Railway Smart Meters

Thesis Research Plan

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October 18, 2017

Outline

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Context and motivation

The railway system is responsible for 1.3% of entire European energy consumption, [1]. The debate on energy efficiency in railways is a well-discussed topic due to its impact on the global energy consumption. The energy efficiency analysis and management requires a detailed mapping of the energy consumption/generation in the railway system. This detailed mapping of the energy flows should include, not only the rolling stock level but also the traction substations and the auxiliary services. The knowledge of all the load curves permits load prevision, peak shaving and energy cost optimization for the entirely of the railway system.

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.

Shift2Rail Framework - Time Targets

Complementary, the time target goals are the establishment of a framework, by 2020, for a European multimodal transport system for the passenger rail, freight and for the urban mobility. By 2030 is expected to triple the length of the existing high-speed passenger rail network, 30% of the road freight over 300 km should shift to rail or waterborne transport and achieve a CO2-free city logistics in major urban centers. By 2050, the medium-distance passenger transport should go by rail and high-speed rail, with the connection of all core network airports to the high-speed railway network. On the freight is expected to have all seaports connected to the rail freight transport system and on the urban mobility, the "conventionally-fueled" cars will not have place in cities by 2050, [2].

Shift2Rail Framework - Innovation Programmes

The Shift2Rail (S2R) carries five innovation programmes, as presented in figure **??**. Framed on the S2R Innovation Programme 3 (IP3) with the focus on the "Cost efficient and reliable infrastructure", it is proposed the development of a Smart Metering Demonstrator (SMD) that achieves a detailed monitoring and supervision of various energy flows on the premises of embracing the entire Railway Transportation System (RTS).

Main Goal

The purpose of any energy management strategy is to build the dynamics of every loads and generators of the power system. This should be performed based on an extensive knowledge of every energy flows. This way, the SMD is required to propose and validate a standard metering architecture that involves the coordination of every measurement performed either in on-board and in ground. In advance, energy data analysis should be provided based on relevant stored data.

Outline

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**
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

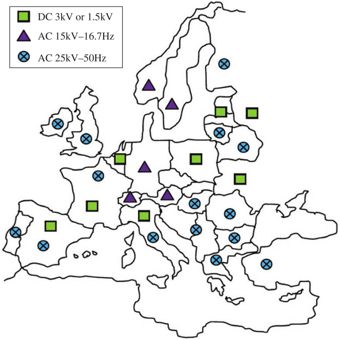

Figure 1: Railway main-line power supply systems in Europe. [3].

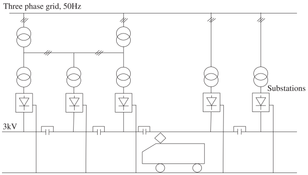

Figure 2: DC supply system architecture. [3].

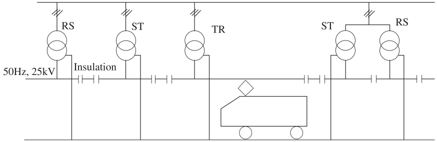

Figure 3: 50 Hz 25 kV supply system. [3].

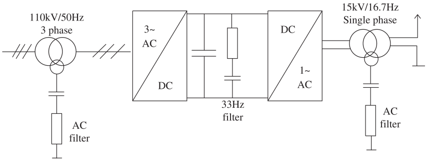

Figure 4: 16.7 Hz 15 kV supply system. [3].

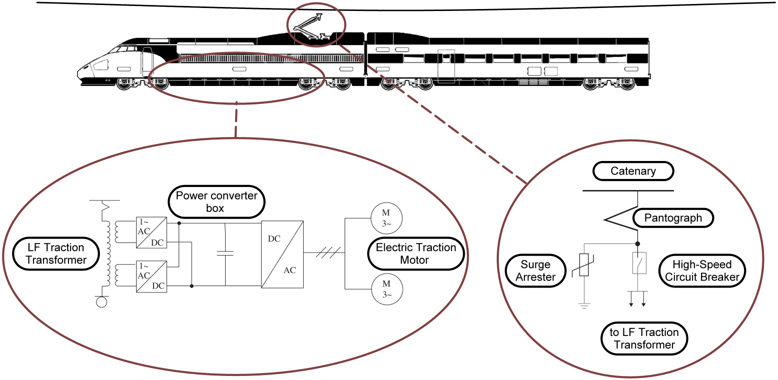

Figure 5: Train Power Components.

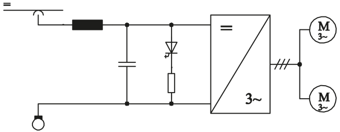

Figure 6: Train internal power circuit of a DC supply system. Adapted from [4].

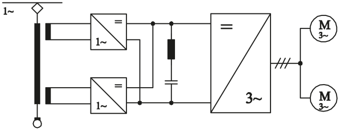

Figure 7: Train internal power circuit of an AC supply system. Adapted from [4].

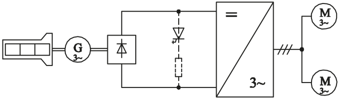

Figure 8: Train internal power circuit of a Diesel electric locomotive with alternator. Adapted from [4].

Case study — Series 3400 train

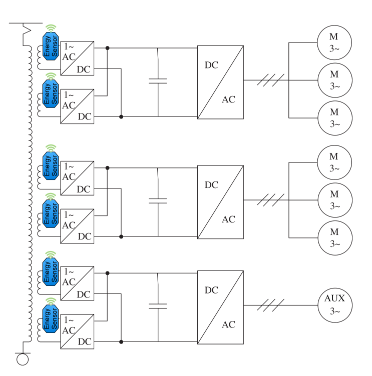

Figure 9: Power architecture of case study train.

Figure 10: Series 3400 case study train. Retrieved from *Comboios de Portugal*

Outline

Transducers

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

Figure 11: 25 kV current transformer. Adapted from *www.railware.it*

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

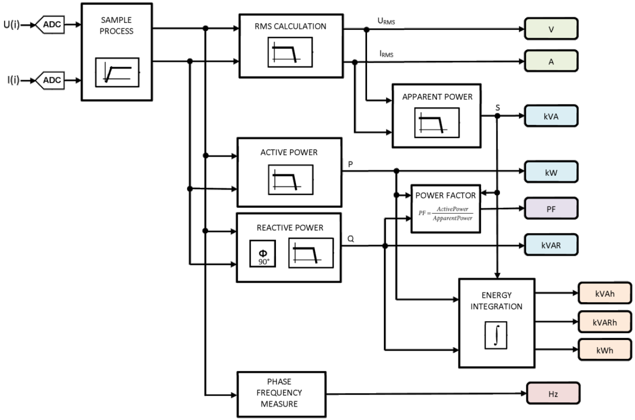

Figure 13: EcoS power calculation function, based on EN50463. Adapted from railware.it

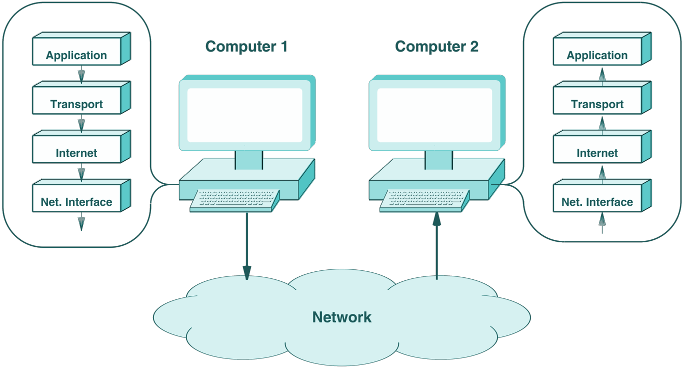

Figure 14: Representation of data flow in a computer network. Adapted from [5].

Wireless Networks — Simulators

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

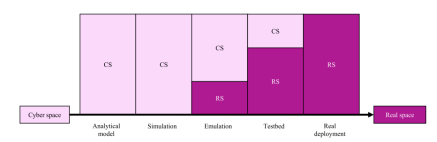

Figure 15: Simulation & emulation framework.

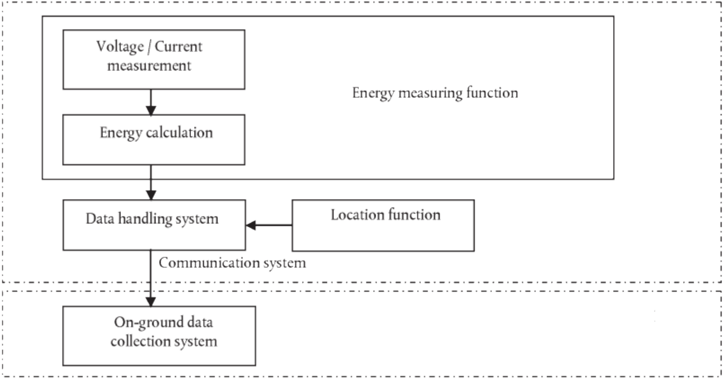

Figure 16: Functions, data flow and regulation scope of on-board energy measurement system.

Decision Support Systems

- Eco-driving — Driving Assistant
- Timetable Scheduling

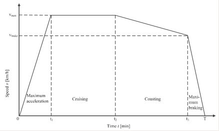

Figure 17: Optimal traction regimes. Adapted from [6].

Outlier Detection Techniques for RTS

- **Classification based techniques.**
  - Bayesian Networks
  - Rule-based techniques
  - Support Vector Machines
- **Statistical based techniques.**
  - Parametric — Gaussian based
  - Non-parametric — Histogram based
  - Non-parametric — Kernel function based
- **Nearest Neighbor-based techniques.**
  - Using distance
  - Using relative density
- **Clustering based techniques.**
- **Spectral Decomposition based techniques.**

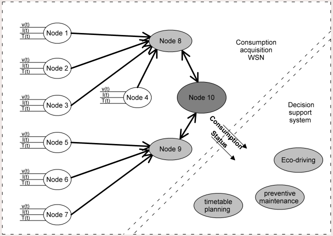

Figure 18: Integration of the WSN with a decision support system.

Outline

Architecture of proposed work

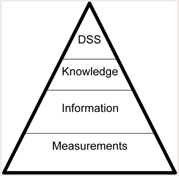

Figure 19: Overall functional architecture of a smart metering system.

Figure 20: Data flow of measurement-information layers.

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

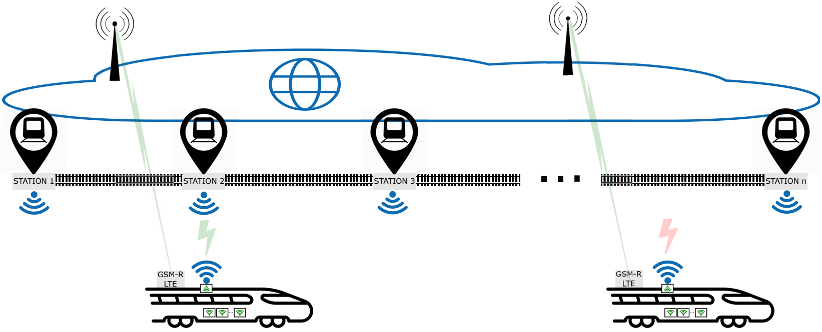

Figure 21: Architecture of proposed work.

Non-intrusive self-powered sensor node

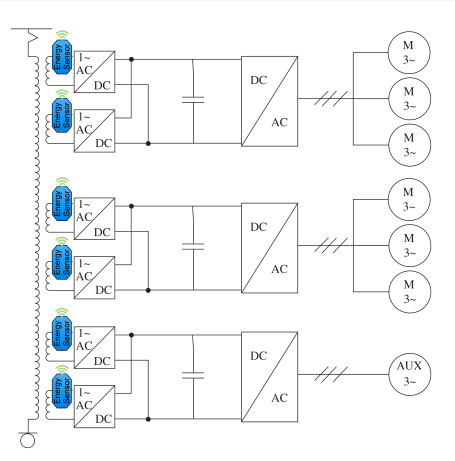

Figure 22: Power architecture of case-study train.

Non-intrusive self-powered sensor node — Methodology

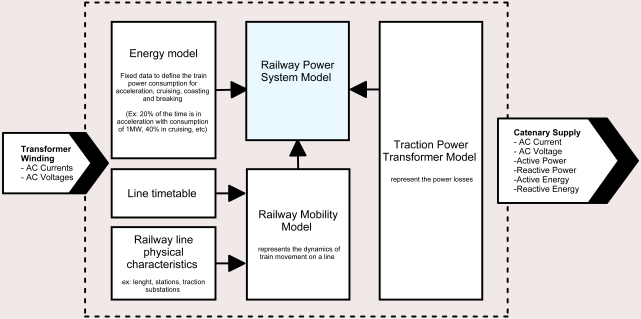

Figure 23: Models needed for simulation. Energy measurement system.

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.

RTS wireless network

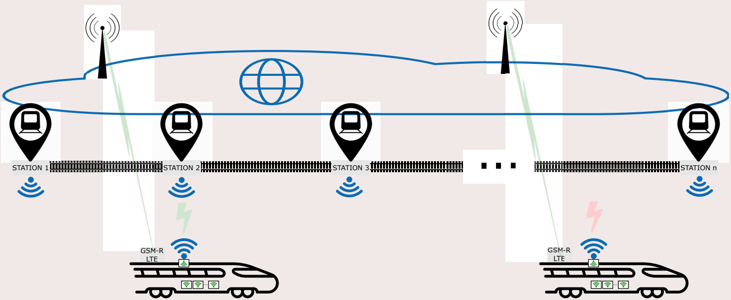

Figure 24: Architecture of proposed work.

RTS wireless network — Methodology

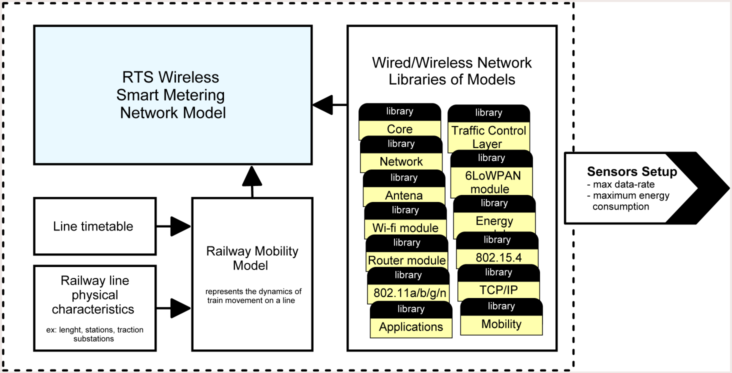

Figure 25: Models needed for simulation - RTS Wireless Network.

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.

Outline

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

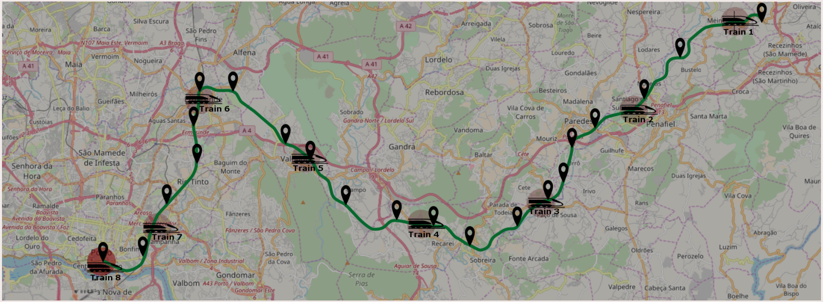

Figure 26: Porto-Caíde railway line: simulation using OMNeT++ network simulator.

Preliminary Work

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

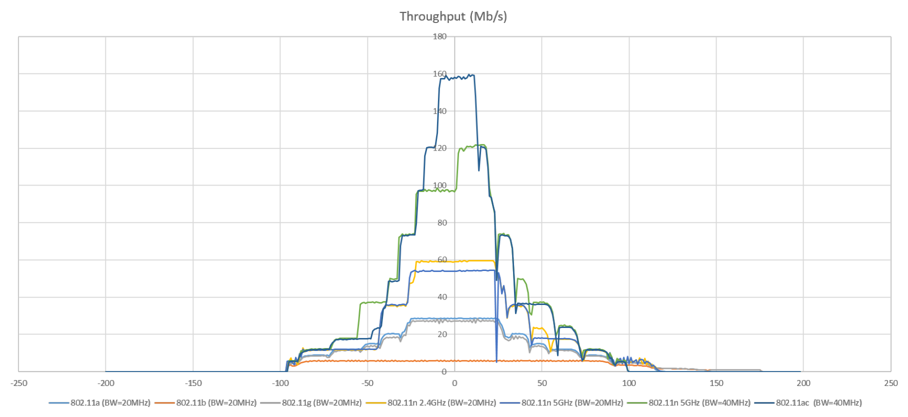

Figure 27: Evaluation of moving node for different 802.11 network standards using NS-3.

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

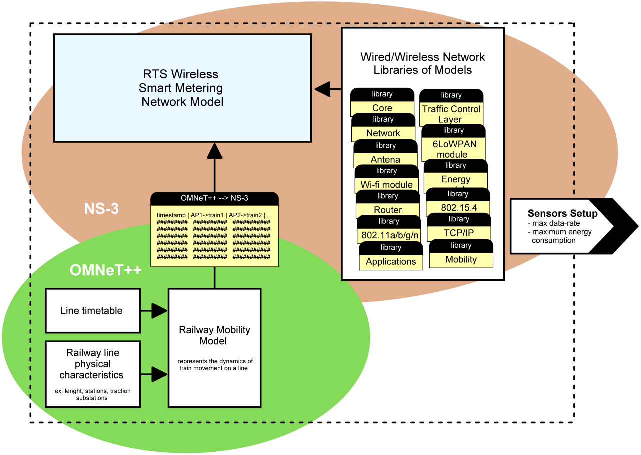

Figure 28: Simulator layers: proposed solution using OMNeT++ and NS-3.

Evaluation of the non-intrusive voltage sensor

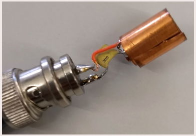

Figure 29: Photo of implemented non-intrusive voltage sensor.

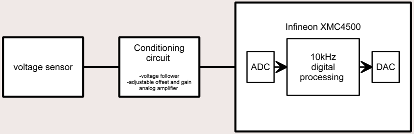

Figure 30: Signal conditioning and digital processing architecture.

Preliminary Work

Evaluation of the non-intrusive voltage sensor

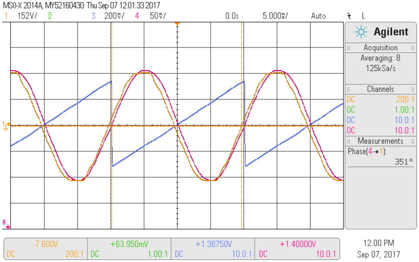

Figure 31: Waveforms of AC voltage (orange), estimated voltage (pink) and estimated phase angle (blue) without phase compensation.

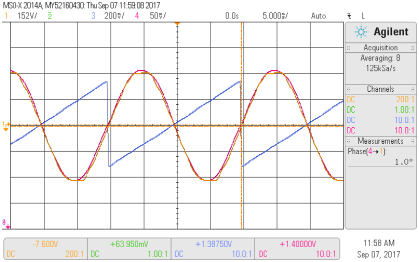

Figure 32: Waveforms of AC voltage (orange), estimated voltage (pink) and estimated phase angle (blue) with phase compensation.

Railway Smart Meters

Thanks for your attention

Questions?

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