Towards a smarter IoT

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Firstly, what do we mean by smart?

- By smart, we mean:
  - Sensitive
  - Intelligent

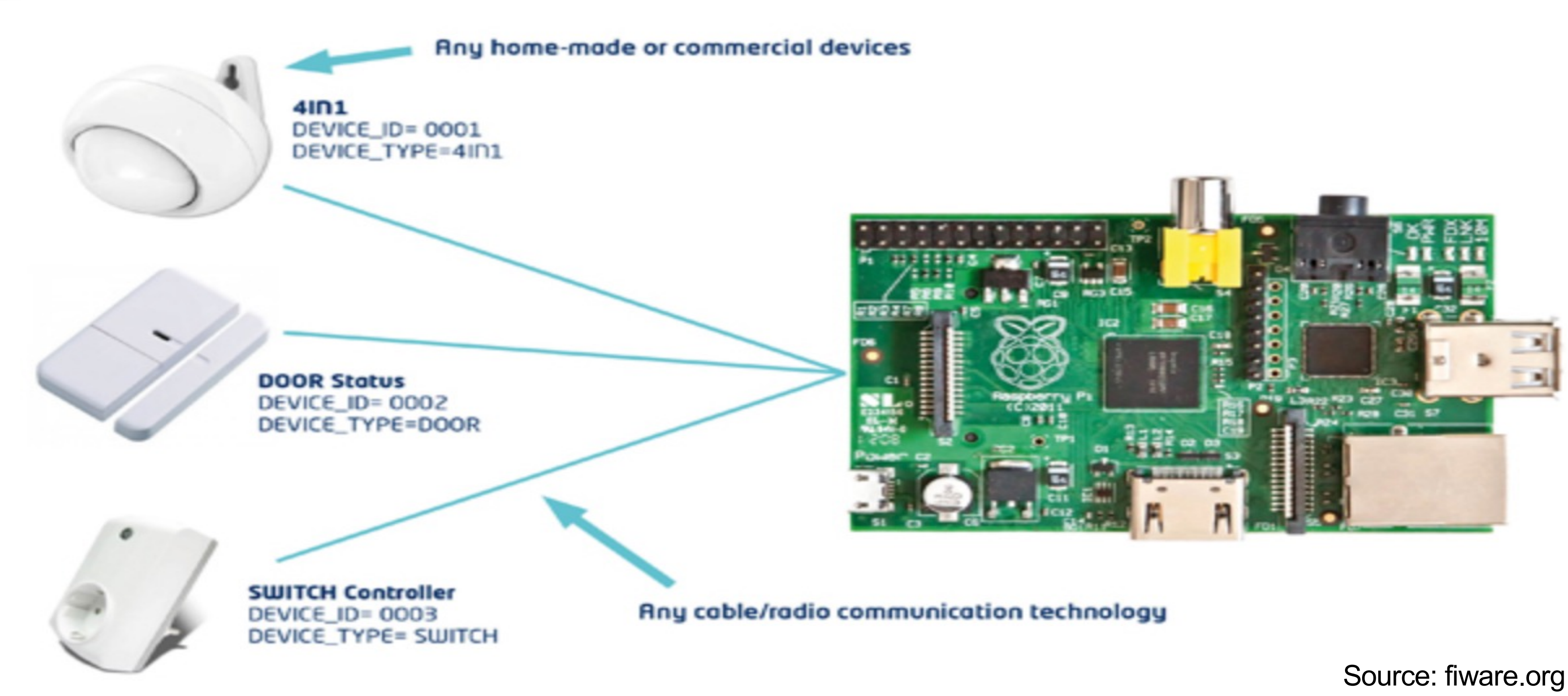
Research Contribution I

- By smart, we mean:
  - Sensitive
  - Intelligent

Key challenge of IoT

- IoT is hard to program
  - It consists of resource constrained devices (e.g. memory and CPU)

IoT hardware heterogeneity



Source: fiware.org

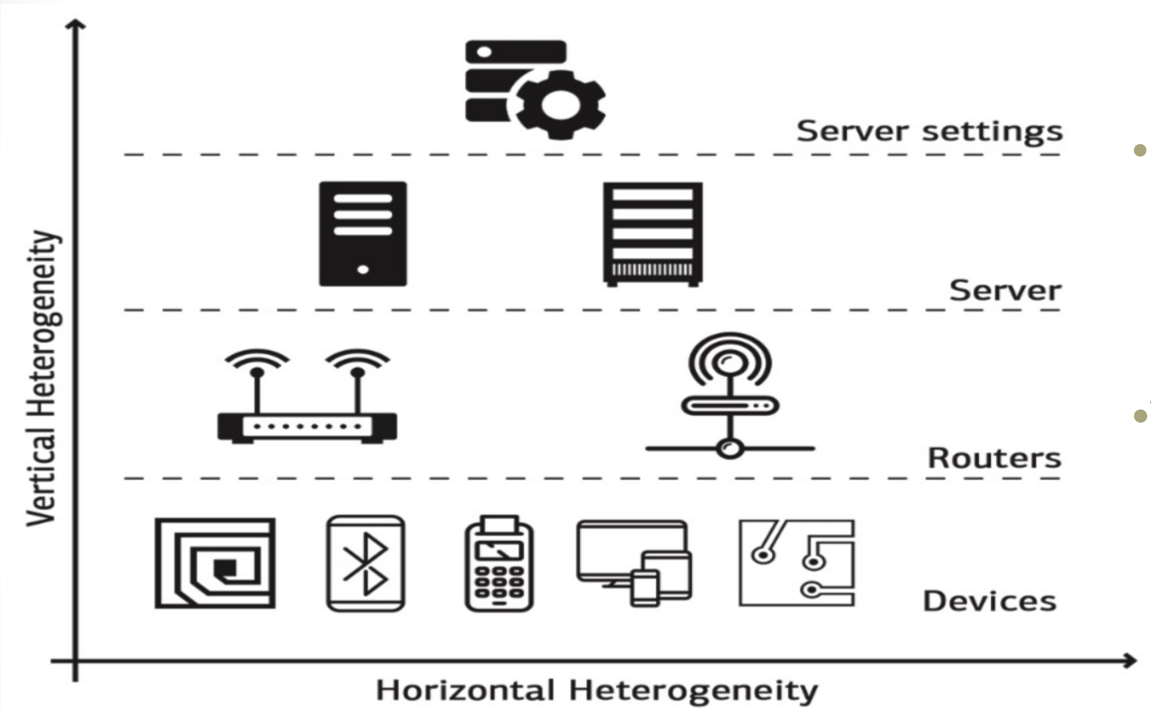
IoT hardware heterogeneity

Source: lowdown.carphonewarehouse.com

IoT hardware heterogeneity

Source: Google Images

Heterogeneity axis of IoT

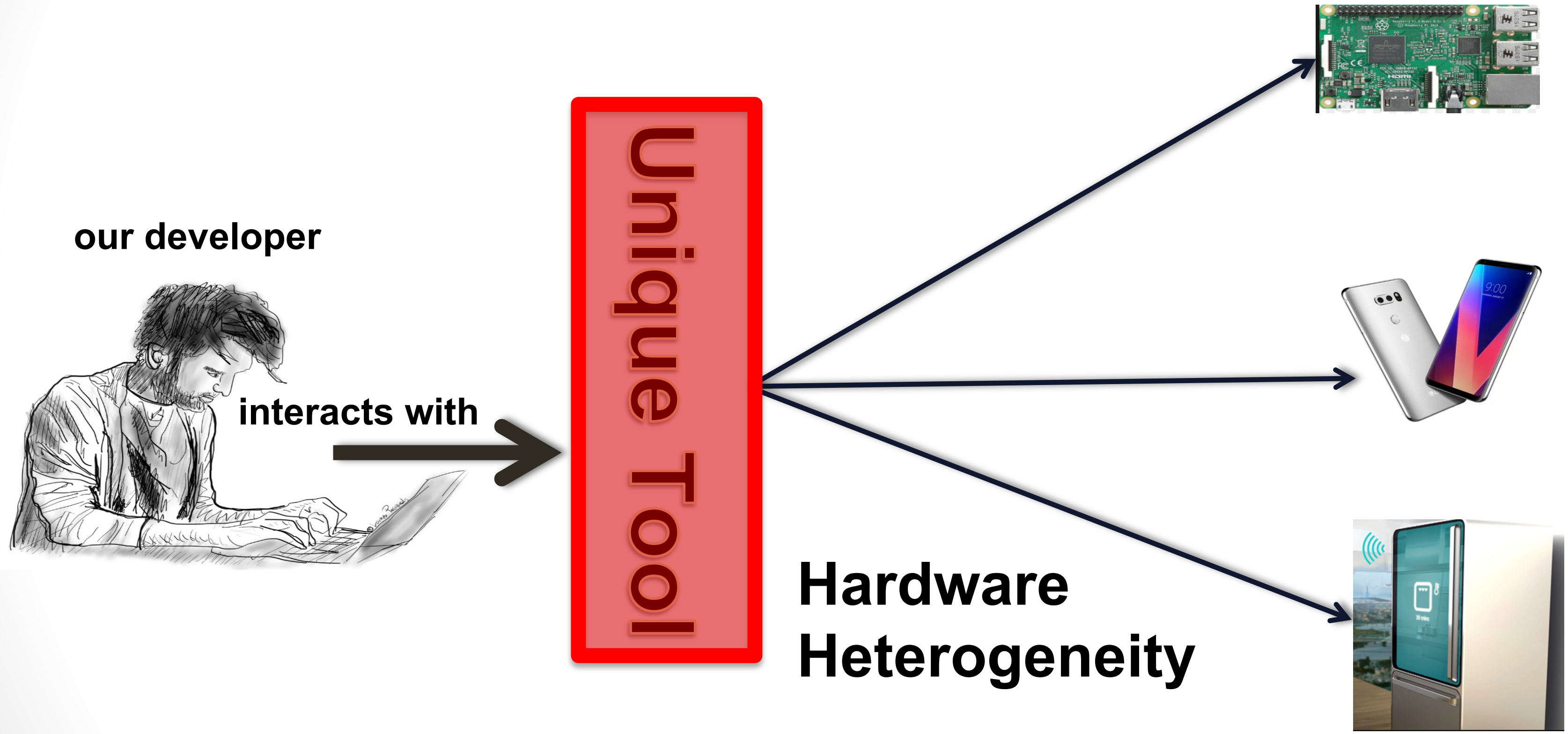


- **Horizontal**: Heterogeneity within classes of devices (e.g. Android and IOS smartphones)
- **Vertical**: across classes of devices (they have distinct memory and processing power - constrainsts)

Source: Aleksandrovics, V.; Filiccevs, E.; Kampars, J.; Internet of Things: Structure, Features and Management. Journal of Information Technology and Management Science , 2016 vol. 19, pp. 78–84

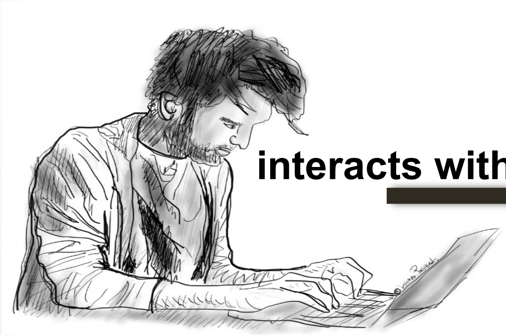
The solution for such a heterogeneous environment?

A unique tool for IoT Hardware Heterogeneity



The need for a unique tool
Software Heterogeneity

our developer



interacts with

Unique Tool

Java
Components

MSCOM,
XPCOM

500 × 477 - tudoinformaticawd.blog...

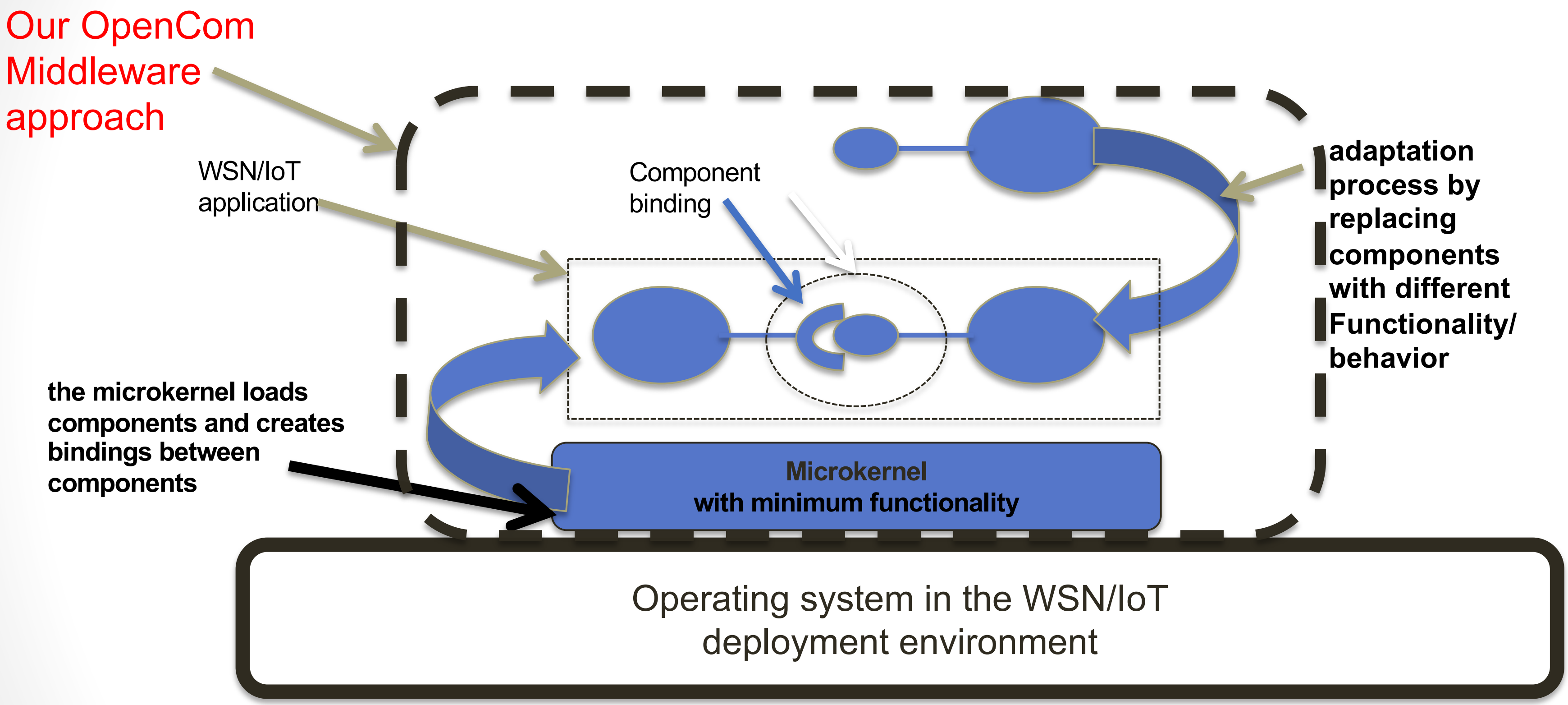
Component-based
Software Heterogeneity

A tailorable platform to target Hardware and Software

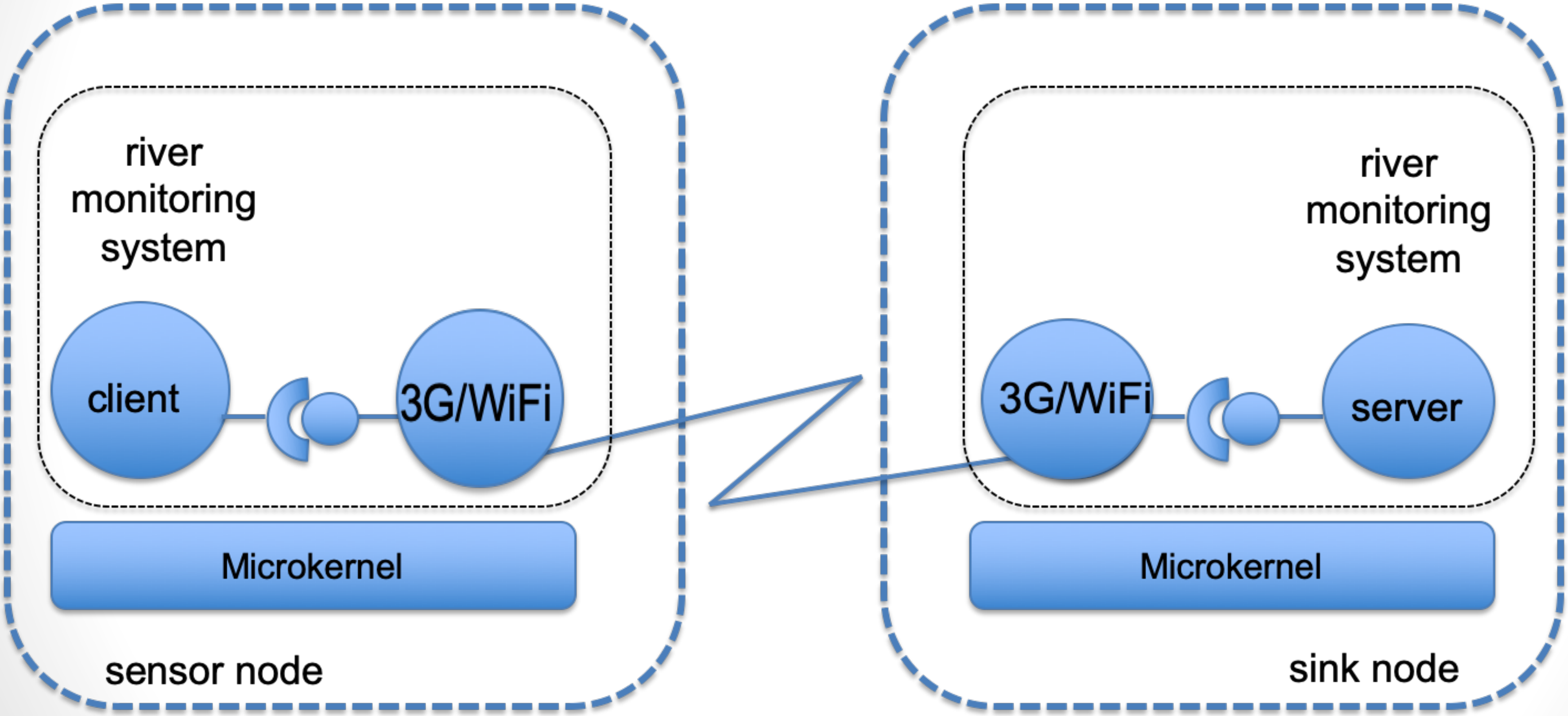
- Components are deployable to extend the software to the targted:
  - **Hardware environment**
    - Sensors, smartphones, UAVs, desktops, etc.
  - **Software platform**
    - Multithreaded, EJB components, .NET components

- Likewise new loaders and binders can be constructed
  - All deployable by the minimal microkernel

Overall Architecture



Application in a WSN



Key publications

- COULSON, G.; BLAIR, G.; GRACE, P.; TAIANI, F.; JOOLIA, A.; LEE, K.; UEYAMA, J.; SIVAHARAN, T. A generic component model for building systems software. **ACM Transactions on Computer Systems**, v. 26, p. 1-42, 2008 **(~300 citations**)

- COULSON, G.; BLAIR, G.; GRACE, P.; TAIANI, F.; JOOLIA, A.; LEE, K.; UEYAMA, J.; GOMES, A. T. A.; YIMIN, Y. NETKIT: a software component-based approach to programmable networking. **ACM SIGCOMM Computer Communication Review.** v. 33, p. 55-66, 2003 **(~170 citations**)

- UEYAMA, J.; MADEIRA, E. R. M. ; TAIANI, F.; CAMARGO, R. Y.; GRACE, P.; COULSON, G. Exploiting a generic approach to construct component-based systems software in Linux environments. **International Journal of Software Engineering and Knowledge Engineering**, v. 20, p. 843, 2010.

- UEYAMA, J.; TAIANI, F.; COULSON, G. ; MADEIRA, E. R. M.; GRACE, P. Component-based System Software: A Generic Approach. In: XXI Simpósio Brasileiro de Engenharia de Software (**SBES**), 2007 – ***segundo melhor artigo***

Technological contribution

e-NOE – Using wireless sensor network and IoT for flood monitoring in urban creeks

Institutes: ICMC/USP, EESC/USP, USC, KUL – Bélgica
Coordination: ICMC/USP

The first devised WSN-based river monitoring system in Brazil

- Sun SPOT based, plus:
  - Solar: solar array
  - Battery: back-up battery

- Diverse range of sensors:
  - Pollution: methane, conductivity, turbidity
  - Depth: hydrostatic level sensors
  - Tampering: vibration-based tamper sensors

source: Google Images

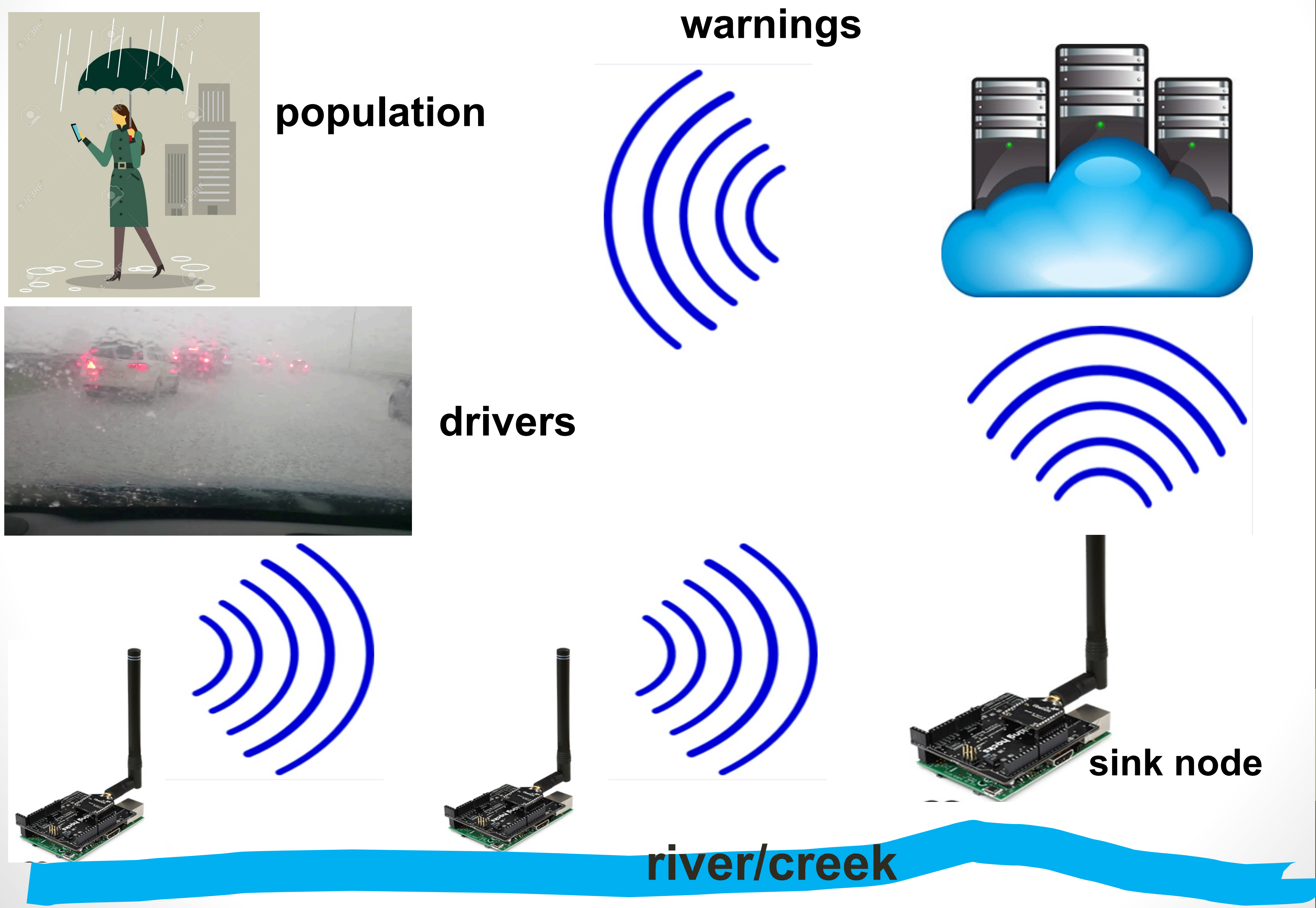
Show sensor diversity

- Arduino
- Raspberry
- PIC-powered Single Board Computer
- Pressure sensor
- Conductivity
- Turbidity (show our turbidity sensor)
- IP Camera

Network diversity

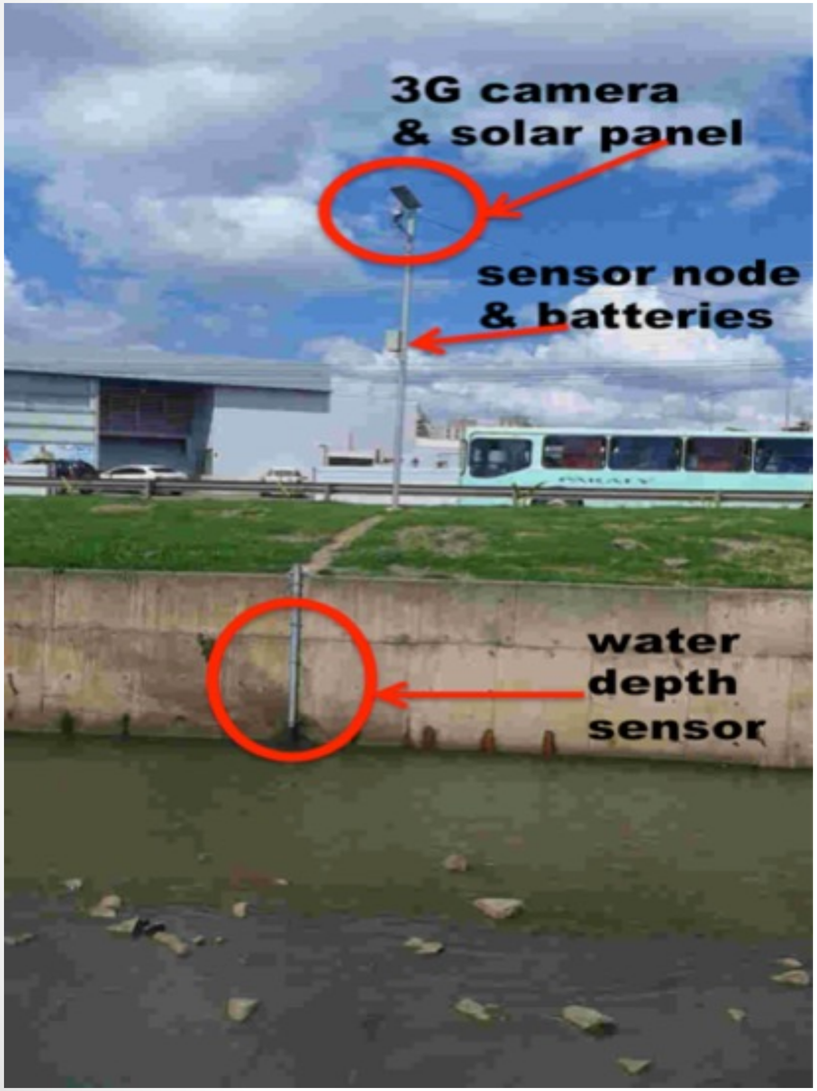
- 3G network
- Ethernet
- ZigBee

eNOE – How does it work?

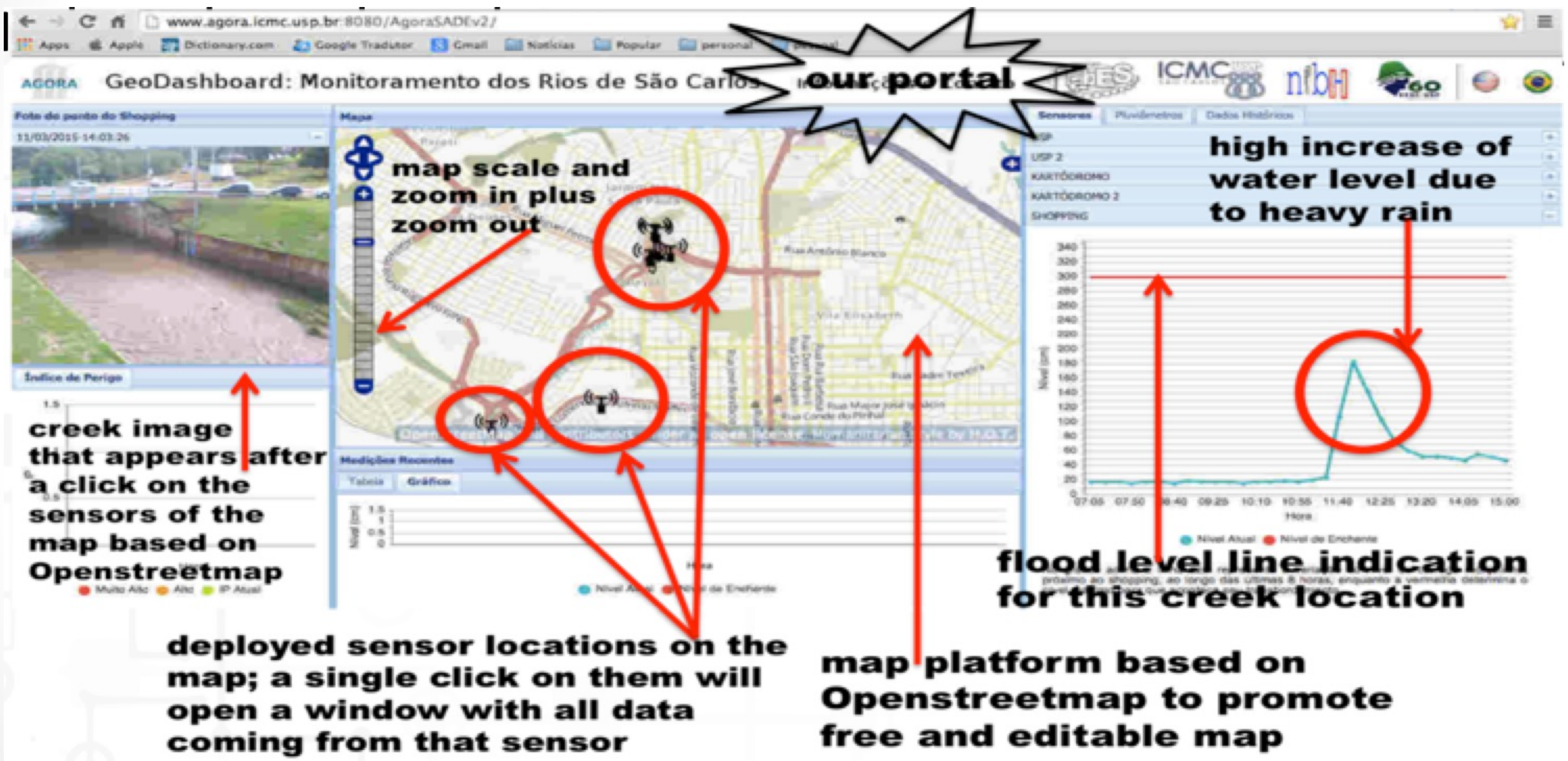


Node deployment with camera

Node deployment with camera



Our frontend system



Real flood detection

Real flood detection

Real flood detection

Real flood detection

Real flood detection

Real flood detection

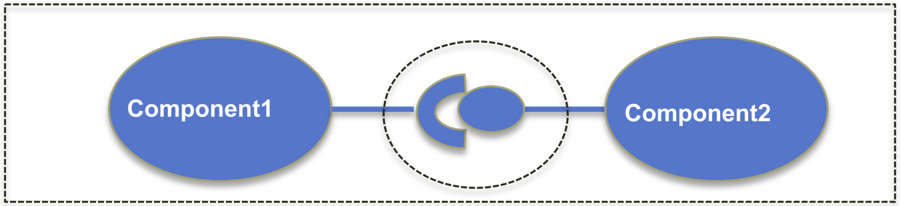
Real flood detection

Is our approach well suited for hostile environments?

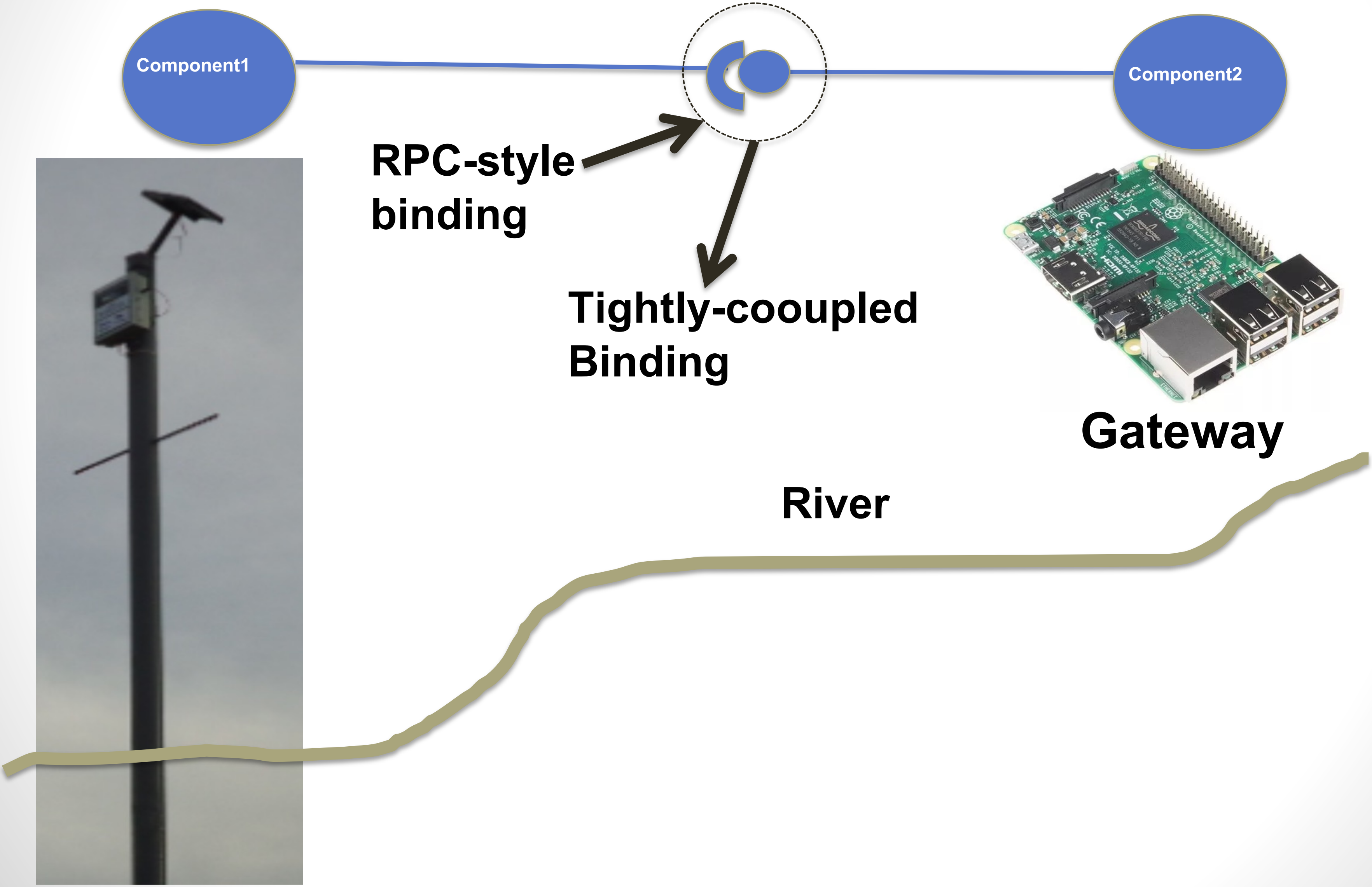
- In particular the binding model?
- i.e., the connection between components?
- Components here are unreliable and may disappear

Problem with the Binding model

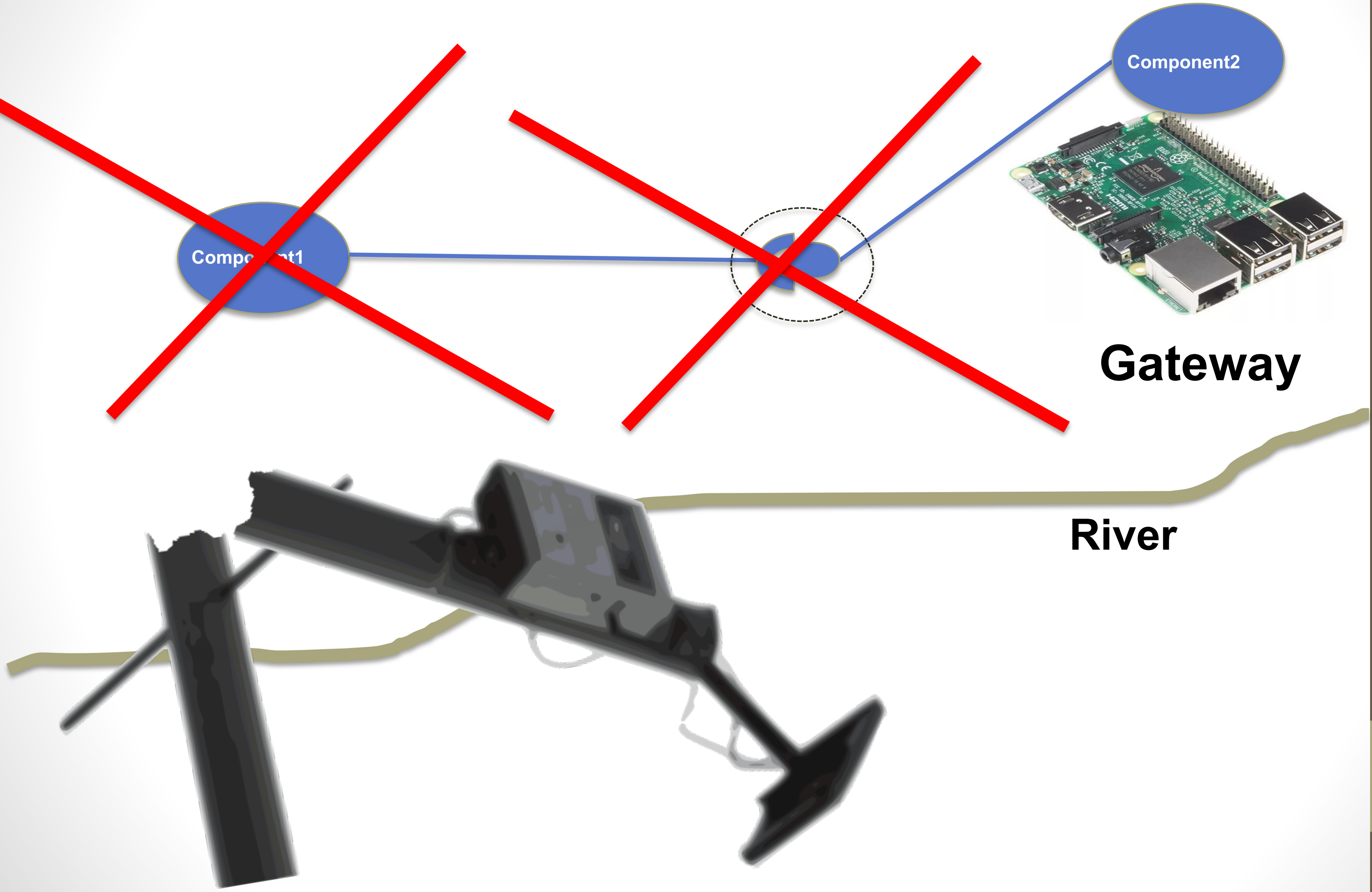
- OpenCom binding are tightly-coupled
- It is not well-suited for IoT systems in hotile environments
- It is implemented as a RPC invocation



Is our approach well suited?



What if the node is destroyed?

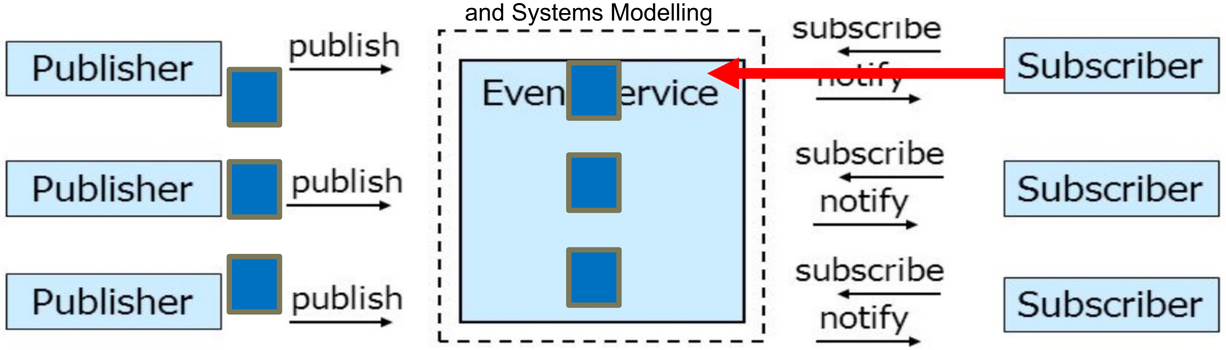


One possible solution: a loosely-coupled component model

- Component model with an **pub-sub bindings**
- Similar to Facebook posts

Hughes, D.; UEYAMA, J.; MENDIONDO, E. M.; MATHYS, N.; HORRE, W.; MICHELS, S.;
A middleware platform to support river monitoring using wireless sensor networks.
Journal of the Brazilian Computer Society, v. 17, p. 85-102, 2011.

Image source: Rathfelder, C. et.al. 2010 Modelling Event-based Communication in Component-based Software Architectures for Performance Predictions. Journal on Software and Systems Modelling



Gateway

Image source: Google Images

Key journal publications

- Hughes, D.; Thoelen, K.; Horré, W.; Matthys, N.; Del Cid, J.; Michiels, S.; Huygens, C.; Joosen, W.; Ueyama, J. Building Wireless Sensor Network Applications with LooCI**. International Journal of Mobile Computing and Multimedia Communications**, v. 2, p. 38-64, 2010

- Hughes, D.; Ueyama, J.; Mendiondo, E.; Matthys, N.; Horré, W.; Michiels, S.; Huygens, C.; Joosen, W.; Man, K.L.; Guan, S. A middleware platform to support river monitoring using wireless sensor networks**. Journal of the Brazilian Computer Society** (Impresso), v. 17, p. 85-102, 2011

- UEYAMA, J.; FAICAL, B. S. ; MANO, L. Y. ; BAYER, G. ; PESSIN, G. ; GOMES, P. H. Enhancing reliability in Wireless Sensor Networks for adaptive river monitoring systems: Reflections on their long-term deployment in Brazil. Journal of Computers Environment and Urban Systems, v. 65, p. 41-52, 2017 **JCR 3.724**

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REPÚBLICA FEDERATIVA DO BRASIL
MINISTÉRIO DA INDÚSTRIA, COMÉRCIO EXTERIOR E SERVIÇOS
INSTITUTO NACIONAL DA PROPRIEDADE INDUSTRIAL
DIRETORIA DE PATENTES, PROGRAMAS DE COMPUTADOR E TOPOGRAFIA DE CIRCUITOS INTEGRADOS

CERTIFICADO DE REGISTRO DE PROGRAMA DE COMPUTADOR

Processo: BR 51 2016 001777-5

O INSTITUTO NACIONAL DA PROPRIEDADE INDUSTRIAL expede o presente Certificado de Registro de Programa de Computador, **válido por 50 anos** a partir de 1º de janeiro subsequente à data de criação indicada, em conformidade com o parágrafo 2º, artigo 2º da Lei Nº 9.609, de 19 de Fevereiro de 1998, e arts. 1º e 2º do Decreto 2.556 de 20 de Abril de 1998.

Título:	**E-NOE - SOFTWARE DE UMA REDE DE SENSORES SEM FIO PARA O MONITORAMENTO DE RIOS URBANOS**
Criação:	23 de janeiro de 2010
Titular(es):	UNIVERSIDADE DE SÃO PAULO (63.025.530/0001-04)
Autor(es):	BRUNO SQUIZATO FAIÇAL (049.257.109-07) GUILHERME SOTTO-MAIOR BAYER (389.696.468-25) JÓ UEYAMA (295.216.702-82) LEANDRO YUKIO MANO ALVES (313.928.108-09)
Linguagem:	LINGUAGEM C
Aplicação:	IF-02, IF-07, MA-04, SM-04
Tipo Prog.:	CD-04, IA-02, SO-06, SO-07, TC-01

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Media coverage

A12 | CORREIO POPULAR

Ciência, tecnologia e inovação

Cenário XXI

RAC

PETROBRAS

Sistema ajuda a prevenir enchentes

Equipamento composto por rede de sensores sem fio e microcomputador pode salvar vidas

Sensores avaliam grau de poluição

Um sensor extra detecta tentativas de furto do produto

Cientista gastou apenas R$ 250,00 no protótipo

Pesquisador propõe instalação de kits no Rio Tietê

Tecnologia

Alerta de enchente em tempo real

Pesquisador da USP desenvolve ferramenta que transmite por SMS informações sobre a cheia de rios a moradores em locais de risco. A alimentação dos sensores por energia solar é outro atrativo do sistema

"Com a integração dos sistemas de GPS, os locais alagados poderão ser evitados pelos veículos"

Jó Ueyama, criador do sistema

Emergenciais

Áreas degradadas como a do Rio Mundaú, em Alagoas, podem ser monitoradas pelo sistema

Media coverage
Revista Pesquisa FAPESP

Alerta contra inundações

Sistema desenvolvido na USP pode ajudar a reduzir transtornos gerados pelo transbordamento de rios urbanos

Yuri Vasconcelos

A cena se repete a cada verão. As chuvas que caem durante essa época do ano elevam o nível dos rios e causam enchentes, colocando em risco vidas humanas e gerando prejuízo para quem vive às margens dos cursos d'água. No último período chuvoso, entre novembro de 2016 e abril de 2017, ocorreram 55 inundações em São Paulo, média de uma a cada três dias, segundo o Centro de Gerenciamento de Emergências (CGE) da prefeitura. Os alagamentos não afetam apenas os moradores da capital paulista. Belo Horizonte, Recife, Campinas e muitas outras cidades brasileiras sofrem com os transbordamentos.

Para lidar com o problema, órgãos de defesa civil e gestão de recursos hídricos, como a Agência Nacional de Águas (ANA), empregam um conjunto de ferramentas para monitorar o nível e a vazão dos rios e alertar a população para o risco de alagamentos. Esse aparato é composto por radares meteorológicos, imagens de satélite, pluviômetros, modelos numéricos de previsão de chuvas e plataformas de coleta de dados para medição do nível de cursos d'água. A fim de contribuir para esse sistema de prevenção e alerta, pesquisadores da Universidade de São Paulo (USP) criaram o e-Noé, uma rede de sensores sem fio para monitorar rios e córregos urbanos.

O dispositivo, já operacional, é formado por um conjunto de sensores submersos instalados em vários pontos do rio sujeitos a alagamentos. Conectados entre si por uma rede sem fio, esses sensores detectam alterações na altura da coluna d'água. Paralelamente, câmeras fotografam o leito do rio, registrando o nível das águas. As imagens e as informações dos sensores são enviadas por sinal de celular para uma infraestrutura de nuvem, onde são acessadas pela Defesa Civil da cidade (*ver infográfico ao lado*).

"Diferentemente da hidrometria convencional, em que os dados só são coletados quando o usuário vai até a estação para extraí-los, numa rede de sensores sem fio, como a nossa, as informações são transmitidas em tempo real para os interessados. O próprio sistema pode emitir automaticamente alertas de enchentes", afirma o cientista da computação Jó Ueyama, do Instituto de Ciências Matemáticas e de Computação da USP de São Carlos e coordenador do projeto. "O nosso modelo, diferentemente de alguns similares importados, também faz previsão de enchentes usando mecanismos de inteligência artificial, como as redes neurais, e permite incorporar sensores de poluição, o que pode ser de grande valia para monitorar a qualidade da água."

Segundo Ueyama, o e-Noé já foi testado com bons resultados nos córregos Monjolinho e Tijuco Preto, de São Carlos, que costumam transbordar, e continua sendo aprimorado. "Vamos investir em energia solar e em baterias de alta capacidade para garantir o fornecimento de energia ao sistema. Estamos em contato com o Instituto Eldorado, de Campinas, que demonstrou interesse em fazer essas adaptações e comercializar o equipamento", conta. O sistema completo, com sensor de pressão, câmera, software para processamento das informações, rede sem fio e modem de telefonia 4G, deverá custar R$ 15 mil, segundo estima Ueyama. "Para cada ponto com risco de alagamento, é preciso instalar um sensor", diz o pesquisador, acrescentando que administrações municipais ou estaduais, responsáveis pelo monitoramento de rios urbanos, e a ANA, encarregada da gestão dos recursos hídricos, são os potenciais clientes da tecnologia.

Alagamento na marginal Tietê leva o caos ao trânsito

By smart, we mean ...

- In a nutshell:
  - How to make a smarter IoT?
- By smart, we mean:
  - Sensitive
  - Intelligent

What about Computational Intelligence?

- Make computers reason and decide
- Evolution
- Data mining
  - Big Data
  - Need integration with Cloud and IoT Sensors
- Two phases:
  - Training
  - Production
- Neural Networks, SVM, Deep Learning, etc.

In this particular research work

- The use of computacional intelligence is to:
  - Extract the key features of collected data set
  - And then use low overhead techiniques for data classification

- Which techiniques we investigated and tested to extract such key features?
  - Chaos Theory
  - Genetic Algorithm

In this particular research work

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But what is Chaos Theory?

- Techinique that finds patterns, fractals and repetitions that are sensitive to the initial conditions

- It helps us in selecting attributes and values of a data set

- That way, we exclude the training step of Machine Learning techiques

- Checkout this example of use

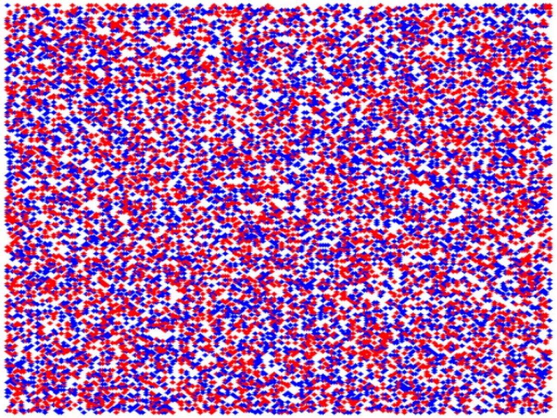
Example of use

- The red cars and blue cars take turns to move

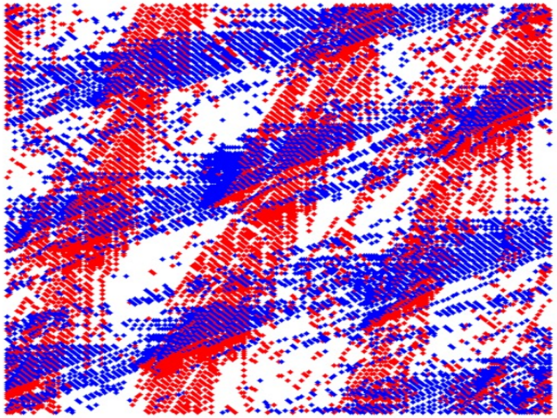
- the red ones only move upwards, and the blue ones move rightwards
- Every time, all the cars of the same color try to move one step if there is no car in front of it

source: Biham–Middleton–Levine traffic model, link http://en.wikipedia.org/wiki/Biham-Middleton-Levine_traffic_model

Initial position



After many iterations



Back to our river monitoring system

- Detecting floods is great ☺
- But, forecasting them beforehand would be even greater ☺
- So that we can timely:
  - Remove population at risk
  - Divert traffics bringing alternative routes
  - Reduce material and life losses

- Also mitigate using alerts and UAVs for this matter
- So let's dive into our flash-flood forecasting approach

- We constructed and made experiments with real data
- Partnership with the São Carlos City Hall

Prefeitura Municipal de São Carlos

Our Approach for flood forecasting

Phase I – Analyzing the time series

- Analyse the time series to **extract the main features**
- It **removes noises** that can hinder the accuracy levels
- It **helps understand** the time series behaviour (e.g. read dependencies)
- It **reconstructs the time series** in a multidimensional space

- We relied on Chaos Theory for the pre-processing of the historical time series consisting of:
  - Date of the reading
  - Location of the sensor
  - Creek height, etc.

Our Approach for flood forecasting

Phase I – Analyzing the time series

- After a good amount of research we proposed the use of the **Chaos Theory**
- Mainly because it helps in analyzing the big time series that we have
- Recap, we read river data every 5 minutes from all sensors

So let's see how it works

Our Approach for flood forecasting

Phase II – Use of the machine learning techiniques

- With the time series in hand
- We used them to run our forecast model
- We tested several techiniques such as Artificial Neural Networks, SVM and MLP

- After a good amount of research, we found out that the best results came from **Chaos Theory** and **MLP** for predicting floods

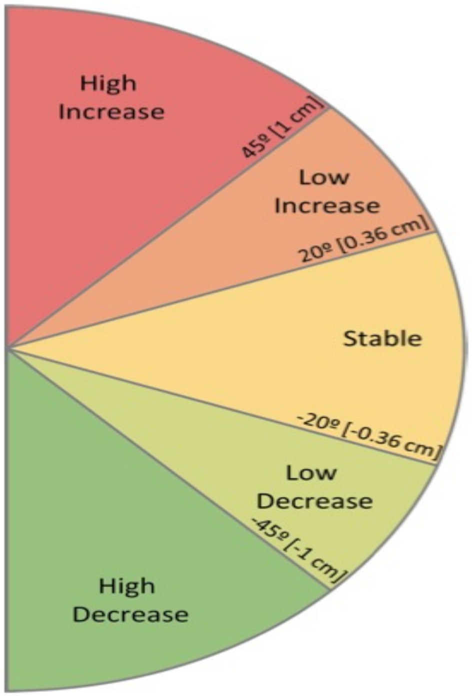
- We also added other variables that helped with our results (e.g. rain gauge)

Our Approach for flood forecasting

Phase II – ML and Classification

- We defined the classification model to establish in which cluster the next reading would fall to:

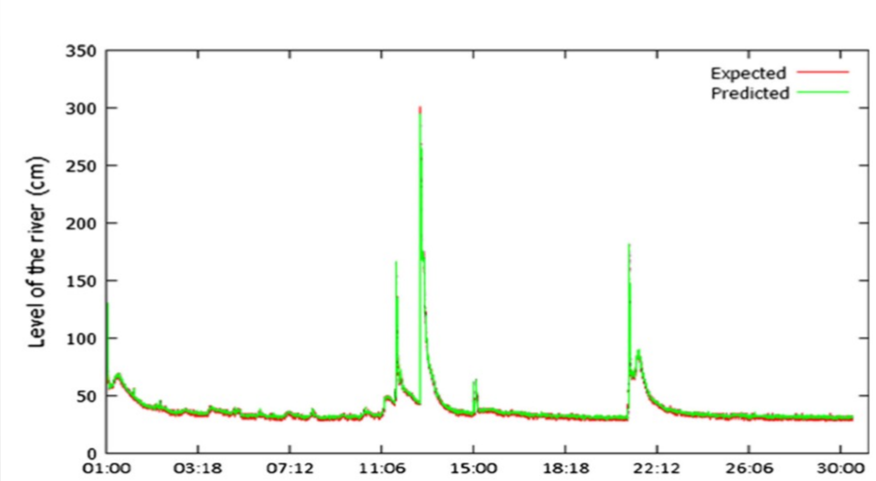
  - High increase
  - Low increase
  - Stable
  - Low decrease
  - High decrease

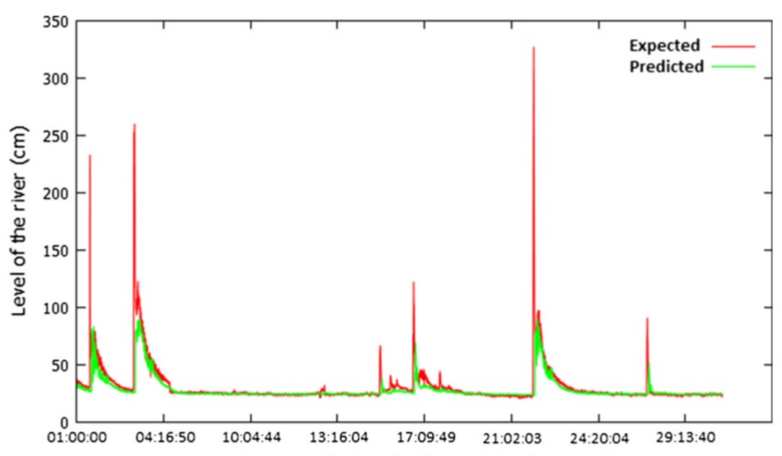


Our Approach for flood forecasting

Results of nowcasting

- We managed to have a good prediction up to 20-minute ahead forecasting
- Need to improve when it comes to an 1-hour nowcasting ☹
- Problems with the “sudden changes”

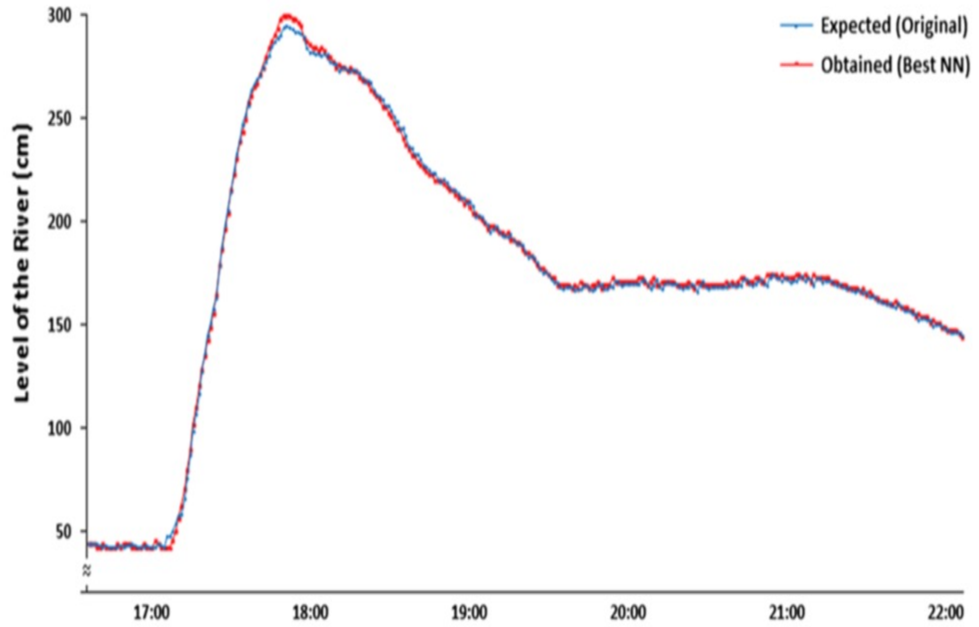




Our Approach for flood forecasting

With the rain gauge:

- It does help with accuracy
- Prediction of 30-minute flash-floods
- Still problems with sudden changes



Key publication

- FURQUIM, G. A.; PESSIN, G.; FAICAL, B. S.; MENDIONDO, E. M.; UEYAMA, J.; “Improving the accuracy of a flood forecasting model by means of machine learning and chaos theory: A case study involving a real wireless sensor network deployment in Brazil”; **Journal of Neural Computing & Applications** (2016) 27:1129–1141

Using multivariable approach for flood detection

Lucas Augusto Vieira Brito
Jó Ueyama

Using multivariable approach for flood detection

- **Problem:**
  - Most models rely on a single source of data for flood detection

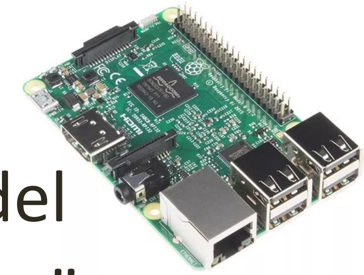
- **Hypothesis:** The use of multi-source can enhance the reliability and also improve resilience

- **Objective:** Use multiple sources such as Climatempo weather forecast website and INPE (national institute for weather forecast) in view of higher reliability

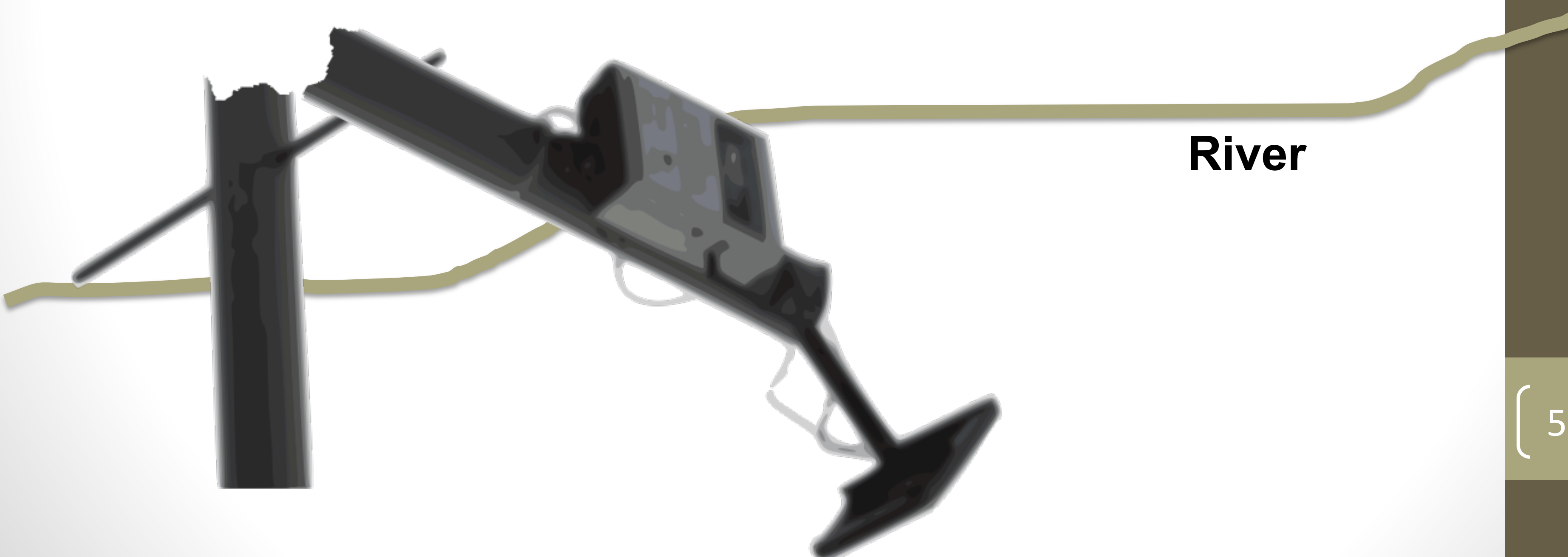
- *In a nutshell, we investigate how the use of data from multiple sources for flood detection helps in reliability*

How can we detect floods in this scenario?

- Counting with data from other sources
- It might provide a more fault-tolerant model
- In particular, if one plataform “breaks down”



Sink node



Experiments with our approach

- Multivariables that we experimented in our approach
- Coming from multiple sources such as Climatempo and INPE
- This includes
  - Maximum temperature
  - Minimum temperature
  - Moisture
  - Precipitation
  - Wind intensity
  - River level (project E- Noé)
  - Basin concentration time

- Data obtained from radars and training replicated 30 times

- Reliability of 95%

Experiments with our approach

- Data Coming from multiple sources such as Climatempo and INPE

- This includes:
  - Maximum temperature
  - Minimum temperature
  - Moisture
  - Precipitation
  - Wind intensity
  - ~~River level (project E- Noé)~~
  - Basin concentration time

- Replicated 30 times
- Reliability of 95%

Obtained Results

Matrix of confusion:

```
=== Confusion Matrix ===

   a   b   <-- classified as
 544 152 |   a = 1
  72 624 |   b = 0
```

SVM (83,7%)

```
=== Confusion Matrix ===

   a   b   <-- classified as
 482 214 |   a = 1
 111 585 |   b = 0
```

MLP (76,7%)

```
=== Confusion Matrix ===

   a   b   <-- classified as
 582 114 |   a = 1
  55 641 |   b = 0
```

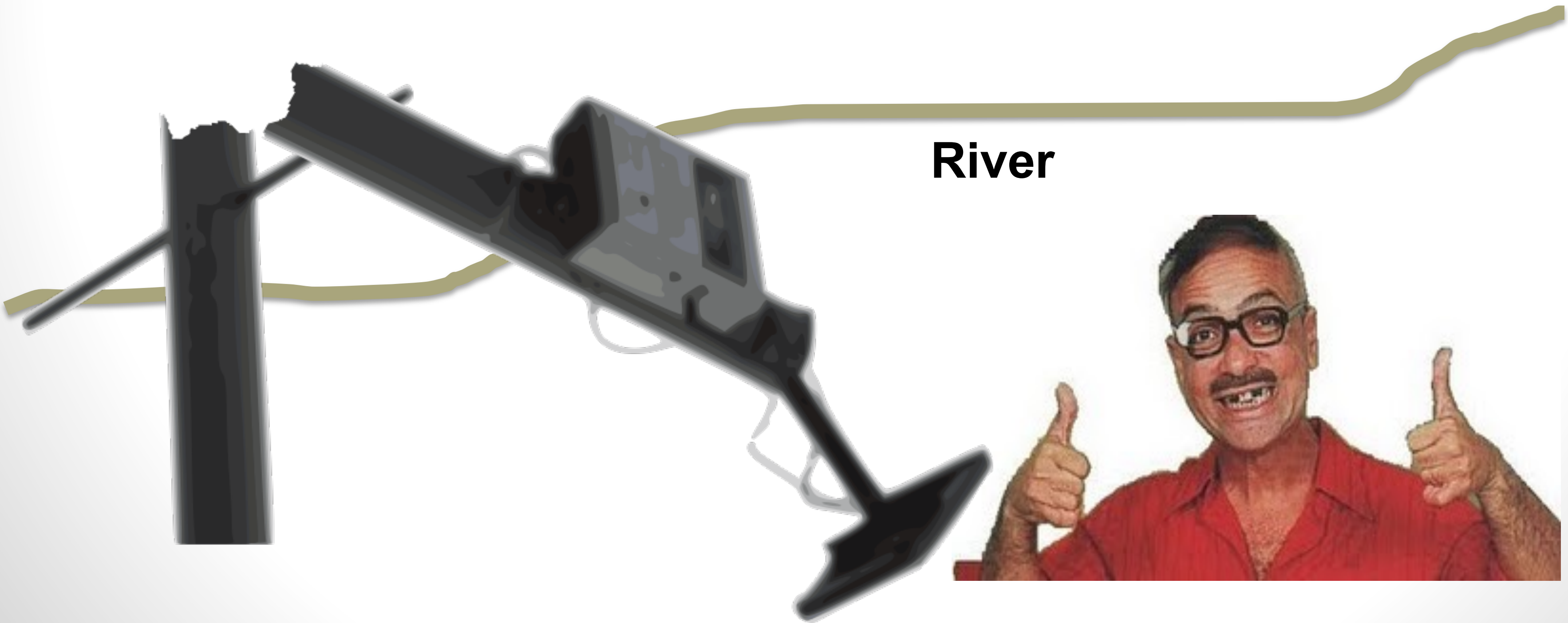
Random Forest (89,9%)

- First we train our model
- And then we run it without the need of our depth sensor node
- This is because we correlate all values

Even in this situation, we can …

- still detect floods given that we investigated the correlation among variables
- This is our so-called multivariable approach

Sink node



Lesson learnt from this research

1. The classification model that uses multivariables (several sources) increases accuracy in flood detection
   - Costly depth sensors can be negligible in this case
   - But needs training before we devise the model

2. In addition, this model has a lower complexity and lower cost
   - When compared to hydrologic models
   - Such models require large amount of computational costs for flood detection

Many Thanks!