VRIJE
UNIVERSITEIT
BRUSSEL

PROJECTS 2024-2025

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Management and Performance Analysis of Sensor Networks

1 General rules and requirements

This document contains the description and requirements of the projects for the course Management and Performance Analysis of Sensor Networks. The goal of the projects is to examine a part of a network protocol and present the results in a scientific manner. Here follow the general requirements that need to be followed for all the projects.

Each project has certain minimal requirements which are mandatory. Each project has also extra requirements which are optional. Doing the extra requirements gives you one bonus point on the project but cannot make the final result exceed a 20/20. The bonus point can only be achieved when the extra requirements are performed well and in full. Only doing half the work will not result in a bonus.

1.1 Choosing tests

Every project has some metrics that you need to measure to help you along, but before you can start doing experiments, you need to know what and how you will measure. You need to reason about what experiments are necessary and how to the trigger specific behavior you want to test. Eg. it does not make sense to measure PDR in a perfect medium with no loss.

While designing the experiments, you need to reason about possible factors that can influence your experiments. Eg. if you do experiments in real, external interference may have an impact on the PDR. If performing experiments in a room with a considerable amount of metallic objects, this may induce echos that can result in interference.

You are thus required to consider these outside sources of interference and think about the magnitude of their impact. If you are doing experiments in real, how are you going to measure the interference?

When performing experiments, you need to think about the representativeness of your setup. If you are looking at routing behavior, it does not make sense to have a small network of only 3 devices with one them being the root. Performing experiments in real is also much harder than in simulation, thus we expect larger networks when simulation is used unless otherwise stated with a well founded reason in your report.

1.2 Correctly measuring and representation in the report

Doing only one measurement can be a fluke. Doing multiple measurements and constraining the final value in a confidence interval gives you a measurement on your correctness.

Always think about what you measure. Of what is it a measurement and in what range do you expect these measurements to fall into. Eg. in a star network, the delay to a central node when using CSMA cannot be higher than $\sim 4s$ or energy consumption cannot be a few million joules.

When presenting the results in your report, the following needs to be present:

- Confidence intervals (3σ with at least 30 bins is enough, but write this down somewhere in your report!)
- Units on axes
- Clear title and description on every chart
- Use SVG charts to keep them readable (no screenshots as they are often not readable)
- Labels in charts are big enough (at least 18pt)

1.3 Correct report structure

For this project, it is required for you to use the VUB template and to structure your text with the following guidelines. You can use both the VUB template for MS Word or LaTeX (our recommendation), but the final report needs to be a PDF. Your report will not be graded if submitted in any other form than PDF. Not complying with the formatting- or structuring

guidelines will result in your report not being graded and getting a zero on the report part of the assignment.

The following sections are expected to be included in the report:

- Introduction: What are you going to do and how
- Hypothesis and reasoning: Why the chosen experiments and which experiments did you perform
- Experimental setup: How are you going to measure. With the information in this part, it needs to be possible to reproduce your results.
- Results: Your results. Here the requirements or good charts is most important.
- Conclusion: What did you learn? What is the take-away of the study? A clear link with hypothesis and results needs to be made here.
- Overview of what each group member did during the experiments, processing of the data, writing of the report (which sections), and the preparation of the presentation.

1.4 Usage of GenAI

For this project it is allowed to use GenAI along the guidelines of the VUB. As a user of GenAI, you remain responsible for the final content in the report. This means that the content needs to be concise and coherent. So, make sure that what you say in one part of a sentence does not contradict another part of a sentence. This will result in a deduction from your grades.

The purpose of a report/presentation is to show that you understand what you are doing and that you can scientifically show the results of your work. Just using GenAI might harm the perceived value of your contribution and in the case where other parts are of less quality, this can be seen as a reason to deduct points from your grades.

Project 1: Orchestra Vs Minimal Schedule

Time Slotted Channel Hopping (TSCH) is a Medium Access Control (MAC) layer protocol, but requires a scheduler to work properly. In this project you will have to compare two schedulers under different circumstances.

Minimum requirements:

- Measure throughput: What is the breaking point for both schedulers?
- Measure latency: What is the latency introduced by both schedulers?
- Behavior under disturbances: How do both schedulers handle disturbances?
- Behavior under different slotframe sizes: What impact does changing the slotframe size have on the performance of both schedulers?

Extra:

- Use real devices (normal motes + sniffer)

Project 2: Unslotted CSMA-CA Vs TSCH Orchestra

In this project, you will look at the differences between unslotted CSMA-CA and TSCH with the Orchestra scheduler.

Minimum requirements:

- Measure throughput: What is the breaking point for both schedulers?
- Measure latency: What is the latency introduced by both protocols?
- Behavior under disturbances: How do both protocols handle disturbances?
- Behavior of the exponential backoff: What is it and how does it impact the performance?

Extra:

- Behavior under different slotframe sizes: What impact does changing the slotframe size have on the performance?
- Write an in depth description of the impact of multiple channels in TSCH compared to the single channel used in Unslotted CSMA-CA.

Project 3: No-Path DAO Vs DCO

The DODAG Cleanup Object (DCO) is a relative new addition the Routing Protocol for Low-Power and Lossy Networks (RPL) standard. It is intended as a replacement of the legacy No-Path DAO to clean up old routes in RPL MOP2. In this project, you will have to look at the differences of both and the performance implications of using the new DCO compared to the legacy No-Path DAO.

Special care needs to given to rare events in this project.

Minimum requirements:

- Investigate the behavior of the network with disturber nodes causing a bad links
- Investigate the behavior with different TX/RX ratios that may cause interference between nodes
- Peak latency (1% highs): What is the 1% highest latency you measure while parent changes are happening.
- Description of experimental setup: For this project it is very important that you measure the correct thing, so we expect a thorough description of the experimental setup.

Extra:

- Discussion of problems with DCO: Provide a thorough description of possible downsides to the new way of updating routes.

Project 4: DIO probing Vs refreshing routes through DAOs on RPL

DIO probing is a technique where a node in a RPL network periodically sends DIO unicast messages to its neighbours. The goal is to continuously get updates on the link quality between a node and its parents. This can then enable a node to find a more suitable preferred parent when the quality of links changes.

On the other hand, it is possible for a network to periodically do a complete refresh of the forwarding tables by increasing the DTSN in the DIO messages. This will then prompt the entire network to look again for suitable parents.

In this project, you will have to look at which strategy is most beneficial in what kind of situation.

Minimum requirements:

- Measure throughput: Both strategies introduce extra control traffic which uses some of the available bandwidth. What is the maximal throughput of normal data packets before the network gets too congested.
- Measure latency: What is the latency introduced by both strategies?
- Network construction time: How long does it take to detect bad links and find new better links?
- Analysis of network stability: Define a measure of network stability and measure the network's stability during the experiments. What are your conclusions?

Extra:

- Discuss when probing is actually interesting compared to when rebuilding the network from scratch is more beneficial.

Project 5: RPL Vs RPL-Lite

RPL is a complex protocol with many large RFC's that need to work together in a constraint environment. RPL Lite is a slimmed down version of RPL implemented in Contiki-NG.

In this project, you will look into the differences of both and determine when one would be more beneficial that the other.

Minimum requirements:

- Measure throughput: What is the breaking point for both protocols?
- Measure latency: What is the latency introduced by both protocols?
- Analysis of network stability: Define a measure of network stability and measure the network's stability during the experiments. What are your conclusions?
- Analysis of differences between the 2 protocols: In depth analysis of which features are common and which are only in RPL or RPL Lite.

Extra:

- In depth discussion on which one makes more sense in a real-life scenario. What kind requirements do you need to make it worthwhile to deviate from a recognized standard like RPL and use something like RPL Lite?

Project 6: Impact of 6LoWPAN

To allow IPv6 packets to be used on low-power embedded devices, some form of compression is required. For this 6LoWPAN was invented. It provides namely framing and compression. The use of 6LoWPAN is, however, not for free as you introduce extra processing on these low-power devices.

In this project, you will investigate the cost of 6LoWPAN and compare it to its benefits.

Minimum requirements:

- Measure throughput: What is the breaking point when using/without framing?
- Measure latency: What is the latency introduced by using compression and framing?
- Impact of framing: What are some clear (dis)advantages when using framing?
- Impact of compression: What are some clear (dis)advantages when using compression?

Extra:

- Discussion on possible improvements to framing: What are some improvements you can think of to improve the current state of framing?

Project 7: BMRF Vs SMRF

Multicast has the possibility of considerably reducing the used bandwidth in a network. IPv6 multicast is, however, sparsely specified for RPL (only one-two paragraphs). This did not stop new multicast protocols to be created in research context. Two of the more interesting results are BMRF and SMRF.

In this project, you will look into the (dis)advantages of both multicast protocols.

Minimum requirements:

- Measure throughput: Measure the maximum throughput for both protocols?
- Measure latency: Measure the latency for both protocols?
- Measure the impact of disturber nodes on both protocols
- Investigate the behavior with different TX/RX ratios that may cause interference between nodes

Extra:

- In depth discussion of the interaction of the MAC-layer on efficient multicast routing. When is one strategy more beneficial than the other? What real world scenarios can you think of that require the flexibility of BMRF, while considering the added complexity?

Project 8: MRHOF Vs OF0

RPL defines the use of an objective function to decide on a preferred parent. The RPL RFC, however, does not define the exact working of this function.

In this project, you will investigate two proposed objective functions available in Contiki-NG.

Minimum requirements:

- Measure throughput: Measure the maximum throughput when using the two objective functions?
- Measure latency: Measure the latency when using the two objective functions?
- Measure the impact of disturber nodes
- Investigate the behavior with different TX/RX ratios that may cause interference between nodes

Extra:

- In depth discussion on the weaknesses of ETX and possible solutions

Project 9: Rust Unslotted CSMA-CA Vs Contiki CSMA

In a world where cybersecurity is ever becoming more important, having more secure operating systems allows for a better foundation to build highly complex telecom applications. One such effort is the Embassy framework written in Rust that recently got a new Unslotted CSMA-CA implementation. Evaluation is already done for the Embassy version, but no comparison study has been made yet with older implementations like the one in Contiki-NG.

In this project, you will recreate the original experiment in Contiki-NG and compare your own results from the evaluation in Embassy.

The original experiment measured PDR and delay on real devices in a low congested and highly congested environment. To artificially increase contention, a specific configuration was created to synchronize the transmission of frames. A central node would broadcast a single frame with a sequence number. The other nodes in its immediate environment would receive this broadcast frame and transmit back a unicast frame to the central node with the same sequence number. This allows to measure the end-to-end delay as you only have a single clock taking the measurements in the central node.

There is, however, one issue. If all neighbouring nodes would transmit at exactly the same time, they would all check the medium at exactly the same time, not sense each other, and transmit all at the same time. This results in a very low PDR as it does not give the nodes to perform the collision avoidance in CSMA-CA. To solve this, every node waits a small random time before sending back the sequence number.

$$t_{\text{wait}} \in \{0, 64, 128, 192\}.$$

Minimum requirements:

- Compare experimental results of Contiki CSMA with previous results of Embassy+Dot15d4
- Synchronizing transmissions
- Measure PDR
- Measure delay

Extra:

- Create a simple mathematical model to give bounds on min/max/avg delay

Project 10a: BMRF with unicast/broadcast in Orchestra

BMRF is a multicast routing protocol for RPL. It has the ability to adaptively change between link-layer unicast and broadcast depending on the amount of interested children. The ability to chose between both makes the decision of the underlying MAC protocol important.

Orchestra provides a mechanism to schedule link-layer broadcast traffic in a common shared slot. Here, the rules of a simplified CSMA apply.

In this project, you will investigate the impact of choosing between unicast/broadcast on the performance of BMRF with TSCH and Orchestra configured at the link-layer.

Minimal requirements:

- Tests in real: Use the dual-motes to perform the experiments.
- Measure latency: Measure the latency when using the two objective functions?
- Measure PDR
- Measure the energy consumption

Extra:

- In depth discussion on whether on not Orchestra is suitable for broadcast traffic in the context of BMRF as multicast routing protocol.

Project 10b: BMRF with unicast/broadcast in Orchestra

BMRF is a multicast routing protocol for RPL. It has the ability to adaptively change between link-layer unicast and broadcast depending on the amount of interested children. The ability to chose between both makes the decision of the underlying MAC protocol important.

Orchestra provides a mechanism to schedule link-layer broadcast traffic in a common shared slot. Here, the rules of a simplified CSMA apply.

In this project, you will investigate the impact of choosing between unicast/broadcast on the performance of BMRF with TSCH and Orchestra configured at the link-layer.

Minimal requirements:

- Tests in simulator: Simulate a network of at least 25 devices
- Measure latency: Measure the latency when using the two objective functions?
- Measure PDR
- Measure the energy consumption
- Create a mathematical model to estimate min/max/avg delay

Extra:

- In depth discussion on whether on not Orchestra is suitable for unicast traffic in the context of BMRF as multicast protocol.