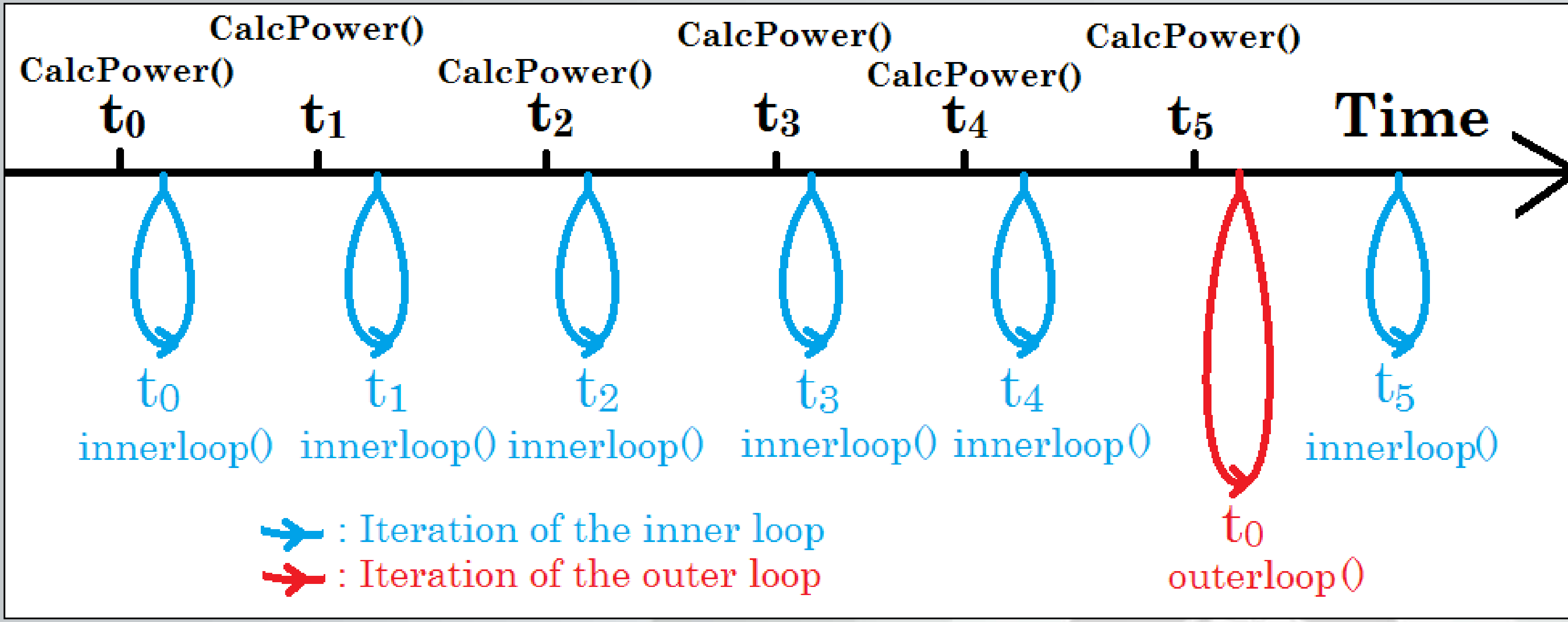
Periodic scheduling of the inner and outer loop
Some functions of the connection manager have been customized.
→Two events have been added to the existing ones:

- EXECUTE-IL
- EXECUTE-OL

Those events are declared in the *"initialize()"* function and defined in the *"handleMessage()".* Their execution is planned thanks to the *"scheduleAt()" function.*

CalcPower() IterationInnerLoop() IterationOuterLoop()

Implementation of the simulation

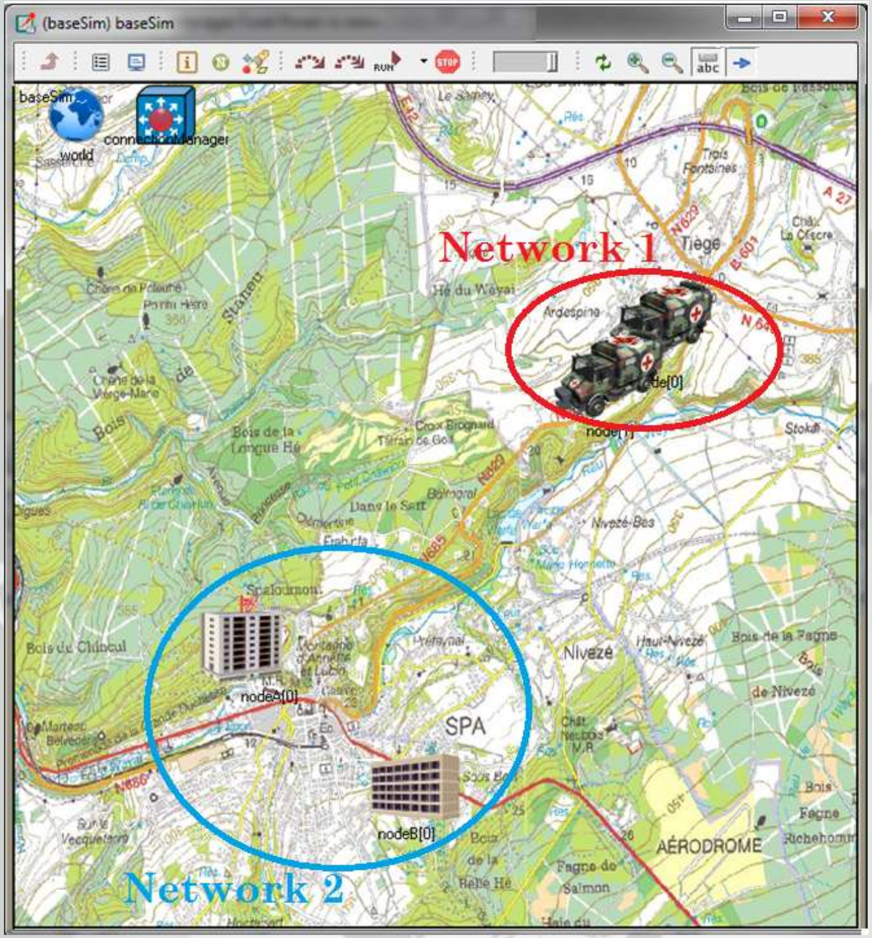


- The convergence of the inner loop is mostly reached after five iterations
- A realistic execution of the inner loop can be assumed every 0,5 second

CalcPower() IterationInnerLoop() IterationOuterLoop()

Simulation results

•2 networks (1 static + 1 mobile: 90km/h)
•2 nodes/network
•4 sub-channels
•Max transmitted power : 10W
•Target data rate: 64kbps



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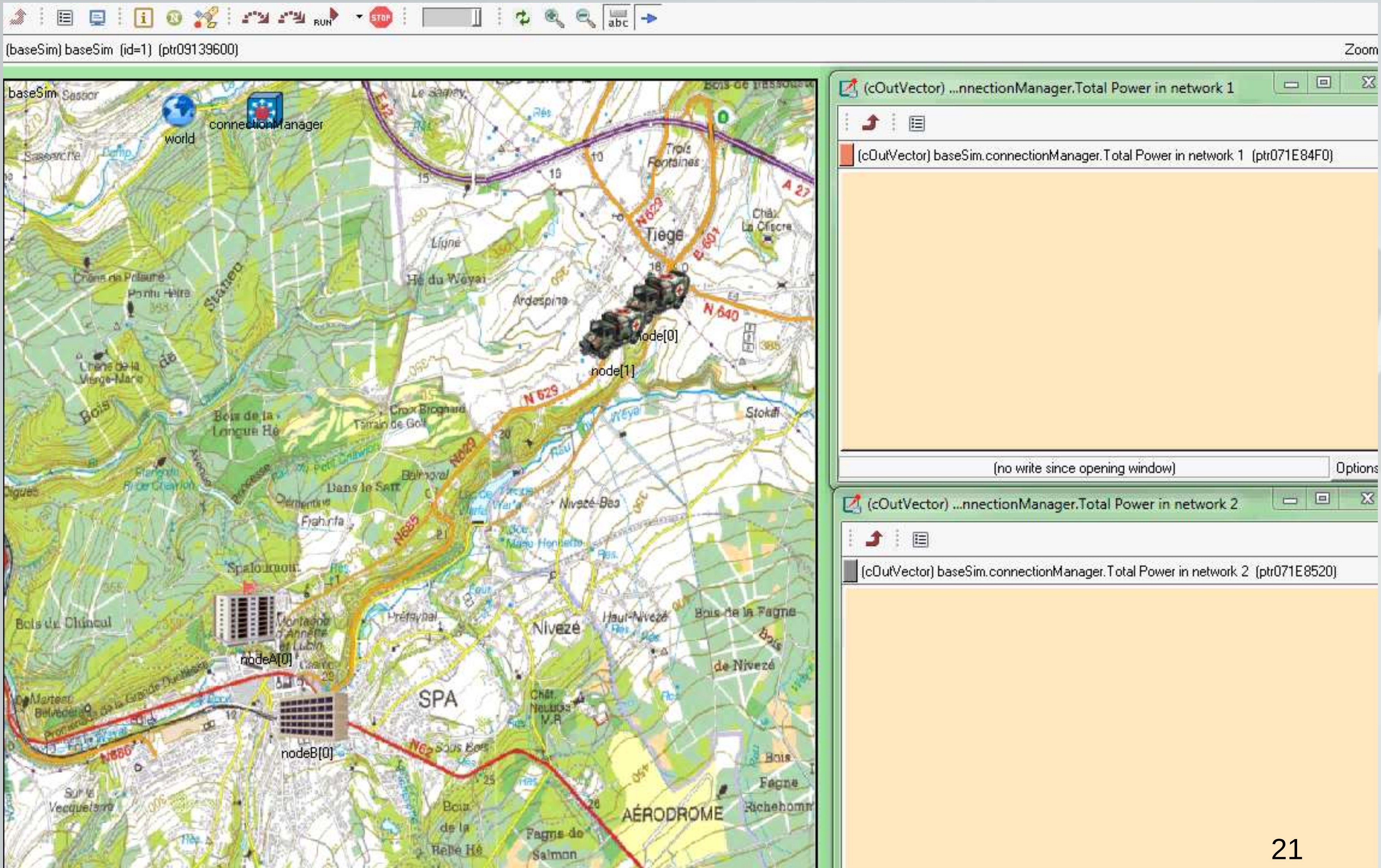
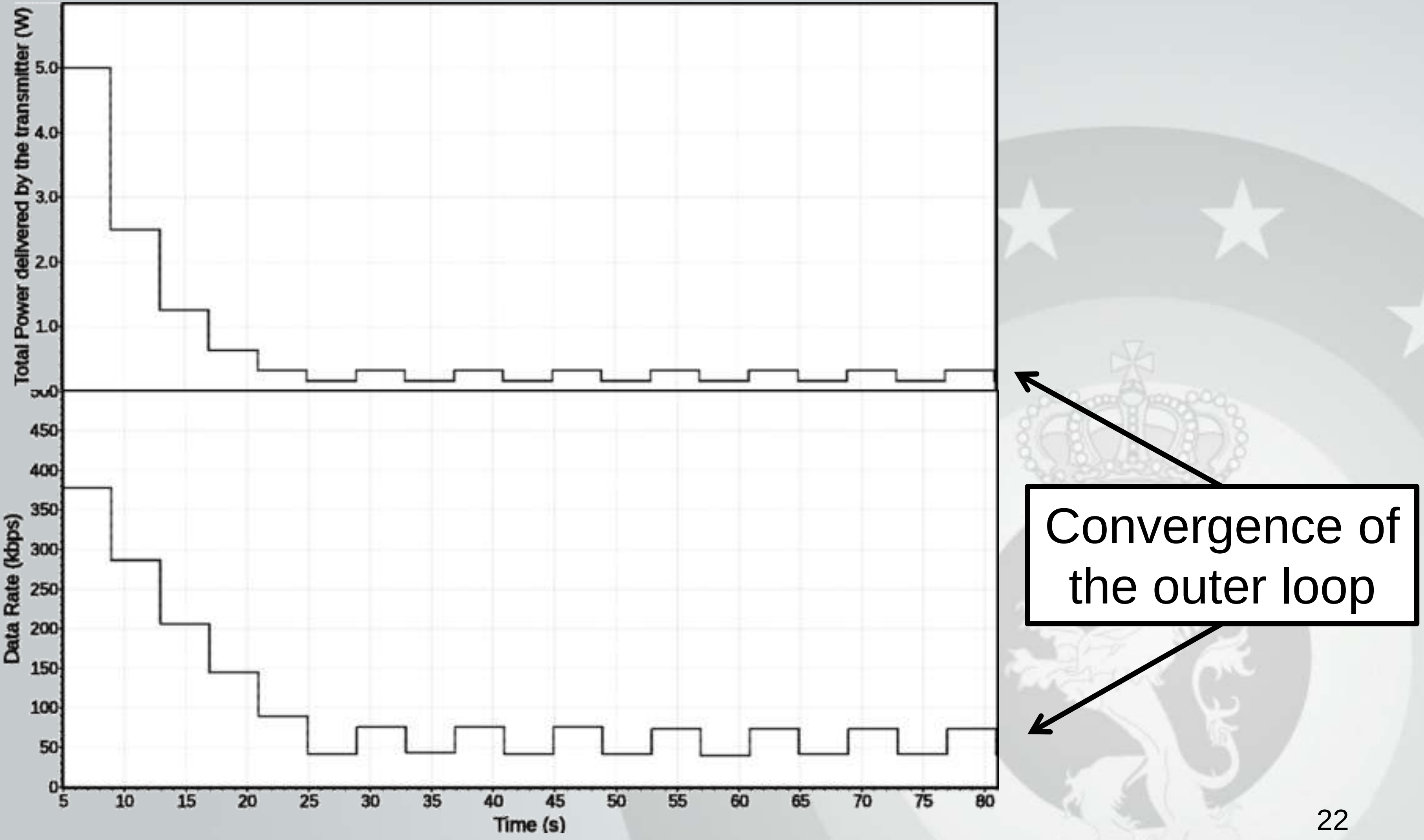
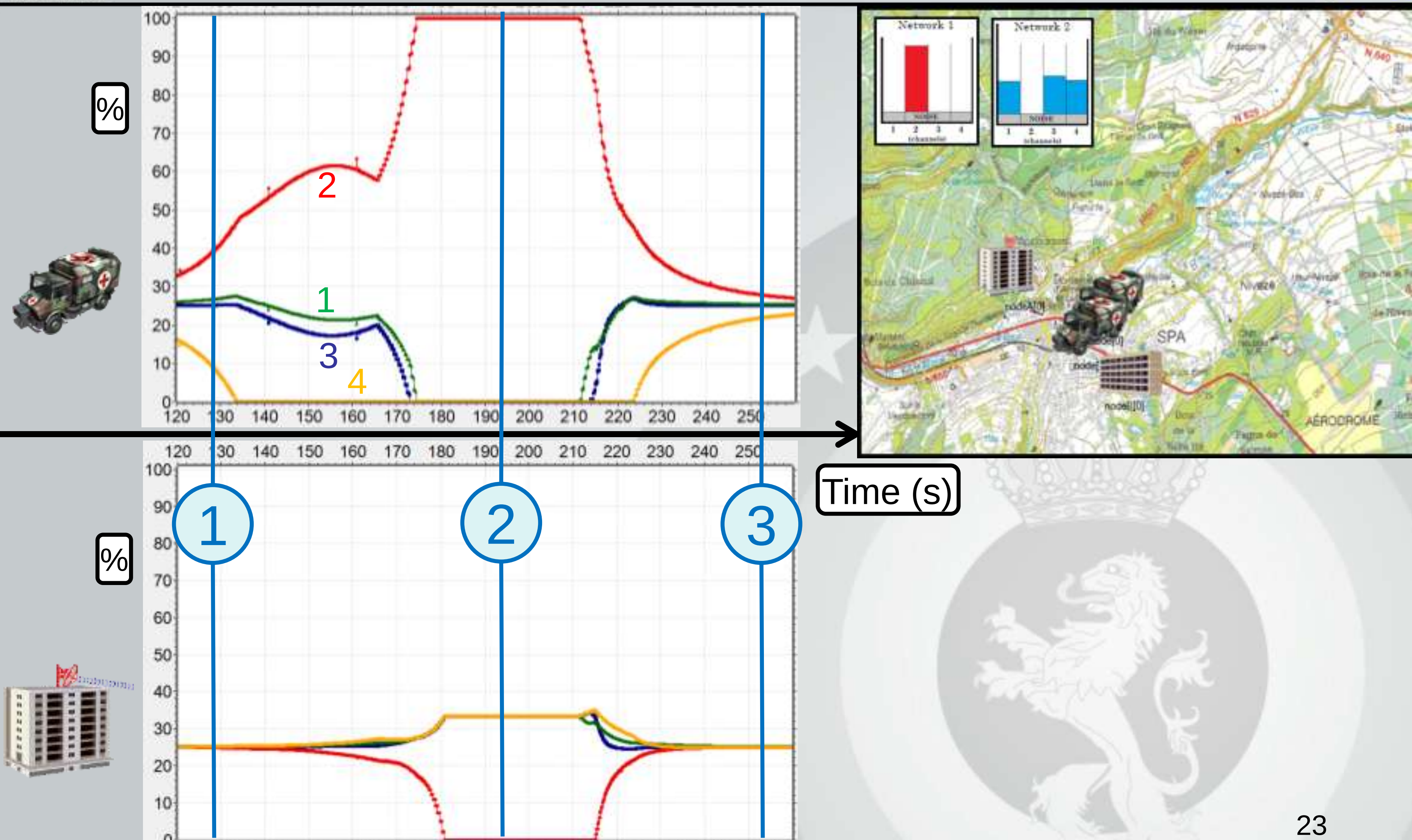
Simulation results



Simulation results



Simulation results



Conclusion

Adaptation of cGate to make possible the use of multiple channels

Creation of maps for stocking data related to the algorithm

Implementation of functions and events necessary for the execution of IWF

Validation of the simulation in the case of 2 networks with 1 Rx and 1 Tx

This implementation will allow the study of the IWFA in more realistic environment

It can be used as a framework to compare different game theory based algorithms

Questions

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