

The Impact of Wireless Communication Networks on Wide Area Monitoring and Protection Applications

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Outline

- Introduction
- Synchronized Measurement Technology
- Wide Area Monitoring and Protection through wireless communication networks
- Results-Impact of 5G in Wide Area Monitoring and Protection applications
- Conclusions

Introduction

- Power system operators experience unprecedented challenges
 - High penetration of renewable energy sources
 - Electricity demand is ever increasing
- Transformation of the bulk power system according to smart grid concept
 - Digitalization of the power system substations
 - Ancillary services provided by distributed energy resources
 - Monitoring and control of the power grid in quasi real time



Synchronized Measurement Technology

Relatively new technology in the market

- Present in the market since the early 1990s

The key element of the SMT is the Phasor Measurement Unit (PMU)

Advanced Monitoring and Control capabilities

GPS synchronized equipment

- Provide accurate synchronized voltage and current phasor measurements

High reporting rate

- 200 phasors per second
- Conventional measurements are updated every 2-5 seconds



Source: Arbiter



Wide Area Monitoring and Control

Wide area monitoring applications

- PMU-based state estimator
- **Monitor tie-lines operating condition in real time**

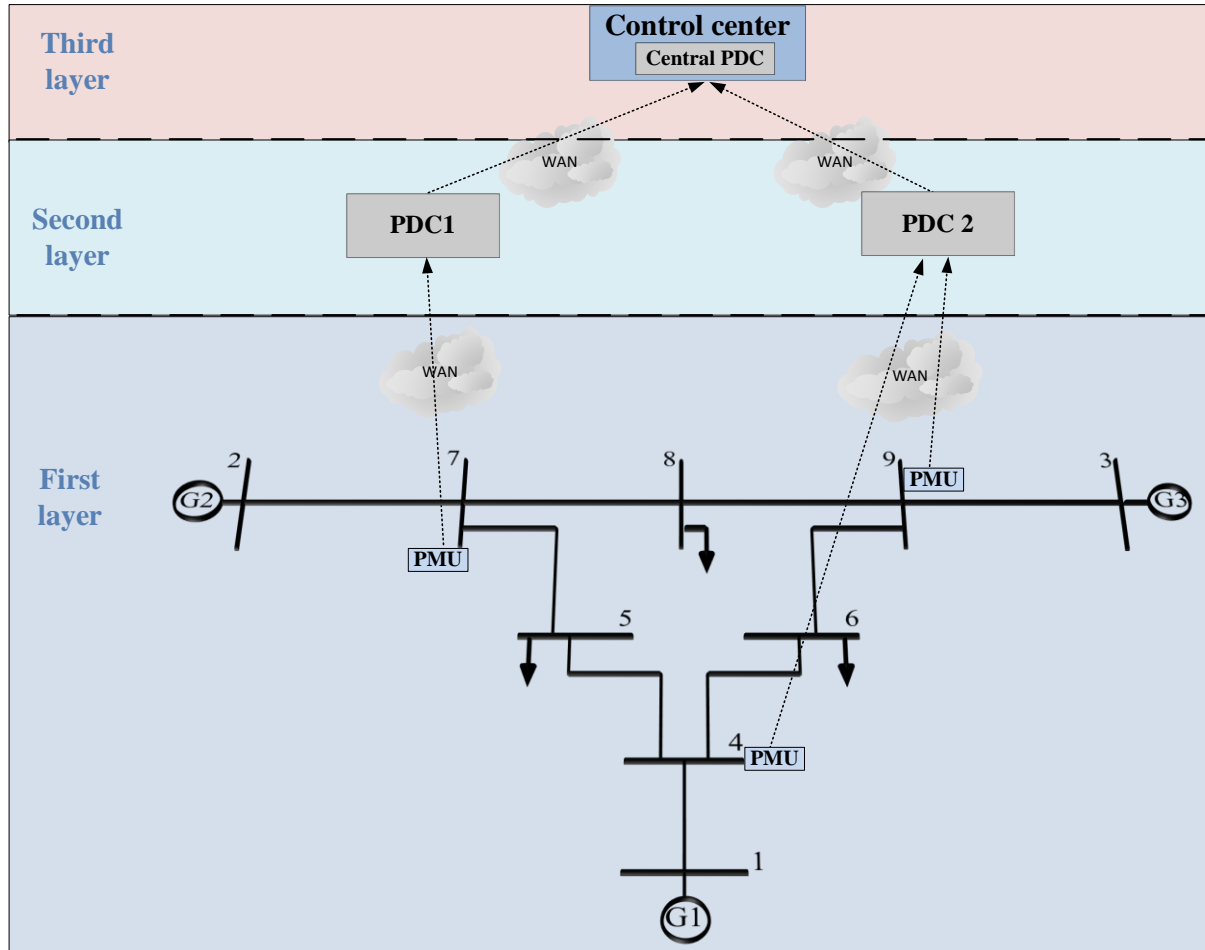
Wide Area Control applications

- Wide area controller
- **Wide area protection**

PMU measurements should be transferred in real time to the applications



PMU communication network architecture



- Multi-layered architecture
- Communication network
 - Wired (fiber optics)
 - **Wireless (3G, 4G, 5G)**
 - Main source of delays
- Phasor Data Concentrator(PDC) is a critical component
 - Time aligns the measurements
 - Waiting time for compensating measurement delays

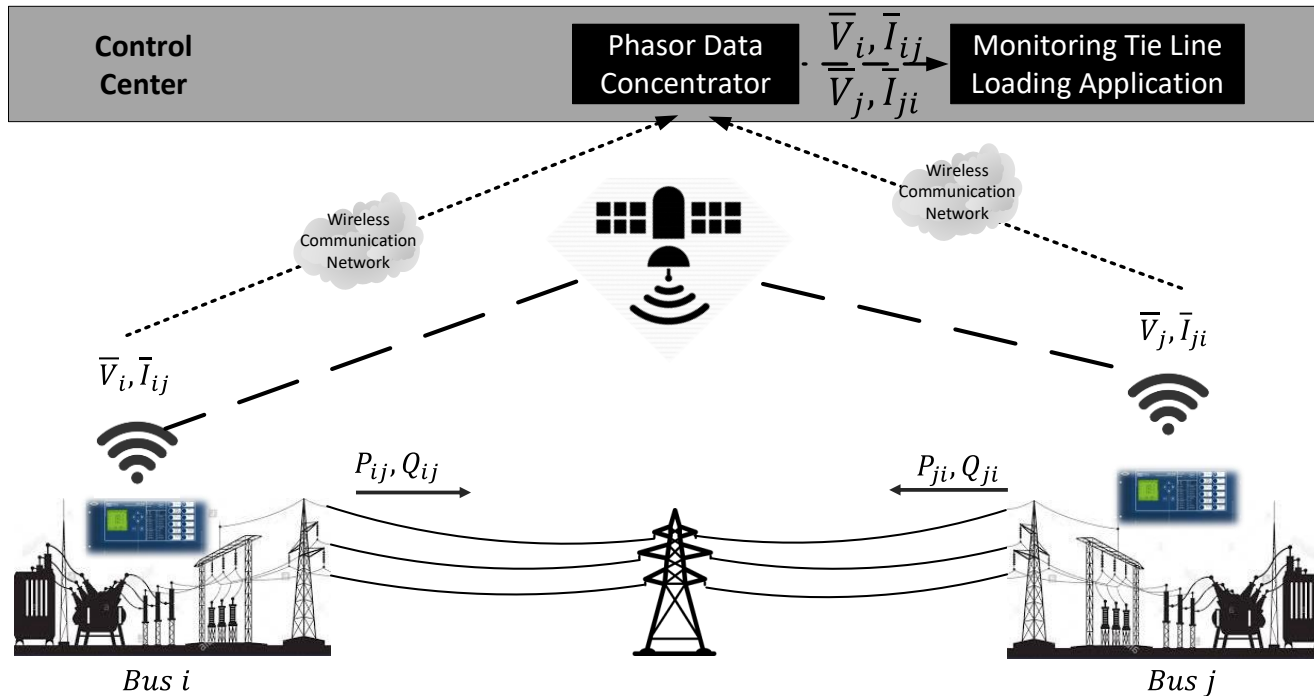
Motivation

Transfer of PMU measurements captured by the two ends of a tie-line

- Monitoring of the tie-line operating condition
- Protection scheme for isolating faults within the tie-line

Investigate the impact of wireless communication network on the accuracy and real time responsiveness of the two applications

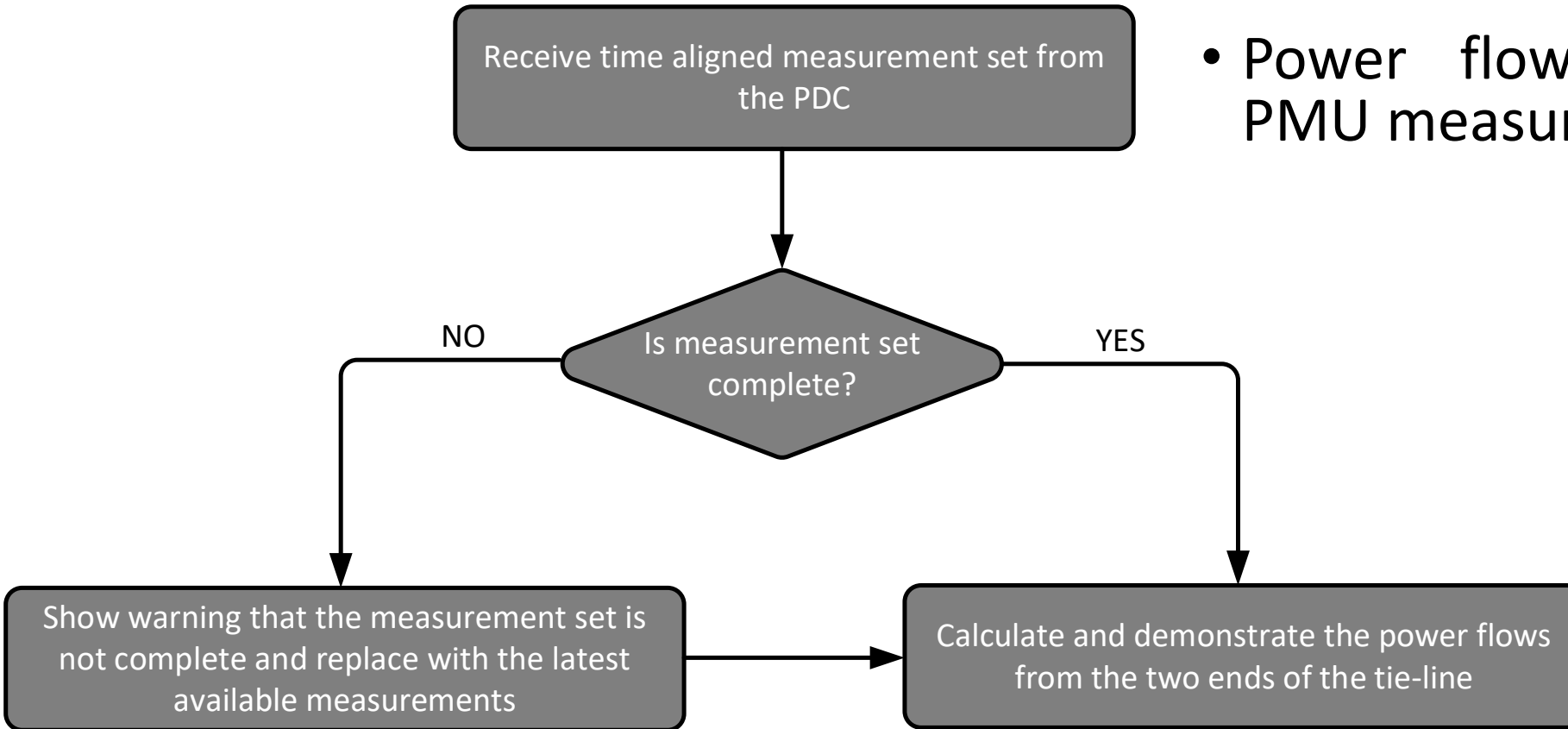
Wide Area Monitoring of a Tie Line



- Tie lines can enhance the reliability of the interconnected systems
- The two ends of the tie line are monitored by PMUs
- PMU measurements are transferred through wireless communication network to the PDC
- In case of large delays (larger than the waiting time of the PDC) the delayed PMU measurements are discarded

Wide Area Monitoring of a Tie Line

- Power flow calculations through PMU measurements



$$P_{ij} = \Re \left\{ \bar{V}_i \left(\bar{I}_{ij} \right)^* \right\}$$

$$Q_{ij} = \Im \left\{ \bar{V}_i \left(\bar{I}_{ij} \right)^* \right\}$$

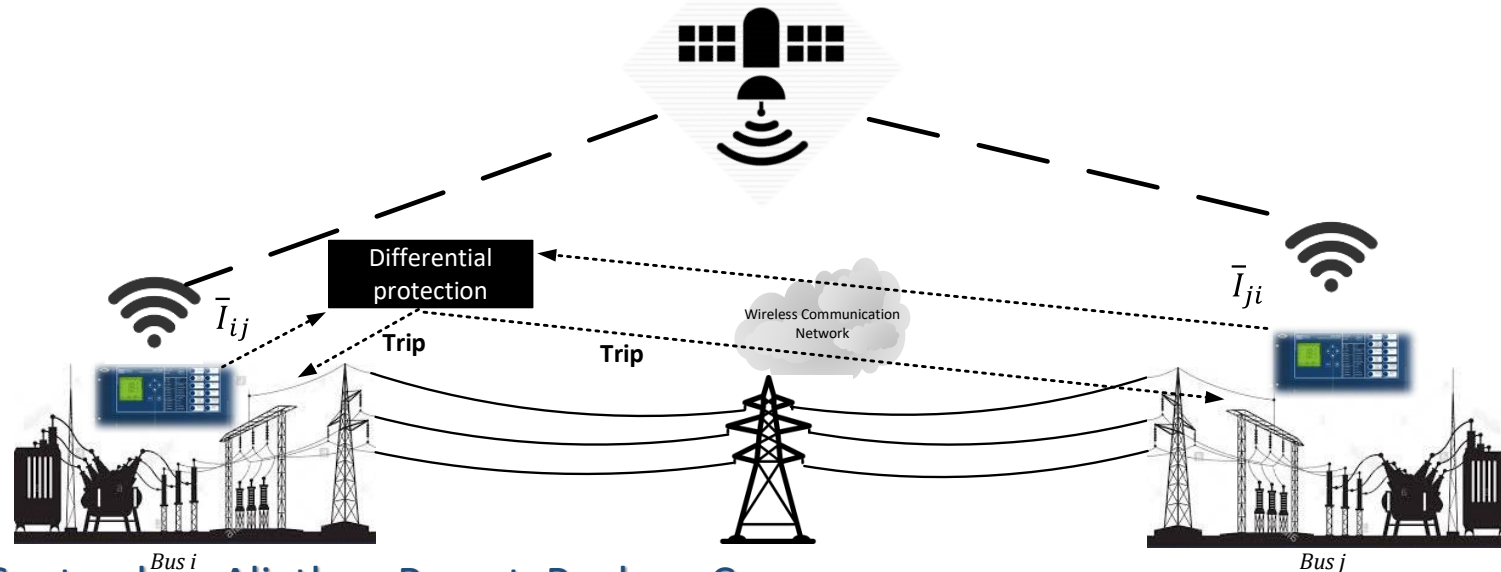
$$P_{ji} = \Re \left\{ \bar{V}_j \left(\bar{I}_{ji} \right)^* \right\}$$

$$Q_{ji} = \Im \left\{ \bar{V}_j \left(\bar{I}_{ji} \right)^* \right\}$$

$\bar{V}_i, \bar{V}_j, \bar{I}_{ij}, \bar{I}_{ji}$ are the voltage and current phasor measurements from the two ends of the tie-line

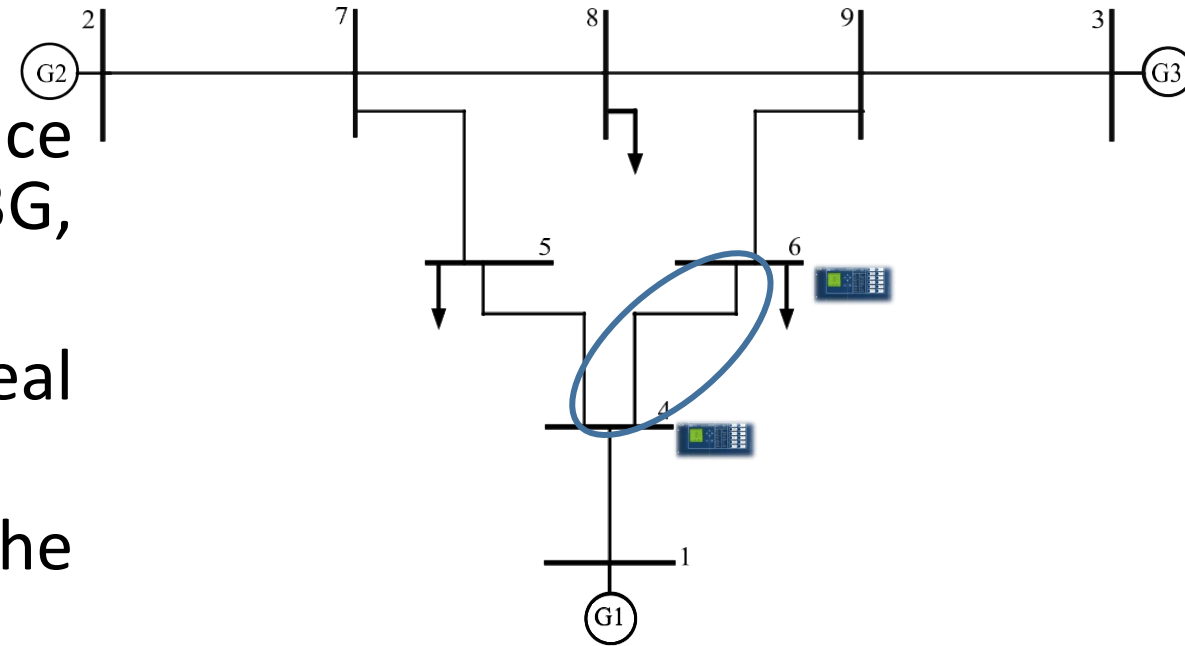
Wide Area Protection of a Tie Line

- Differential protection of the tie-line by comparing the current phasor measurements of the two ends with the same time stamp:
 - Executed at the substation level → No need for a PDC
 - Normal operating condition or fault outside the transmission line → Currents will have a small difference
 - Fault within the range of the transmission line → Currents will have a difference larger than 100 A



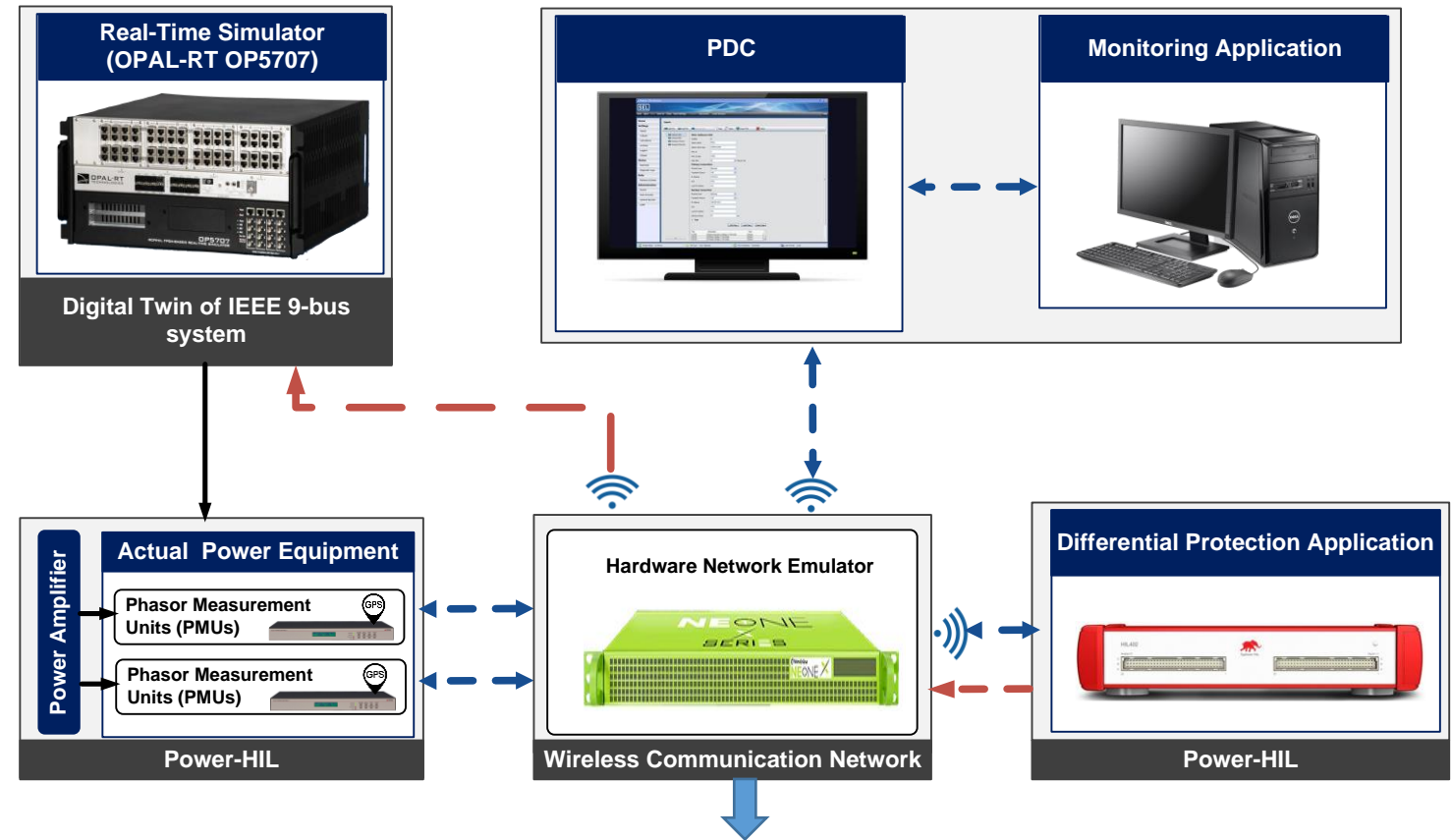
5G Impact on Wide Area Monitoring and Protection

- For both applications PMU measurements are transferred through wireless communication network
- Comparison of the application performance when the wireless network is based on 3G, 4G, and 5G characteristics
- IEEE 9-bus system emulated in OPAL-RT real time simulator
- Hardware in the loop framework for the investigations of this work



Laboratory Setup

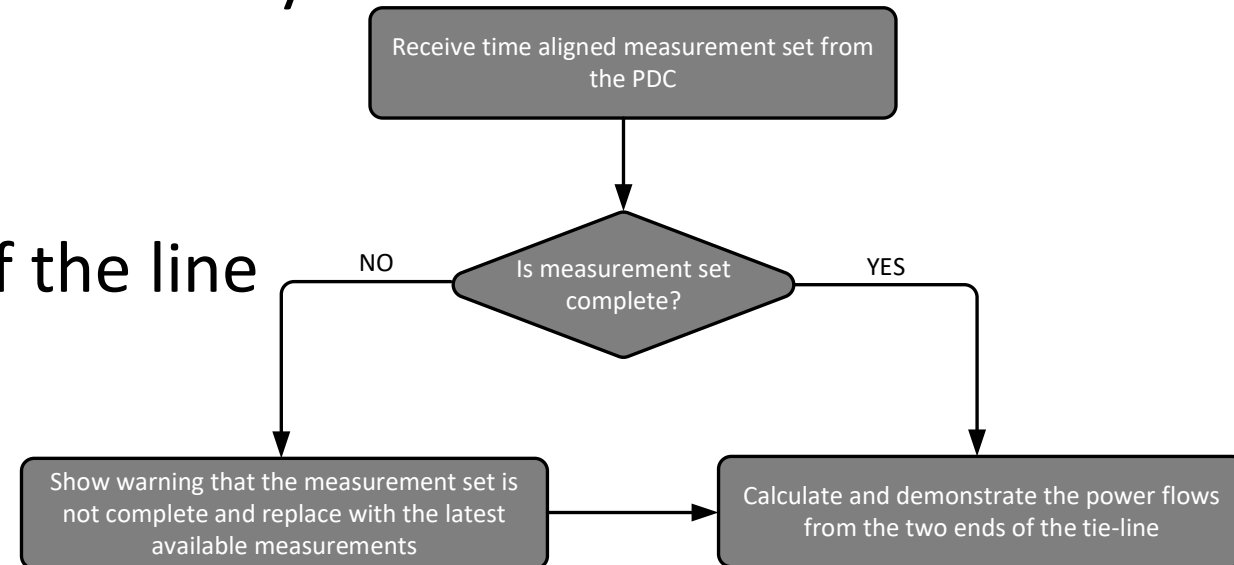
- Use of real PMU measurements to the applications
- Emulate the characteristics of 3G, 4G, 5G networks
- Observe in real time the response of the power system



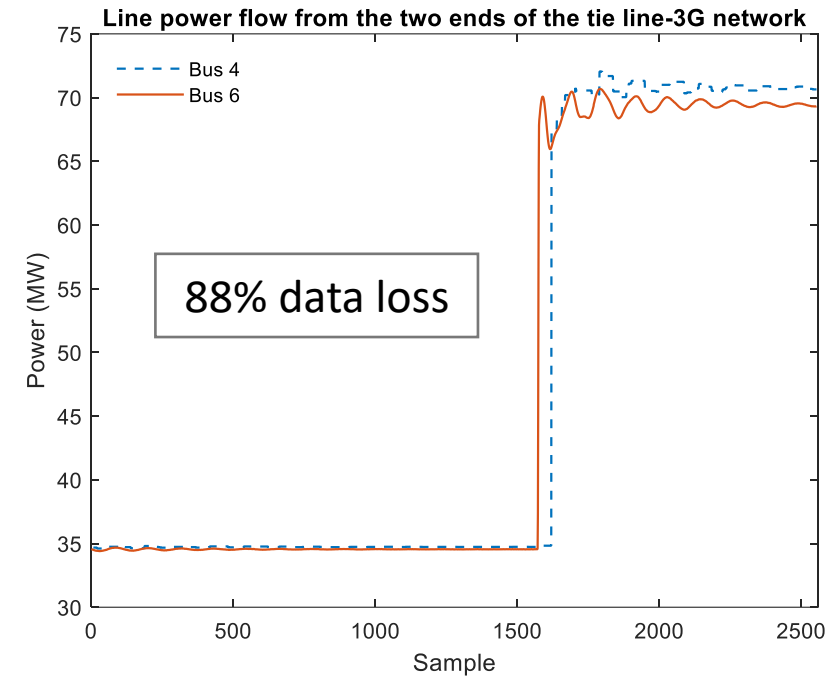
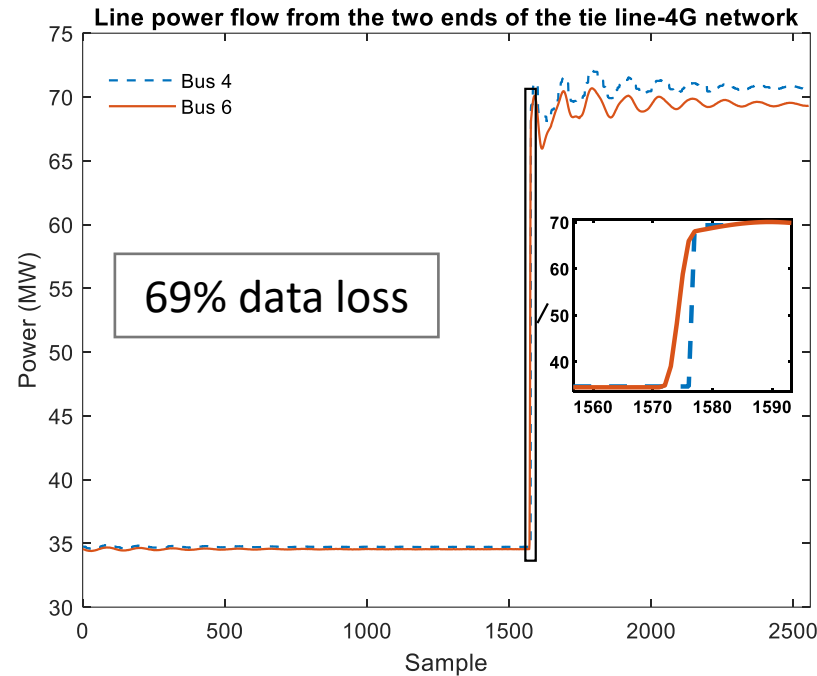
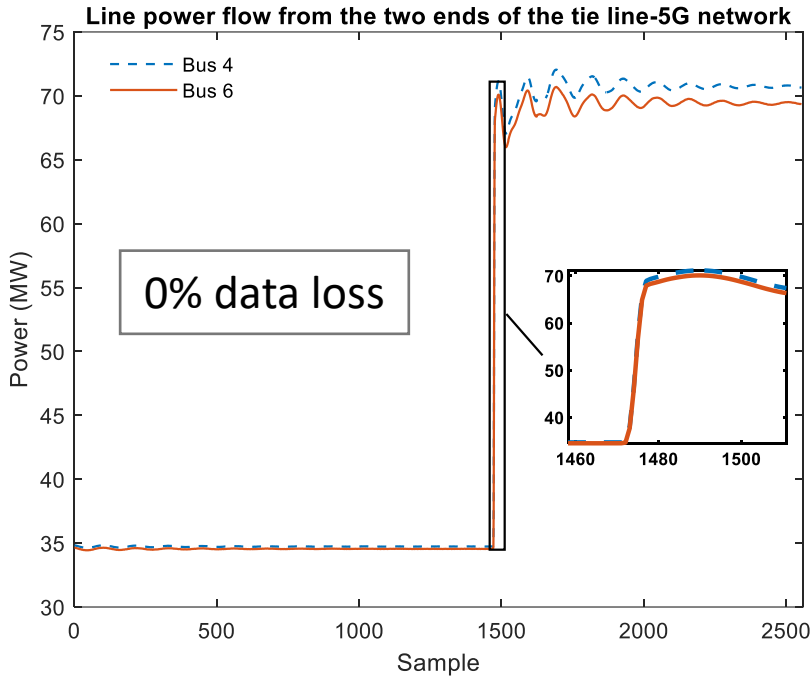
Communication Network	Uniform distribution limits	
	Minimum (ms)	Maximum (ms)
5G	3	10
4G	20	60
3G	20	150

Wide Area Monitoring-Scenario

- PMU measurements are stored to the PDC with a corresponding delay according to the type of wireless network
- PDC has maximum waiting time of 40 milliseconds
- The PMU measurements are discarded if they are not arrived within 40 milliseconds interval
- Line loading is increased by 35 MW
- Change should be visible at both ends of the line



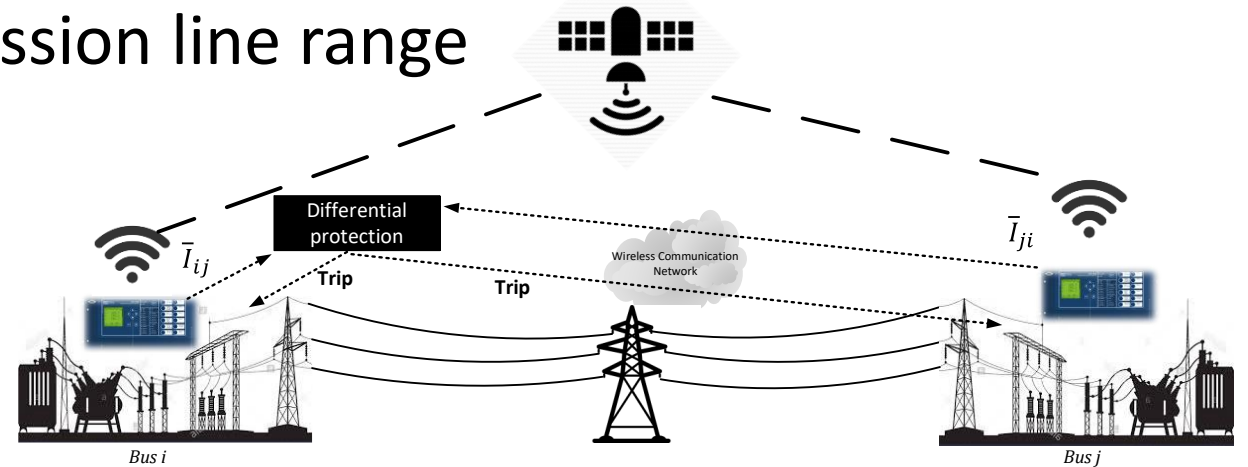
Wide Area Monitoring-Results



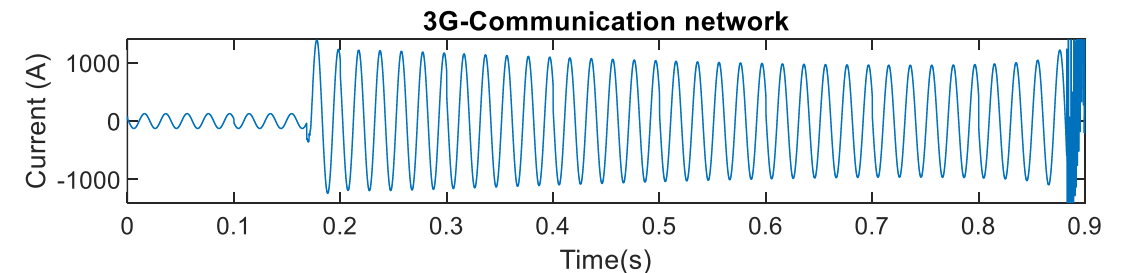
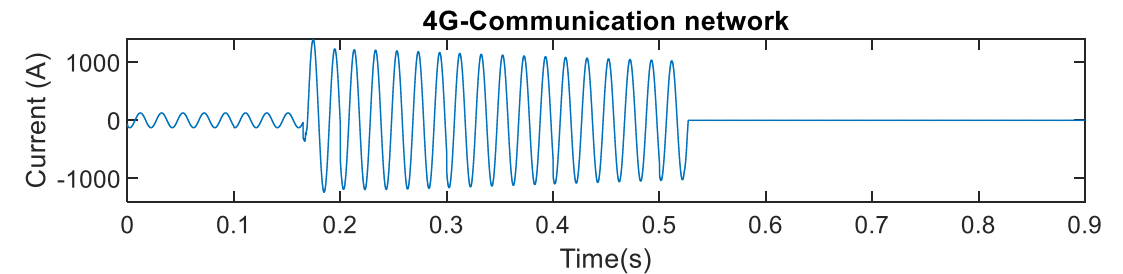
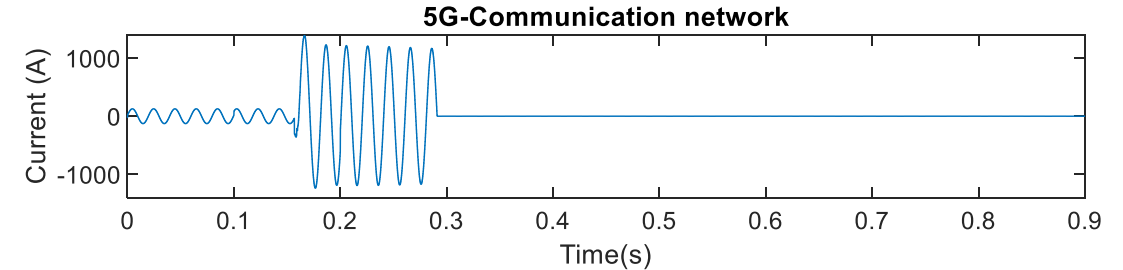
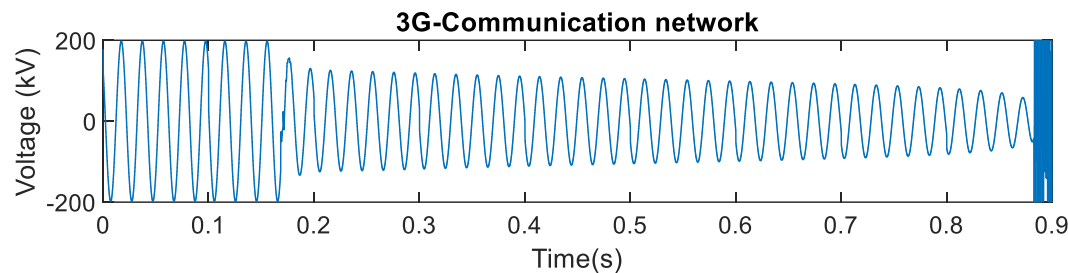
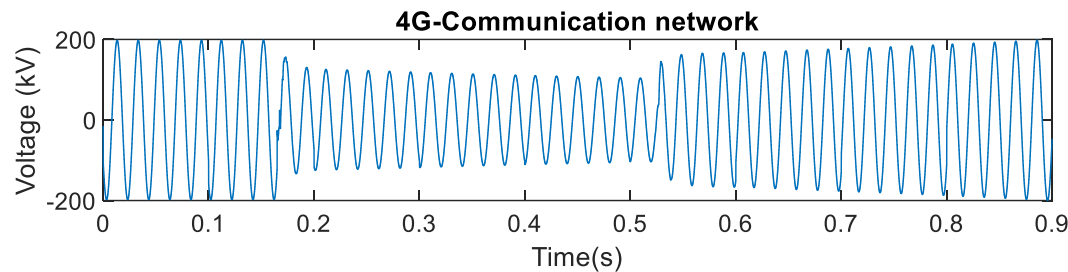
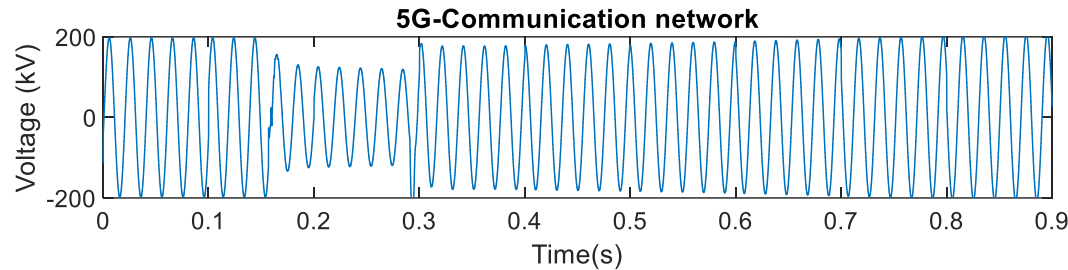
- 5G network enhances the accuracy of the wide area monitoring application
- The application has the worst performance when 3G network
- The application has a moderate performance with 4G network

Wide Area Differential Protection-Scenario

- Applied a three-phase fault with 60 Ω fault resistance to the tie-transmission line that connects bus 4 and bus 6
- Transfer of the measurements from bus 6 to bus 4 where the differential application is executed
- Differential application sends trip command to the breakers of the line to open in case of a fault in the transmission line range



Wide Area Protection-Results



- With 5G and 4G the fault is cleared before the system goes to instability
- The system is led to instability in case of the 3G network

Conclusions

- This work investigates how the use of the wireless networks (3G, 4G, and 5G) impacts the performance of two wide area applications
- The 3G network impacts negatively the wide area monitoring and protection applications→unsuitable for usage within a WAMPC system
- The 4G wireless network imposes delays to the transfer of the PMU measurements that affect the performance of the applications→the accuracy and real-time responsiveness of the applications is improved.
- The two considered applications achieve their best performance when a 5G communication network is used for transferring the PMU measurements.

Acknowledgement



Demonstration of **5G** solutions for
SMART energy **GRIDs** of the future



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