LEADING-EDGE

International Water Association

Leading-Edge Asset Management

2nd IWA Leading-Edge Conference & Exhibition on

Strategic Asset Management

Extended Period Simulation in the Estimation of the Economic Level of Reliability for the Rehabilitation of Water Distribution Systems

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WDS Optimal Rehabilitation

Objective Function : → Minimise Structural Costs

(e.g.: Deb 1976; Alperovits and Shamir, 1977; Bhave 1978; Walski, 1985)

Objective Function : → Maximise System Reliability

(e.g.: Su et al., 1987; Lansey and Mays, 1989)

MULTIOBJECTIVE OPTIMISATION UNDER UNCERTAIN DEMAND

Multi-Objective Problem

(e.g.: Deb et al., 2000; Farmani et al., 2003; Babayan et al., 2004; Kapelan et al., 2004; Prasad and Nam-Sik Park, 2004)

1) Which solution should be adopted?

WDS Optimal rehabilitation:
Multiobjective Problem

Which rehabilitation solution should be adopted?

Reliability increase ➡ Structural costs increase

System failure ➡ Lost revenue

⬇

Optimisation Model for Cost-Reliability estimation:
Economic Level of Reliability (ELR)

(Tricarico, 2005; Tricarico et al., 2006; De Marinis et al.,2006)

Optimisation Problem Formulation

Objectives :

- Minimise Rehabilitation Cost $C_{ST}(D_1, D_2, \ldots, D_{Nd})$
- Maximise Design Reliability $R = \Pr\left[H_i \geq H_{i,\min}\right] \quad \forall i \in \{1,.., N_n\}$
- Minimise Lost Revenue $C_{LR}(R, C_W)$

Constraints:

- Hydraulic model equation
- Decison Variable search bounds

Decision variables: Pipe rehabilitation options

Uncertain input variables: Nodal demands (characterised using PDF – probabilistic approach)

Optimisation Problem Formulation

Min $C_{Tot} = C_{ST} + C_{LR}$

Max $R = \Pr\left[H_i \geq H_{i,\min}\right] \quad \forall i \in \{1,..,N_n\}$

Constraints:

- Hydraulic model equation
- Decison Variable search bounds

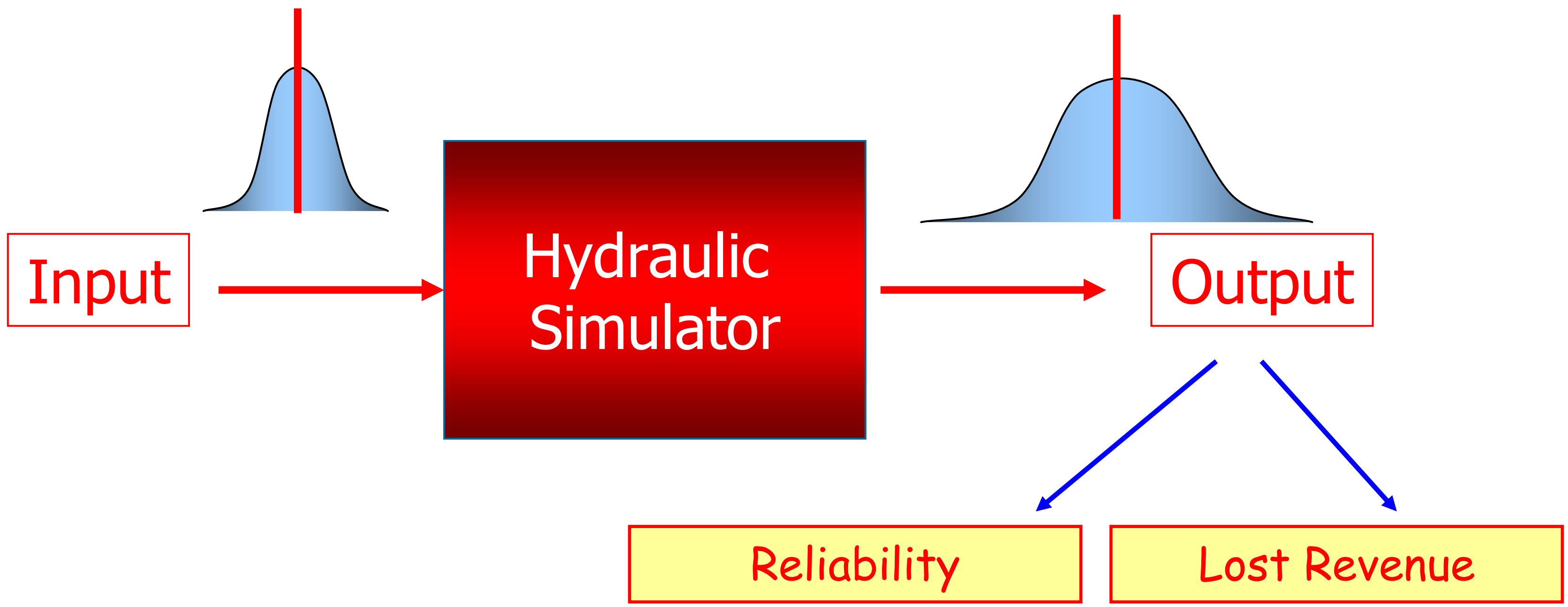
Decision variables: Pipe rehabilitation options

Uncertain input variables: Nodal demands (characterised using PDF – probabilistic approach)

rNSGAII Optimisation Method
(Kapelan et al., 2004)

- Based on NSGAII (Deb et al., 2000)
- Effectively exploits the fact that the GA search process is of stochastic nature with a population of solutions evaluated at each generation
- Evaluates the average chromosome fitness over its life, using small number of samples for each new evaluation
- Identifies Pareto optimal solutions using the concept of minimum chromosome age (MA)

Uncertainty Quantification
Probabilistic Approach



- WDS reliability estimated as fractions of samples simultaneously satisfying minimum head constraints

Lost Revenue

$$C_{LR} = W_t \cdot C_W$$

$$C'_{LR} = C_{LR} \cdot [1+(1+i)^{-n}]/i$$

n = system lifespan

i = interest rate

$$W_t = \sum_{i=1}^{N_n} \int_0^t \left(Q_{D,i}(t) - Q_{d,i}(t)\right)dt = \sum_{i=1}^{N_n} \int_0^t \left(1-\alpha_i(H_i(t))\right)Q_{D,i}(t)dt$$

$$Q_{d,i} = \alpha_i(H_i) \cdot Q_{D,i}$$ $$(i = 1, \ldots, N_n)$$

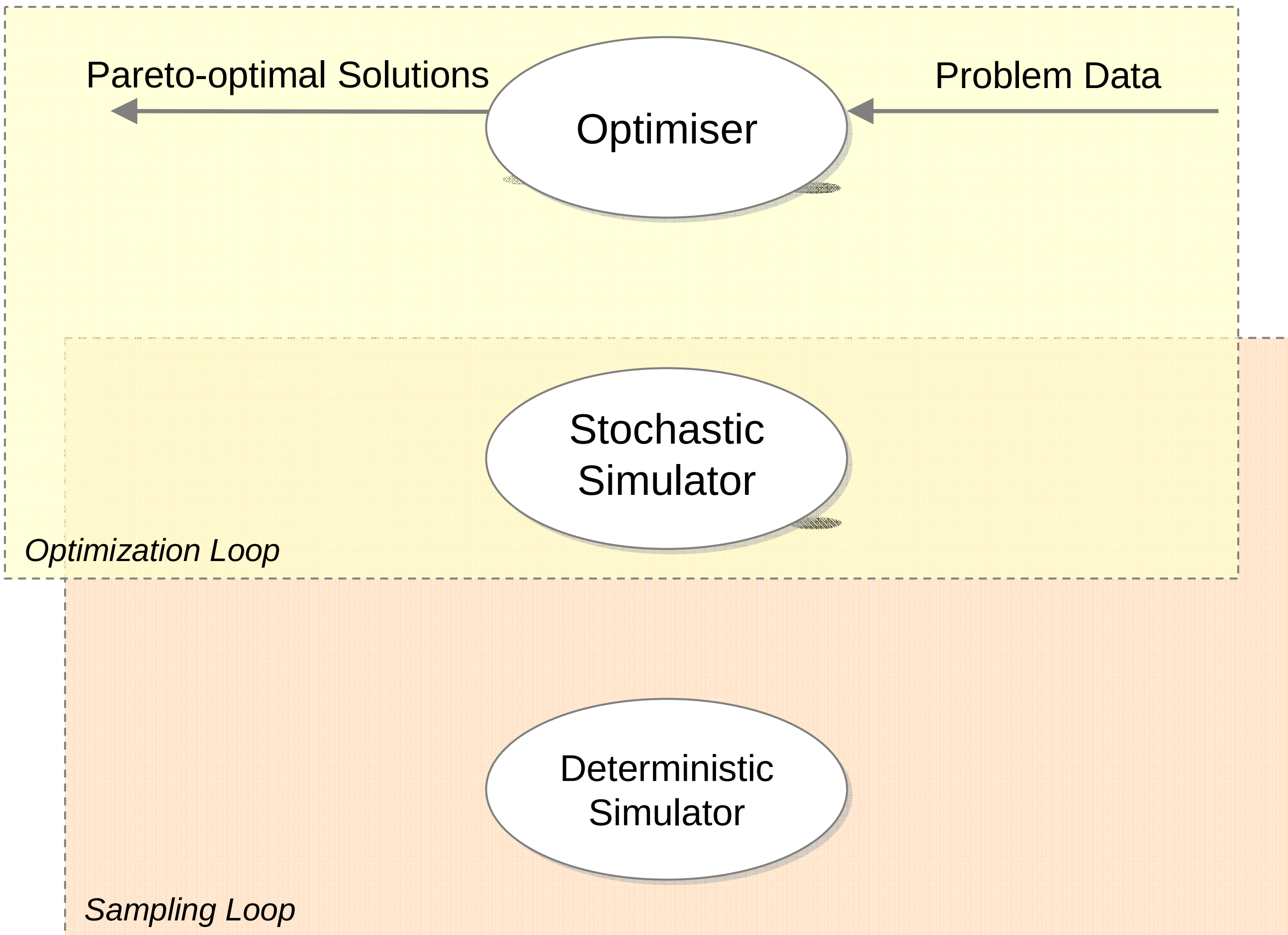
Q_d= delivered flow

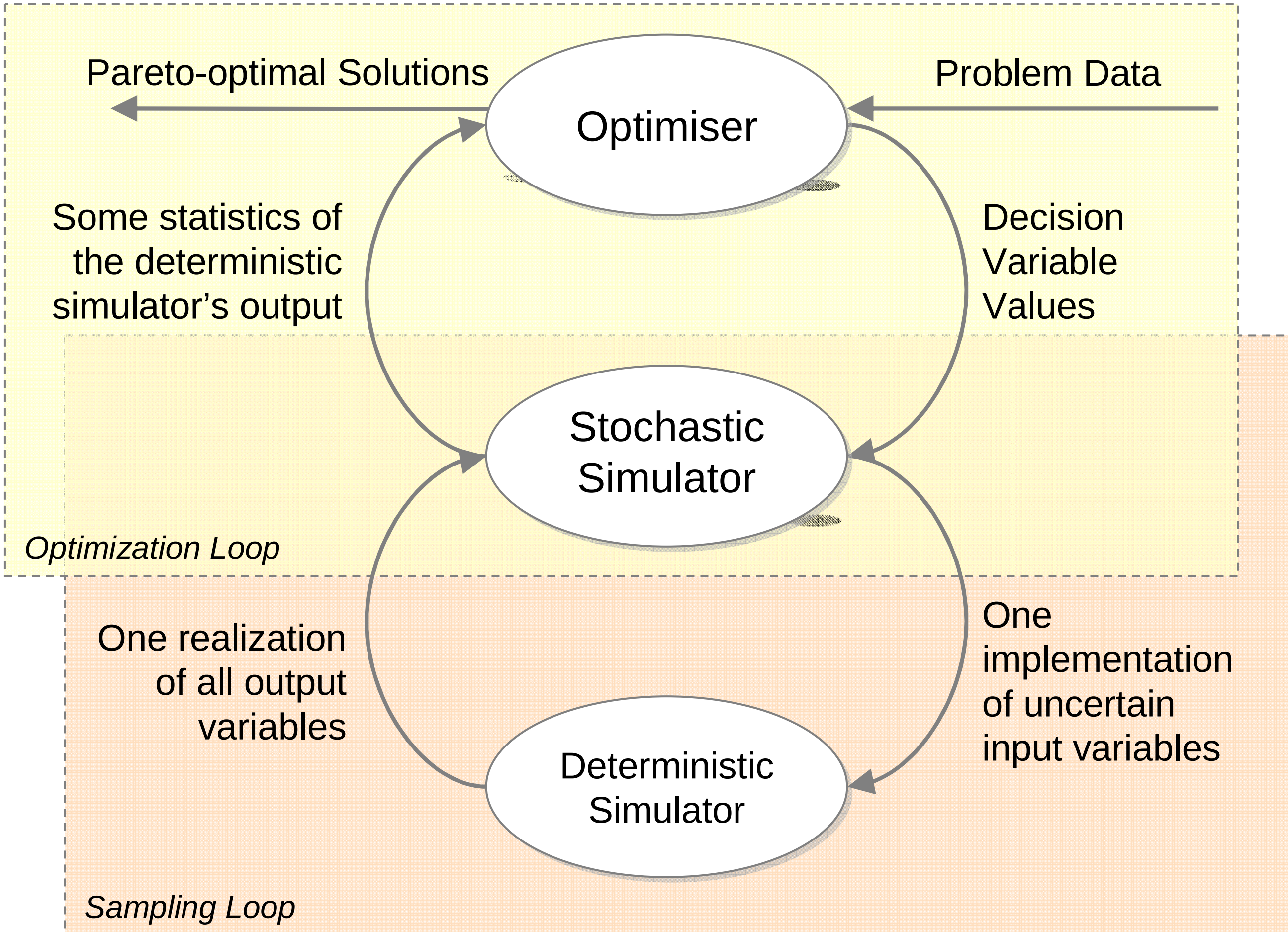
Q_D=required flow

$$\begin{array}{ll} H_i < z_i & \alpha_i(H_i) = 0 \\ z_i \le H_i \le H_{i,\min} & \alpha_i(H_i) = \dfrac{H_i - z_i}{H_{i,\min} - z_i} \\ H_{i,\min} < H_i & \alpha_i(H_i) = 1 \end{array}$$

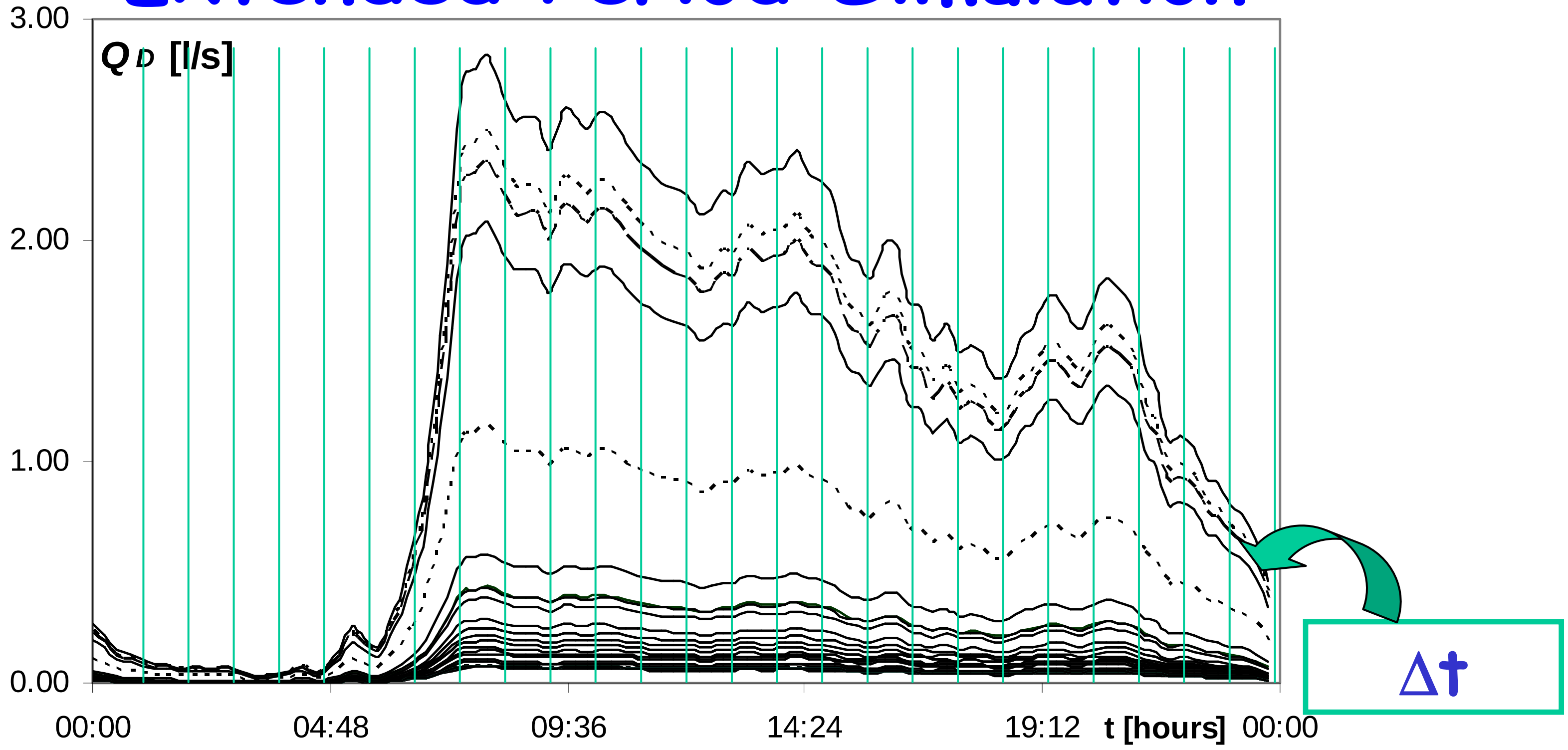
$$\alpha_i(H_i) \in [0-1]$$

Optimisation Problem


Pareto-optimal Solutions
Optimiser
Problem Data
Stochastic Simulator
Optimization Loop
Deterministic Simulator
Sampling Loop


Pareto-optimal Solutions
Problem Data
Optimiser
Some statistics of the deterministic simulator's output
Decision Variable Values
Stochastic Simulator
Optimization Loop
One realization of all output variables
One implementation of uncertain input variables
Deterministic Simulator
Sampling Loop

Extended Period Simulation:

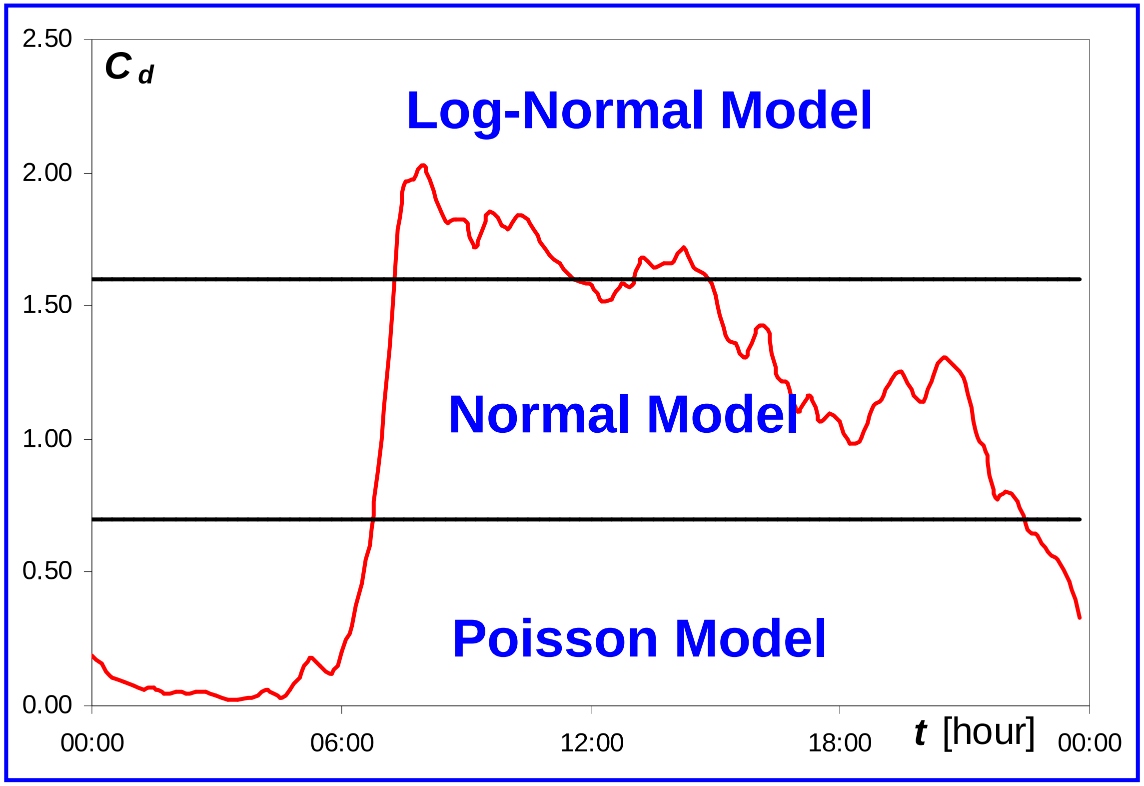


For each Δt, random demand samples are generated and used in a hydraulic simulator in order to obtain the corresponding nodal heads, from which the C_{LR} and the ***R*** are evaluated.

R estimated as the fraction of the total number of samples for which the minimum head condition is satisfied for all nodes of the network simultaneously and for each Δt in which the day has been segregated.

Probabilistic Approach:

$$C_d = \frac{Q_i}{\mu_q}$$



(de Marinis et al., 2006; Tricarico, 2005; Tricarico et al., 2006)

deEPANET Implementation
(Morley et al., 2006)

•deEPANET (Distributed Evaluation for EPANET) uses a client/server network architecture for parallelizing the computational load of repeated hydraulic analyses

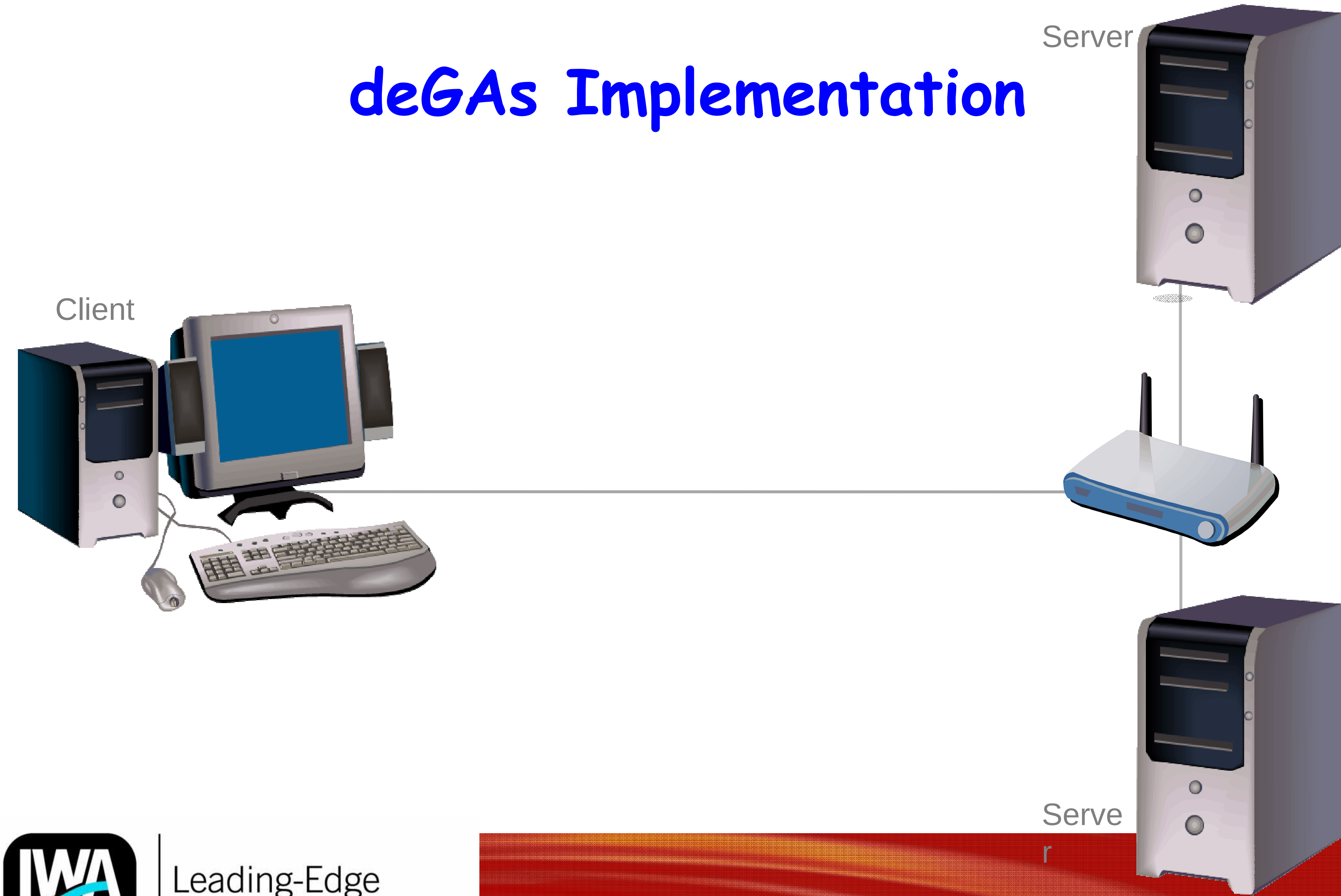
•Servers may service many clients simultaneously

•Servers may co-exist on the same machines as clients in order to exploit multi-processor capabilities

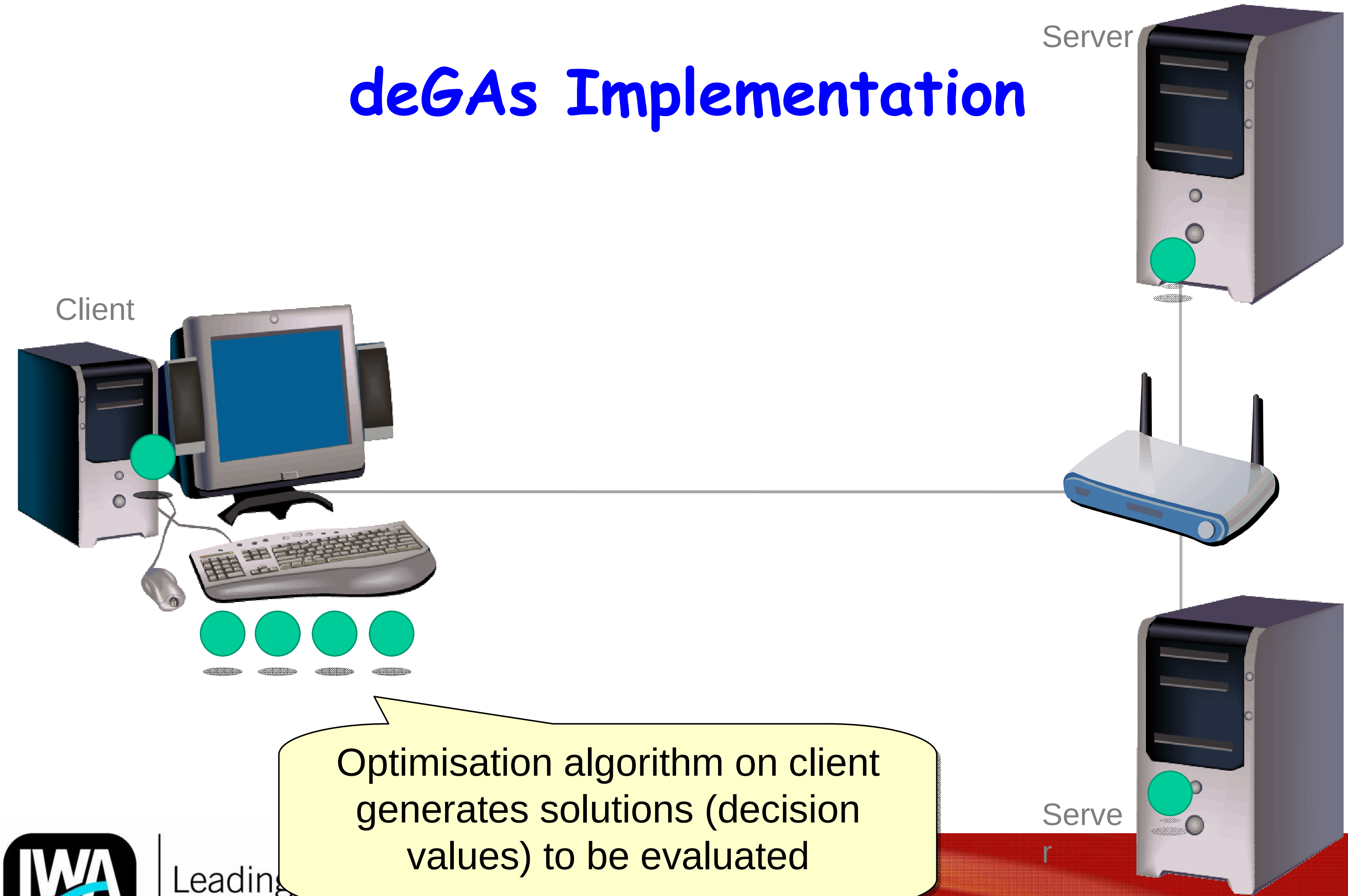
deGAs/deEPANET Implementation

- deGAs derives from the Distributed EPANET solver deEPANET and differs in that it employs the industry standard MPI (Message Passing Interface) and is no longer restricted to Hydraulic computation and can be used for a wide variety of optimization analyses
- Use of MPI allows deGAs to run on Beowulf or similar cluster architectures as well as conventional LAN environments.

deGAs Implementation

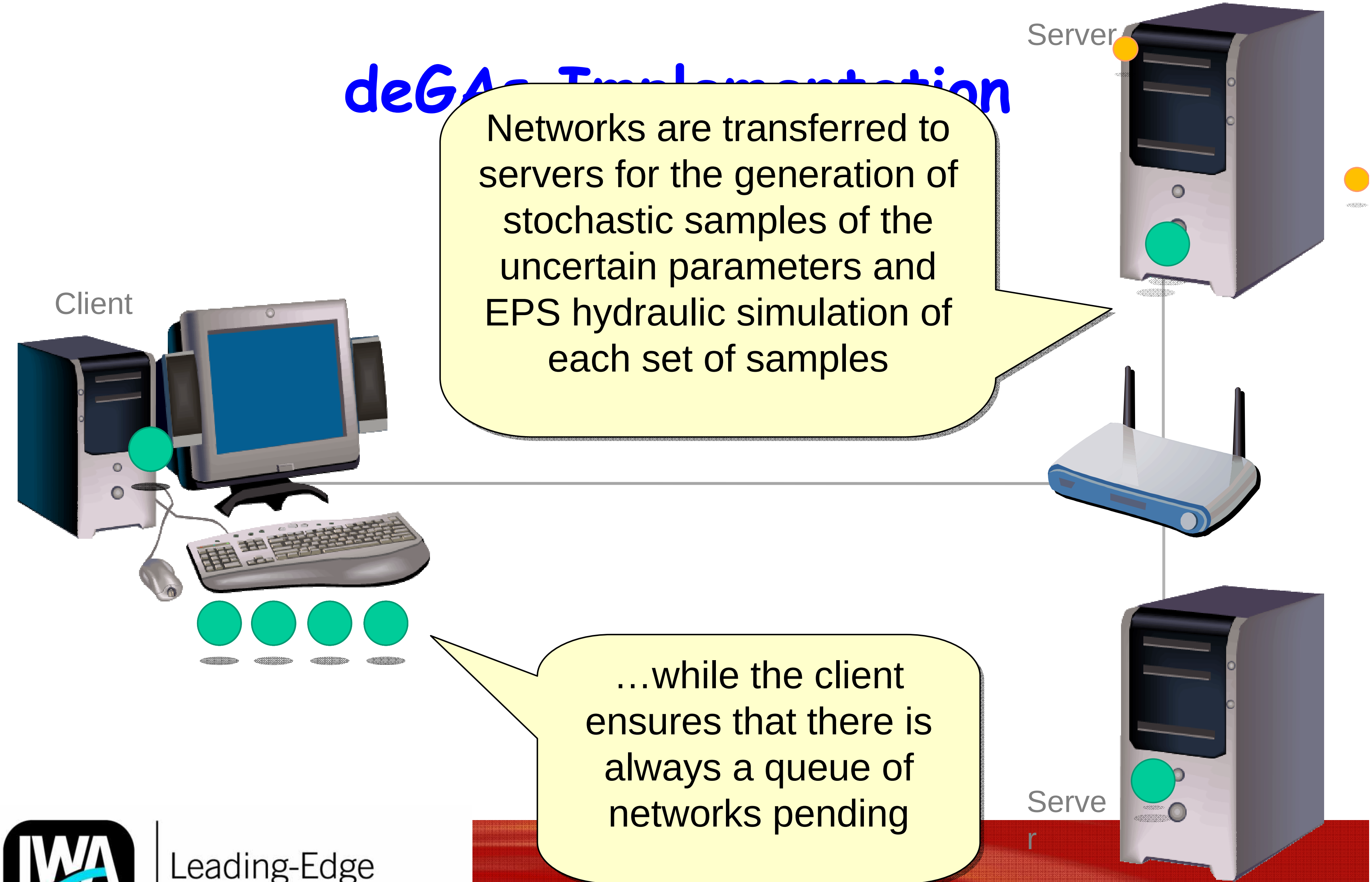


deGAs Implementation

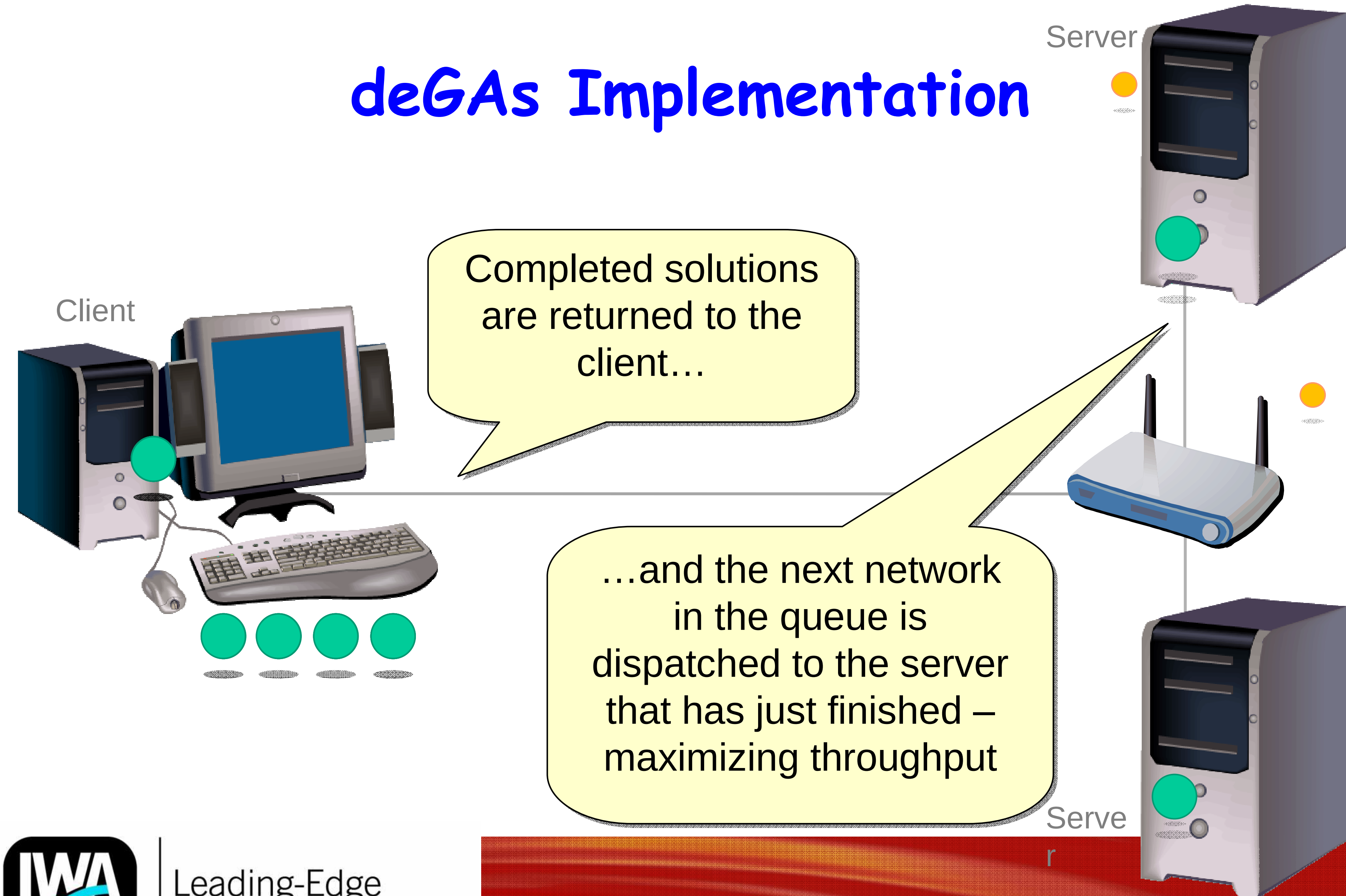


Optimisation algorithm on client generates solutions (decision values) to be evaluated

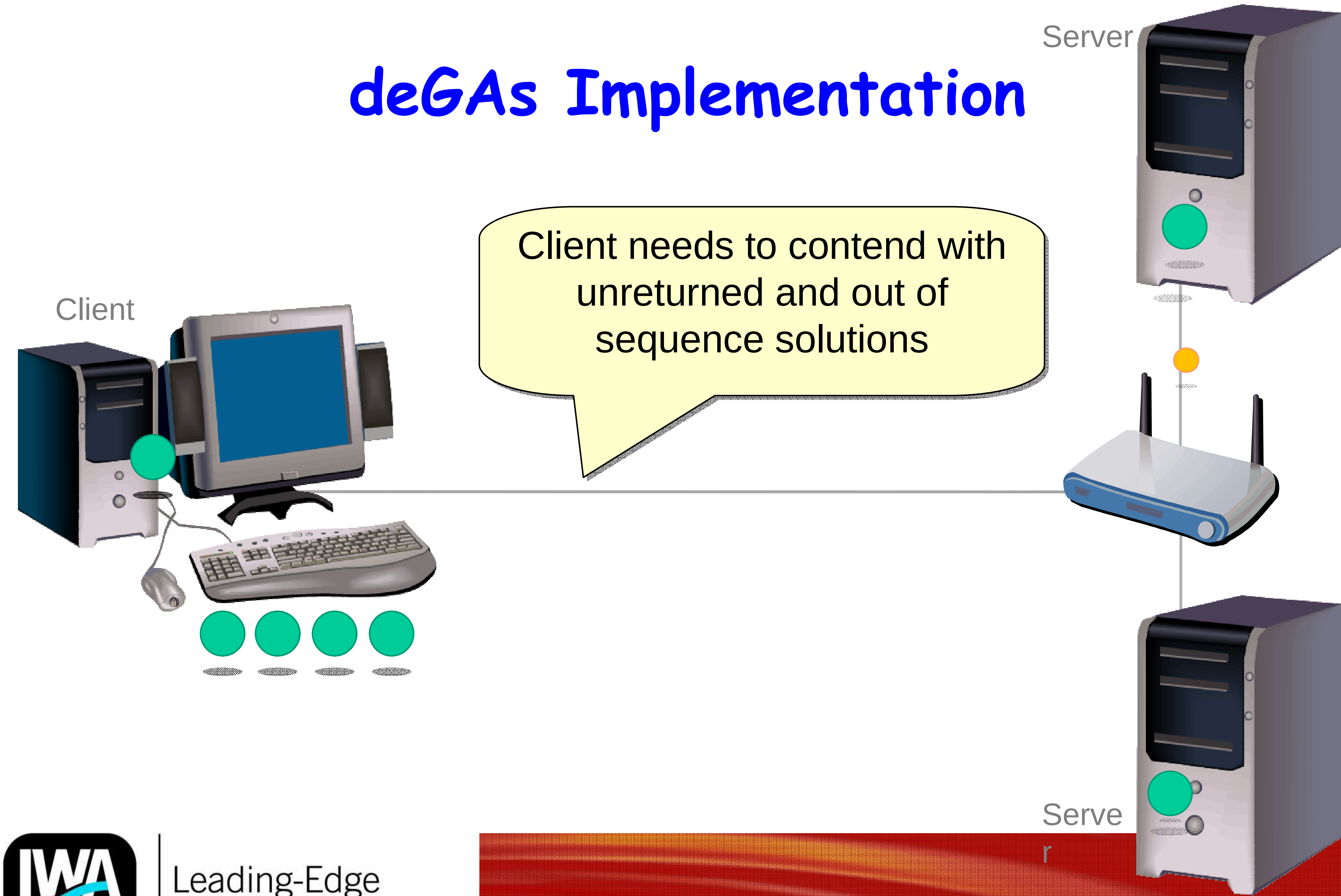
deGAs Implementation



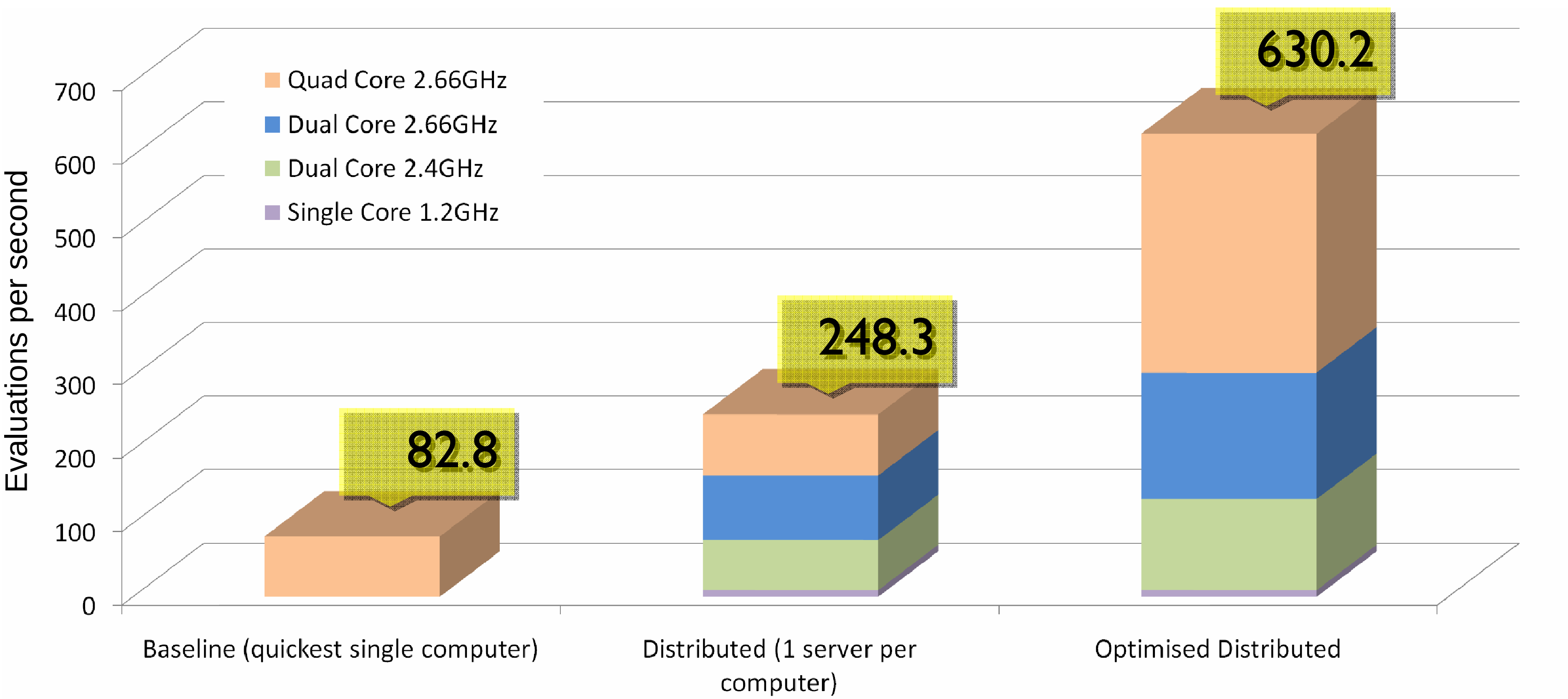
deGAs Implementation



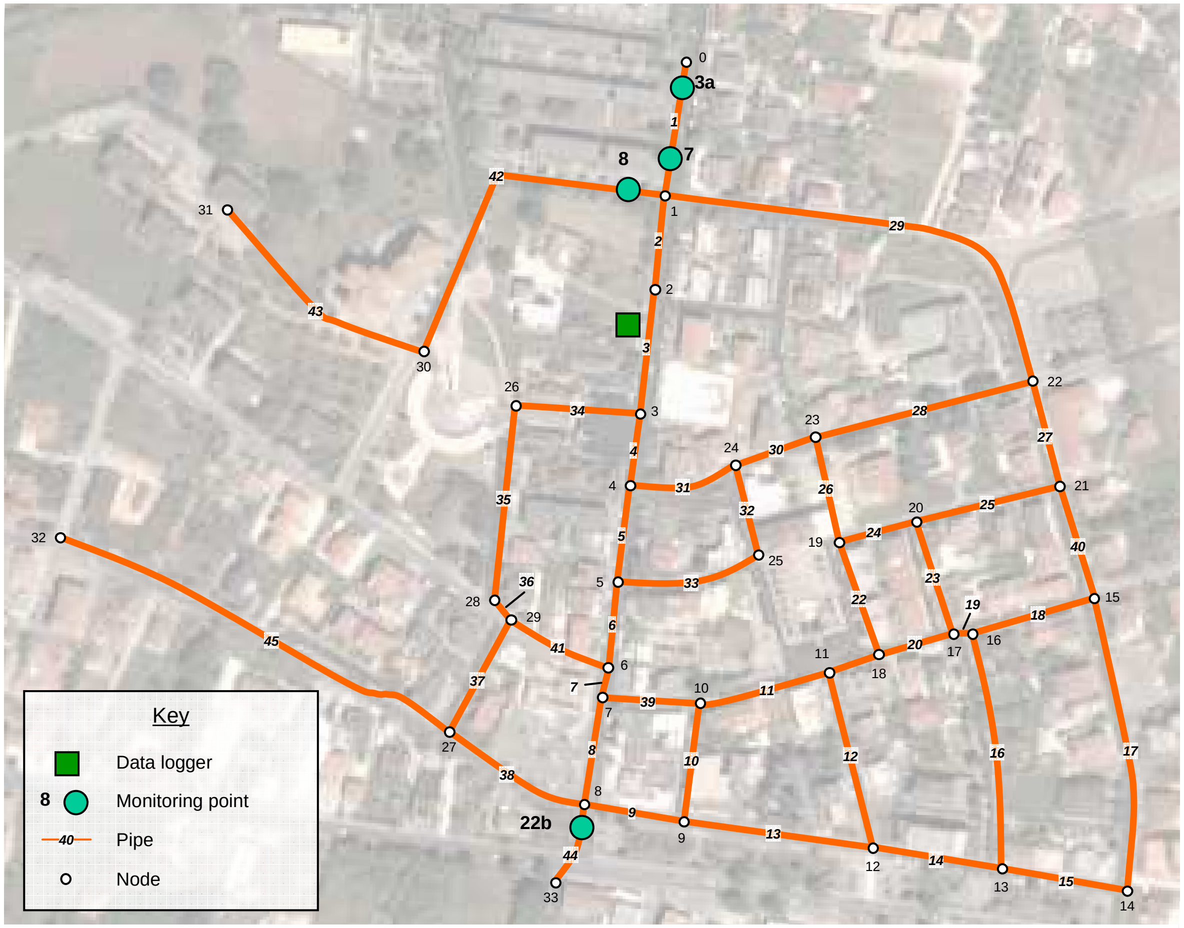
deGAs Implementation



deGAs Performance Impact

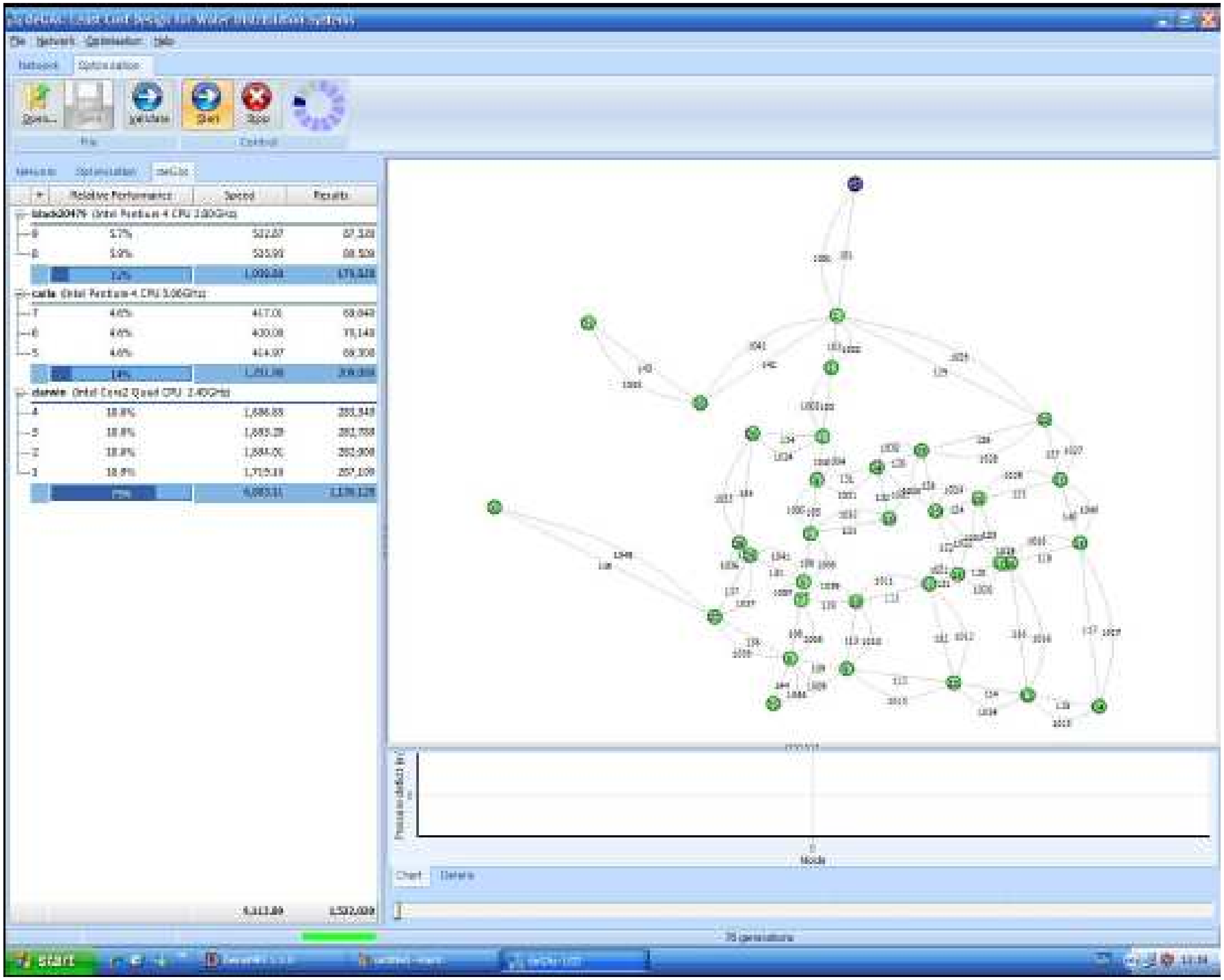


PSG Case Study



Network topology:

- 12 loops;
- 45 pipes;
- 33 junction nodes;
- 1 reservoir.



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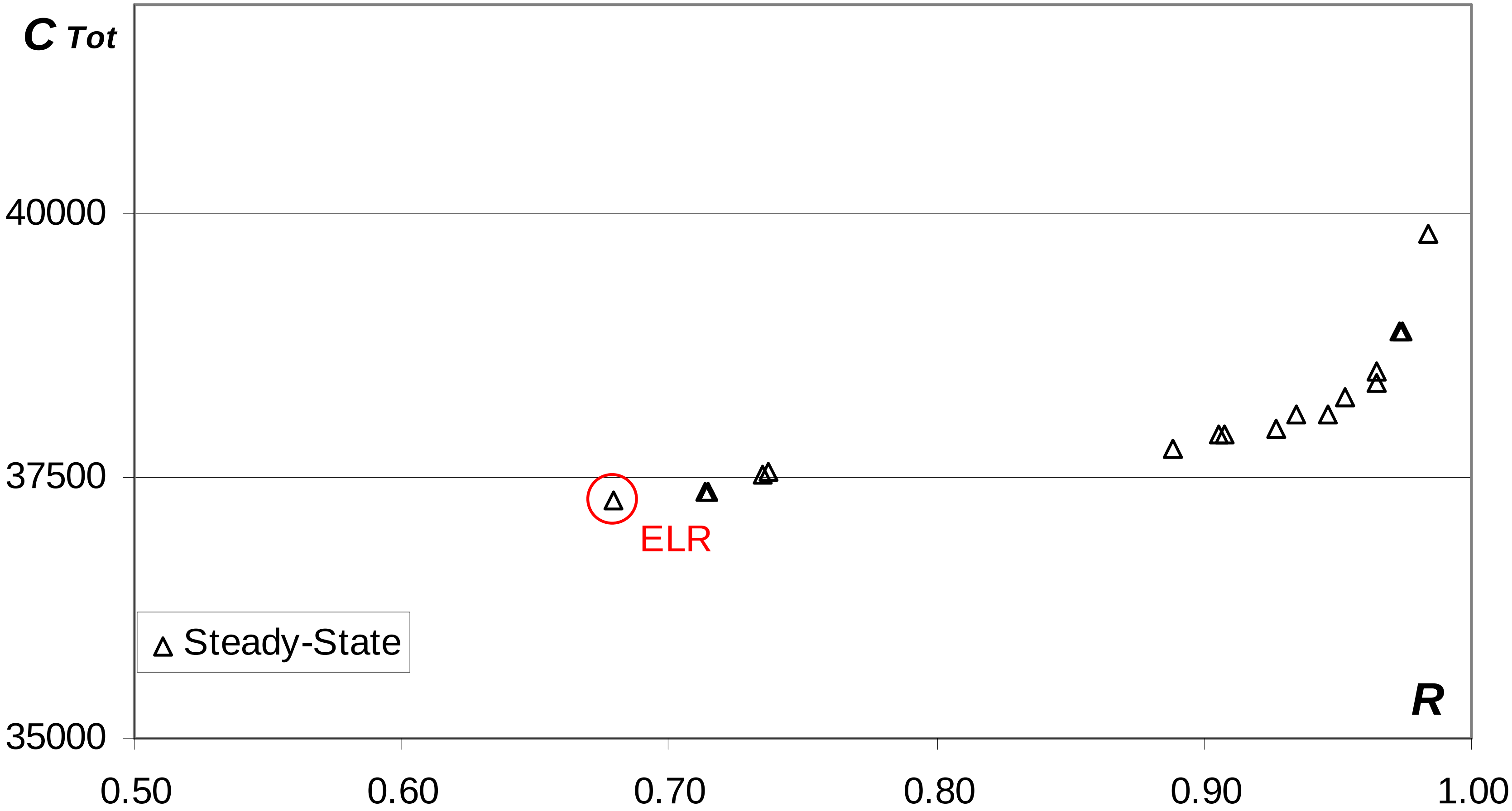
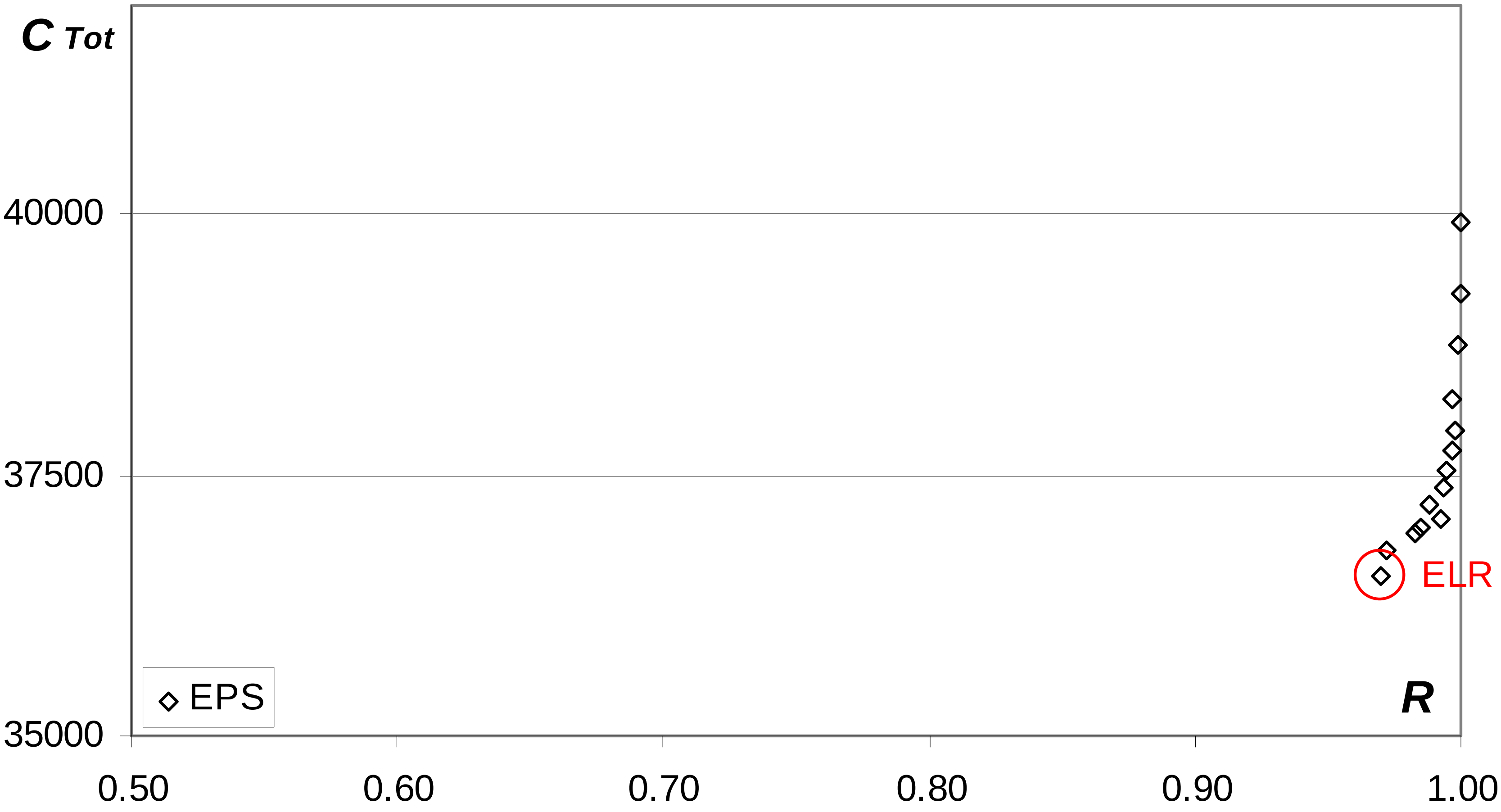
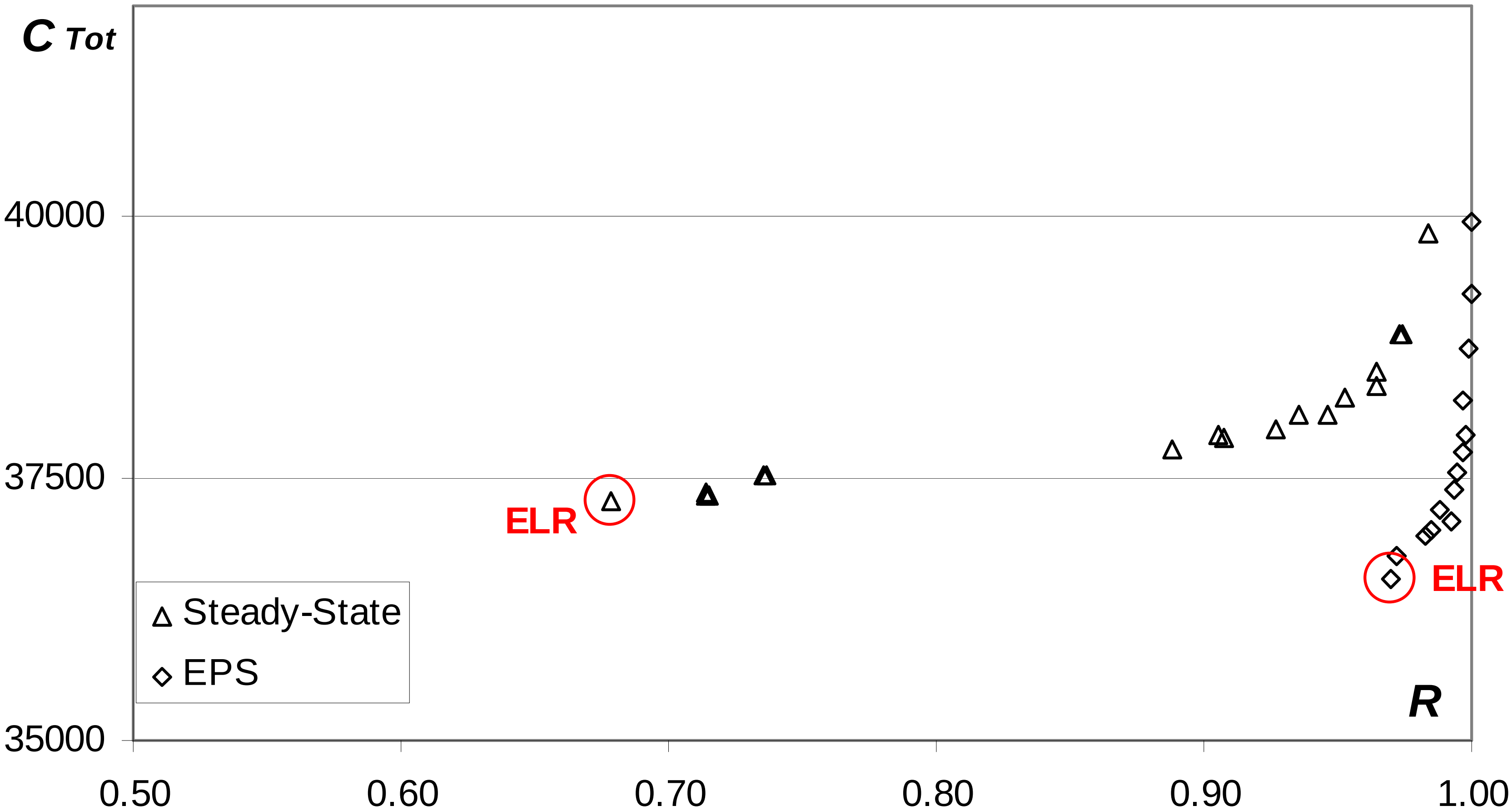
Pareto Optimal Front



Pareto Optimal Front



Pareto Optimal Front



Conclusions:

- A stochastic multiobjective optimisation problem based on the cost of reliability has been solved in order to estimate the optimal rehabilitation solutions to be adopted in a water distribution system by means of both a **Steady State** and an **Extended Period Simulation (EPS)** analysis; reliability threshold values have been defined: ELR

- The EPS analysis leads to analyse more realistic behaviour of the network obtaining more accurate network rehabilitation configurations: Steady-State solutions are dominated by EPS ones.

- The EPS analysis was facilitated by means of the use of the **deEPANET** (Distributed Evaluation for EPANET) software which has significantly shortened the runtimes for the optimisation algorithm.