

# Railway Smart Meters

## Thesis Research Plan

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# Outline

- 1 Introduction
- 2 Railway Transportation System
  - Power system of Railway Transportation System
  - Train Power Supply System
- 3 Remote Monitoring in Railways
  - Energy transducers and Smart metering in railways
  - Wireless Networks and Decision Support Systems
- 4 Thesis Proposal
  - Architecture of proposed work
  - Non-intrusive self-powered sensor node
  - RTS wireless network
  - Thesis Work Plan
- 5 Preliminary Work
  - Implementation of a point-to-point communication between a moving train and a station
  - Evaluation of the non-intrusive voltage sensor

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# Introduction

## Context and motivation of PhD

### Context and motivation

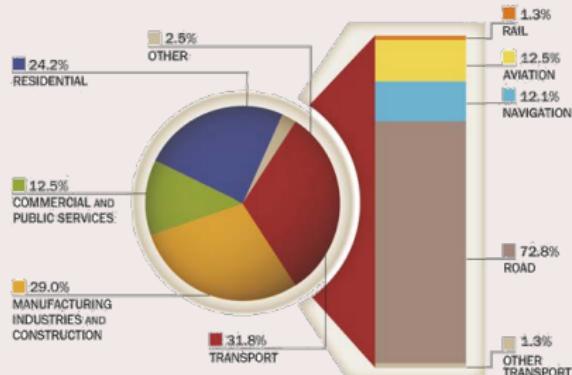


Figure 1: Global Energy Consumption. [1].



Figure 2: Global Transportation Share. [1].

# Introduction

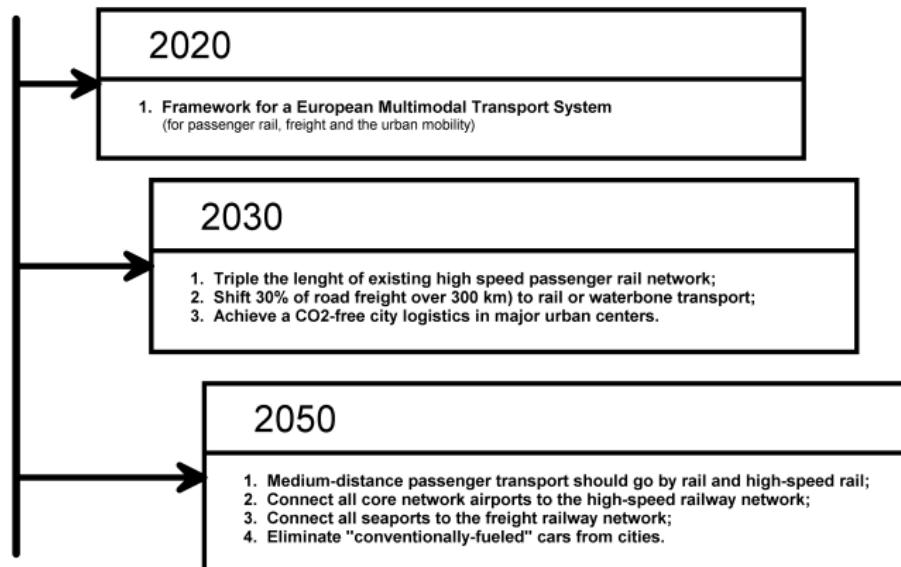
Context and motivation of PhD

## Shift2Rail Framework - Main Goal

- 1. Cutting the life-cycle cost of railway transport by, at least, 50%;
- 2. Doubling the railway capacity;
- 3. Increasing the reliability and punctuality by 50%, at least.

# Introduction

## Context and motivation of PhD



**Figure 3:** Shift2Rail Framework - Time Targets. [2]

# Introduction

## Context and motivation of PhD

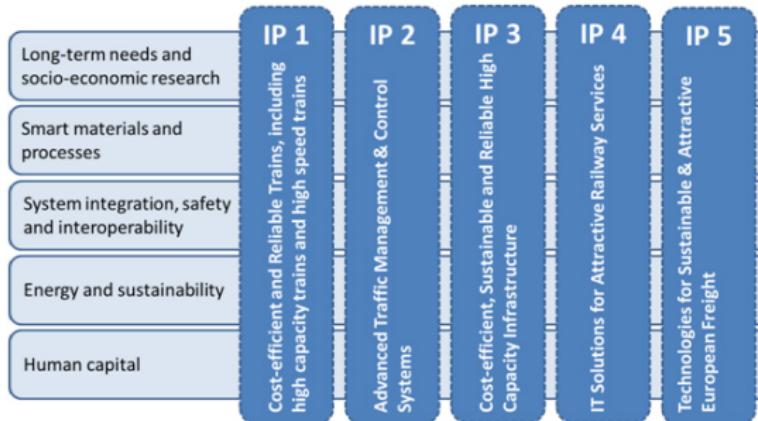


Figure 4: Shift2Rail Framework - Innovation Programmes. [2]

# Introduction

## Context and motivation of PhD

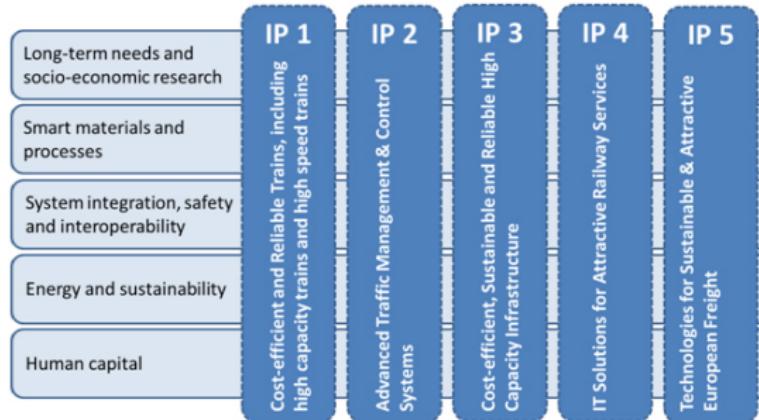


Figure 4: Shift2Rail Framework - Innovation Programmes. [2]

## Smart Meter Demonstrator

- Towards detailed monitoring and supervision of energy flows;

# Introduction

## Objectives

### Objectives

- Research on **railway energy models**, and **development/implementation of a metering system** for railway power flow monitoring. This is expected to be based on a non-intrusive self-powered sensor node inserted into train power system.
- Research on **communication network models** for a Railway Transportation System (RTS) wireless network with **validation through simulation frameworks. Development and implementation** of RTS wireless network to store the energy information data of railway into central database.

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# Power system of Railway Transportation System

## Overview of Existing European Railway Power Systems

Table 1: Catenary topology and vehicle characteristics of different railway vehicles. [3].

	Catenary topology		Vehicle characteristics	
	DC supply	AC supply	Power	Top speed
<b>Tram</b>	600V DC, 750V DC, 900V DC	-	150–300kW	50–70km/h
<b>Metro</b>	750V DC, 1500V DC	-	350kW–1MW	80km/h
<b>Train</b>	750V DC, 1500V DC, 3000V DC	15kV AC (16.7Hz) and 25kV AC (50Hz)	200kW–8MW	120–350km/h
<b>Locomotive</b>	750V DC, 1500V DC, 3000V DC	15kV AC (16.7Hz) and 25kV AC (50Hz)	500kW–8MW	100–200km/h

# Railway Transportation System

## Power system of Railway Transportation System

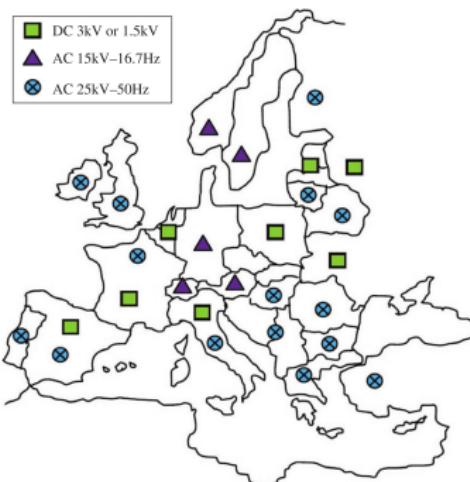


Figure 5: Railway main-line power supply systems in Europe. [3].

# Railway Transportation System

## Power system of Railway Transportation System

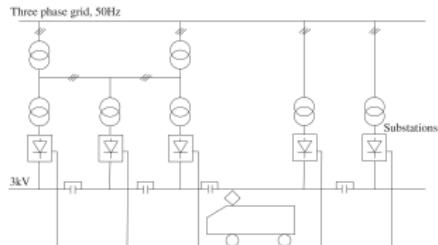


Figure 6: DC supply system architecture. [3].

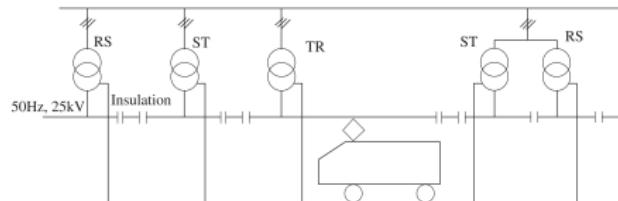


Figure 7: 50 Hz 25 kV supply system. [3].

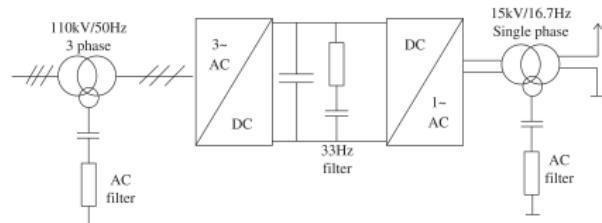
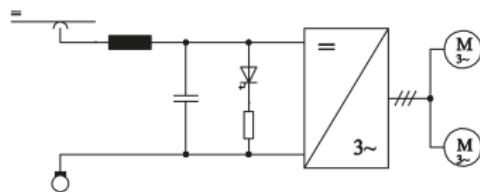


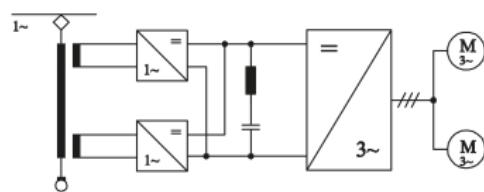
Figure 8: 16.7 Hz 15 kV supply system. [3].

# Railway Transportation System

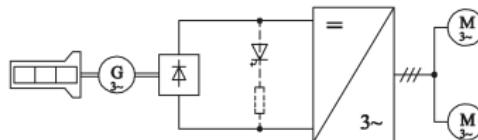
## Train Power Supply System



**Figure 9:** Train internal power circuit of a DC supply system. Adapted from [4].



**Figure 10:** Train internal power circuit of an AC supply system. Adapted from [4].



**Figure 11:** Train internal power circuit of a Diesel electric locomotive with alternator. Adapted from [4].

# Railway Transportation System

## Case study — Series 3400 train

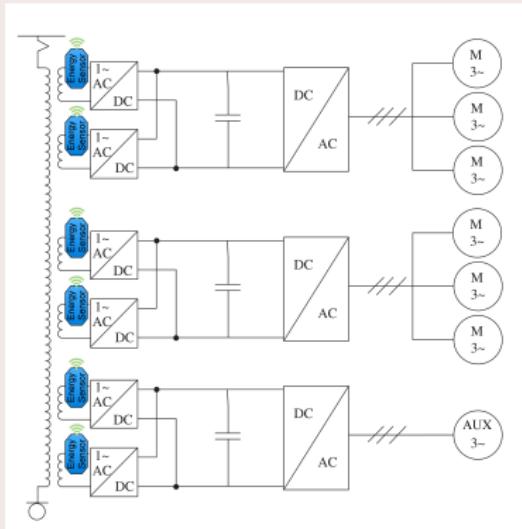


Figure 12: Power architecture of case study train.



Figure 13: Series 3400 case study train.  
Retrieved from *Comboios de Portugal*

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# Remote Monitoring in Railways

## Energy transducers

### Transducers

- Magnetic Coupling
- Magneto Resistance
- Faraday Induction
- Hall Effect



Figure 14: 25 kV current transformer.  
Adapted from [www.railware.it](http://www.railware.it)



Figure 15: 25 kV voltage transformer.  
Adapted from [www.railware.it](http://www.railware.it)

# Remote Monitoring in Railways

## Energy transducers — Power Calculation Function

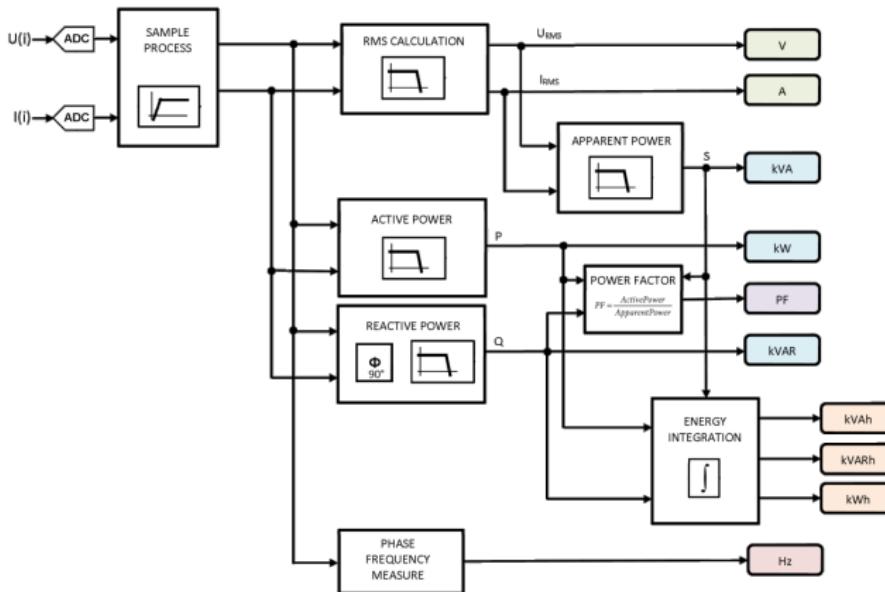


Figure 16: EcoS power calculation function, based on EN50463. Adapted from railware.it

# Remote Monitoring in Railways

## Smart metering in railways

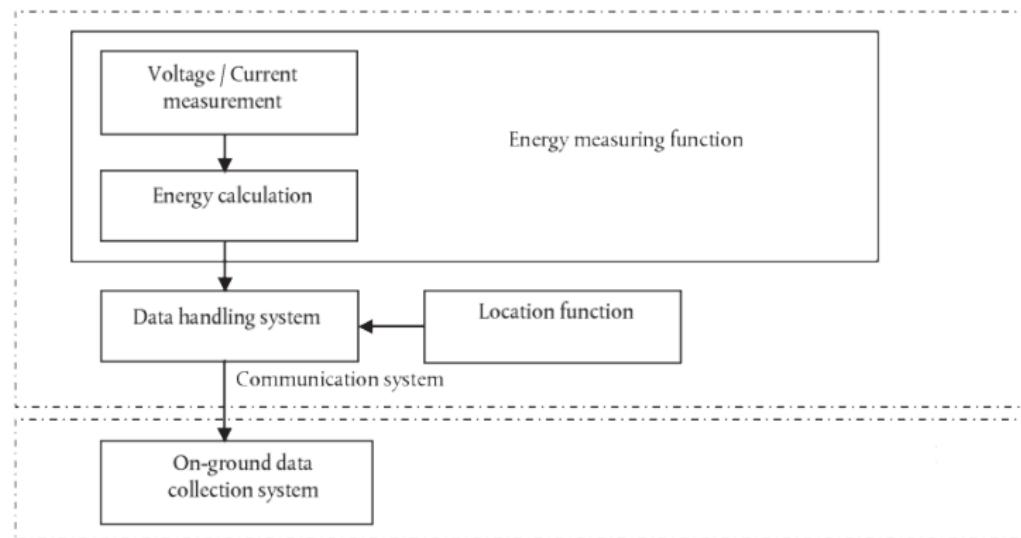


Figure 17: Functions, data flow and regulation scope of on-board energy measurement system.

# Remote Monitoring in Railways

## Wireless Networks

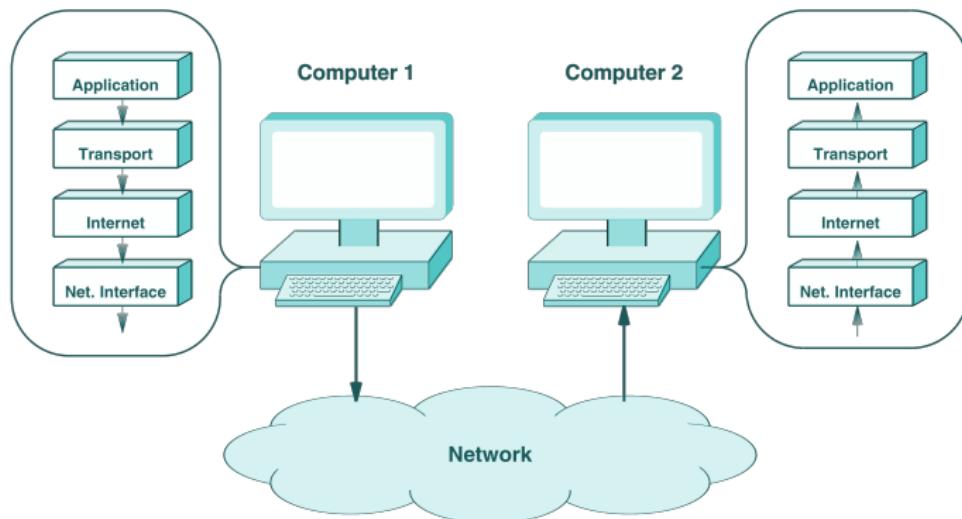


Figure 18: Representation of data flow in a computer network. Adapted from [5].

# Remote Monitoring in Railways

## Wireless Networks — Simulators

### Wireless Networks — Simulators

- NS-3
- OMNeT++
- QualNet 7.0 + EXata 5
- MatLab + Simulink

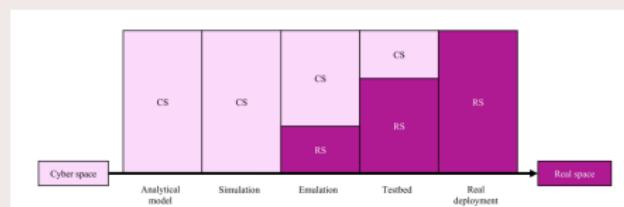


Figure 19: Simulation & emulation framework.

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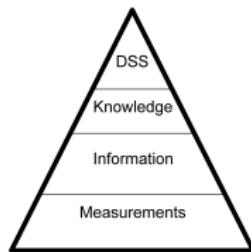
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# Thesis Proposal

## Architecture of proposed work



**Figure 20:** Overall functional architecture of a smart metering system.



**Figure 21:** Data flow of measurement-information layers.

# Thesis Proposal

## Architecture of proposed work

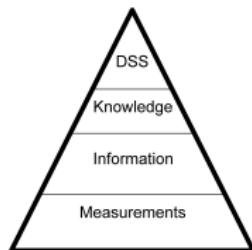


Figure 20: Overall functional architecture of a smart metering system.



Figure 21: Data flow of measurement-information layers.

## Architecture of proposed work

- ① Non-intrusive self-powered sensor node;
- ② RTS wireless network

# Thesis Proposal

## Architecture of proposed work

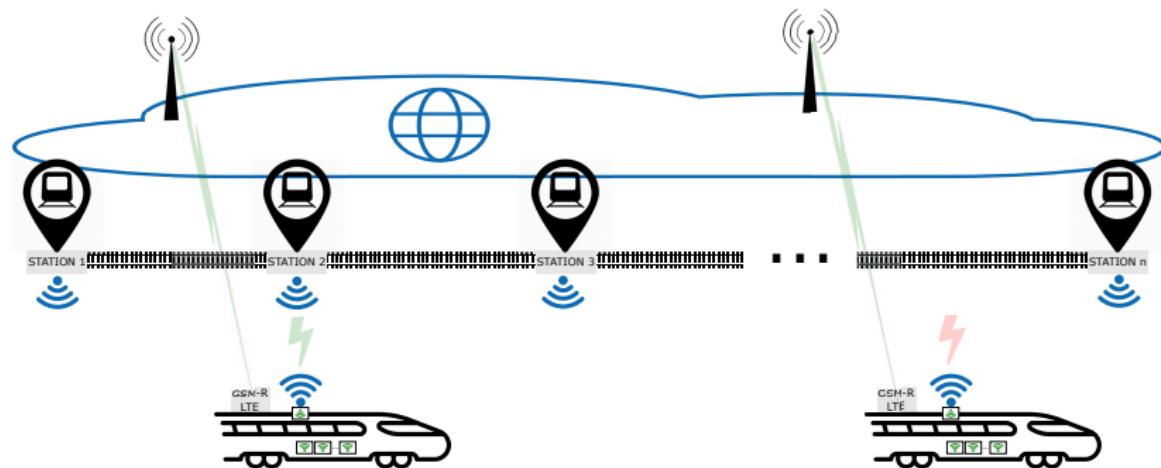


Figure 22: Architecture of proposed work.

# Thesis Proposal

## Non-intrusive self-powered sensor node

### Non-intrusive self-powered sensor node

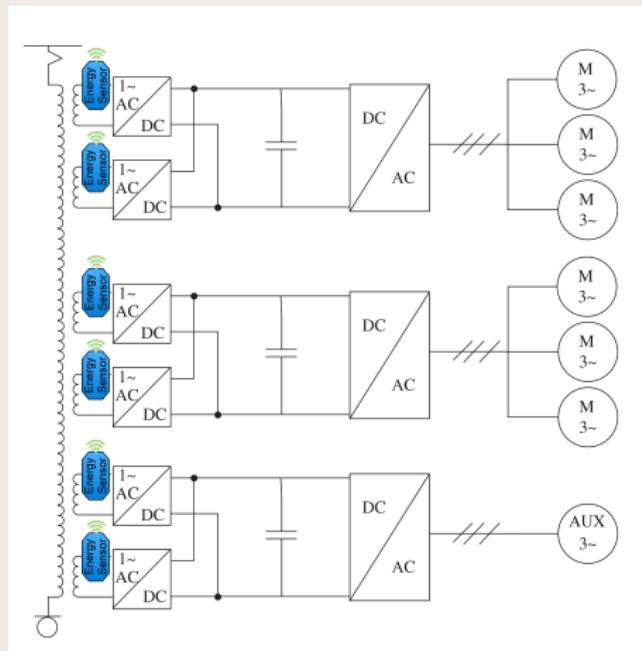


Figure 23: Power architecture of case-study train.

# Thesis Proposal

## Non-intrusive self-powered sensor node

### Non-intrusive self-powered sensor node — Methodology

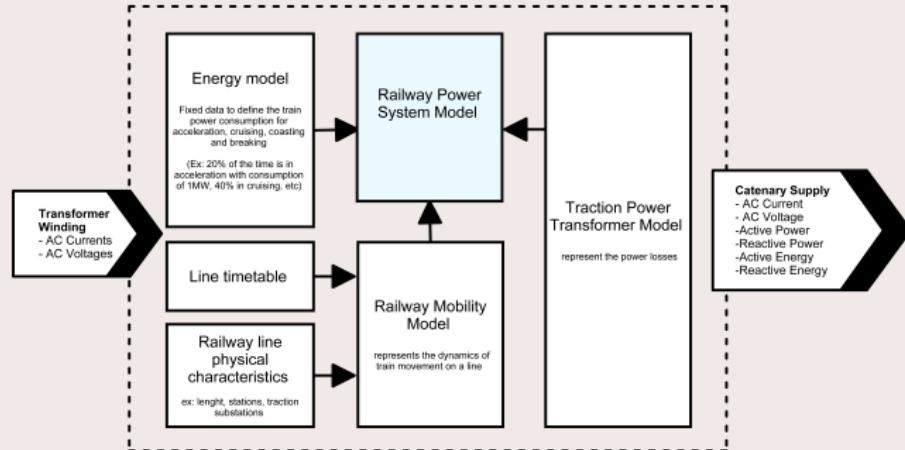


Figure 24: Models needed for simulation. Energy measurement system.

# Thesis Proposal

## Non-intrusive self-powered sensor node

### Non-intrusive self-powered sensor node — Contributions

- **New energy metering architecture**, according to some specifications such as the usage of a non-intrusive approach. This architecture will generate energy information about the power flow of the railway system.
- **Accurate estimation of power flow** into catenary, based on on-board measurements. The available parameters will be: (1) the RMS voltage, current and apparent power, (2) the instantaneous active power, reactive power, power factor and frequency, and (3) the cumulative energy consumptions in terms of kVAh, kVARh and KWh.

# Thesis Proposal

## RTS wireless network

### RTS wireless network

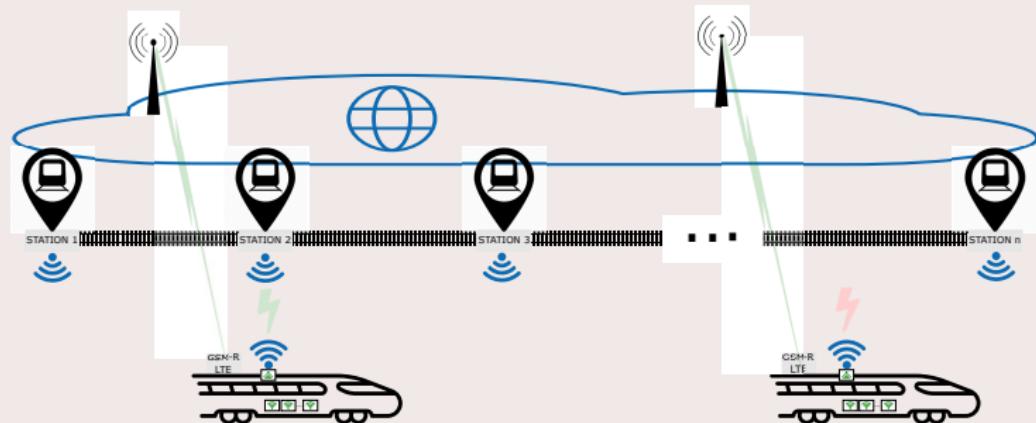


Figure 25: Architecture of proposed work.

# Thesis Proposal

## RTS wireless network

### RTS wireless network — Methodology

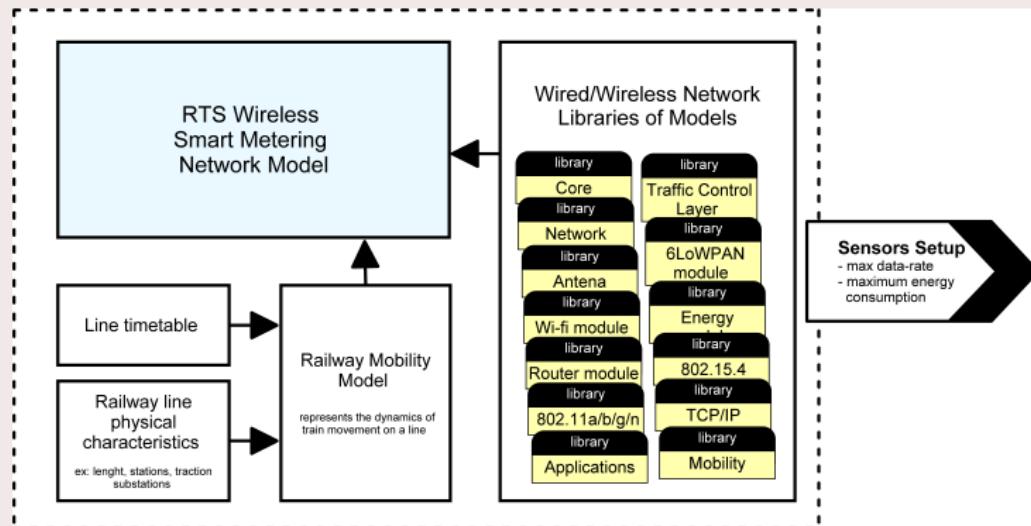


Figure 26: Models needed for simulation - RTS Wireless Network.

# Thesis Proposal

## RTS wireless network

### RTS wireless network — Contributions

- **Availability of measured data** from trains where currently limited/inexistent energy measurement is performed.
- Data-rate increase of energy measurements, which will result on direct **increase on the quality of information of energy**. This increase will overcome the 5-minute data-rate that currently are used in energy meters.
- A further contribution can be the reduction of the dependence of broadband real-time/continuous communication (such as Long-Term Evolution (LTE)), with the direct cost reduction of information transmission of energy RTS data.

# Thesis Proposal

## Work Plan

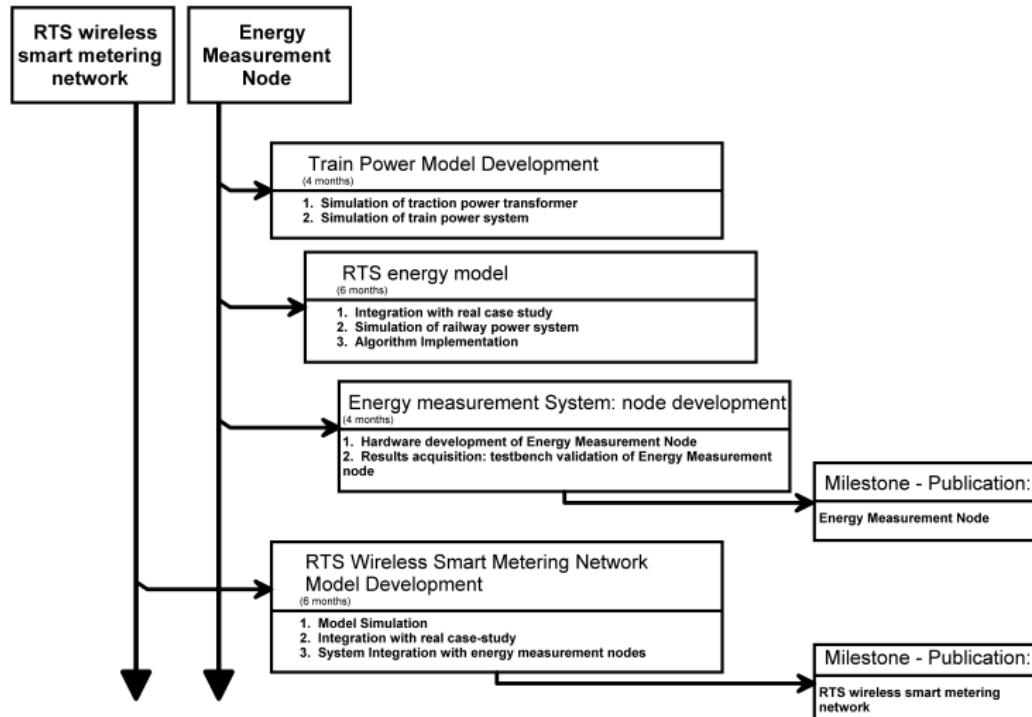


Figure 27: PhD Work Plan.

# Thesis Proposal

## Work Plan

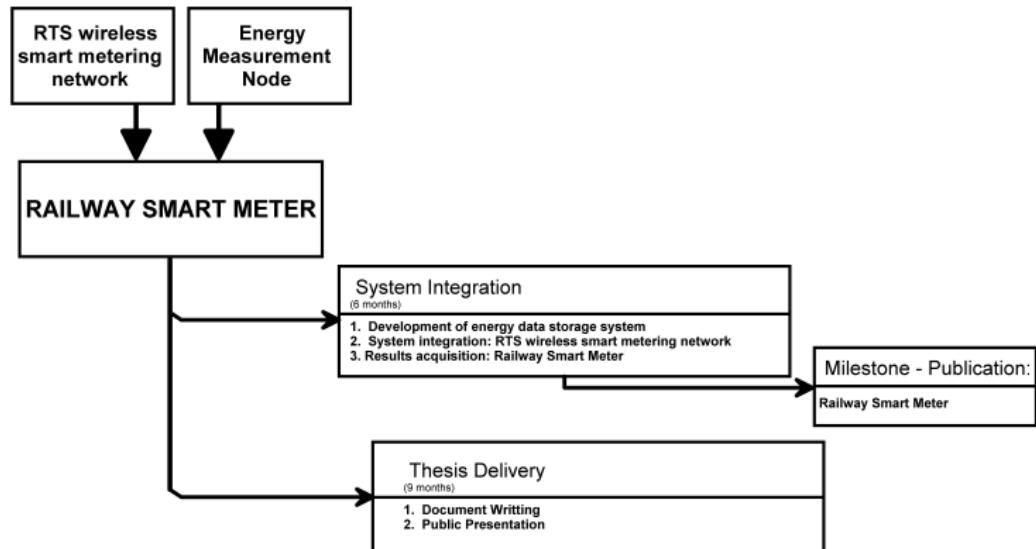


Figure 28: PhD Work Plan.

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# Preliminary Work

Implementation of a point-to-point communication between a moving train and a station

## Implementation of a point-to-point communication between a moving train and a station

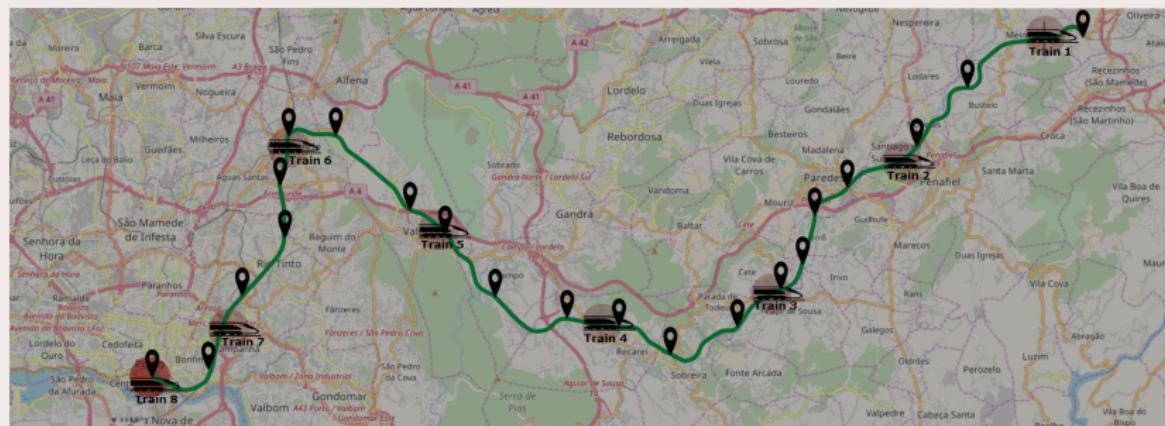


Figure 29: Porto-Caíde railway line: simulation using OMNeT++ network simulator.

# Preliminary Work

Implementation of a point-to-point communication between a moving train and a station

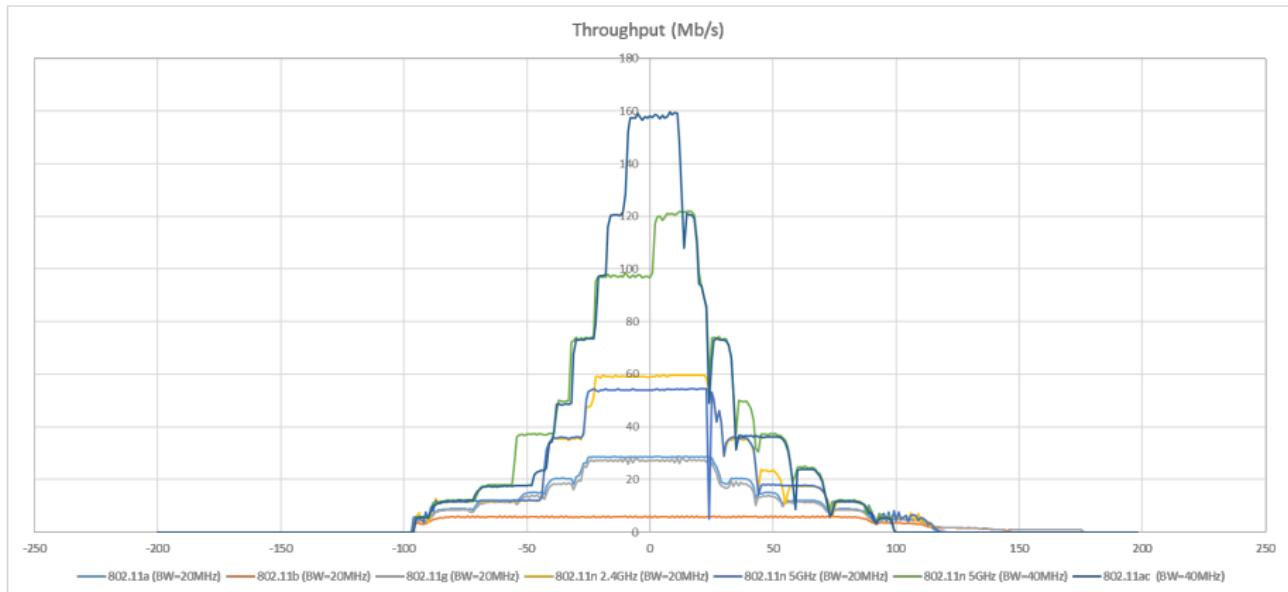


Figure 30: Evaluation of moving node for different 802.11 network standards using NS-3.

# Preliminary Work

Implementation of a point-to-point communication between a moving train and a station

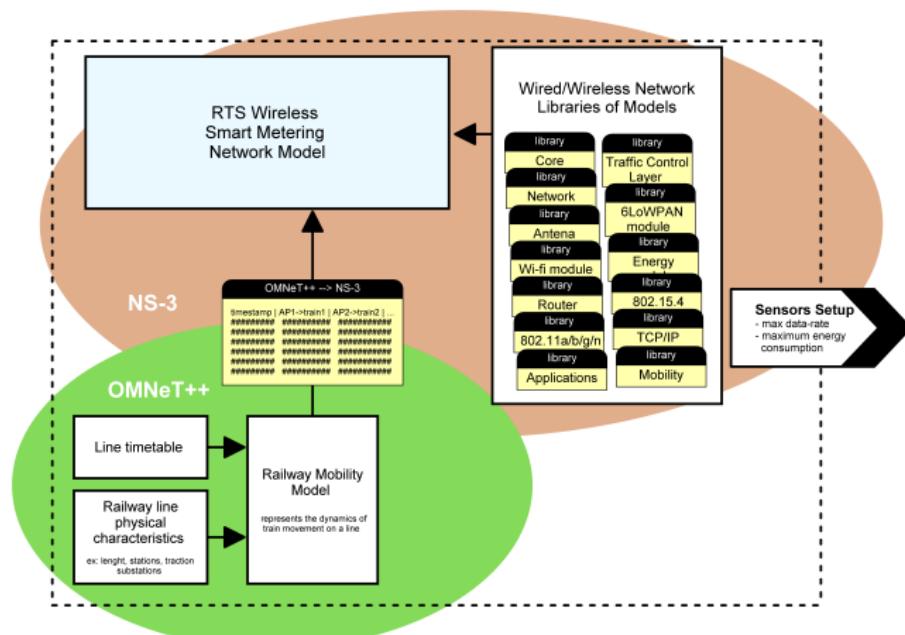


Figure 31: Simulator layers: proposed solution using OMNeT++ and NS-3.

# Preliminary Work

## Evaluation of the non-intrusive voltage sensor

### Evaluation of the non-intrusive voltage sensor



Figure 32: Photo of implemented non-intrusive voltage sensor.

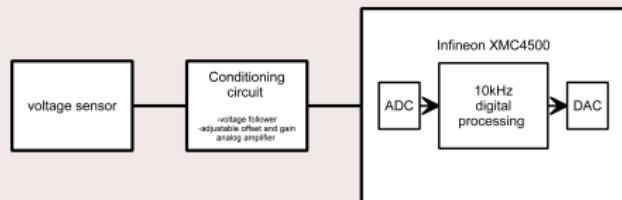
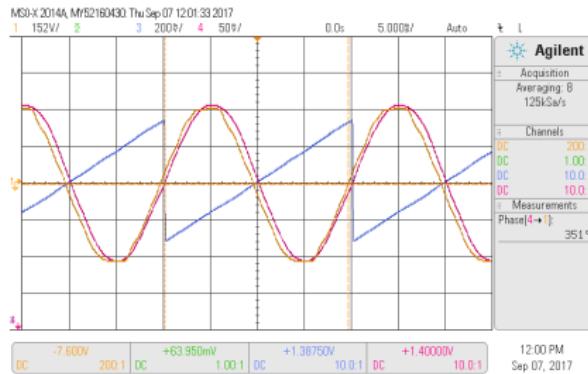


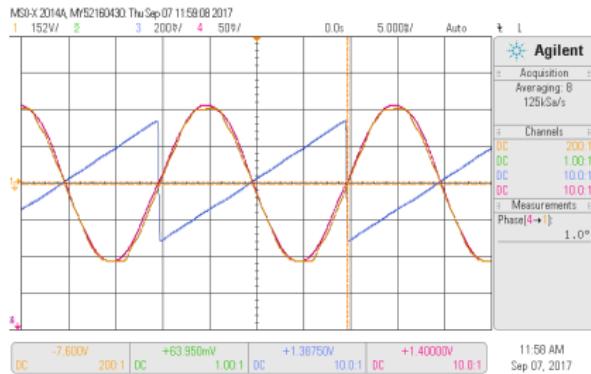
Figure 33: Signal conditioning and digital processing architecture.

# Preliminary Work

## Evaluation of the non-intrusive voltage sensor



**Figure 34:** Waveforms of AC voltage (orange), estimated voltage (pink) and estimated phase angle (blue) without phase compensation.



**Figure 35:** Waveforms of AC voltage (orange), estimated voltage (pink) and estimated phase angle (blue) with phase compensation.

## Railway Smart Meters

Thanks for your attention  
Questions?

# Bibliography I

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-  D. E. Comer, *Computer Networks and Internets*, 5th ed. Upper Saddle River, NJ, USA: Prentice Hall Press, 2008.

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G. M. Scheepmaker, R. M. Goverde, and L. G. Kroon, "Review of energy-efficient train control and timetabling," *European Journal of Operational Research*, vol. 257, no. 2, pp. 355 – 376, 2017.