Railway Smart Meters

Thesis Research Plan

Vítor A. Morais
Supervisor: António P. Martins (UPorto)
Co-supervisor: João L. Afonso (UMinho)

Doctoral Program in Electrical and Computer Engineering
Department of Electrical and Computer Engineering
Engineering Faculty — University of Porto

November 22, 2017

Outline

Outline

Introduction

Context and motivation of PhD

Context and motivation

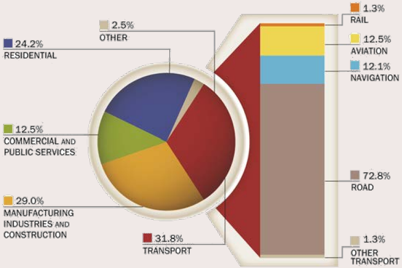

Figure 1: Global Energy Consumption. [1].

	Passenger PKM	Freight TKM	Total TU
ROAD	82.8%	51.1%	71.9%
AVIATION	9.0%	0.1%	5.9%
NAVIGATION	0.6%	36.9%	13.1%
RAIL	7.6%	11.9%	9.1%

Figure 2: Global Transportation Share. [1].

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

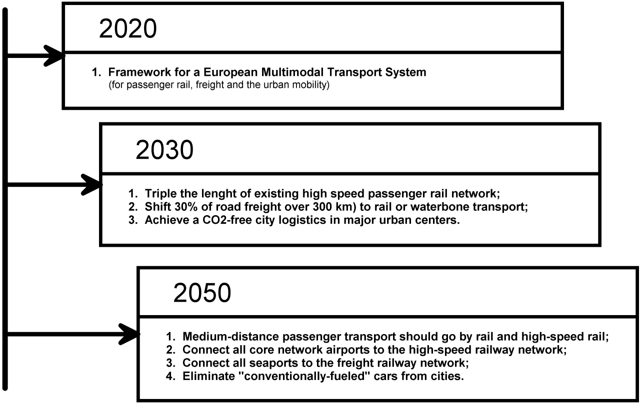

Figure 3: Shift2Rail Framework - Time Targets. [2]

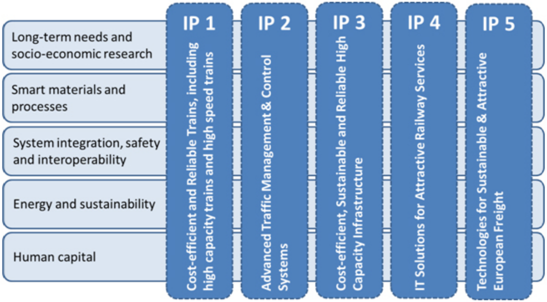

Figure 4: Shift2Rail Framework - Innovation Programmes. [2]

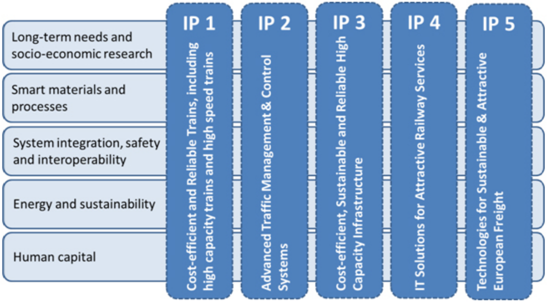

Figure 4: Shift2Rail Framework - Innovation Programmes. [2]

Smart Meter Demonstrator

- Towards detailed monitoring and supervision of energy flows;

Objectives

- Research on **railway energy models**, and **development/implementation of a metering system** for railway power flow monitoring.
- 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.

Outline

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**
Tram	600V DC, 750V DC, 900V DC	-	150–300kW	50–70km/h
Metro	750V DC, 1500V DC	-	350kW–1MW	80km/h
Train	750V DC, 1500V DC, 3000V DC	15kV AC (16.7Hz) and 25kV AC (50Hz)	200kW–8MW	120–350km/h
Locomotive	750V DC, 1500V DC, 3000V DC	15kV AC (16.7Hz) and 25kV AC (50Hz)	500kW–8MW	100–200km/h

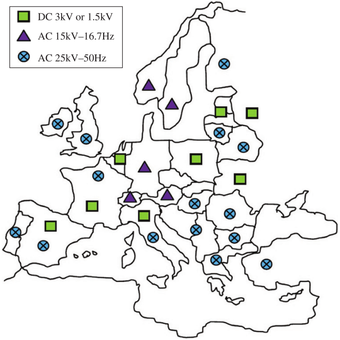

Figure 5: Railway main-line power supply systems in Europe. [3].

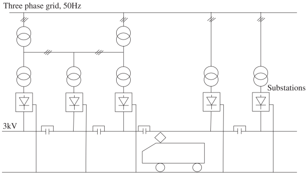

Figure 6: DC supply system architecture. [3].

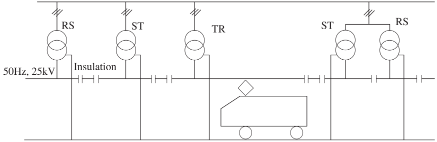

Figure 7: 50 Hz 25 kV supply system. [3].

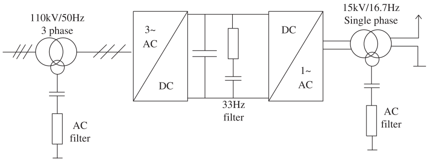

Figure 8: 16.7 Hz 15 kV supply system. [3].

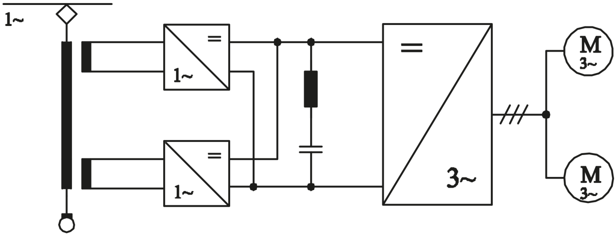

Figure 9: Train internal power circuit of an AC supply system. Adapted from [4].

Case study — Series 3400 train

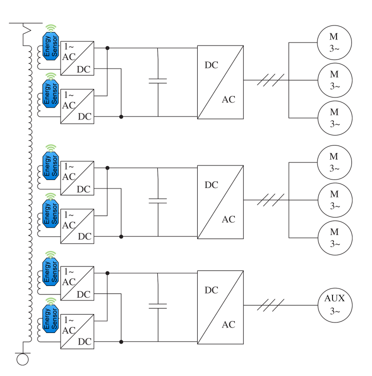

Figure 10: Power architecture of case study train.

Figure 11: Series 3400 case study train. Retrieved from *Comboios de Portugal*

Outline

Transducers

Figure 12: 25 kV current transformer. Adapted from *www.railware.it*

Figure 13: 25 kV voltage transformer. Adapted from *www.railware.it*

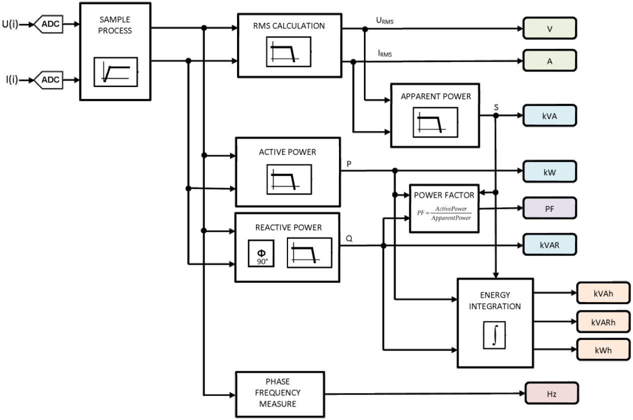

Figure 14: EcoS power calculation function, based on EN50463. Adapted from railware.it

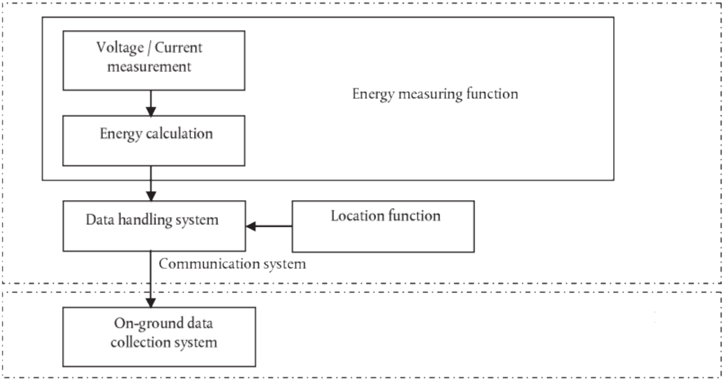

Figure 15: Functions, data flow and regulation scope of on-board energy measurement system.

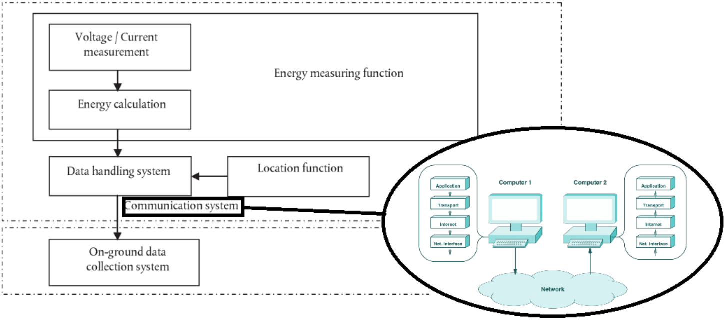

Figure 16: Detail in the communication system: integration with wireless computer networks. Adapted from [5].

Wireless Networks — Simulators

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

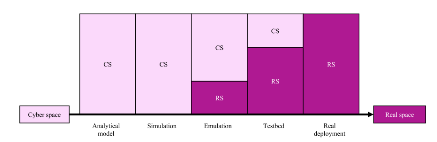

Figure 17: Simulation & emulation framework.

Literature Review

- Power System of Railway Transportation System
- Energy Sensors
- Wireless Networks
- Smart Metering
- **Decision Support Systems**
- **Issues and Problems in WSN — Outliers**

Outline

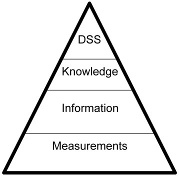

Figure 18: Overall functional architecture of a smart metering system.

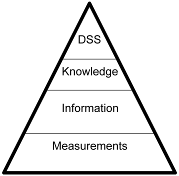

Figure 18: Overall functional architecture of a smart metering system.

Figure 19: Data flow of measurement-information layers.

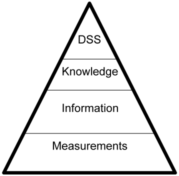

Figure 18: Overall functional architecture of a smart metering system.

Figure 19: Data flow of measurement-information layers.

Architecture of proposed work

1. Energy metering node:
   Non-intrusive self-powered sensor node;
2. Data transmission & Storage System:
   RTS wireless network

Part 1 — Energy metering node:
Non-intrusive self-powered sensor node

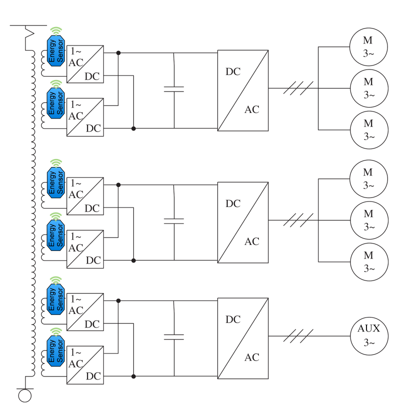

Figure 20: Power architecture of case-study train.

Energy metering node — Methodology

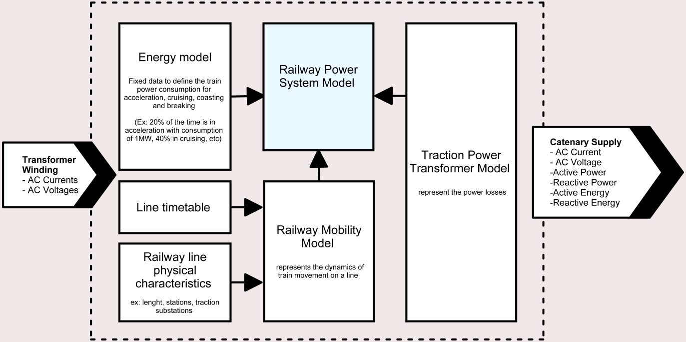

Figure 21: Models needed for simulation. Energy measurement system.

Energy metering 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.

Part 2 — Data transmission & Storage System: RTS wireless network

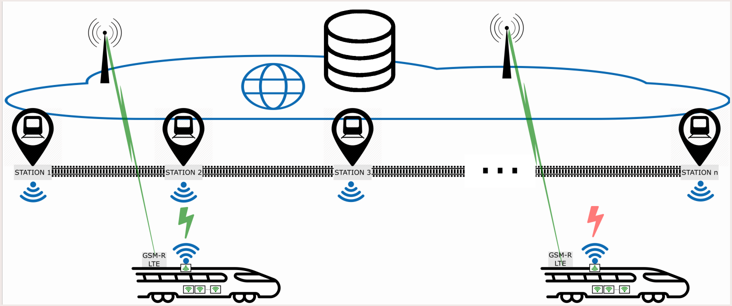

Figure 22: Data transmission & Storage System.

RTS wireless network — Methodology

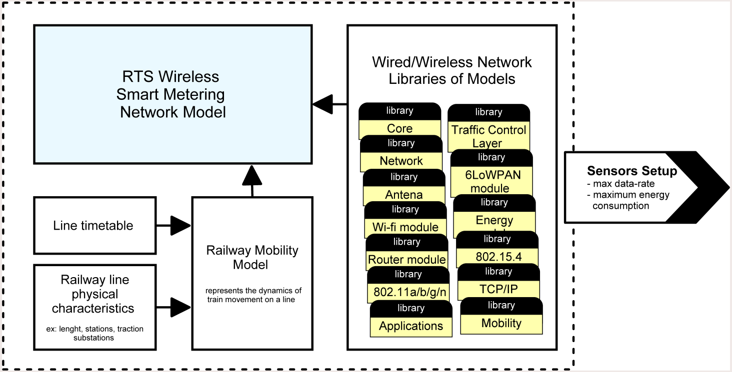

Figure 23: Models needed for simulation - RTS Wireless Network.

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.

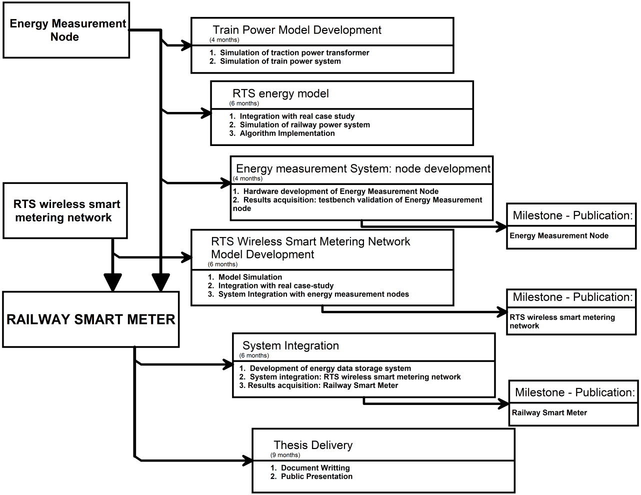

Figure 24: PhD Work Plan.

Outline

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

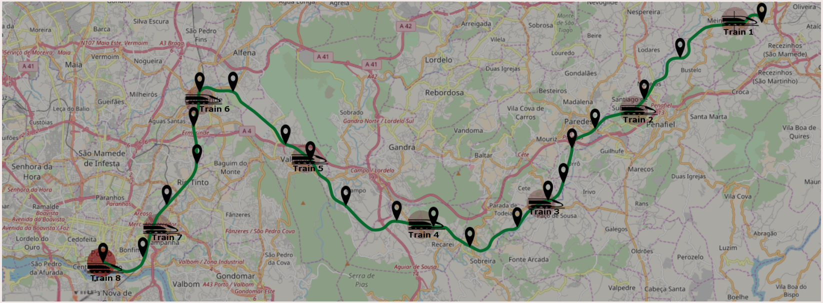

Figure 25: Porto-Caíde railway line: simulation using OMNeT++ network simulator.

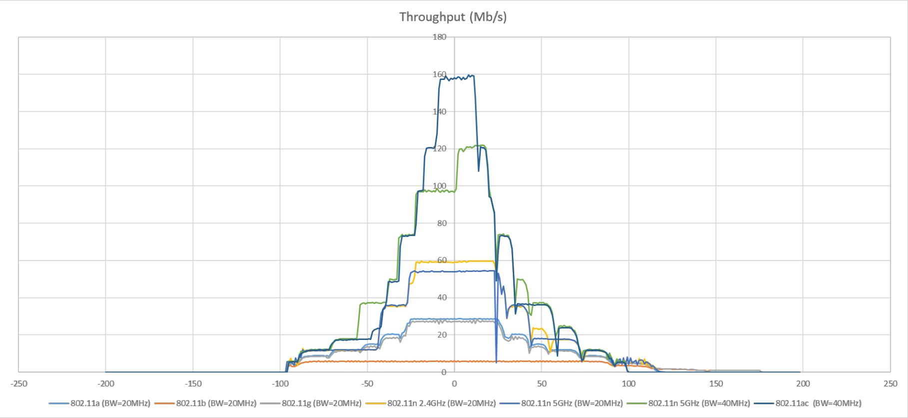

Figure 26: Evaluation of moving node for different 802.11 network standards using NS-3.

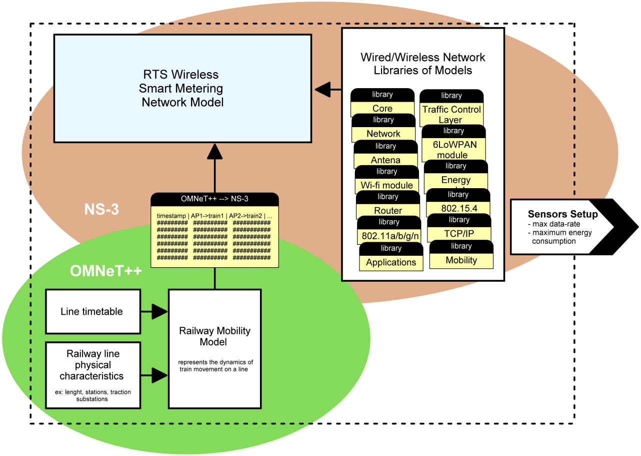

Figure 27: Simulator layers: proposed solution using OMNeT++ and NS-3.

Evaluation of the non-intrusive voltage sensor

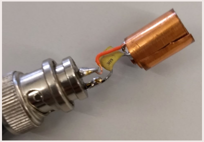

Figure 28: Photo of implemented non-intrusive voltage sensor. Based on [6]

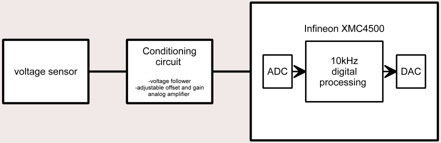

Figure 29: Signal conditioning and digital processing architecture.

Preliminary Work

Evaluation of the non-intrusive voltage sensor

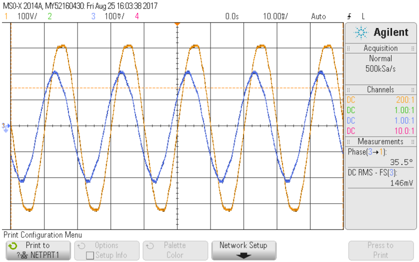

Figure 30: Waveforms of acquired and sensed voltages in normal conditions: AC main voltage (orange) and voltage in sensor (blue).

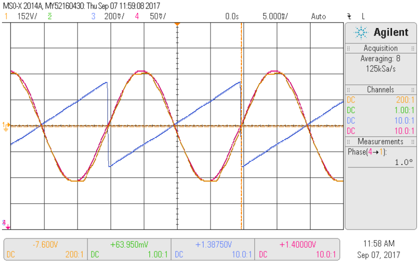

Figure 31: Waveforms of AC voltage (orange), estimated voltage (pink) and estimated phase angle (blue) with phase compensation.

Railway Smart Meters

Thanks for your attention

Questions?

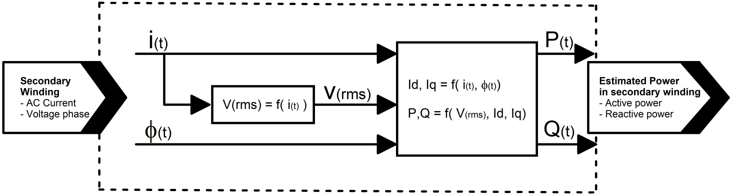

Figure 32: Secondary power estimation.

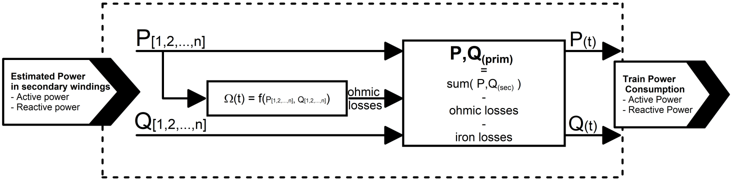

Figure 33: Train power estimation.

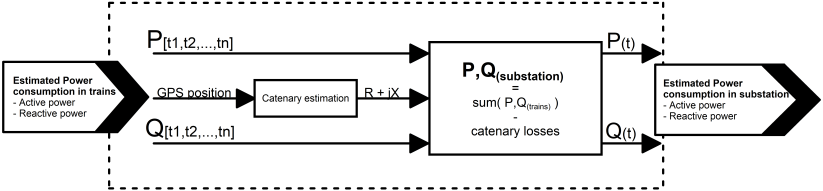

Figure 34: Substation power estimation.

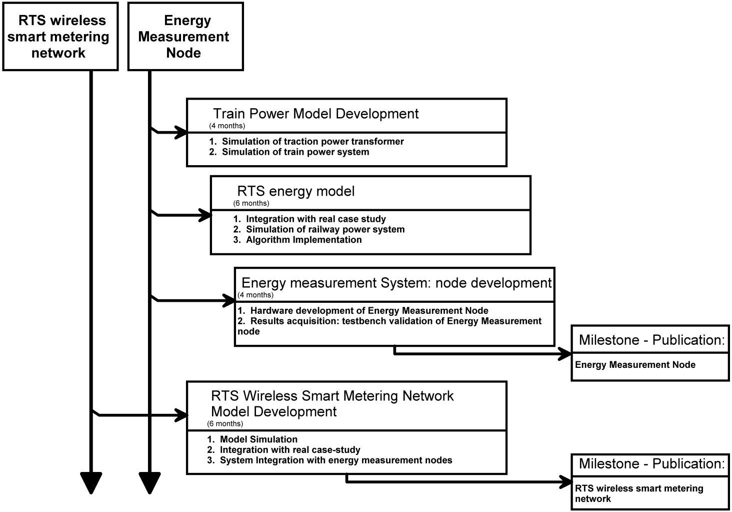

Figure 35: PhD Work Plan.

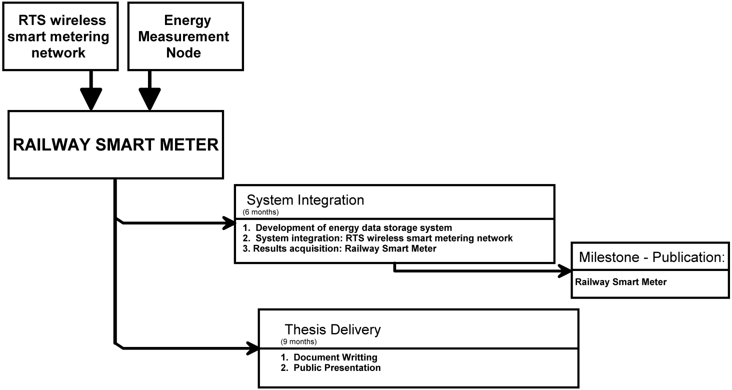

Figure 36: PhD Work Plan.

- F. Birol and J.-P. Loubinoux, "2016 Edition of the UIC-IEA Railway Handbook on Energy Consumption and CO2 Emissions focuses on sustainability targets," IEA and UIC, Tech. Rep., 2016.
- Shift2Rail Joint Undertaking, "Shift2Rail Joint Undertaking Multi-Annual Action Plan," Shift2Rail, Tech. Rep., 2015.
- G. Abad and X. Agirre, *Power Electronics and Electric Drives for Traction Applications*, G. Abad, Ed. John Wiley & Sons, Ltd., 2016.
- A. Steimel, *Electric Traction — Motive Power and Energy Supply: Basics and Practical Experience*. Oldenbourg Industrieverlag, 2008.
- D. E. Comer, *Computer Networks and Internets*, 5th ed. Upper Saddle River, NJ, USA: Prentice Hall Press, 2008.

Bibliography II

D. Brunelli, C. Villani, D. Balsamo, and L. Benini, "Non-invasive voltage measurement in a three-phase autonomous meter," *Microsystem Technologies*, vol. 22, no. 7, pp. 1915–1926, Jul 2016.