

Metody programowania równoległego

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Kod programów jak i skrypty do uruchamiania programów zamieściłem w sprawozdaniu. Dane znajdują się na końcu.

Część 1 - Komunikacja P2P

Programy do pomiaru przepustowości zostały napisane w języku `c` i były wykonywane na klastrze `vnode-*.dydaktyka.icsr.agh.edu.pl`. Celem zadania jest zmierzenie wartości opóźnienia i charakterystyki przepustowości połączeń w klastrze.

Funkcje wykorzystane do komunikacji:

- `ssend` - Synchronous blocking send.

Blokuje dopóki odbiorca nie odebrał wiadomości. Po wykonaniu tej funkcji można bezpiecznie korzystać z przekazanego bufora.

- `ibsend` - Asynchronous non-blocking send.

Funkcja ta stworzy kopię przekazanych danych i wyśle ją w późniejszym czasie. Funkcja nie blokuje wywołującego, i po jej wywołaniu nie można modyfikować bufora gdyż mógł on jeszcze nie zostać skopiowany. Do sprawdzenia czy bufora można użyć służy funkcja `MPI_Test` lub `MPI_Wait`.

Pomiary wykonywałem w następujący sposób. Z góry ustaliłem ilość danych do przesłania - 100MB. Dla każdej rozważanej wielkości wiadomości obliczałem ile wiadomości trzeba wysłać aby przesłać ustaloną wyżej ilość danych. Na podstawie czasu potrzebnego na wykonanie transferu tych danych obliczałem przepustowość.

Jako MB - przyjąłem (być może zaskakująco) 10^6 B zgodnie z układem SI.

Zmierzyłem wiadomości w zakresie 1B-10MB, przy czym większość zmierzonych rozmiarów (około 300) mieści się poniżej 250kB, pozostałych jest około 100. Dla każdej wielkości wiadomości powtórzyłem pomiar trzykrotnie.

Kod Źródłowy i Skrypty

- ibsend.c

```

#include <mpi.h>
#include <stdbool.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#ifdef DEBUG
#define DEBUG_PRINTF(...) printf(__VA_ARGS__)
#else
#define DEBUG_PRINTF(...) \
    do { \
        } while (0)
#endif

#define INFO_PRINTF(...) \
    do { \
        printf("INFO: " __VA_ARGS__); \
        puts(""); \
    } while (0)

int message_id(int round_id, bool ping_message) {
    return round_id * 2 + ping_message;
}

char* allocate_n_bytes(int n_bytes) { return malloc(sizeof(char) * n_bytes); }

int compute_transferred_data_single_round_bytes(int message_size) {
    return 2 * message_size;
}

long int compute_rounds_count(long int n_bytes_to_transer, int message_size) {
    return n_bytes_to_transer /
        compute_transferred_data_single_round_bytes(message_size);
}

double compute_throughput_mbit_s(long int ping_pong_rounds, int message_size,
                                double measured_time) {
    long int transfered_data_bytes =
        compute_transferred_data_single_round_bytes(message_size) *
        ping_pong_rounds;
    return ((transfered_data_bytes * 8) / 1e6) / measured_time;
}

int main(int argc, char* argv[]) {
    // mpi related
    MPI_Init(&argc, &argv);
    int world_rank;
    MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);
    int world_size;
    MPI_Comm_size(MPI_COMM_WORLD, &world_size);

    // args,
    // - message_size in bytes
    // - data to be transferred in bytes
    // - output_file with measurements.
    int partner_rank = (world_rank + 1) % 2;
    int message_size_bytes = strtol(argv[1], NULL, 10);
    long int bytes_to_transfer = strtol(argv[2], NULL, 10);

    long int ping_pong_rounds =
        compute_rounds_count(bytes_to_transfer, message_size_bytes);

```

```

char* data_file = argv[3];
FILE* datafile_fp = fopen(data_file, "a+");

// allocate buffer
int buffer_attached_size = sizeof(char) * message_size_bytes + MPI_BSEND_OVERHEAD;
char* buffer_attached = allocate_n_bytes(buffer_attached_size);
MPI_Buffer_attach(buffer_attached, buffer_attached_size);

// master
// send ping, receive pong
if (world_rank == 0) {
    INFO_PRINTF(
        "Bytes to transfer: %ld, ping_pong_rounds: %ld, message_size: %d",
        bytes_to_transfer, ping_pong_rounds, message_size_bytes);
    int ping_buffer_size = message_size_bytes;
    char* ping_message = allocate_n_bytes(message_size_bytes);
    int pong_buffer_size = message_size_bytes;
    char* pong_buffer = allocate_n_bytes(message_size_bytes);

    // synchronization
    MPI_Barrier(MPI_COMM_WORLD);
    double start_wtime = MPI_Wtime();
    long int round_id;
    for (round_id = 0; round_id < ping_pong_rounds; round_id++) {
        MPI_Request request;
        ping_message[round_id % message_size_bytes] = (char) rand();
        MPI_Ibsend(ping_message, ping_buffer_size, MPI_CHAR, partner_rank,
            message_id(round_id, true), MPI_COMM_WORLD, &request);
        DEBUG_PRINTF("Round: %ld, sent: %s\n", round_id, ping_message);

        MPI_Recv(pong_buffer, pong_buffer_size, MPI_CHAR, partner_rank,
            message_id(round_id, false), MPI_COMM_WORLD, MPI_STATUS_IGNORE);
        DEBUG_PRINTF("Round: %ld, received: %s\n", round_id, pong_buffer);

        // Let's wait for the MPI_Ibsend to complete before progressing further.
        // Should return immediately in our case since message must've been sent at this point.
        MPI_Wait(&request, MPI_STATUS_IGNORE);
        // Detach the buffer. It blocks until all messages stored are sent.
        MPI_Buffer_detach(&buffer_attached, &buffer_attached_size);
        // reattach the buffer.
        MPI_Buffer_attach(buffer_attached, buffer_attached_size);
    }

    double end_wtime = MPI_Wtime();
    double measured_time = end_wtime - start_wtime;

    double throughput = compute_throughput_mbit_s(
        ping_pong_rounds, message_size_bytes, measured_time);
    INFO_PRINTF("Measured_time: %.6fs, Throughput: %.6f[Mbit/s]", measured_time,
        throughput);
    fprintf(datafile_fp, "%d %.6f\n", message_size_bytes, throughput);

    // slave
    // receive ping, send back pong
} else {
    int pong_buffer_size = message_size_bytes;
    char* pong_message = allocate_n_bytes(message_size_bytes);
    int ping_buffer_size = message_size_bytes;
    char* ping_buffer = allocate_n_bytes(message_size_bytes);

    // synchronization
    MPI_Barrier(MPI_COMM_WORLD);
    MPI_Request request;
    long int round_id;
    for (round_id = 0; round_id < ping_pong_rounds; round_id++) {
        if (round_id != 0) {
            // Let's wait for the MPI_Ibsend to complete before progressing further.
            // Should return immediately in our case since message must've been sent at

```

```

// should return immediately in our case since message must've been sent at
this point.
    MPI_Wait(&request, MPI_STATUS_IGNORE);
    // Detach the buffer. It blocks until all messages stored are sent.
    MPI_Buffer_detach(&buffer_attached, &buffer_attached_size);
    // reattach the buffer.
    MPI_Buffer_attach(buffer_attached, buffer_attached_size);
}
MPI_Recv(ping_buffer, ping_buffer_size, MPI_CHAR, partner_rank,
        message_id(round_id, true), MPI_COMM_WORLD, MPI_STATUS_IGNORE);
DEBUG_PRINTF("Round: %ld, received: %s\n", round_id, ping_buffer);

pong_message[round_id % message_size_bytes] = ping_buffer[round_id % message_
size_bytes];
DEBUG_PRINTF("%c", pong_message[round_id % message_size_bytes]);
MPI_Ibsend(pong_message, pong_buffer_size, MPI_CHAR, partner_rank,
        message_id(round_id, false), MPI_COMM_WORLD, &request);
DEBUG_PRINTF("Round: %ld, sent: %s\n", round_id, pong_message);
}
}
MPI_Finalize();
return 0;
}

```

- ssend.c

```

#include <mpi.h>
#include <stdbool.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#ifdef DEBUG
#define DEBUG_PRINTF(...) printf(__VA_ARGS__)
#else
#define DEBUG_PRINTF(...) \
    do { \
    } while (0)
#endif

#define INFO_PRINTF(...) \
    do { \
        printf("INFO: " __VA_ARGS__); \
        puts(""); \
    } while (0)

int message_id(int round_id, bool ping_message) {
    return round_id * 2 + ping_message;
}

char* allocate_n_bytes(int n_bytes) { return malloc(sizeof(char) * n_bytes); }

int compute_transferred_data_single_round_bytes(int message_size) {
    return 2 * message_size;
}

long int compute_rounds_count(long int n_bytes_to_transer, int message_size) {
    return n_bytes_to_transer /
        compute_transferred_data_single_round_bytes(message_size);
}

double compute_throughput_mbit_s(long int ping_pong_rounds, int message_size,
                                double measured_time) {
    long int transfered_data_bytes =
        compute_transferred_data_single_round_bytes(message_size) *
        ping_pong_rounds;

```

```

        ping_pong_rounds,

    return ((transferred_data_bytes * 8) / 1e6) / measured_time;
}

int main(int argc, char* argv[]) {
    // mpi related
    MPI_Init(&argc, &argv);
    int world_rank;
    MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);
    int world_size;
    MPI_Comm_size(MPI_COMM_WORLD, &world_size);

    // args,
    // - message_size in bytes
    // - data to be transferred in bytes
    // - output_file with measurements.
    int partner_rank = (world_rank + 1) % 2;
    int message_size_bytes = strtol(argv[1], NULL, 10);
    long int bytes_to_transfer = strtol(argv[2], NULL, 10);

    long int ping_pong_rounds =
        compute_rounds_count(bytes_to_transfer, message_size_bytes);

    char* data_file = argv[3];
    FILE* datafile_fp = fopen(data_file, "a+");

    // master
    // send ping, receive pong
    if (world_rank == 0) {
        INFO_PRINTF(
            "Bytes to transfer: %ld, ping_pong_rounds: %ld, message_size: %d",
            bytes_to_transfer, ping_pong_rounds, message_size_bytes);
        int ping_buffer_size = message_size_bytes;
        char* ping_message = allocate_n_bytes(message_size_bytes);
        int pong_buffer_size = message_size_bytes;
        char* pong_buffer = allocate_n_bytes(message_size_bytes);

        // synchronization
        MPI_Barrier(MPI_COMM_WORLD);
        double start_wtime = MPI_Wtime();
        long int round_id;
        for (round_id = 0; round_id < ping_pong_rounds; round_id++) {
            ping_message[round_id % message_size_bytes] = (char) rand();
            MPI_Send(ping_message, ping_buffer_size, MPI_CHAR, partner_rank,
                    message_id(round_id, true), MPI_COMM_WORLD);
            DEBUG_PRINTF("Round: %ld, sent: %s\n", round_id, ping_message);

            MPI_Recv(pong_buffer, pong_buffer_size, MPI_CHAR, partner_rank,
                    message_id(round_id, false), MPI_COMM_WORLD, MPI_STATUS_IGNORE);
            DEBUG_PRINTF("Round: %ld, received: %s\n", round_id, pong_buffer);
        }

        double end_wtime = MPI_Wtime();
        double measured_time = end_wtime - start_wtime;

        double throughput = compute_throughput_mbit_s(
            ping_pong_rounds, message_size_bytes, measured_time);
        INFO_PRINTF("Measured_time: %.6fs, Throughput: %.6f[Mbit/s]", measured_time,
                    throughput);
        fprintf(datafile_fp, "%d %.6f\n", message_size_bytes, throughput);

        // slave
        // receive ping, send back pong
    } else {
        int pong_buffer_size = message_size_bytes;
        char* pong_message = allocate_n_bytes(message_size_bytes);
        int ping_buffer_size = message_size_bytes;
        char* ping_buffer = allocate_n_bytes(message_size_bytes);

        // synchronization

```

```

// Synchronization

MPI_Barrier(MPI_COMM_WORLD);
long int round_id;
for (round_id = 0; round_id < ping_pong_rounds; round_id++) {
    MPI_Recv(ping_buffer, ping_buffer_size, MPI_CHAR, partner_rank,
            message_id(round_id, true), MPI_COMM_WORLD, MPI_STATUS_IGNORE);
    DEBUG_PRINTF("Round: %ld, received: %s\n", round_id, ping_buffer);

    pong_message[round_id % message_size_bytes] = ping_buffer[round_id % message_
size_bytes];
    DEBUG_PRINTF("%c", pong_message[round_id % message_size_bytes]);
    MPI_Send(pong_message, pong_buffer_size, MPI_CHAR, partner_rank,
            message_id(round_id, false), MPI_COMM_WORLD);
    DEBUG_PRINTF("Round: %ld, sent: %s\n", round_id, pong_message);
}
}

MPI_Finalize();
return 0;
}

```

Skrypty do uruchamiania:

- run.sh

```
#!/bin/bash
```

```
export VNODE_CLUSTER_SINGLE_NODE=true
make ssend-multiple-runs
make ibsend-multiple-runs
```

```
export VNODE_CLUSTER_SINGLE_NODE=false
export VNODE_CLUSTER_TWO_NODES=true
make ssend-multiple-runs
make ibsend-multiple-runs
```

- makefile (nie był to najlepszy pomysł, dużo prościej byłoby po prostu użyć basha)

```

CC = "mpicc"
MPIEXEC = "mpiexec"
NODE_SUFFIX = "single_node"
IBSEND_PREFIX = "ibsend"
SSEND_PREFIX = "ssend"
MEASUREMENTS_DIR = "measurements"
ifeq (${VNODE_CLUSTER_SINGLE_NODE}, true)
    MPIEXEC = mpiexec -machinefile ./vcluster-config/single_node
endif
ifeq (${VNODE_CLUSTER_TWO_NODES}, true)
    MPIEXEC = mpiexec -machinefile ./vcluster-config/two_nodes
    NODE_SUFFIX = "two_nodes"
endif

TRIALS ?= 3
DATA_FILE_ID ?= 0
DATA_TO_BE_TRANFERRED_BYTES = 100000000 # 100 MB

MESSAGE_STEP_SIZE_BYTES = 100000 # 100 kB
MAX_MESSAGE_SIZE = 10000000 # 10 MB

MESSAGE_STEP_SMALL_STEP_SIZE_BYTES = 1000 # 5kB
SMALL_STEP_THRESHOLD_BYTES = 250000 # 250kb

MESSAGE_STEP_VERY_SMALL_STEP_SIZE_BYTES = 100 # 100B

```

```

VERY_SMALL_STEP_THRESHOLD_BYTES = 5000 # 5 kB
# ~ 50 + 250 + 100 measurements.

# ibsend
ibsend-plot:
    ./gnuplot/composite_stats.sh "$(/$(MEASUREMENTS_DIR)/$(IBSEND_PREFIX)_$(NODE_SUFFIX)-*.dat" > ".build/$(IBSEND_PREFIX)_$(NODE_SUFFIX)_composite.dat"
    gnuplot -persistent gnuplot/$(IBSEND_PREFIX)_$(NODE_SUFFIX).gpi

ibsend-multiple-runs:
    for (( i=1; i<=${TRIALS}; i++ )) ; do \
        $(MAKE) ibsend-run DATA_FILE_ID=$$i ; \
    done

ibsend-run: build/ibsend
    mkdir -p ./${MEASUREMENTS_DIR}
    rm -f "${MEASUREMENTS_DIR}/ibsend-${DATA_FILE_ID}.dat"

    message_size="1" ; while [[ $$message_size -le $(VERY_SMALL_STEP_THRESHOLD_BYTES) ]] ; do \
        $(MPIEXEC) -n 2 ./build/ibsend $$message_size ${DATA_TO_BE_TRANSFERRED_BYTES} \
        "${MEASUREMENTS_DIR}/${IBSEND_PREFIX}_${NODE_SUFFIX}-${DATA_FILE_ID}.dat"; \
        ((message_size = message_size + $(MESSAGE_STEP_VERY_SMALL_STEP_SIZE_BYTES)) \
    )) ; \
    done

    message_size=$(VERY_SMALL_STEP_THRESHOLD_BYTES) ; while [[ $$message_size -le $(SMALL_STEP_THRESHOLD_BYTES) ]] ; do \
        $(MPIEXEC) -n 2 ./build/ibsend $$message_size ${DATA_TO_BE_TRANSFERRED_BYTES} \
        "${MEASUREMENTS_DIR}/${IBSEND_PREFIX}_${NODE_SUFFIX}-${DATA_FILE_ID}.dat"; \
        ((message_size = message_size + $(MESSAGE_STEP_SMALL_STEP_SIZE_BYTES))) ; \
    done

    message_size=$(MESSAGE_STEP_SIZE_BYTES) ; while [[ $$message_size -le $(MAX_MESSAGE_SIZE) ]] ; do \
        $(MPIEXEC) -n 2 ./build/ibsend $$message_size ${DATA_TO_BE_TRANSFERRED_BYTES} \
        "${MEASUREMENTS_DIR}/${IBSEND_PREFIX}_${NODE_SUFFIX}-${DATA_FILE_ID}.dat"; \
        ((message_size = message_size + $(MESSAGE_STEP_SIZE_BYTES))) ; \
    done

build/ibsend: src/ibsend.c build
    $(CC) -o build/ibsend src/ibsend.c

# ssend
ssend-plot:
    ./gnuplot/composite_stats.sh "$(/$(MEASUREMENTS_DIR)/$(SSEND_PREFIX)_$(NODE_SUFFIX)-*.dat" > ".build/$(SSEND_PREFIX)_$(NODE_SUFFIX)_composite.dat"
    gnuplot -persistent gnuplot/$(SSEND_PREFIX)_$(NODE_SUFFIX).gpi

ssend-multiple-runs:
    for (( i=1; i<=${TRIALS}; i++ )) ; do \
        $(MAKE) ssend-run DATA_FILE_ID=$$i ; \
    done

ssend-run: build/ssend
    mkdir -p ./${MEASUREMENTS_DIR}
    rm -f "${MEASUREMENTS_DIR}/ssend-${DATA_FILE_ID}.dat"

    message_size="1" ; while [[ $$message_size -le $(VERY_SMALL_STEP_THRESHOLD_BYTES) ]] ; do \
        $(MPIEXEC) -n 2 ./build/ssend $$message_size ${DATA_TO_BE_TRANSFERRED_BYTES} \
        "${MEASUREMENTS_DIR}/${SSEND_PREFIX}_${NODE_SUFFIX}-${DATA_FILE_ID}.dat"; \
        ((message_size = message_size + $(MESSAGE_STEP_VERY_SMALL_STEP_SIZE_BYTES)) \
    )) ; \
    done

    message_size=$(VERY_SMALL_STEP_THRESHOLD_BYTES) ; while [[ $$message_size -le $(SMALL_STEP_THRESHOLD_BYTES) ]] ; do \
        $(MPIEXEC) -n 2 ./build/ssend $$message_size ${DATA_TO_BE_TRANSFERRED_BYTES} \
        "${MEASUREMENTS_DIR}/${SSEND_PREFIX}_${NODE_SUFFIX}-${DATA_FILE_ID}.dat"; \
        ((message_size = message_size + $(MESSAGE_STEP_SMALL_STEP_SIZE_BYTES))) ; \
    done

    message_size=$(MESSAGE_STEP_SIZE_BYTES) ; while [[ $$message_size -le $(MAX_MESSAGE_SIZE) ]] ; do \
        $(MPIEXEC) -n 2 ./build/ssend $$message_size ${DATA_TO_BE_TRANSFERRED_BYTES} \
        "${MEASUREMENTS_DIR}/${SSEND_PREFIX}_${NODE_SUFFIX}-${DATA_FILE_ID}.dat"; \
        ((message_size = message_size + $(MESSAGE_STEP_SIZE_BYTES))) ; \
    done

```



```

    ${MEASUREMENTS_DIR}/${SSEND_PREFIX}-${NODE_SUFFIX}-${DATA_FILE_ID}.dat , \
        ((message_size = message_size + $(MESSAGE_STEP_SMALL_STEP_SIZE_BYTES))) ; \
done

message_size=$(MESSAGE_STEP_SIZE_BYTES) ; while [[ $$message_size -le $(MAX_MES
SAGE_SIZE) ]] ; do \
    $(MPIEXEC) -n 2 ./build/ssend $$message_size ${DATA_TO_BE_TRANSFERRED_BYTES}
"${MEASUREMENTS_DIR}/${SSEND_PREFIX}-${NODE_SUFFIX}-${DATA_FILE_ID}.dat"; \
    ((message_size = message_size + $(MESSAGE_STEP_SIZE_BYTES))) ; \
done

build/ssend: src/ssend.c build
    $(CC) -o build/ssend src/ssend.c

# ping-pong
run-ping-pong: build/ping_pong
    $(MPIEXEC) -n 2 ./build/ping_pong 16

ping-pong-measure-multiple-runs:
    for (( i=1; i≤${TRIALS}; i++ )) ; do \
        $(MAKE) ping-pong-measure DATA_FILE_ID=$$i ; \
    done

ping-pong-measure: build/ping_pong
    rm -f "build/ping_pong-${DATA_FILE_ID}.dat"
    for n in 1 64 256 1024 65536 1048576 ; do \
        $(MPIEXEC) -n 2 ./build/ping_pong $$n "build/ping_pong-${DATA_FILE_ID}.dat"
    ; \
done

ping-pong-plot:
    ./gnuplot/composite_stats.sh "./build/ping_pong-*.dat" > "./build/ping_pong_com
posite.dat"
    gnuplot -persistent gnuplot/ping_pong.gpi

build/ping_pong: src/ping_pong.c build
    $(CC) -o build/ping_pong src/ping_pong.c

build:
    mkdir -p ./build

clean:
    rm -rf ./build/*

```

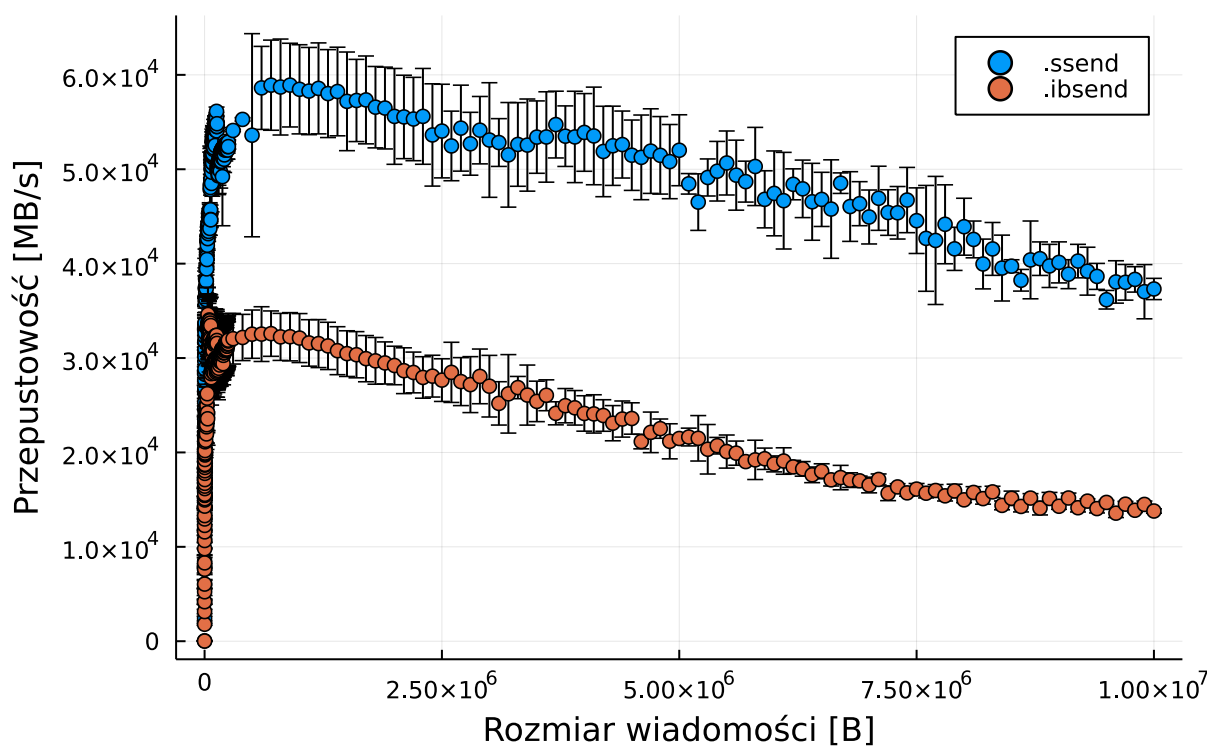
Przepustowość na pojedynczym węźle

Na pojedynczym węźle przepustowość P2P jest olbrzymia. Największy throughput uzyskujemy dla wiadomości o rozmiarze 100kB - 1MB, później throughput zaczyna spadać. Dla bardzo małych wiadomości throughput jest bardzo niski gdyż narzut ze względu na komunikację między procesami jest znacznie większy od narzutu ze względu na przenoszenie danych.

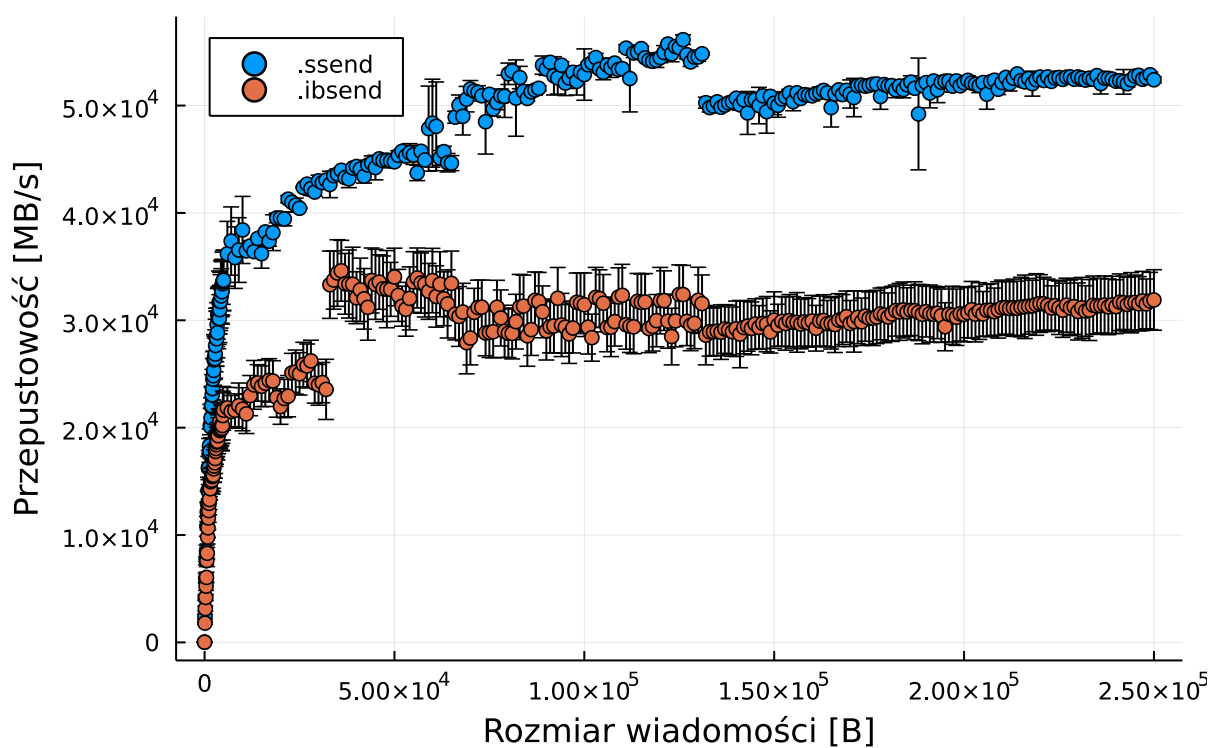
Ssend osiąga większy throughput od ibsend ze względu na fakt, że ssend nie robi dodatkowych kopii i to koszt tego kopiowania widzimy na wykresie. Gdyby program na którym testujemy nie działał na zasadzie wyślij-ping, odbierz-ping, wyślij-pong, odbierz-pong tylko raczej wyślij kilkanaście wiadomości i jakiś czas później sprawdź czy zostały wysłane to myślę, że buforowanie wiadomości miałoby pozytywny wpływ na performance.

Poniżej przedstawiłem wykresy przepustowości dla wszystkich przetestowanych rozmiarów i tylko dla mniejszych rozmiarów wiadomości.

Przepustowość na pojedynczym węźle



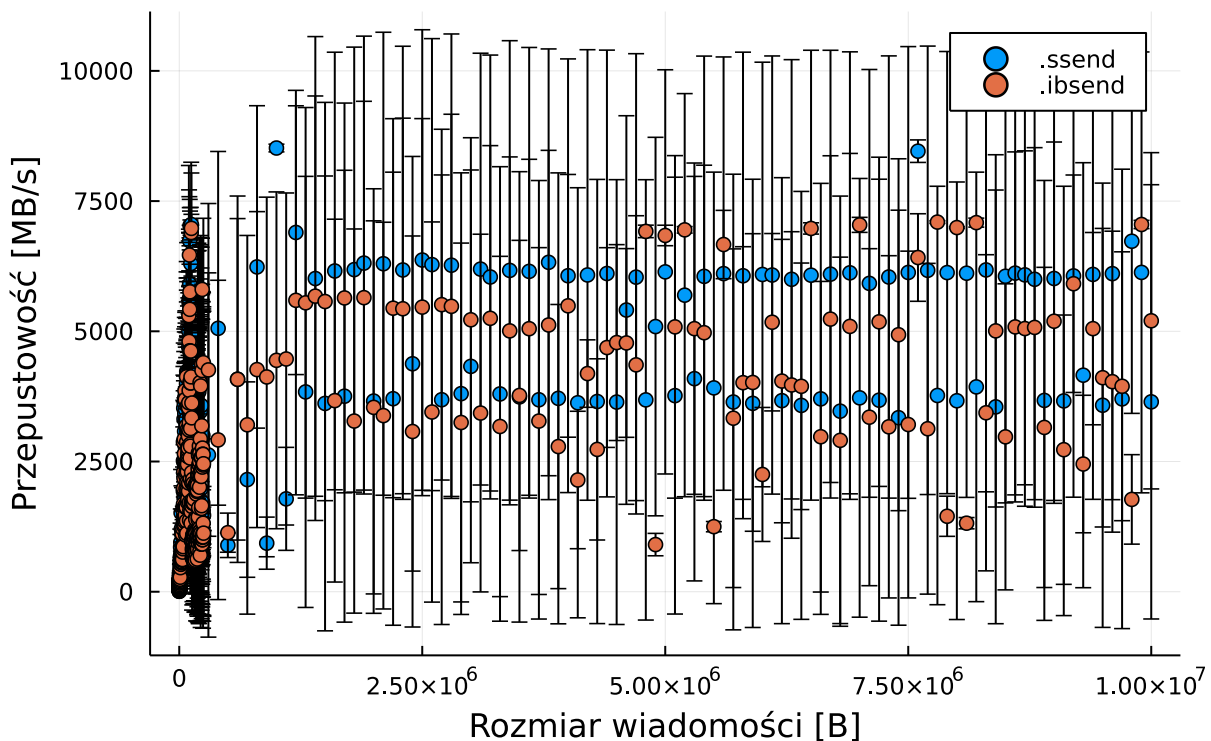
Przepustowość na pojedynczym węźle



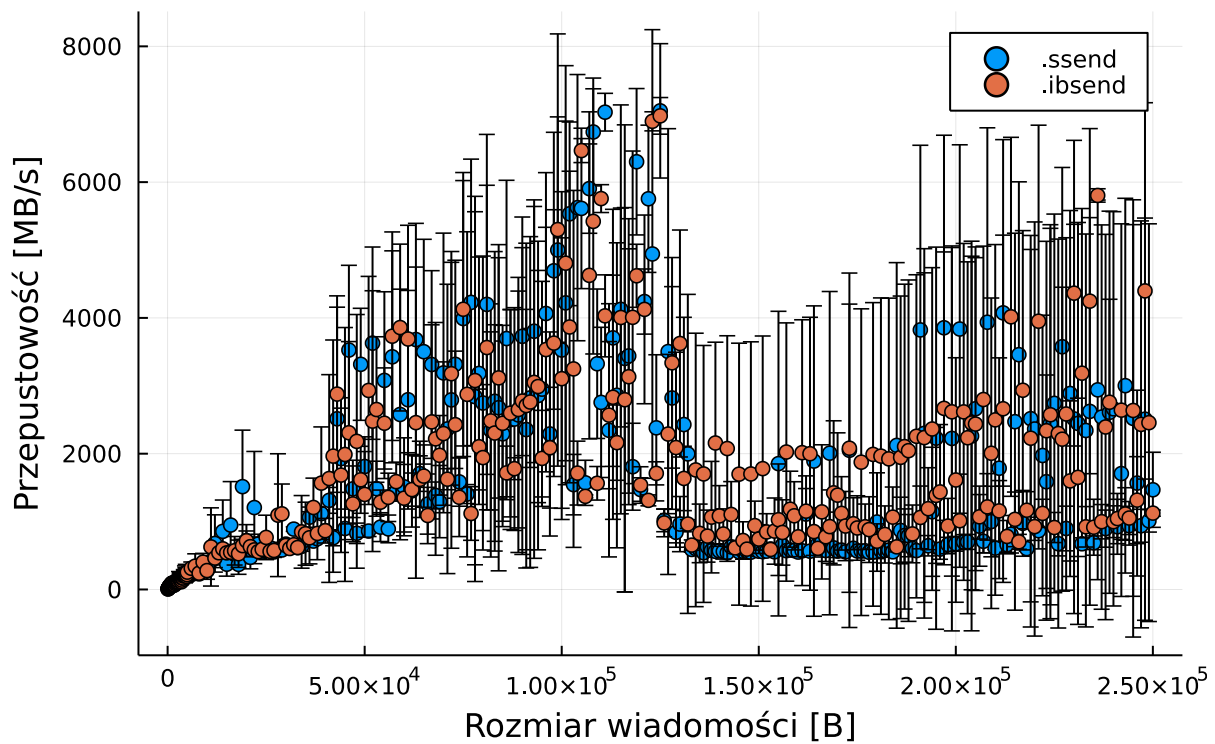
Przepustowość na dwóch węzłach

Tutaj wykonane pomiary były obarczone bardzo dużą wariancją. Wykres wygląda o tyle podobnie, że znowu małe rozmiary wiadomości dają niską przepustowość i wraz ze wzrostem rozmiaru wiadomości osiągamy coraz lepszą przepustowość. Mimo wszystko widać, że przepustowość spadła conajmniej 10-krotnie ze względu na komunikację przez sieć. Nie widać tutaj też trendu: im większy rozmiar wiadomości tym throughput zaczyna spadać. Różnice pomiędzy funkcjami wydają się być pomijalne, głównie ze względu na dominujący narzut w samej komunikacji. Widać też ciekawy spadek przepustowości w okolicach $1.25 \cdot 10^5 \text{ kB}$ choć ciężko powiedzieć czym jest spowodowany.

Przepustowość na dwóch maszynach



Przepustowość na dwóch maszynach



Opóźnienie

Na podstawie zebranych danych można oszacować opóźnienie (czyli czas na wysłanie 1B) w komunikacji.

W przypadku funkcji `ssend` jest to:

- jeden węzeł: $7.0e-5 \pm 7.5e-5s$
- dwa węzły: $0.03837 \pm 0.00027s$

W przypadku funkcji `ibsend` jest to:

- jeden węzeł: $7.0e-5 \pm 7.4e-5s$
- dwa węzły: $0.038 \pm 0.0074s$

Część 2 - Badanie efektywności programu równoległego

Program do szacowania liczby pi metodą monte carlo został napisany w języku c . Wyniki zostały zebrane z wielokrotnego uruchomienia go na prometeuszu. Program posiada znikomą część sekwencyjną (faza reduce, gdy czekamy na wyniki od pozostałych węzłów) stąd możemy go porównywać do programu idealnie równoległego.

Pomiary

Pomiary wykonałem dla pięciu liczb punktów:

- $\pi s1: 20000000 = 2 \cdot 10^7$
- $\pi s2: 40000000 = 4 \cdot 10^7$ - mniej niż sekunda dla jednego węzła.
- $\pi s3: 400000000 = 4 \cdot 10^8$
- $\pi s4: 4000000000 = 4 \cdot 10^9$
- $\pi s5: 20000000000 = 2 \cdot 10^{10}$ - ponad minuta ze wszystkimi węzłami.

Pomiary zostały powtórzone wielokrotnie (między 10-20 razy) oprócz grupy $\pi s5$ gdzie udało mi się je wykonać tylko raz i rozpocząć drugi pomiar.

Większość wykresów jest podzielona na dwa ze względu na fakt, że wykresy wyglądają dość nieczytelnie z pięcioma grupami.

Kod Źródłowy i Skrypty

- pi.c

```
#include <float.h>
#include <math.h>
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define TIME_SEED time(NULL)
#ifndef DBL_DECIMAL_DIG
#define DBL_DECIMAL_DIG 17
#endif

long long int compute_points_within(long long int n) {
    long long int i, count;
    double x, y, z;
    count = 0;
    for (i = 0; i < n; ++i) {
        x = (double)rand() / RAND_MAX;
        y = (double)rand() / RAND_MAX;
        z = x * x + y * y;
        if (z <= 1) {
            count++;
        }
    }
    return count;
}

/*
    Useful mpi functions:
    - Scatter - divides data (we have almost no data to scatter)
    - Gather - gathers data to (we don't need to gather ourselves)
    - Reduce - sums all the data. (we need master which will hold the
    reduced data)
*/

int main(int argc, char* argv[]) {
    MPI_Init(&argc, &argv);

    int rank, n_nodes, seed;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &n_nodes);
    seed = TIME_SEED + rank * n_nodes;
    srand(seed);

    long long int n_points;
    n_points = strtoll(argv[1], NULL, 10);

    MPI_Barrier(MPI_COMM_WORLD);
    double start_time = MPI_Wtime();
    long long int local_n_points = n_points / n_nodes;
    long long int local_within = compute_points_within(local_n_points);
    long long int total_within;
    MPI_Reduce(&local_within, &total_within, 1, MPI_LONG_LONG_INT, MPI_SUM, 0,
        MPI_COMM_WORLD);
    if (rank == 0) {
        double pi = (((double)total_within) / n_points) * 4;
        double time = MPI_Wtime() - start_time;
        printf("%d,%.*f,%.*f,%lld,%lld\n", n_nodes, DBL_DECIMAL_DIG, pi,
            DBL_DECIMAL_DIG, time, n_points, total_within);
    }
}
```

```

    MPI_Finalize();
    return 0;
}

```

- makefile

```

CC = "mpicc"
MPIEXEC = "mpiexec"

build/ping_pong: src/pi.c build
    $(CC) -o build/pi src/pi.c

build:
    mkdir -p ./build

clean:
    rm -rf ./build/*

```

- run.sh

```

#!/bin/bash -l
#SBATCH --nodes 1
#SBATCH --ntasks 12
#SBATCH --time=01:00:00
#SBATCH --partition=plgrid-short
#SBATCH --account=plgmp22
#SBATCH --sockets-per-node=2

module add plgrid/tools/openmpi
make

for repeat in {1..20}; do
    for points in {40000000,400000000,4000000000}; do
        for nodes in {1..12}; do
            mpiexec -np $nodes ./build/pi $points | tee -a data/data.csv
        done
    done
done

```

- run-small.sh

```

#!/bin/bash -l
#SBATCH --nodes 1
#SBATCH --ntasks 12
#SBATCH --time=01:00:00
#SBATCH --partition=plgrid-short
#SBATCH --account=plgmp22
#SBATCH --sockets-per-node=2

module add plgrid/tools/openmpi
make

for repeat in {1..20}; do
    for points in 20000000; do
        for nodes in {1..12}; do
            mpiexec -np $nodes ./build/pi $points | tee -a data/data.csv
        done
    done
done

```

- run-med.sh

```
#!/bin/bash -l
#SBATCH --nodes 1
#SBATCH --ntasks 12
#SBATCH --time=01:00:00
#SBATCH --partition=plgrid-short
#SBATCH --account=plgmpr22
#SBATCH --sockets-per-node=2

module add plgrid/tools/openmpi
make

for repeat in {1..20}; do
    for points in 4000000000; do
        for nodes in {1..12}; do
            mpiexec -np $nodes ./build/pi $points | tee -a data/data.csv
        done
    done
done
```

- run-big.sh

```
#!/bin/bash -l
#SBATCH --nodes 1
#SBATCH --ntasks 12
#SBATCH --time=01:00:00
#SBATCH --partition=plgrid-short
#SBATCH --account=plgmpr22
#SBATCH --sockets-per-node=2

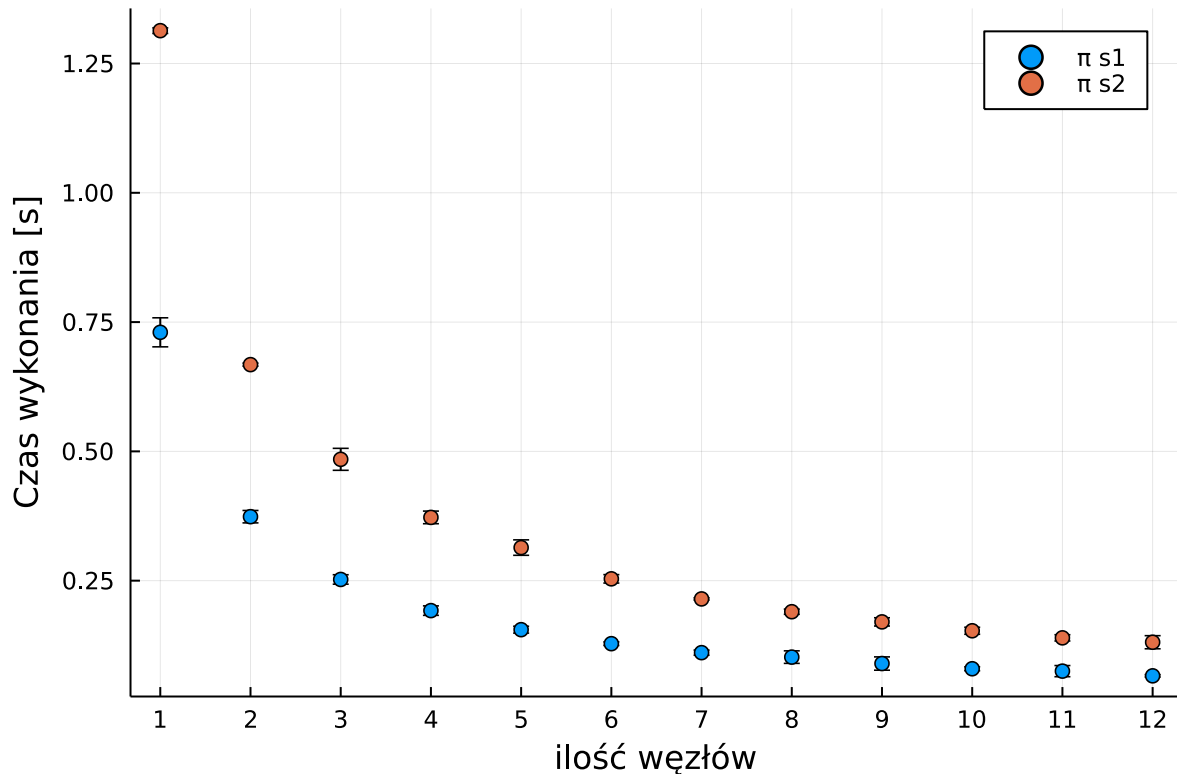
module add plgrid/tools/openmpi
make

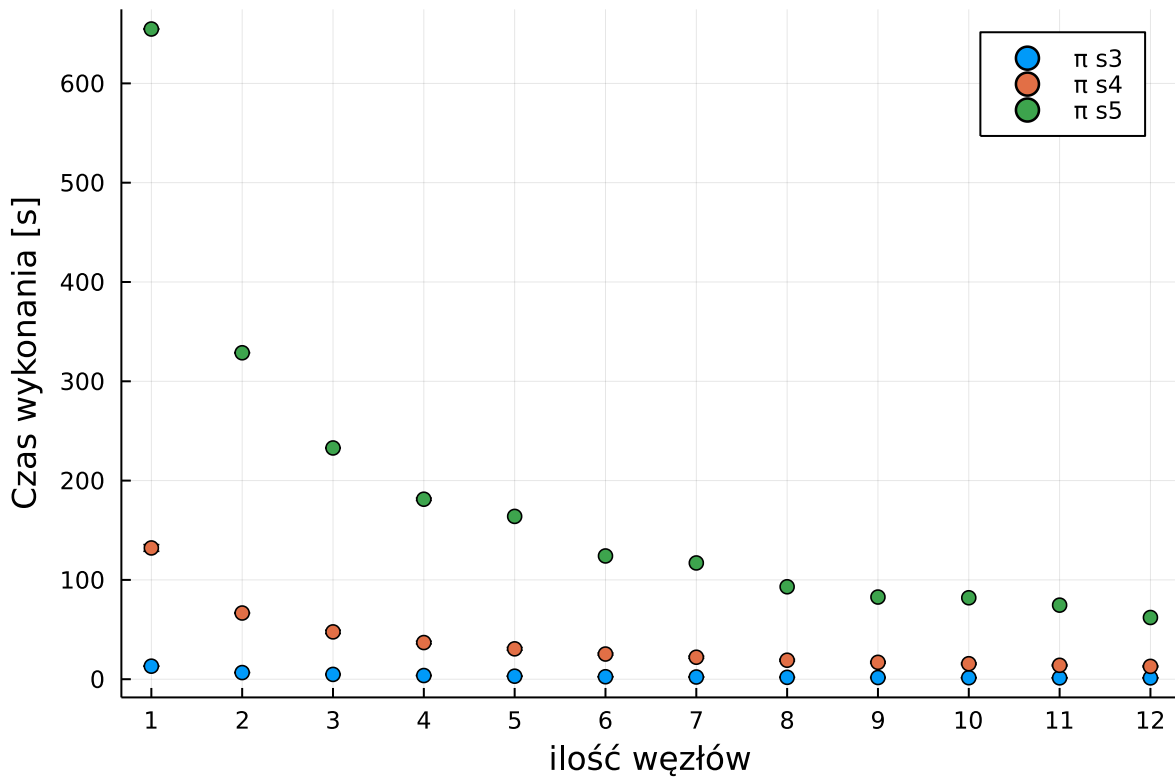
for repeat in {1..20}; do
    for points in 20000000000; do
        for nodes in {1..12}; do
            mpiexec -np $nodes ./build/pi $points | tee -a data/data.csv
        done
    done
done
```


Czas wykonania

Widzimy, że czas wykonania w zależności od liczby węzłów przypomina funkcję $\frac{1}{x}$. Nie obserwujemy tutaj sytuacji w której dodawanie węzłów nie przyspiesza obliczenia. Można się było odrobinę spodziewać jakiegoś spadku przy 8 węzłach ze względu na to, że tyle mieści się w jednym sockecie, a później mamy droższą komunikację między socketami natomiast w tym problemie sama przepustowość komunikacji nie jest tak istotna bo nie przesyłamy dużych ilości danych.

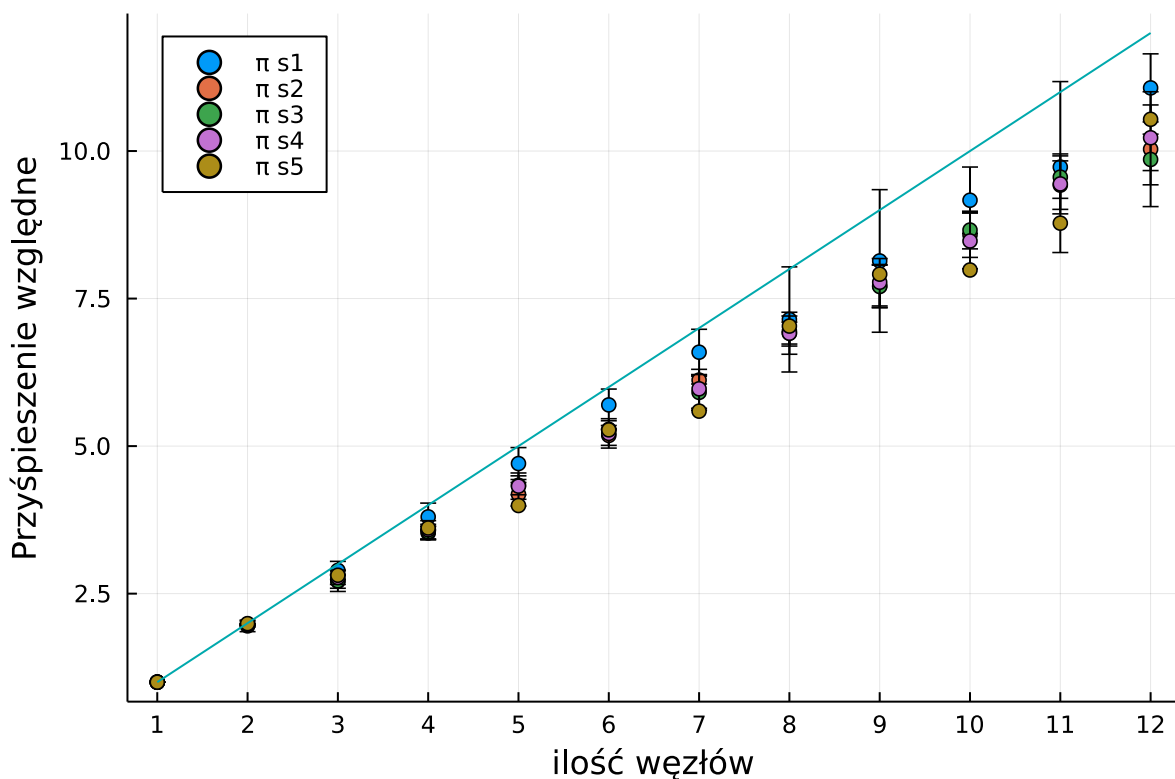
Przy większej ilości węzłów zysk z każdego następnego węzła nie jest aż tak zauważalny jak dla kilku węzłów.





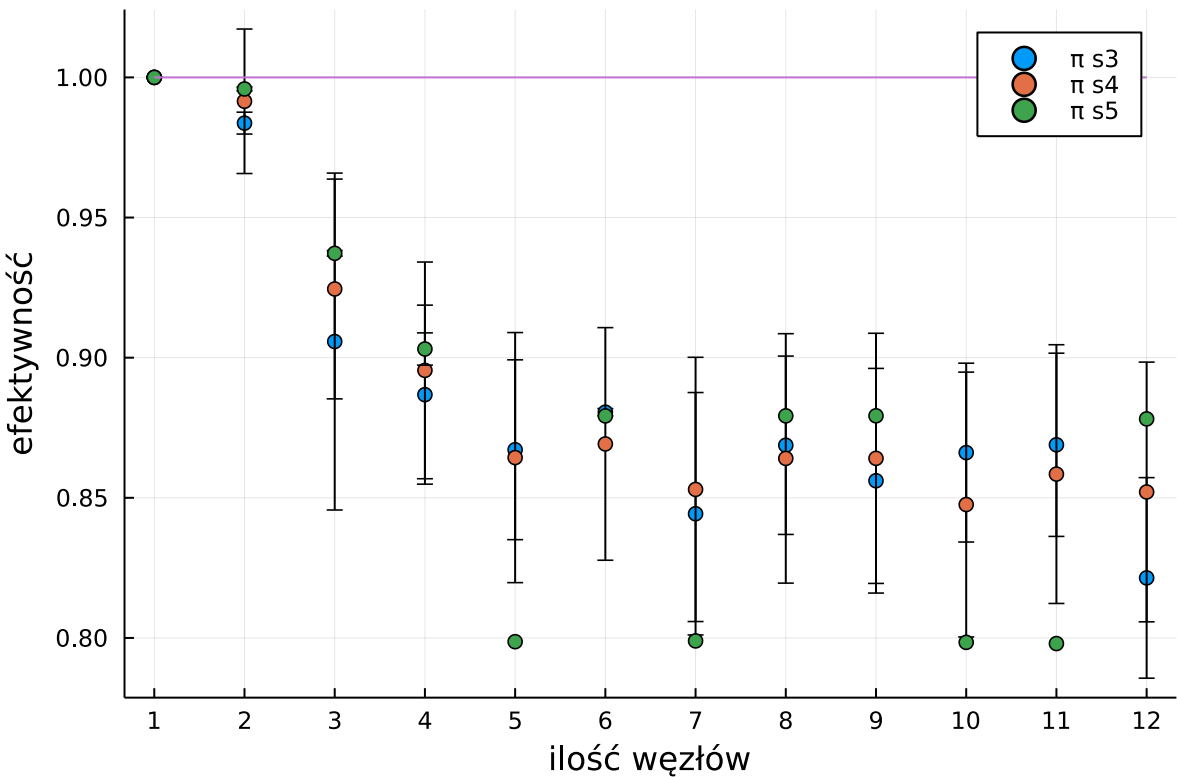
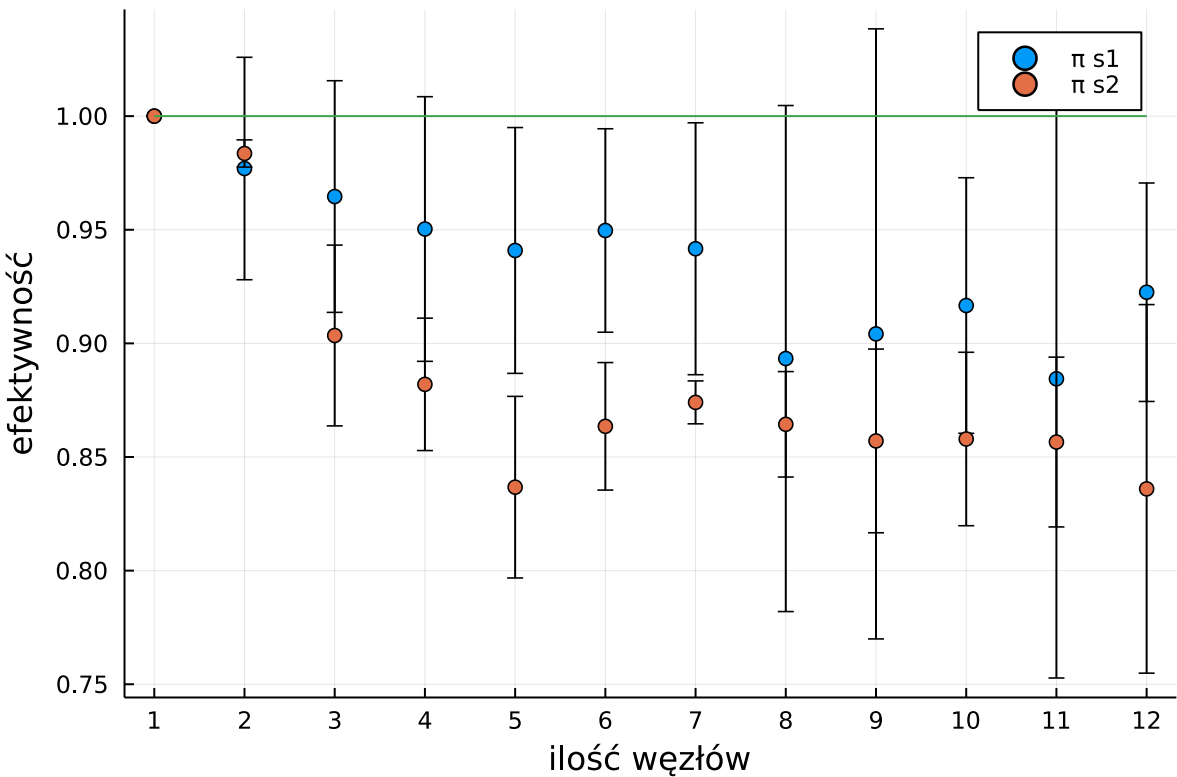
Przyspieszenie względne

Widać, że o ile na początku trzymamy się idealne przyspieszenia to wraz z dodawaniem nowych węzłów odchodzimy od tej linii. Jest to spowodowane częścią sekwencyjną naszego programu. Nawet jeśli podzieliśmy nasz problem na równe kawałki to różne węzły mogą skończyć swoje obliczenia w różnym czasie co zmusza nas na czekanie w części sekwencyjnej.



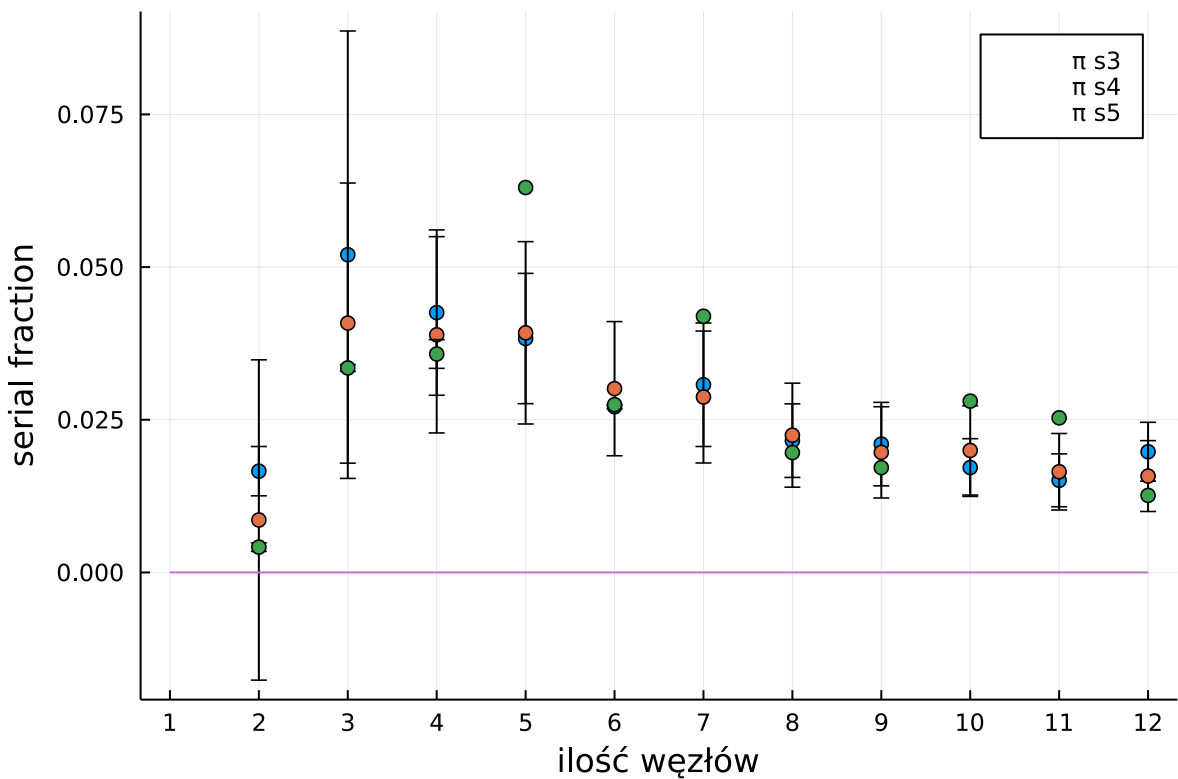
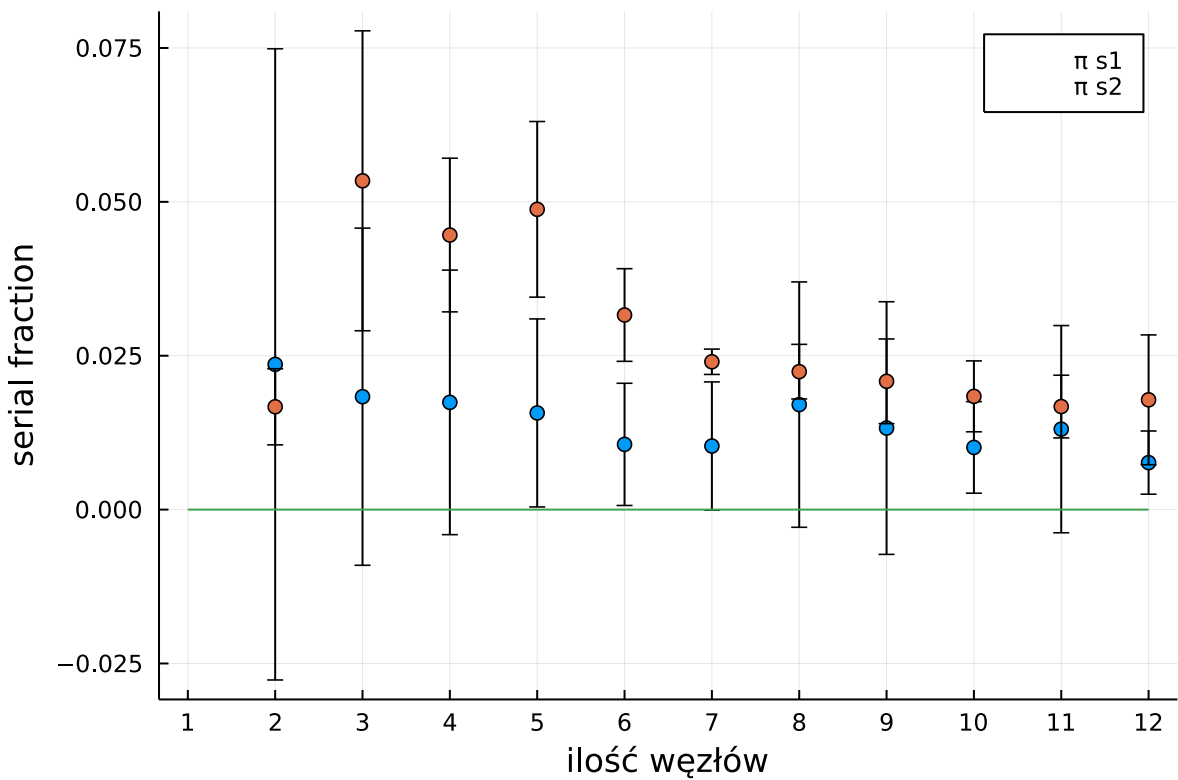
Efektywność

Efektywność utrzymuje się pomiędzy 0.8 - 1.0, co wydaje się być rozsądnym zakresem. Idealną wartością dla efektywności byłaby wartość 1. Wydaje się, że mniejsze liczby punktów osiągały lepszą efektywność. To przypuszczalnie dlatego, że różnice w czasie wykonania programu na różnych węzłach są bardziej widoczne im ten program się dłużej wykonuje, a to w efekcie zwiększa sekwencyjną część czekania na wyniki.



Część Sekwencyjna

Wykresy pokazują niezerową część sekwencyjną, która idealnie byłaby zerowa. Dla naszego problemu ma ona bardzo niską wartość.



md

Dane

#	size	throughput
1	1	26.604645
2	101	2143.612665
3	201	3897.478119
4	301	5471.784119
5	401	7167.238085
6	501	7794.56977
7	601	9760.471801
8	701	11118.622952
9	801	11591.217686
10	901	12710.625469
11	1001	15031.918344
12	1101	14648.09267
13	1201	15901.524341
14	1301	16585.886639
15	1401	15962.287351
16	1501	18065.006926
17	1601	18092.655542
18	1701	18759.65331
19	1801	19876.551338
20	1901	20076.843967
21	2001	20993.137912
22	2101	21647.008646
23	2201	22305.786649
24	2301	22248.775094
25	2401	23252.995117
26	2501	23588.846606
27	2601	24290.919872
28	2701	24209.379363
29	2801	24262.246939
30	2901	24855.610674
31	3001	25309.219926
32	3101	25779.628899
33	3201	25353.757621
34	3301	27295.003047
35	3401	26164.754287
36	3501	27907.528844
37	3601	26907.631654
38	3701	27346.317307
39	3801	28302.624492
40	3901	27583.863789
41	4001	28381.052703
42	4101	28632.400633
43	4201	28896.079152
44	4301	30137.462094
45	4401	29355.804456
46	4501	29955.976655
47	4601	29183.059111
48	4701	30037.250255

48	4700	30037.237233
49	4800	31167.576178
50	4900	30541.577309
51	5000	30485.460674
52	6000	32724.824514
53	7000	33709.175686
54	8000	34344.000573
55	9000	34530.357495
56	10000	36607.89666
57	11000	36469.750706
58	12000	37272.59559
59	13000	36452.523546
60	14000	37653.930852
61	15000	34732.682412
62	16000	38243.462998
63	17000	37619.036589
64	18000	36264.904604
65	19000	39920.805894
66	20000	39433.121798
67	21000	39626.911258
68	22000	41606.130562
69	23000	41041.994981
70	24000	40444.435017
71	25000	40499.242022
72	26000	42363.942606
73	27000	42848.743451
74	28000	42391.509602
75	29000	41819.453628
76	30000	43529.226552
77	31000	43084.447651
78	32000	43501.659445
79	33000	43298.415957
80	34000	43595.989169
81	35000	43381.158383
82	36000	43940.191527
83	37000	43486.22373
84	38000	43020.268558
85	39000	44038.705634
86	40000	44268.228713
87	41000	43919.363004
88	42000	43517.366497
89	43000	44888.974399
90	44000	44085.393993
91	45000	44796.887093
92	46000	45129.505021
93	47000	45358.721209
94	48000	45018.53634
95	49000	44849.916731
96	50000	44685.619923
97	51000	45627.819653
98	52000	45712.5500

98	52000	45712.5508
99	53000	45004.883046
100	54000	46049.58934
101	55000	45987.467353
102	56000	44445.030422
103	57000	45865.644944
104	58000	45046.181874
105	59000	45332.205905
106	60000	45974.930063
107	61000	45479.343678
108	62000	44326.479748
109	63000	45599.343578
110	64000	45665.016584
111	65000	43859.163817
112	66000	48948.058558
113	67000	48973.372274
114	68000	49423.134498
115	69000	50623.496164
116	70000	50613.424417
117	71000	51138.358054
118	72000	50676.979241
119	73000	51199.116814
120	74000	45122.262472
121	75000	51151.141513
122	76000	50454.419208
123	77000	50724.978986
124	78000	50305.990918
125	79000	48625.123163
126	80000	53135.333893
127	81000	53277.941512
128	82000	46613.567709
129	83000	51439.902719
130	84000	51092.204221
131	85000	50795.084546
132	86000	51570.43876
133	87000	51558.98476
134	88000	51857.792625
135	89000	52788.204157
136	90000	53548.583153
137	91000	53580.485778
138	92000	50704.655464
139	93000	52229.016769
140	94000	53719.378361
141	95000	52881.539314
142	96000	53319.664028
143	97000	53177.616527
144	98000	53272.677097
145	99000	53029.250592
146	100000	53032.877622
147	101000	53613.954452
148	102000	53688.781858

148	102000	53682.794858
149	103000	54734.335273
150	104000	53343.43637
151	105000	52412.742175
152	106000	54412.945904
153	107000	54345.95529
154	108000	54045.837016
155	109000	53158.508935
156	110000	53449.91656
157	111000	55491.71051
158	112000	49021.276846
159	113000	54419.718816
160	114000	54905.453011
161	115000	55052.652897
162	116000	54349.776692
163	117000	54134.173003
164	118000	53869.700354
165	119000	54327.983134
166	120000	54409.05754
167	121000	55679.488315
168	122000	55668.014827
169	123000	55622.022048
170	124000	55078.492154
171	125000	55184.579962
172	126000	56369.547795
173	127000	54388.648206
174	128000	54428.505132
175	129000	54369.941861
176	130000	54950.783087
177	131000	54948.086538
178	132000	49851.328413
179	133000	49582.321191
180	134000	50147.79016
181	135000	50238.864511
182	136000	49870.283927
183	137000	50298.867195
184	138000	50008.061128
185	139000	50064.276012
186	140000	50716.74211
187	141000	50579.407449
188	142000	50782.230572
189	143000	50820.176254
190	144000	50596.691307
191	145000	50808.101275
192	146000	48040.598662
193	147000	51081.310693
194	148000	50829.486725
195	149000	50802.883805
196	150000	48997.102301
197	151000	50480.369201
198	152000	50017.701070

198	152000	50067.781872
199	153000	50719.841179
200	154000	51445.970442
201	155000	49412.162016
202	156000	50787.945952
203	157000	50747.12061
204	158000	51256.885707
205	159000	50788.660493
206	160000	50989.703214
207	161000	51017.537961
208	162000	50883.095691
209	163000	51690.282269
210	164000	51467.196708
211	165000	50705.894929
212	166000	51389.448255
213	167000	51687.416608
214	168000	51322.173351
215	169000	51385.538546
216	170000	51434.589605
217	171000	51897.715509
218	172000	52098.646501
219	173000	52059.610138
220	174000	52062.800224
221	175000	51913.245525
222	176000	52265.841758
223	177000	52234.968698
224	178000	51841.436216
225	179000	51796.364686
226	180000	51733.143046
227	181000	51755.131684
228	182000	50655.942329
229	183000	51900.056295
230	184000	51847.916743
231	185000	52281.61078
232	186000	52739.955741
233	187000	51852.836947
234	188000	52284.171089
235	189000	52083.743633
236	190000	52359.709179
237	191000	52055.393581
238	192000	52464.598786
239	193000	50090.649317
240	194000	52208.116048
241	195000	52375.193329
242	196000	51947.605165
243	197000	51775.06719
244	198000	52583.487149
245	199000	51823.082897
246	200000	53023.659176
247	201000	51989.16237

248	202000	51693.292891
249	203000	51879.043476
250	204000	52486.558317
251	205000	52430.608995
252	206000	51884.477173
253	207000	52839.531848
254	208000	52706.447206
255	209000	50962.416432
256	210000	52105.777799
257	211000	52687.430892
258	212000	52847.80609
259	213000	52468.078423
260	214000	52758.095022
261	215000	52762.998271
262	216000	52257.692087
263	217000	52901.465746
264	218000	52917.528173
265	219000	52270.107746
266	220000	52462.613383
267	221000	52145.669146
268	222000	52734.803065
269	223000	52213.668959
270	224000	53061.636927
271	225000	52375.552832
272	226000	52261.122012
273	227000	52980.12375
274	228000	53116.060572
275	229000	52239.267583
276	230000	53026.255082
277	231000	52314.026249
278	232000	52976.769163
279	233000	52491.602378
280	234000	52444.221444
281	235000	52662.176579
282	236000	50926.606497
283	237000	52442.465124
284	238000	52584.479466
285	239000	52186.612474
286	240000	51932.698129
287	241000	52723.863718
288	242000	53289.440716
289	243000	51696.843166
290	244000	52333.748209
291	245000	52801.363643
292	246000	52871.019633
293	247000	52372.478382
294	248000	52532.901784
295	249000	53000.006775
296	250000	52712.955777
297	100000	48095.679844

298	200000	51461.484901
299	300000	54008.103219
300	400000	55228.178287
301	500000	55200.921265
302	600000	56392.100216
303	700000	56262.723989
304	800000	56465.752674
305	900000	56344.263921
306	1000000	55646.747044
307	1100000	55910.875686
308	1200000	55689.185326
309	1300000	54872.515254
310	1400000	55013.70746
311	1500000	53827.150533
312	1600000	54334.72608
313	1700000	54688.116687
314	1800000	54109.277165
315	1900000	54222.732771
316	2000000	54209.234547
317	2100000	53473.639488
318	2200000	52236.555445
319	2300000	52675.032603
320	2400000	52551.111343
321	2500000	52519.067147
322	2600000	52171.37545
323	2700000	51473.111917
324	2800000	49646.916888
325	2900000	51681.069016
326	3000000	47623.789116
327	3100000	52281.39624
328	3200000	46875.325194
329	3300000	50902.37156
330	3400000	46923.760597
331	3500000	49059.846569
332	3600000	48103.765281
333	3700000	50702.694747
334	3800000	50006.454206
335	3900000	47965.650069
336	4000000	49183.5202
337	4100000	47559.974487
338	4200000	46353.938295
339	4300000	47695.059084
340	4400000	48530.794549
341	4500000	47205.365392
342	4600000	46422.56525
343	4700000	46804.621051
344	4800000	47008.033156
345	4900000	46628.489493
346	5000000	47727.628584
347	5100000	47844.812252

348	5200000	44692.767282
349	5300000	47122.709997
350	5400000	46808.042573
351	5500000	46750.950222
352	5600000	45443.206626
353	5700000	46411.128949
354	5800000	45729.389065
355	5900000	47087.638895
356	6000000	44113.081975
357	6100000	43458.637727
358	6200000	46516.107974
359	6300000	44422.943252
360	6400000	42430.804832
361	6500000	44479.858292
362	6600000	44379.976193
363	6700000	47436.408766
364	6800000	42628.135027
365	6900000	43722.373119
366	7000000	43036.518899
367	7100000	43174.982082
368	7200000	43123.44447
369	7300000	43519.117633
370	7400000	42748.178841
371	7500000	40786.295346
372	7600000	36556.733943
373	7700000	42072.810031
374	7800000	39726.46456
375	7900000	39613.944801
376	8000000	40431.593328
377	8100000	40417.00692
378	8200000	40709.649329
379	8300000	38807.466815
380	8400000	36100.829817
381	8500000	39597.472094
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1078	240000	52547.715259
1079	241000	51880.67408
1080	242000	51006.420005
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1103	1500000	63213.868088
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- `begin`
- `ssend_single = CSV.read("lab1/measurements/csv/ssend_single_node.csv", DataFrame)`
- `HTMLTable(ssend_single)`

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9	901	71.496787
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11	1101	81.464636
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13	1301	89.269371
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21	2101	109.792122
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23	2301	110.45157
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38	3801	233.314455
39	3901	241.317081
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• begin
•   ssend_two = CSV.read("lab1/measurements/csv/ssend_two_nodes.csv", DataFrame)
•   HTMLTable(ssend_two)
• end

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7	601	7665.19463
8	701	8747.641008
9	801	9796.561595
10	901	11584.328077
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12	1101	12867.912286
13	1201	13170.689079
14	1301	13400.634371
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• begin
•   ibsend_single = CSV.read("lab1/measurements/csv/ibsend_single_node.csv",
   DataFrame)
•   HTMLTable(ibsend_single)
• end
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4	401	35.505738
5	501	61.326294
6	601	59.738992
7	701	63.366151
8	801	60.510411
9	901	101.036163
10	1001	102.816189
11	1101	111.831883
12	1201	61.062895
13	1301	132.184476
14	1401	51.276342
15	1501	94.025159
16	1601	104.352468
17	1701	82.332899
18	1801	73.809349
19	1901	108.531709
20	2001	75.678604
21	2101	158.195342
22	2201	152.566361
23	2301	149.730776
24	2401	149.316184
25	2501	90.92639
26	2601	133.198561
27	2701	136.047262
28	2801	95.599591
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30	3001	228.04533
31	3101	259.702976
32	3201	239.821725
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38	3801	220.535616
39	3901	124.79121
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1076	241000	617.889365
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1101	1600000	7683.730311
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1111	2600000	7664.176536
1112	2700000	1624.019518
1113	2800000	7594.279834
1114	2900000	1275.560425
1115	3000000	7199.186202
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1136	5100000	1288.800714
1137	5200000	6920.741623
1138	5300000	1379.287338
1139	5400000	6798.483319
1140	5500000	1262.1201

```

• begin
•   ibsend_two = CSV.read("lab1/measurements/csv/ibsend_two_nodes.csv", DataFrame)
•   HTMLTable(ibsend_two)
• end

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5	5	3.1417265	0.328202073	40000000	31417265
6	6	3.1410319	0.249536213	40000000	31410319
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9	9	3.1414544	0.166613544	40000000	31414544
10	10	3.141758	0.163792211	40000000	31417580
11	11	3.1417875	0.137656593	40000000	31417875
12	12	3.1415781	0.124379535	40000000	31415781
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14	2	3.14157005	6.656127382	400000000	314157005
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18	6	3.14164514	2.483526645	400000000	314164514
19	7	3.14173483	2.3431825120000003	400000000	314173483
20	8	3.14160533	1.861831783	400000000	314160533
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23	11	3.14164121	1.354018619	400000000	314164121
24	12	3.14152398	1.365432517	400000000	314152398
25	1	3.141585315	131.111207091	4000000000	3141585315
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27	3	3.141574823	47.087538477	4000000000	3141574823
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66	6	3.141622042	24.824621849	4000000000	3141622042
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578	2	3.141590675	66.214457709	4000000000	3141590675
579	3	3.141551665	46.881321715	4000000000	3141551665
580	4	3.141596119	36.372565865	4000000000	3141596119
581	5	3.141649442	29.781124312	4000000000	3141649442
582	6	3.141564894	27.31396789	4000000000	3141564894
583	7	3.141551896	21.294152607	4000000000	3141551896
584	8	3.141597893	18.629469621	4000000000	3141597893
585	9	3.141593263	18.222309101	4000000000	3141593263
586	10	3.141587249	14.89775108	4000000000	3141587249
587	11	3.141597352	14.902442004	4000000000	3141597352
588	12	3.141550605	12.453627167	4000000000	3141550605
589	1	3.141632394	131.105611957	4000000000	3141632394
590	2	3.141591273	66.246498231	4000000000	3141591273
591	3	3.14163404	46.838979591	4000000000	3141634040
592	4	3.141551942	36.465505881	4000000000	3141551942
593	5	3.141603757	32.770395659	4000000000	3141603757

```

• begin
•   raw_data_pi =CSV.read("lab2/data/data.csv", DataFrame)
•   HTMLTable(raw_data_pi)
• end

```

