Simulation of a Sigfox Based Case Study in NS3 Workshop on ns-3

June 23, 2022

Presented By:
Muhammad Naeem
mnaeem@cs.aau.dk





Presented By: Muhammad Naeem

► Sigfox protocol module for ns-3.

Objectives

Transmission Procedur

Activity Diagram

Implementation in NS3

Network Performance Graph

Energy Consumption

Model

Hardwara

Hardware

Current Consump

Battery Lifetime

Conclusion

Future Works

16

Contact Information

Contact information



- Sigfox protocol module for ns-3.
- Performed simulations to study how a dense network would perform.

Presented By: Muhammad Naeem

Objectives

NS3

Case Study

Conclusion

Future Works



- ► Sigfox protocol module for ns-3.
- Performed simulations to study how a dense network would perform.
- Built the energy model based on Sigfox radio specifications and hardware datasheet.

Presented By: Muhammad Naeem

Objectives

Sinfoy Proto

Transmission Procedure

Implementation in

Network Performance

Energy Consumption

Model Consump

Case Study

Hardware

Hardware

Current Consump

Battery Lifetime

Thresholds

Conclusion

Future Works

Contact Information



- Sigfox protocol module for ns-3.
- Performed simulations to study how a dense network would perform.
- Built the energy model based on Sigfox radio specifications and hardware datasheet.
- Tuned the model's parameters using real measured data.

Presented By: Muhammad Naeem

Objectives

Case Study

Future Works

Department of Computer

Science Aalborg University Denmark



- ► Sigfox protocol module for ns-3.
- Performed simulations to study how a dense network would perform.
- ► Built the energy model based on Sigfox radio specifications and hardware datasheet.
- ► Tuned the model's parameters using real measured data.
- All major energy-consuming states and actions of a Sigfox node

Presented By: Muhammad Naeem

Objectives

Sigfoy Protoc

Transmission Procedure

Implementation in

NS3 Network Performance

Graph

Energy Consumption

nergy Consumption

ase Study

Hardwara

Hardware

Energy Current Consumption

attery Lifetime

Thresholds

Conclusion

Future Works

Contact Information



- ► Sigfox protocol module for ns-3.
- Performed simulations to study how a dense network would perform.
- ► Built the energy model based on Sigfox radio specifications and hardware datasheet.
- ► Tuned the model's parameters using real measured data.
- ► All major energy-consuming states and actions of a Sigfox node
- Novel battery model that takes into account the self-discharge current.

Presented By: Muhammad Naeem

Objectives

Sigfox Protoc

Transmission Procedure

mplementation in

NS3 Network Performance

Graph

nergy Consumption

ase Study

Llordunoro

Hardware

inergy

ttery Lifetime

Threeholds

onclusion

Conclusion

Future Works

Contact Information



- ► Sigfox protocol module for ns-3.
- Performed simulations to study how a dense network would perform.
- ► Built the energy model based on Sigfox radio specifications and hardware datasheet.
- ► Tuned the model's parameters using real measured data.
- All major energy-consuming states and actions of a Sigfox node
- Novel battery model that takes into account the self-discharge current.
- Results comparison with the analysis of the Sigfox protocol performed using Statistical Model Checking.

Presented By: Muhammad Naeem

Objectives

Sigfox Protoc

Activity Diagram

Implementation in

Network Performance Graph

nergy Consumption

se Study

Hardware

Hardware

urrent Consumption

Battery Lifetime

Conclusion

Future Works

Contact Information





Figure: Basic Architecture of the Sigfox Protocol

Presented By: Muhammad Naeem

Objectives

Sigfox Protocol

Transmission Procedure

Implementation in

Network Performance Graph

Model Model

Case Study

Hardware

Current Consumption

Battery Lifetime

Conclusion

Future Works

16

Contact Information



► A Sigfox node can send up to 6 messages per hour (144 messages per day) with up to 12 bytes of payload each, and receive up to 4 8-byte messages per day.

Presented By: Muhammad Naeem

Objective

Sigfox Protocol

Transmission Procedure

Activity Diagram

Implementation in NS3

Network Performance Graph

nergy Consumption odel

Case Study

lardware

Current Consumpt

Battery Lifetime

Conclusion

Future Works

Contact Information

...IINS-3

- A Sigfox node can send up to 6 messages per hour (144 messages per day) with up to 12 bytes of payload each, and receive up to 4 8-byte messages per day.
- ▶ We considered the latest Sigfox specification SPECS-1.5.

Presented By: Muhammad Naeem

Objective:

Sigfox Protocol

Transmission Procedure

Activity Diagram

Implementation in NS3

Network Performance Graph

nergy Consumptio odel

Case Study

Hardware

Current Consump

Battery Lifetime

Conclusion

Future Works

Contact Information



- ➤ A Sigfox node can send up to 6 messages per hour (144 messages per day) with up to 12 bytes of payload each, and receive up to 4 8-byte messages per day.
- ▶ We considered the latest Sigfox specification SPECS-1.5.

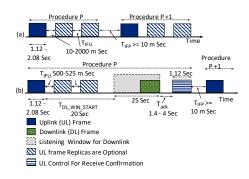


Figure: Sigfox transmission Procedures

Presented By: Muhammad Naeem

Objectives

Sigfox Protocol

Transmission Procedure

Implementation in

Network Performance Graph

Energy Consumptio Model

Case Stud

Hardware

Fnerov

urrent Consumpti

Battery Lifetime

Conclusion

Future Works

Department of Computer

Science Aalborg University Denmark



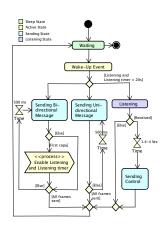


Figure: Activity Diagram of a Sigfox Module

Presented By: Muhammad Naeem

Objectives

Sigfox Protocol

Activity Diagram

Implementation in NS3

Network Performance Graph

Energy Consumpt Model

Case Study

Hardware

Current Consumption

Battery Lifetime

Conclusion

Future Works

Contact Information

Department of Computer Science Aalborg University Departs

16



Applications:

► Sigfox-Large-Network:

Sigfox-Energy-Model:

Presented By: Muhammad Naeem

Implementation in

NS3

Case Study

Future Works



Applications:

► Sigfox-Large-Network:

Analyse the model behaviour especially the physical layer.

Performed simulations to estimate the packet success rate with a dense network.

► Sigfox-Energy-Model:

Presented By: Muhammad Naeem

Objectives

Sigfox Prote

Transmission Procedure
Activity Diagram

5 Implementation in

Network Performance Graph

nergy Consumption

ase Study

Hardware

Fnerov Fnerov

Current Consumpti

Battery Lifetime

Conclusion

Conclusion

Future Works

Contact Information





Applications:

► Sigfox-Large-Network:

Analyse the model behaviour especially the physical layer.

Performed simulations to estimate the packet success rate with a dense network.

► Sigfox-Energy-Model:

To model energy consumption behaviour of the Sigfox sensor node with different transmission strategies.

Presented By: Muhammad Naeem

Objectives

Sigfox Protocol

5 Implementation in

NS3

Graph
Energy Consumption

ase Study

Hardware

Hardware

Current Consumpt

Battery Lifetime

onclusion

Future Works

1 01010 1101110

Contact Information



Applications:

► Sigfox-Large-Network:

Analyse the model behaviour especially the physical layer.

Performed simulations to estimate the packet success rate with a dense network.

➤ Sigfox-Energy-Model:

To model energy consumption behaviour of the Sigfox sensor node with different transmission strategies.

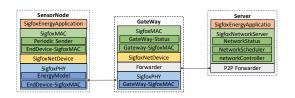


Figure: Block diagram of important models of the designed module



Objectives

Transmission Procedure

5 Implementation in

Network Performance Graph

Case Study

Hardware

Hardware

Current Consum

Battery Lifetime

Conclusion

Future Works

Contact Information

Network Performance Graph



Estimating the packet success rate for a network composed of several thousands of devices, both in the cases of 1 and 3 MAC-layer repetitions for each APP-layer packet.

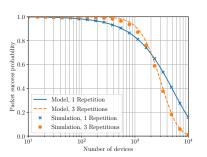


Figure: Packet Success Probability as Computed by Analysis and Simulation

Presented By: Muhammad Naeem

Objectives

Sigfox Pro

Transmission Procedure

Implementation in

Network Performance Graph

nergy Consumption

Model

Case Study

Hardware

Current Consum

Battery Lifetime

Conclusion

Future Works

Contact Information

Analytical Model for Energy Consumption



▶ In our model the energy in a battery satisfies the first order differential equation E' = -AE - B, with A and B being parameters that describe the energy dynamics of the system. The general solution to the equation is

$$E = e^{-At}(E_0 + B/A) - B/A$$

E₀: Initial energy

B: Total current powering the electronics

A: Self - discharge

Presented By: Muhammad Naeem

Objectives

Sigfox Protocol

Activity Diagram

Implementation in

Network Performance Graph

Energy Consumption Model

Case Study

Hardware Energy

> Current Consumpt Battery Lifetime

Conclusion

Conclusion

Future Works

Contact Information

Case Study



▶ Distributed ONline monitoring of the Urban waTer cycle (DONUT) Project.



Figure: Urban water monitoring systems

Presented By: Muhammad Naeem

Case Study

Future Works



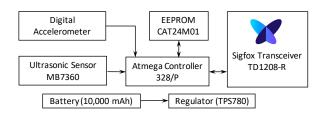


Figure: Basic Hardware Architecture of the Sensor Node

Presented By: Muhammad Naeem

Objectives

Sigfox Protocol

Activity Diagram

Implementation in NS3

Network Performanc Graph

Model Consumpt

Case Study

Hardware

Current Consump

Battery Lifetime

Conclusion

Future Works

16

Contact Information

Case Study Combined Energy Consumption



Table: DC Power Supply Characteristics

Sym	Parameter	Datasheet Value		Measured value
		Min	Max	Value
V_{DD}	Supply Voltages	3.3 V	-	3.3 V
I _{Sleep}	Power Saving Mode	2.35μ <i>A</i>	$4.35\mu A$	27.84μ <i>A</i>
I_{RX}	Active CPU + RX Mode Current	13mA	16mA	19.05mA
I_{TX}	Active CPU + TX Mode Current	50mA	50mA	47.03mA
I _{App}	Continues Appli- cation Current	10.8μ <i>A</i>	10.8μ <i>A</i>	4300μA
I _{Msr}	Sensor Measur- ing Current	5.9mA	6.8mA	6.58mA

Presented By: Muhammad Naeem

Energy

Conclusion

Future Works

16

Simulation Results in NS3

Current Consumption

111NS-3

► The current consumption graph aligned with the Sigfox protocol.

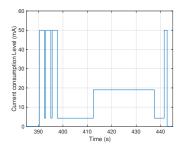


Figure: Sigfox Current Consumption Cycle

Presented By: Muhammad Naeem

Case Study

Current Consumption

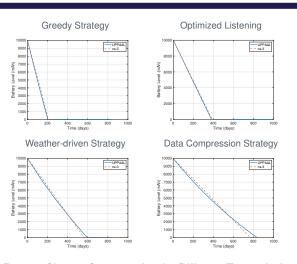
16

Future Works

Simulation Results in NS3

Battery Consumption Graphs





Presented By: Muhammad Naeem

Objectives

Sigfox Protocol

Activity Diagram

Implementation in

Network Performance Graph

Energy Consumption

Case Study

Hardware

Current Consumption

Battery Lifetime

Conclusion

Future Works

ruture work

16

Contact Information

Department of Computer Science Aalborg University Denmark

Figure: Battery Charge Consumption for Different Transmission Strategy

Simulation Results in NS3

Data Compression Strategy with Different Thresholds



- ▶ Data compression strategy is parametric with respect to the threshold that leads to sending data.
- Slightly increasing threshold avoid waving in water height and optimize lifetime.

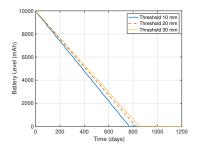


Figure: Battery Charge Consumption for Different Thresholds using Data Compression Strategy Presented By: Muhammad Naeem

Objectives

Transmission Procedure

mplementation in

Network Performance

nergy Consumption

Case Study

Hardware

Hardware Energy

Battery Lifetime

Thresholds

onclusion.

Conclusion

Future Works

Contact Information



► This paper presents a module to simulate the Sigfox protocol with the ns-3 simulator.

Presented By: Muhammad Naeem

Objectives

Sigfox Proto

Transmission Procedure

Implementation in

Network Performance

nergy Consumption

nergy Consumpti odel

Case Study

Hardware

Energy

Battery Lifetime

Battery Lifetime Thresholds

14 Conclusion

Future Works

16

Contact Information

Contact information



- ► This paper presents a module to simulate the Sigfox protocol with the ns-3 simulator.
- ➤ To the best of our knowledge, the module is the first implementation of the Sigfox protocol to date.

Presented By: Muhammad Naeem

Objectives

Sigfox Proto

Activity Diagram

Implementation in

Network Performance

nergy Consumption

odel

Case Study

Hardware

Energy

Current Consump

Battery Lifetime

Conclusion

Conclusion

Future Works

Contact Information



- ► This paper presents a module to simulate the Sigfox protocol with the ns-3 simulator.
- ➤ To the best of our knowledge, the module is the first implementation of the Sigfox protocol to date.
- ► The model was used to accurately simulate the power consumption and battery lifetime of a Sigfox node, and it includes the behavior of battery self-discharge.

Presented By: Muhammad Naeem

Conclusion

Future Works



- ► This paper presents a module to simulate the Sigfox protocol with the ns-3 simulator.
- ➤ To the best of our knowledge, the module is the first implementation of the Sigfox protocol to date.
- ► The model was used to accurately simulate the power consumption and battery lifetime of a Sigfox node, and it includes the behavior of battery self-discharge.
- ► Furthermore, we calibrated the model using measurement data from real hardware.

Presented By: Muhammad Naeem

Case Study

Conclusion

Future Works



- ► This paper presents a module to simulate the Sigfox protocol with the ns-3 simulator.
- ➤ To the best of our knowledge, the module is the first implementation of the Sigfox protocol to date.
- ► The model was used to accurately simulate the power consumption and battery lifetime of a Sigfox node, and it includes the behavior of battery self-discharge.
- ► Furthermore, we calibrated the model using measurement data from real hardware.
- The results of our simulations allow to select a communication strategy that extends from 202 days to 2.3 years the lifetime of a Sigfox based sensor node powered by a 10,000 mAh battery.

Presented By: Muhammad Naeem

Case Study

Conclusion

Future Works



▶ The module is able to simulate communication via the Sigfox protocol between end-devices and Gateways.

Presented By: Muhammad Naeem

Case Study

15 Future Works



- ► The module is able to simulate communication via the Sigfox protocol between end-devices and Gateways.
- ► Simulation of a complete Sigfox deployment would require to extend the Gateway model with an application layer that transfers received data to a network server or a Sigfox backend.

Presented By: Muhammad Naeem

Objectives

Sigfox Pi

Transmission Procedure

Implementation in

NS3

Graph

nergy Consumption

Case Study

-lardware

nerav

Current Consur

Battery Lifetime

Thresholds

Conclusion

15 Future Works

Contact Information



- ► The module is able to simulate communication via the Sigfox protocol between end-devices and Gateways.
- ➤ Simulation of a complete Sigfox deployment would require to extend the Gateway model with an application layer that transfers received data to a network server or a Sigfox backend.
- ► This extension is not in the scope of this work.

Presented By: Muhammad Naeem

Objectives

Sigfox P

Transmission Procedure

Implementation in

NS3

Network Performance Graph

nergy Consumption

Case Study

Jase Sidu

Hardware

Energy

Surrent Consump

Battery Lifetime

onclusion

Conclusion

15) Future Works

Contact Information

Department of Computer





- ► The module is able to simulate communication via the Sigfox protocol between end-devices and Gateways.
- ➤ Simulation of a complete Sigfox deployment would require to extend the Gateway model with an application layer that transfers received data to a network server or a Sigfox backend.
- ► This extension is not in the scope of this work.
- ► Thus, the implementation of a complete Sigfox IoT solution is left as future work.

Presented By: Muhammad Naeem

Objectives

Sigfox Pr

Activity Diagram

Implementation in

Network Performance Graph

Energy Consumption

Case Study

Hardware

Hardware

Energy Current Consur

attery Lifetime

Battery Lifetime

Conclusion

Conclusion

15 Future Works

Contact Information

Feedback Contact Information



Presented By: Muhammad Naeem

https://vbn.aau.dk/en/persons/147438 Selma Lagerløfs Vej 300, 1-2-59 9220 Aalborg Ø

Code Link:https://github.com/DEIS-Tools/ns3-sigfox Thank you for your Attention



Presented By: Muhammad Naeem

Objectives

Sigfox Protoc

Activity Diagram

Implementation in

Network Performanc

Energy Consumption

Model Model

Case Study

-lardware

Hardware

Current Consu

Battery Lifetime

Threshold

Conclusion

Future Works

Contact Information

Contact Information