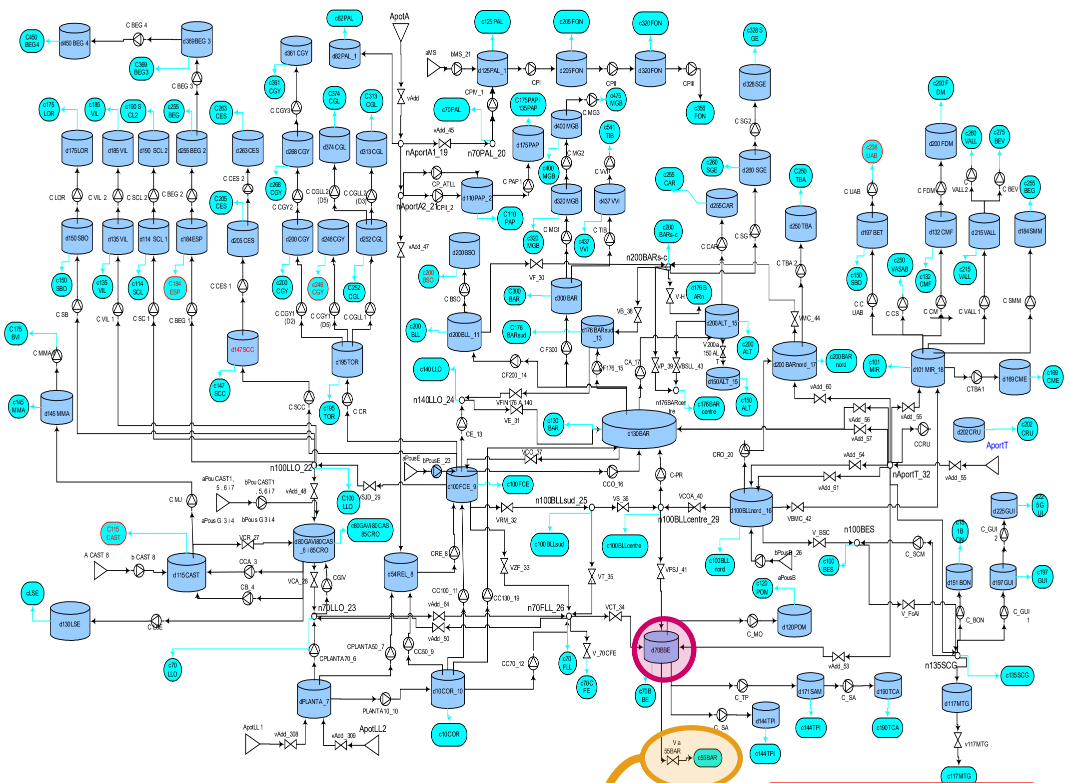
Leak Detection and Localization in Water Distribution Networks

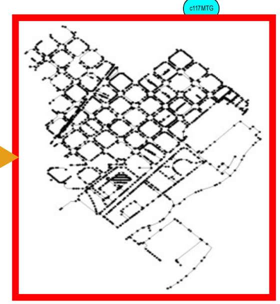
Joaquim Blesa Izquierdo

CS2AC-UPC - Supervision, Safety and Automatic Control Center
ESAII-UPC- Automatic Control Department

BCN WDN: Transportation layer



Nova Icària District
Metered Area
(DMA)



- General overview:

Municipalities supplied	23
Supply area	424 km^2
Population supplied	2.922.773
Average demand	7 m^3/s

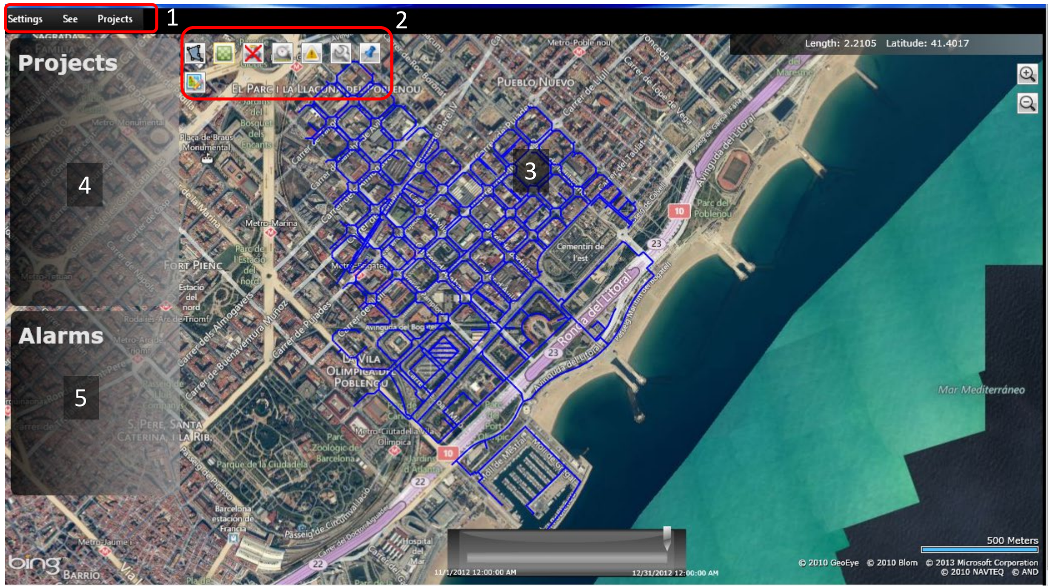
- Network parameters:

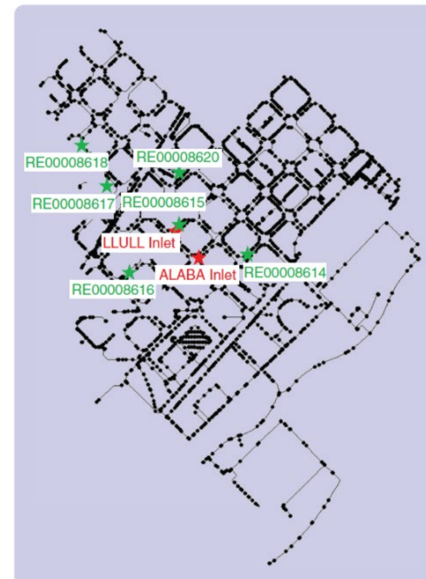
Pipes length	4.645 km
Pressure floors	113
Sectors	218

- Facilities

Remote stations	98
Water storage tanks	81
Valves	64
Flow meters	92
Pumps / Pumping stations	180 / 84
Chlorine dosing devices	23
Chlorine analyzers	74

BCN WDN: Nova Icària DMA





Jordi Meseguer, Josep M. Mirats-Tur, Gabriela Cembrano, Vicenç Puig, Joseba Quevedo, Ramón Pérez, Gerard Sanz, David Ibarra, A decision support system for on-line leakage localization,Environmental Modelling & Software,Volume 60, 2014,Pages 331-345,

flow and pressure sensors in the 2 water inlets and pressure sensors in 6 inner nodes

Rough estimation of the demands in the 3377 nodes (trimestral water bills of users)

Leak Localization in Water Distribution Networks (WDN)

Leaks in WDNs:

- Produce a waste of water
- Compromise the quality of the service
- Increase consumer bills
- Can damage the WDN infrastructure and affect other networks:
  - electrical and gas networks

Recent international competition

https://battledim.ucy.ac.cy/

Leak Localization in Water Distribution Networks (WDN)

Recent international competition

https://battledim.ucy.ac.cy/

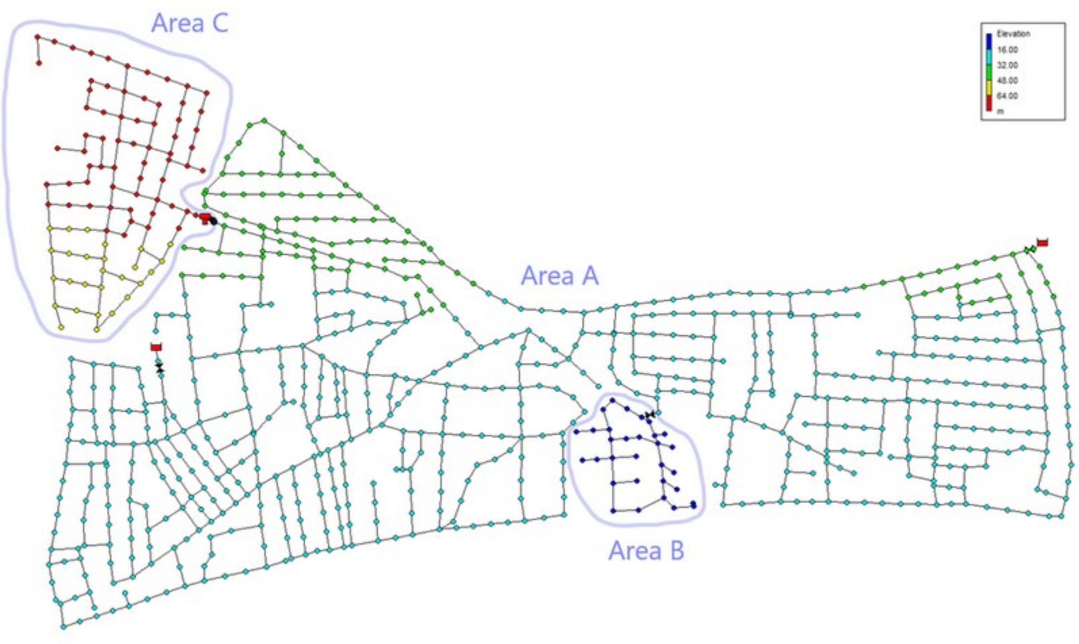
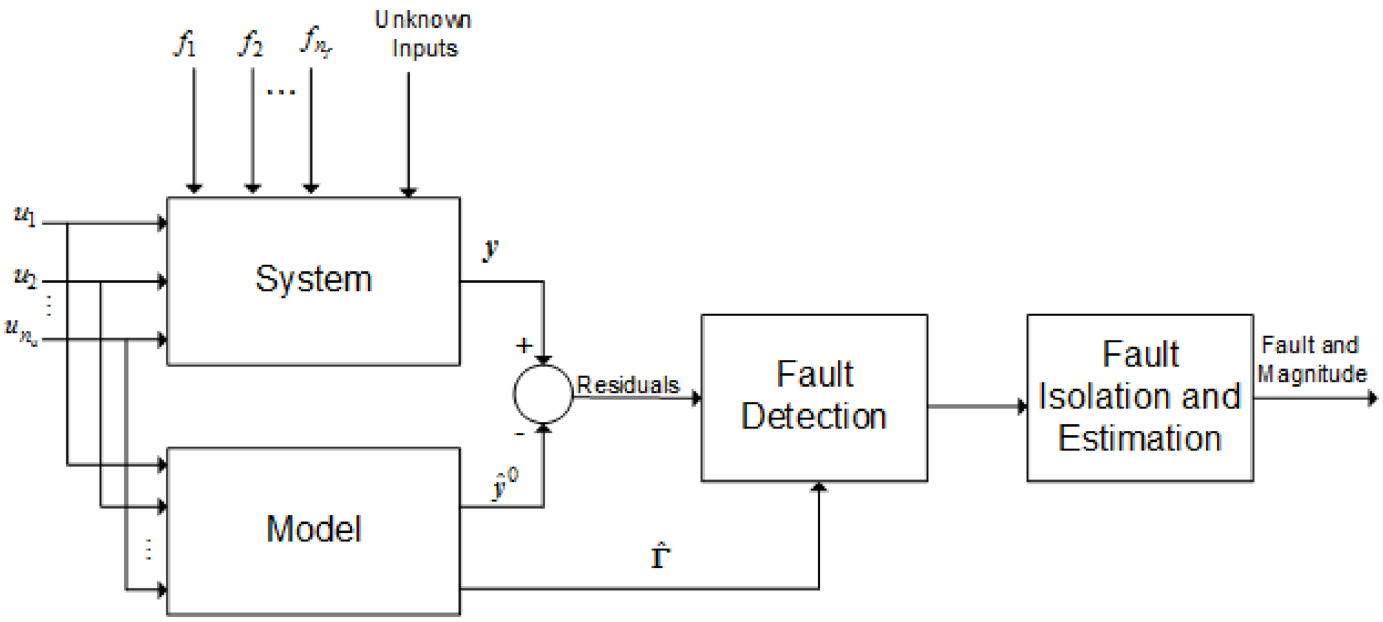
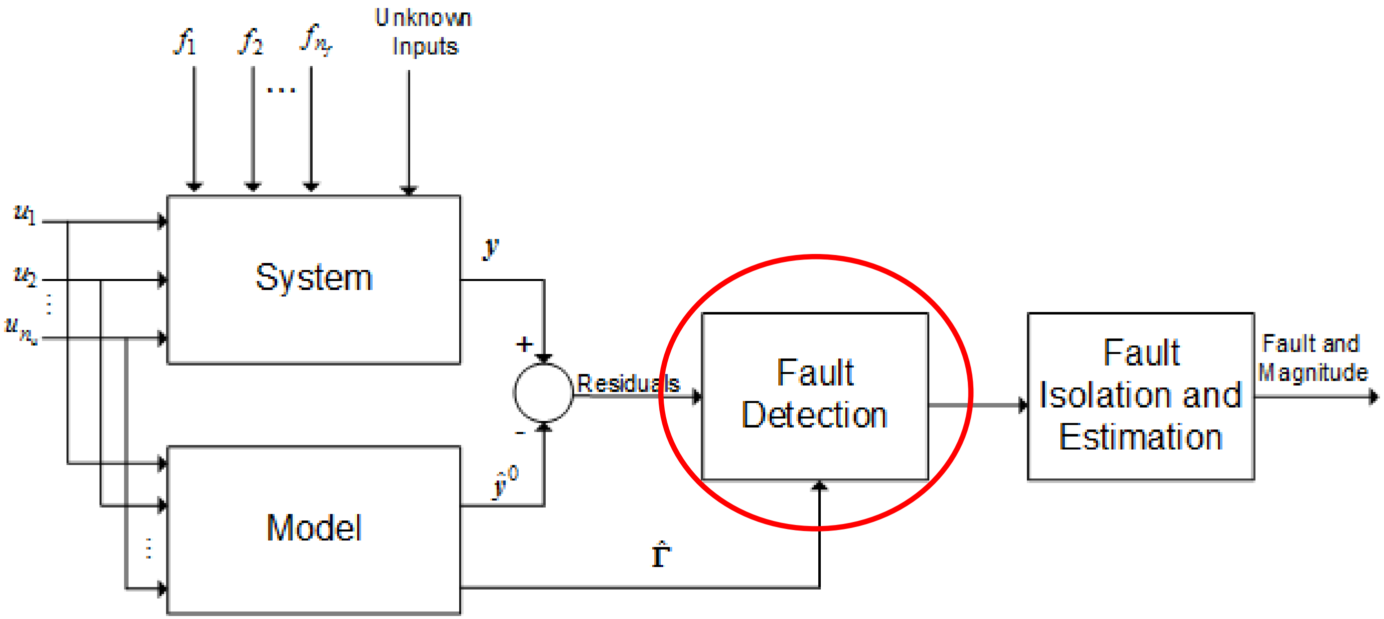


Fig.1: The L-Town Benchmark Network

Model Based FDI Scheme



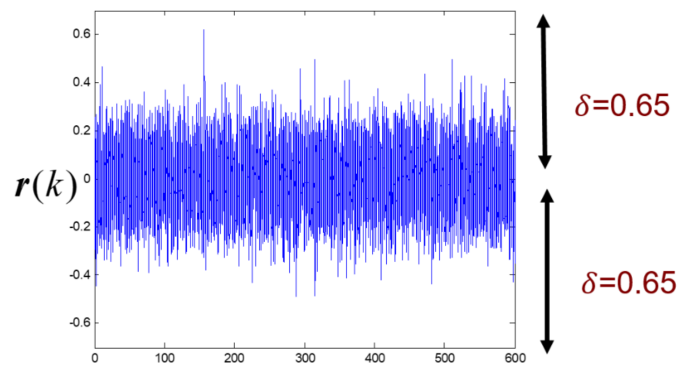
Model Based FDI Scheme: Fault Detection



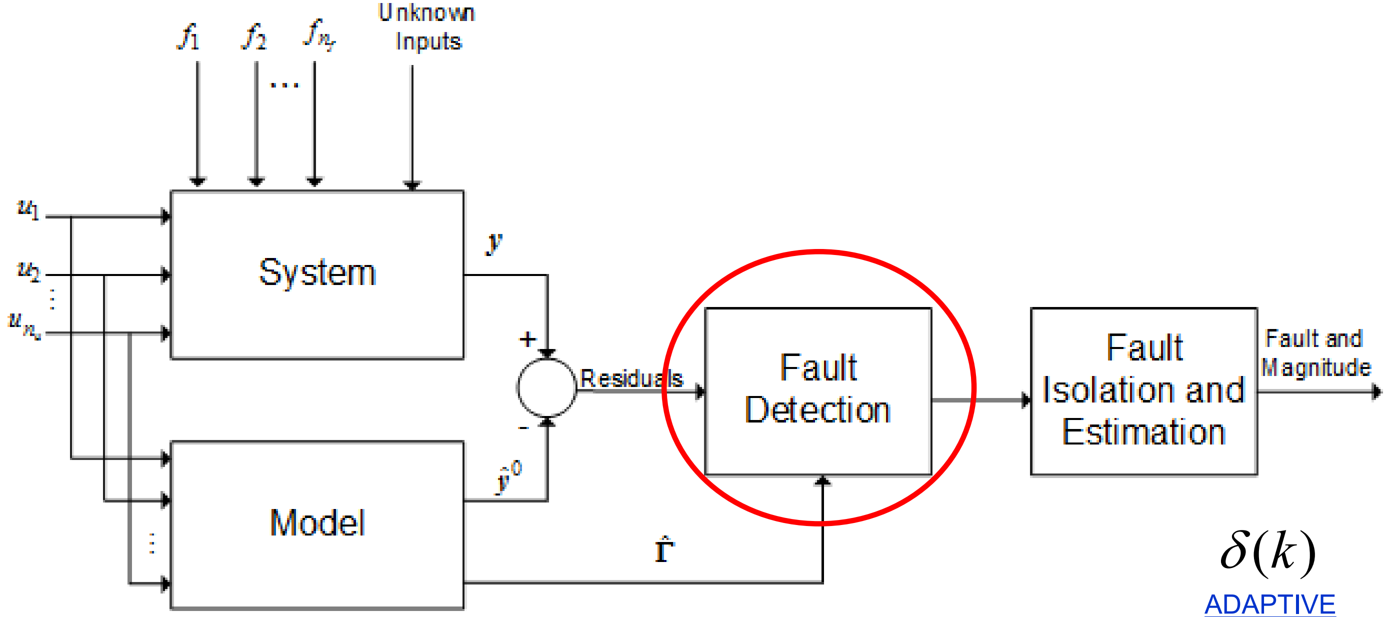
$$
\begin{cases}
|r(k)| \le \delta \Rightarrow \phi(k) = 0 \quad \text{(No Fault)} \\
|r(k)| > \delta \Rightarrow \phi(k) = 1 \quad \text{(Fault)}
\end{cases}
$$

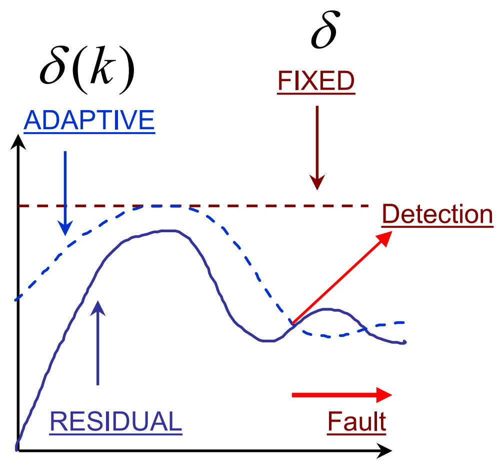
If enough data is available in a fault free scenario, threshold δ can be computed as

$$\delta = \beta \max_{i=1,\cdots,L} \|r(i)\|$$



Model Based FDI Scheme: Fault Detection

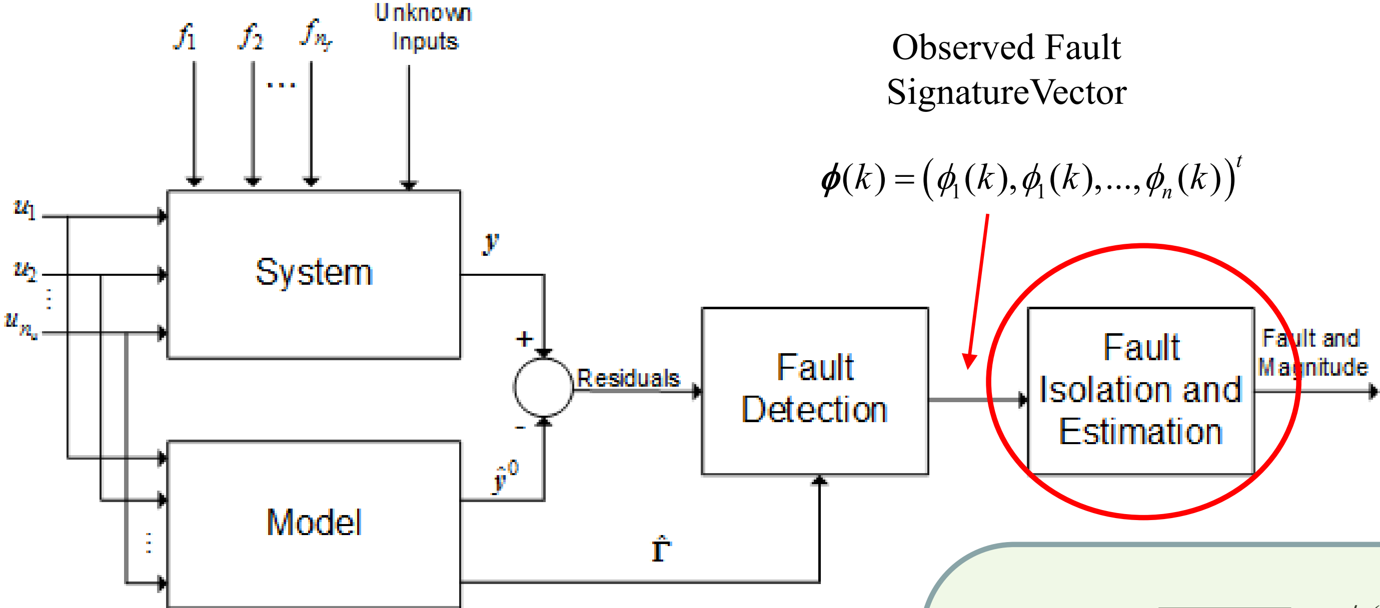


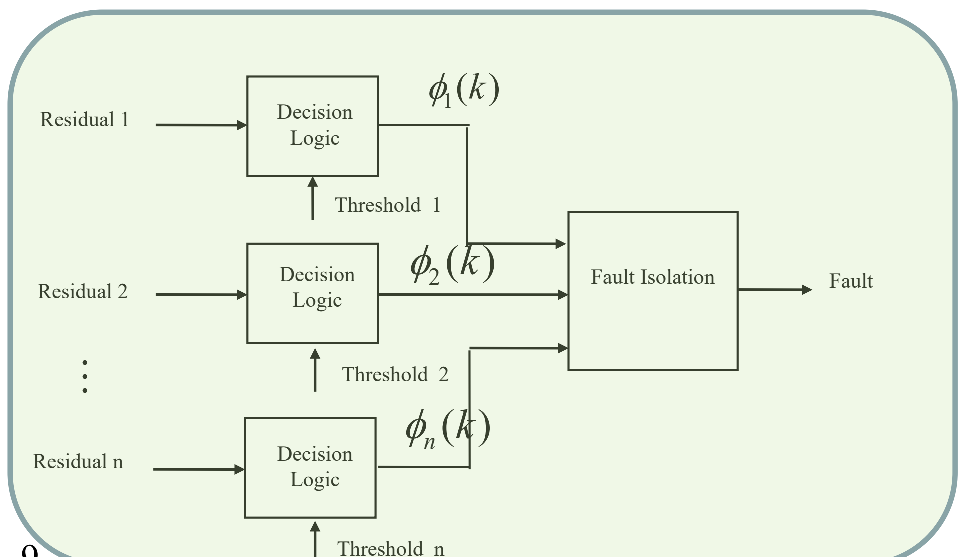


$$
\begin{cases}
|r(k)| \le \delta(k) \Rightarrow \phi(k) = 0 \quad \text{(No Fault)} \\
|r(k)| > \delta(k) \Rightarrow \phi(k) = 1 \quad \text{(Fault)}
\end{cases}
$$

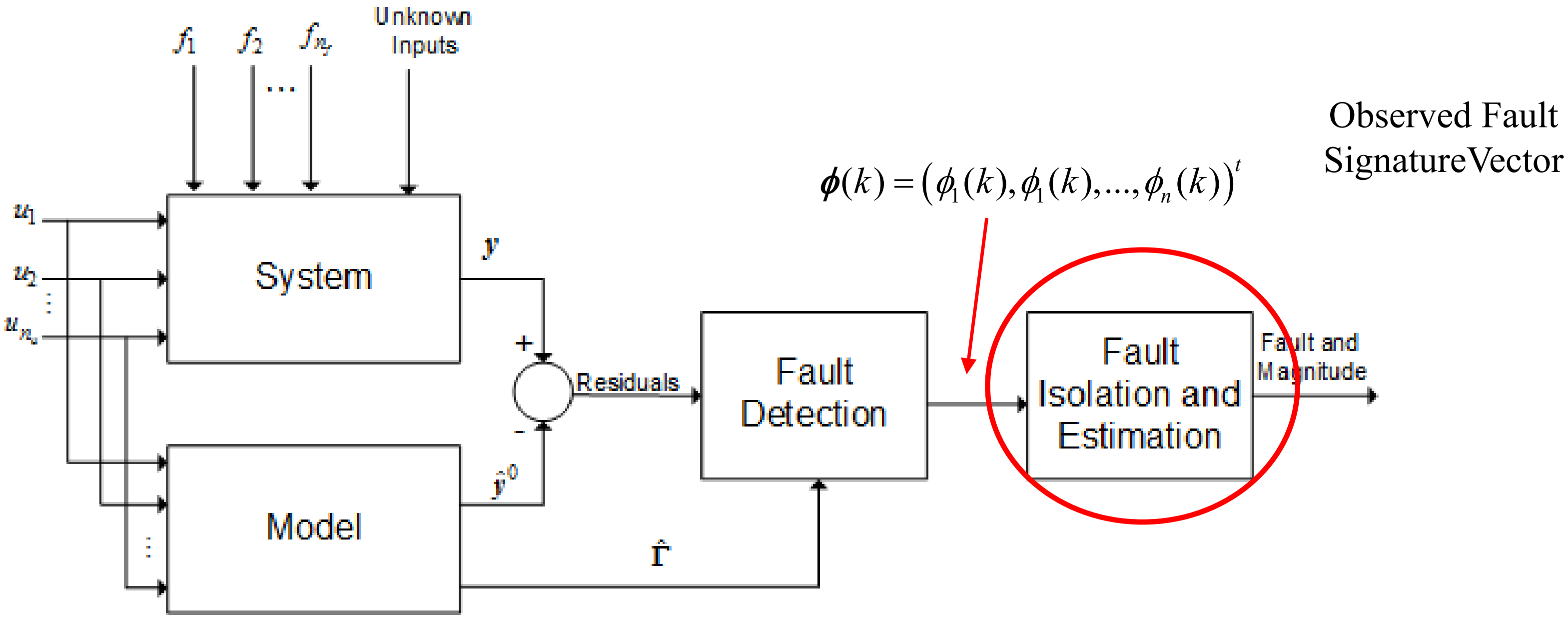
How to compute $\delta(k)$?

Model Based FDI Scheme: Fault Isolation





Model Based FDI Scheme: Fault Isolation



Fault Signature Matrix

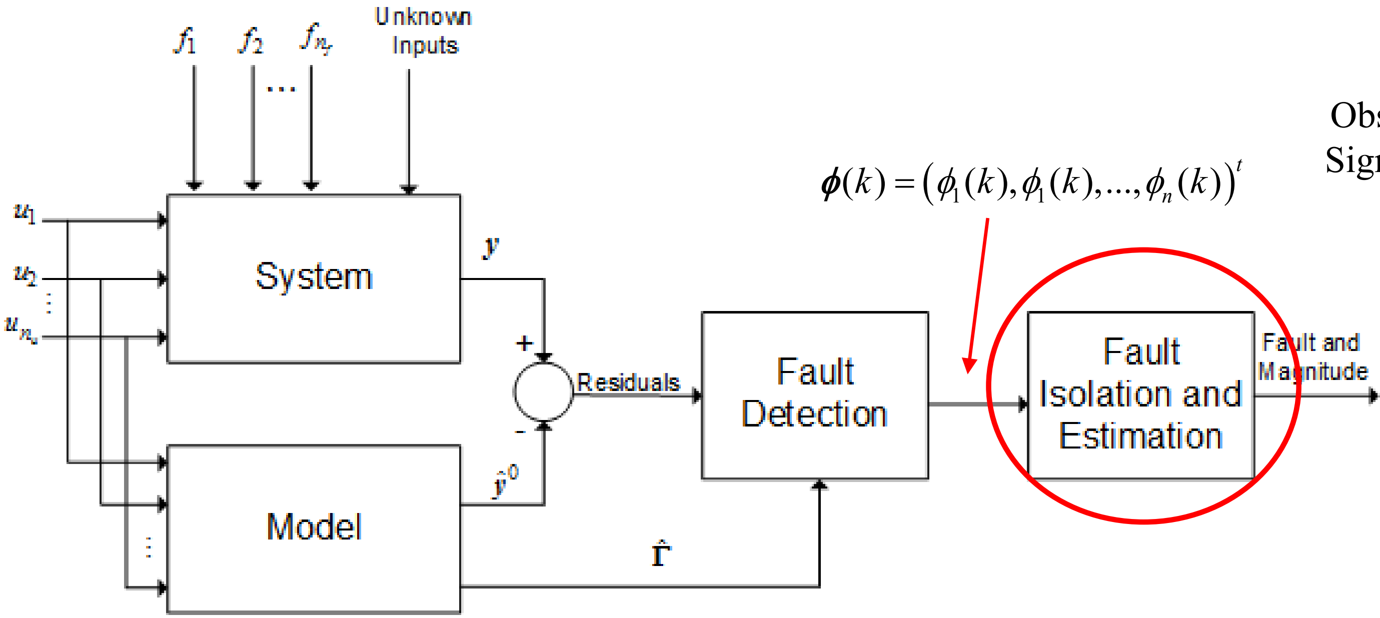
$$\boldsymbol{\phi}(k) = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} \longrightarrow$$

	f1	f2	f3	f4	f5	f6	f7
r1	1	0	1	0	0	0	1
r2	1	1	0	1	0	0	0
r3	1	0	1	0	0	1	0
r4	0	0	0	1	1	0	1

Most probable fault

$\longrightarrow$ f2

Model Based FDI Scheme: Fault Isolation



Observed Fault SignatureVector

$$\boldsymbol{\phi}(k) = \left(\phi_1(k), \phi_1(k), \ldots, \phi_n(k)\right)^t$$

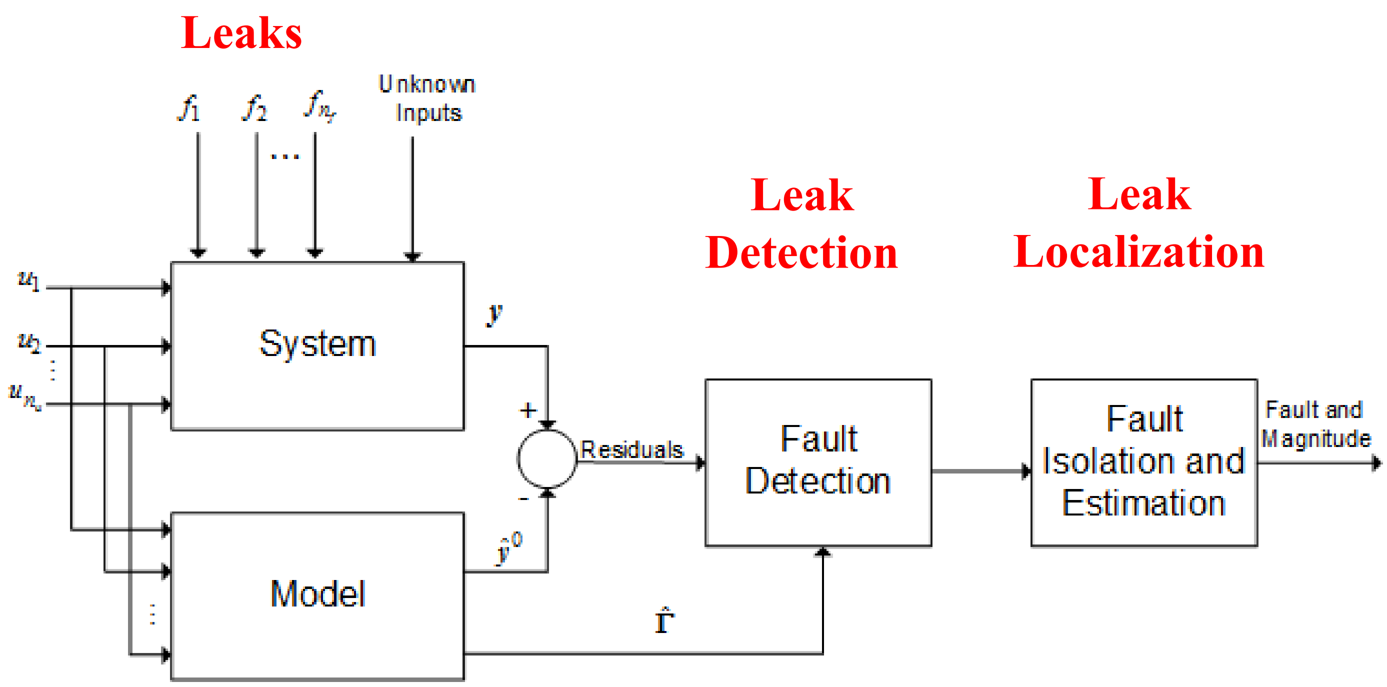
Fault Signature Matrix

$$\boldsymbol{\phi}(k) = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

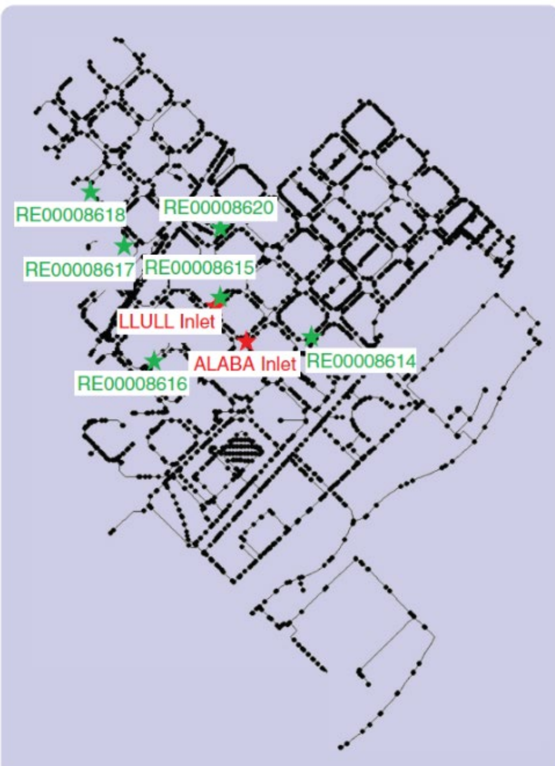
	f1	f2	f3	f4	f5	f6	f7
r1	1	1	1	1	1	1	1
r2	1	1	1	1	1	1	1
r3	1	1	1	1	1	1	1
r4	1	1	1	1	1	1	1

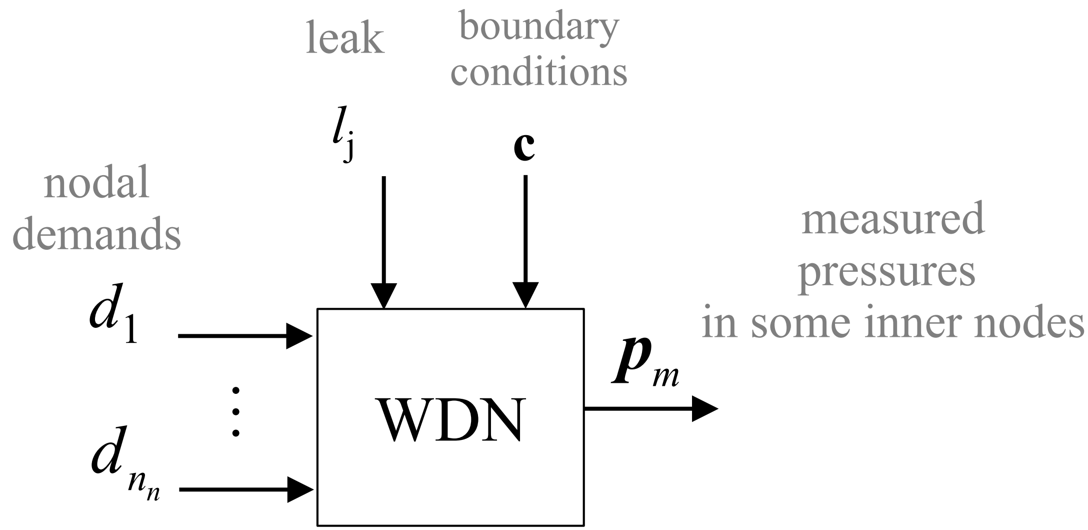
Enhanced isolation methods

Model Based FDI Scheme

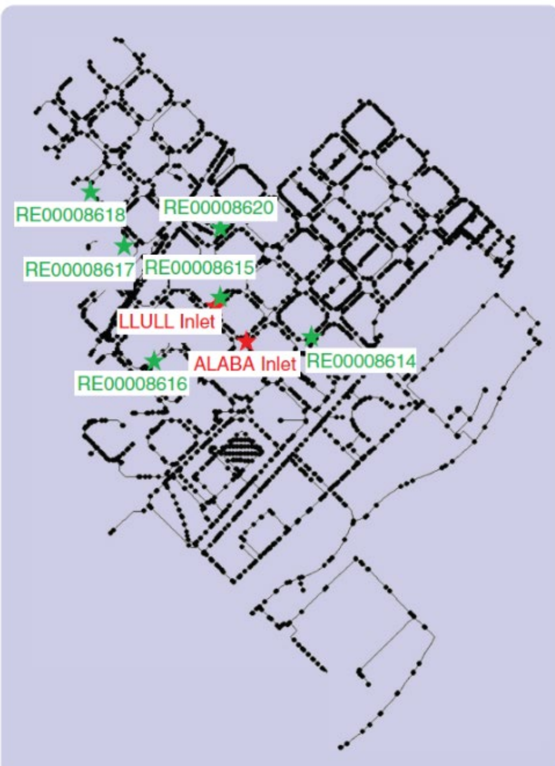


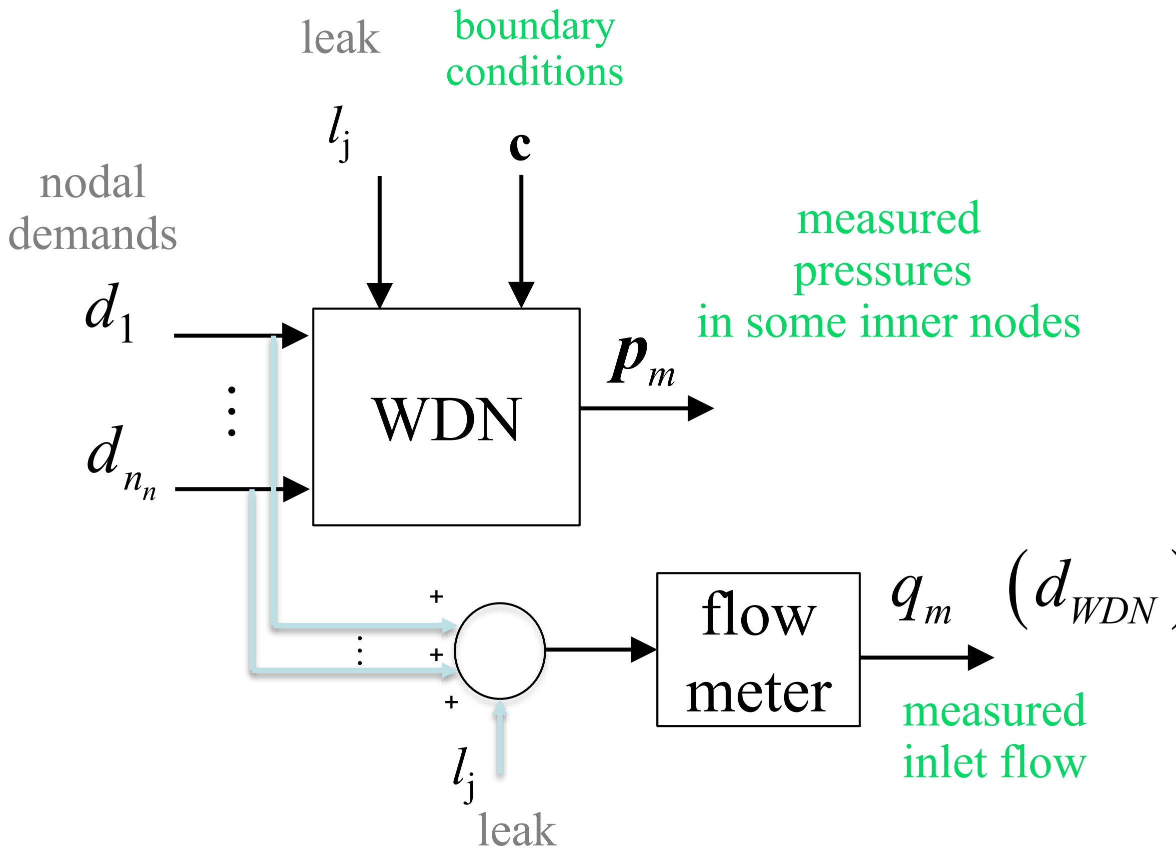
WDN System


RE00008618
RE00008620
RE00008617
RE00008615
LLULL Inlet
ALABA Inlet
RE00008614
RE00008616

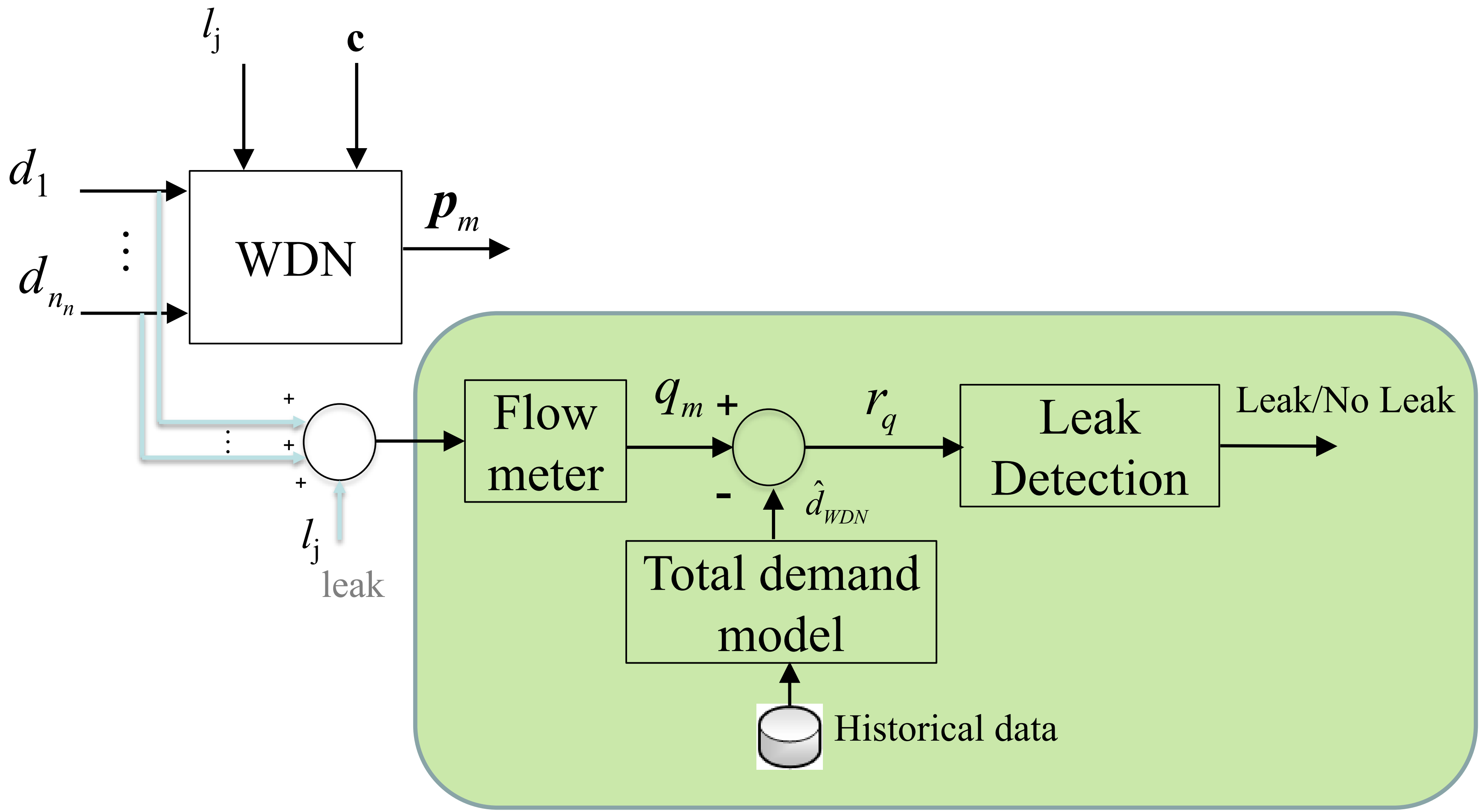

leak
boundary conditions
l_j
c
nodal demands
d_1
d_{n_n}
WDN
p_m
measured pressures in some inner nodes

WDN measured variables





WDN Leak Detection

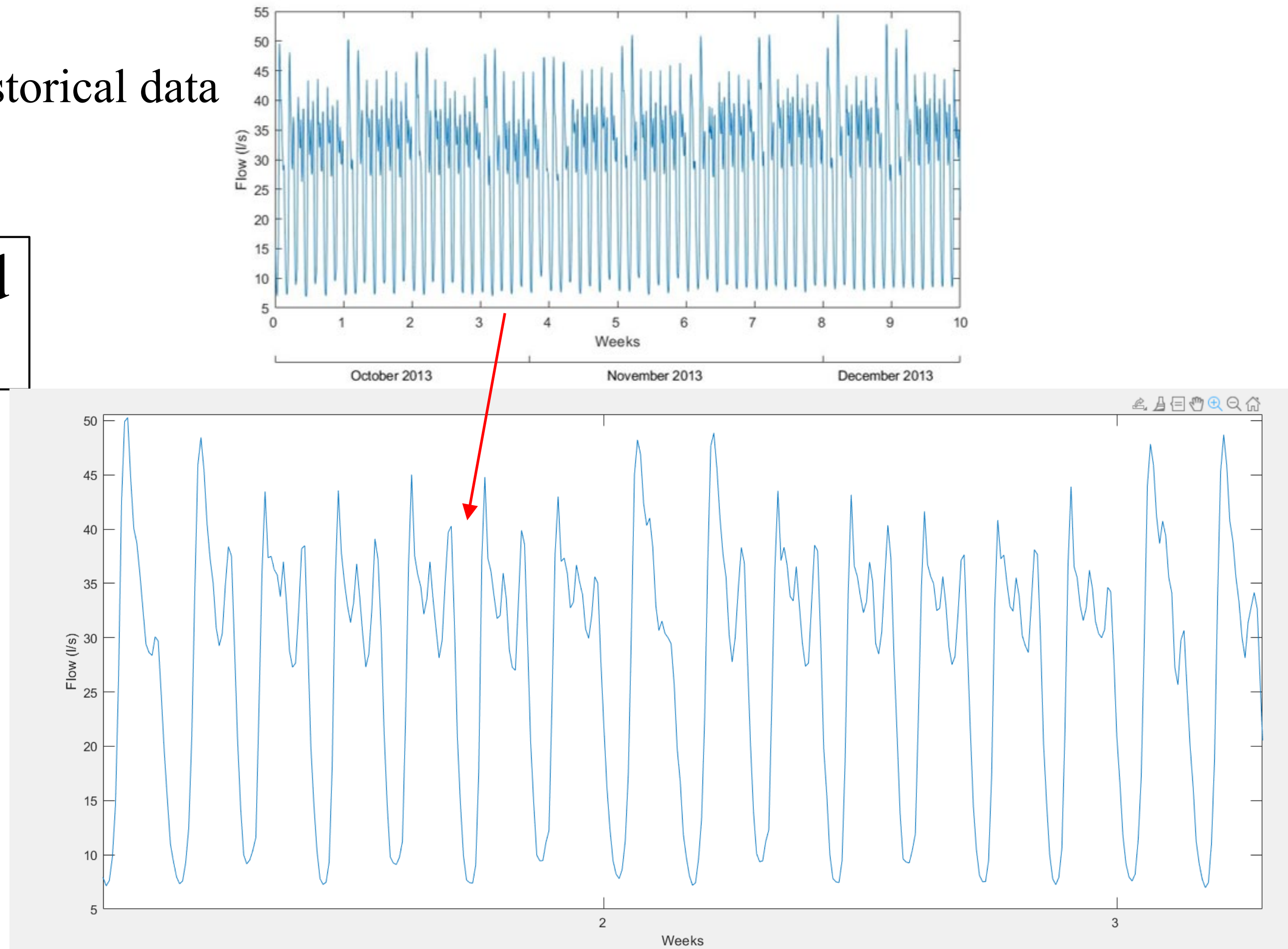


WDN Demand Model

Historical data

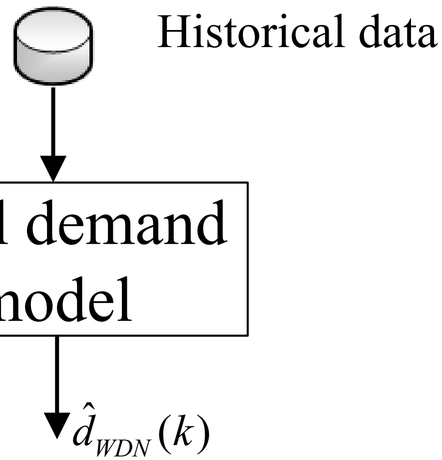
Total demand model

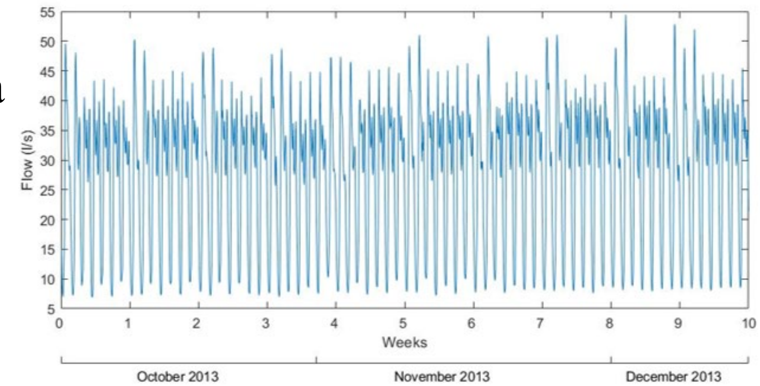
$\hat{d}_{WDN}(k)$

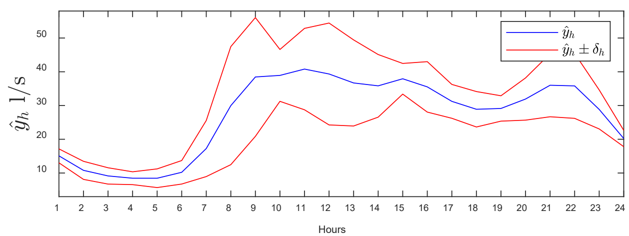


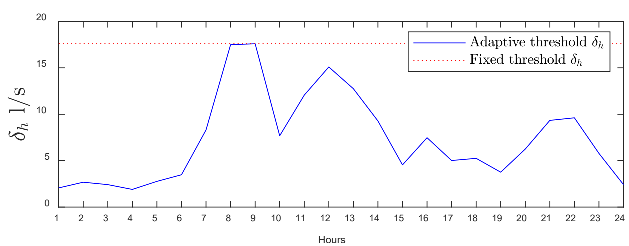
Sample time: raw data 5-15min but filtered hourly

WDN Demand Model









$$q_m(k) = \hat{d}_{WDN}(k) + e(k) \qquad k = 0,1,\ldots.$$

$$\hat{d}_{WDN}(k) = \hat{y}_h$$

$$h = mod(k, 24)$$

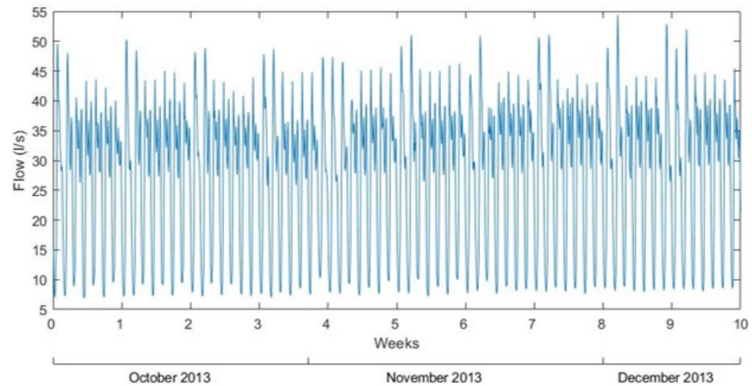
$$\hat{y}_h = \frac{1}{N_{day}} \sum_{d_{ay}=0}^{N_{day}-1} q_m(h + 24d_{ay})$$

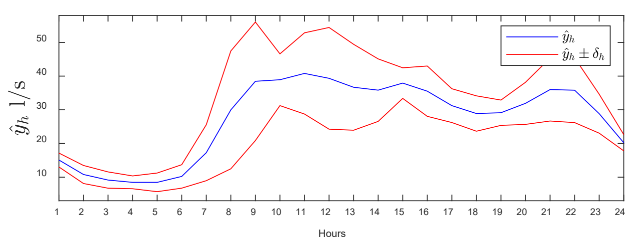
WDN Leak Detection: Adaptive threshold

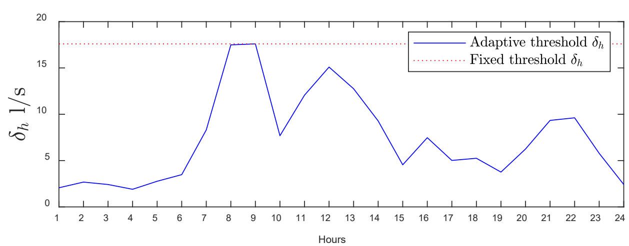
Historical data

Total demand model

$\hat{d}_{WDN}(k)$







Adaptive threshold

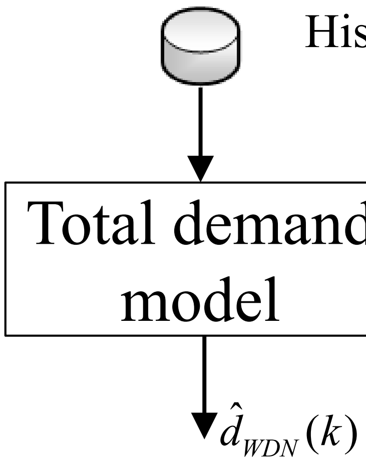
$$\delta_h = \max_{d_{ay}=0,\ldots,N_{d-1}} \left| q_m(h + 24d_{ay}) - \hat{y}_h \right|$$

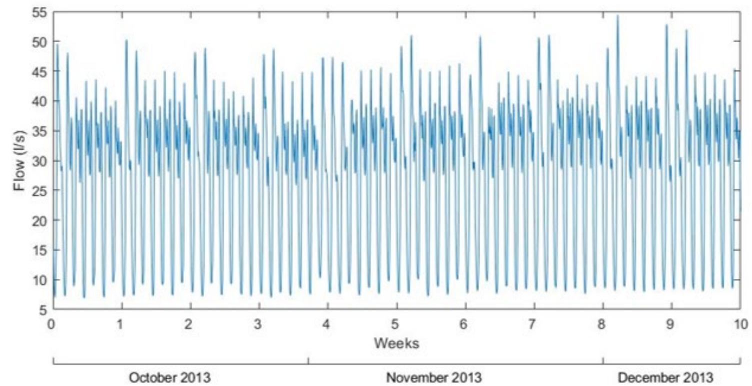
$$r(k) = q_m(k) - \hat{d}_{WDN}(k)$$

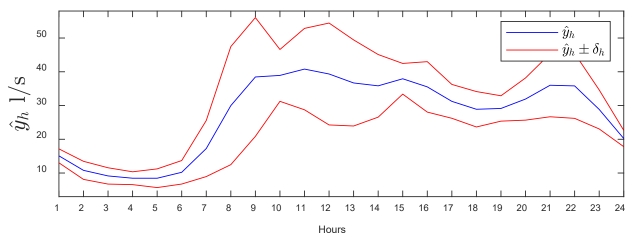
$$\begin{cases} r(k) \leq \beta\delta_h \Rightarrow \phi(k) = 0 \ \ \text{(No Fault)} \\ r(k) > \beta\delta_h \Rightarrow \phi(k) = 1 \ \ \text{(Fault)} \end{cases}$$

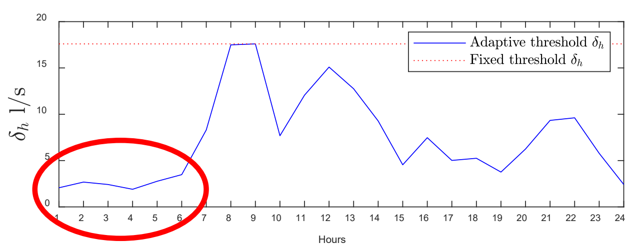
$\beta > 1$ $\qquad$ $h = mod(k, 24)$

WDN Leak Detection: Adaptive threshold









Minimum flow analysis

Adaptive threshold

$$\delta_h = \max_{d_{ay}=0,\ldots,N_{d-1}} \left| q_m(h + 24 d_{ay}) - \hat{y}_h \right|$$

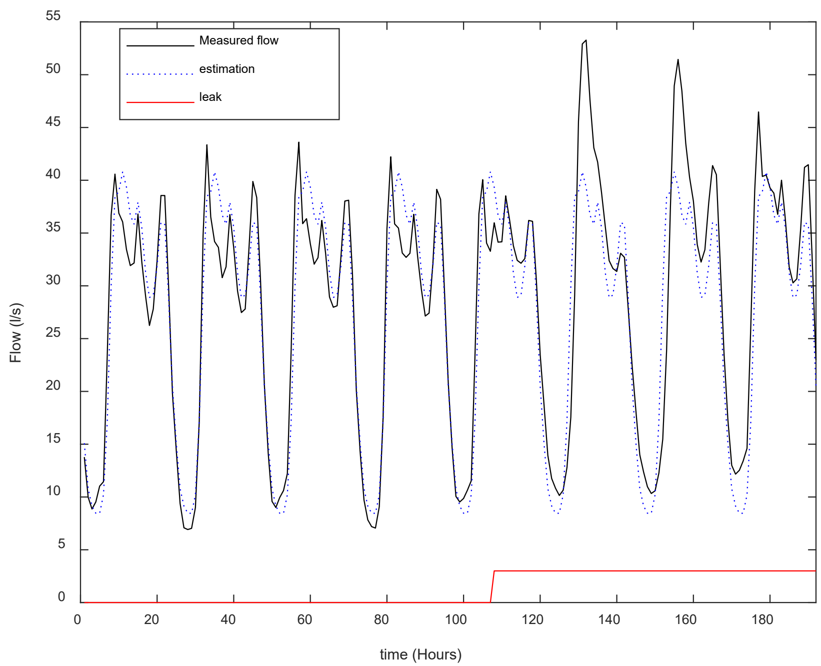
$$r(k) = q_m(k) - \hat{d}_{WDN}(k)$$

$$\begin{cases} r(k) \le \beta\delta_h \Rightarrow \phi(k) = 0 \quad \text{(No Fault)} \\ r(k) > \beta\delta_h \Rightarrow \phi(k) = 1 \quad \text{(Fault)} \end{cases}$$

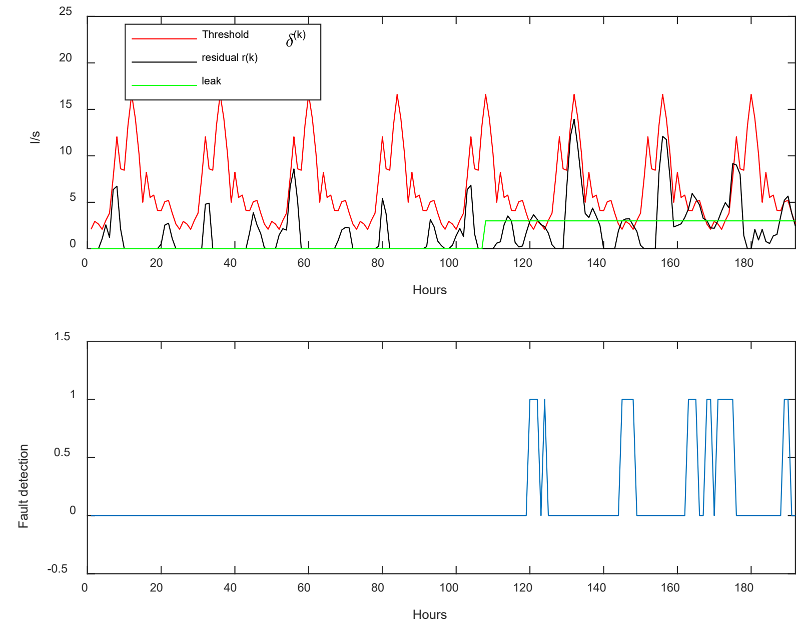
$$\beta > 1 \qquad h = mod(k, 24)$$

WDN Leak Detection: example

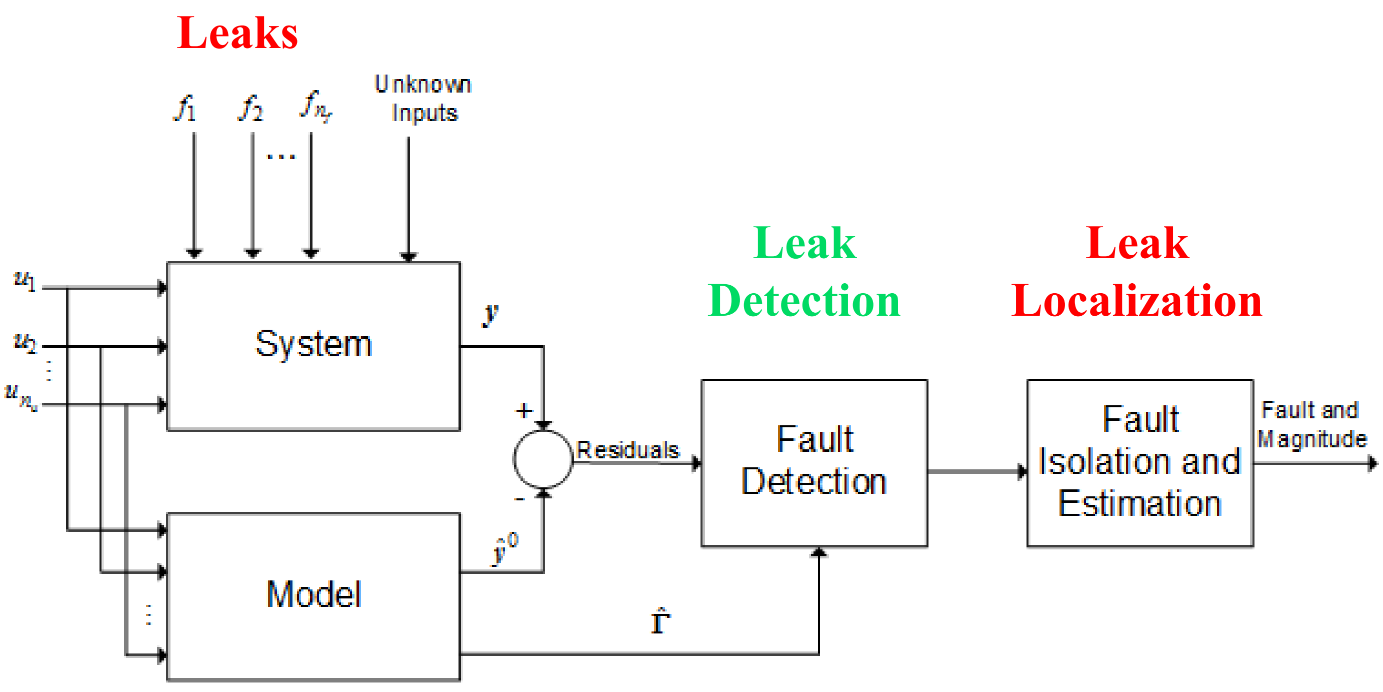
Flow



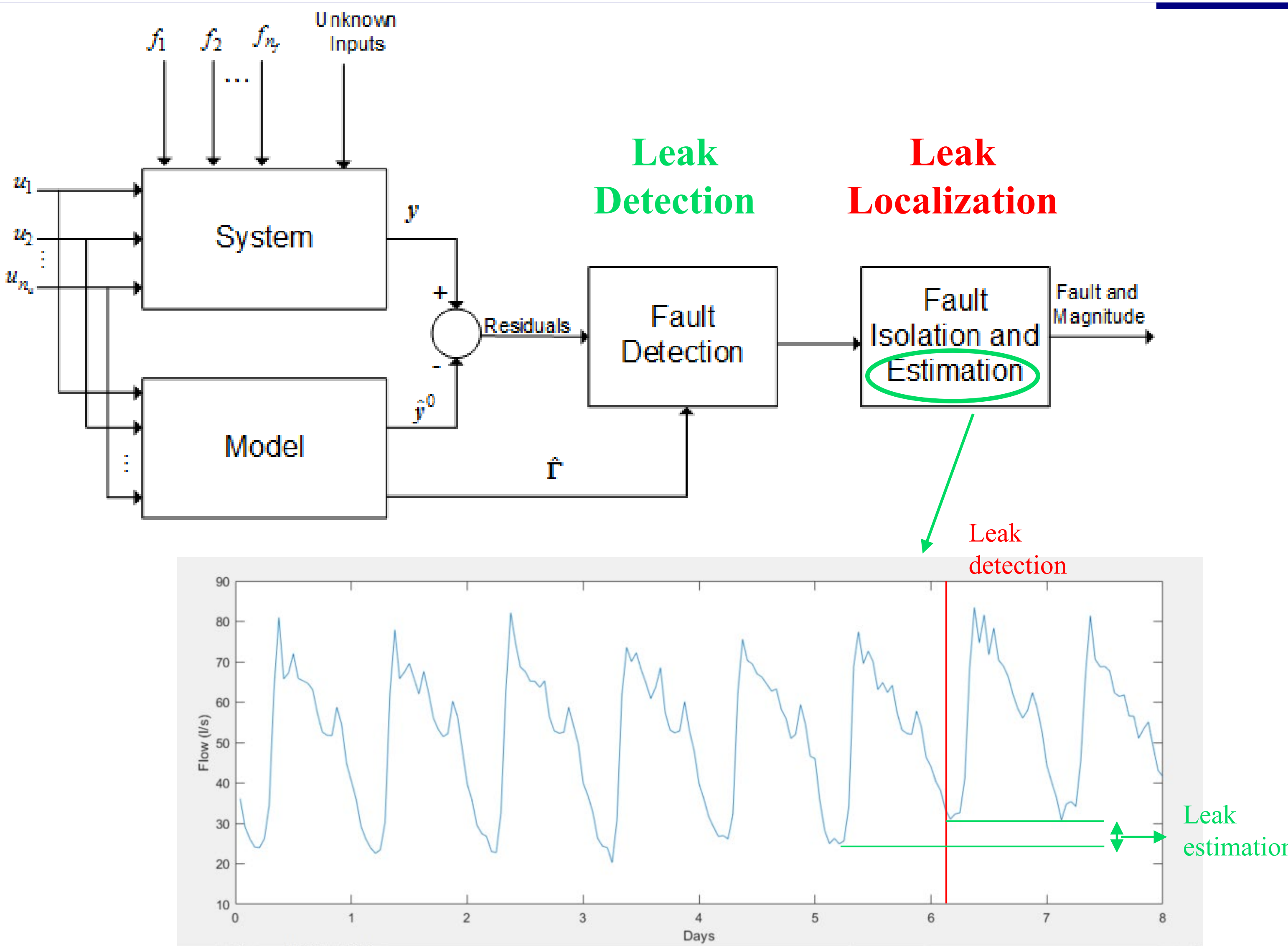
Residual



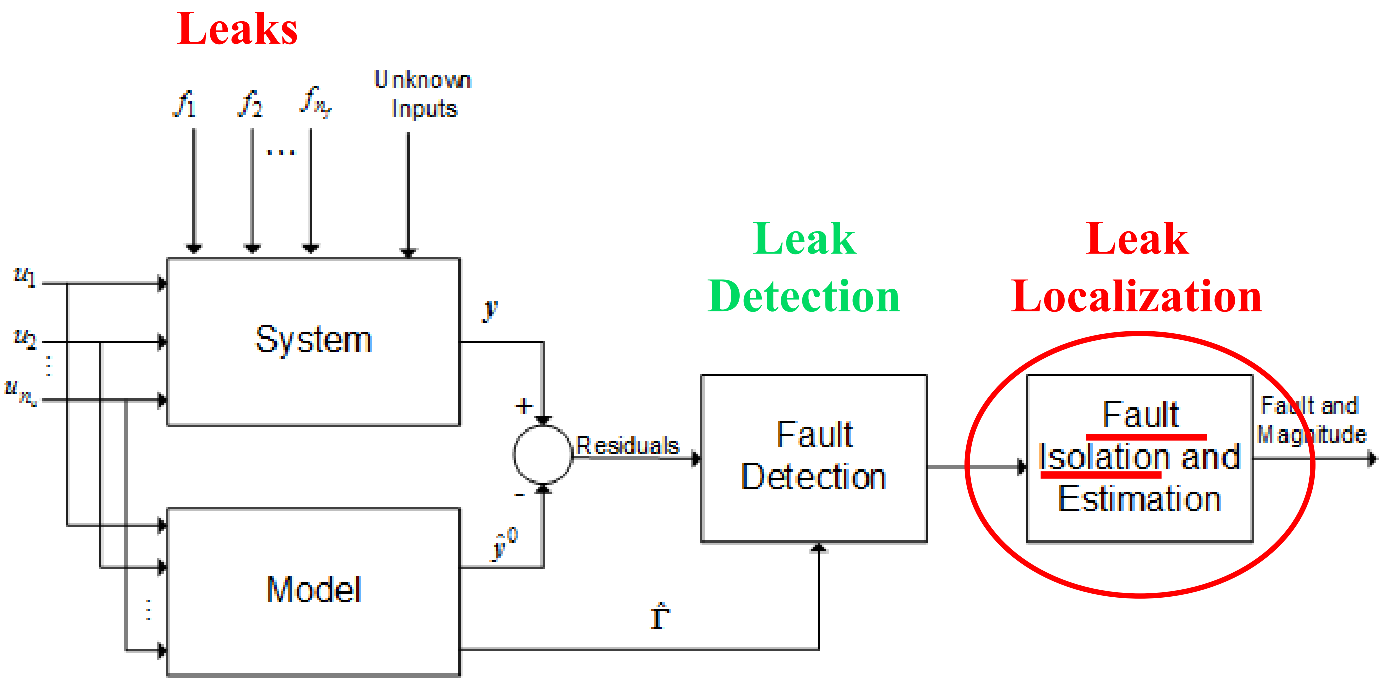
Model Based FDI Scheme



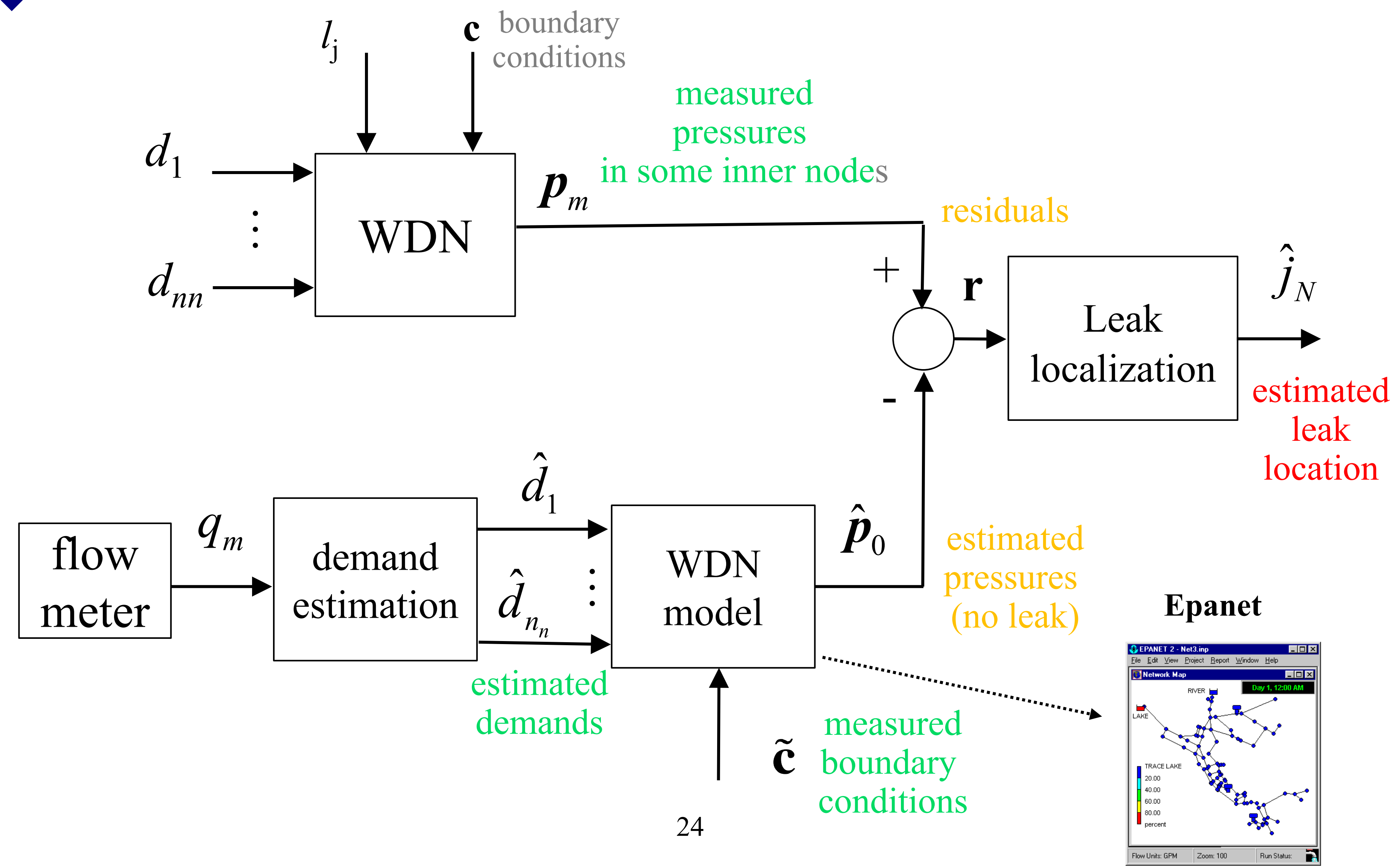
Model Based FDI Scheme



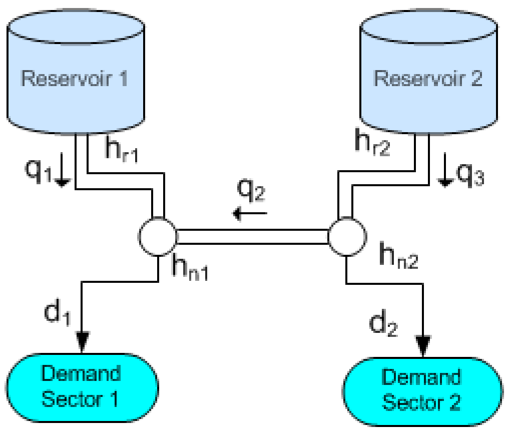
Model Based FDI Scheme



Pressure Residuals



Simple WDN: Model



Pipes: Hazen-Williams equations

$$q_1 = \left(\frac{h_{r1} - h_{n1}}{R_1}\right)^{a^{-1}}, \quad q_2 = \left(\frac{h_{n2} - h_{n1}}{R_2}\right)^{a^{-1}}, \quad q_3 = \left(\frac{h_{r2} - h_{n2}}{R_3}\right)^{a^{-1}}$$

$a = 1.852 \quad \Rightarrow$ Static Non-linear equations

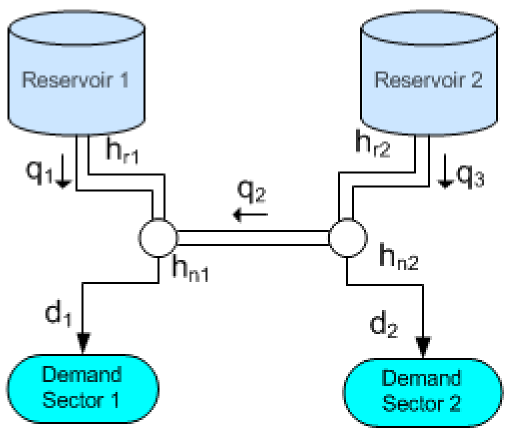
Nodes: Mass balance equations

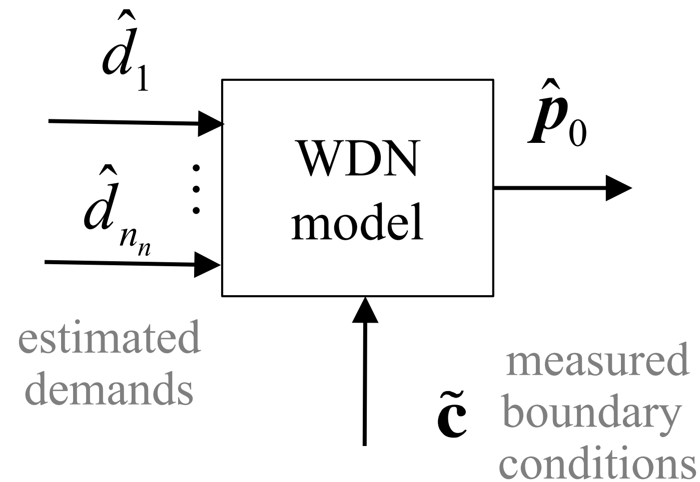
$$q_1 + q_2 - d_1 = 0$$
$$q_3 - q_2 - d_2 = 0$$

h_{r1}, h_{r2}, h_{n1} and h_{n2} denote heads (elevation+pressure)

$$h_{r1} = p_{r1} + z_{r1}$$
$$h_{r2} = p_{r2} + z_{r2}$$
$$h_{n1} = p_{n1} + z_{n1}$$
$$h_{n2} = p_{n2} + z_{n2}$$

Simple WDN: Model





WDN Model

Given:

Boundary conditions c h_{r1}, h_{r2}

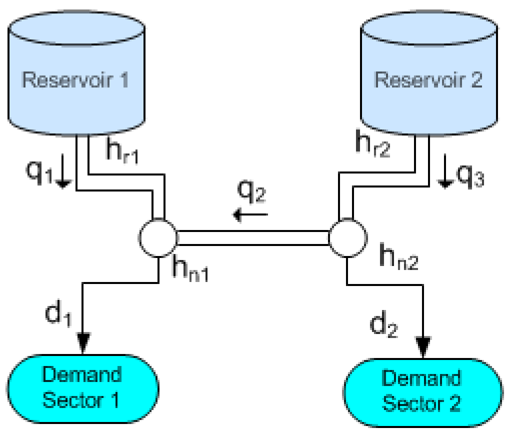
User demands d_1 and d_2

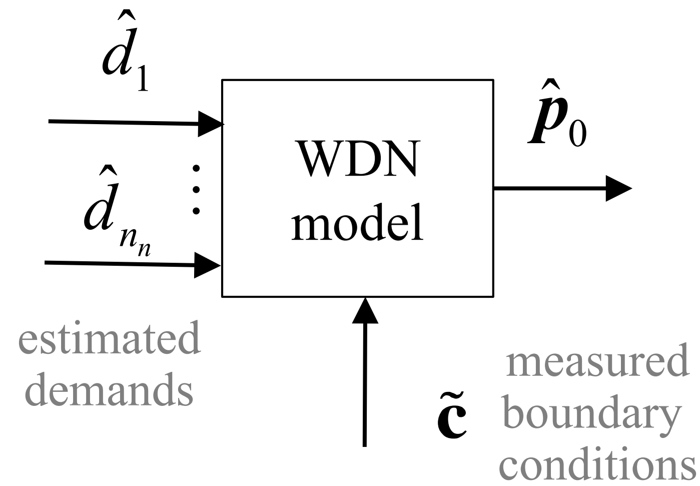
Compute:

Inner pressures $\hat{\boldsymbol{p}}_0 = \left(p_{n1}^0, p_{n2}^0\right)^t$

Flow in pipes q_1, q_2 and q_3

Simple WDN: Model





WDN Model

Given:

Boundary conditions c h_{r1}, h_{r2}

User demands d_1 and d_2

Compute:

Inner pressures $\hat{\boldsymbol{p}}_0 = \left(p_{n1}, p_{n2}\right)^t$

Flow in pipes q_1, q_2 and q_3

5 equations and 5 unknown variables

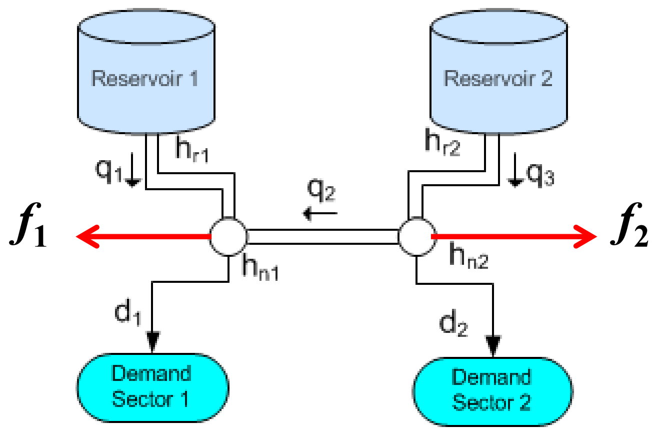
$$q_1 = \left(\frac{h_{r1} - h_{n1}}{R_1}\right)^{a^{-1}}, \quad q_2 = \left(\frac{h_{n2} - h_{n1}}{R_2}\right)^{a^{-1}}, \quad q_3 = \left(\frac{h_{r2} - h_{n2}}{R_3}\right)^{a^{-1}}$$

$$q_1 + q_2 - d_1 = 0$$

$$q_3 - q_2 - d_2 = 0$$

Non linear

Simple WDN: Model with leaks



Leaks (single leak scenarios)

Leak f_1

$$q_1 + q_2 - d_1 = f_1$$
$$q_3 - q_2 - d_2 = 0$$

Leak f_2

$$q_1 + q_2 - d_1 = 0$$
$$q_3 - q_2 - d_2 = f_2$$

Model

$$\hat{\boldsymbol{p}}_{f_1} = \left(p_{n1}^{f_1}, p_{n2}^{f_1}\right)^t$$

$$\hat{\boldsymbol{p}}_{f_2} = \left(p_{n1}^{f_2}, p_{n2}^{f_2}\right)^t$$

Residuals

$$\boldsymbol{r} = \hat{\boldsymbol{p}}_m - \hat{\boldsymbol{p}}_0 = \left(r_1, r_2\right)^t$$
$$r_1 = p_{n1}^m - p_{n1}^0$$
$$r_2 = p_{n2}^m - p_{n2}^0$$

Ideal case (No modeling errors)

Leak free

$$r_1 = 0$$
$$r_2 = 0$$

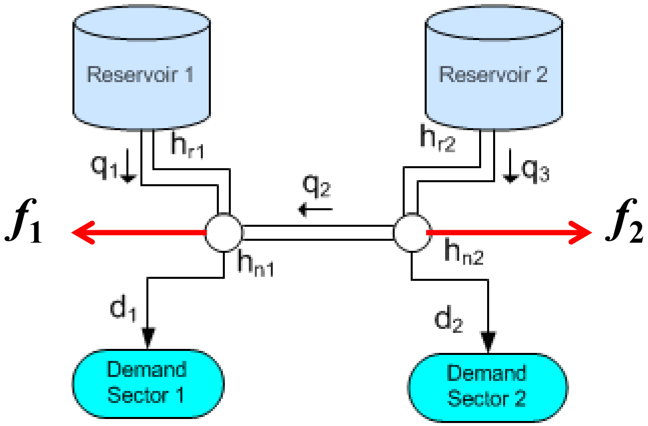
Leak f_1

$$r_1 = p_{n1}^{f_1} - p_{n1}^0 \neq 0$$
$$r_2 = p_{n2}^{f_1} - p_{n2}^0 \neq 0$$

Leak f_2

$$r_1 = p_{n1}^{f_2} - p_{n1}^0 \neq 0$$
$$r_2 = p_{n2}^{f_2} - p_{n2}^0 \neq 0$$

Simple WDN: Binary FSM



Leaks (single leak scenarios)

Leak f_1

$$r_1 = p_{n1}^{f_1} - p_{n1}^{0} \neq 0$$

$$r_2 = p_{n2}^{f_1} - p_{n2}^{0} \neq 0$$

Leak f_2

$$r_1 = p_{n1}^{f_2} - p_{n1}^{0} \neq 0$$

$$r_2 = p_{n2}^{f_2} - p_{n2}^{0} \neq 0$$

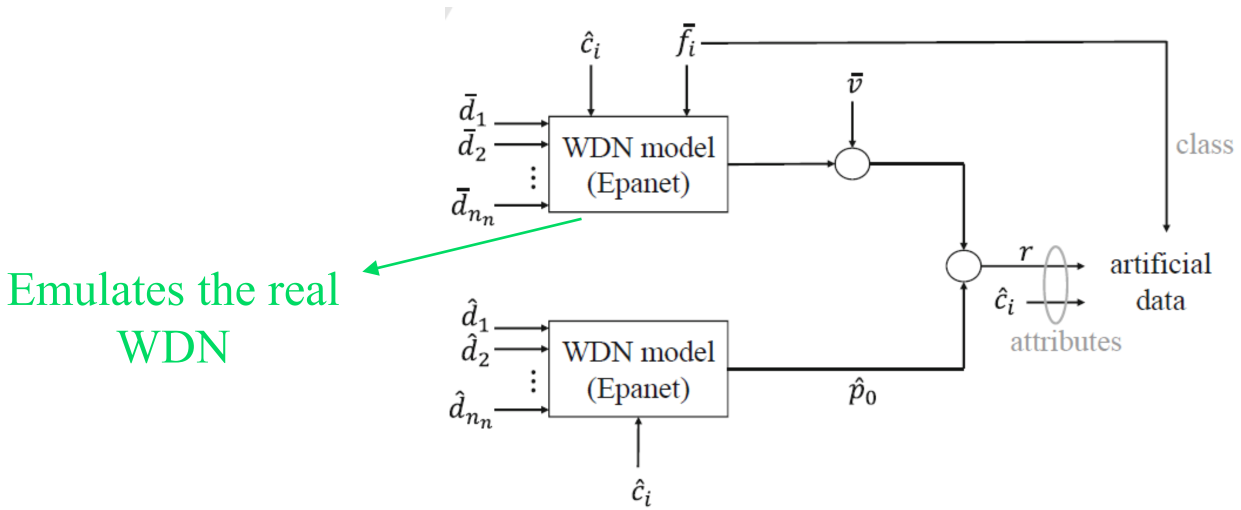
FSM

	f_1	f_2
r_1	1	1
r_2	1	1

Not isolable!

Residual Sensitivity: Model analysis

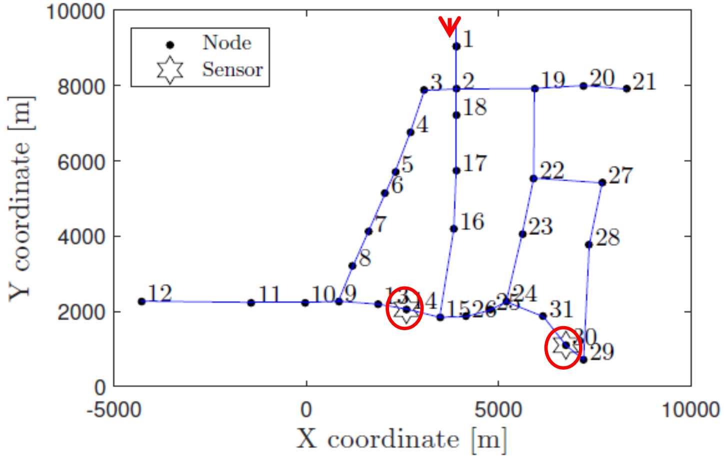
Evaluation of the effect of the different leaks in the residuals



Considering different uncertainties:

- Leak sizes (error in leak estimation)
- Error in user demands estimations
- Sensor noises

Residual Sensitivity: Simplified WDN of Hanoi



- Hanoi example 31 Nodes and 31 pipes

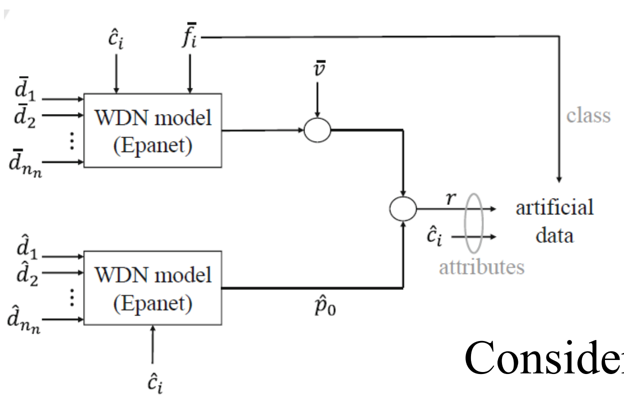
  1 flow and 1 pressure sensors (inlet)

  2 pressure sensors in nodes 14 and 30

  Estimation in the demand nodes:

$$d_i = \alpha_i d_{WDN} \qquad i = 1, \ldots, 31$$

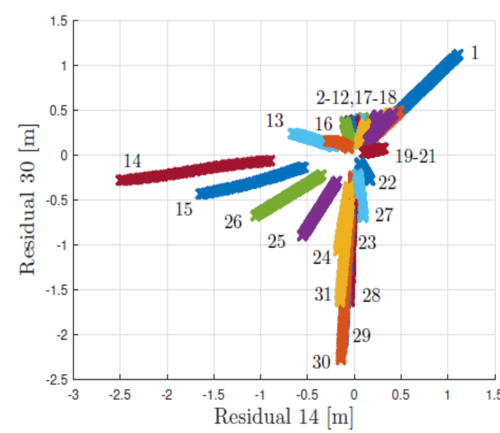
$$\sum_{i=1}^{31} \alpha_i = 1$$



$$\tilde{v} = 0$$

$$\tilde{d}_i = \hat{d}_i \qquad \forall i = 1, \ldots, N$$

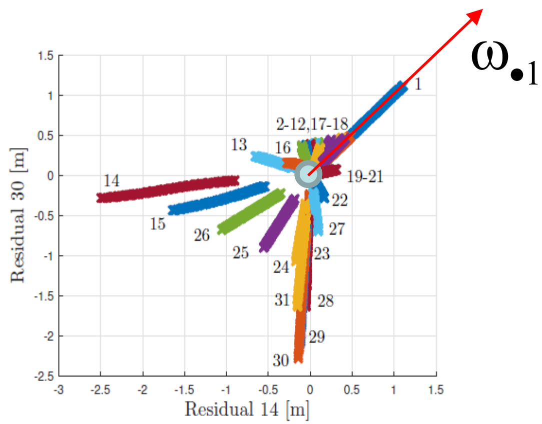
Considering different leak sizes



Residual Sensitivity: Leak Sensitivity Matrix

Leak residual pattern

$$\omega_{\bullet j} = \begin{pmatrix} \dfrac{\partial r_1}{\partial f_j} \\ \vdots \\ \dfrac{\partial r_n}{\partial f_j} \end{pmatrix}$$



Leak sensitivity matrix

$$\Omega = \begin{pmatrix} \omega_{\bullet 1} & \cdots & \omega_{\bullet m} \end{pmatrix}$$

$\omega_{\bullet j} \in \mathbb{R}^n$ n number of sensors

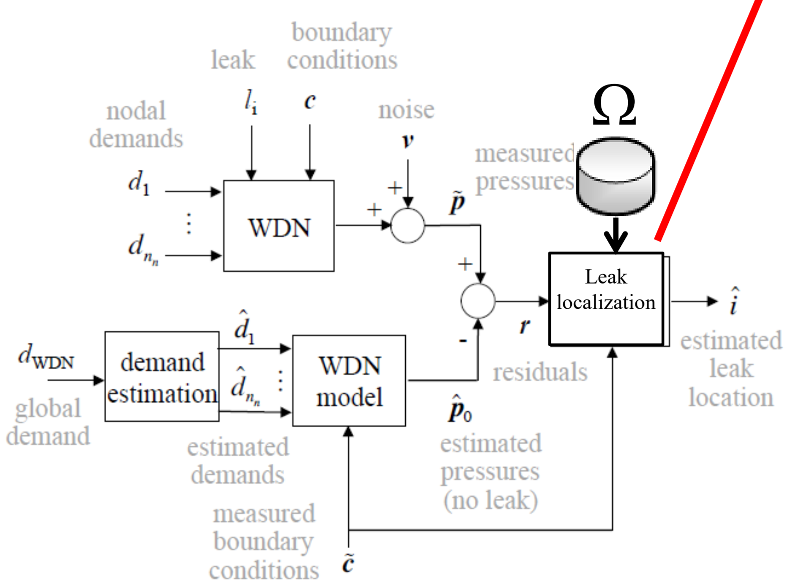
$\Omega \in \mathbb{R}^{n \times m}$ m number of leaks

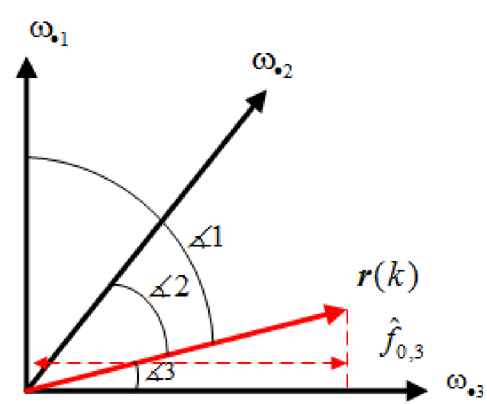
WDN Hanoi $\omega_{\bullet j} \in \mathbb{R}^2$ $\Omega = \begin{pmatrix} \omega_{\bullet 1} & \cdots & \omega_{\bullet 31} \end{pmatrix}$ $\Omega \in \mathbb{R}^{2 \times 31}$

Leak Localization: Correlation analysis method

Given $\boldsymbol{r}(k)$ the most probable leak can be determined by:

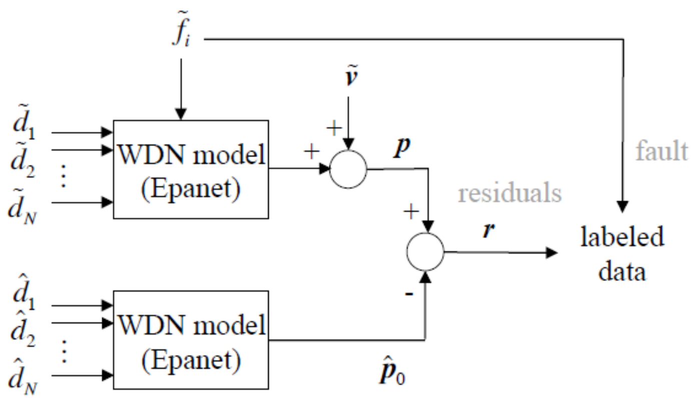
$$\hat{i}(k) = \arg \max_{j\in\{1,\ldots,m\}} \rho\left(\boldsymbol{r}(k), \omega_{\bullet \mathrm{j}}\right) \quad \text{where} \quad \rho\left(\boldsymbol{r}(k), \omega_{\bullet \mathrm{j}}\right) = \frac{\left\langle \boldsymbol{r}(k), \omega_{\bullet \mathrm{j}} \right\rangle}{\left\|\boldsymbol{r}(k)\right\| \left\|\omega_{\bullet \mathrm{j}}\right\|} = \cos \measuredangle \in [-1,1]$$





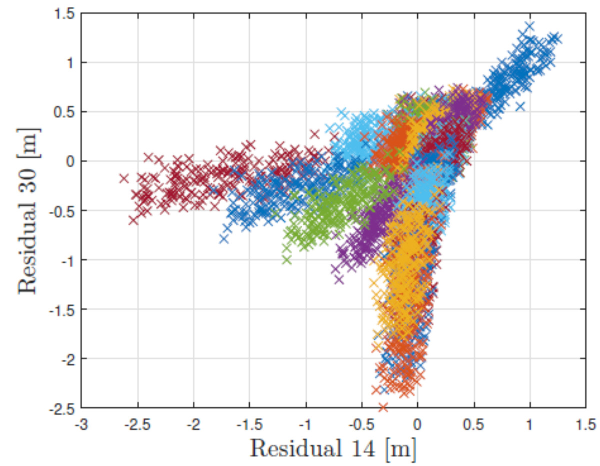
Leak Localization: Correlation analysis method

Sensor noises and demand estimation errors



$$\tilde{v} \neq 0$$

$$\tilde{d}_i \neq \hat{d}_i \qquad \forall i = 1, \ldots, N$$



Sensitivity matrix Depend on boundary conditions

$$\Omega(c) = \begin{pmatrix} \omega_{\bullet 1}(c) & \cdots & \omega_{\bullet m}(c) \end{pmatrix}$$

As c is measured every instant k

$$\boxed{\Omega(k) = \begin{pmatrix} \omega_{\bullet 1}(k) & \cdots & \omega_{\bullet m}(k) \end{pmatrix}}$$

Leak Localization:
Correlation analysis method (improved)

Leak localization

$$\hat{i}(k) = \arg\max_{j\in\{1,\dots,m\}} \rho\left(\overline{\boldsymbol{r}}(k), \overline{\varpi}_{\bullet j}(k)\right) \quad \left\{ \begin{array}{l} \overline{\boldsymbol{r}}(k) = \left(\boldsymbol{r}(k),\dots,\boldsymbol{r}(k-M)\right) \\ \overline{\varpi}_{\bullet j}(k) = \left(\overline{\varpi}_{\bullet j}^{T}(k),\dots,\overline{\varpi}_{\bullet j}^{T}(k-M)\right)^{T} \end{array} \right.$$

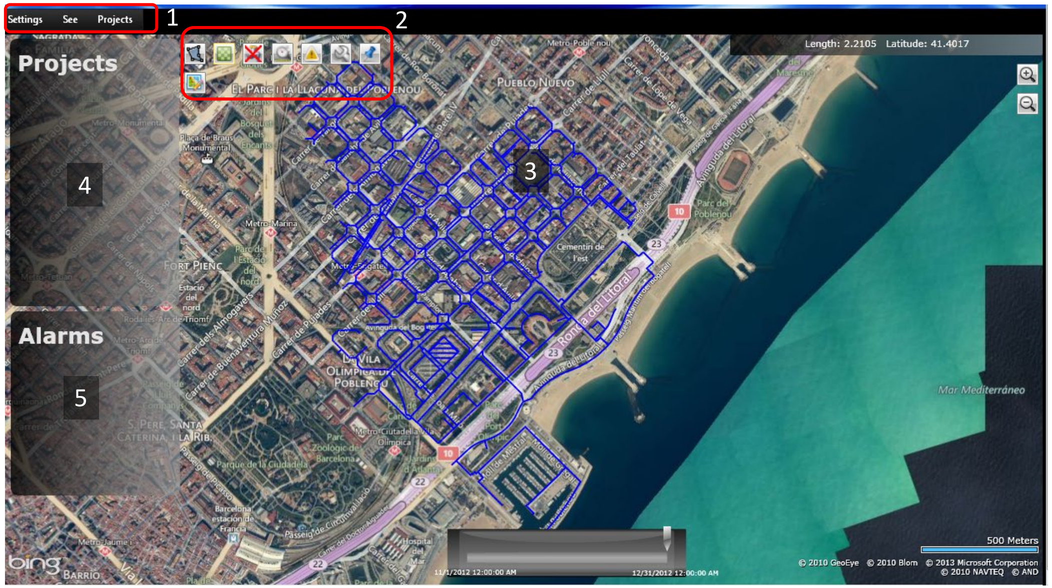
where

$$M = \min\left(N-1, k-k_{leak}\right)$$

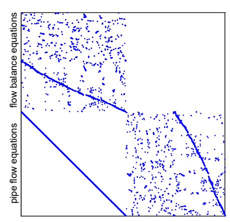
with

- N is the time horizon
- k_{leak} is the time instant when the leak was detected

Nova Icària DMA



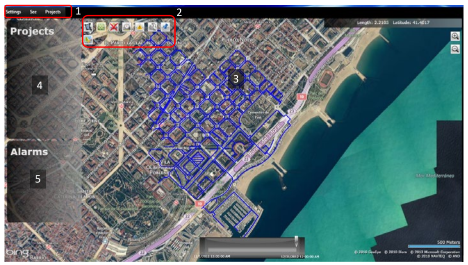
- 3377 Nodes and 3442 pipes
  - 3377 flow balance equations
  - 3442 pipe flow equations

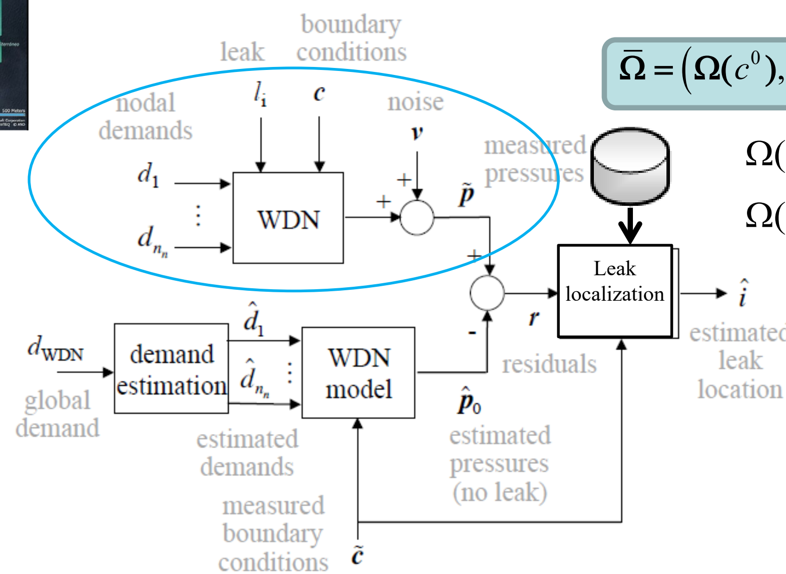


2 water inlets (flow and pressure sensor) and pressure sensors in 6 inner nodes

Rough estimation of the demands in the 3377 nodes (trimestral water bills of users)

Nova Icària DMA: Leak localization scheme





$$\bar{\Omega} = \left(\Omega(c^0), \Omega(c^1), \cdots, \Omega(c^\theta)\right)$$

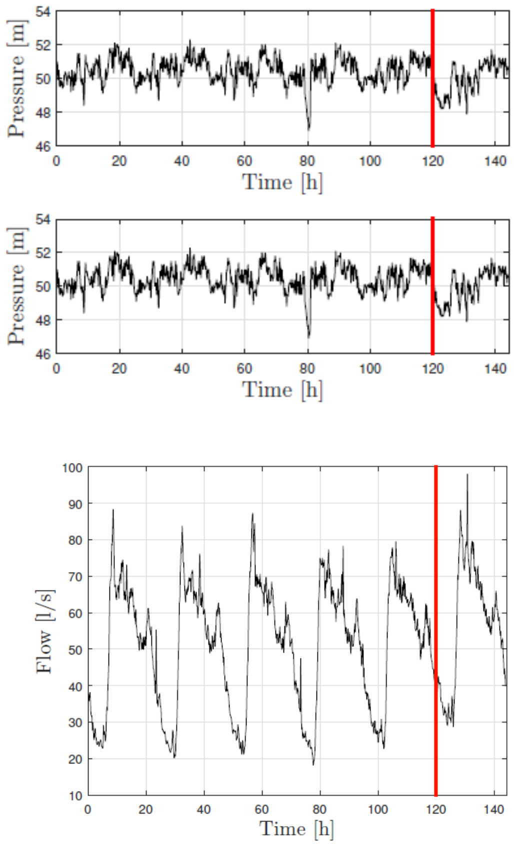
$$\Omega(c^i) \in \mathbb{R}^{6\times 3377}$$

$$\Omega(c^i) = \left(\omega_{\bullet 1}(c^i) \quad \cdots \quad \omega_{\bullet m}(c^i)\right)$$

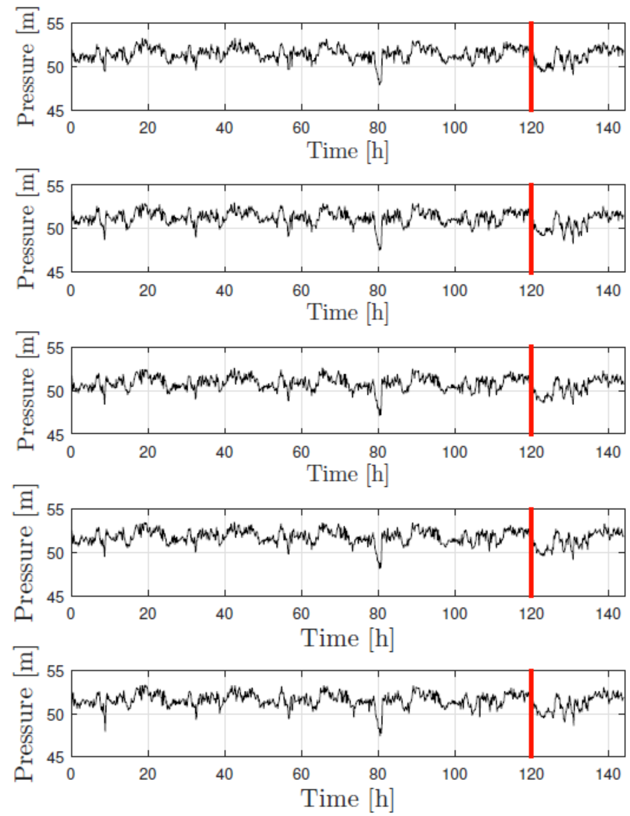
$$\hat{i}(k) = \arg \max_{j\in\{1,\ldots,m\}} \rho\left(\bar{\boldsymbol{r}}(k), \bar{\omega}_{\bullet j}(k)\right)$$

Nova Icària DMA: Real Measurements

Boundary conditions



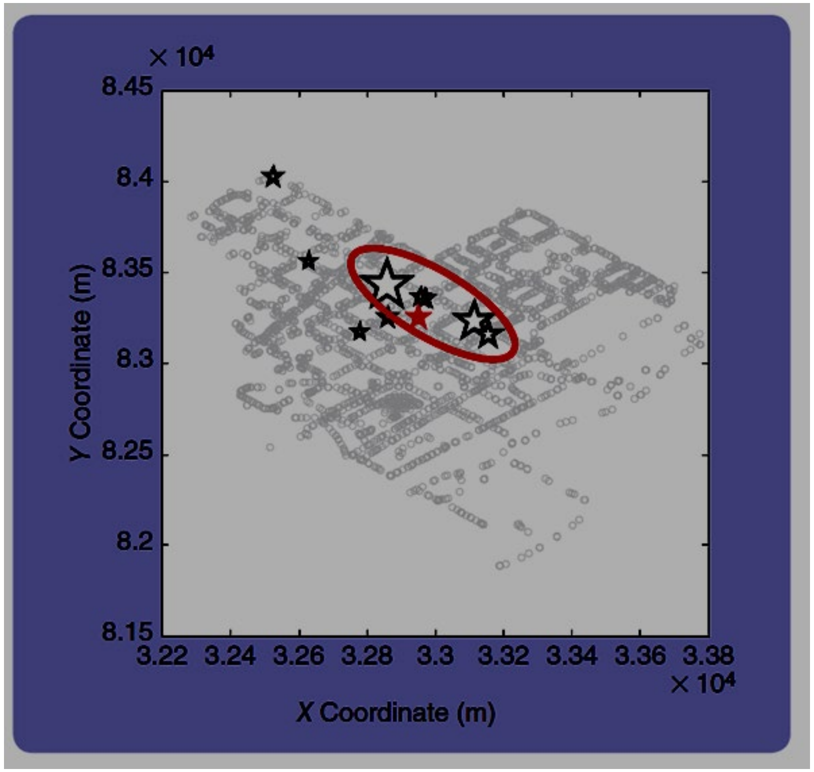
Inner Pressure Measurements



Nova Icària DMA:

Real leak localization results

Less than 100 m leak localization error 24

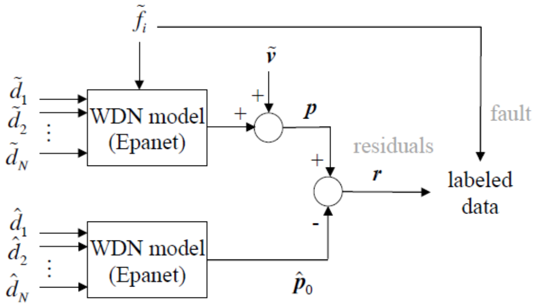


- Perez R.et al. (2014). **Leak Localization in Water Networks: A Model-Based Methodology Using Pressure Sensors Applied to a Real Network in Barcelona** [Applications of Control], in IEEE Control Systems, vol. 34, no. 4, pp. 24-36.

Nova Icària DMA: General performance assessment

Example

Average Topological Distance (ATD): is the average value of the minimum distance in nodes between the node provided by the leak localization algorithm as most probable leak candidate and the node with the real leak. (Simulating *M* leak scenarios)



Confusion Matrix

	$\hat{l}_1$	$\cdots$	$\hat{l}_i$	$\cdots$	$\hat{l}_{n_c}$
l_1	$\Gamma_{1,1}$	$\cdots$	$\Gamma_{1,i}$	$\cdots$	Γ_{1,n_c}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
l_i	$\Gamma_{i,1}$	$\cdots$	$\Gamma_{i,i}$	$\cdots$	Γ_{i,n_c}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
l_{n_c}	$\Gamma_{n_c,1}$	$\cdots$	$\Gamma_{n_c,i}$	$\cdots$	Γ_{n_c,n_c}

$$\boxed{\mathrm{ATD} = \frac{\sum_{i=1}^{n_c}\sum_{j=1}^{n_c}\Gamma_{i,j}\mathrm{D}_{i,j}}{\sum_{i=1}^{n_c}\sum_{j=1}^{n_c}\Gamma_{i,j}}}$$

D: Distance matrix

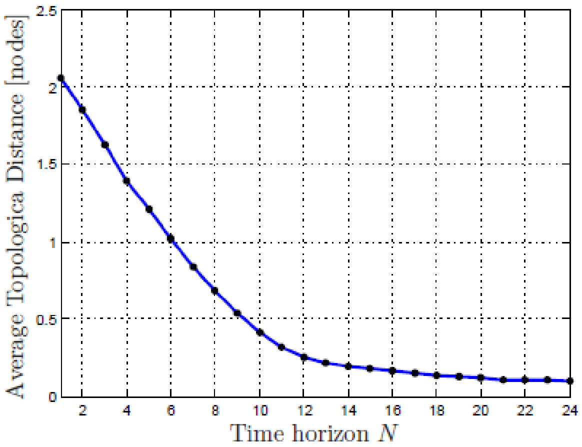
Nova Icària DMA: General performance assessment

Example

Hanoi WDN

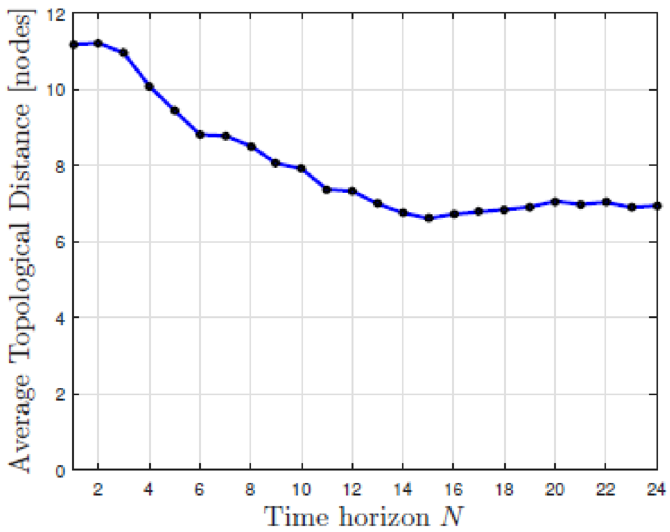
Uncertainties:

- 10% in user demands
- 25-75l/s leaks
- +- 0.25 [mwc]



Nova Icària DMA

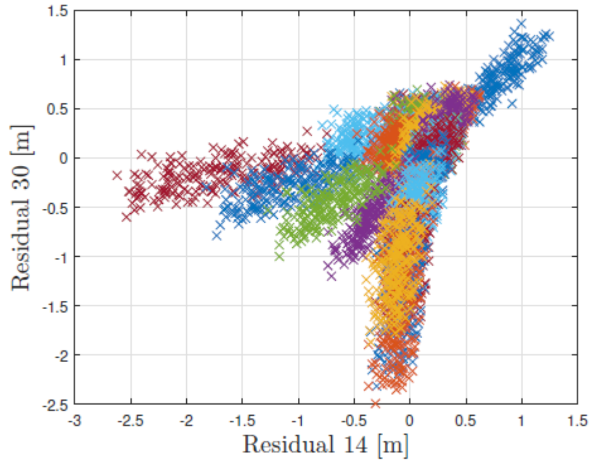
Uncertainties: Taken from the real data (NOT trivial)

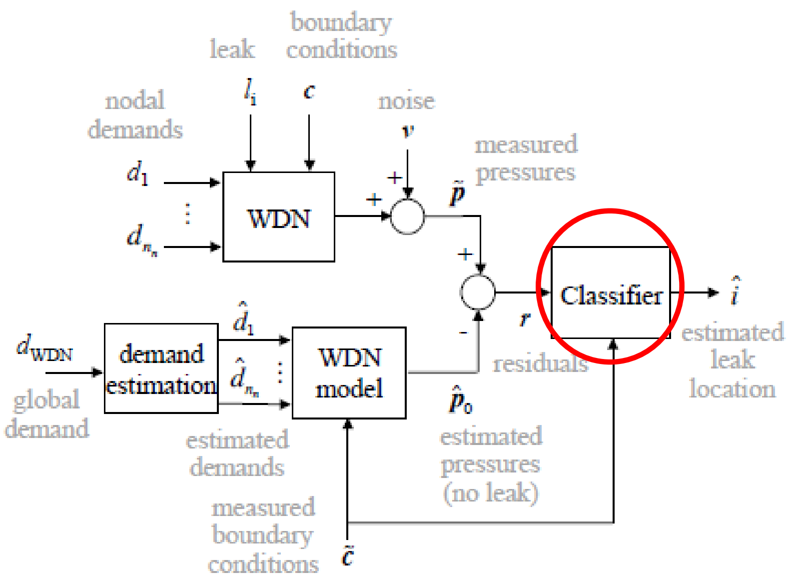


- Pérez, R., Cugueró, J., Blesa, J., Sanz, G., Cugueró M.A., (2016). ***Uncertainty effect on leak localisation in a DMA***. Proceedings of the 2016 3rd Conference on Control and Fault-Tolerant Systems (SysTol), Barcelona (Spain), pp. 313-318.
- Pérez, R., Sanz, G., Cugueró, M.À., Blesa, J., Cugueró, J. (2015). ***Parameter Uncertainty Modelling in Water Distribution Network Models***. 13th Computing and Control for the Water Industry Conference, Leicester (England). Procedia Engineering, Elsevier, 119. pp. 1108-113.

Classifiers: mixed model-based/data-driven approaches

Leak localization





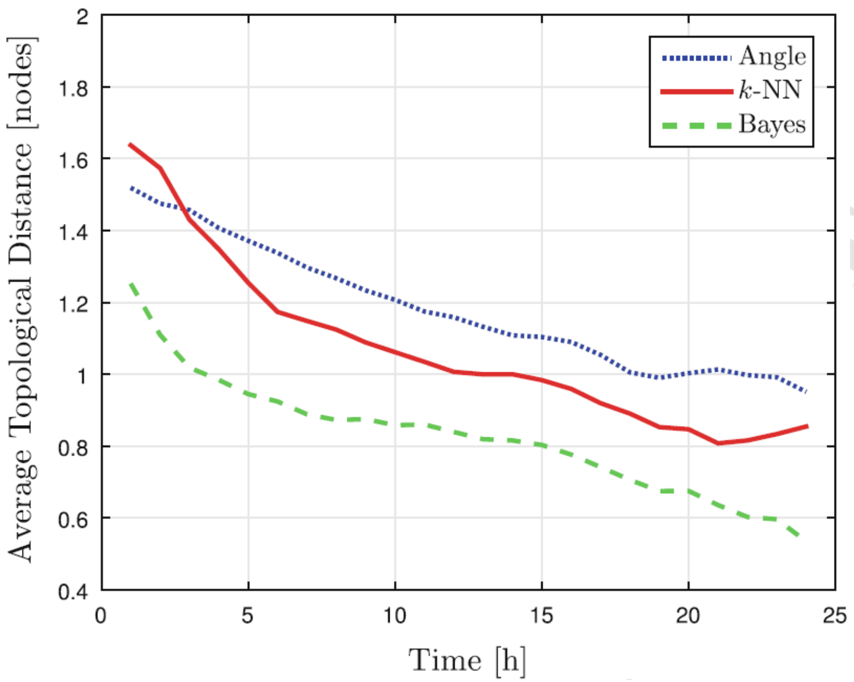
- Soldevila, A., Blesa, J., Tornil-Sin, S., Duviella, E., Fernandez-Canti, R.M, Puig, R. (2016). **Leak localization** in water distribution networks using a **mixed model-based/data-driven approach**, ***Control Engineering Practice*, 55, 162-173**.

- Soldevila, A., Fernandez-Cantí, R.M. , Blesa, J., Tornil-Sin, S., Puig, V. (2017) **Leak localization in water distribution networks using Bayesian classifiers**. Journal of Process Control, 55: 1-9, 2017

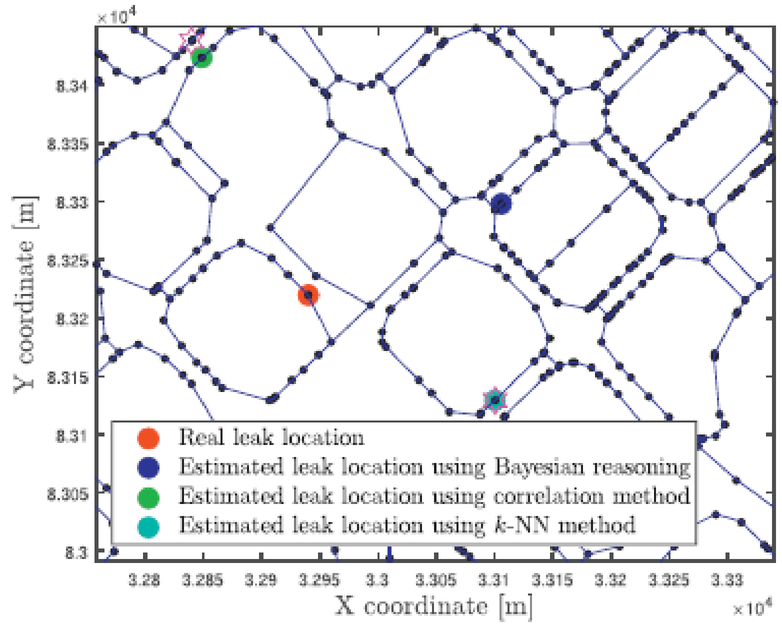
Classifiers

Leak localization Results

Simulated leaks

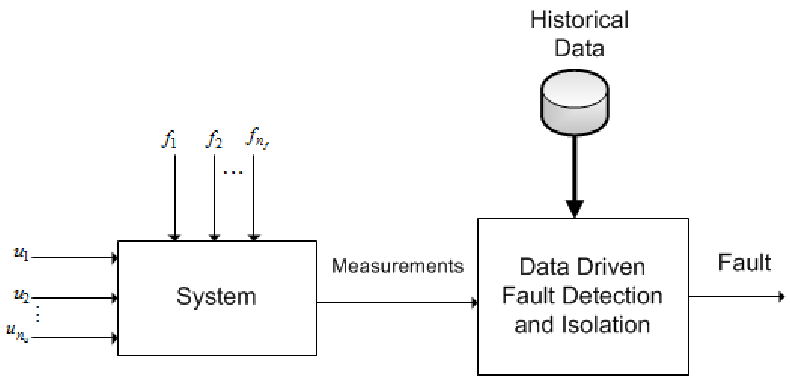


Real leaks



Bayes classifier provided the best results

Data-Driven WDN Leak Localization: Scheme

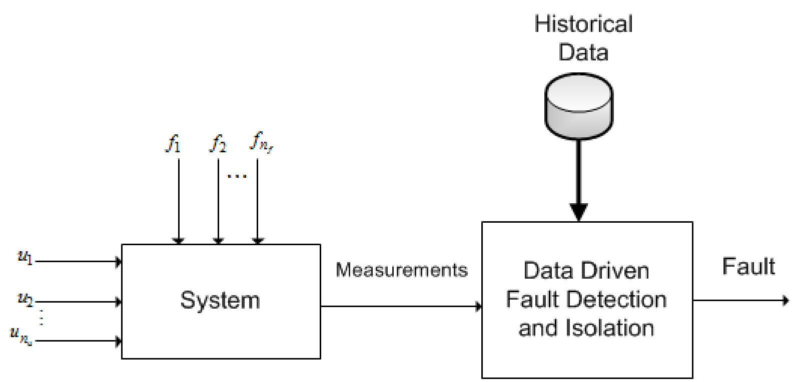


- Data about system operation is available, classified according to the faults or **not**.
- It is used to train a classifier: statistical classifier, neural network, support vector machine,…
- On-line: classifier fed with incoming data…

Data-Driven WDN Leak Localization: Data-driven vs. model-based

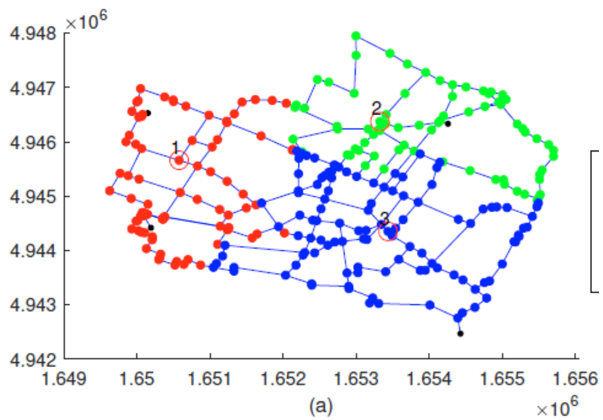
- Model-based methods:
  - Availability of real data in advance is not required.
  - They are capable to face not previously experimented situations, including multiple faults.
  - Limitations in their application to complex systems (A model is necessary)
- Data-driven methods:
  - Applicable to real complex and large scale systems (non-linear, many measured variables).
  - Require of real data for faulty operation.
  - Are not able to manage new situations.

Data-Driven WDN Leak Localization: Main Problem



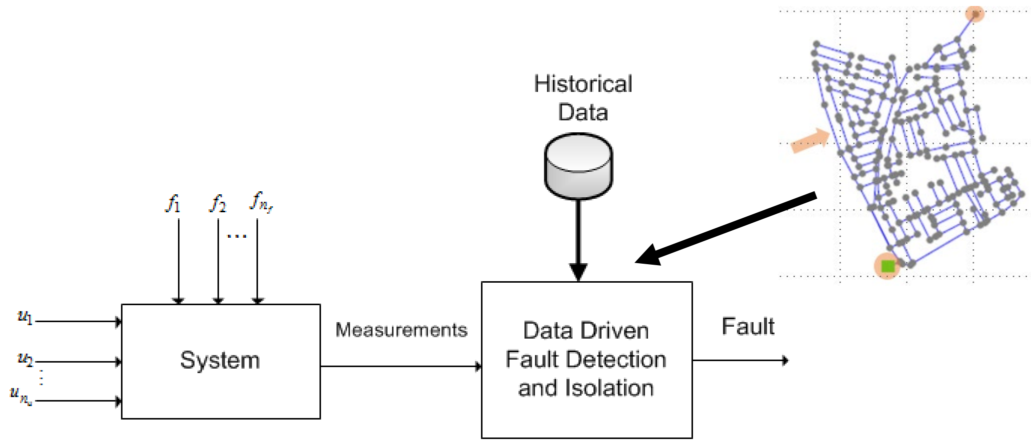
Main Problem: a priori Leak data

Idea: To produce artificial leaks in some points



- Alves, D., Blesa, J., Duviella, E., & Rajaoarisoa, L. (2022). Data-driven leak localization in WDN using pressure sensor and hydraulic information. IFAC-PapersOnLine, 55(5), 96-101.

Data-Driven WDN Leak Localization: Alternative Scheme



WDN Topology

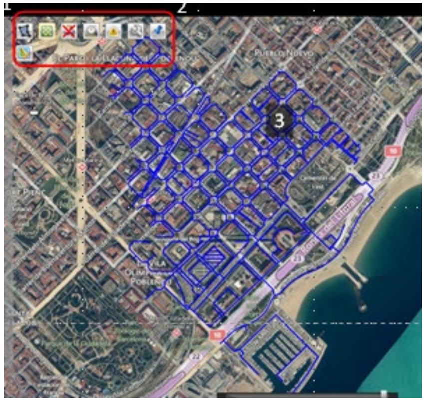
- Soldevila, A., Blesa, J., Fernandez-Canti, R. M., Tornil-Sin, S., & Puig, V. (2019). Data-driven approach for leak localization in water distribution networks using pressure sensors and spatial interpolation. Water, 11(7), 1500.

- Soldevila, A., Blesa, J., Jensen, T. N., Tornil-Sin, S., Fernandez-Canti, R. M., & Puig, V. (2020). Leak localization method for water-distribution networks using a data-driven model and Dempster–Shafer reasoning. IEEE transactions on control systems technology, 29(3), 937-948.

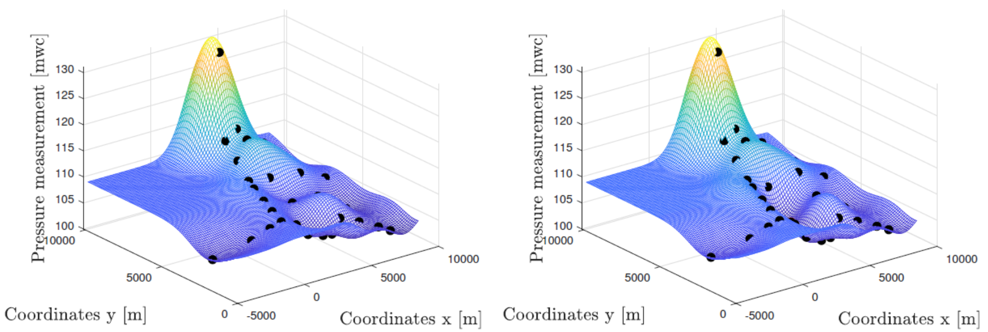
- Alves, D., Blesa, J., Duviella, E., & Rajaoarisoa, L. (2021). Robust data-driven leak localization in water distribution networks using pressure measurements and topological information. *Sensors*, *21*(22), 7551.

Data-Driven WDN Leak Localization: Alternative Scheme (Example 1)

- Soldevila, A., Blesa, J., Fernandez-Canti, R. M., Tornil-Sin, S., & Puig, V. (2019). Data-driven approach for leak localization in water distribution networks using pressure sensors and spatial interpolation. Water, 11(7), 1500.



Kriging Interpolation



(**a**) Pressure map without leak.

(**b**) Pressure map with leak.

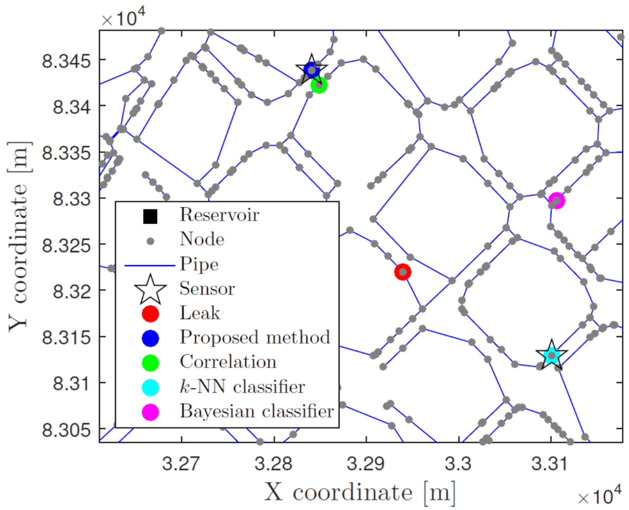


Figure 10. Nova Icària leak localization results.

Data-Driven WDN Leak Localization: Alternative Scheme (Example 2)

- Soldevila, A., Blesa, J., Jensen, T. N., Tornil-Sin, S., Fernandez-Canti, R. M., & Puig, V. (2020). Leak localization method for water-distribution networks using a data-driven model and Dempster–Shafer reasoning. IEEE transactions on control systems technology, 29(3), 937-948.

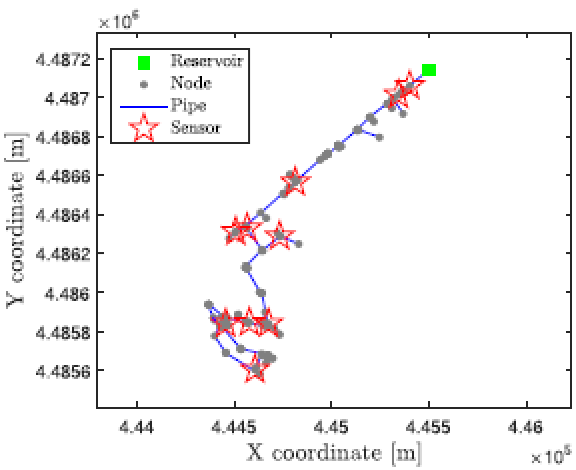


Fig. 6. Madrid DMA1 topological network.

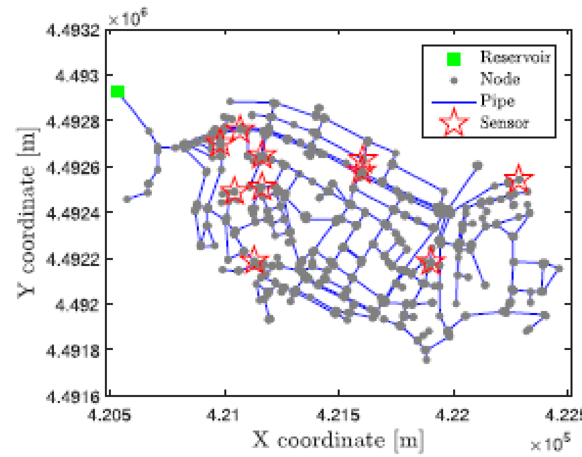


Fig. 12. Madrid DMA2 topological network.

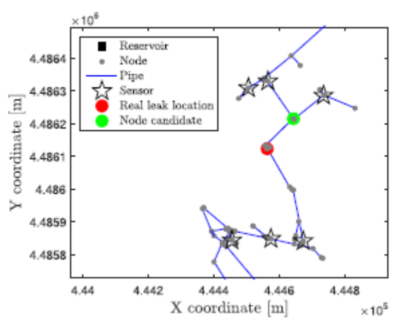


Fig. 11. Leak localization results in Madrid DMA1 real case.

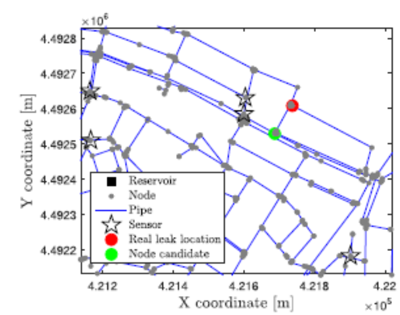


Fig. 17. Leak localization results in Madrid DMA2 real case.

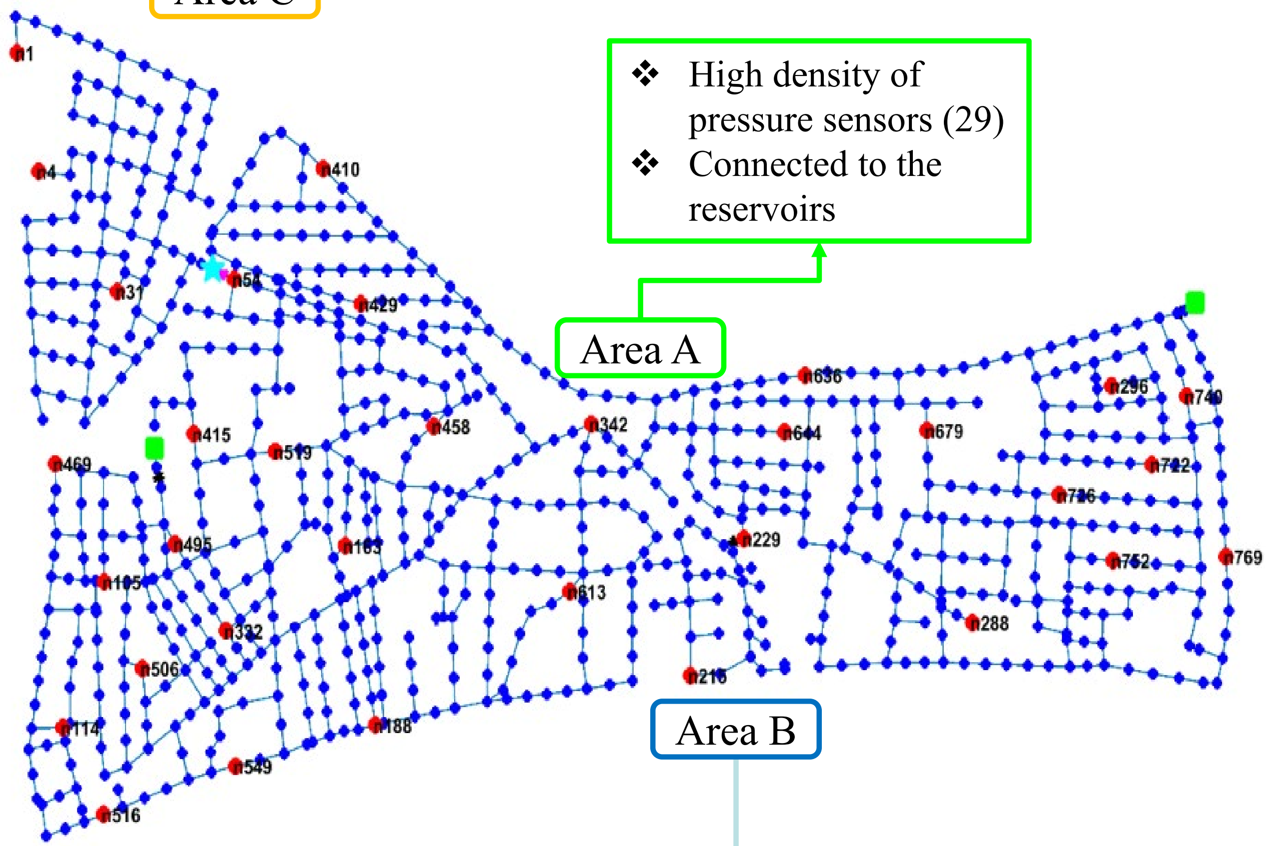
WDN Leak Localization: Data-Driven or Model-Based?

Area C

- ❖ Low density of pressure sensors (3)
- ❖ Water inlet through a tank
- ❖ High density of AMRs

- ○ 785 junctions
- ○ 909 pipes
- ○ 2 water inlets/reservoirs
- ○ 1 tank
- ○ 3 PRV

- ❖ Very low density of measuring devices (1)
- ❖ Separated from Area A through a PRV



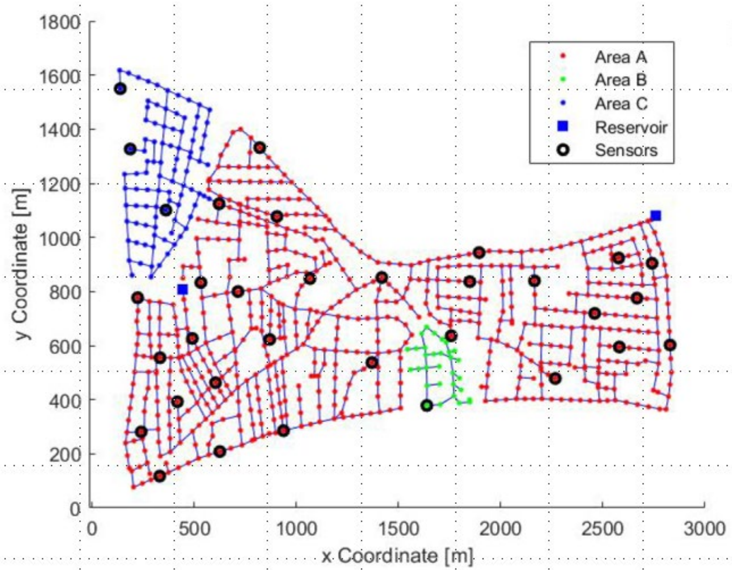
Area A

- ❖ High density of pressure sensors (29)
- ❖ Connected to the reservoirs

Area B

Vrachimis, S.G., Eliades, D.G., Taormina, R., Ostfeld, A., Kapelan, Z., Liu, S., Kyriakou, M., Pavlou, P., Qiu, M., and Polycarpou, M.M. (2020). **BattLeDIM: Battle of the Leakage Detection and Isolation Methods**.

WDN Leak Localization: Data-Driven or Model-Based?

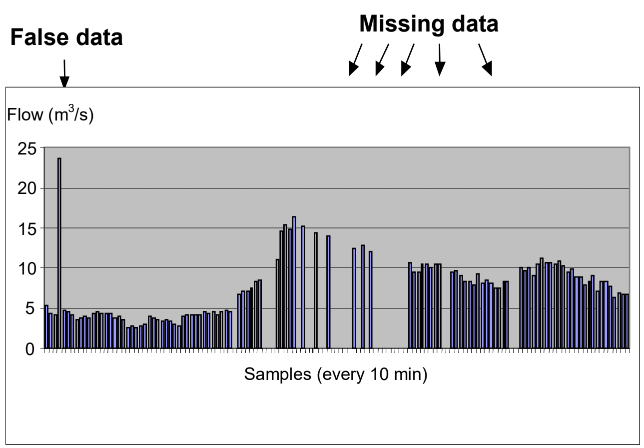


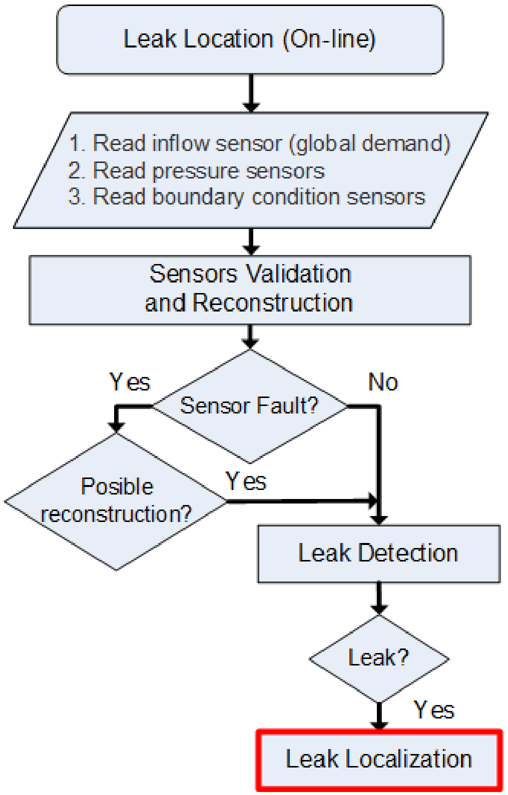
Area A: Data Driven
Areas B and C: Model Based

- Romero-Ben, L., Alves, D., Blesa, J., Cembrano, G., Puig, V., & Duviella, E. (2022). Leak localization in water distribution networks using data-driven and model-based approaches. *Journal of Water Resources Planning and Management*, *148*(5), 04022016.

- Romero-Ben, L., Alves, D., Blesa, J., Cembrano, G., Puig, V., & Duviella, E. (2023). Leak detection and localization in water distribution networks: Review and perspective. *Annual Reviews in Control*, *55*, 392-419.

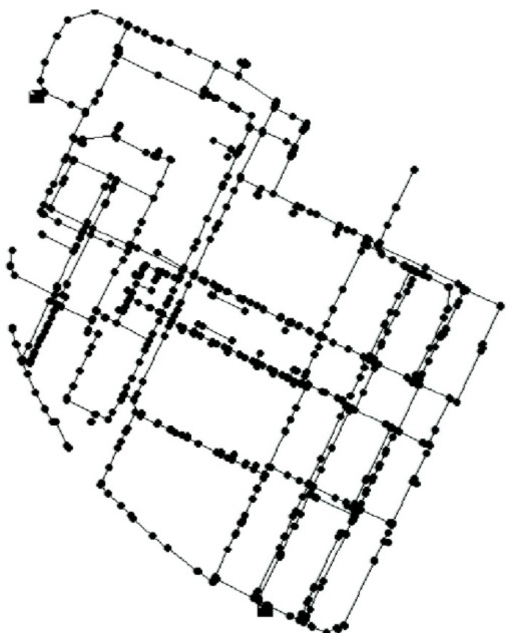
Other problems:
Data Validation/Reconstruction





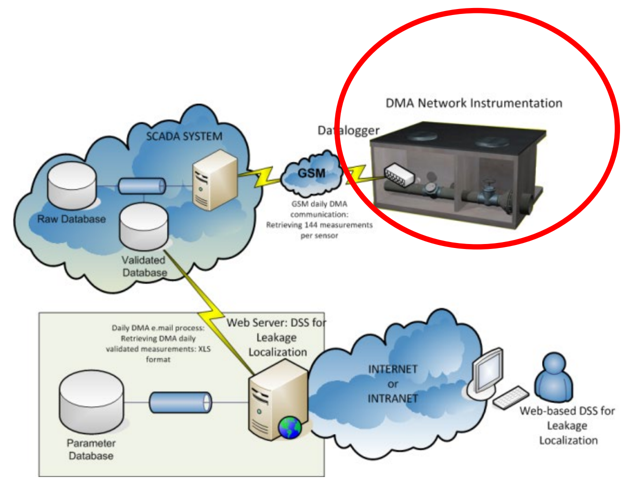
Optimal Sensor Placement: Other problems

Optimize leak localization performance



Mercabarna DMA

881 nodes and 927 pipes:
311 Sensor Candidates



Install m_p sensors (e.g. m_p=5)

Optimal Sensor Placement: Other Problems

Optimization problem

GIVEN a candidate sensor set **S**, a leak set **F**, a leak sensitivity matrix **Ω**, and the number m_p of pressure sensors to be installed associated to a new **Ω***

$$\Omega \in \mathbb{R}^{|S| \times |F|} \rightarrow \Omega^* \in \mathbb{R}^{m_p \times |F|}$$

FIND the m_p-sensor configuration $S^\star \subseteq \mathbf{S}$ such that:

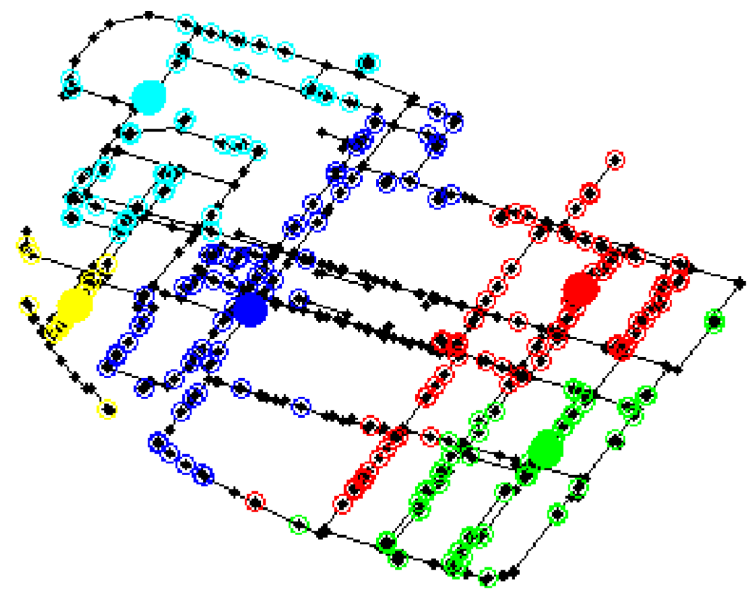
a **index (I)** is maximized. , i.e. $I(S^\star) \geq I(S)$ for any $S \subseteq \mathbf{S}$ such that $|S| = m_p$.

Combinatory problem 311 candidates and m_p =5 sensors $C_5^{311} = 2.34 \times 10^{10}$

Which Leak locatability index I ? **I=ATD?**

Optimal Sensor placement: Some insights

Combininatorial problem: Reduce the number of candidates with similar rows of $\bar{\mathbf{\Omega}}$ (e.g. clustering)



$$\bar{\mathbf{\Omega}} = \left(\mathbf{\Omega}\left(c^{0}\right), \mathbf{\Omega}\left(c^{1}\right), \cdots, \mathbf{\Omega}\left(c^{s\theta}\right)\right)$$

Leak locatability index

To find a indirect indicator I(**Ω***)
With very low computational cost

$$I = \sum_{(f_k, f_l) \in \mathbb{F}} 1 - \frac{\omega_{\bullet k}^{T} \cdot \omega_{\bullet l}}{||\omega_{\bullet k}|| \, ||\omega_{\bullet l}||}$$

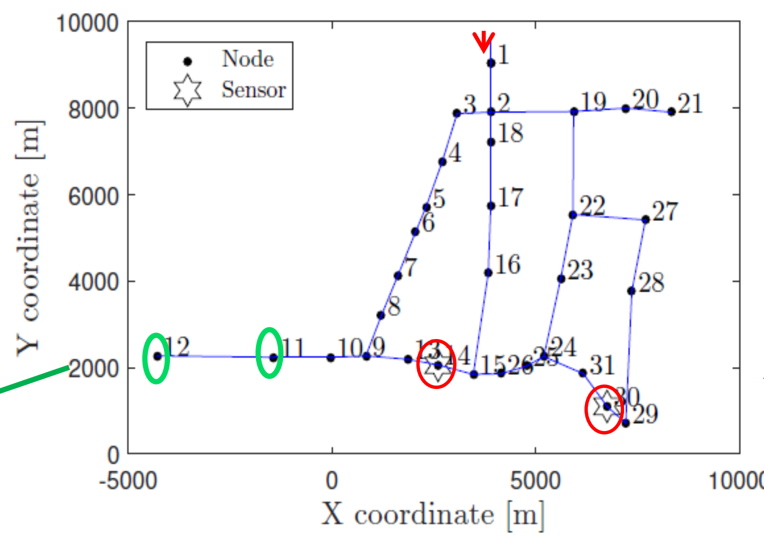
$$R_j^{\alpha_{th}} = \max_{f_i \in \mathbf{F}_j^{\alpha_{th}}(\Omega^*)} d_{ij}$$

Worst leak expansion distance

ATD=> very high computational cost

Optimal Sensor Placement: Other Problems

Some insights

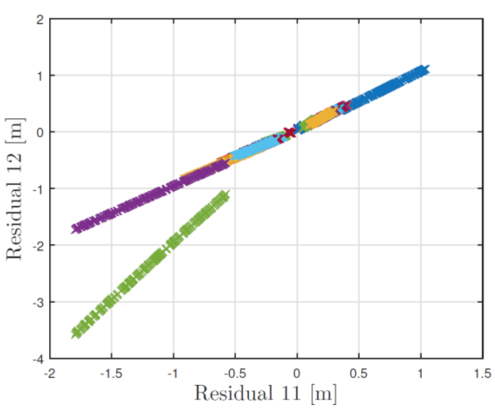


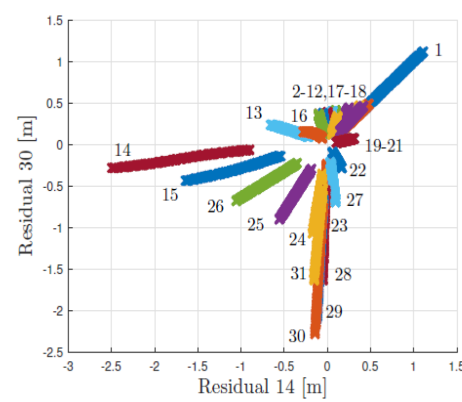
<u>Sensor configuration 1:</u>
Sensors 11 and 12

Ω_1^*

<u>Sensor configuration 2:</u>
Sensors 14 and 30

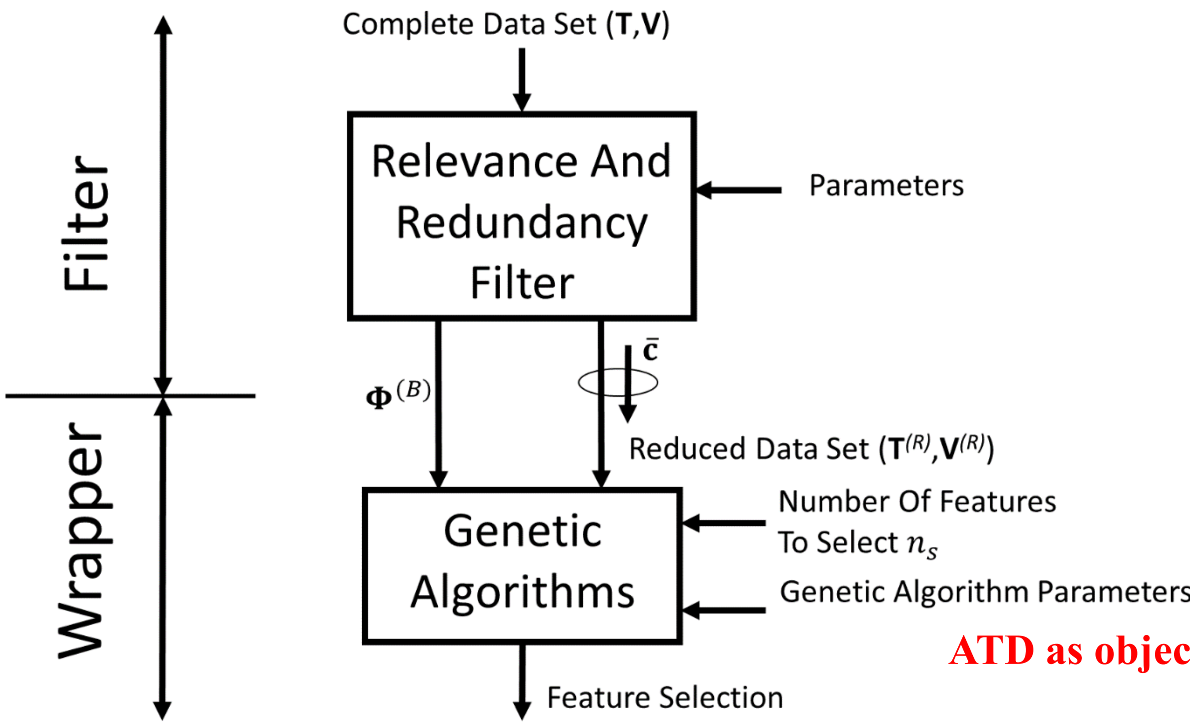
Ω_2^*





Classifiers

Sensor Placement as a Feature Selection Problem



ATD as objective function!

- Soldevila, A., Blesa, J., Tornil-Sin, S., Fernandez-Cantí, R.M. , Puig, V. (2018). **Sensor placement** for classifier-based leak localization in water distribution networks **using hybrid feature selection**. *Computers and Chemical Engineering*, 108, pp. 152-162